Evaluation of Multi-sensory Feedback in Virtual and Real Remote Environments in a USAR Robot Teleoperation Scenario

by

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Abstract

The area of Human-Robot Interaction deals with problems not only related to robots interacting with humans, but also with problems related to humans interacting and controlling robots. This dissertation focuses on the latter and evaluates multi-sensory (vision, hearing, touch, smell) feedback interfaces as a means to improve robot-operator cognition and performance. A set of four empirical studies using both simulated and real robotic systems evaluated a set of multi-sensory feedback interfaces with various levels of complexity. The task scenario for the robot in these studies involved the search for victims in a debris-filled environment after a fictitious catastrophic event (*e.g.*, earthquake) took place.

The results show that, if well-designed, multi-sensory feedback interfaces can indeed improve the robot operator data perception and performance. Improvements in operator performance were detected for navigation and search tasks despite minor increases in workload. In fact, some of the multi-sensory interfaces evaluated even led to a reduction in workload.

The results also point out that redundant feedback is not always beneficial to the operator. While introducing the concept of operator omni-directional perception, that is, the operator's capability of perceiving data or events coming from all senses and in all directions, this work explains that feedback redundancy is only beneficial when it enhances the operator omni-directional perception of data relevant to the task at hand.

Last, the comprehensive methodology employed and refined over the course of the four studies is suggested as a starting point for the design of future HRI user studies.

In summary, this work sheds some light on the benefits and challenges multi-sensory feedback interfaces bring, specifically on teleoperated robotics. It adds to our current

understanding of these kinds of interfaces and provides a few insights to assist the continuation of research in the area.

Dedicatory

I would like to dedicate this work to my father, whom, during his last years of life, had his son kept away from him in a foreign land while in pursuit of his academic dreams. Dad, despite your absence, I am certain you would be proud of me now, not because of the work I have accomplished or its results, but because of how I have accomplished it: through hard work and honestly. May every remaining action I may take in this life bring me closer to becoming the wise, commonsensible and humorous man you were.

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1. Introduction

1.1. Overview

We perform tasks effectively in the real world using our highly advanced human senses. Through constant evolution and repetition, humans are able to effortlessly take in, filter, fuse, and make sense of huge amounts of high-fidelity visual, auditory, touch, smell, and taste stimuli. Furthermore, due to our extremely versatile nature, we are able to adapt to input/output (I/O) mechanisms in order to use tools and computers, and operate machines and robots, even if their interfaces are sub-optimally designed.

While robotic systems are assuming an ever-increasing role in our lives, current Human-Robot Interaction (HRI) interfaces for teleoperated robotic systems seldom take advantage of the high-bandwidth, multi-sensory capacity offered by their human operators. Instead, they present all the necessary information to the eyes alone using visual displays. Although our visual sensory system is highly evolved, its capacity is not limitless, and its overuse may demand excessive mental effort from the robot operator and limit his ability to efficiently and effectively perform the tasks he has been assigned.

The reasons for the predominance of visual-only HRI interfaces include: (a) the ease with which information can be displayed on computer monitors, (b) a lack of understanding within the interface design community of the salient aspects of displays for other sensory modalities, and (c) a lack of methods for evaluating multi-sensory interface effectiveness. There is still no consensus among HRI researchers on what the fundamental criteria for evaluating human-robot interfaces are. While *performance* is one valid measure of interface effectiveness, other higher-level measures, such as *workload*, *presence*, and *situation awareness (SA)* are also important indicators, though they appear less frequently in the literature. Moreover, because HRI labs have different sets of robots that are typically expensive to purchase, reproducing the exact conditions of another researcher's previous research work becomes more difficult, hampering the validation of results and standardization amongst the research community.

The goal of this work is to design multi-sensory feedback robot interfaces and measure how they cognitively impact both the robot operator and his effectiveness and efficiency when performing common HRI tasks such as search and navigation. To this end, a set of four studies with virtual and real robots was carried out to evaluate the impact of gradually enhancing interface feedback over multiple senses during a simple urban search-and-rescue (USAR) robot teleoperation task. The evaluation methodology progressively enhanced along these studies brings together separate but related metrics from the Virtual Reality (VR), HRI, and HCI communities.

With the support of multiple positive study results, the author claims that redistributing the feedback from visually intense HRI interfaces to properly-designed multi-sensory interfaces can improve robot use. In addition, the methodology used for assessing multi-sensory interfaces is left as a reference for future work in this area. Last, through this research work I hope to motivate the HRI community to reduce their reliance on visual-only interfaces and increase the use of multi-sensory interfaces to further enhance robot operator data perception and cognition, but more importantly to improve efficiency and effectiveness of robot-related tasks.

1.2. Definitions

In order to delve into the field of HRI, an understanding of a common set of definitions is necessary. This section highlights core concepts in HRI and VR, such as SA and immersion. They will be defined from an HRI perspective, although some concepts may also be presented with definitions that are more general. In this and all other chapters, terms in *italics* will be found. These are concepts small enough to not deserve a detailed explanation, but important enough to be briefly explained in the text or in the Glossary.

1.2.1. Robot

Robots are artificial virtual or electro-mechanical agents. As pointed out by Scholtz (Sch04), however, there is no standard definition of what a robot is. Similar to humans themselves, they are capable of perceiving their surrounding environment, reasoning about it, and applying some actions to it according to goals, be the latter human programmed in their memories or acquired through their own experiences with the surrounding environment.

Robots can be classified into three groups. The first group comprises industrial robots, which are used in modern manufacturing companies. They generally have very little intelligence and perform specific repetitive tasks with a high level of precision. The second group includes service robots which have features that are the opposite of industrial robots. They are more intelligent and perform a set of various tasks that do not require precise results, but yet achieve general goals (Bien & Lee, 2007). The third group consists of robots with special missions (Drury et al., 2006a) (Drury et al., 2006b; Murphy, 2004; Aubrey *et al.*, 2008). These robots are designed to perform specific tasks. However, unlike industrial robots, the tasks to be performed are generally very complex. Because of this, these robots require not only a high level of artificial intelligence, but also an operator to guide the robot and help it accomplish its goals. This research work focuses on this last group.

Mission robots are typically capable of navigating through their environments and making complex physical movements to manipulate objects and affect the state of the environment. Most of the time, however, these robots are not completely autonomous, being operated, remotely or locally, by one or more human specialists.

Like any other tool, robots enhance human capabilities, enabling an operator to perform tasks that he would not be able to do bare-handedly. These advanced tools can perceive more information from the environment by sensing even human extra-sensorial data such as radiation, temperature, pressure, humidity and specific gas levels (Yanco et al., 2006). They are also more resistant to human-hazardous environments and to larger ranges of atmospheric conditions, and have been used for undersea exploration, fire rescue, and duct cleaning (Koh et al., 2001).

The construction of a robot is a non-trivial task and requires knowledge from different areas of engineering, as well as Computer Science, Psychology, Mechanical and Electrical Engineering, Industrial Design and others. The evaluation of an entire robotic system, including the robot and the team of humans behind it, is therefore an even more difficult task to carry out.

1.2.2. Human-Robot Interaction

Human Robot Interaction (HRI) is the area of research that deals with robot-related HCI kinds of problems. It comprises not only research on improving interactions between humans and robots, but more specifically on enhancing the remote operation of robots and the human perception of robot sensed data. It accomplishes that by improving the HRI system interface, that is, the part of the system that allows the human to interact with the robot. With the help of the area of Artificial Intelligence (AI), it also includes the development of autonomous robot behavior so that robots can interact among themselves and humans with little human intervention (Adams & Skubic, 2005; Crandall & Cummings, 2007).

1.2.3. Task

A task is any activity that a user (or robot operator) has to accomplish within an environment through the system interface (e.g., achieving a goal or state), and differs from the concept of an *action*. A set of actions may contribute or not to the performance of a task in a virtual or remote environment.

A task can be divided into four main parts (Parasuraman et al., 2000):

1) *Information acquisition:* gathering information from the robot and its surrounding environment;
2) *Information analysis:* understanding what the gathered information means;
3) *Decision and action selection:* deciding what is the next action the HRI system should perform;
4) *Action implementation:* performing that action.

As noted by Miller & Parasuraman (2007), the tasks that an HRI system can perform can generally be categorized into a hierarchy of subtasks in order to enhance performance and optimize workload. The concept of workload is explained in section 1.2.8.

1.2.4. Pose

Pose can be defined as the current physical configuration of the robot's limbs and joints. A pose may limit the set of tasks a robot can perform, not only because of inappropriate robot shape, but also because the tools available may differ from one configuration to another (Drury et al., 2006b).

The complexity in the number of robot poses may be measured by the number of joints and *degrees-of-freedom* in each joint. The higher the number, the greater the operator's *cognitive* *load* and interaction time will be. Proper interface design may reduce the effort to understand the complexity of a robot pose.

1.2.5. Artificial Intelligence

In general terms, artificial intelligence (AI) defines the capacity of a machine to reason about a situation and take actions that maximize its chances of success in performing a task. Tasks may span from playing chess well to finding optimal paths between locations, expressing feelings, controlling a vehicle or simply avoiding conflict. In HRI, this concept is mostly related to a robot’s levels of autonomy (section 1.2.7) and its capacity of recognizing external events (Adams, 2005; Bien & Lee, 2007; Humphrey et al., 2008).

1.2.6. Delegation

According to the Merriam-Webster dictionary (Merriam-Webster, 2009), delegation can be defined as: (1) the act of empowering to act for another or (2) a group of people that is chosen to represent others. For HRI, delegation can be understood as the act of designating tasks for a group of one or more entities, be they humans or not.

Delegation, also called tasking, task management, or dynamic function allocation (DFA) (Calefato et al., 2008), can also be described as a real-time division of labor (Miller & Parasuraman, 2007). Its dynamicity contrasts with the concept of application design, where division of labor is done during the creation of a system and becomes static when the system is finished. As described in the next section, delegation can be done manually or autonomously.

1.2.7. Autonomy

Autonomy is defined in HRI as how independent a robot is from humans or other external intervention when performing actions to complete a task. In other words, it defines how well behaved a robot is when left alone. One way to estimate the level of autonomy or automation of a robot during a task is by measuring how much time the robot spends performing the task on its own versus requesting operator assistance and being intervened by the operator (Yanco & Drury, 2002; Zeltzer, 1992). The robot may assume the same level of autonomy for an entire task or change between levels of autonomy along the task subparts (Miller & Parasuraman, 2007). The more autonomous a robot, the higher is its level of autonomy.

One important point about autonomy is that changing its level may have unpredictable effects on human performance as part of an HRI system. The correct design of autonomy makes it beneficial for the robot-operator task relationship (Dekker & Hollnagel, 2004; Dekker & Woods, 2002) by enabling a conversation between human and machine through which a decision-making and status awareness consensus can be reached (Miller et al., 2005). This paradigm is also called the "Horse-Rider paradigm" (Calefato et al., 2008). The performance of such a mixed system must be measured using its robot and operator parts in conjunction.

Autonomy is often designed to deal with only a subset of the situations faced by the HRI system and becomes useless if an unforeseen situation occurs (Parasuraman et al., 2000). Because of this, it is generally implemented only in highly reliable parts of a system or in parts whose tasks have low *risk*.

1.2.7.1. Levels of Autonomy

The levels of autonomy (LOAs) for a robot, also called interaction scheme or autonomy mode (Crandall & Goodrich, 2002), may be defined according to different operation modes it can assume. Scales to grade different levels of automation have already been created (Sheridan & Verplank, 1978; Sheridan & Parasuraman, 2006), part of which originated from the rather controversial Maba-maba list (Fallon, 2010; DW04; Parasuraman et al., 2000). A simplification of these scales is presented below and attempts to categorize the most distinctive levels of automation:

- *Fully controlled:* the operator directly controls each and every action of the robot (Yanco et al., 2004). The latter has no autonomy. This level of autonomy is commonly called teleoperation.
- *Shared control:* both robot and operator make decisions about the robot's final behavior. It can be subdivided into:
    - *Safe teleoperation:* the robot is still being controlled, but can perform some actions on its own to guarantee its survival or success, such as avoiding obstacles unseen or ignored by its operator (Yanco et al., 2006; Goodrich et al., 2001);
    - *Semi-autonomous:* The robot is able to take some decisions and actions on its own, but requires assistance in certain situations (Adams, 2006). This mode of operation can also be called standard shared operation mode. An example of a semi-autonomous interface design technique is the use of way points for navigation (Skubic et al., 2006; Goodrich et al., 2001);
    - *High-level of autonomy:* the robot is almost completely autonomous, requiring minimal or more-abstract user intervention such as in social or service robots (Bien & Lee, 2007). The operation of these types of robots is often referred to as collaborative tasking mode (Yanco et al., 2006).
- *Fully autonomous:* the robot is completely autonomous. Currently, this only realistically occurs in virtual robots, called *bots*.

Often, intermediate LOAs reach better results (Parasuraman et al., 2003; Miller &

Parasuraman, 2007). A high LOA may lead to a mismatch between how autonomous, robust and reliable the operator thinks a system is (Parasuraman et al., 2000) and how it actually is (Murphy, 2004), which may lead to undesirable operator behaviors such as *overreliance* (overtrust, naïve trust) and *complacency*. In addition, the more autonomous the system is, the higher its level of *reliance* or *trust* should be so that, in case of error, *compliance* on the part of the operator occurs without hesitation (Sheridan & Parasuraman, 2006; Moray, 2003). Reliance can be achieved by making the system *robust* with a *transparent* and *affordable* interface (Skubic et al., 2006).

1.2.8. Workload

Workload is the amount of work attributed to each member of an HRI team. It is dependent on factors such as:

- *Intra-Robot autonomy:* The less autonomous a robot is, the higher the operator's workload (Scholtz, 2003);
- *Number of robots being controlled:* as the number of robots to be controlled increases, so does the operator's workload (Humphrey et al., 2008; Parasuraman et al., 2005). Inter-agent autonomy plays an essential role in reducing workload by allowing robots to work collaboratively as a *coalition* (Adams, 2005);
- *Interface complexity:* the greater the different types of data that need to be assimilated by the user are, the higher the operator *cognitive overhead* and workload will be (Johnson et al., 2003; Miller & Parasuraman, 2007);
- *World complexity:* as the complexity or entropy (Crandall & Goodrich, 2002) of the remote world where the robot is increases, the chances of decreased performance and higher workload also grow.

It is essential that a careful mapping of sensor data to an operator's sensorial system be performed during system design to reduce workload and avoid *incidents* and *accidents*. If humans are present in the system, proper workload distribution among human and robot team members is also important to remove bottlenecks and increase global performance.

1.2.9. Situation Awareness

Situation awareness (SA) is an important concept in HRI (Endsley & Garland, 2000) and has been studied in many application areas, including unmanned aerial vehicles (UAVs) and unmanned vehicles (UVs) (Drury et al., 2006a; Freedman & Adams, 2007). The definition of SA, along with other definitions such as workload and complacency, and their experimental usefulness, has been a matter of debate in the last decade (Dekker & Hollnagel, 2004; Dekker & Woods, 2002; Parasuraman et al., 2000).

In general terms, SA can be defined as the amount of knowledge about the state of a remote environment and the HRI system that the user (or operator) has based on the information presented to him/her by the system itself.

Situation awareness is categorized into three levels (Endsley & Garland, 2000):

- *Level 1 – Perception:* The operator perceives cues in the environment, that is, notices important information;
- *Level 2 – Comprehension:* The operator integrates, stores, and retains the perceived information. In other words, this level involves not only finding chunks of information, but also making sense of them;
- *Level 3 – Projection:* The operator forecasts future situation events and dynamics from the current situation. This level of awareness allows timely actions and is a characteristic of an expert user.

An HRI interface is composed of many types of information displays. These displays define the interface *degrees-of-freedom*. A competent operator assumes an *eutactic behavior* (Moray, 2003), that is, he knows how frequently parts of the interface must be monitored and for how long (fixation time) in order to obtain optimal results. To avoid *complacency* or *skepticism* when monitoring autonomous systems, it has been a topic of discussion whether each part of the interface should be optimally monitored following its Nyquist update frequency or if other approaches such as the use of alarms should be considered (Parasuraman et al., 2008) (Moray, 2003; Senders, 1964). Operator workload, system (Endsley & Garland, 2000) or environmental (Freedman & Adams, 2007) factors tend to influence operator SA levels.

The concept of situation awareness has also been extended to an entire HRI team (Freedman & Adams, 2007) where SA levels comprise the SA of the robots plus the SA of the human team. In this case, SA is directly related to other robot-interaction concepts such as *neglection, interaction time, switch time* and *fan out* (Goodrich et al., 2001; Goodrich et al., 2005) (see the Glossary for definitions in italics).

1.2.10. Human-Robot Ratio

The relation between the number of humans and robots in a system can be specificed using the *human-robot ratio* which is, as implied, the ratio between the number H of humans over the number R of robots involved in an HRI system (Yanco & Drury, 2002; Yanco & Drury, 2004). Hence, if there is only one operator for controlling one or more robots, this ratio should be smaller than or equal to 1.

1.2.11. Immersion

Immersion can be defined as an objective measurement of the degree of perceptual freedom of a certain real or virtual reality that a sensorial interface portrays to the user (Zanbaka et al., 2005; Bowman et al., 2005). In other words, it is the measure of realistically representing a reality. It can be measured by the quality of display devices and user interaction in an HRI system (Zeltzer, 1992). A *display device* is more generally interpreted in this work as any device that provides the user with sensory feedback for any of the five senses, not just for vision.

1.2.12. Presence

Many definitions for presence have been proposed in the Virtual Reality (VR) and Tele-robotics communities (Zeltzer, 1992; Draper et al., 1998; Mantovani & Riva, 2001; Steuer, 1992). In general terms, presence is the sensation that the user has of really being in the world that is presented to him/her by the system interface.

A general methodology for accurately measuring presence is still unknown. However, some factors that relate to presence are known, such as a user's level of immersion. It is also known that presence may positively affect user performance. Three methods are currently in use for measuring presence (Insko, 2003):

- *Subjective:* The user is asked about his level of presence (Slater, 1999);
- *Behavioral:* Presence is measured based on the user's behavior while using the system, such as ducking when a virtual object approaches the user rapidly;
- *Physiological:* Physiological properties of the user's body, such as heart beat rate, skin conductance, and skin temperature, can be monitored while the user is using the system (Meehan et al., 2002). These factors are then related to the level of presence of the user in the environment.

The HRI community has applied similar measurements to other metrics such as situation awareness (Crandall & Cummings, 2007), but SA and presence are not the same concept, and high levels in one does not necessarily imply a high level in the other.

1.2.13. Telerobotics

Telerobotics can be defined as "*a direct and continuous human control by the teleoperator"* or as "*a machine that extends a person's sensing and/or manipulating capability to a location remote from that person"* (Sheridan, 1999). It also refers to research in remotely operated robots of any complexity.

1.2.14. Data Sonification

Data sonification is the use of sound to provide a better understanding and analysis of data by listening to it instead of looking at it. It is more commonly associated with the use of non-speech sound (Hermann & Hunt, 2005).

Interactive sonification is a subcategory of sonification applications. It is defined as "the use of sound within a tightly closed human-computer interface where the auditory signal provides information about data under analysis" (Hermann & Hunt, 2005). In other words, sounds are defined in real-time as the user explores the data space that the sonification represents. Chapter 2 will present more details on this topic.

1.2.15. Omni-Directional Perception

The concept of omni-directional perception has been associated in the past with robotic locomotion (Rojas & Föster, 2006; West, 2013), and vision (Nieuwenhuisen et al., 2013). The remotely operated robot is equipped with sensors that enable it to perceive data coming from all directions in the surrounding environment. A good example of this is the identification of objects and sounds around the robot. This capability allows data sensed by the robot to be associated with spatial information. Omni-directionally robot-sensed data then becomes spatialized data because it can originate and be sensed from any direction and location around the robot. In other words, the robot is not limited to sensing data in the direction toward which it is moving or has its camera pointing.

In this work, we introduce the concept of omni-directional perception from the perspective of the user or robot operator. The idea is that the operator should perceive data coming from all directions in the same way the robot is able to sense them. Spatially displaying the robot-sensed data to the user in the same way as it was captured might enable the user to more easily put himself or herself in the place of the robot and more efficiently and effectively understand the situation of the remote environment surrounding the robot. More importantly, it allows attention resources to be cognitively distributed and balanced among different senses (Wickens, 2008), instead of being solely handled by human visual perception.

The display of omni-directional data to the user is only possible if the interface feedback is not restricted to the sense of vision, which is inherently directional. The use of multi-sensory feedback interfaces, which can display robot-sensed data to multiple senses other than just to the sense of vision, have the capacity to present robot-sensed data spatially and the potential to improve the user's omni-directional perception. The multi-sensory feedback level of an interface can be associated with VR concept of interface immersveness. As in VR, however, having an immersive or multi-sensory feedback interface does not necessarily lead to higher levels of presence and improvements in the user's omni-directional data perception. Interface design plays an important role in leading to such improvements.

In consonance with Wicken's multiple resource theory (Wickens, 2008), the author believes that improvements in user omni-directional perception can lead to improvements in cognitive load, presence and SA and, consequently, impact task-related performance measures, such as navigation and search measures. However, this causal relationship has never been empirically validated. This work contains a set of studies that attempt to delineate the relationship between these experimental measures and different levels of multi-sensoriality and omni-directionality in a robot interface.

1.3. Problem Statement

In order to fully appreciate the challenges for which this work aims to find solutions, it is important to gain a broad summary of the current context in HRI interface research in which it is immersed.

In terms of display devices, monitors and portable devices are the common way of outputting data to the operator in HRI. In VR, the variety of devices tends to be greater and spread over the five senses, although video, audio, and haptic feedback are more frequently used in descending order of prevalence. Devices that are commonly used for robot control include keyboards, mice, joysticks, touchscreens and simple speech commands (Correa et al., 2010). This work aims to integrate a wider range of output devices to provide a more immersive, effective and efficient interface for the robot operator.

Regarding interface evaluation in more-traditional HCI it is important to consider the naturalness of the mappings of data to display. For example, if a virtual character bumps into a wall, is it more natural to alert the player with spatialized sound emanating from the point of contact or to give the user a vibration using a wearable haptic device? Similarly, if a motion sensor on a robot detects movement to the left and behind the robot, is it more natural to display this visually in a tiled window, or to use vibration (Yanco et al., 2004)? Different types of *mental transformations* are required for successful teleoperation (DeJong et al., 2006), and reducing the effort required to perform these transformations can significantly reduce task time and improve interaction accuracy.

Both HRI and 3D User Interaction (3DUI) deal with the problem of improving interaction with a remote environment, be it a physical or a virtual one. In fact, research in HRI could benefit from research in the area of 3DUI (Bowman et al., 2005). Interfaces for 3DUI and VR focus on recreating a first-person experience, and can be thought of as human-to-human mappings of sensory input and output. In teleoperated HRI, while some input maps directly to the human senses (*e.g.*, camera feeds to a first-person visual view), others have no clear human-sensory analogs, such as motion sensors or sonar. More importantly, optimal mappings do not necessarily need to be visual-only mappings. They can potentially involve multiple human senses. Determining *a priori* these optimal machine-to-human mappings, however, is very challenging.

In this work we aim to evaluate some of these different multi-sensory mappings in the context of a robot teleoperation interface. Following state-of-the-art multidisciplinary literature surveys and research, a set of interfaces are proposed and designed. Through formal empirical studies, the levels of effectiveness of these interfaces are comparatively assessed, and the efficiency and effectiveness with which users can perform the representative tasks with each of them is measured. Draper *et al.* (1998) discuss ways of thinking about presence and SA, and suggest two methods to design user interfaces for presence: the anthropomorphic approach and the informatic approach. As Burke *et al.* (2004) point out, “robots have been designed from the robot point of view. While this focus was appropriate in developing the existing hardware and software robot platforms, it is not team-centric.” Both of these research groups advocate a human-centered design approach, and this is the approach adopted here for designing our interfaces.

The ultimate goal of the work proposed here is improving human perception, cognition and performance during robot tasks in 3D real and virtual environments, making better use of non-visual human sensory channels, and providing the research community with a valid set of instruments for assessing effectiveness of multi-sensory interfaces in HCI, VR and HRI.

1.4. Original and Significant Contributions

The main contribution of this dissertation is to provide evidence of the benefits in representation, perception and cognition that the use of multi-sensory feedback interfaces can bring to HRI systems and how to measure them. This will be done in the context of urban search-and-rescue (USAR) robot teleoperation.

The contribution of this dissertation can be divided as follows:

1. **Verify benefits of multi-sensory interfaces:** we define a set of multi-sensory interfaces that lead to improvements in operator performance, efficiency or cognitive load in the context of USAR telerobotics. These interfaces are tested using a consistent set of controlled user studies;
2. **Explore how far the benefits of multisensory interfaces go:** we provide a glimpse of how complex multi-sensory interfaces can be before they become unwieldy, that is, before the effort to understand them overcomes the benefits they can bring. As far as the author knows, this is the first time the effects of these rather elaborate interfaces (involving up to four senses) are explored in this domain.
3. **Evaluate the impact of redundant feedback on these interfaces:** we determine when and how presenting the same type of feedback through different senses is beneficial to the user. Three of the four studies presented cover this topic and lead to interesting results.

4. **Design a reusable methodology for testing HRI interfaces:** by gradually enhancing our evaluation techniques through multiple studies, we have constructed an initial methodology that may guide future multi-sensory HRI interface evaluations in a more standardized manner. The work brings together and iteratively improves separate but related metrics from VR and HRI which may potentially be reused by other researchers.
5. **Introduce the concept of user omni-directional perception:** omni-directional perception is presented here not from the point of the machine or robot, but from the perspective of the user. The concept is brought up as it is impacted by the use of multi-sensory feedback interfaces.

The impact of the proposed work is both broad and deep. Whenever we take advantage of automation, *e.g.*, driving a car, we relinquish some amount of low-level control and understanding in exchange for increased productivity, accuracy, or enjoyment. However, we are at the mercy of the interface designer in terms of how effective we can be, given the reduced amount of available information. If such a design is solely restricted to one human sense, our interface awareness and human perceptual capacities are greatly constrained. Challenging though it may seem, adding feedback to more human senses in a robotic interface not only expands the user's perceptual horizon, but also has the potential to lead to more natural interface designs. Therefore, the use of multiple senses in the design of robotic interfaces as supported by this work has a broad impact on the interface research community.

While the current work focuses on HRI for rescue robots only and includes only one robot, this work explores deeply the area of USAR telerobotics, and presents interface designs based on current guidelines and built upon current interfaces in the area. Such an effort enabled the provision of a base interface experience as enhanced as currently possible. The interface designs presented also explore many types of multi-sensory feedback, encompassing feedback for all senses but the sense of taste.

As a consequence of this approach, and allowing the necessary adjustments, the author believes that the results obtained here could be similarly extended and obtained not only for other types of mission robots, but for other more general types of industrial and social robots, as well as for the simultaneous control of multiple robots.

1.5. Roadmap

The remainder of this work is organized as follows. Chapter 2 discusses topics from different research areas that are relevant to this work. Chapter 3 explains in detail the studies carried out and their results. Chapter 4 reviews the contributions and draws conclusions for this work. It is followed in sequence by the glossary, references and appendices. The latter contains all the data for the four studies presented. Such data is referenced in previous chapters, especially in chapter 3.

2. Literature Review

Humans perform tasks effectively in the real world by combining information from their five senses of sight, hearing, touch, smell, and taste. Our increasing acceptance and reliance on electro-mechanical, digital and virtual machines (*e.g.*, robots, 3D games) to be extensions of ourselves requires us to monitor and assess their performance, and alter their actions should the need arise. Through these extensions, we are confronted with an ever increasing number of low-fidelity sensors, putting us at a greater distance, both physically and cognitively, from the high-fidelity physical world with which we are accustomed to interacting. Humans can filter and integrate large amounts of multi-sensory data in complex, real-world situations, but performing tasks effectively and efficiently in sensorially deprived environments depends almost exclusively on the available interface elements provided by the system. Therefore, there is a growing need for people to interact effectively in sensorially deprived 3D environments.

A surgeon performs a laparoscopic procedure by manipulating tools with constrained degrees of freedom while looking at a video feed from a camera that has possibly been rotated so that a movement of a tool in the "up" direction is shown as down on the screen, or right is swapped with left (Berkelman & Ma, 2009). Teleoperators of robotic devices, such as rescue robots, must deal with similar situations where awareness of the current state of things can get confusing very quickly with possibly catastrophic results. For example, we are taught that when backing a car up, or when changing lanes on the highway, it is best for the driver to turn her head around, in addition to using her mirrors, to look before acting. Because the act of turning the head becomes more difficult as we age, it is reasonable to believe that more drivers will perform these tasks without directly looking, increasing the number of automobile accidents. One possible solution to this is to use feedback from sensors on the car to alert drivers to the environment around them. How to best "display" the information (e.g., sound, vibration, video) in all of the above examples is a Human-Computer Interaction (HCI) question that is nevertheless very relevant to robot interface design.

The fundamental challenges involved in the area of Human-Robot Interaction (HRI) that are motivating researchers lately are related not only to making robots assume human behaviors and tasks and thus have the potential for broad applicability in our society, but also to providing robot "users" feedback.

One feature that greatly affects a robot's applicability to society is its level of autonomy. The more autonomously and unsupervised an HRI system can perform without posing any danger, the higher is its potential to become an independent social agent. But designing a safe robot capable of coping with the unpredictable situations in the real world is a complex task (Dautenhahn, 2007; Bien & Lee, 2007; Miller & Parasuraman, 2007).

Even for urban search-and-rescue (USAR) tasks, Casper & Murphy (Casper & Murphy, 2002) highlight the need for AI support in performing complete search coverage, collaborative teleoperation, and topological mapping (Nielsen & Goodrich, 2006), but argue the problems related to accomplishing the tasks because of sensing and data transmission and power resource limitations. Therefore, in USAR, there is a need to not only enhance robot AI, but also optimize how resources are used to make the robot operator more aware of the situation and hence use his own brain to find solutions to complex situations he may be exposed to. This brings us to the second abovementioned issue of providing robot users feedback.

In the context of USAR (Casper et al., 2000), video and audio feeds, analog data transmission, and wireless Ethernet are generally the only means to get data in and out of the robot. Specifically for USAR, signal frequencies around 450Mhz are preferred for building penetration. However, because of the need for sharing channels, and problems with signal interferences among others, such communication is sometimes not enough to allow the operator to perceive the environment as if he was physically present in the remote environment.

Furthermore, the robot sensors should allow the operator to detect features in the environment that would be impossible to detect even if the operator was there in person, such as detecting heat and CO_2 level variations in the remote environment that may indicate the location of victims nearby. Therefore, it is extremely important to integrate vision algorithms to process image input according to what needs to be detected or monitored in the environment and adapt to different conditions imposed by the environment, such as illumination, dust, and video quality. Much is yet to be done in this direction.

The study of HCI focuses on supporting dialog between people and machines. This dialog can be viewed as a continuous loop of the human interpreting the state of the machine and, by using affordances, altering such a state. A similar dialog occurs in HRI, this time between the robot and its controlling human team as seen in Figure 2.1, which was adapted from the work of Crandall & Goodrich (Crandall & Goodrich, 2002). It shows how local input is converted into remote actuation and how remote sensing is converted into local feedback. The work presented here is focused in the latter part, that is, how to locally display remotely robot-sensed data as feedback to the robot operator.

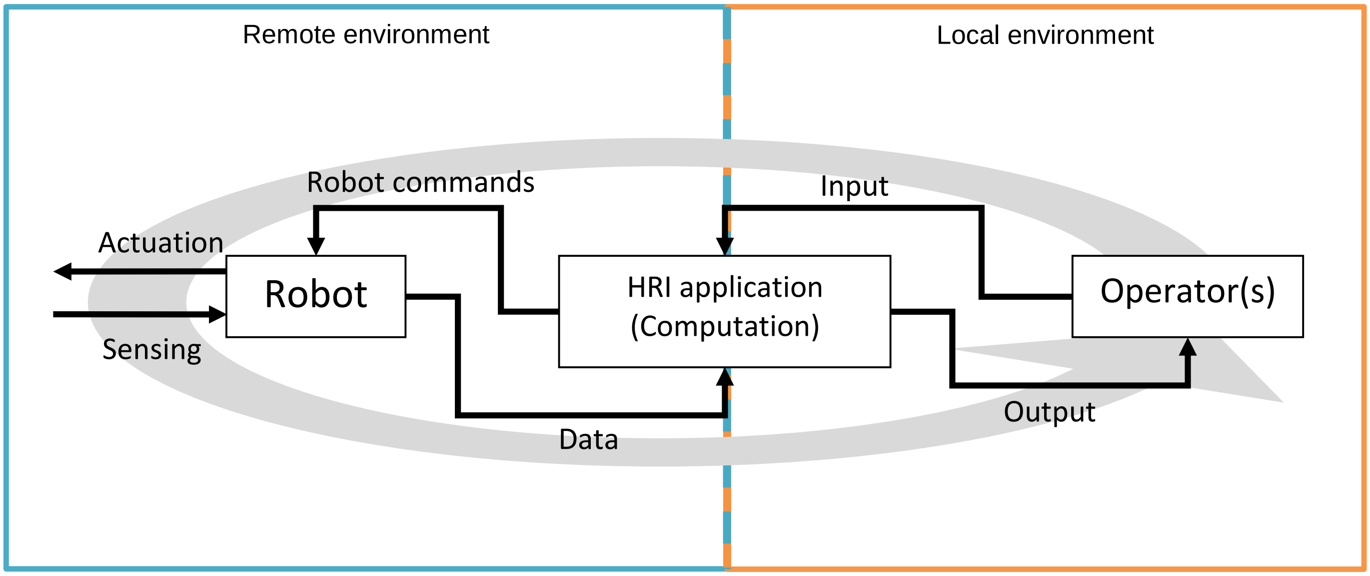


Figure 2.1: HRI interaction loop (Crandall & Goodrich, 2002).

Urban search-and-rescue (USAR) robotics has been identified by both the National Research Council (NRC, 2002) and the Computing Research Association (CRA, 2003) as a critical technology area. Chen *et al.* (2006) give a good overview of how various current HRI technologies can be applied to Army robotic applications, but focus mainly on feedback for human senses in isolation. Robin Murphy (Murphy, 2004) gives a thorough description of the state of USAR robotics, based on significant experience in both real-world (e.g., the World Trade Center disaster) and simulated exercises. Murphy identifies visual search as one of the most appropriate tasks to study for USAR robots, because it requires cooperative perception by the members of the robot team. USAR fits into the class of fielded applications, which involve significant teleoperation, with the robot performing as an extension of the controlling human operator.

As robot teams are being used ever more often to perform more complex tasks, coordination between operators, supervisors, and robots is becoming a complicated problem whose solution requires the use of not only technological but also social and psychological skills.

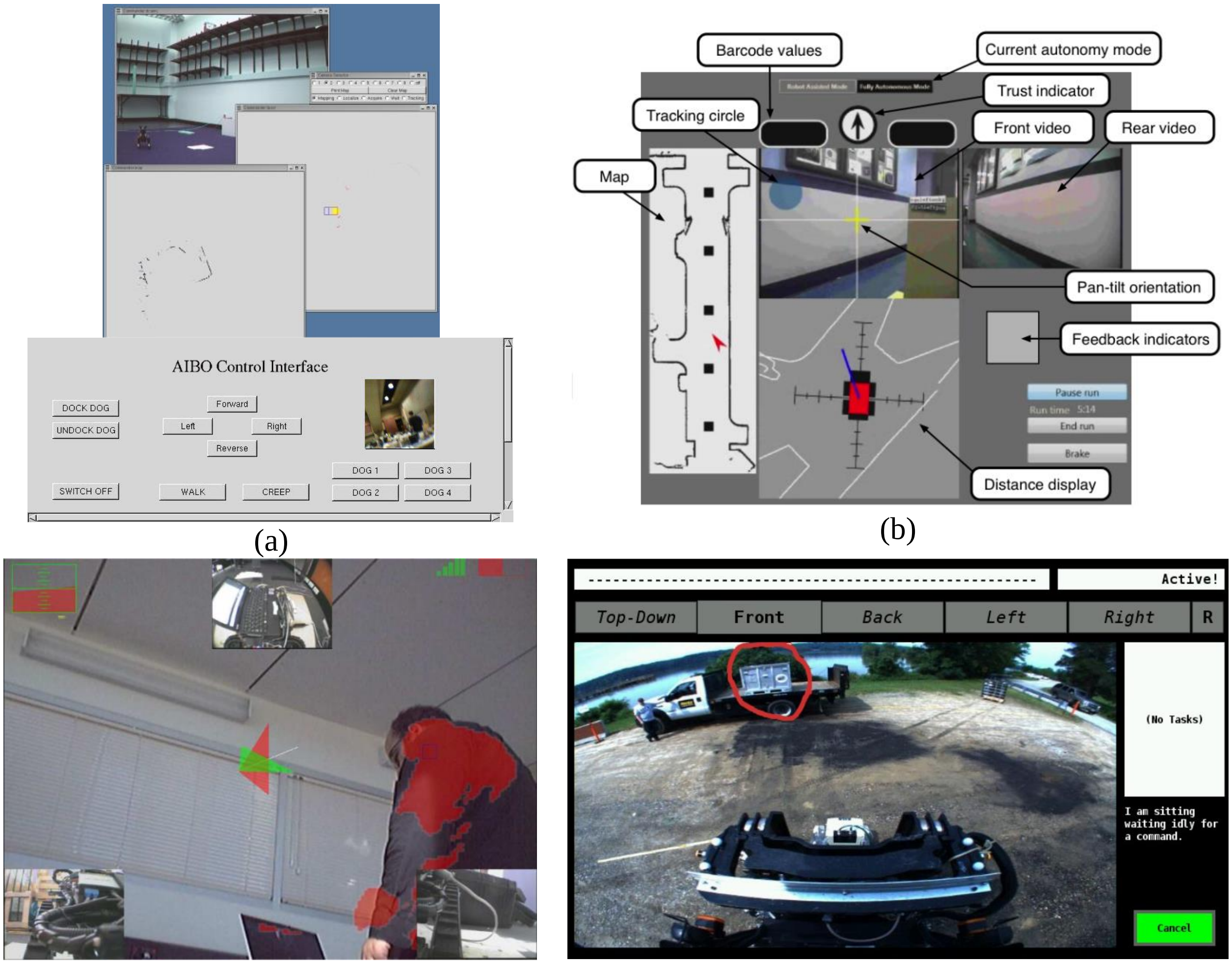
The VR and HRI communities need effective interface design principles and infrastructure for creating and experimenting with multi-sensory interfaces. The following scenario illustrates how HRI, specifically for USAR, could benefit from such an infrastructure.

USAR scenario: A team of experts is deployed on the site of a building collapse, caused by a recent earthquake, with their rescue robot equipped with various sensors (*e.g.*, heat, motion, sonar, video, CO_2). The USAR team's main task is to safely explore the area and search for any survivors stuck in the wreckage. The team is composed of two members with distinct roles: an operator, who controls the robot, and a supervisor, who makes decisions about the actions to be taken by the team and performs the search task. Communication with other teams may be done by either of the team members. Data from the robot sensors is transmitted back to the team and displayed on computer monitors, from which the team must decide on the robot's next move. However, each type of data is displayed in a separate part of the screen (Figure 2.2a), requiring team members to mentally fuse them to gain a better understanding of the environment around the robot (Yanco et al., 2004). In addition, the computer interface used by the operator to control both the robot, its camera, and switch between the many open windows on screen is a mouse and a keyboard or touchscreen on a laptop or tablet. The team either operates the robot close to the entrance where the robot was released on the collapsed site or in a sheltered location nearby. In the latter case, a special team member is responsible for releasing and retrieving the robot in the collapsed site. The same interface is shared by both team members, and it must simultaneously attend to the interaction needs for all of its users.

This scenario underscores the increasing need people have to use intuitive interfaces for field operations, receive and rapidly make sense of large amounts of dynamically changing data, transform it into usable information, and to make decisions about actions to take. Rather than requiring team members to understand and fuse all of the visual data from the robot, the HRI system should have interfaces for each team member, where data is fused in the most optimal way to meet their specific activity requirements. Other interface optimizations could also consist of offloading some of the data to non-visual displays such as audio, touch or smell feedback displays. This is the main motivation behind the research work presented here.

For input controls, they should be mapped to more intuitive interfaces. For example, head and body tracking could be used to define the robot and camera orientation. With training, the use of more and varied input and output modalities could then increase the team's feeling of “tele-existence” (Tachi, 1992), that is, the feeling of “being there” as the robot itself, or at least of being in the space that the robot is occupying. While effective mapping of operator input to robot actuation is an important area of study, it is beyond the scope of this dissertation. The work presented here will instead focus on mapping sensor information to operator displays and use relatively standard input control techniques.

Even though USAR interfaces have evolved significantly in terms of data fusion as can be seen in Figure 2.2, they still heavily rely on visual displays only. To this point, the display problem has mainly been treated as a data visualization problem, and solutions have focused almost exclusively on feeding the sensor data to the eyes. Very few attempts have been made to offload robot information to other sensory modalities or combine the data to reduce cognitive load and improve understanding. The main focus of this work is to explore how well display of information can be done, and discover new scientific principles for multi-sensory display in HRI.



(a) (b) (c) (d)

Figure 2.2: Operator display for urban search and rescue robots. (a) Separate tiled windows (Yanco et al., 2004),(b) multiple windows arranged on screen (Desai et al., 2013a), (c) Single view with overlaid visual sensor displays (Kadous et al., 2006), (d) interchangeable windows with single view layout for operation of a forklift (Correa et al., 2010).

Bi-sensory interfaces have been shown to help search in the past. The work of Gröhn et al. (Gröhn et al., 2005) has shown that audio and visual cues for searching objects are more effective than just providing either of them. In fact, they complement each other. Auditory cues are utilized in the beginning to locate the approximate location of a searched object, while visual cues are used to approach the object once it was visible.

The disadvantages of bi-sensory interfaces have also been discussed in the past. Gunther et al. (Gunther et al., 2004) compared search tasks for objects that emit sound to those that don't.

The comparison was made in terms of the efficiency with which objects are located, as well as environment understanding. Having sounds helped in finding objects, but not in getting a better understanding of the environment. When no sound was present, more visual cues were captured by subjects and that led to better environment understanding.

Survey articles underscore the timeliness of the work proposed here. A report by the 2004 joint DARPA/NSF interdisciplinary study on HRI (Burke et al., 2004) lists among the most important future research directions:

1. Developing and delivering cues to facilitate remote perception;
2. Interaction modalities, both input and output, that depart from today's typical means - keyboards, mice, displays - and can be used in various physical environments;
3. Designing tools for developing human-robot interfaces;
4. Evaluation methodologies and metrics to assess research progress of human-robot teams.

Burke *et al.* (Burke et al., 2004) provide an interesting perspective on issues for HRI research growth, including a list of research directions for the area of HRI, such as studies on levels of autonomy, cognitive studies on human limitations in human-robot tasks, interaction modalities, and scalable and adaptable UI. From their perspective, research on HRI should be focused on three categories: representation, cognition, and control. This research work focuses on representation and cognition, but also on perception, which consists of the operator awareness of the displayed sensory information.

The remainder of this chapter provides a more thorough review of the state-of-the-art of research in the field of HRI, specifically in teleoperated HRI. It provides a general categorization structure of interfaces, devices, taxonomies and techniques in the area.

Some of the definitions in the field were already covered in section 1.2. Section 2.1 identifies the users involved in human-robot interaction. Section 2.2 describes the technology used in the field. Section 2.3 provides a list of current HRI techniques. Section 2.4 discusses taxonomies and requirements. Section 2.5 gives an overview of the common metrics for validation and verification of a human-robot system. Last, section 2.6 gives some conclusions and visions for future work.

2.1. Users

Most HRI researchers have found that at least two people are needed for one USAR robot (Murphy, 2004), one acting as the *operator* and the other acting as the *problem holder* or *supervisor* (Woods et al., 2004). Additionally, robots may be part of a team of humans or robot coalition (Adams, 2006) and cooperate in a shared environment (Atherton *et al.*, 2006). Scholtz (Scholtz, 2003) describes five roles humans can take in USAR HRI: supervisor, operator, mechanic, peer or team mate, and bystander, each of which demands different information and SA.

The *supervisor* (or sensor/payload operator) is a person who monitors sensors and cameras and controls the overall situation (Miller & Parasuraman, 2007). The *operator*'s (or pilot's) role is to ensure the robot is acting as expected. Whenever the robot is unable to autonomously deal with a situation, the operator intervenes to make it perform the right action. A *mechanic* assists in the resolution of remote hardware and software issues that the operator cannot remotely resolve. The *peer* or *team mate* represents other supervisors and operators that are controlling other robots or other parts of the robot. The *bystander's* job is to affect the robot actions by directly interacting with it in the remote environment.

For some tasks, such as USAR, HRI teams are coordinated individually by leaders and in general by managers. Although such personnel are not directly in contact with the robot, they constantly communicate with the robot teams, access relevant data, coordinate the many HRI teams and decide the feasibility of certain activities or the course of the mission as a role (Murphy, 2004; Casper et al., 2000; Osuka et al., 2002).

Other roles include *mentor*, who teaches or leads, and an information consumer who simply obtains information (e.g., in a reconaissace task) (Goodrich & Schultz, 2007). Depending on the complexity of the search and resuce task, roles can become very specialized. For wilderness search and resuce (WiSAR) operations using UAVs, for example, specific roles for video analyst and ground searcher are required (Adams *et al.*, 2009).

Human tasks in a human-robot team (HRT) include: mission (re)planning, robot path (re)planning, robot monitoring, sensor analysis and scanning, and target designation (Crandall & Cummings, 2007).

2.1.1. Teamwork

Interaction between members inside or among teams is crucial to goal achievement (Casper & Murphy, 2002). Establishing etiquette rules is recommended to guarantee objective, concise and unambiguous communication (Sheridan & Parasuraman, 2006). Depending on the task, environmental stressors and fatigue levels may affect the performance of the team as a whole, from a human and also from a robotic perspective (Miller & Parasuraman, 2007; Murphy, 2004; Freedman & Adams, 2007).

2.1.2. Team Composition

Some research groups work with a single robot and multiple operators (Murphy, 2004; Osuka et al., 2002; Yanco et al., 2004). Most research on cognitive load presents experiments where a single operator looks over a set of robots (Goodrich et al., 2001; Adams, 2006; Crandall & Cummings, 2007; Humphrey et al., 2008; Parasuraman et al., 2003). But reducing the human-robot ratio may not always be possible.

Different types of robots with different roles may also be involved in a task. *Marsupial robots*, for example, are larger robots whose main role is to protect and carry other smaller robots to task areas (Murphy, 2004). Once a desired location is reached, the smaller robots are released to perform their tasks (Osuka et al., 2002).

When having one operator control more than one robot, many issues may occur, such as uncalibrated trust (Desai et al., 2013a), mode error, reduced situation awareness, loss of operator skill, and unbalanced mental workload (Parasuraman et al., 2005). Most of these can be associated with the constant switching among different robot situations (Goodrich et al., 2005; Burke et al., 2004). Casper & Murphy (Casper & Murphy, 2002) have reported that USAR operators could not perform as well without a supervisor, due to the workload required in controlling the robot itself and performing a search task.

Figure 2.3 is a refinement of the work of Yanco and Drury (Yanco & Drury, 2004) that presents the possible relations between the number of robots and the number of operators. Figure 2.3 also derives a similar relation between the operator-robot team and the number of tasks they may perform. There might also be collaboration between humans and robots (Yanco & Drury, 2002; Yanco & Drury, 2004). The refinement and optimal matching between the number of operators, number of robots, and number of tasks for an HRI system is a non-trivial problem that requires the attention from researchers with a great deal of experience and knowledge in human-robot interaction.

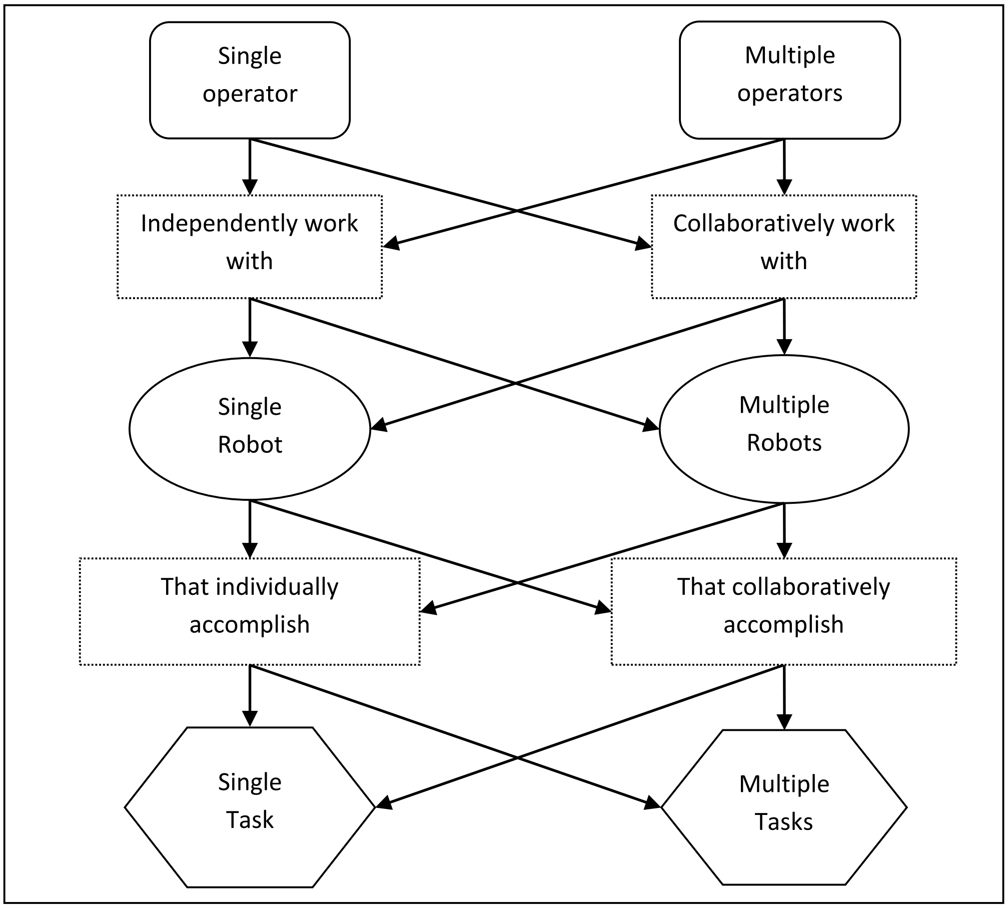


Figure 2.3: Potential configurations between operators, robots and tasks.

2.1.3. Team Presence

While the operator is directly controlling the teleoperated robot, the robot output is shared among the entire team, but parts of the interface are more important for some members than for others. Hence, the sense of presence from the point-of-view of each member must be measured according to their role. However, since presence measurement is currently still a topic of prolific research even in general terms, measuring presence for each of the specific categories of users in the HRI domain is an open topic.

2.2. Technology

The design of technology used in teleoperated HRI is mostly directed towards four types of users: operators, supervisors, mechanics and information consumers (GS09). Although there are systems to assist in the interaction with bystanders, such as the ones used in gesture and face recognition (Song et al., 2010), in practice in USAR this higher level of processing is typically done by the operator and/or supervisor themselves. Because of this, the technology presented here is directed to these types of users and divided in four categories (Table 2.1).

Table 2.1: Relation between the four technology categories in HRI.

	Operator side (local):	*Robot side (remote):*
Sense (In):	*Displays:* Hardware and software that process and present data from sensors to operators and robot AI.	*Sensors:* Hardware and software that capture data from the HRI system and the remote environment to be transmitted to operators and robot AI;
Response (Out):	*Input:* Hardware and software interfaces that collect and process data from operators and robot AI to be transmitted to the robot and other operators or robots.	*Actuators:* Hardware and software that transform data from operators and robot AI into interactions between the HRI system and the remote environment surrounding the robot.

2.2.1. Sensors

Table 2.2 lists the most common types of sensors used in HRI systems, partly extracted from Sciavicco and Siciliano (2000). On the description column in Table 2.2, notice the prevalence of visual-related sensors in obtaining information from the environment.

Another way of categorizing sensors is according to how they perceive the environment. In this case, sensor categories could be divided as radiation (Suarez & Murphy, 2012; Zhang et al., 2013), physical properties, movement, chemical (Aubrey *et al.*, 2008) and mechanical sensors.

Table 2.2: Sensor types used in HRI.

Type	*Description*
Visual	*Purpose:* 2D camera feed analysis, 3D perception of the environment, visual extra-human perception (infrared, radiation, spectrum filtering), atmospheric and structural analysis (e.g., void spaces location in USAR). *Used by:* operators, supervisors, mechanics. *Hardware:* emitters (flash lights, laser diodes, lasers, infrareds) and receivers (photoelectric sensors, cameras).
Haptic	*Purpose:* detect collisions, vibration, tilt sensing and forces applied to joints or an external object surface. *Used by:* operators *Hardware:* collision sensors, force sensing resistors (FSRs) and contact sensors such as strain gauges, shaft torque sensors, wrist force sensors.
Proximity	*Purpose:* collision avoidance, fall avoidance. *Used by:* operators. *Hardware:* capacitive proximity sensors, photoelectric sensors, but also range sensors such as visual sensors.
Atmospheric	*Purpose:* detect humidity, temperature, pressure. *Used by:* operators, supervisors, mechanics. *Hardware:* humidity, temperature, pressure.
Olfactory	*Purpose:* atmospheric analysis and specific gases detection, such as CO_2. *Used by:* supervisors, operators. *Hardware:* chemical sensors.
Audio	*Purpose:* Perceive sound or noise in the environment or in the robot, structural analysis. *Used by:* operators, supervisors, mechanics. *Hardware:* (directional) microphones, ultrasonic emitters and receivers.
Pose, Position and Velocity sensors.	*Purpose:* detect location and orientation of robot or its parts and as well as speed of movement. *Used by:* operators, supervisors. *Hardware:* GPS systems, accelerometers, gyroscopes, potentiometer, linear variable differential transformers (LVDT), inductosyns, encoders, resolvers, inertia measurement units (IMUs), tachometers, strain gauges.

2.2.2. Input

Table 2.3 lists input devices used in HRI in terms of potential applicability and user category. They range from simple PC devices to virtual-reality and application-specific ones.

Table 2.3: Input device types used in HRI.

Type	*Input Capabilities*	*Applicability*	*Used by*
Keyboard	-Sequential character input.	-Symbolic input; -Graphical user interface (GUI) control; -General param. control.	Operators, supervisors, mechanics.
Mouse	-2 DOF input; -Binary input.	-GUI control; -General param. control.	Operators, supervisors, mechanics.
Joystick and gamepads	-2 , 3 or 6DOF input.	-Robot navigation; -Camera/sensor control.	Operators.
Touchscreen	-Binary input.	-GUI control; -General param. control.	Operators, supervisors.
Tablet displays	-Binary input; -2 DOF input.	-GUI control; -Camera/sensor control; -Robot navigation.	Operators, supervisors.
Audio input	-Analog input.	-Speech recognition; -Voice recognition; -Command issuing; -Team coordination.	Operators, supervisors.
Motion tracking	-2, 3 or 6DOF input.	-Monitoring and search; -Robot control; -Interface interaction; -Actuation.	Operator, supervisors.

2.2.3. Output

Displays are used to present or output data about the status of the robot to its operator. They can be categorized according to the sense they relate to: audio, visual and data (Yanco & Drury, 2004), the latter encompassing interfaces for the remaining three, seldom-used human senses. However, data is often mapped into a visual abstraction on the GUI. Due to high human sensitivity to visual information over information provided through other senses, this approach tends to be effective (JAK93; Kobayashi et al., 2005).

Despite optimization efforts, visual data overload is still a problem in HRI interfaces and leads to operator cognitive overhead and a decrease in productivity. On the other hand, the use of senses other than vision to reduce overload is increasing (Zelek & Asmar, 2003; Calhoun et al., 2003; Lindeman et al., 2008). Lindeman *et al.* (Lindeman et al., 2006; Lindeman et al., 2003; Lindeman & Yanagida, 2003; Sibert et al., 2006) have presented results of using vibro-tactile displays on the hips, back, and thorax. Other types of haptic feedback displays have been proposed in VR, a review of which can be found in Zelek & Asmar (Zelek & Asmar, 2003). Force feedback has also been explored in robot tele-manipulation (Griffin et al., 2005; Mitra & Niemeyer, 2008; Johannes et al., 2013). Table 2.4 gives an overview of the types of displays used in HRI and VR (Bowman et al., 2005).

Table 2.4: Display device types used in HRI.

Type	*Hardware*	*Output capabilities*	*Applicability*
Visual	-LCD / CRT displays -Head-mounted displays, CAVEs, other stereo-display devices*	-Visual stereo and mono display.	-Camera feed display, processed image and human vision; -Thermal imaging and infrared data; -Ultra-violet data; -Ultrasound data; -Other sensors data; -Map view; -Mission diagrams.
Auditory	-Speakers -Headphone -Bone conduction headset*	-Aural surround, stereo and mono display.	-Environment sound; -Team communication; -Sensor monitoring.
Haptic	-Vibro-tactors (1D-2D) -Force-feedback joysticks* -Phantom(Phantom, 2014)* -Falcon* -Gloves and exoskeleton*	-Localized 3D spatial haptic display.	-Information alerts; -Directional cueing; -Environment information and feedback.
Olfactory	-Air cannon (Yanagida et al., 2004) * -Tube-delivery system* -Fan-based system*	-Smell display.	-Atmospheric data.

**: Used in VR but not yet in HRI.*

2.2.4. Actuators

Actuators define the HRI technology used to physically interact with the environment. Table 2.5 lists the devices commonly classified as actuators (Sciavicco & Siciliano, 2000) and used by the operator as such.

Table 2.5: Actuator types used in HRI.

Type	*Applicability*	*Hardware*
Electric motors	-Locomotion; -Movement; -Grabbing & moving objects; -Pose control.	-Robotic joints (rotary, prismatic); -Stepper motors; -Linear motors; -Etc.
Artificial muscles	-Precise limb movement.	-Collision sensors, -Force sensing resistors (FSRs); -Contact sensors.
Pneumatic motors *Hydraulic motors*	-Used in industry for diverse purposes, but not used for mobile robotics.	
Shape memory alloys	-Used for providing small movements.	
Electro-active Polymers (EAPs)	-Biological muscle behavior emulation.	

2.3. Interaction Techniques

A mission-specific HRI system consists of a set of technologies and methodologies combined to solve a problem in a specific domain. Robots are used as a communication channel between the environment and specialists (Berkelman & Ma, 2009).

In every case that such a robot is used, the accompanying HRI system is required to have the following set of features:

- Sensors to gather data from the remote environment;
- Display devices to present processed data to the user;
- Input devices to give the operator control over the robot;
- A processing unit to convert data from the user to the robot and vice-versa;
- An autonomous reasoning unit to react to the input from the environment in place of the operator. This is not a necessary feature but it has become increasingly common.

Human-robot interaction techniques implement these features in an HRI system. This section groups HRI techniques according to these important features.

2.3.1. Output Techniques

This section describes the methodologies, algorithms and hardware setups that have been used to display data to the user or robot.

2.3.1.1. Visual Feedback

As mentioned in section 2.2.3, visual techniques generally include LCD or CRT monitors to display data to the operator. But what and how data is displayed varies for each application. Common techniques exist, however, and they are presented in this section.

A technique called 3D mapping consists of discovering object positions in 3D space relative to the robot by analyzing different types of environmental data. Such data may be the output from sonar, cameras, or photoelectric sensors, for example. Each system has its own way of processing data (Johnson et al., 2003; Nielsen et al., 2007; Yanco et al., 2006), but there are well-known and more widely used techniques (Zelek & Asmar, 2003), such as optical flow, stereo and probabilistic vision (Zelek & Asmar, 2003), and point clouds (Suarez & Murphy, 2012; Zhang et al., 2013).

Different robot perspectives have also been used to improve the amount and organization of visual information on screen (Atherton *et al.*, 2006; Cooper & Goodrich, 2008; Nielsen et al., 2007; Nielsen & Goodrich, 2006). They represent camera models similar to the ones used in virtual environments (VEs), such as first-person view (Micire et al., 2011; Drury et al., 2006b), third-person view (Nielsen & Goodrich, 2006) and map, god-like or bird's-eye view (Dury et al., 2003), the latter using either a robot-up or egocentric perspective or a north-up or geocentric perspective (Bowman et al., 2005). Gestures and facial expressions visual displays (monitors or robotic units) can also be used to convey feedback.

2.3.1.2. Aural *Feedback*

Audio feedback can be used to display robot data in either analog (e.g., direct sound stream) or symbolic (e.g., speech sysnthesis and sound icons) forms. Aural feedback has been shown to improve user performance in search (Gröhn et al., 2005; Gunther et al., 2004) and remote vehicle-control (Nehme & Cummings, 2006) tasks.

An area closely related to aural feedback is data sonification, which attempts to explore representation of any kind of data through sound. Research in this area encompasses a wide gamut of application areas, such as art (Maes et al., 2010; Größhauser & Hermann, 2010), security monitoring (Höferlin et al., 2011), safe driving (Spath et al., 2007; Larsson et al., 2006), search (Gonot et al., 2007; Gröhn et al., 2005), geo-location (Zhao et al., 2005), text-writing (Rinott, 2004), process-control (Walker & Kramer, 2005), remote-vehicle control (Nehme & Cummings, 2006), and image analysis (Dewhurst, 2010).

2.3.1.2.1. Properties of Hearing that Affect Sound Display

Because of the omni-directional nature with which humans perceive sound, audio feedback can be effectively used to provide alerts and reminders and call the user's visual attention to specific parts of the graphical user interface at which he is not looking. While speech is always presented in a sequential and therefore time-consuming mode, non-speech audio provides the possibility to encode multiple bits of information in a parallel manner, for example, by using the different attributes of sound, such as pitch (Golledge, 2011), rhythm, loudness, timbre (Shinn-Cunningham et al., 2005), and location (Lindeman et al., 2008; Sheridan & Parasuraman, 2006). Moreover, non-speech sound is much less disruptive than speech (Spath et al., 2007).

In fact, human auditory perception is actually capable of separating out at least a few sound sources and focus on a specific one, the so called "Cocktail party effect" (Gonot et al., 2007). Audio source location identification is usually determined by the human auditory system thanks to the Interaural Time Difference (Dubus & Bresin, 2011). Because humans generally tend to underestimate the distance of sound sources (Loomis et al., 1998), spatially separating sound sources could decrease the mental effort of selective attention.

However, according to Zhao *et al.* (2005), human auditory perception is less synoptic than visual perception. In other words, it is harder to merge data from different audio sources than to merge data from different visual sources.

In terms of the acceptable real-time audio feedback delay relative to other senses, the levels of delay acceptable seem to vary depending on how they are integrated with other senses. A 20 ms delay between visual and sound is an acceptable and imperceptive value for most users (Maes et al., 2010). However, when sound feedback is integrated with haptic feedback, the acceptable audio delay drops to 2 ms (Difilippo & Pai, 2000).

2.3.1.2.2. Sonification Techniques

Different data sonification techniques exist (De Campo, 2007). The most commonly found techniques in the literature can be broadly separated in three categories: continuous data representation (e.g., audification (Hermann & Hunt, 2005) and parameter mapping (Hermann & Ritter, 1999)), discrete point data representation (e.g., earcons (Larsson et al., 2006)), auditory icons (Larsson et al., 2006; Barrass, 2005; Brazil, 2009), and spearcons (Wersényi, 2009)) and model data representation (e.g., sonic mapping (Brazil, 2009; Pauletto & Hunt, 2004; Dubus & Bresin, 2011; Nasir & Roberts, 2007)).

The imitation of sound properties that the user commonly perceives in real world objects (e.g., large or slow-moving objects generate louder and lower pitch sounds, while fast-moving or small objects generate quieter and higher pitch sounds) is among the most popular ways to map sounds (Hermann & Ritter, 1999; Walker & Kramer, 2005). Pitch is known to be one of the most prominently used attributes of sound (Dubus & Bresin, 2011). There are also mappings commonly associated with specific physical properties. For example, distance is generally related to sound level, frequency and size to pitch, and velocity to tempo. Spatialization, that is, making sounds feel they originate from a specific point in space, is almost only used to render kinematic quantities (NR07; Gonot et al., 2007).

The number of sounds that can be differentiated by a human varies according to the sound frequencies, their pattern, location, as well as the listener’s physiological features (e.g., the size and shape of ears) and sound listening experience. Among the factors that affect audio feedback perception are continuity/discreteness, realism/cartoonification (Rocchesso et al., 2004), (un)expectability (Wersényi, 2009), urgency (Larsson, 2009; Larsson et al., 2006), and verbality (Edworthy & Hellier, 2000).

2.3.1.2.3. Interactive Sonification

The area of interactive sonification involves display of sound by interactions through input devices with virtual environments and their objects (Diniz et al., 2010) or even by the direct capture of body gestures (Maes et al., 2010; Größhauser & Hermann, 2010). According to Hunt and Hermann (Hermann & Hunt, 2005), interactive audio perception implies that the the data-to-sound mappings depend on context, goals, and the user's interaction. In addition, these mappings determine whether they allow the practiced user to build an expectation of the behavior of the sound-producing system and hence experience *flow*.

2.3.1.3. Tactile Feedback

Broadly speaking, our sense of touch can be divided into kinesthetic and cutaneous sub-senses. Kinesthetic stimulation maps roughly to forces being exerted on, and sensed by, mechanoreceptors in the joints, tendons, and muscles. For example, we feel the weight of a heavy object held in an upturned palm because the object weight exerts forces on the wrist, elbow, and shoulder joints, and we exert opposite forces to counter the weight. *Proprioception* is another example of a kinesthetic sense. Cutaneous or tactile stimuli, in contrast, are sensed through mechanoreceptors in the skin. The various kinds of receptors allow us to sense other types of stimuli, such as thermal properties, vibration of varying frequencies, pressure, and pain. Since the skin is the largest organ in the body, cutaneous cues are an attractive method of displaying information.

Because we are using vibro-tactile feedback in our studies, the related work here presented focuses on tactile instead of kinesthetic feedback (Dominjon & Lecuyer, 2005). Tactile cues have been used as display devices on various parts of the body such as the forehead, tongue, palms, wrist, elbows, chest, abdomen, back, thighs, knees, and foot sole (Lindeman, 2003; Zelek

& Asmar, 2003).

Based on Lindeman (Lindeman, 2003), the parameters that can be directly mapped to data output from the robot or the environment are summarized in Table 2.6, accompanied by suggestions for the sensor data type they can represent. These mappings are intuitive propositions, not experimentally validated. In Table 2.6, *analog display* presents a continuous range of values and *symbolic output* presents codes or symbols that an operator may recognize or associate with some idea.

Table 2.6: Vibro-tactile parameters and suggested mappings (Lindeman, 2003).

Tactor configuration parameters	*Suggested outputs*
Intensity	Analog display
Frequency	Analog display
Vibration duration	Symbolic output or analog display
Sequence of different/equal vibrations interspersed by non-vibration periods (pulses)	Symbolic output or analog display
Spatial arrangement	Symbolic output or analog display

2.3.1.4. Olfactory Feedback

Olfactory feedback has been explored in VR and different technologies have been devised for providing it to users. The most common ones are projection-based devices using wind (Noguchi et al., 2009), air puffs (Yanagida et al., 2004), or close-to-nose tube-delivery devices (Narumi et al., 2011; Yamada et al., 2006). Effects of smell in human cognition and performance have been measured in the past (Herz, 2009; Moss et al., 2003), but no research was found that applied smell to remote teleoperation or as a source of aid in a search task as is done in our fourth study described in section 3.5.

2.3.1.5. *Gustatory* Feedback

Many researchers have come up with different solutions for providing gustatory or palatal feedback. There are devices that provide the correct tactual and aural sensation when one is drinking (Hashimoto et al., 2006) or eating (Iwata et al., 2004). Others devices present a range of flavors to the users (Nakamura & Miyashita, 2012) through a mix of flavors (Maynes-Aminzade, 2005), scents (Narumi et al., 2011) and provision of electrical current (Ranasinghe et al., 2012). Other devices simply enhance the current experience of eating (Tanaka et al., 2011).

Though not explored in this work, a relationship between taste feedback and robot teleoperation could be envisioned. The sense of taste could be associated with chemical or thermal temperature data collected from air or soil from a remote robot. The operator would then make decisions on whether to proceed on a certain route or get new soil samples based on the feedback.

2.3.2. Input Techniques

In Human-robot interaction, specifically in robot teleoperation, input techniques vary according to the types of user and robot, and the application goals. Because the focus of this work is on output, input techniques for teleoperated robots will be covered briefly in this section.

In terms of level of action, a robot may receive input and represent it in exactly the same way as the movement of the operator's body, called *direct mapping*, or map it to other types of movement or control as an *indirect mapping* (Poupyrev et al., 2000; Poupyrev et al., 1999). An example of direct mapping is using arm movement to control a robotic arm. An example of indirect mapping is using a joystick to control robot movement speed. Input is also used for system control, such as setting up the robot's control parameters and algorithms. Input may be done remotely with a machine solely dedicated to that purpose (Taylor II et al., 2001).

Most of the time robot input works in imperative mode. However, reasoning robots exist that can learn from bystanders or team members nearby (Murphy, 2004). In addition, computer vision and AI may aid its decision of what it should consider as valid or relevant input. Operability may be categorized in terms of locality. A robot is operated locally (directly) when operator and robot are in the same place, or remotely (indirectly), when they are in adjacent rooms, such as operating a robot arm in a laboratory or factory, or when operator and robot are geographically apart from each other (Hill & Bodt, 2007).

2.3.3. Other 3D User Interaction Techniques Relevant for HRI

Research in HRI could benefit from research in the area of 3D User Interaction (3DUI) (Burns et al., 2005) (Henry & Furness, 1993; Mine et al., 1997; Larssen et al., 2006; Razzaque et al., 2002; Usoh et al., 1999; Zanbaka et al., 2005). The main difference between HRI and 3DUI techniques is that, while the latter has unlimited access to information about the environment, the former is limited by the data given by the sensing devices, which might even be imprecise or incorrect.

3DUI techniques may be divided into selection (Atherton *et al.*, 2006) and manipulation, travel, wayfinding (Billinghurst & Weghorst, 1995; (Micire et al., 2011), system control and symbolic input (Bowman et al., 2005) techniques. Recently a trend towards the addition of *body gesture* and *perception* has also been discussed among researchers. Steinfeld *et al.* (Steinfeld et al., 2006) divides HRI tasks in five categories for task-oriented mobile robots. They are perception, navigation, manipulation, management, and social. Notice how closely-related these are to the abovementioned five areas of research in 3DUI. Both of these are shown for comparison in Table 2.7. Notice there is some overlap between the two taxonomies. A recommendation by the author is that both research communities should discuss whether these two taxonomies should actually converge towards a single taxonomy, since the only overall difference is that interactions take place with a real versus a virtual world.

A superset encompassing both categorizations is proposed in Table 2.7 as a generic *Host Interactions Categorization*. A *host* is the remote entity the user or operator is in control. The host is used by the user or operator to observe and potentially affect the remote or virtual environment and interact with other co-located entities. Host management relates to the control of multiple robots in HRI or virtual entities or avatars in 3DUI. Host perception encompasses techniques to aid how the user perceives (*i.e.*: perception of output and host-body display and mapping of host-body to user-body) and interacts with the host robot or avatar it is controlling (*i.e.*: input mapping between user-body to host-body and between their physical and mental/processing capabilities). Pose finding indicates techniques that allow the positioning of the host physical or virtual representation to allow it to perform a manipulation. The other categories are the same ones used in the two previous categorizations. As techniques grow in number and variety, however, it is expected that further sub-categories be added to each of the types of interaction. Tables 2.8 through 2.10 in section 2.5.5.1 provide some insight on potential sub-categories that could be added to the list on Table 2.7.

Tables 2.8 through 2.12 seem to indicate that the VR and 3DUI interface evaluation techniques could be effectively utilized for evaluating HRI interfaces. The methodology developed along the studies presented in this work attempts to do exactly that. It merges techniques used in VR, 3DUI and HRI, and applies them to the evaluation of multi-sensory interfaces for USAR robot teleoperation.

Table 2.7: The first two columns respectively show research areas in 3DUI and HRI (the latter for task-oriented mobile robots).The third column presents the proposed Host Interaction Categorization as a merge of the 3DUI and HRI categorizations

3DUI	HRI	Host Interaction Categorization
Selection	Perception	• Perception: 1) Environment; 2) Host.
Manipulation	Manipulation	• Selection
Travel	Navigation	• Manipulation 1) Pose-finding.
Wayfinding		• Navigation: 1) Wayfinding; 2) Travel.
System control	Management	• Host Management
Symbolic input		• System Control
Body gesture and perception	Social	• Symbolic Input • Social Interaction

2.4. HRI Taxonomies and Requirements

As mentioned by Miller & Parasuraman (Miller & Parasuraman, 2007) human-robot tasks have already been categorized and classified using various HCI models, such as GOMS (Yanco et al., 2004), Plan-Goal graphs, PERT, Critical Path Method charts, Petri Nets, Hierarchical task network planner, and CIRCA among others. Requirements for HRI systems have also been emphasized as a result of data collected during robot competitions (Yanco et al., 2004; Osuka et al., 2002). Yanco & Drury (Yanco & Drury, 2004) have devised a taxonomy for HRI systems and reported on other existing ones. The results obtained by these research groups are a good starting point during the analysis and design of HRI systems.

2.5. Experimental Validation and Verification

HRI techniques and interfaces must be validated and verified before they are put into use. This section explains how this process can be accomplished.

The techniques to assess an HRI system may be categorized as pre-experimental, experimental, post-experimental and atemporal assessment techniques. Most techniques presented here evaluate either the entire system or its software and hardware. There are techniques, however, that evaluate the operator only, such as the widely used NASA-TLX (Hart, 2006; Parasuraman et al., 2005; Nielsen et al., 2007), which is applied during or after an experiment. Others are used to define how to measure certain parameters, such as awareness (SAGAT and SCAPE methods) (Drury et al., 2006a; Yanco & Drury, 2002).

2.5.1. Pre-Experimental Assessment

Pre-experimental assessment implies following a set of guidelines during system development. Guideline examples include those of Scholtz (Scholtz, 2002; Scholtz, 2003) and Drury (Drury et al., 2004) (Dury et al., 2003). Robot simulation has also been used as a pre-experimental assessment technique (Lewis et al., 2003). A similar approach is taken in the research work presented here.

2.5.2. Experimental Assessment

Experimental assessment may be objective or subjective. Examples of objective assessment are video monitoring and software and hardware logging (Yanco et al., 2004). Techniques include thinking aloud (Dury et al., 2003; Steinfeld et al., 2006), SAGAT and its derivations (Drury et al., 2006a). Notice, however, that techniques such as video monitoring may still be subjectively biased by the experimenter intervention during the process of information extraction from the video stream. Examples of subjective assessment are information annotation using pen and paper and post-filtering collected data as explained above (Yanco et al., 2004; Osuka et al., 2002). Techniques include SART (Parasuraman et al., 2005).

2.5.3. *Post*-Experimental Assessment

Post-experimental assessment collects subject opinion after the experiment is over. Questionnaires are commonly used, whose answers are recorded in audio or paper.

2.5.4. Atemporal Assessment

HRI assessment may also be performed on an HRI system independent of experiments. A common way of doing this is through inspection or, that is, making sure the system works as expected. This approach is also called *heuristic evaluation* can be done subjectively or through a formal assessment.

2.5.5. HRI Metrics

In order to evaluate the usefulness of any system, a set of metrics is required. This section describes commonly used VR and HRI metrics.

2.5.5.1. Task Metrics

An HRI system may be evaluated according to a variety of task metrics. Here, they are categorized mostly according to Steinfeld (Steinfeld et al., 2006), Crandall & Cummings (2007) and Goodrich (Goodrich et al., 2005). Some are recognized as general performance metrics that are system independent, such as effectiveness and efficiency. Others are more specific to HRI tasks. They are categorized according to common HRI tasks: navigation, perception, management, manipulation and social tasks (Table 2.8, Table 2.9 and Table 2.10 respectively).

Table 2.8: Common metrics for Navigation and perception tasks.

Navigation	-Effectiveness metrics	-Percentage of navigation task completed; -Coverage of area; -Deviation from planned route; -Obstacles avoided or, not yet, but that could be overcome; -Global and local navigation awareness.	
	-Efficiency metrics	-Time to complete task; -Operator time for the task; -Average time for obstacle extraction; -Number of obstacle encounters.	
	-Non-planned looping /workload metrics	-Interventions per unit time; -Ratio of operator time to robot time.	
Perception	-Passive perception metrics:	-Detection measures; -Recognition measures; -Judgment of extent; -Judgment of motion.	
	-Active perception metrics:	-Active identification metrics:	-Efficiency; -Effort.
		-Stationary search metrics:	-Detection accuracy for targets within range; -Efficiency as time to search or -non-overlapping coverage; -Ratio of coverage to sensor coverage; -Operator confidence in sensor coverage.
		-Active search metrics:	-Efficiency; -Number of identification errors; -Degree of operator fusion.

Table 2.9: Common metrics for manipulation and social tasks.

Manipulation	-Degree of mental computation; -Contact errors.
Social	-Interaction characteristics; -Persuasiveness; -Trust; -Engagement; -Compliance.

Table 2.10: Common metrics for management tasks.

Management	- Fan out metrics:	- Attention allocation efficiency; - Interaction efficiency; - Neglection times; - Switch time delay.
	- Intervention response time metrics:	- Time to deliver request from the robot; - Time for the operator to notice request; - Situation awareness and planning time; - Execution time.
	- Level of autonomy discrepancies	

2.5.5.2. *Performance Metrics*

Performance metrics also exist for HRI. They are divided according to which part of the system is being evaluated: the entire system, or only the robot or operator (Table 2.11 and Table *2.12*).

Table 2.11: Common metrics for system performance.

System	- Quantitative performance metrics:	- Effectiveness; - Efficiency.
	- Subjective ratings metrics:	- Ease of use; - Ease of learning.
	- Appropriate utilization of mixed-initiative metrics:	- Number of requests for assistance made by robot; - Number of requests for assistance made by operator; - Number of interruptions of operator rated as non-critical; - Functional primitive decomposition; - Interaction effort.

Table 2.12: Common metrics for operator and robot performance.

Operator	- Situation awareness (SA) metrics:	- Human-robot SA; - Human-human SA; - Robot-human SA; - Robot-robot SA; - Human's overall mission SA; - Robot's overall mission SA.
	- Workload. - Accuracy of mental models of device operation. - Time to learn; - Ability to remember; - Error rate; - Subjective satistfaction.	
Robot	- Self-awareness; - Human awareness; - Autonomy.	

2.5.5.3. Other *Types of Metrics*

HRI researchers have also defined metrics according to other features in the system, such as human-robot ratio or robot type. Previous work in the VR and HRI fields suggests that levels of operator presence, SA, and workload are good measures of overall interface effectiveness (Slater et al., 1994; Endsley & Garland, 2000; Hill & Bodt, 2007). As these measures are not independent (*e.g.*, better SA can reduce workload), the redundancy can be used to cross-validate the measures.

1. For presence (Mantovani & Riva, 2001; Slater & Usoh, 1994; Slater et al., 1994; Usoh et al., 2000; Lindeman, 1999; Interrante et al., 2007; Lindeman et al., 2004; Kontarinis & Howe, 1995; Lindeman et al., 1999) (Zeltzer, 1992; Fontaine, 1992), the SUS-PQ (Usoh et al., 1999) questionnaire is used, along with Witmer & Singer's (Witmer & Singer, 1998) ITQ questionnaire to predict user likelihood of achieving presence.
2. For SA (Endsley & Garland, 2000; Drury et al., 2004; Drury et al., 2006a; Scholtz et al., 2004; Desai et al., 2013b), the SAGAT and SART questionnaires are used (Endsley et al., 1998). An approach for measuring SA is asking the operator to draw a map with the places traversed by the robot (Billinghurst & Weghorst, 1995) and to pinpoint victims' locations. Another approach is to ask about environment changes after or in-between tasks (Goodrich et al., 2005);
3. For workload (Hill & Bodt, 2007; Goodrich & Olsen, 2003; Zhao et al., 2005), Hart & Staveland's (Hart & Staveland, 1988) NASA Task Load Index (NASA-TLX) questionnaire (Hart, 2006) asks the user to rate differenct kinds of workload, such as mental or physical, for a performed task upon its completion. Other physiological measures, such as heart rate, heart-rate variability, skin conductance, and skin temperature are used to determine user engagement (Rowe et al., 1998; Meehan et al., 2002) and dynamically alter interface elements (Steinfeld et al., 2006);

4. For cognitive load, biometrics can be used (Ikehara & Crosby, 2005), or secondary tasks such as the Stroop task (Gwizdka, 2010). Performance on a secondary task can be usedto measure the impact on cognitive load that the robot interface has when the user is performing the main task.

One of the research challenges confronting HRI researchers today is determining the appropriateness of these instruments. While there is support in the literature for them, apart from the NASA-TLX, we are unaware of any that have been extensively or specifically used to measure the effects of multi-sensory cues in teleoperation (Ghinea et al., 2011). Therefore, some of the abovementioned metrics and questionnaires are used in the research presented here as a starting point. Throughout the empirical studies, depending on their appropriateness, the techniques used will be improved and refined for subsequent studies.

2.6. Conclusions

This chapter has covered the state-of-the-art in HRI and related areas. It gave an overview of input and output interfaces, introduced the core concepts in depth, detailing important taxonomies, techniques and metrics for designing a robotic interface.

This concludes the VR and HRI literature review of HRI. Some of the concepts presented here are applied to the design of the interfaces used in the studies reported next, but are also considered during experimental evaluation.

3. Empirical Studies

3.1. Summary

This chapter describes the four studies that were carried out to evaluate the use of multi-sensory feedback in robot teleoperation. The studies are contextualized in the area of Human-Robot Interaction (HRI) called urban search-and-rescue (USAR) robotics, where a robot is remotely operated to give rescuers access to human-hazardous areas and rescue survivors and victims.

For all four studies presented in this chapter, subjects had to control a robot located in a remote virtual or real environment. The task for all studies was the same: search for red objects in a debris filled environment as effectively and efficiently as possible. After the task, subjects were asked to report the location of the objects found by sketching a map of the environment and pointing out the location of these objects. A summary of the four studies is presented below.

- **Study 1 - Vibro-tactile vs. Visual Feedback in Virtual Robot USAR:** Most of the feedback received by operators of a robot-teleoperation system is graphical. When a large variety of robot data needs to be displayed however, this may lead to operator cognitive overload. This study focuses on cognitively off-loading visual feedback to the sense of touch, and as a consequence, increasing the level of operator performance and situation awareness. Graphical and vibro-tactile versions of feedback delivery for collision-related sections of the interface were evaluated in a search task using a virtual teleoperated robot. Results indicate that the combined use of both graphical and vibro-tactile feedback interfaces led to an increase in the quality of sketch maps, a possible indication of increased levels of operator situation awareness, but also a slight decrease in the number of robot collisions.

- **Study 2 - Comparing Different Types of Vibro-tactile Feedback in Virtual Robot USAR:** This study further explores study #1 vibro-tactile interface and evaluates the performance effects of adding different modes of vibro-tactile feedback for collision proximity to a virtual robot's interface during a search task in a virtual environment. One varies vibration intensity, while other varies frequency of vibratory pulses. Results indicate that the addition of any of the vibro-tactile feedback modes caused positive performance effects, especially for the intensity variation mode. Nevertheless, both modes also had an impact on comfort for prolonged use.

- **Study 3 - Exploring Multi-Sensory Feedback Interfaces and Redundant Feedback in Virtual Robot USAR:** Multi-sensory displays can be designed for the purpose of creating a more-natural interface for users and reducing the cognitive load of visual-only displays. However, the optimal amount of information that can be perceived through multi- sensory displays without making them more cognitively demanding than visual-only displays is unclear. Moreover, the effects of using redundant feedback across senses on multi- sensory displays are not well understood. As an attempt to elucidate these issues, this study evaluates the effects of increasing the amount of multi-sensory feedback on an USAR virtual teleoperation interface. While objective data showed that increasing the number of senses in the interface from two to three still led to an improvement in performance, subjective feedback indicated that multi-sensory interfaces with redundant feedback may impose an extra cognitive burden on users.

- **Study 4 - Further Exploring Multi-sensory Feedback Interface in Virtual USAR and Validating Previous Results with a Real Robot:** Previous studies have evaluated multi-sensory interfaces in robot teleoperation using a virtual robot in a USAR scenario. However, whether the same results can be obtained using a real robot in a real-world task is still unknown. This study aims at verifying that the previous results can also be achieved with a real robot experiment in the same context. In addition to that, it also adds the sense of smell to the interface and evaluates the efficacy and suitability of this type of feedback. The results show that that the types of feedback led to similar results, although the pool of subjects was statistically small. Some differences in results for the touch feedback were obtained as a consequence of factors not present in previous studies simulations such as input response delay and robot friction with the ground. While the sense of audio led to overall improvements in performance much as in study 3, the same was not true for the vibro-tactile feedback. The smell feedback improved search performance, showing applicability of multi-sensory interfaces to areas other than navigation. It also showed that redundant feedback might work well in covering for interface design flaws present in the original type of feedback. The results verified, at least in part, that the same improvements obtained with a virtual rotobt can also be obtained with a real robot.

3.2. Study #1: Vibro-tactile vs. Visual Feedback in Virtual Robot USAR

3.2.1. Motivation

This first study attempts to help answer the question of whether the use of a bi-sensory interface can help the user better operate a robot and perform a search task. In addition, it compares the provision of a certain type of feedback through individual senses versus through both senses (redundant feedback). To answer these questions, the study evaluates the impact on situation awareness (SA) and performance when part of the data transmitted by the robot is displayed to the operator using the senses of touch instead of the sense of vision.

Specifically, the proposed interface uses a body-worn vibro-tactile display to provide feedback to the operator for collision proximity between the robot and the remote environment. In a four-way comparison, as shown in Table 3.1, the use of vibro-tactile feedback is compared with the use of no feedback, the use of visual-only feedback, and the use of both visual and vibro-tactile feedback in the performance of a simple search task.

Table 3.1: The four experimental conditions for study #1.

Codition	Graphical Ring	Vibro-tactile belt
Control		
Ring	yes	
Vibro-tactile		yes
Both	yes	yes

3.2.2. Robot Interface

A Collision-Proximity Feedback (CPF) interface has been designed following a superset of the guidelines proposed in the field of USAR HRI and by merging successful features from interface designs tested by other research groups. Our design (Figure 3.1) uses as a starting point the interface proposed by Nielsen (Nielsen & Goodrich, 2006; Nielsen et al., 2007). In this work, a simulated robot was used instead of a physical one, in order to quickly prototype different interface elements.

The operator is presented with a third-person view of a 3D virtual representation of the robot, called its avatar. The real robot size and the size of its avatar (relative to the map blueprint) match the size of a standard search robot (0.51m × 0.46m × 0.25m). Data collected by the robot sensors are also presented, including a video feed from a pan-tilt camera mounted on the robot, the location of object surfaces near the robot, and potential collision locations.

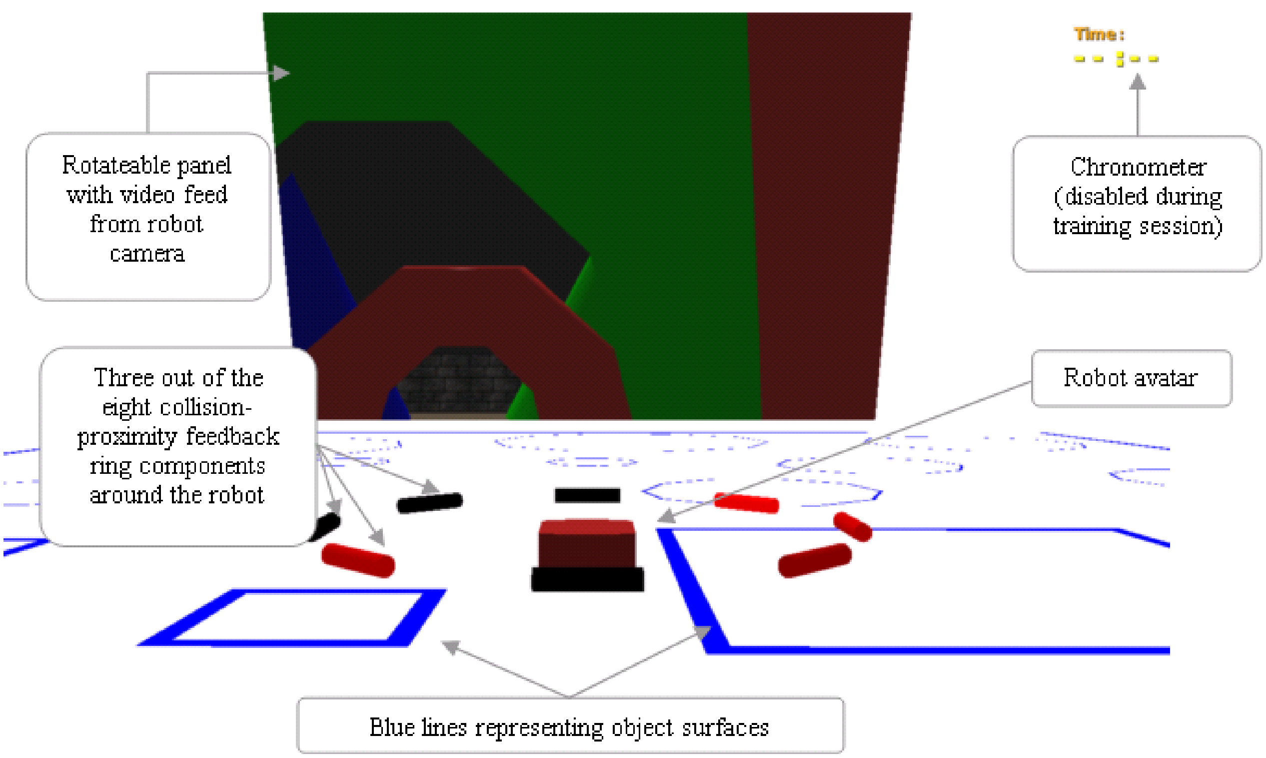


Figure 3.1: Visual interface for study #1.

The robot camera has a field-of-view of 60º. A panel located in front of the robot avatar projects data from the robot's simulated camera. The camera, and hence the panel, can be rotated about both the vertical and horizontal axes, up to an angle of 100° horizontally and 45° vertically, relative to the front of the robot. The camera-panel rotations occur relative to the robot avatar and match the remote virtual robot camera rotations controlled by operator input.

The robot avatar consists of a red box in the middle of the screen. A graphical ring with eight cylindrical objects surrounding the robot avatar indicates imminent collisions near the robot, similar to the Sensory EgoSphere proposed by Johnson (Johnson et al., 2003) but with a more specific purpose: the brighter the red color in the ring the closer to a collision point the robot is. The ring's radius and height are set so that it can be seen in its entirety from the back of the robot at an inclined downward angle, it does not occlude the front of the robot and it is aligned with the approximate height of the simulated robot proximity sensors.

The same type of feedback is also provided as vibration through the vibro-tactile interface, henceforth called the TactaBelt (Lindeman, 2003) (Figure 3.2b). The TactaBelt consists of eight pager motors, also called *tactors*, arranged in a belt with the motors evenly spaced around and above the user's waistline. The more intense a tactor in the TactaBelt vibrates, the closer the robot is to colliding in that direction, similar to the feedback technique proposed by Cassineli (Cassinelli et al., 2006).

Both visual and vibro-tactile feedback interfaces are only activated when an object is within a distance d from the robot ($d \leq 1.25$m, based on subjective feedback during pilot study). Directional feedback values for the ring-cylinder redness and tactor vibration vary continuously from near zero, when the distance is close to d, to near their maximum values when the robot is about to collide with the object.

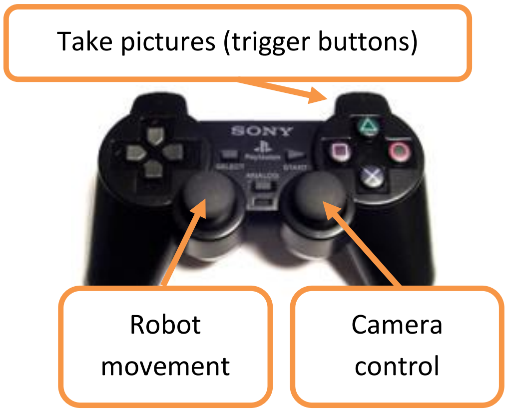
A map of the environment is gradually projected on the ground in the form of blue lines as the robot captures data from the environment. These blue lines represent the locations of objects and wall surfaces detected by the robot sensors. The detection of these lines was simulated using trigger boxes in the game engine. Whenever the robot intersects the volume of a line trigger box, the line appears.

The robot avatar position on the map matches the virtual robot position in the real world virtual environment (VE). These positions are always synchronized.

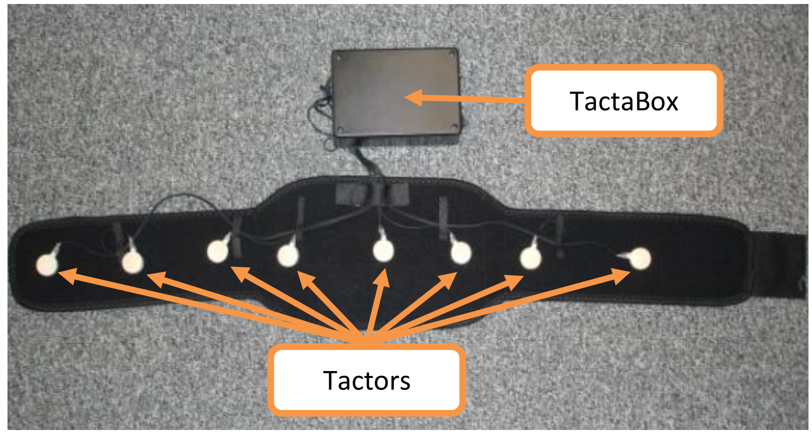
A timer is presented in the top right hand corner of the screen. It is triggered once the training session finishes. The robot is then transferred to another VE where the actual experiment takes place. This transition and both VEs are further described in section 3.2.5.

The controller used in the experiment was a Sony PlayStation2 Dual-shock (Figure 3.2a). The controller allowed the subject to move the robot backward and forward and rotate the robot to the left or right. The robot rotation was controlled using differential drive, which meant the robot could rotate in place or while in movement, similar to how a military tank is controlled. The pan-tilt movement of the camera was inverted and moving the joystick forward would move the camera down. This camera control option was chosen based on subject preference during a pilot study.

The machine used for running the experiment was a Dell XPS 600 with 2 GB RAM and a Pentium (R) D Dual-core 3GHz processor. The graphics card used was a GeForce 7800 GTX with 256MB of memory. The environment was run in a window with resolution of 1280x1024 at an average frame rate of 30 frames-per-second (fps) on a 20" Viewsonic Q20wb LCD monitor placed on top of an office table and approximately aligned with the subject's view height. The monitor was positioned at an approximate distance of 0.5m from the subject's eyes.



(a)



(b)

Figure 3.2: Interface used in addition to the standard LCD monitor in study #1: (a) PlayStation® 2 dual-shock controller; (b) TactaBelt.

3.2.3. Task

The task subjects had to complete consisted of locating red spheres, with a radius of 0.25m, in the ruins of a small closed environment. Subjects were informed they would have to search for as many red spheres as they could while avoiding collisions between the robot and the environment. They were also asked to perform the task in as little time as possible. Additionally, they were also informed beforehand that they would have to report the location of the spheres found once the search task was over using the pictures they took with the robot camera as a reference.

A total of nine spheres were hidden. Subjects did not know in advance the number of spheres. The search task would stop whenever subjects thought they have searched and found all spheres. To end the task search, they would have find the exit door in the house, which was marked with an exit sign above it, and pass the robot through it. Once the search task was over, they would sketch a detailed map of the task space with the approximate location of the spheres.

3.2.4. Hypotheses

Previous results obtained from other research groups have shown improvements in performance when vibro-tactile displays (Blom & Beckhaus, 2010; Bloomfield & Badler, 2007; Burke et al., 2006; Herbst & Stark, 2005; Lindeman et al., 2005; Ryu & Kim, 2004) and enhanced visual interfaces (Johnson et al., 2003) were used. Based on these results, we claim that the use of the graphical ring and the TactaBelt should cause an improvement in subjects' perception of the surrounding environment, indicating an increase in their situation awareness level. This should be especially evident through a reduction in the number of collisions. Improvement should also be visible in the results collected by other dependent variables. These variables will be described in detail in section 3.2.5.

By making navigation more intuitive with the addition of directional feedback, and less visual with the addition of vibro-tactile feedback, we hypothesize that subjects using the enhanced interfaces will be able to focus more on the task, find a larger number of objects, and better understand how the environment is organized. The first two ability-enhancement effects may be understood as a consequence of a lower cognitive load while the second and third may be seen as a result of higher levels of situation awareness. Therefore, task time, number of collisions, number of objects found, and understanding of the positions of objects are measurements that are relevant to the validation or rejection of our hypotheses.

The following two hypotheses are considered for this first study (S1):

S1H1. Subjects using either the vibro-tactile or the graphical ring feedback interface should have an increase in navigational performance and situation awareness (SA) measured by four factors: a reduction in the number of collisions (local SA improvement), a reduction *in the time taken to perform the task (performance improvement), an increase in the number of objects found (performance improvement) and a better reporting of the location of the objects and understanding of the environment through the sktechmap (global SA and memory accuracy improvements) in relation to the control group, which is using neither the graphical ring nor TactaBelt.*

S1H2. Subjects who are using both the vibro-tactile and the graphical ring feedback interfaces should have an even larger increase in navigational performance and situation awareness.

3.2.5. Methodology

A study was carried out to confirm the above-stated hypotheses that the use of either or both feedback modalities would result in an improvement in operator performance and situation awareness.

There are at least two ways to compare user interfaces. The first one, lab interfaces, attempts to hold constant all aspects of the interfaces being compared, with the exception of the independent variables. These experiments allow statements to be made about the effects of the variations in the interfaces, but suffer from the fact that for use in the field, an interface designer might construct a vastly different interface given the value of the independent variable. This leads to the comparison of interfaces that vary greatly, but are more "optimized" given the independent variable. This motivates the design of a second type of experiment, where interfaces are constructed that represent the best efforts of the UI designer given the independent variables being studied, called fielded interfaces.

For this and the subsequent studies, we opted for a fielded interface experiment. We designed our interface to approximate an interface that is actually used by research groups and experts in performing USAR tasks as much as possible. This was done by adding to our interface common features of these interfaces, such as a gradually presenting map blueprint of the world and allowing the subject to navigate the robot and perform the search task. Despite the challenges in having many potential variables that may affect subject performance, it was only by taking this approach that we could detect the correct effect of inserting a multi-sensory proximity feedback interface to the application in a reasonably realistic USAR context.

3.2.5.1. Independent Variable

The independent variable for the study was the type of collision-proximity feedback (CPF) interface. Subjects were divided into four groups: the first group ("None") operated the robot without using any CPF interface. The second ("Ring") received this type of feedback from the graphical ring. The third ("Vibro-tactile") received this type of feedback from the TactaBelt. The fourth ("Both") received this type of feedback from both the graphical ring and TactaBelt.

3.2.5.2. Dependent Variables

The dependent variables for the study were the number of collisions, the time taken to accomplish the search task, the number of spheres found, and the quality of the sketchmaps. The rating for the latter is explained ate the end of section 3.2.5.4. The first two were measured objectively using the robot application.

The number of spheres found was reported by subjects, but was also counted by the experiment observer, since subjects might miscount the spheres they found. The former counting is considered here as a subjective measure of the number of spheres found, while the latter is considered as an objective measure of that number, despite that it is still prone to subjective error.

The sketchmaps are maps drawn by the subjects once the experiment is over. These are considered subjective measures. They were graded solely by the experimenter.

3.2.5.3. Study environment

The robot side of the system was simulated using a VE. In fact, two VEs, built using the C4 game engine (C4 Game Engine, 2012), were used by the application. The first VE was the simulated world where the robot was present and where it should complete the search task (Figure 3.3). In the context of the AAAI Rescue Robotics Competition, the environment is qualified as being in the yellow level of the competition, where the robot traverses the entire world by moving around the same ground level with some debris spread across the floor (Jacoff et al., 2003). The second VE represented the robot teleoperation interface as seen from the operator's point of view (Figure 3.1).

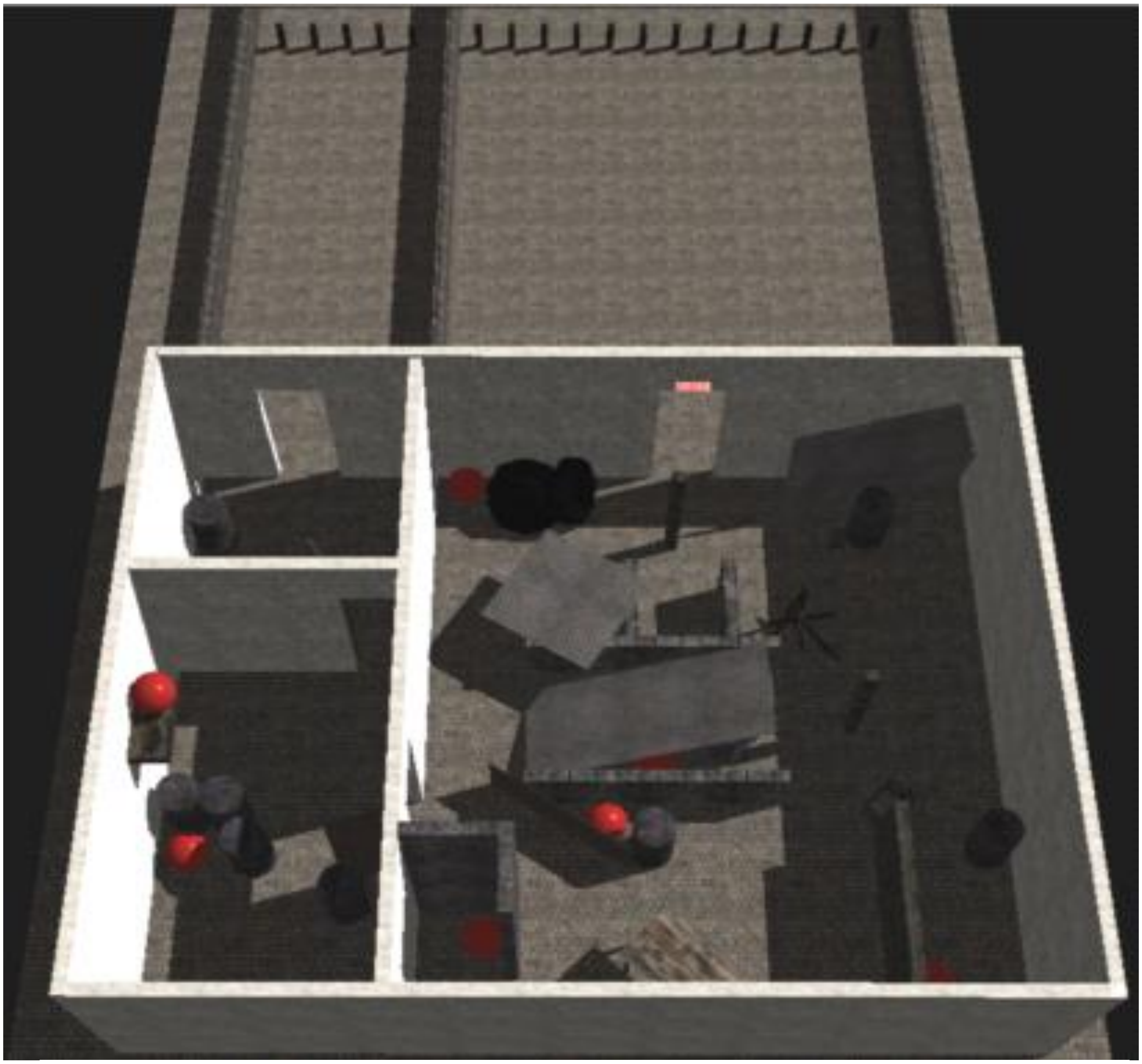


Figure 3.3: Study #1 task virtual environment from a bird's eye view.

3.2.5.4. Experimental Procedure

The study consisted of a between-subjects experiment. Hence, each subject was exposed to only one of the four available interfaces. In this and succeeding studies, subjects were not color-blind and had their visual acuity corrected if necessary.

All subjects wore the TactaBelt, but the interface was not active during the experiment for half of them. The neoprene belt with Velcro-attached tactors adapted to most subjects waists without problems. When subjects were very slim or the opposite, the tactors were repositioned so they were correctly aligned with the cardinal and intermediate directions relative to the subject's waist.

Subjects could control the robot and its camera using the two analog joysticks of the gamepad. Two trigger buttons on the gamepad allowed subjects to take pictures of the environment. These pictures were used by subjects in the map-sketching exercise that followed the search task as explained in more detail below.

The user study can be summarized by a list of eight steps for each subject, some of which are further explained in the paragraphs following this list.

1. Institutional Review Board (IRB) approved consent forms were read and signed;
2. Demographic information was collected;
3. The experiment instructions and a Q&A session occurred;
4. Robot controls for the experiment were explained;
5. The training session task was explained, questions answered, and the subject started this session when ready;
6. After the training session, the experimenter explained that the robot would be moved to the world where the real task would be performed and briefly reviewed the objective of the latter. The experiment started when the subject was ready;
7. During the main experiment, the experimenter took general notes about the subject and his or her performance;

8. Once the main experiment task was over, the subject filled in a post-task questionnaire containing the sketchmap and asking for general experiment feedback.

The demographics questionnaire collected subject information about their gender, age, how often they played videogames and used or worked with robots. For the last two questions, the possible answers were one of the four following Likert scale values: “daily” (1), “weekly” (2), “seldom” (3) or “never” (4). Other than the answer from these questions, no general spatial ability information was collected from subjects.

A single page of instructions contained a description of the experiment, the task to be completed, the interface, and how subjects should behave before, during, and after the experiment

The training session happened in a virtual training room (15m x 15m) larger than the one for the real task session (8m x 10m). The training room (Figure 3.4) contained large colored geometric primitives. A single red sphere was hidden behind one of these primitives. The training task for this room was to find the hidden red sphere and take a picture of it. This gave subjects time (~4 min.) to practice and become accustomed to the robot controls. During this session, if subjects seemed to be already comfortable with the robot controls but were having problems in finding the red sphere, the experimenter would intervene and give them hints on the location of the sphere so that they could practice taking pictures, ask questions, and then move on to the real experiment.

In the real task room, objects such as doorways, barrels and tables were represented in their size in reality (Figure 3.3). The data on the location and time of the collisions was recorded as well as the time spent in performing the task. Additionally, the periods of time spent during the training session and sketching the location of the spheres were recorded for some of the subjects; the idea of collecting such data only came up half-way through the studies. Subjects did not have access to a bird's eye view such as the one presented in Figures 3.3 and 3.4.

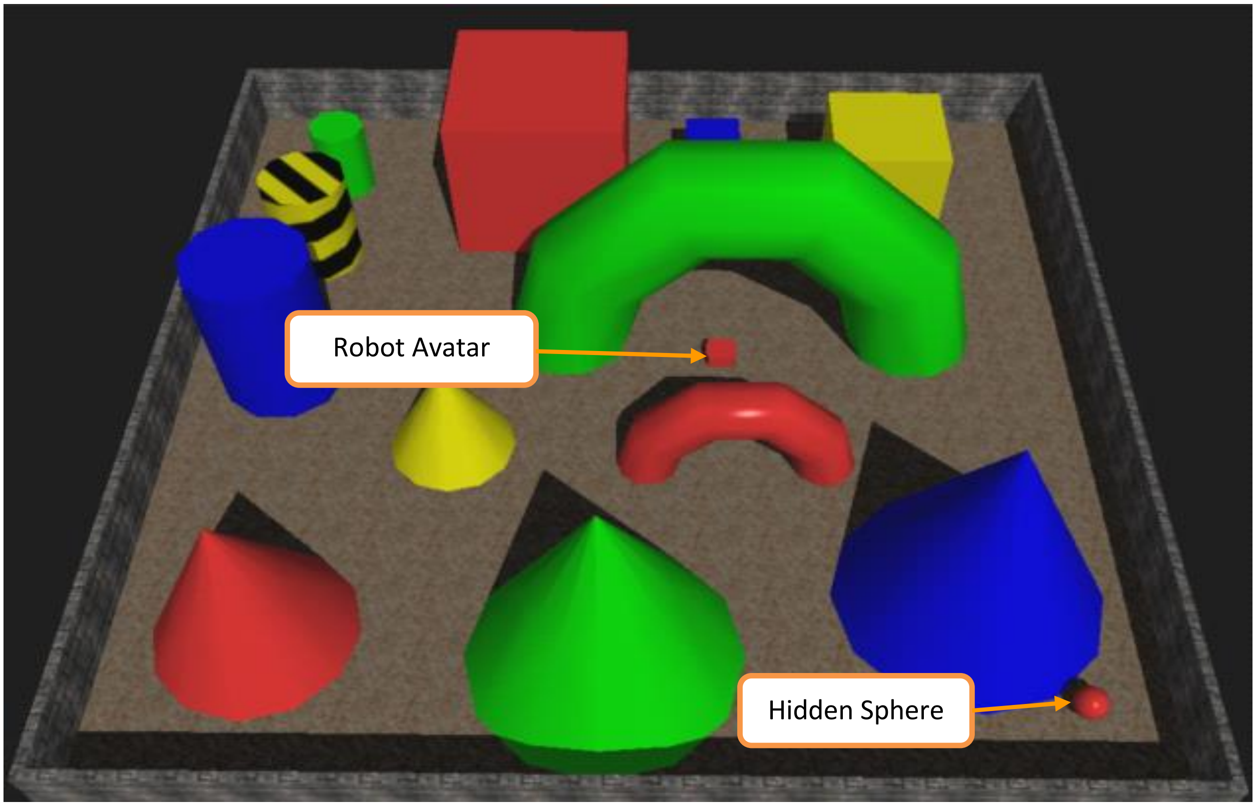


Figure 3.4: Training environment in study #1 from a bird's eye view.

The post-task questionnaire asked subjects to report the number of spheres found and their location by sketching a map of the environment. They were provided with the pictures they took during their traversal of the environment to help them in sketching. The images were displayed with a resolution of 800 x 640 pixels on a Web page.

The sketchmaps were evaluated following the criteria proposed by Billinghurst & Weghorst (Billinghurst & Weghorst, 1995). The first criterion was map goodness, which was evaluated on a scale from 1 to 5, instead of the original scale from 1 to 3. The criterion for grading map goodness was how well the sketched map would help in guiding someone through the environment. The second criterion was counting the number of objects of different classes or groups that were drawn. The objects were divided into three groups: walls, doorways, and debris. These groups were scored separately. Each object found corresponded to a one-point increment to their object group score. The third criterion was a general scoring and analysis of the correct placement of objects relative to other nearby objects. Sphere placement was not considered during grading of any criteria, since the pictures taken would allow subjects to position them correctly relative to nearby objects most of the time.

3.2.5.5. Other Materials

Other materials used in this user study, such as the script used by the experimenter, the study instruction sheet, and the questions contained in the user study post-task questionnaire, are found in Appendix A.1.

3.2.6. Results

All the comparisons among the results for study #1 presented in this section were made using a single-factor ANOVA with confidence level of $\alpha = 0.05$. The f and p values for the data analyses that resulted in relevant and statistically signifcant results are presented in tables. Further details about results that were not statistically signifcant can be obtained in Appendix A.2.

Multimodality was detected in the histograms for task time, number of collisions, and number of spheres found. In order to normalize these results in terms of time and reduce the effect of multimodality, we have also adopted in our analysis the measures of number of spheres found per minute and number of collisions per minute instead of considering only number of spheres found and number of collisions.

Sections where a *statistically significant difference* (SSD) in results was found have their titles marked with an asterisk (*). If only a trend was found, the title of that section is marked with a plus sign (+).

3.2.6.1. Demographics

A total of 13 female and 14 male university students have participated. All groups had 7 subjects, except group "Ring", which had 6. A comparison between genders for the dependent variables showed no SSD. The mean age was 20.52, with standard deviation of 5.24.

No SSD was found among groups in terms of videogame experience, although subjects in group "Both" had a lower average than others, that is, they had a slightly higher level of experience. Interestingly, videogame experience did prove to have a statistically significant effect on the result for number of collisions between groups "Weekly" and "Never" (f=5.18, p=0.04). Groups with different levels of videogame experience were also compared in terms of task time, number of spheres found, and map goodness, but none of these showed any SSDs.

Only two groups had subjects with robot experience. However, robot experience did not have any statistically significant effect on the results of any of the dependent variables.

3.2.6.2. Task Time+

A comparison of task time among collision-proximity feedback (CPF) interface groups led to no SSD, that is, these interfaces had little to no impact on task time. A trend between groups None and Ring was detected however ($F = 4.665$, $p = 0.054$, A.2.5.1), indicating that subjects with the ring interface took longer to perform the task than subjects in the control group.

3.2.6.3. Number *of Collisions**

A comparison of the number of collisions between groups showed SSDs between groups ("None", "Ring") (F = 6.695, p = 0.025, A.2.6.1) and ("Ring", "Vibro-tactile") (F = 5.079 p = 0.046, A.2.6.1). No difference was found for any of the other pairs of groups. For group "Both", the cause for non-significant difference in the results might have been the high variation found in subject data from this group (s_n: 33.30), although the largest variation value was obtained in group "Ring". However, a trend for the ("Ring", "Both") pair was detected (p = 0.066). This is close to being significant. The redundant feedback has improved the average number of collisions compared to the ring-only interface. We conjecture that this indicates how the redundant feedback provided by vibro-tactile interface seemed to have balanced out negative effects on collision avoidance caused by the graphical ring interface due to occlusion.

For the number of collisions per minute, no statistically significant difference was found amongst groups, although a visually perceptible difference in results is noticeable among groups (Figure 3.5, A.2.7), where the "Both" group has the lower result. Due to no SSD, the part of both hypotheses referring to an improvement in the number of collisions caused by the use of CPF interfaces is not supported.

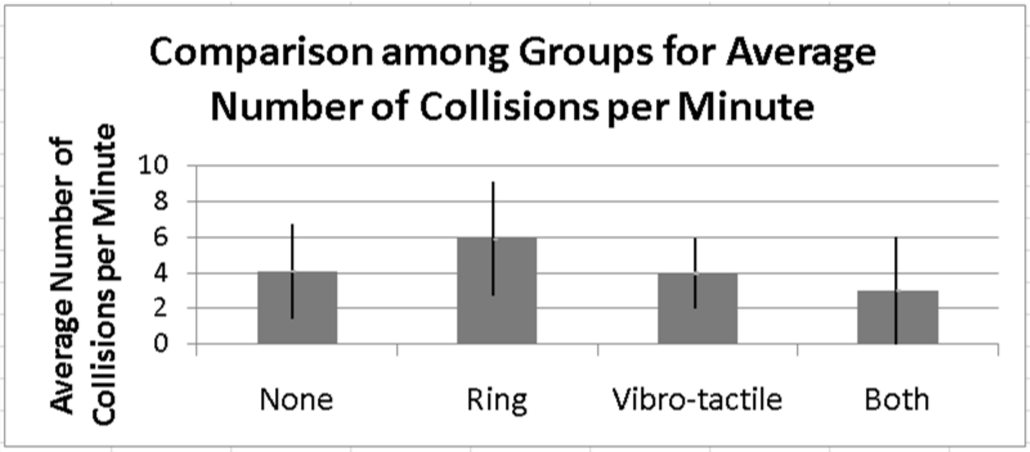


Figure 3.5: Number of collisions per minute per interface group in study #1. Lines define ± standard deviation.

*3.2.6.4. Number of Spheres Found**

For the number of spheres found per minute (Figure 3.6, A.2.9.1), a statistically significant difference between groups "Ring" and "Both" was found (F = 11.17, p = 0.0066). This only indicates that the use of the Ring interface by itself seems to lead to a smaller number of spheres found while the vibro-tactile interface seem to have no effect on improving the number of spheres found. This means that the part of both hypotheses that refers to an improvement in the number of spheres found caused by the use of CPF interfaces is not supported. The fact that "None" has the highest mean indicates that the use of feedback interfaces has some impact on subjects' cognitive load and search performance, but such impact is not statistically significant.

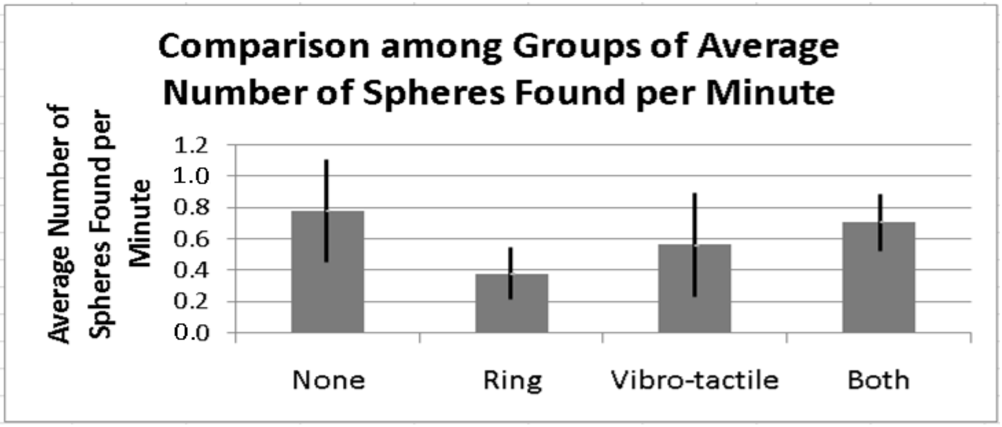


Figure 3.6: Number of spheres per minute per interface group in study #1. Lines define ± standard deviation.

A comparison of the number of spheres found among interface groups also showed no SSD. Nevertheless, a slight increase is perceived in the median value of the number of spheres found as the interface group changes from group "None" (no interface enhancement is used) moving through groups "Ring" and "Vibro-tactile" (some interface enhancement is used) towards group "Both" (both interface enhancements are used), the latter having the highest median value (Figure 3.7, A.2.8.1).

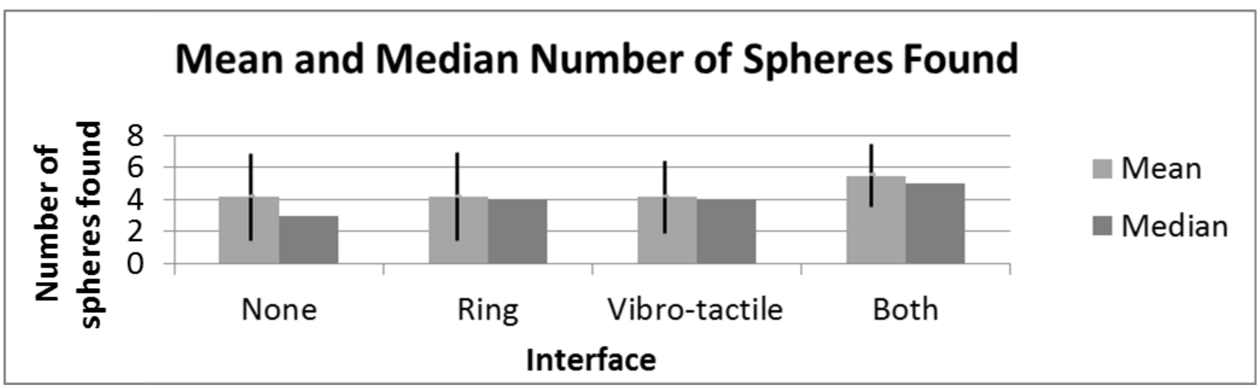


Figure 3.7: Mean and median per group for the number of spheres found in study #1.

Interestingly, a trend was found when the number of spheres found by female versus male subjects was compared (F = 3.690, p = 0.066, A.2.24), males having a higher score. It is not clear what the reason behind this effect is.

3.2.6.5. Map Quality

Map samples sketched during the experiment as well as the blueprint of the original scene are presented in Figure 3.8. Maps scored as 1 provided no help as a guidance tool through the environment. Maps scored as 2 had the description of a few features of the environment represented with a large number of mistakes in terms of spatial representation. Maps scored as 3 had some features of the environment well placed and described in text, but still had major errors in their sketches, such as the number of rooms and doorways. Maps scored as 4 described the environment correctly except for the misplacement of some objects and walls. Maps graded as 5 had the environment almost completely correct and all the objects found were correctly placed.

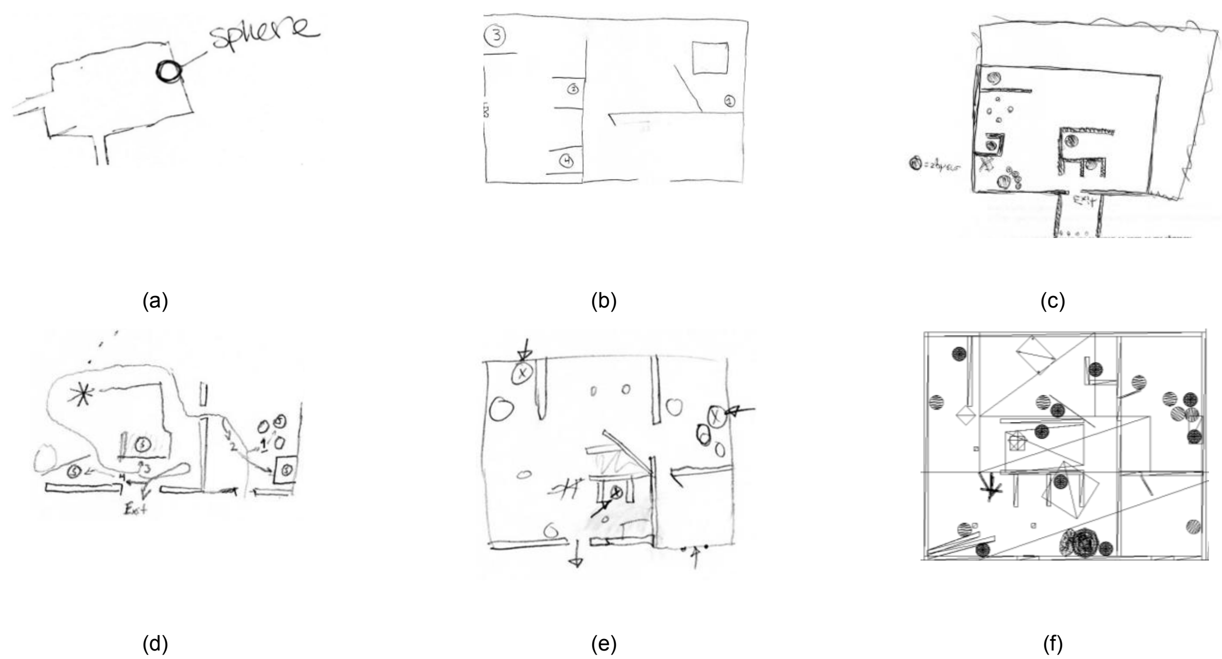


Figure 3.8: Sketchmap samples from study #1 for maps with different scores: (a) goodness score = 1; (b) goodness score = 2; (c) goodness score = 3; (d) goodness score = 4; (e) goodness score = 5; (f) original map.

Some subjects also added extra features to their descriptions of the scene, by drawing the approximate path they went through during the search task (Figure 3.8d) or the order with which they found the spheres and how these related to the pictures taken (Figure 3.8b and Figure 3.8c). Almost half of the subjects failed to make good representations of the environment, and had their maps graded as 1 or 2. When comparing groups with different levels of map goodness to task time, no SSD was found. Good and poor maps were sketched by subjects who spent from 4 minutes to 20 minutes in the environment.

Since sketchmaps must be scored only by one person, results may be affected by subjectivity and thus scoring effectiveness needs to be validated. In this study, the first evaluation criterion, map goodness, was used as a general score for map quality. However, we ensured map quality results were in accordance with the results obtained by the other more specific criteria: object counts for walls, doorways and debris, and their relative position to nearby objects. Please refer to (de Barros et al., 2009) for more details.

When comparing map goodness with the type of CPF interface used, a SSD was found only between groups "None" and "Both" (F = 5.654, p = 0.035, A.2.4). Figure 3.9 presents a histogram for interface types colored according to levels of map goodness and more clearly represents this variation for group "Both". Notice that there is a trend towards significance between groups "Vibro-tactile" and "Both". This might be an indication that using the "Ring" interface together with the TactaBelt is better than using the TactaBelt by itself. The average rating per interface group can be seen in Figure 3.10.

Notice in the group "Both" graph column of Figure 3.9 the absence of sketchmaps rated with goodness levels 1 or 2. This is an important result, because it may indicate the positive effect caused by the CPF interfaces on subject's SA levels. In addition, notice a larger variation in map goodness for groups “Ring” and “Vibro-tactile” compared to group “None”. It indicates that using CPF interfaces separately may result in a positive or negative effect on individual operators, but no improvement on average.

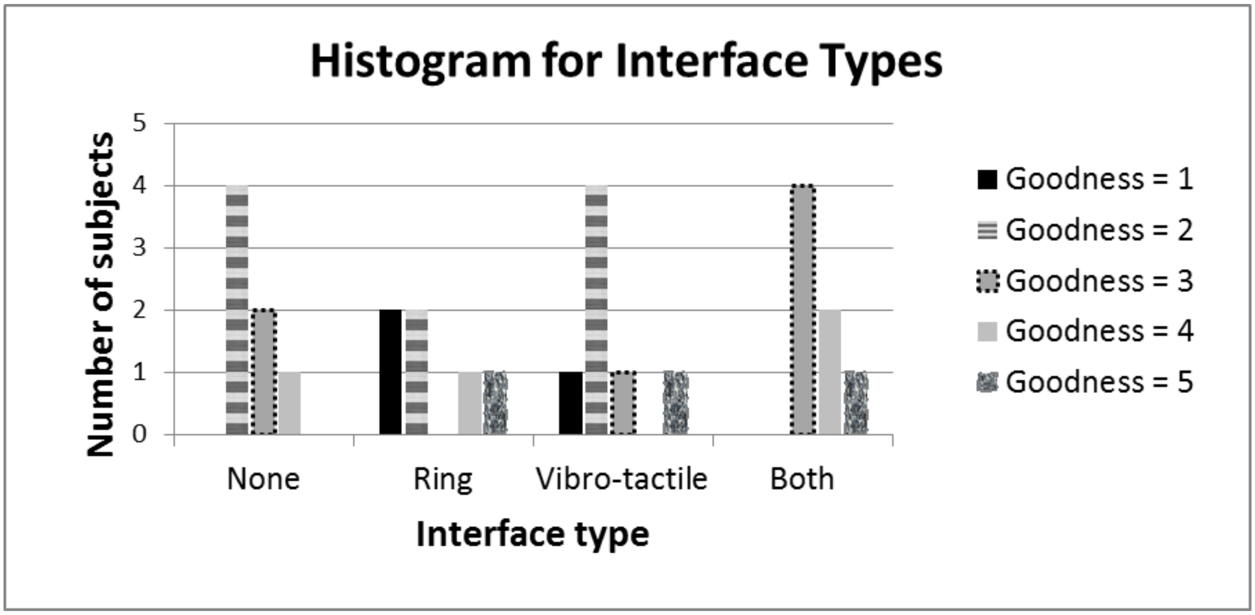


Figure 3.9: Map quality ratings distribution among different groups in study #1.

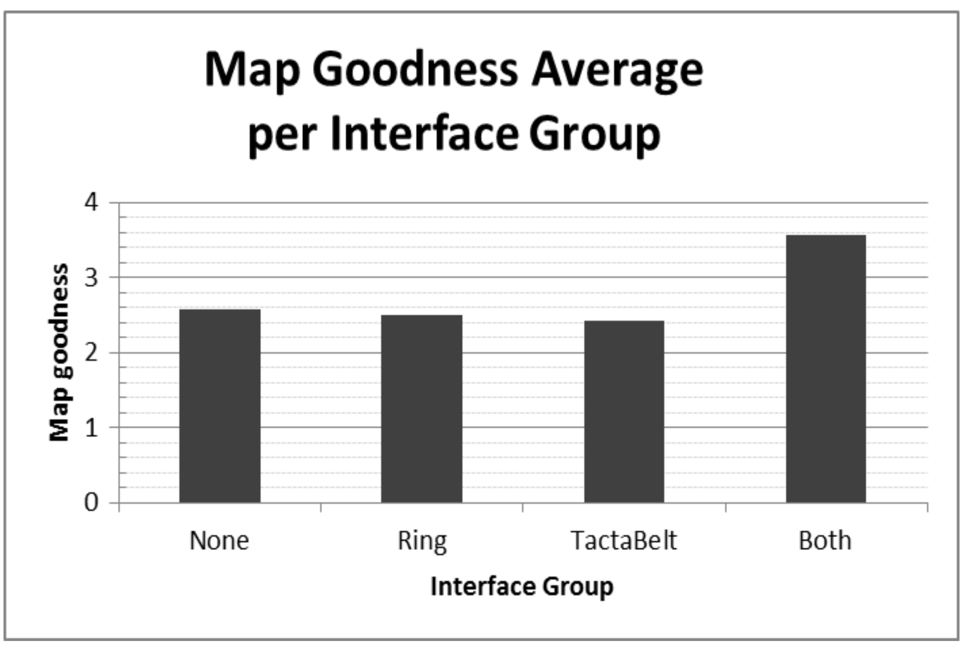


Figure 3.10: Map quality average ratings among different groups in study #1.

3.2.7. Discussion

Results have shown that gender, age, robot experience, and videogame experience did not have any biasing effect on the results obtained from this user study. However, our analysis confirms that videogame experience may bias results in case the groups are not properly balanced as in our study. This is an important variable to consider in future similar HRI studies.

Our results have also shown that the use of CPF interfaces had no negative or positive effect on the time-normalized number of spheres found. For the number of spheres found per minute, the “Ring” group performed worse than the “Both” group with SSD. This means that while the use of both CPF interfaces might have improved overall navigation, the sole use of the “Ring” interface led to worse results than the control group.

In terms of task time we did notice that the Ring interface led to a slight increase in task time. This might have been due to it blocking the view of the operator and hence hindering robot navigation. Although subjects commented on their difficulty in navigating with the robot, the comments were vague and did not provide evidence that could associate them to the ring occlusion problem.

With respect to number of collisions, the “Ring” interface group performed worse than interface groups “None” and “Vibro-tactile”. A trend was also detected between groups “Ring” and “Both”. Once again, this might be due to the fact that the ring itself occludes part of the blueprints on the ground around the robot, making it harder for the operator to visually discern closeness of nearby objects and navigate the robot around the environment. This negative effect seemed to have been counter-balanced by the use of complementary vibro-tactile feedback in the “Both” group, whose collision-count was not statistically worse than any of the other groups and whose average collision-count per minute had the smallest value. However, the group "None" was the one that generated the lowest average number of collisions. It could be that the vibro-tactile feedback causes distraction and a visual-only feedback allows more concentration. This seems to indicate that we cannot yet reach any positive or negative conclusions about the effect of CPF interfaces in collision avoidance and improvement of subject's level of local situation awareness.

The most interesting result was that group "Both" outperformed the "None" interface group in map goodness scores. This result shows that the combined use of both CPF interfaces might have been beneficial for the operator in terms of understanding of the virtual environment and location of objects. This result could be associated with an increase in operator global situation awareness. The fact that the coupled CPF interfaces did not affect task time, number of collisions or spheres found, combined with the fact that task-time had no correlation with increase in sketchmap quality, seem to support the claim that only CPF interfaces could have caused the increase sketchmap quality. The improvement caused by the use of redundant multi-sensory feedback goes in hand with previous research results in different tasks and applications (Burke et al., 2006; Herbst & Stark, 2005). The small population that participated in this study (6-7 per group), however, does not allow us to reach that conclusion with statistical soundness yet. A user study with a larger population size would be required for that.

3.2.8. Conclusions

The fact that group "Both" drew better maps than all other groups, and that the vibro-tactile interface had no negative impact for all conditions, may indicate that the use of this interface in conjunction with other graphical CPF interfaces can improve operator situation awareness without detriment to cognitive load. Interestingly, the results seem to point to an increase in global situation awareness instead of local situation awareness.

In terms of collisions, it appears that the current version of the ring feedback interface needs to be improved, as it blocks the operator view of the map blueprint. Although the results with the graphic ring interface were opposite to what our hypotheses stated, we believe that a more in-depth study must be performed in order to verify whether this is indeed an invalid approach.

From the results obtained from this study, it seems that the vibro-tactile feedback seems to have helped navigation, but such help was enhanced when redundant feedback from the graphical ring was present. None of the types of feedback was good enough by itself. Instead, they seemed to complement each other. However, that does not mean that the use of redundant feedback must always be required. If the display of feedback through one sense suffices for the operator to understand the information presented, redundancy might become useless. The succeeding studies will further explore this question from different perspectives.

By looking at the results obtained in this first study, we believe that the use of multi-sensory interfaces, including vibro-tactile ones, may be potentially beneficial to the robot operator compared to a visual only interface. However, from the results obtained for the ring interface, it is clear that data display in this bi-sensory interface still needs further optimization.

In the study to follow, the plan was to explore different ways of providing vibro-tactile feedback other than varying vibratory intensity, such as providing vibratory patterns. Other ideas include the creation of an improved version of the graphical feedback interface that may not necessarily be a ring, and adding more feedback mechanisms from the robot to operator that are already commonly used graphically in HRI interfaces, such as CO_2 level meters. These ideas will be explored in studies #3 and #4.

3.3. Study #2: Comparing Different Types of Vibro-tactile Feedback in Virtual Robot USAR

3.3.1. Motivation

This study builds on the results from the first study (de Barros et al., 2011), and aims to evaluate the impact on performance when the robot interface is enhanced with different types of vibro-tactile feedback displays for robot collision avoidance in a search task. The idea is to compare how providing vibro-tactile feedback in different ways can impact user perception of data and overall task performance. Two vibro-tactile interfaces were compared to a no-vibration control case: a vibration intensity variation mode and a vibratory pulse frequency mode. The type of data provided was related to collision-proximity feedback (CPF) as in study #1.

3.3.2. Robot Interface

The robot interface design in Figure 3.11 is similar to the one from our previous study (de Barros et al., 2011). The only differences from the interface used in study #1 are the enhanced robot avatar and the presentation of object surfaces near the robot on the map blueprint. Object surfaces are now detected by performing raycasting on the remote scene.This provides a more accurate simulation of the robot sensors. The rest of the interface, belt and controller were identical.

Notice, however, that in this study the graphical ring is no longer present. The reason for that is that we want to reassess the impact of adding only CPF through vibro-tactile feedback, without having CPF data being redundantly presented through visuals. This will help us identify how well the operator can “read” the vibro-tactile data being displayed.

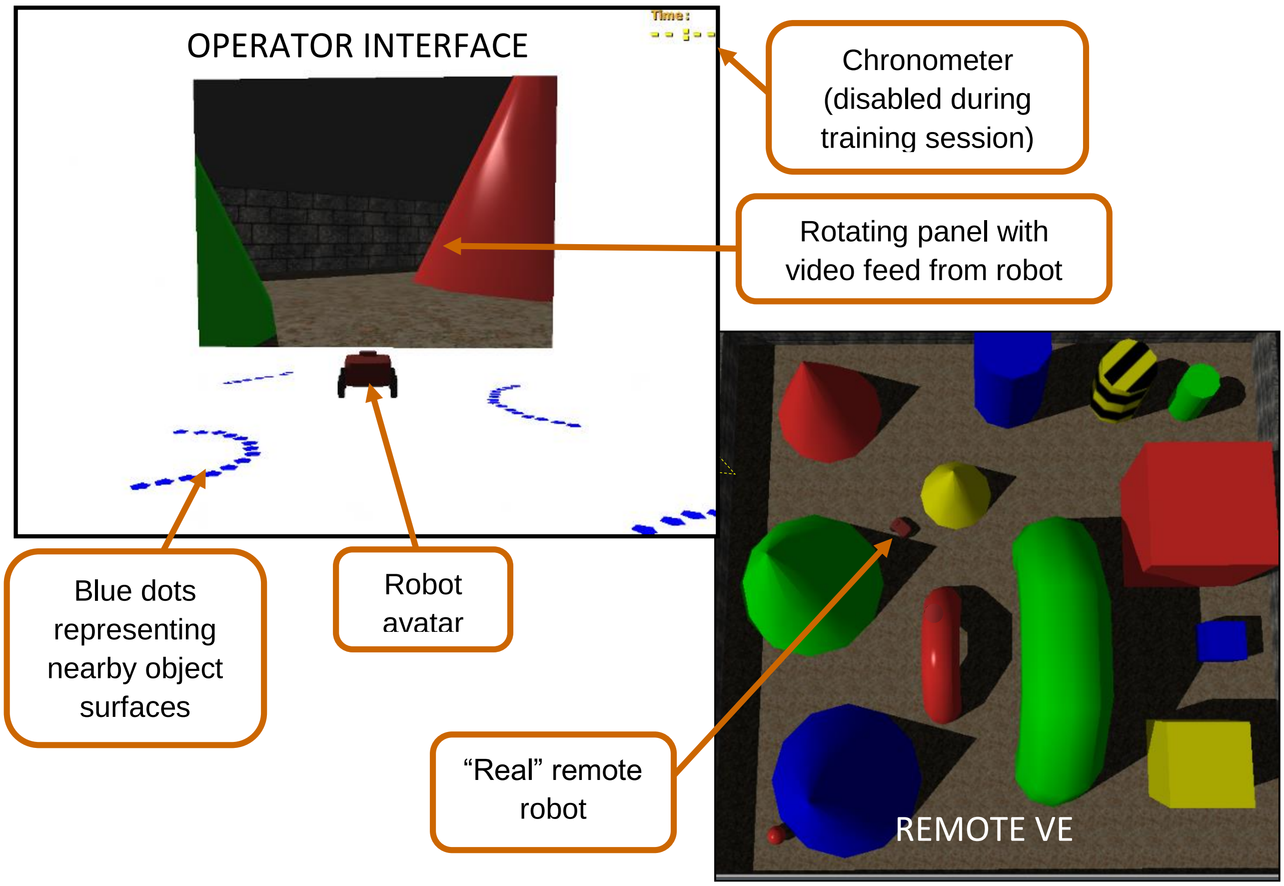


Figure 3.11: Visual interface (left), and bird’s eye view of training room (right) for study #2.

In this study, two vibro-tactile feedback modes are explored (Figure 3.12). In the first one (*Intensity*, or *I*), the closer the robot is to colliding in the direction the tactor points, the more intense a tactor in the TactaBelt continuously vibrates, similar to the work of Cassineli (Cassinelli et al., 2006) and study #1. In the second mode (*Frequency*, or *F*), the more frequently a tactor vibration pulsates or “beeps”, the closer the robot is to colliding in the direction the tactor points. Notice that this mode differs from the former one because the vibration is not continuous. In both modes, the vibro-tactile feedback is only activated when the robot is within a distance *d* from an object ($d \leq 1.25$m). Regardless of the vibration mode used, if an actual collision occurs in a certain direction, the tactor pointing in that direction vibrates continuously at the maximum calibrated vibration intensity. This calibrated intensity was determined through subjective feedback during a pilot study. These two modes were selected because they represent the same data with two levels of complexity and accuracy. The range of intensity and frequency variations were wide enough that their variation could be perceived by anyone with normal skin sensitivity. Very high frequencies for the pulsing behavior could not be used, because the tactor motor had to be allowed some time to decelerate its rotational speed to zero after a single pulse. This limitation in frequency guaranteed that there would always be a period without vibration between adjacent pulses.

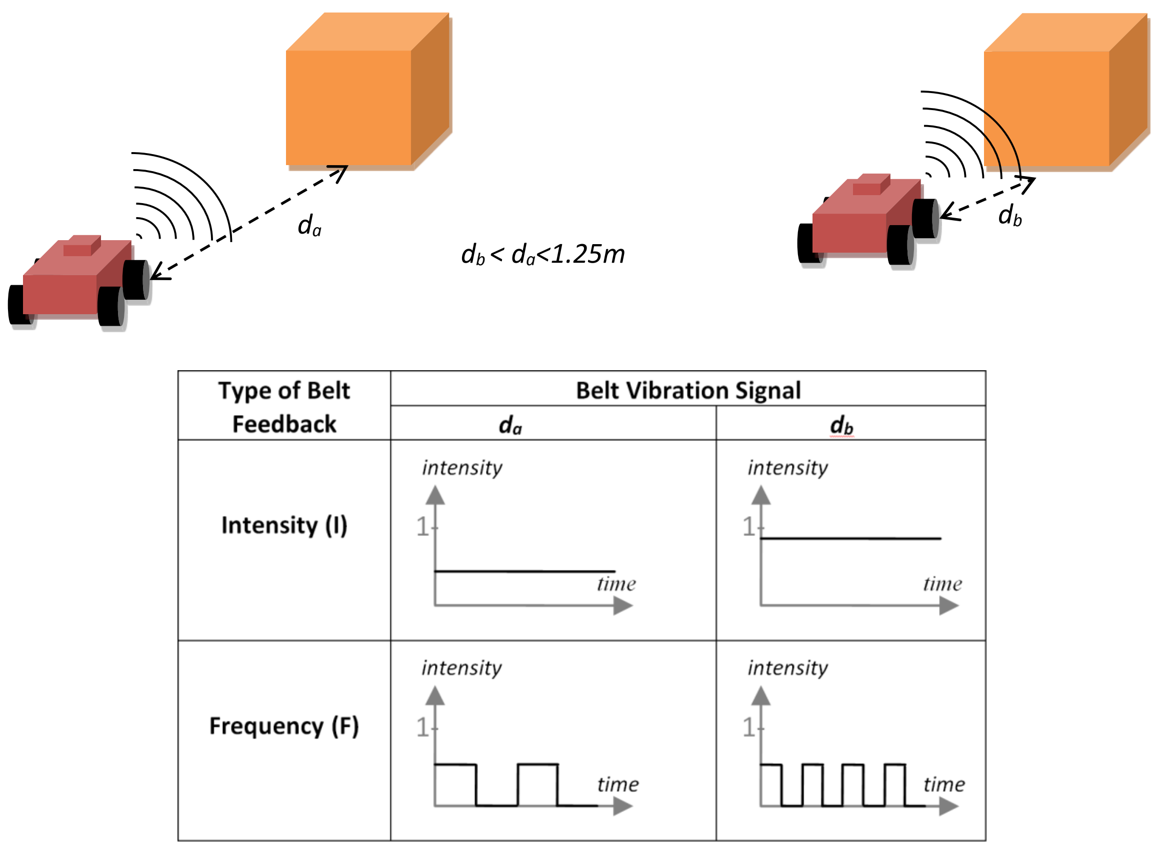


Figure 3.12: Vibro-tactile feedback behavior types used in study #2.

An ASUS G50V laptop with 4 GB RAM and an Intel® Core®2 Duo P4750 (2.13 GHz) processor with a 15.4" LCD monitor was used. It was positioned on top of an office table at 0.5m from subject's eyes. The graphics card was a 512MB GeForce 9800M GT. The environment was run in a window with resolution of 1024 × 768 at an average frame rate of 17 fps.

3.3.3. Task

To evaluate the validity of the interfaces proposed, the same search task as in study #1 was used. The only difference was that there were now twelve spheres hidden instead of only nine. The reasoning behind adding more spheres was to provide a wider range of variation in subject's sphere-search performance. It is expected that the chances of detecting variations in search performance due to interface use are expected to increase if more spheres are available.

3.3.4. Hypotheses

The use of vibro-tactile and enhanced interfaces has been shown to improve user performance (Blom & Beckhaus, 2010; Bloomfield & Badler, 2007; Burke et al., 2006; Herbst & Stark, 2005; Lindeman et al., 2005; Johnson et al., 2003). The results of study #1 (de Barros et al., 2009) have shown that using both a vibro-tactile display and a visual display for collision proximity feedback (CPF) can improve performance in a simple USAR task. This study evaluates the isolated impact on cognitive load for different vibro-tactile feedback modes, through the analysis of search performance variables, sketchmaps and subject questionnaires.

In a pilot study preceding this study, subjects reported that the Frequency interface gave more accurate feedback for estimating the distance between the robot and surrounding objects, but it was more annoying and difficult to use. The Intensity interface, on the other hand, was reported to be easier to understand but not very accurate in estimating distances.

Based on these pilot study results, and because this study (S2) deals with a population comprised of college students mostly inexperienced in using robots for USAR, we hypothesize that:

S2H1. Using either vibro-tactile feedback interface should lead to an improvement in performance and SA in the search task compared to the control case;

S2H2. Using the Intensity interface should lead to a higher performance and SA improvement compared to the Frequency interface because of its ease of use and due to the lack of experience of subjects with such an environment.

3.3.5. Methodology

The empirical study was designed to confirm whether the use of either proposed vibro-tactile feedback interface would lead to a reduction in operator cognitive load related to navigation. A within-subjects design was selected for this study. This design enabled a more comparative subjective interface feedback to be obtained. With the proper experimental procedures and data analysis, it also enabled the achievement of more statistically significant results while using a smaller pool of subjects. As in study#1 (section 3.2.5) (de Barros et al., 2011), a fielded interface approach was used.

3.3.5.1. Independent Variable

The *independent variable* was the type of CPF interface, which includes the vibro-tactile interfaces “Intensity” (I) and “Frequency” (F) described in section 3.3.2 and a control case without vibro-tactile feedback (“None” or “N”).

3.3.5.2. Dependent Variables

The eight *dependent variables* were the time taken to complete the search task, the number of collisions, the number of collisions per minute, the ratio between number of collisions and path length, the number of spheres found, the number of spheres found per minute, the ratio between number of spheres found and path length, and the quality of the sketchmaps. When comparing the dependent variables in this study to the ones used in study #1, notice that, for this study, the number of collisions and the number of spheres found are now being normalized not only by task time, but also by path length.

In addition to that, in order to reduce variation of results among subjects (see Figure 3.14), variables were also normalized on a per-subject basis. Such normalization helped neutralize noise added due to users varying levels of experience with robot, RCV and videogame interfaces.

Here is an example that explains this per-subject normalization process: if subject *A*, for a dependent variable *X*, had the following results (*Interface 1*, *Interface 2*, *Interface 3*) = (10, 20, 30), these values would be converted to (10/60, 20/60, 30/60) ~ (0.17, 0.33, 0.5). The results then become a percetual value, the sum of the results leading to 100% or 1.0. For all four studies, results reported as "percentual" or "percentage" have been normalized using this approach.

3.3.5.3. Study environment

The experiment (Figure 3.13) and training (Figure 3.11) VEs as well as the robot interface (Figure 3.12) were built using the C4 game engine (C4 Game Engine, 2012) similarly to study #1. This time however, due to the within subjects design, different worlds had to be used for each interface and their order randomized. The experiment VEs difficulty level was still yellow

(Jacoff et al., 2003). Figure 3.13 shows an example of what the subjects could see through the robot virtual camera.

Figure 3.13: Sample robot camera view from where the virtual robot is located in study #2.

3.3.5.4. Experimental Procedure

As stated earlier, a within subjects design was used in study #2. Each subject was sequentially exposed to three interface designs. Subjects were exposed to them in different orders, randomized among treatments using a Latin Square to compensate for effects within treatments. Each interface was considered one treatment or trial.

In the beginning of the experiment, demographic information was collected and a spatial aptitude test was applied. After that, instructions about the experiment were given and then the sequence of treatments was performed.

As in study#1, subjects were allowed to use the robot camera to take pictures of the environment and spheres they found. After each treatment, and using the pictures taken as a reference, subjects were asked to report the number of spheres found by drawing a map of the environment explored. After that, they filled-in a post-questionnaire giving their impressions about the interface they were just exposed to. After each treatment, subjects were also asked to fill-in the NASA-TLX workload questionnaire (Hart, 2006; Hart & Staveland, 1988).

After all three treatments, subjects were asked to fill-in a summative questionnaire where they would comparatively rate all interfaces. For all treatments, subjects had to wear the belt, even for the control case.

Each subject took at most two hours to complete the study with some subjects completing it in only one hour. The procedure to which each subject was submitted was the following:

1. Institutional Review Board (IRB) approved consent forms were read and signed;
2. Demographic information was collected;
3. A spatial aptitude paper test was administered;
4. The experiment instructions and a Q&A session occurred;
5. Robot controls for the experiment were explained;
6. The training session task was explained, questions answered, and the subject started training when ready;
7. The transition from training to the real task was explained by the experimenter who also briefly reviewed the task goal. The experiment started when the subject was ready;
8. During the main experiment, the subject behavior and on-screen actions were recorded on

video;

9. Once the treatment was over, the subject filled in a treatment questionnaire where they drew the sketchmap and were asked for subjective opinions on the interface used;
10. Steps 5 - 9 were repeated for the other two interface modes;
11. Once the three treatments were over, a final questionnaire asked to rate the interfaces in terms of presence and comfort levels based on the SUS (Kennedy & Land, 1993; Kennedy et al., 1993) and SSQ questionnaires (Usoh et al., 2000).

Subject gender and age, how often they played video games and used or worked with robots was collected in the demographics questionnaire. The spatial aptitude paper test had nine questions, including painted cube faces association and map orientation questions. Subjects had strictly five minutes to complete the test, otherwise questions would be left blank.

The instruction page given to subjects explained the experiment procedure, the task and the interface. Apart from answering questions, the experiment explanation and procedure was automated using a digital slideshow. This approach helped avoid bias caused by explanation mistakes by the experimenter.

Each training session world was identical to study #1 (Figure 3.11), with the exception that there were now three of them organized differently. The task was again to find a red sphere and take a picture of it. As in study #1, objects in the experiment room represented real life-size debris (Figure 3.13). The experiment time and the location and time of the collisions were recorded. A sample of the information recorded is presented in Figure 3.14.

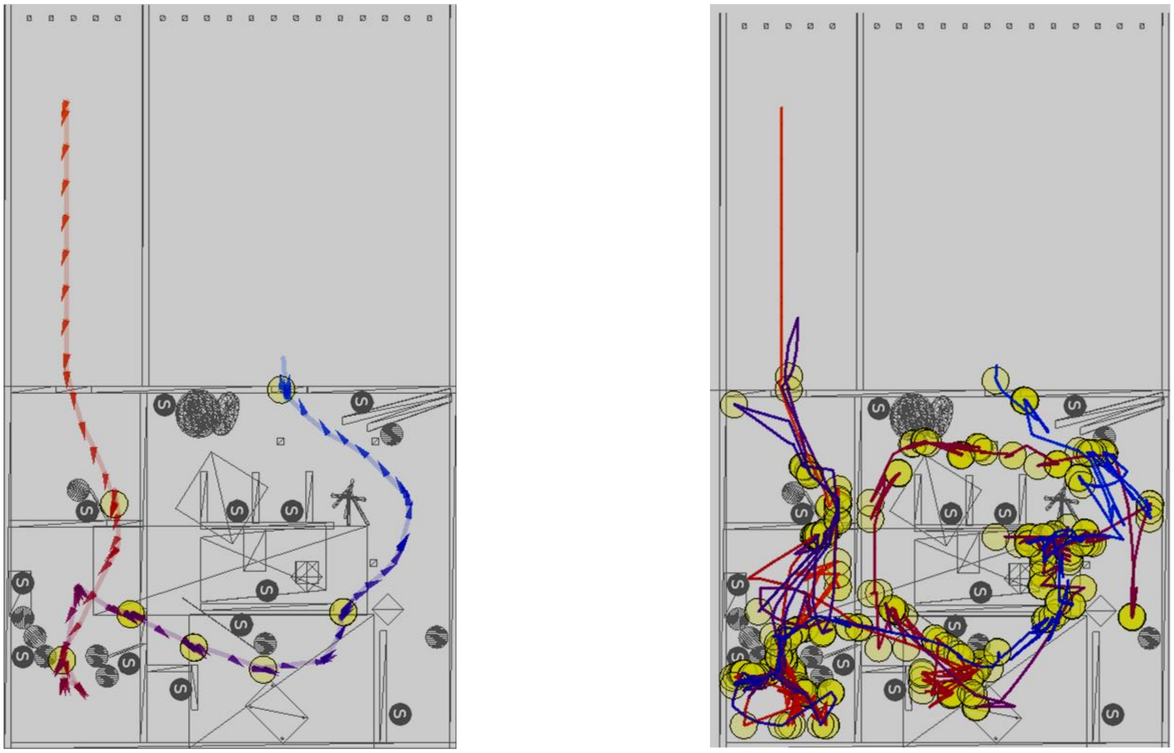


Figure 3.14: Sample data collected for two treatments of different subjects in study #2. Behavioral variation between subejcts is evident. Each yellow circle presents a collision, circles with an "S" in the middle represent the spheres being searched for and the triangular arrows along the path represent the robot camera orientation. Both paths start in orange and end in blue.

For each treatment questionnaire, subjects had to draw sketchmaps, report the number of spheres found and answer questions about their levels of presence and comfort using the interfaces. The feedback for subjective impressions were given on a Likert scale (1-7) and included questions about the interface difficulty of use and levels of nausea, dizziness, and presence, adapted from the SUS (Kennedy & Land, 1993; Kennedy et al., 1993) and SSQ questionnaires (Usoh et al., 2000). In the final questionnaire, subjects rated all interfaces on a Likert scale (1-7).

The sketchmaps were evaluated using Billinghurst & Weghorst (Billinghurst & Weghorst, 1995) approach, but resized to a scale from 1 to 5. The definition used for grading map goodness was the same as in study #1 (de Barros et al., 2011), that is, how well the sketched map would help in guiding one through the environment.

3.3.5.5. Other Materials

Other materials used in this study, such as the script used by the experimenter, the information contained in the user study instruction sheet, and the questions contained in the user study post-task questionnaire, are found in Appendix B.1.

3.3.6. Results

This section presents all the relevant results for this second study. Data for all the data analysis can be found in appendix B.2.

Our results were obtained using a single-factor ANOVA with confidence level of α = 0.05. Results close to significance had a confidence level of α = 0.1 and were described as trends. When a statistically significant difference (SSD) among more than two groups was found, a Tukey test (HSD, 95% confidence level) was performed to reveal the groups that differed from each other. In some cases, ANOVAs were also applied to compare groups in a pair-wise fashion.

For questionnaire ratings, Friedman tests were used to compare all groups together, while Wilcoxon tests were used to compare them in a pair-wise fashion. Sections where SSD results were found have their titles marked with an asterisk (*). If only a trend was found, the title of that section is marked with a plus sign (+).

3.3.6.1. *Demographics*

A total of 14 female and 22 male university students participated in the study (mean age: 19.67, S.D.: 1.49, B.2.1).

3.3.6.2. Task Time

Task time represents the time spent by a subject from the start of the search task until the robot passed through the exit door. For task time, no SSD was found among these groups ($F = 0.135$, $p = 0.874$, B.2.7).

3.3.6.3. Number of Collisions*

This variable accounts for the total number of collisions between the robot and the remote environment. For different interface types, no SSD was found for this variable ($F = 0.283$, $p = 0.754$, B.2.6). Nonetheless, compared to the control case, the Frequency interface seemed to have decreased the dispersion of results and the mean, while the Intensity interface led to more dispersion. On the other hand, the median for both interfaces decreased, the Intensity interface leading to a larger reduction. Hence, for this dependent variable, the results seem to support S2H1, but only partially since no SSD was found. Notice in Table 3.2 the large values in standard deviation. Despite the attempt of a further analysis (removing outliers), still no SSD was found. However, when this variable was normalized on a per-subject basis (Figure 3.15, B.2.6.1), SSDs were found between groups *None* and *Frequency* ($F = 7.481$, $p = 0.008$), and *None* and *Intensity* ($F = 4.808$, $p = 0.032$).

Collisions-per-minute represents a time-normalized value for the number of collisions and confirms the obtained results by the latter variable. Even though no SSD was found for different CPF interfaces ($F = 1.416$, $p = 0.247$, B.2.8), both CPF interfaces decreased the variable mean and median values; when normalized on a per-subject basis, SSDs were again found between groups *None* and *Frequency* ($F = 9.672$, $p = 0.003$, B.2.8.1), and *None* and *Intensity* ($F = 13.28$, $p < 0.001$, B.2.8.1).

Collisions-per-path-length represents a space-normalized value for the number of collisions. Despite such normalization, no SSD was found for different interfaces ($F = 0.875$, $p = 0.420$, B.2.9). This variable's results were also scaled by a factor of 100 in Table 3.2. As seen on this table, both vibro-tactile interfaces have decreased in the median and mean values of this variable. For the intensity interface, even the dispersion was reduced. And, again, when normalized on a per-subject basis, SSDs were once again found between groups *None* and *Frequency* ($F = 9.172$, $p = 0.003$, B.2.9.1), and *None* and *Intensity* ($F = 13.82$, $p < 0.001$, B.2.9.1).

3.3.6.4. Number of Spheres Found

Contradicting the hypotheses for the number of spheres found, when comparing groups using different interfaces types, no SSD was detected ($F = 0.183$, $p = 0.833$, B.2.4). In fact, both non-normalized and normalized versions of this dependent variable led to no SSDs.

The time and path normalized number of spheres found variables have however, led to an increase in spread for the Frequency interface, indicating that further subject training might be required for this interface.

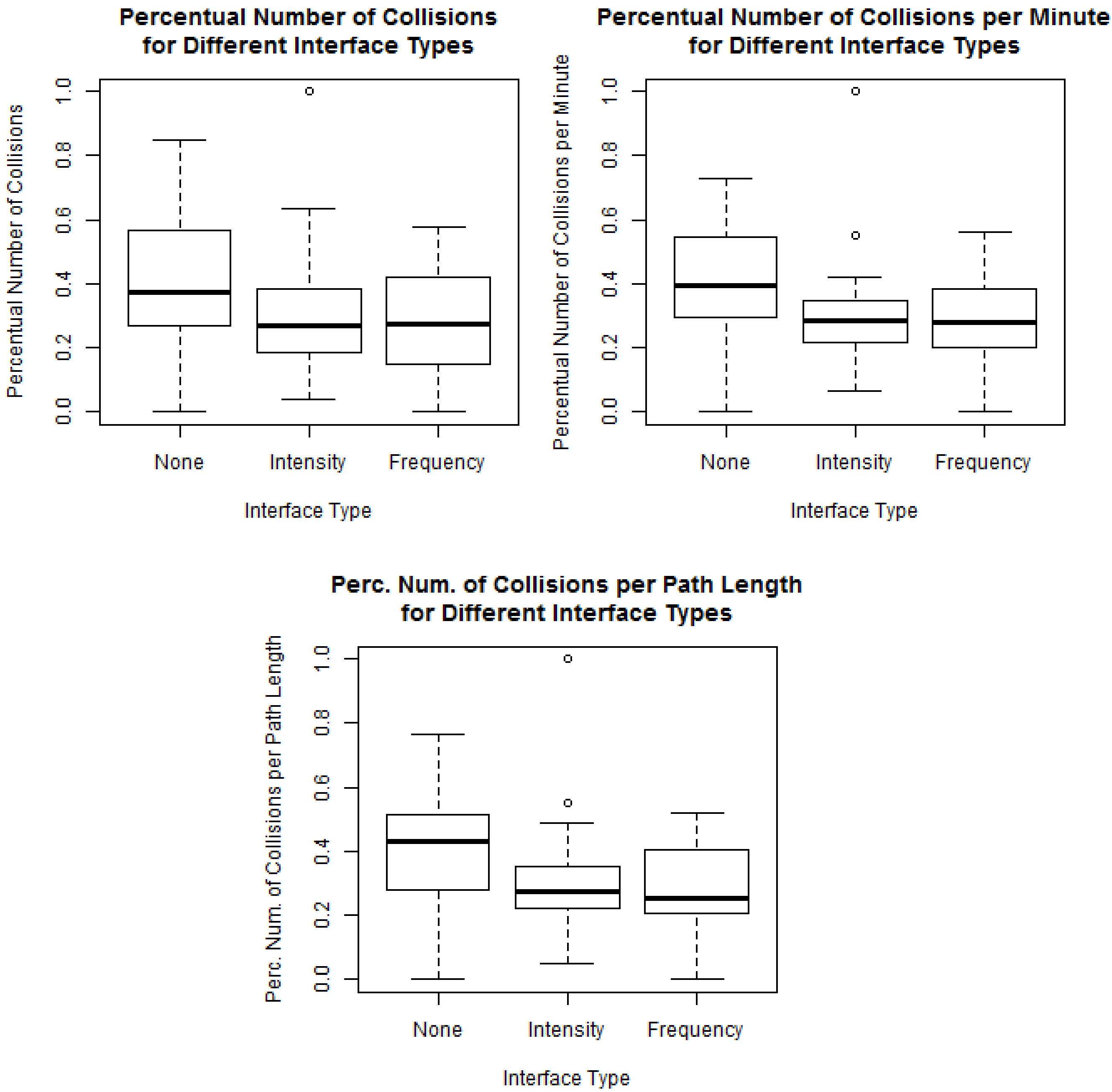


Figure 3.15: In study #2, both types of vibro-tactile feedback showed statistically significant performance improvements in the data for normalized number of collisions, normalized number of collisions per minute and normalized number of collisions per path length.

Table 3.2: Dependent variable non-normalized data for different interfaces in study #2. The SSDs below were obtained with the subject-normalized versions of the data presented in this table.

	Measure		None	Intensity	Frequency
*	***N.Collisions*** f_o = 0.283 f_w = 4.373	***Mean:*** ***S.D.:*** ***Median:***	58.994 82.121 35.500	57.907* 106.802 22.500	45.639** 52.382 25.500
	N. spheres f_o = 0.183 f_w = 0.549	***Mean:*** ***S.D.:*** ***Median:***	5.972 2.772 6.000	6.361 2.576 6.500	6.194 2.847 6.000
	Task Time (sec.): f_o = 0.135 f_w = 0.471	***Mean:*** ***S.D.:*** ***Median:***	594.722 466.919 478.000	613.917 434.875 479.000	563.472 335.013 475.000
***	***N. Coll./Min.*** f_o = 1.416 f_w = 8.067	***Mean:*** ***S.D.:*** ***Median:***	4.982 2.893 4.814	3.854** 3.286 3.074	4.032*** 2.981 3.243
	N. Sphs. /Min. f_o = 0.160 f_w = 0.161	***Mean:*** ***S.D.:*** ***Median:***	0.727 0.410 0.758	0.775 0.395 0.677	0.775 0.443 0.698
	Path Length f_o = 0.028 f_w = 0.061	***Mean:*** ***S.D.:*** ***Median:***	82.830 49.220 70.458	84.984 51.654 70.963	82.472 45.508 68.983
***	***N.Coll./P. Lgth.*** f_o= 0.875 f_w= 8.072	***Mean:*** ***S.D.:*** ***Median:***	0.593 0.419 0.469	0.474** 0.491 0.342	0.475*** 0.400 0.337
	N. Sphs./P. Lgth. f_o = 0.084 f_w = 0.1914	***Mean:*** ***S.D.:*** ***Median:***	0.083 0.051 0.078	0.087 0.040 0.084	0.086 0.047 0.084
•	***Map Quality*** f_o = 0.378 f_w = 2.397	***Mean:*** ***S.D.:*** ***Median:***	2.694• 1.348 2.000	2.722• 1.406 2.000	2.472 1.253 2.000
• p < 0.1; * p < 0.05; ** p < 0.01; *** p < 0.001					

3.3.6.5. Map Quality+

Sketchmaps are a measure of the operator's situation awareness (SA). If cognitive load was decreased by the use of multi-sensory interfaces, such a decrease should lead to a higher level of map quality and SA, since the operator will be able to pay more attention to the environment surrounding the robot instead of paying attention to robot controls.

As in study#1, maps were graded on a scale from 1 to 5 (de Barros et al., 2011). When comparing groups with different interfaces, no SSD was found for sketchmaps ($F = 0.378$, $p = 0.686$, Table 3.2 and B.2.3). Nevertheless, the use of the Frequency interface led to a slight reduction for both the mean and the dispersion of the quality of grades. The analysis of the normalized map quality (Figure 3.16) has shown a trend showing degradation in map quality for the Frequency Interface compared to the other two interfaces ($F = 2.397$, $p = 0.096$, B.2.3.1).

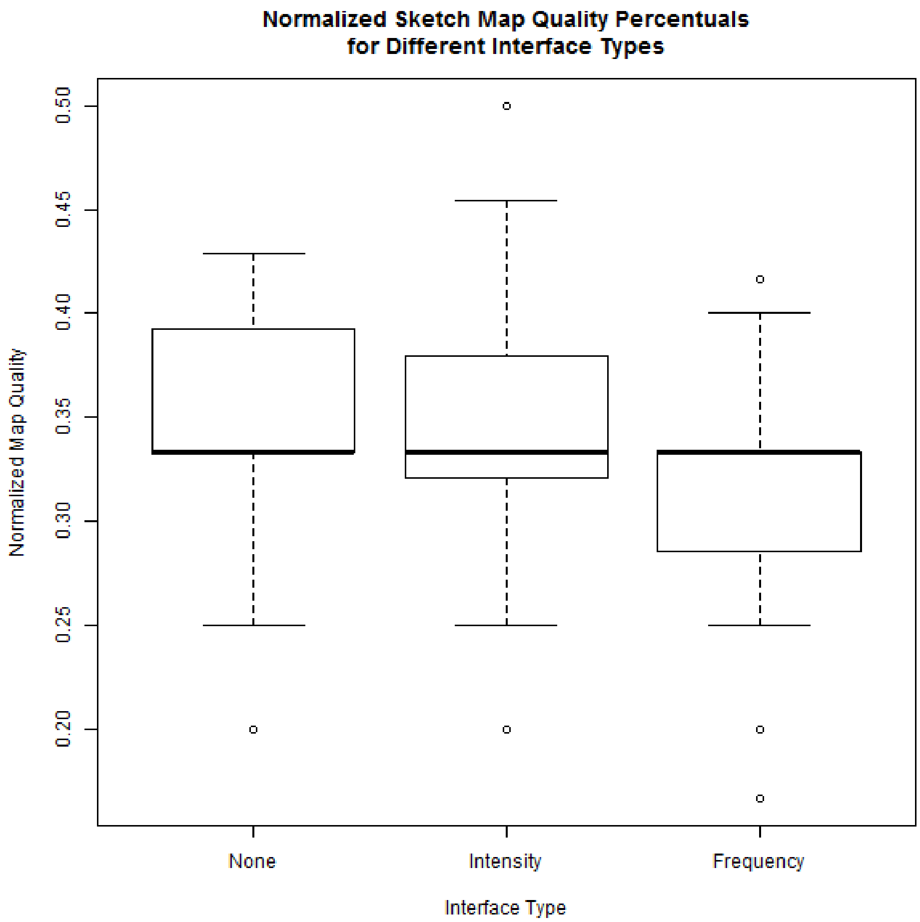


Figure 3.16: Frequency interface of study #2 led to a small degradation in map quality.

*3.3.6.6. Treatment Questionnaires**

For the treatment questionnaires subjective rating questions, one SSD and a few trends were detected (Table 3.3, B.2.2). In Table 3.3, the black lines represent groups of interfaces with results statistically equal. If no line is present, all interface results were statistically equal.

Table 3.3: Comparison of treatment questionnaires for different interfaces.

Measure	Interfaces Stats. Summary				Pair-wise comparison			
		N	I	F		NI	NF	IF
***Difficulty*:**	***Mean***	5.083	4.899	5.083	***W***	181.5	140.0	82.5
(Friedman	***S.D.***	1.381	1.430	1.422	***Z***	1.093	-0.284	-0.916
χ^2= 1.299	***Med.***	5.0	5.0	5.0	***p***	0.285	0.809	0.403
p = 0.522)					***R***	0.129	-0.033	-0.108
BeingThere:	***Mean***	3.556	3.994	3.917	***W***	129.0	96.5	97.5
• *(Friedman*	***S.D.***	1.576	1.372	1.500	***Z***	-1.703	-1.691	0.468
χ^2= 3.515	***Med.***	3.0	4.0	4.0	***p***	**0.087**	**0.095**	0.661
p = 0.173)					***R***	-0.201	-0.199	0.055
Reality:	***Mean***	3.556	3.667	3.250	***W***	101.5	209.5	172.5
• *(Friedman*	***S.D.***	1.780	1.656	1.318	***Z***	-0.355	1.022	1.802
χ^2= 1.787	***Med.***	4.0	4.0	3.0	***p***	0.752	0.321	**0.074**
p = 0.409)					***R***	-0.042	0.120	0.212
Visited:	***Mean***	3.306	4.083	3.694	***W***	18.0	44.0	148.0
** *(Friedman*	***S.D.***	1.954	1.663	1.910	***Z***	-3.135	-1.692	1.507
χ^2= 9.407	***Med.***	3.0	4.0	3.0	***p***	**0.001**	**0.092**	0.141
***p* = 0.009**)					***R***	-0.370	-0.199	0.178
Walking	***Mean***	3.000	3.167	2.861	***W***	110.5	74.0	159.5
(Friedman	***S.D.***	1.971	1.781	1.791	***Z***	-0.488	0.104	1.222
χ^2 = 1.238	***Med.***	2.0	3.0	2.0	***p***	0.631	0.901	0.231
p = 0.538)					***R***	-0.057	0.012	0.144
Nausea	***Mean***	1.944	2.056	2.306	***W***	45.5	27.0	27.5
• *(Friedman*	***S.D.***	1.530	1.433	1.704	***Z***	-0.916	-1.818	-0.967
χ^2 = 3.964	***Med.***	1.0	1.0	1.0	***p***	0.401	**0.084**	0.328
p = 0.138)					***R***	-0.108	-0.214	-0.114
Dizziness	***Mean***	1.972	2.056	2.139	***W***	51.5	34.0	32.5
(Friedman	***S.D.***	1.558	1.453	1.641	***Z***	-0.706	-0.845	-0.574
χ^2= 1.088	***Med.***	1.0	1.0	1.0	***p***	0.537	0.426	0.637
p = 0.581)					***R***	-0.083	-0.100	-0.068

• p < 0.1; * p < 0.05; ** p < 0.01; *** p < 0.001

Compared to interface None, the Saw vs. Visited scores (6th question in section B.1.4) were higher (χ^2 = 9.407, *p* = 0.009, B.2.2.4) for both Frequency and Intensity interfaces. In other words, both of these interfaces, but especially the Intensity interface, made subjects feel more as if they had visited the environment as opposed to feel as simply having seen it.

Improvements in the results of other ratings were visible, but not statistically significant. For example, a trend showed that both Frequency (*w* = 96.5, *z* = -1.691, *p* = 0.095, *r* = -0.199, B.2.2.2) and Intensity (*w* = 129.0, *z* = -1.703, *p* = 0.087, *r* = -0.201, B.2.2.2) interfaces seemed to have enhanced the sense of being there. On the other hand, the Frequency interface caused an increase in nausea levels (*w* = 27.0, *z* = -1.818, *p* = 0.084, *r* = -0.214, B.2.2.6) compared to the control case. A trend using a Wilcoxon test also showed that the Frequency interface had a lower score for Reality compared to the Intensity interface (*w* = 172.5, *z* = 1.802, *p* = 0.074, *r* = 0.212, B.2.2.3). Overall, and in support of S2H2, the Intensity interface seemed to have received more positive scores than the Frequency interface.

*3.3.6.7. Final questionnaires**

The main goal of the final questionnaire was to obtain a global comparative view of the three interfaces from the subject's perspective. In Table 3.4, the black lines represent groups of interfaces with results statistically equal.

No SSD was detected for the scores of difficulty, though a trend was detected between the Intensity and Frequency interfaces (*w* = 93.5, *z* = -1.737, *p* = 0.082, *r* = -0.205, B.2.5.1). The Frequency interface had a higher mean difficulty score than the Intensity interface. SSDs were not detected for the help-in-understanding-environment and straight-forwardness variables. On average, the Intensity interface was rated as more straight-forward than the Frequency interface.

For the difficulty scores, there was a visible improvement in the average score for the interfaces with vibro-tactile feedback, but no SSD was found. A similar effect was perceived for the help-in-understanding-environment variable for the Intensity interface. For the straight-forwardness score, a reduction in the dispersion for the Intensity interface was also perceived.

A SSD was found for the scores of distraction (F = 56.573, p < 0.001, B.2.5.3) and comfort (F = 19.969, p < 0.001, B.2.5.4). For the former, the Frequency interface was the most distracting, followed by the Intensity interface. The comfort scores were similar, the Frequency interface being the most uncomfortable, followed by the Intensity interface.

Table 3.4: Comparison of final questionnaire results for different interfaces in study #2.

	Measure		Interfaces Stats. Summary				Pair-wise comparison		
			N	I	F		NI	NF	IF
•	***Difficulty*:**	***Mean***	3.486	3.257	3.829	***W***	245.5	196.0	93.5
	(Friedman	***S.D.***	2.049	1.597	2.036	***Z***	0.513	-0.850	-1.737
	χ^2= 2.243	***Med.***	4.0	3.0	3.0	***p***	0.618	0.402	**0.082**
	p = 0.326)					***R***	0.060	-0.100	-0.205
•	***Straightf.:***	***Mean***	5.057	5.143	4.657	***W***	157.5	147.0	203.5
	(Friedman	***S.D.***	1.714	1.556	1.830	***Z***	-0.598	1.368	1.634
	χ^2= 3.857	***Med.***	5.0	5.0	5.0	***p***	0.556	0.175	**0.105**
	p = 0.145)					***R***	-0.070	0.161	0.193
***	***NotDistract.:***	***Mean***	6.839	4.000	2.771	***W***	465.0	595.0	237.5
	(Friedman	***S.D.***	0.453	2.072	1.880	***Z***	5.060	5.178	2.982
	χ^2= 54.496	***Med.***	7.0	4.0	2.0	***p***	**0.000**	**0.000**	**0.002**
	p < 0.001)					***R***	0.596	0.610	0.351
***	***Comfort:***	***Mean***	5.722	3.861	3.167	***W***	417.0	484.0	152.5
	(Friedman	***S.D.***	1.767	1.854	1.699	***Z***	3.867	4.224	1.954
	χ^2= 27.133	***Med.***	6.0	4.0	3.0	***p***	**0.000**	**0.000**	**0.053**
	p < 0.001)					***R***	0.456	0.498	0.230
	H. Underst.	***Mean***	4.250	4.556	4.000	***W***	213.5	339.0	174.5
	(Friedman	***S.D.***	1.713	1.731	1.805	***Z***	-0.822	0.657	0.907
	χ^2 = 1.295	***Med.***	4.0	5.0	4.0	***p***	0.412	0.518	0.373
	p = 0.523)					***R***	-0.097	0.077	0.107

• p < 0.1; * p < 0.05; ** p < 0.01; *** p < 0.001

It seems that both Frequency and Intensity caused improvements, but also led to some problems in terms of distraction and health. The vibration of the tators was too frequent at times and distracted subjects form the visual search task. Additionally, such vibration also caused skin itchiness in some subjects. Once again in support of S2H2, overall the Intensity Interface seems to have obtained better scores than the Frequency interface.

3.3.6.8. Learning Effects for Different Interfaces

For the analyses above, subject treatments were divided into groups according to the interface used. In sequence, these groups were compared within themselves to see if there was an effect on dependent variables when using an interface in the first, second, or third treatments. To achieve that, these groups were further divided into three subgroups that contained occurrences of each interface in each of the three treatments as shown in Table 3.5.

The data for all variables were normalized on a per-subject basis before being statistically processed using the same previously described method for the results in Table 3.2. In addition, as an attempt to make learning effects more clearly displayed, the subgroup results are arranged differently for each condition to match the order with which such condition was presented during trials. That is, “N” (None) subgroup results are presented in the order NIF (1^{st}), FNI (2^{nd}), IFN (3^{rd}), while “I” (Intensity) subgroup results order is IFN (1^{st}), NIF (2^{nd}), FNI (3^{rd}), and “F” (Frequency) subgroup results order is FNI (1^{st}), IFN (2^{nd}), NIF (3^{rd}). The black lines represent groups of interfaces with results statistically equal. The number of decimal digits has been reduced to save table row space, but they can be found with more accuracy in appendix B.2 for each of their respective variables (e.g., section B.2.3.2 for Map Quality).

Table ***3.5*** illustrates the compromise when using a within-subjects experiment design: learning effects. Even though such an effect did not impact as much the results for collision-related variables, it might well have been the cause for not having achieved statistically significant results for the sphere-finding variables. Notice that these differences are indeed statistically stronger for these sphere-finding variables, but this was anticipated. As subjects perform the trials and learn about the virtual environment and how the spheres are hidden, it is only expected that subjects will also learn how to better search for these spheres in later trials.

Table 3.5: Learning effects on dependent variables for study #2.

Measure per Interface		Interface Order (Mean, S.D., Median) 1st	2nd	3rd	f-value
Task Time	N	(785.7, 728.8, 533.5)*	(523.4,249.0, 420.0)	(475.1,199.1, 434.5)	3.5*
	I	(718.1, 483.9, 536.0)	(642.9, 561.4, 437.5)**	(480.7, 142.8, 482.5)*	5.6**
	F	(622.0, 387.7, 573.0)	(526.6, 274.2, 502.0)	(542.0, 354.8, 448.5)	1.8
Number of Colls.	N	(93.1, 126.3, 48.0)**	(41.1, 27.2, 31.0)	(42.7, 53.5, 19.5)	4.7*
	I	(84.2, 138.9, 29.5)	(63.5, 121.6, 22.5)**	(26.1, 18.4, 20.5)**	8.2**
	F	(44.0 , 37.7, 36.5)*	(46.8, 58.0, 22.0)	(46.1, 62.7, 20.5)	2.7•
N. Sph. Found	N	(5.0, 2.9, 4.5)	(6.1, 2.2, 6.0)*	(6.8, 3.1, 6.5)**	6.8**
	I	(5.4, 2.6, 5.0)	(7.2, 2.0, 7.0)*	(6.4, 2.8, 7.0)•	2.7•
	F	(5.2, 3.4, 5.5)*	(5.9, 2.5, 5.0)*	(7.4, 2.2, 7.5)	3.5*
N. of Col./Min.	N	(6.0, 2.3, 5.9)*	(4.7, 2.0, 4.3)	(4.3, 3.9, 3.4)	2.8•
	I	(4.7, 4.6, 3.1)	(3.7, 3.0, 2.8)*	(3.1, 1.8, 2.8)*	4.2*
	F	(4.0, 2.4, 3.4)	(4.4, 3.9, 4.1)	(3.6, 2.6, 2.5)	1.2
N. of Sph. Found/Min.	N	(0.5,0.3, 0.5)	(0.8, 0.3, 0.8)***	(0.9, 0.4, 0.9)***	19.9***
	I	(0.6, 0.3, 0.6)	(0.9, 0.4, 0.8)**	(0.8, 0.3, 0.7)***	3.2***
	F	(0.5, 0.3, 0.5)	(0.8, 0.4, 0.7)	(1.0, 0.4, 1.0)	9.7***
N. Colls. /P.Lgth.	N	(72.1, 37.5, 72.2)	(50.8, 21.3, 44.7)	(55.0, 58.7, 42.8)	2.3
	I	(65.2, 73.4, 37.2)	(43.5, 36.7, 33.5)*	(33.4, 18.9, 31.5)*	5.5**
	F	(45.5, 33.1, 33.2)	(50.3, 50.8, 39.9)	(46.8, 37.3, 30.8)	1.2
N. Sph. /P. Lgth.	N	(5.4 , 3.8 , 5.5)	(8.2 , 3.1, 7.8)***	(11.1, 6.4, 10.1)***	15.7***
	I	(6.8, 3.3, 6.8)	(10.7, 4.6, 10.1)**	(8.4, 3.2, 8.6)**	3.3**
	F	(5.4, 3.5, 5.8)	(8.7, 4.4, 8.3)	(11.8, 4.1, 11.5)	10.4***
Ql. maps	N	(2.5, 1.4, 2.0)	(2.6, 1.4, 2.0)	(3.0, 1.3, 3.0)	1.5
	I	(2.7, 1.2, 2.5)	(2.8, 1.7, 2.5)•	(2.7, 1.4, 2.0)*	2.9•
	F	(2.0, 0.9, 2.0)	(2.9, 1.4, 2.5)*	(2.5, 1.2, 2.5)*	3.2•

• $p < 0.1$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

3.3.6.9. Comments

Subjective feedback about the interface and the experiment in general was collected in both final and treatment questionnaires. The Frequency interface was mentioned more times (7 times) as a better mode than the Intensity interface compared to the other way around (4 times). However, and supporting S2H2, subjects reported the Intensity interface to be less precise but easier to learn, while the Frequency interface was harder to comprehend but more precise. The precision refers to how easy it was for subjects to detect variations in the the signal displayed by the tactors for each mode. Because variations in Intensity mode tended to be harder to detect once the skin got asccostumed to the vibration after prolonged use, the Frequency interface pulsing behavior led users to better differentiate variations in the data and hence better estimate distances.

Subjects have also pointed to the fact that the Intensity interface made the perception of multiple tactors of the belt as a single vibrational display easier. In other words, a set of adjacent tactors vibrating at different intensities around a subject's waist could be easily seen as the smooth display of a single object sensed at different distances in an average direction. For the Frequency interface, because the pulses of adjacent tactors varied in frequency, fusing the data in such a way was more difficult.

3.3.7. Discussion

This study continued the work developed in study #1 on multi-sensory vibro-tactile interfaces (de Barros et al., 2009) and explored novel ways to represent robot sensed data, specifically collision-proximity feedback (CPF) through vibro-tactile feedback. Intensity and Frequency CPF interfaces were proposed and it was claimed they would enhance subject performance (S2H1) and that the Intensity interface would outperform the Frequency interface (S2H2).

In accordance with our expectations, both of the proposed hypotheses were validated by the results obtained at least for part of the dependent variables considered. In terms of S2H1, the results have shown that using the TactaBelt with either vibro-tactile configuration appears to indeed have caused a positive impact in navigation performance. The lack of statistical strength in the sphere-finding results, however, might have been due to the learning effects presented in Table 3.5, but could have also been caused by subjects' diverse experience levels with advanced interfaces as could be noticed by the path trace results in Figure 3.14.

In terms of S2H2, the only objective data result that supported this hypotheses was the degradation in map quality by the use of Frequency interfaces compared to the more synoptic Intensity interface. Nevertheless, in support of S2H2, the subjective data collected by both questionnaires did provide evidence for subjects' preference for the Intensity interface by the results obtained for difficulty, straight-forwardness, comfort and distraction measures as well as subjects comments.

The above results together with the results of the previous experiment (de Barros et al., 2011) lead us to believe that the use of vibro-tactile feedback interfaces does enhance performance even if no redundant visual feedback is present. This study's results have also shown that care must be taken when designing the multi-sensory interfaces using vibro-tactile feedback. Vibration pattern, intensity and exposure time must be adjusted to avoid user distraction and discomfort.

In terms of SA, the map quality results provided a glimpse of the potential impact in cognitive load of using more complex CPF interfaces. However, a new experiment with a parallel task needs to be performed to further investigate any such effects.

The feedback obtained from questionnaires seems to suggest that the Intensity interface is easier to use and learn than the Frequency interface. This is in agreement with the pilot study comments and, in fact, makes sense, since the representation of information is more complex with the Frequency interface. This feedback has also pointed out deficiencies in the CPF interfaces such as long activation periods for the tactors dring a specific situation or task.

Interestingly, it was also pointed out by subjects during the pilot and user study that the Frequency interface was more accurate. This claim also seems reasonable because the vibration intensity variations generated by the Intensity interface were harder to distinguish than the vibration-frequency pulse variations generated by the Frequency interface. This is due to the way the skin sensitivity changes when exposed to constant vibration after prolonged periods, making it more difficult to differentiate vibrations coming from adjacent tactors for the Intensity interface.

Despite the positive results obtained for the Intensity interface in this study, we believe it is still too early to decide whether the Frequency or the Intensity interface is better for practical use. Such a question can only be answered when a study with USAR experts is implemented, since their experience may impact the choice of interface. With the current results, however, it seems that the Intensity interface is the better choice for inexperienced users.

3.3.8. Conclusion

The analysis of different types of vibro-tactile feedback for USAR robot teleoperation interfaces has offered a new insight into how vibro-tactile feedback integrates into these interfaces. It contributes as evidence of the usefulness of multi-sensory interfaces in HRI.

Nonetheless, this work was simply an initial step towards the integration of multi-sensory interfaces for USAR robots. A more thorough batch of tests using multiple senses (visual, auditory, tactile, olfactory) and encompassing different data representations must be carried out in order to further our understanding of the benefits and drawbacks brought by the use of multi-sensory interfaces.

In view of the overwhelming number of interface configurations that are possible to be designed, the initial scope of such multi-sensory interface exploration should be restricted to understanding how much these interfaces can increase in complexity without cognitively overloading the operator and identifying the impact of adding new senses to the interface. Moreover, research into the choice of sensors and data to associate with each of the senses should be conducted. For the context of the research presented here, CPF data seems to be in alignment with the type of vibro-tactile feedback provided and the task at hand.

For other senses, a similar alignment should also be sought out. Audio feedback should integrate with events that naturally generate sound in the real world (e.g., playing a sound when the robot bumps into an object). Similarly, smell feedback should be associated with events that are related to the perception of smell (e.g., associating a smell to how much smoke is in the air). Association events should be viable even for the sense of taste (e.g., soil and liquid samples obtained by the robot should taste different to the operator depending on the type and level of a chemical being measured by the robot sensors).

User studies #3 and #4 to follow add feedback for the senses of hearing and smell on top of the current bi-sensory (vision, touch) interface presented in this study and evaluate the effect of such enhancements. Moreover, they will further explore the role that redundant feedback plays on multi-sensory interfaces. Additionally, study #4 will verify whether the results obtained for multi-sensory interfaces in a robot simulation can be reproduced using a real robot in a remote physical environment.

3.4. Study #3: Exploring Multi-Sensory Feedback Interfaces and Redundant Feedback in Virtual Robot USAR

3.4.1. Motivation

The current work builds on the results o the two previous studies and evaluates the effect of adding audio feedback to a bi-sensory interface (vision and touch), and the effect of presenting data redundantly across user senses.

3.4.2. Robot Interface

Results from previous studies (de Barros et al., 2011; de Barros & Lindeman, 2012) suggest that vibro-tactile feedback by itself is not the best navigation interface among the interfaces available. Instead, it should be used as a supplement to other interfaces (Pielot & Boll, 2010). In this work, three multi-sensory interfaces with increasing complexity were created by supplementing a vibro-tactile one with extra feedback.

The first interface used in this new study (Interface 1) is a control case interface and the starting point for the enhancements done by the two other interfaces following it. It is based on the study #2 Intensity interface in section 3.3.2 (de Barros & Lindeman, 2012). It fuses information as close as possible to the operator's point of focus, around the parafoveal area (Kaber et al., 2006). The vibro-tactile feedback belt and gamepad controls are the same ones used in the previous studies as well.

Interface 2 builds upon Interface 1 by adding sound feedback to it using a stylized (cartoonified and metonymic) approach similar to what is done in videogames. The first type of sound feedback is a stereoscopic bump sound when collisions between the virtual robot and the

VE occur. The second one is an engine sound that increases in pitch as speed increases. The motivation behind the engine sound is to provide feedback on the robot's moving speed.

Interface 3 builds upon Interface 2 but adds extra visual feedback to the interface (Figure 3.17). A ring of eight dots is displayed on the top of the robot and mimics the current state of the vibro-tactile belt. It is an improvement over previous work on redundant CPF displays (de Barros et al., 2011), which used a ring ofcoloured cylinders arrayed in 3D around the virtual robot. The positioning on the belt of each tactor is associated with one of the dots in the ring and their locations match. The more intensely a tactor vibrates, the more red the dot associated with that tactor becomes (as opposed to its original color black). The second added visual feature is a speedometer positioned on the back of the robot as a redundant display for the engine sound. Table 3.6 summarizes the features for each interface.

Sound feedback was displayed through an Ion iHP03 headset. The headset was worn for all treatments. The same ASUS G50V laptop and office space set-up used in study #2 were used for this study. The environment was run with a resolution of 1024×768 at a refresh rate of 17 fps.

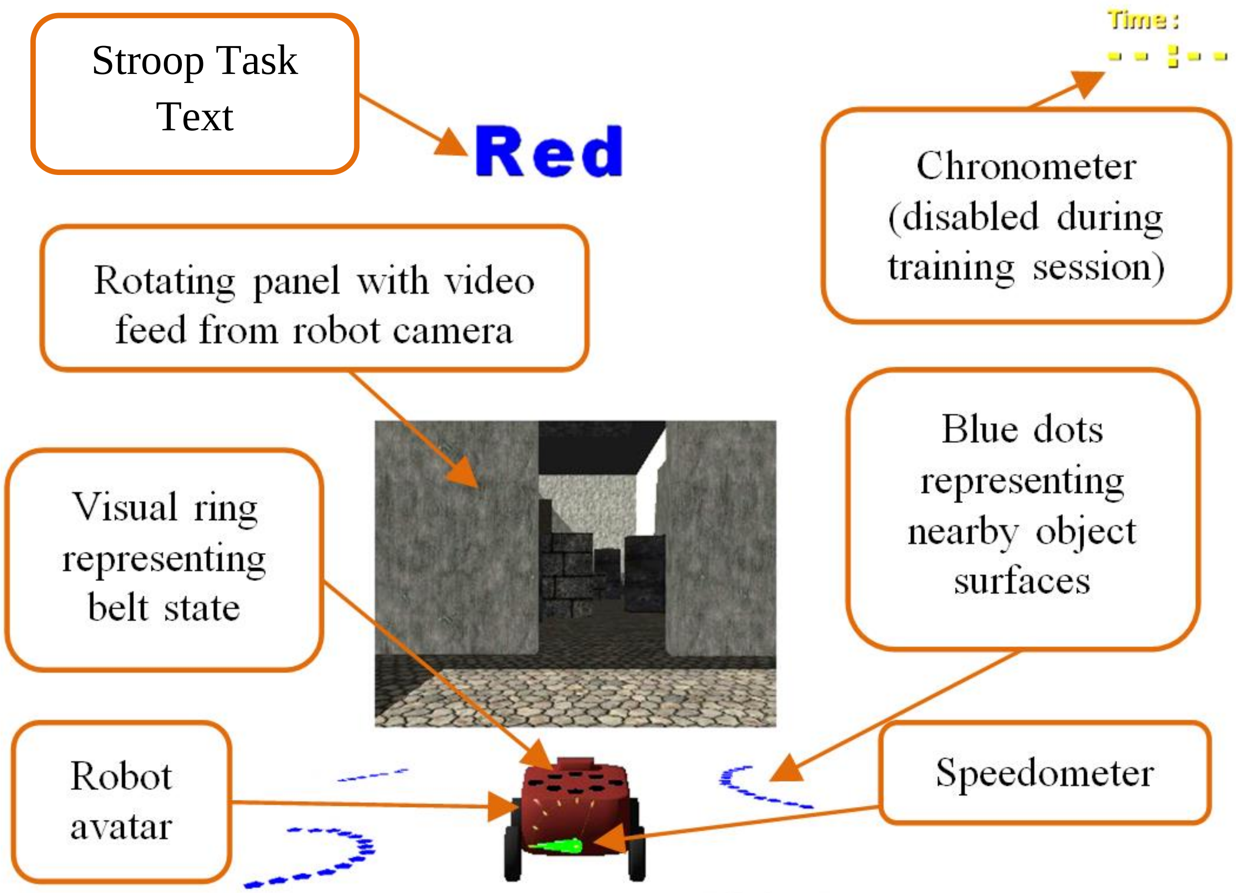


Figure 3.17: Visual components for all three interfaces of study #3. The visual ring and speedometer are only part of Interface 3.

Table 3.6: Display features for each interface treatment in study #3.

Interface Number	Standard Visual Interface	Vibro-tactile feedback	Audio feedback	Visual ring and speedometer
1	X	X		
2	X	X	X	
3	X	X	X	X

3.4.3. Task

To evaluate the validity of the proposed interfaces, the same primary task used in study #2 was designed: search for twelve red spheres (radius: 0.25m) in a debris-filled environment. However, this study also asked subjects to perform the secondary Stroop task.

3.4.4. Hypotheses

As seen in previous studies, the use of vibro-tactile and enhanced interfaces has been shown to improve user performance (Blom & Beckhaus, 2010; Burke et al., 2006; Herbst & Stark, 2005; Johnson et al., 2003; de Barros & Lindeman, 2012). What is not a consensus yet among these and other studies (Van Erp & Van Veen, 2004; de Barros et al., 2011), however, is whether the use of redundant feedback actually brings overall benefits.

Additionally, for study #1, it was not clear whether using redundant feedback as a CPF visual ring (de Barros et al., 2011) would bring benefits due to the ring interface occlusion problem. This motivated us to improve on this interface and create a similar ring structure, but now sitting on top of the robot avatar to resolve the reported occlusion problem. With this new ring layout, it is possible that the redundant visual display benefits outweigh any potential disadvantages.

It has been claimed in the past that high levels of workload can lead to lower levels of SA (Endsley & Garland, 2000). This study attempts to measure the impact on SA and performance of adding redundant and complementary audio-visual displays to a control interface with vibration and visual feedback. It is expeted that variations in cognitive load and workload (as captured by the Stroop task and NASA-TLX test results) could cause variations in SA. The effect of interface use on SA is measured by the evaluation of sketchmaps (global SA) and navigation performance (local SA). Performance is measured in terms of robot task time, navigation, and search. Based on the insights collected from previous work, and with the interface enhancements proposed, the following two results are hypothesized:

S3H1. Adding redundant and complementary sound feedback to the control interface should improve performance and SA in the search task;

S3H2. Adding redundant visual feedback should lead to even further improvements in performance and SA in the search task.

3.4.5. Methodology

The experiment consisted of a within-subjects design where the search task was performed by each subject for all interface types. Because this study also had the same design as study #2 (three trials within subjects) the interface and virtual world presentation order for each subject was done exactly as in study #2 using Latin Square.

However, in addition to the search task as in study #2, subjects also had to perform a secondary task: a visual Stroop task (Gwizdka, 2010). Subjects had to indicate whether the color of a word matched its meaning. For example, in Figure 3.17, the word "red" does not match its color. Words such as this one were presented periodically (every 20±~5s) for a period of 7.5±~2.5s, disappearing after that. Subjects were asked to answer the Stroop task as soon as they noticed the word on the screen using two buttons on the gamepad. The purpose of this task was to measure subject cognitive load variations due to exposure to interfaces with different levels of multi-sensory complexity.

3.4.5.1. Independent Variable

As mentioned earlier, the *independent variable* (*IV*) was the type of interface, with three possible treatments: Interface 1 (control), Interface 2 (audio-enhanced) and Interface 3 (audio and visually-enhanced).

3.4.5.2. Dependent Variables

3.4.5.2.1. Main measures

The objective *dependent variables* (*DV*) were the time taken to complete the search task, the average robot speed, the number of collisions, the number of spheres found, the number of collisions per minute, the ratio between number of collisions and path length, the number of spheres found per minute, the ratio between number of spheres found and path length, and the quality of the sketchmaps. These variables were normalized on a per-subject basis as described in section 3.3.5.2.

3.4.5.2.2. Stroop Task Measures

Cognitive load was compared using the Stroop task results. The Stroop task objective *DV*s were the percentage of incorrect responses, response time, and percentage of unanswered questions. These measures are reasonably common ones (Walker & Kramer, 2005). The first two variables were analyzed for three data subsets: responses to questions where color and text matched, responses to questions where color and text did not match, and all responses. These variables were also normalized on a per-subject basis.

3.4.5.2.3. NASA-TLX Measures

The NASA-TLX test (Hart & Staveland, 1988; Hart, 2006) was taken after each of the interface treatments to measure user workload.

3.4.5.2.4. Questionnaire Measures

For subjective *D.V.s*, the treatment and final questionnaires compared subjects' impressions of each interface as in study #2.

3.4.5.3. Study environment

The physical space and virtual environments used were the same as in study #2. As in the previous two studies, this study's VE had difficulty level yellow (Jacoff et al., 2003).

3.4.5.4. *Experimental* Procedure

The study took approximately 1.5±0.5 hours per subject. The experiment procedure steps are listed in Table 3.7. For each trial, the time and location of collisions were recorded. Subject gender and age, how often they used computers, played video games, used robots, used remote-controlled ground/aerial/aquatic vehicles (RCVs) and used gamepads was collected in the demographics questionnaire. For all but the first two questions, a Likert scale with four values ("daily" (1), "weekly" (2), "seldom" (3) or "never" (4)) was used. The spatial aptitude test was identical to the one used in study #2. The instructions page explained the experiment procedure, the task and the interface.

The training sessions used the same environments and task as study #2. They lasted approximately 4 minutes per subject. The treatment questionnaire subjective questions (3-8) were adapted from the SUS (Usoh et al., 2000) and SSQ (Kennedy & Land, 1993; Kennedy et al., 1993) questionnaires and followed a Likert scale (1-7). The final questionnaire questions 1-5 were also given on a Likert scale (1-7).

The sketchmaps were evaluated using the same approach as previous studies (Billinghurst & Weghorst, 1995). This time, maps were graded twice by two evaluators.

Table 3.7: Experimental procedure in study #3 for one subject.

Step	Description
1	Institutional Review Board approved consent forms;
2	Demographics questionnaire;
3	Spatial aptitude test;
4	Study instructions and Q&A session;
5	User puts belt and headset. Robot interface explained;
6	Task review;
7	Training explanation and Q&A followed by training task;
8	Study task review and Q&A followed by study task;
9	During task, video and objective data is recorded;
10	Trial is over: treatment questionnaire with sketchmap;
11	NASA-TLX questionnaire;
12	Five-minute break before next trial;
13	Steps 7-12 repeated for the other two interface treatments;
14	Three treatments are over: final questionnaire.

3.4.5.5. Other Materials

Other materials used in this study, such as the script used by the experimenter, the information contained in the user study instruction sheet, and the questions contained in the user study post-task questionnaire, are found in Appendix C.1.

3.4.6. Results

This section presents all the relevant results for study #3. Data for all the data analysis of this study can be found in appendix C.2.

Our results were obtained using a single-factor ANOVA with confidence level of α = 0.05. Results close to significance had a confidence level of α = 0.1 and were described as trends.

When a statistically significant difference (SSD) among more than two groups was found, a Tukey test (HSD, 95% confidence level) was performed to reveal the groups that differed from each other. In some cases, ANOVAs were also applied to compare groups in a pair-wise fashion.

For questionnaire ratings, Friedman tests were used to compare all groups together, while Wilcoxon tests were used to compare them in a pair-wise fashion. Sections where SSD results were found have their titles marked with an asterisk (*). If only a trend was found, the title of that section is marked with a plus sign (+).

3.4.6.1. Demographics*

In terms of demographics, a total of 18 university students participated in the study. Their average age was 25 years ($\sigma = 3.18$, C.2.1). The average videogame experience was 2.7 on a 4 scale (1 = daily, 4 = never) and the average robot experience was 3.5 on the same scale, that is subjects were expectedly more experienced with videogames than robots.

In terms of experience levels among groups exposed to interfaces in different orders, SSDs were found for computer and remotely-controlled vehicle (RCV) experience levels. Group with interface order 123 had more computer experience than Group 312 ($\chi^2 = 5.2$, $p = 0.074$, C.2.1.5). On the other hand, Group 312 had more RCV experience than Group 123 ($\chi^2 = 5.571$, $p = 0.062$, C.2.1.6). These differences were one of the main motivators for applying the data normalization referred to in section 3.4.5.2 and explained in section 3.3.5.2.

In terms of spatial aptitude scores, no SSD was found among groups of subjects with different trial orders ($F = 1.000$, $p = 0.391$, C.2.1.8).

3.4.6.2. Task Time

For task time, no SSD was found among these groups.

*3.4.6.3. Number of Collisions**

Two collision-related variables led to relevant results. For the normalized number of collisions per minute (Figure 3.18a, C.2.8.1), trends were found between pairs of interfaces (1, 2) (F = 3.70, $p = 0.06$) and (1, 3) (F = 3.65, $p = 0.06$). For the normalized number of collisions per path length (Figure 3.18b, C.2.9.1), SSDs were found for the same pairs of interfaces (1, 2) (F = 4.32, $p = 0.04$) and (1, 3) (F = 4.16, $p = 0.05$). These results support S3H1, but not S3H2.

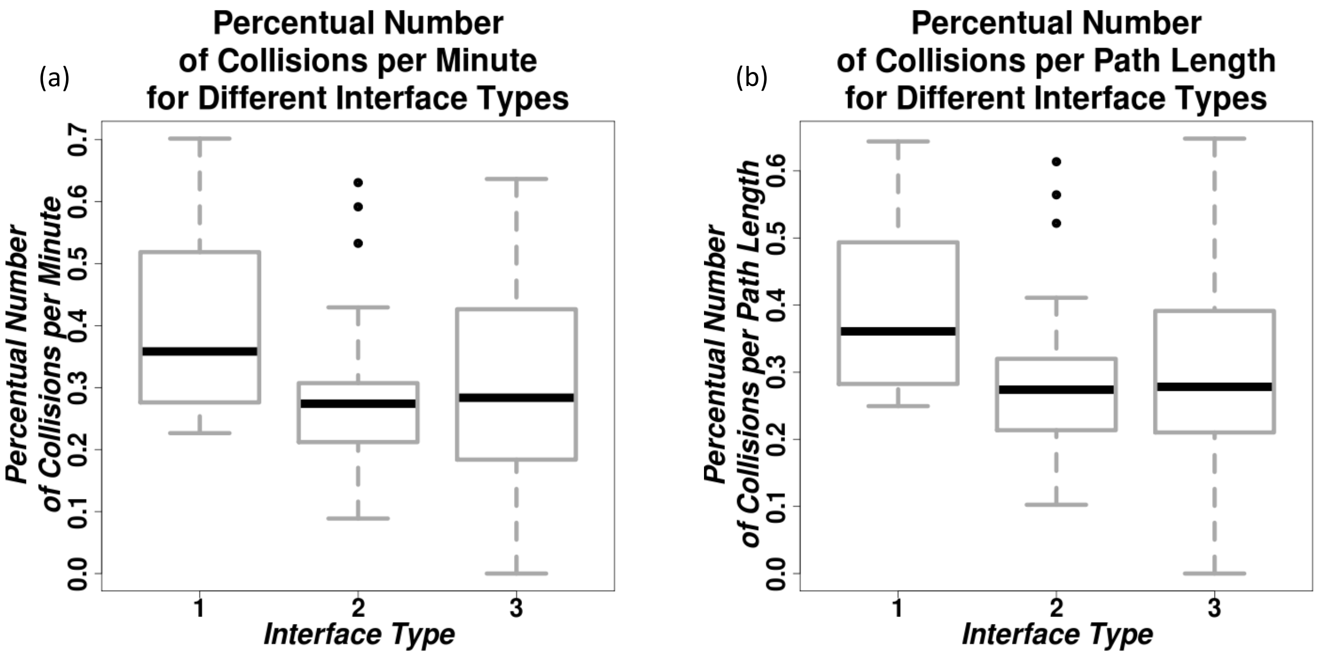


Figure 3.18: Both Interface 2 and Interface 3 in study #3 caused a decrease in number of collisions: (a) per minute; (b) per path length.

3.4.6.4. Average Robot Speed

Although a difference in speed was visually noticeable, it was not statistically significant (Figure 3.19, C.2.15). Had it been so, such variation in speed could have been a potential explanation for the reduction in the number of collisions. Notice the increase in spread from nterface 1 through 3. This seem to show that the interface enhancements have impacted subjects in different ways in terms of speed.

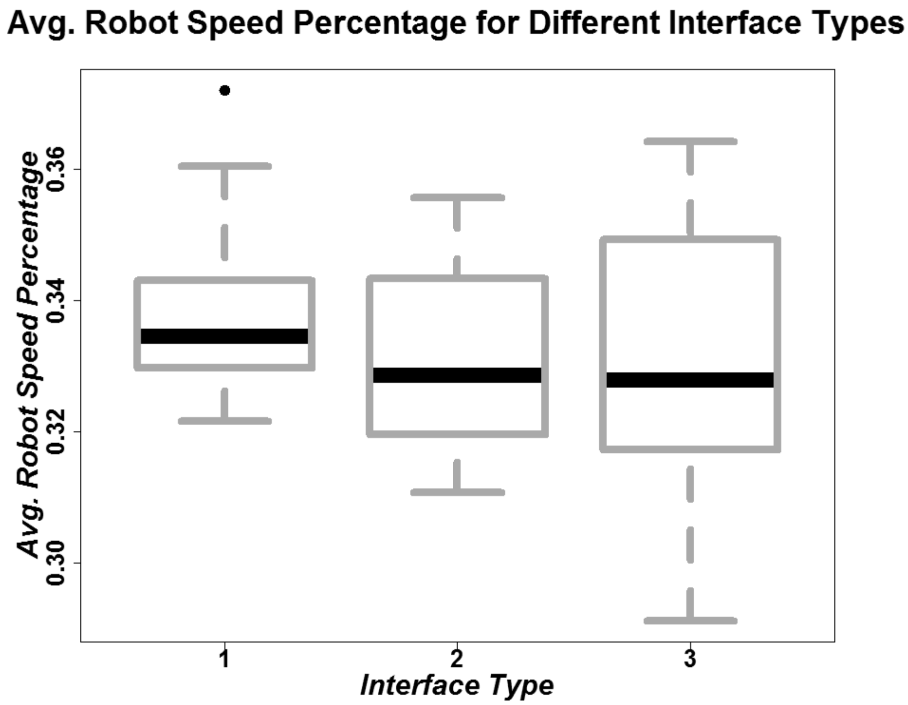


Figure 3.19: Robot speed percentual variation for different interfaces in study #3.

3.4.6.5. Number of Spheres Found

For the variables related to the number of spheres found by subjects, no SSDs were detected. This means even though navigation performance was improved in terms of number of collisions, the same was not true for search performance.

Table 3.8: Mean, median and standard deviation of the number of spheres found for the different interface types in study #3. No SSDs detected.

	Mean	*Std. Dev.*	*Median*
None	5.972	2.772	6.000
Intensity	6.361	2.576	6.500
Frequency	6.194	2.847	6.000

3.4.6.6. Map Quality

The interfaces did not have an effect on the sketchmaps scores with statistical significance.

Table 3.9: Mean, median and standard deviation of the map quality ratings for the different interface types in study #3. No SSDs detected.

	Mean	Std. Dev.	Median
None	2.694	1.348	2.000
Intensity	2.722	1.406	2.000
Frequency	2.472	1.253	2.000

3.4.6.7. Stroop Task Cognitive Load

No SSDs were obtained by the analysis of the Stroop task data, although there was a slight decrease in response time for Interface 2 and Interface 3, as can be seen in Figure 3.20a (C.2.14.2.1). In addition, Interface 2 has also shown a small reduction in the number of unanswered Stroop question (Figure 3.20b, C.2.14.3.1), but no SSD was detected for either of these.

It is important to notice that the Stroop task itself adds to the cognitive load of the subjects. It attepts to consume any remaining unused cognitive resources from the user. Therefore, the Stroop taks as a secondary task is really only effective when it can actually fill up or overflow those resources. If the primary task itself is too easy, it is unlikely that the Stroop task will use the large amount of cognitive resources available and hence be able to measure variations in cognitive load and workload due to the use of different interfaces.

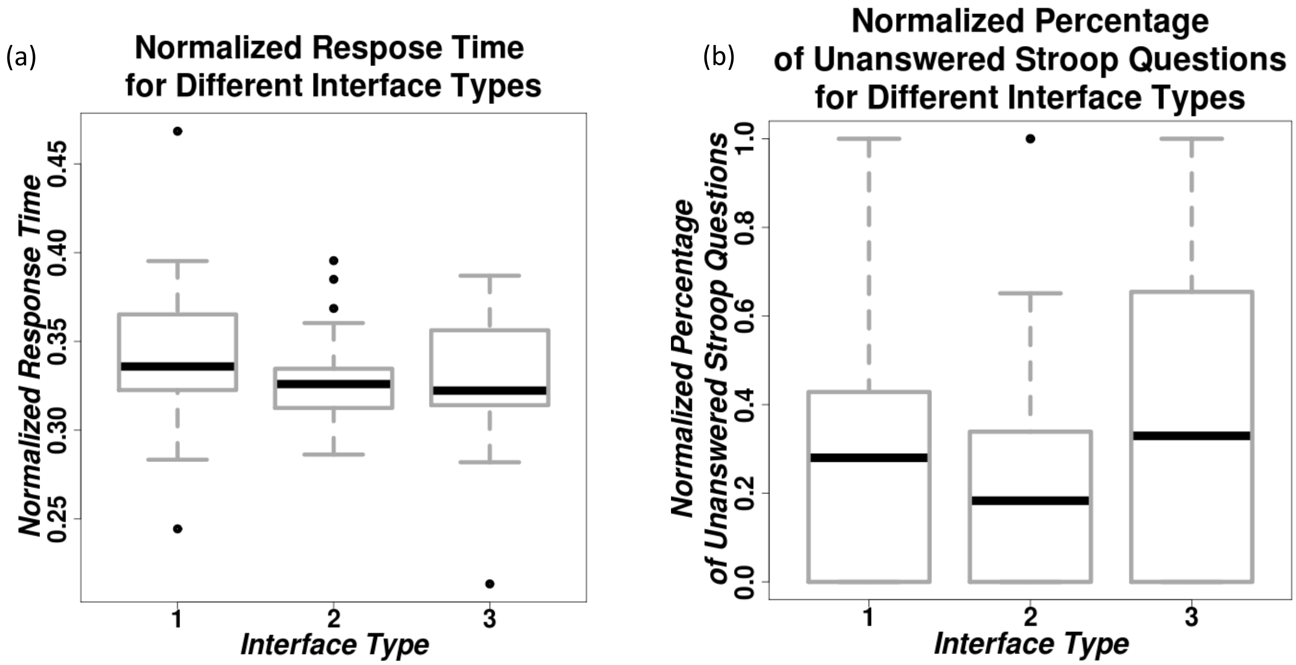


Figure 3.20: Stroop task results for (a) normalized response time and (b) normalized percentage of unanswered questions in study #3.

3.4.6.8. NASA-TLX Workload+

For the NASA-TLX questionnaire, a trend indicated that Interface 2 had a higher temporal workload score than Interface 1 (w = 37.0, z = -1.87, p = 0.06, r = -0.31, Figure 3.21a, C.2.13.3.1). This measure indicates how hurried or rushed subjects felt during the task. Subjects felt more in a rush when exposed to Interface 2 (higher score). Because no difference in task time was detected among interface groups, the only other factor that could have affected subjects' rush levels would have to be related to the visual timer on screen and subjects' behavior towards it. A plausible explanation would be that subjects were able to check the timer more often to see how efficiently they were doing. This behavioral change would only be possible if the rest of the interface was less cognitively demanding. Hence, an increase in timer look-ups could have been due to a decrease in cognitive demand from the rest of the interface. If this claim is true, such a decrease would support S3H1.

For the NASA-TLX performance measure, a trend has indicated a lower rating for Interface 3 compared to Interface 1 (w = 103.0, z = 1.80, p = 0.08, r = 0.30, Figure 3.21b, C.2.13.4.1). This measure indicates how successful subjects felt in accomplishing the task. In other words, Interface 3 made subjects feel as if they performed worse than with Interface 1. This result goes against what was predicted in S3H2.

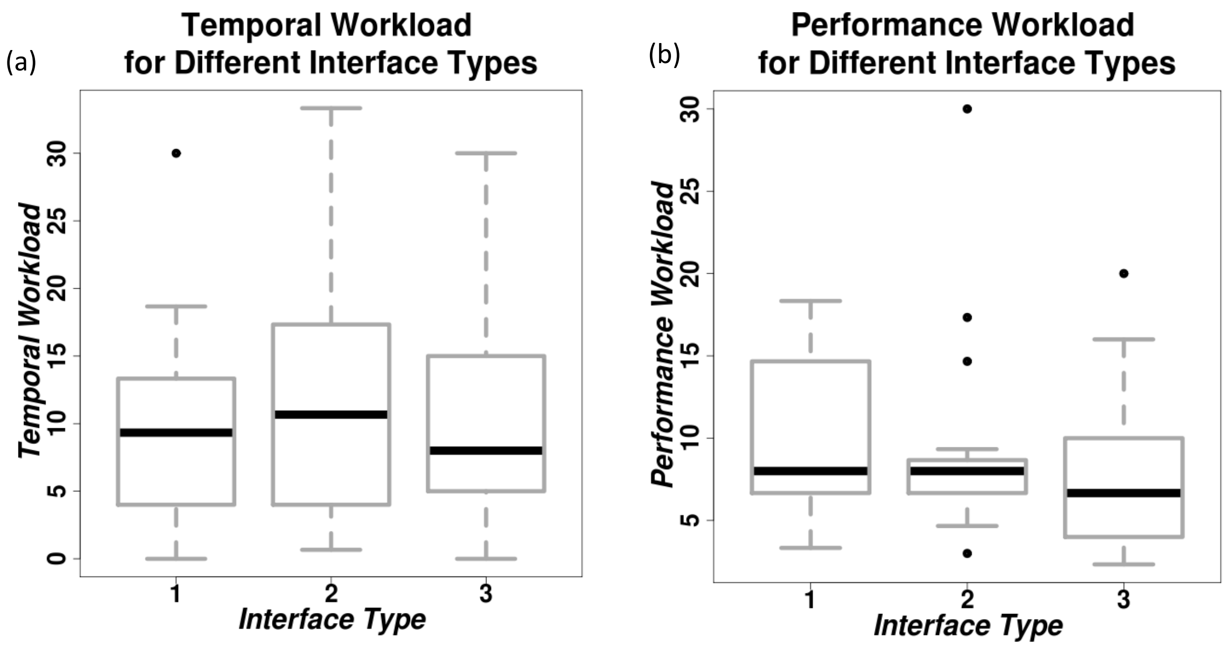


Figure 3.21: In study #3: (a) Subjects felt significantly more rushed when using Interface 2 than with Interface 1; (b) Interface 3 caused subjects to feel as if they performed worse than Interface 1.

*3.4.6.9. Questionnaire**

For the treatment questionnaires, a SSD was found for the sense of “being there” for Interface 1 and Interface 2 (χ^2 = 6.28, p = 0.04, Figure 3.22a, C.2.2.2). The latter led to higher “being there” levels compared to the former. Moreover, a SSD was also found for *Walking* results between Interface 2 and Interface 3 (χ^2 = 7.82, p = 0.02, Figure 3.22b, C.2.2.5). When exposed to Interface 3, moving around the computer-generated world seemed to subjects to be more like walking than when exposed to Interface 2. These results seem to go against the prediction in S3H2 once again.

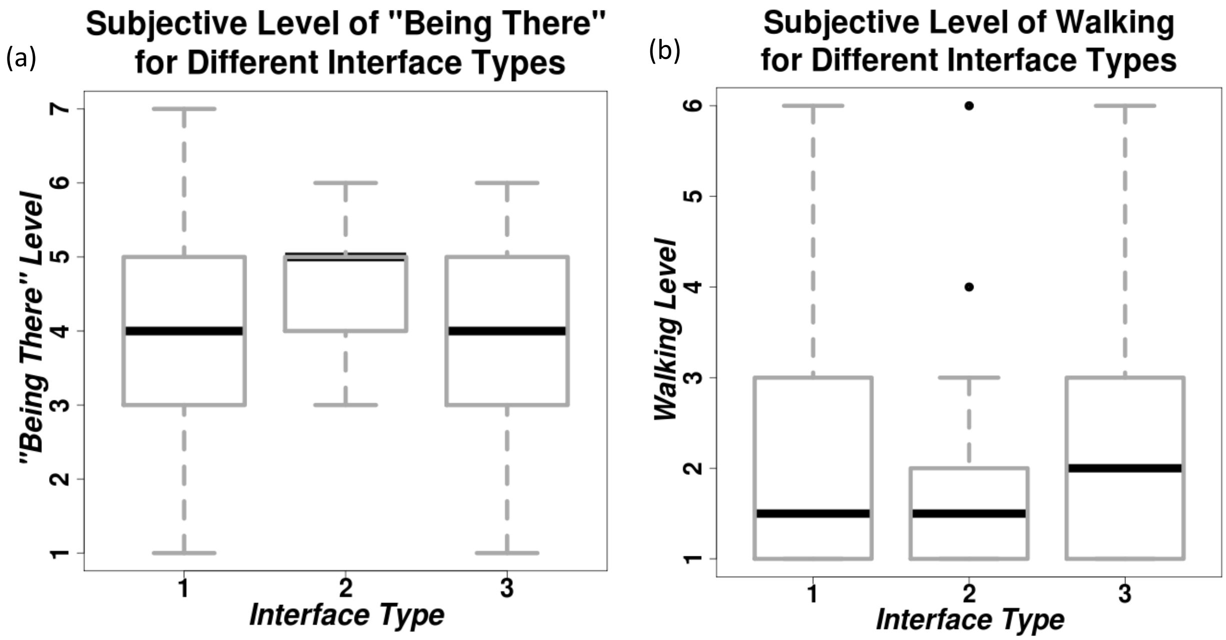


Figure 3.22: (a) Interface 2 increased user sense of being in the VE; (b) Interface 3 made users feel more like walking rather than driving.

The final questionnaire showed interesting results, especially for Interface 2. On the one hand, a pair-wise Wilcoxon test showed Interface 2 was more difficult to use than Interface 1 ($w = 18.5$, $z = -1.75$, $p = 0.09$, $r = -0.29$, Figure 3.23a, C.2.5.1). On the other hand, Interface 2 was more comfortable to use than Interface 1 ($\chi^2 = 5.51$, $p = 0.06$, Figure 3.23b, C.2.5.4). It also more positively impacted the comprehension of the environment compared again to Interface 1 ($\chi^2 = 10.98$, $p < 0.01$, $d.o.f. = 2$, Figure 3.23c, C.2.5.5). In Figure 3.23a, notice also how data variation was reduced for enhanced interfaces, especially Interface 3. This is an indication that subjects opinion was more consistent for these interfaces than for the control one.

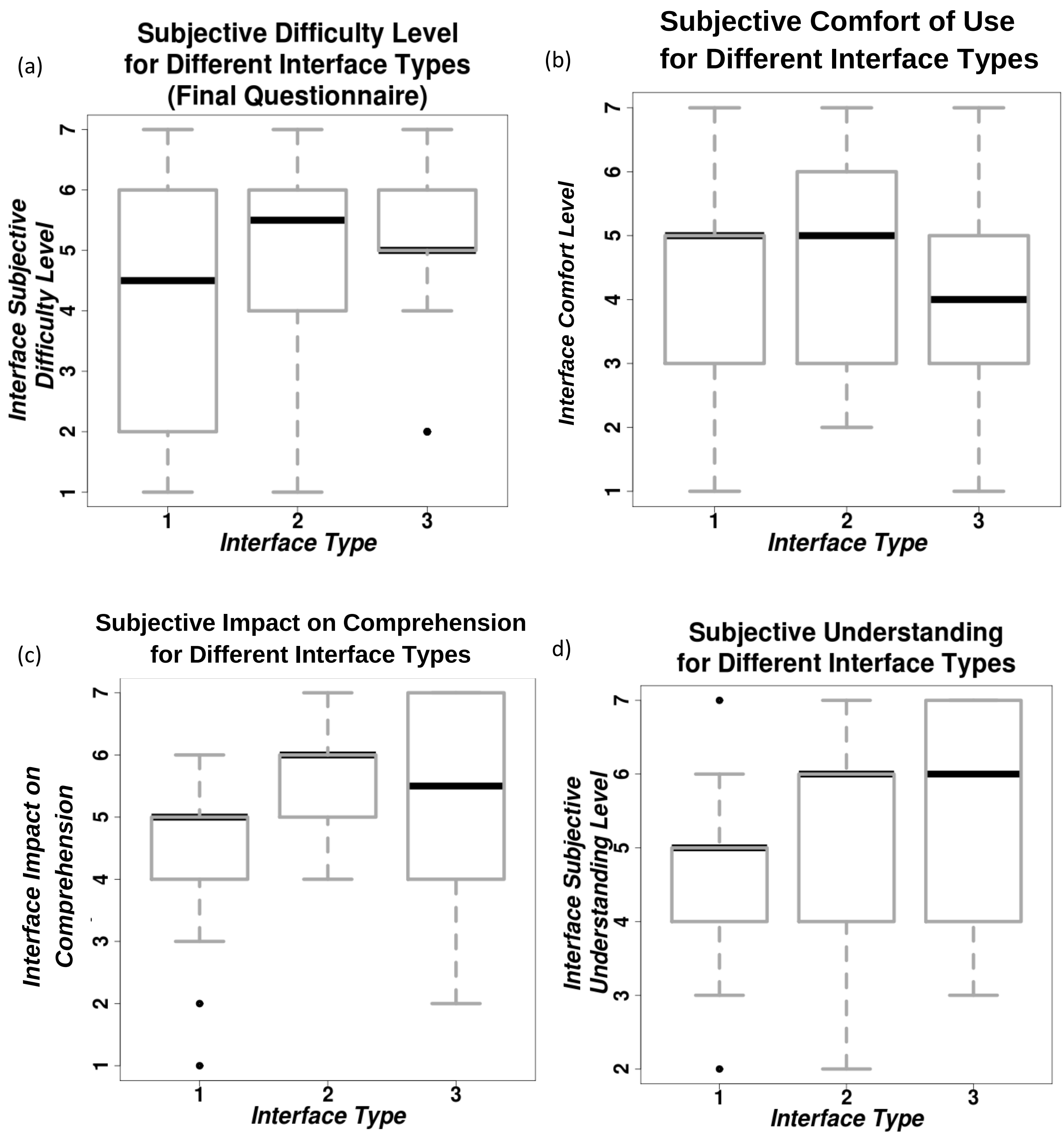


Figure 3.23: In study #3: (a) Interface 2 was deemed more difficult to use than Interface 1, but it was also (b) more comfortable and (c) better impacted comprehension than Interface 1; (d) both Interfaces 2 and 3 helped better understand the environment than Interface 1.

Interface straightforwardness levels also differed (χ^2 = 5.52, p = 0.06, Figure 3.23d, C.2.5.2). Using Interface 2 and Interface 3 made it more straightforward to understand the data presented than using Interface 1. A pair-wise Wilcoxon test showed that Interface 2 had a statistically significant increase compared to Interface 1 (w = 10.0, z = -2.15, p = 0.04, r = -0.36). The same pair-wise comparison for Interface 3 and Interface 1 only showed a trend however (w = 15.0, z = -1.89, p = 0.07, r = -0.31). For Figures 32.23c and 3.23d, notice how interface 3 led to more variation in the data. This seem to indicate that this interface affected subjects differently with regard to these variables.

These results from the final questionnaire seem to support S3H1, but do not present any evidence in support of S3H2.

3.4.6.10. Comments

Subject comments were collected on the treatment and final questionnaires. The comments were categorized according to interface features (e.g., touch, audio, extra GUI, map) or experimental features (e.g., Stroop task, learning effects). For each category, the comments were divided into positive and negative ones.

There was a prevalence of positive comments directed to the audio interface. One subject stated: “Adding the audio feedback made it feel much less like a simulation and more like a real task. Hearing collisions and the motor made it feel like I was actually driving a robot.” Another said, “The sound made it much easier to figure out what the robot was doing. It was clear when there was a collision.” Most comments praised the collision sound, but not so much the motor sound.

For the belt, it seemed that having it on all the time, even when it was evident no collision was imminent, annoyed subjects. A few subjects admitted that the belt was useful for navigation however. Many subjects seemed to ignore the belt feedback for the vast majority of the time and only used it when either a collision had already occurred or when passing through narrower places. These comments agree with the ones obtained in study #2 (de Barros & Lindeman, 2012).

In terms of redundant feedback, the redundant visual feedback seemed to have distracted more than helped. One subject mentioned: “The visual speed feedback was not very useful at all, since the auditory speed feedback conveyed the idea much more effectively, so the visual speedometer became a distraction.” These comments support the slight worsening in results for Interface 3 as shown in Figure 3.22b and Figure 3.20.

Subjects’ comments confirm the results obtained from subjective and objective measures, and supporting S3H1, but rejecting S3H2.

3.4.7. Discussion

The main goal of study #3 was to search for answers to the question of how much one can make use of multi-sensory displays to improve user experience and performance before an overwhelming amount of multi-sensory information counter-balances the benefits of having such an interface. As a second goal, this study aimed at assessing the potential benefits, if any, of having redundant feedback in multi-sensory displays.

In study #2 (de Barros & Lindeman, 2012), it was shown that, in the context of virtual robot teleoperation, adding touch-feedback to a visual-only interface as an aid to collision avoidance significantly improved user performance. In addition, study #1 (de Barros et al., 2011) showed that adding redundant visual feedback for representing the same information as touch feedback could lead to a performance decrease, although the reason for that was assumed to be occlusion problems and not the fact that display of information was redundant.

Based on the interface and experiment results of these and other previous studies, our current study explored enhancing a visual-tactile interface with audio and redundant visual displays. Our enhancements over previously proposed interfaces allowed us to more accurately measure not only the impact of adding feedback to an extra human sense, but also to measure the effects of different types of redundant feedback in multi-sensory displays.

Unlike the belt feedback, which provided collision proximity feedback as the robot approached the surface of a nearby object, the collision audio display provided feedback only after a collision had occurred. This difference in feedback behavior led to an interesting result. Even though the audio feedback provided was an after-the-fact type of feedback, it led to further reductions in the number of collisions with the environment. But the audio display could not have helped reduce collisions in the same way as the touch display because of this difference in the time of the feedback. And the speed with which subjects moved the robot was not significantly affected by the engine sound feedback. Hence, two possible explanations for such reductions are:

1. The sound feedback made the remote VE feel more real and helped subjects become more immersed and focused on the task, leading them to perform the task with fewer collisions;
2. The sound feedback allowed subjects to better understand the relative distances between the robot and the remote VE. By experimenting with collisions a few times, subjects used sound feedback to learn what visual distance to maintain from walls to better avoid collisions from a robot camera perspective.

Both explanations matched subjects' feedback on the topic, inidicating that perhaps both of these are actually true. However, the author believes that the latter is a more plausible one. The distance estimation between the robot and the remote VE was not as easy to do using only the vibro-tactile feedback from the belt due to the continuous nature of the cues it provided. Hence, the sound feedback supplemented such cues with more accurate estimations. And even though these sound feedback events were displayed only after a collision occurred, they taught subjects how to better make their distance estimation and void further collisions in the future.

Subjective feedback and objective data indicated that the engine sound did not have a major role in improving understanding of the spatial relationship between robot and environment. Nevertheless, it was reported that this sound did improve their presence levels. It might also have improved their control of robot speed. Even though no SSD was detected for the speed variable, the minimal variation in its average values for different interfaces could be a reflection of a change in subjects' navigational behavior. Hence, the addition of the sense of hearing to the multi-sensory display has indeed improved performance and our first hypothesis (S3H1) is confirmed.

Our second hypothesis (S3H2), on the other hand, was not supported. As mentioned earlier, results from similar studies on redundant feedback were inconsistent (de Barros & Lindeman, 2012; Van Erp & Van Veen, 2004). This work showed that redundant feedback may not always improve performance. In fact, its effect may vary depending on how the multi-sensory interface is integrated.

One explanation for the degradation in results for Interface 3 is considered here. It seems that the addition of new visual features created a new point on the screen users needed to focus on. The basic visual interface (used in Interface 1 and Interface 2) already demanded a great deal of the user's attention, containing points of focus for the timer on the top-right corner, the Stroop task text field, the robot camera panel and the map blueprint. Hence, adding more focus points in

Interface 3 might have reduced user performance more than the amount of performance improvement that the addition of such interface features could have added.

However, would the same results be obtained if the extra visual information added was novel instead of redundant? In the case of this study, because the information displayed by the enhanced visual display was already being presented in other forms, no information was gained for most subjects, who already effectively read that same information through the vibro-tactile belt. For these subjects, the visual enhancements were either ignored or caused distraction, the latter to the detriment of their performance. Nonetheless, it would be interesting to compare the improvement results of individually using an audio-visual-only interface or a visual-only interface with the speedometer and visual ring added to the current audio-visual-tactile interface. After all, the order with which the multi-sensory features were gradually added among treatments and interacted with each other in this study might also have had an impact on the results obtained.

Last, the use of the touch and audio feedback as opposed to the visual feedback for collision detection and proximity might be an indication that, when offered the same information through different multi-sensory displays, users may try to balance load among multiple senses as an attempt to reduce their overall cognitive load. Interesting though this claim may seem, the results obtained in this study do not support this notion. Such multi-sense load balancing could have been caused simply by user preference for the vibro-tactile interface design over the ring interface design. The verification of either justification and the search for an answer to the question stated in the previous paragraph is the subject of future work.

3.4.8. Conclusions

The main goal of this study was to advance one more step towards understanding the effects of multi-sensory interfaces on users. We have explored the effects of adding audio to an existing visual-tactile interface. The context in which this exploration took place was in a virtual robot teleoperation search task in a 3D virtual environment.

The study has shown that adding audio as the third sense to the bi-sensorial interface (visuals, touch) of study #2 resulted in further improvements in navigation performance. This means the user had not yet been cognitively overwhelmed by the control case display and could still process further multi-sensory data without detriment on performance.

This study also presented evidence indicating that displaying more data to a certain sense (vision) when it is already in high cognitive demand is detrimental to performance if the added data does not improve the user's SA of the system and environment. It remains to be seen how much of an effect the information relevance of the newly added visual data has on counter-balancing such degradation in performance. In order to measure such an effect, a new study needs to be carried out to compare the impact of a multi-sensory interface by adding more visual data that is not yet conveyed through other senses (novel data) versus adding visual data that is already conveyed through another sense (redundant data).

Redundancy could be beneficial to mitigate the fact that vision is uni-directional. A visual display could become at least partially omni- or multi-directional by adding redundant feedback through senses such as hearing and touch. The larger the number of focus points on screen, and the larger their relative distance on screen, the higher are the chances that the user will miss some information or event. However, having data redundancy spread across a multi-sensory display in a balanced, fused, non-distracting and non-obtrusive manner could reduce event misses and increase SA and comprehension.

Following the same thread of reasoning, it would be interesting to explore the validity of the following more general statement:

CL1: Redundant data over multiple senses brings no benefit to the user of a multi-sensory display that already maximizes the user's omni-directional perception of relevant data.

In other words, the more omni-directional a display is, the more data can be perceived by the user simultaneously, the smaller the chances that changes in the data displayed are missed, and hence, the smaller the need for providing redundant data displays. Admittedly, the study presented here barely scratches the surface of such a topic. Similar studies exploring the optimization of multi-sensory omni-directionality must be performed and their results cross-validated for this statement to be considered as plausible.

Nevertheless, the question of how complex multi-sensory displays can get is still not completely answered. In the context of this study, it was seen that using three senses in an USAR robot interface proved to be better than using only two, especially in terms of navigation, but what if more senses are considered? Is it possible to display data to olfactory and gustatory senses to improve displays for practical applications? Are the results obtained in all previous studies reproducible in a real robot scenario? The fourth and last study aims to explore the sense of smell in the same USAR context and validate the results obtained with a simulated environment in a physical environment with a real robot.

3.5. Study #4: Further Exploring Multi-sensory Feedback Interface in Virtual USAR and Validating Previous Results with a Real Robot

3.5.1. Motivation

The motivation of this fourth study was two-fold. Firstly, we wanted to validate with a real robot and environment the results previously obtained in studies #1, #2 and #3 with a simulated robot and environment. Secondly, we also wanted to explore further multi-sensory enhancements to the robot interface and how they impact user performance. For this study we built our multi-sensory robot and updated the previous interface so that it could display robot-sensed data not only through visuals, audio and vibration, but also through smell. The specification of the robot design and architecture as well as the interface improvements are detailed next, followed by the study methodology, results and their analysis and discussion.

3.5.2. Robot

The robot used was a custom-made four-wheel rover as seen in Figure 3.24.

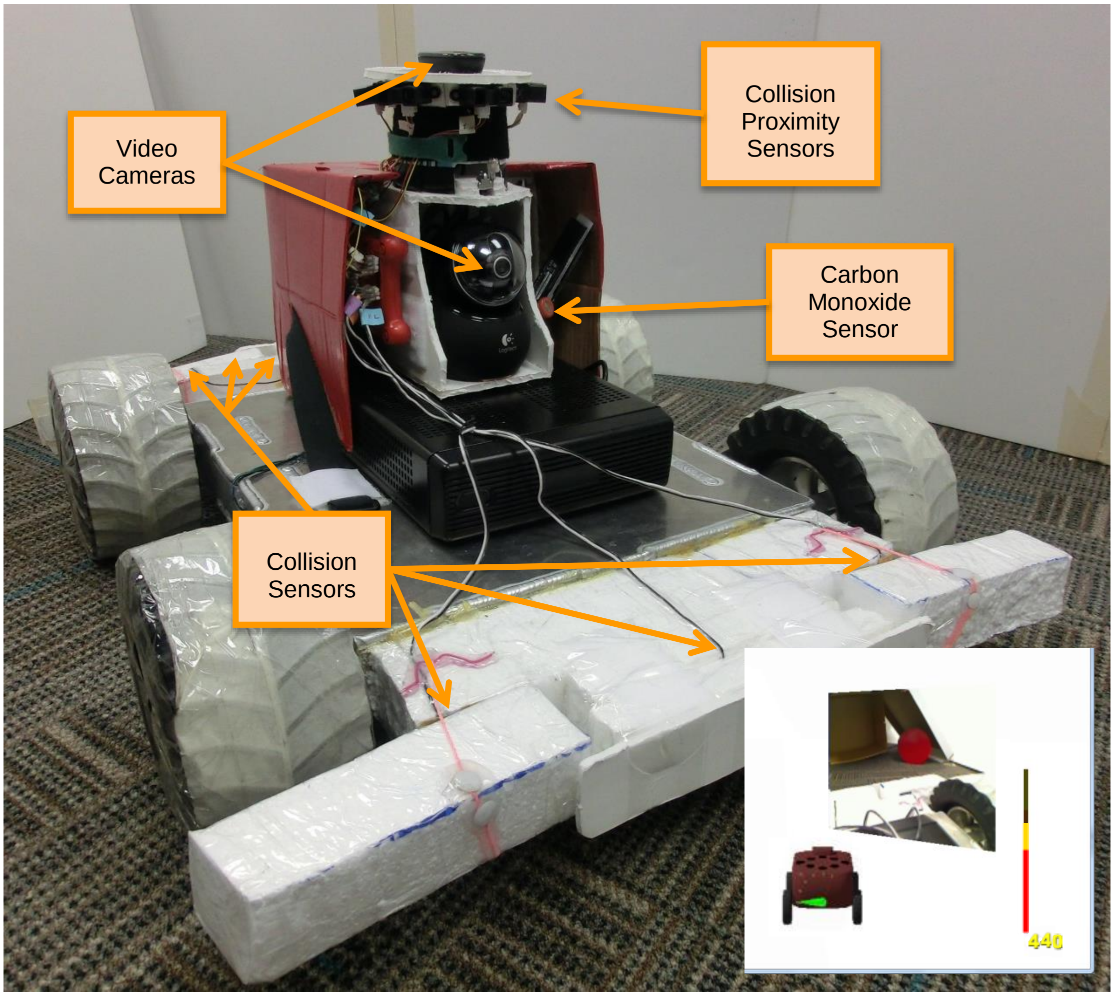


Figure 3.24: Robot used in study #4.

The robotic chassis (Figure 3.25) used was an All-Terrain Robot (ATR) that can handle outdoor terrain, but it was still small enough to be navigated indoors. Four motors allowed differential drive. A battery pack (24V, 4,500mAHr NiMH, 2 x 10, Figure 3.26a), was placed inside the robot chassis and used only by the motors. A power switch for motors could be accessed from outside the chassis and enabled running the robot sensors without the motors on. Tape and a garden hose (see Figure 3.25) were put around the chassis wheels to reduce friction with the carpet of the lab where the study took place. This reduction in friction reduced the amount of power needed to move the robot. As a consequence, it made the robot more easily navigable by making the transition from stopped to moving less abrupt when the user pressed the robot-movement joystick in the gamepad.

The details for the platform chassis are the following:

- Four-wheel drive, independent drive shafts;
- 42mm 24V DC motors at 252RPMs;
- Four 6.75 inch diameter wheels;
- Sabertooth dual 25A motor driver control board;
- Theoretical top speed: ~5MPH.

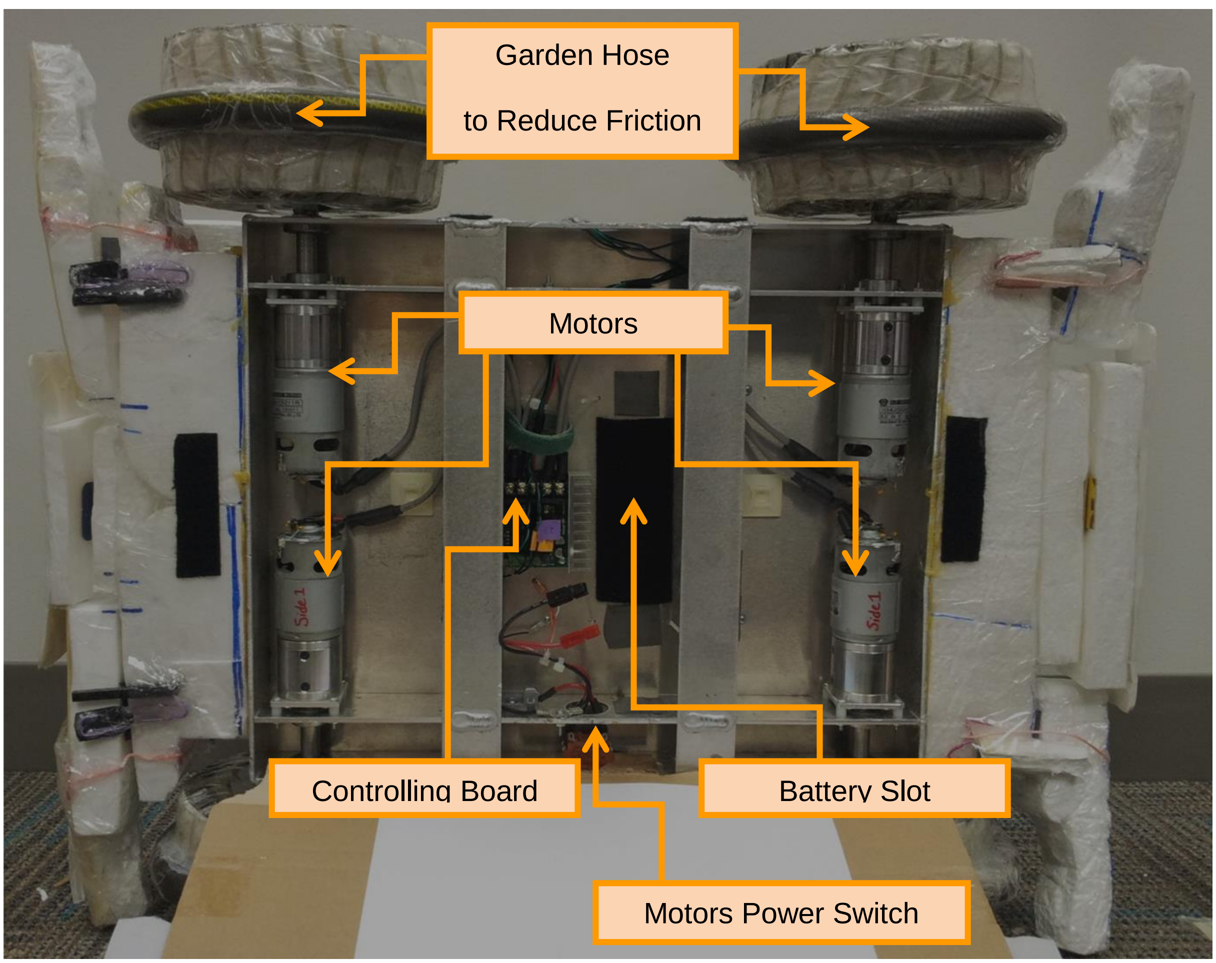


Figure 3.25: Inside view of robot platform.

The four motors were operated through a Sabertooth board which was connected to the Neuron Robotics DyIO board. The latter was in turn connected to the computer on top of the robotic platform. The computer had an ATOM processor (1.66GHz, 1 core, 2 threads with HT) with 2GB RAM and a 64GB SSD disk. The latter minimizes disk damage while the robot is in movement. The mother board had PCI-Express, VGA, USB 2.0 and SATA and was protected by a ventilated metallic black box. The computer was powered by a second battery (12V, 13Ah, NiMH, 2 x 5, Figure 3.26c) sitting on top of the chassis behind the computer. This battery was connected to the computer after going through a fuse and a power switch (Figure 3.26b).

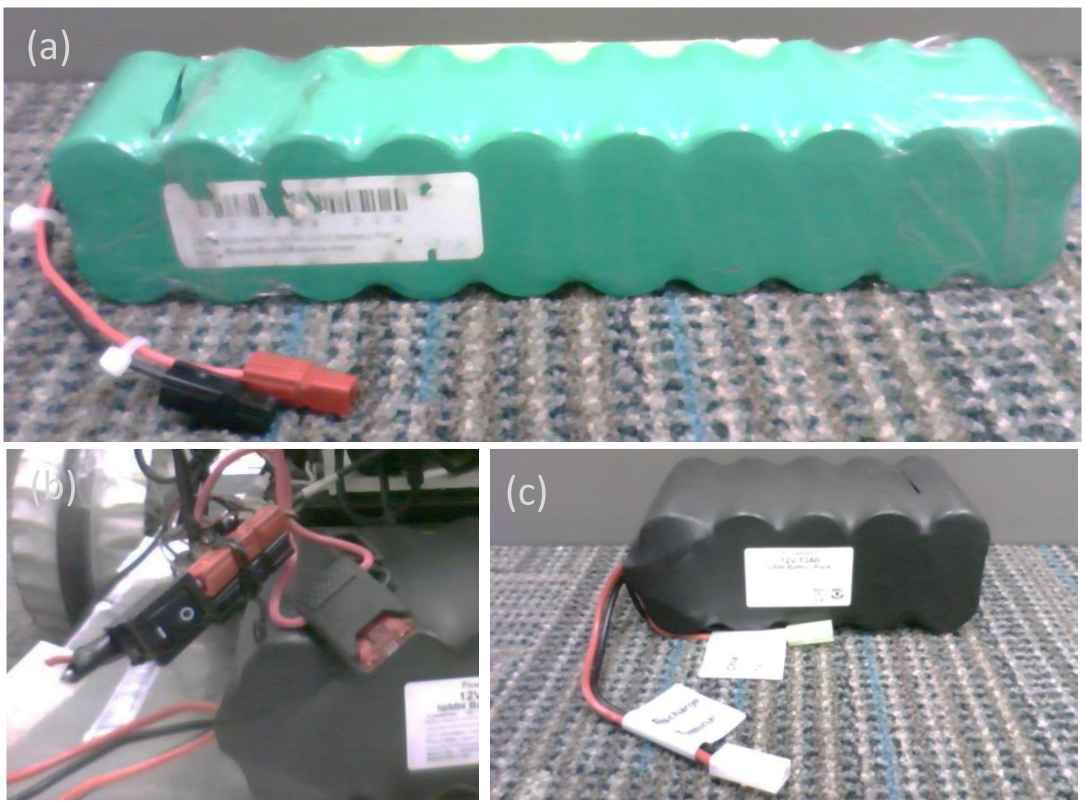


Figure 3.26: (a) the battery for powering the robot motors, (b) the power switch and fuse for the robot computer battery, and (c) the battery for powering the robot computer.

All the sensors used in the robot, including the cameras and the wireless network card, were connected to the computer via USB. A Neuron Robotics DyIO board (Neuron Robotics,

2014) was used to connect the robot sensors. The detail on the USB devices and robot sensors is presented below:

- **Logitech Quickcam Orbit MP Digital:** This pan-tilt camera was used to capture video in front of the robot to replace the virtual video data that was displayed in the panel in front of the robot avatar in previous studies.
- **Logitech C270 webcam:** this camera was pointing upward and was used to detect augmented reality markers placed on the ceiling. The purpose of these markers is explained in section 3.5.6.
- **Neuron Robotics DyIO board (Figure 3.27):** The control for the motors and the data captured from all other robot sensors was done through this board. The sensors used were the following:
    - **Omron Snap Action Switch:** Six of these were attached to the strengthened Styrofoam bumpers on the front and back of the robot and used as collision sensors. They were positioned to the center-front, front-left, front-right, center-back, back-left and back-right of the robot.
    - **Infrared sensors (Sharp IR Distance Sensor GP2Y0A02YK):** Six of these were organized in a circle around the robot and detected proximity of objects in six homogeneously spread directions at the angle of 0° (forward), 60°, 120°, 180°, 240° and 300°.
    - **Carbon monoxide sensor MQ-7 (5V, 33Ω → 0.15A):** this was used to detect CO levels in the environment around the robot. Even though it was properly installed and working, it was not used in the study.

- **Potentiometer:** A small potentiometer was attached to the top of the orbit camera to detect its pan angle and send that information back to the robot application through the Neuron Robotics DyIO board. The pitch angle of the camera could not be obtained and was approximated through software.

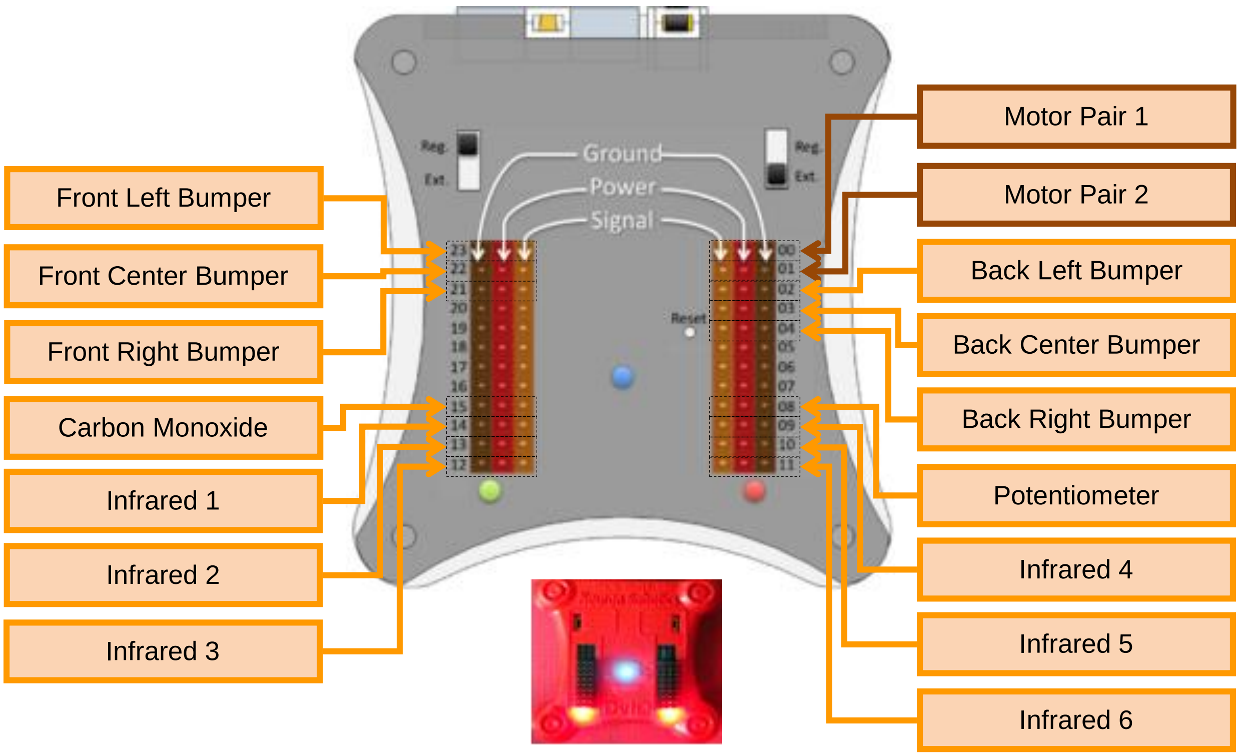


Figure 3.27: Neuron Robotics DyIO and the sensor channel configuration used in study #4. The motor pairs are the only input channels, the other ones are output channels with data coming from the robot.

In addition to the sensors, the DyIO was also responsible for sending the signals to the Sabertooth board to control the wheel motors. The motors were paired into left and right motors that were controlled independently.

In terms of software, the operating system used in the robot was Microsoft Windows® 7. To operate the camera pan-tilt camera in front of the Robot, scripts were developed using the

Robotrealm API and software (Roborealm, 2014). The camera used to detect the markers on the ceiling was operated using a simple C++ program using the ARToolkit. The remaining sensors were operated through a small Java program run in the Eclipse IDE (Eclipse, 2013) that used the Neuron Robotics SDK (Neuron Robotics, 2014) to communicate with the DyIO sensor board.

On the robot operator side a DELL XPS 630i (Dell, 2013) (Intel® Core™ 2 Duo, 4GB RAM, 2 × Nvidia GeForce 9800 GT) desktop machine was used. The operating system in the machine was Windows Vista. The visual interface (Figure 3.31) was similar to the one in all previous experiments, which was developed using the C4 game engine (C4 Game Engine, 2012). A few differences are visible, however. The map blueprint was removed due to resource constraints. Additionally, a visual bar has been added to visually represent the CO sensor.Apart from that, the difference is that now real sensors are connected and program libraries were created to accomplish data communication with the robot. Connected to the computer were all output devices used in this study, except for the smell display (Figure 3.28d). These were:

- A computer monitor (Viewsonic Optiquest Q20wb, Figure 3.28a): The computer monitor displayed visual feedback.
- A stereophonic headset displayed audio feedback. It also blocked exterior noise (Figure 3.28b);
- The TactaBelt displayed vibro-tactile feedback (Figure 3.28c).

The audio and visual feedback was displayed using the C4 engine, as well as RoboRealm library. The latter was used to capture the video stream from the robot pan-tilt camera to the C4 game engine. A custom program communicated with the smell server to send information to the smell display through the robot wireless local area network.

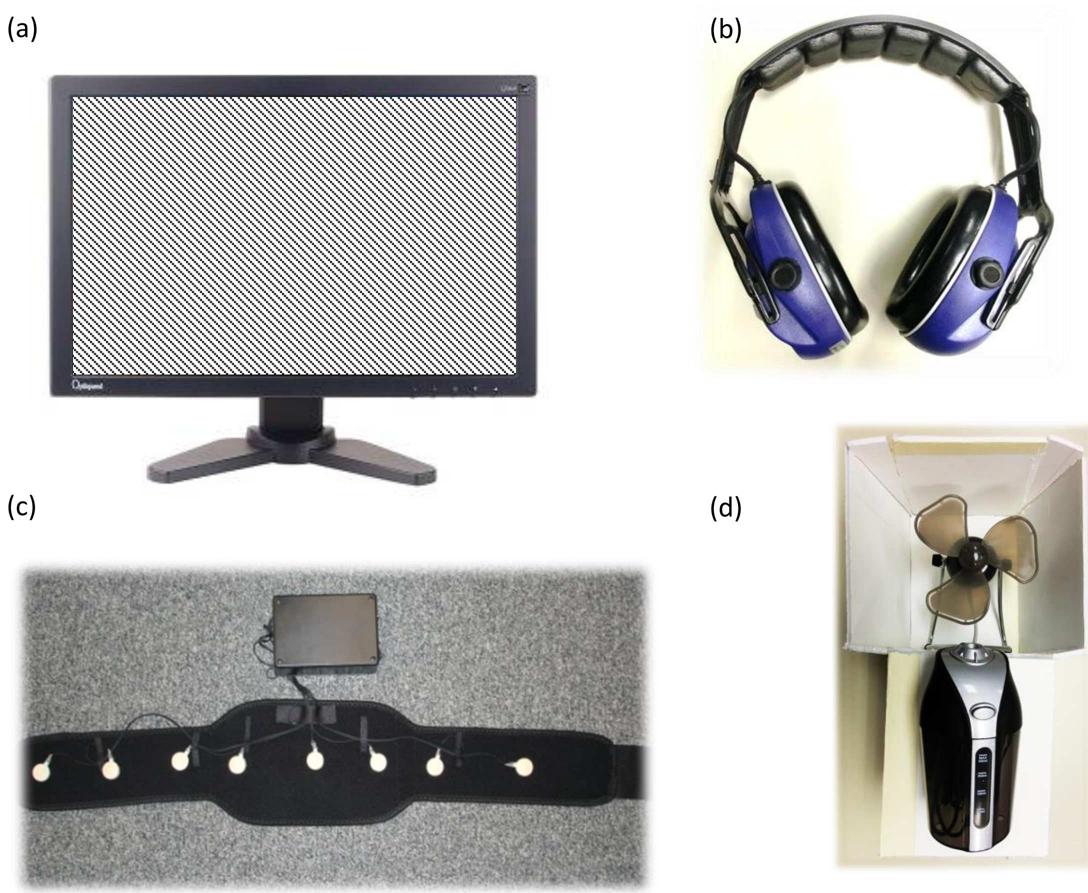


Figure 3.28: Output devices used in study #4: (a) 20" computer monitor, (b) stereosphonic headset, (c) TactaBelt, and (d) smell feedback device.

The smell display server (DELL OptiPlex GX 620, Pentium D326 2.66GHz, 512MB, Integrated Intel Graphics Media Accelator 950) uses Fedora Linux as its operating System. The smell display is composed of a humidifier and a small USB fan (Figure 3.28d). The humidifier is filled with approximately 100 ml of water and 5ml of rosemary essential oil.

The humidifier is connected to a USB hub (D-Link® 7-Port Hi-Speed USB 2.0 Hub, DUB-H7) whose power is computer controlled on a per-port basis (Figure 3.29). The use of the USB hub as an intermediary power controlling unit allows us to expand the variety and intensity of smells to be displayed by adding more humidifiers to the other USB ports available in the hub. In this study, only one port and humidifier has been used.

The control of the amount of smell dispersed to the operator is done by controlling the continuous amount of time the humidifier is left on. The more time the humidifier is kept continuously on, the more intense the smell becomes. The smell display server uses a simple C++ program together with shell scripts to control the state of the USB ports on the hub connected to the computer and hence control when and for how long the USB port to which the humidifier is connected should be on. The smell could be easily felt within 1 – 2 seconds after it has been released by the humidifier.

The humidifier is placed on the lower compartment of the white box (6” x 12” x 6”) supporting the fan, so that it is hidden from the subjects view (Figure 3.29). Hiding is necessary so that subjects will not know when the humidifier is on or not by looking at it. And since the fan of the smell device is kept on during the entire study, the only way for subjects to detect if the smell feedback device is on or not is by actually sensing the variation in smell in the air being blown by the device. The smell device was placed on the front-left of the user, at approximately half a meter from his left arm and horizontally pointing towards his head direciton. The device dimensions were 6” x 6” x 12” (width x depth x height).

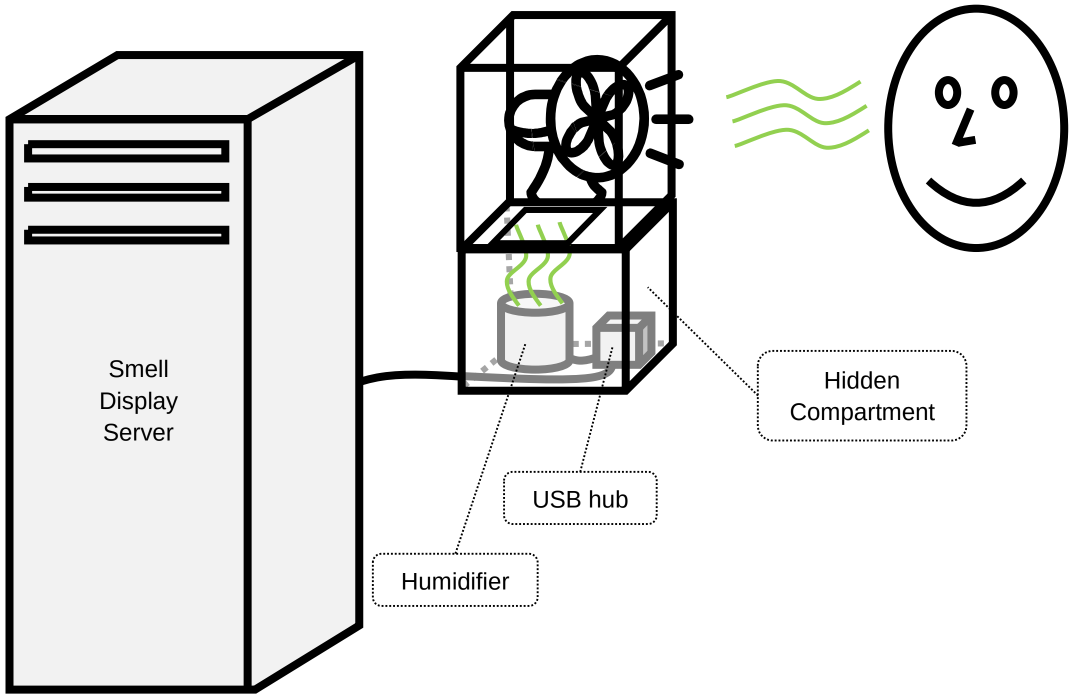


Figure 3.29: Study #4 smell device schematics.

Figure 3.30 presents an overview of how data communication took place in the developed HRI system. Input from the operator came from a single source of input, which was the gamepad as in the three previous studies. Feedback to the operator came mostly from the operator computer through the game engine rendering the robot interface, with the exception of the smell feedback which had to run on a Linux machine. The notes following Figure 3.30 give details on the projects used for each part in the architecture and available on-line (de Barros & Lindeman, 2014). However, due to the game engine copyrights, not all code used in the study is available.

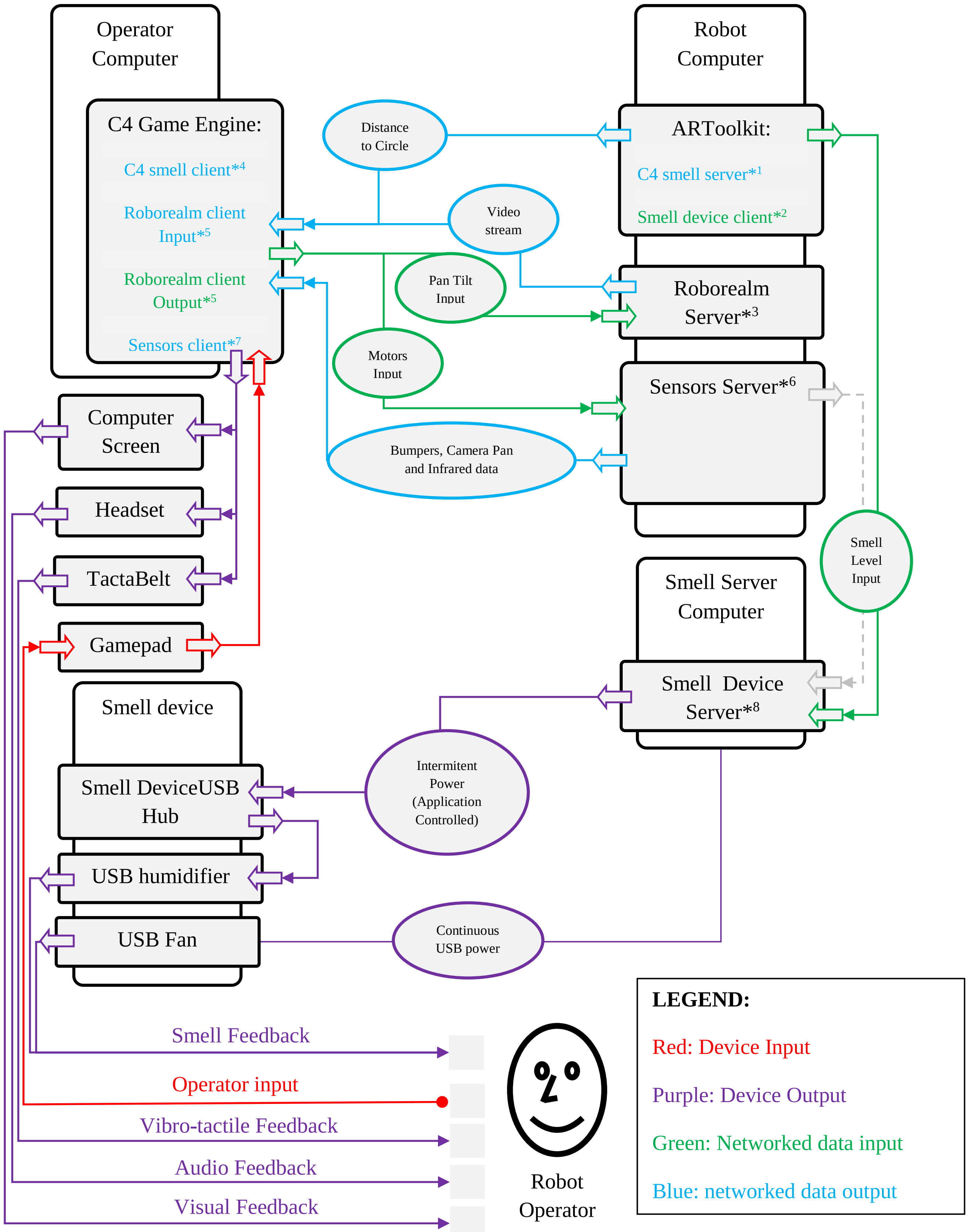


Figure 3.30: Architecture for robot communication between operator, computer, smell server and robot for study #4. Please notice asterisk comments on the next page.

Notes for Figure 3.30:

*[1] – ARToolkit (Kato & Billinghurst, 1999) simpleTest2 project (C++) integrated with smellDisplayC4Diplomat (C++) server side (SmellDisplayC4Diplomat project, DistanceRequestsServer_ServerThread) through SmellDisplayC4Diplomat.dll to send robot-circle distance updates to the C4 game engine;

*[2] – ARToolkit (Kato & Billinghurst, 1999) simpleTest2 project (C++) integrated with smellDisplayC4Diplomat (C++) server side (SmellDisplayC4Diplomat project, UpdateSmellDevice_ClientThread) through SmellDisplayC4Diplomat.dll to send smell level messages to the smell device server;

*[3] – Roborealm IDE with pre-configured scripts that process both camera control input and video output using the Roborealm library installed in the robot;

*[4] – C4 Game project (C++) integrated with smellDisplayC4Diplomat (C++) client side (SmellDisplayC4Diplomat project, UpdateDistanceRobotMarker_ClientThread) through SmellDisplayC4Diplomat.dll to process camera control output and video input;

*[5] – C4 Game project (C++) integrated with RoboRealmInterface (C++) client side (RRC4Diplomat project) through RRC4Diplomat.dll;

*[6] – HIVEUSARBotNRController project (Java) integrated with NRC4Diplomat (C++, JNI) server side (NRC4Diplomat_ServerRobot project) through NRC4Diplomat.dll to capture and output bumpers, camera pan and infrared data. If the CO sensor is used, it also processes and outputs CO levels as data for the smell server. Currently, this feature is disabled.

*[7] – C4 Game project (C++) integrated with NRC4Diplomat and the sensors Database (C++, NRC4Diplomat project) through NRC4Diplomat.dll.

*[8] – SmellServer/ServerEcho program (C++) that processes smell level messages from the smellDisplayC4Diplomat server side and runs scripts to control flow of power in the specific

The operator computer transmitted data input to operate the robot motors and pan-tilt camera to the robot computer. These sources of input were the only way the operator could affect the robot and hence the remote physical environment the robot was in.

For visual, audio and vibro-tactile feedback, the robot-sensed data was sent to the operator machine back to the game engine, which would process such data and convert it into displayable data through the respective output devices. Visual feedback for the CO sensor was also transmitted to the game engine. The CO level in the air was simulated using the distance between the robot and fiducial markers attached on the ceiling above each of the red circles in the remote environment that were to be located by the operator. Cardboard circles were used in this study to replace the virtual spheres used in previous studies. They were oriented to face the robot likely view position and make them easily visible through the robot camera.

For smell feedback, the distance-to-marker data obtained from the ARToolkit application was converted into smell intensity levels and transmitted to the Smell server. This server would trigger custom USB-hub-power-controlling scripts to adjust the intensity and persistence of the smell based on the intensity level received.

Most of the code was implemented in C++, with the exception of the interface to the Neuron Robotics DyIO, which was implemented in Java and integrated to the rest of the application using JNI.

3.5.3. Robot Interface

The interface used in this study was an improved version of the one used in study #3. It consisted of the same 3D visual interface where the robot is viewed from the back.

In order to explain the interface, the task needs to be briefly explained .More details of the task can be found in section 3.5.4. The task was similar to the one of previous studies. It consisted of searching for red objects. This time, however, the objects to be searched were red cardboard circles instead of red spheres as seen in Figure 3.31.

In this study, the video panel now presents a video from the robot's pan-tilt camera as can be seen on Figure 3.31. Subjects could use this panel to perform the search task and look down at the robot wheels and chassis. Subjects could use this lower view of the robot to better understand the distance between the robot and the surrounding objects, and clarify the robot situation during a frontal or lateral collision.

In addition, a CO display bar was added to the interface to indicate the current levels of CO in the robot location. This design was based on other USAR interfaces that measure CO or CO_2 levels (Yanco et al., 2006). Because the study was run in a university lab, the levels of CO in the area could not be changed to keep the environment safe for humans. As previously mentioned, the change of CO level in the air was simulated with the use of augmented reality markers placed on the lab ceiling above the location of each of the circles. The markers were detected using the ARToolkit library (Kato & Billinghurst, 1999) (see section 3.5.3). The robot camera that was always pointing to the ceiling would detect proximity to the closest marker and calculate the distance between the robot and the marker. The closer the robot would be to the marker, the higher the level of CO that would be reported by the camera application. Only one marker would be processed at a time, but circles were arranged in the lab so that they were far enough away that their markers would not interfere with the detection mechanism. The result of this approach was that the closer the robot was to a red circle, the higher was level of CO reported by the feedback interface.

The map blueprint that was presented on the virtual ground in previous studies has been removed in this study because there was not enough resources to reproduce it in the real robot scenario. Because the position of the robot is now unknown, it was not possible to place the blueprint details relative to the robot avatar on the visual interface. As there was also no virtual world to be displayed, the environment where the robot avatar would move was simply a blank virtual space (Figure 3.31).

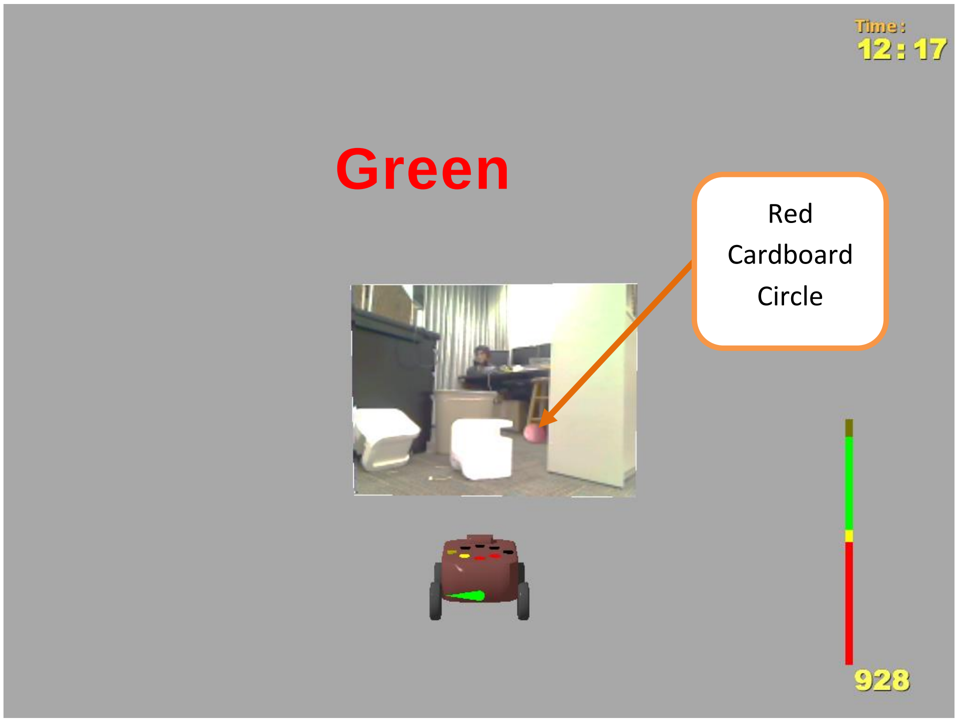


Figure 3.31: Visual interface for study #4.

Our previous studies have show that the improvements in multi-sensory interfaces are present even when the blueprint is present. In this study, multi-sensory interfaces should lead to improvements that are perhaps even better than the ones detected in previous studies since the control visual interface does not have the blueprint and thus provide less visual feedback to the user.

The dots on top of the robot avatar that were used to visually display CPF data were still present. However, now they represent CPF data with shades of yellow, while collision is represented in red. For example, in Figure 3.301, by looking at the colored dots, it is not only apparent that the robot has a large object behind it due to the large range of colored dots close to its back, but it is also apparent that the robot is already colliding with an object on its rear right as signaled by the center-back and back-right red dots. This differentiation in the coloring of the dots was done to further improve the understanding of the collision state around the robot.

The audio and vibro-tactile feedback behaved identically to the third study, although the feedback is now coming from the robot sensors.

The smell feedback device was placed laterally to the computer monitor, with its fan at the height of the user's face and pointing in its direction. The closer the robot was (< 1m) to one of the circles that had to be found the more intensely a smell of rosemary would be displayed. The smell of rosemary was selected based on results of previous studies from other researchers showing its positive effects on memory (Herz, 2009).

3.5.4. Task

The task in the study is the same as in previous studies, with the difference that now a real robot is being controlled in a real debris-filled environment. Another difference is that, once subjects felt they have performed an in-depth search of the environment and found as many red circles and they could, they would have to drive the robot back to its start location instead of leaving the environment through an exit door as in previous studies.

3.5.5. Hypotheses

The hypotheses stated here are based on the results obtained from studies #1, #2 and #3 and other research studies.

First of all, adding the vibration and audio feedback should lead to similar results as in study #3, even though these types of feedback are being added in an order that is different from study #3 (see section 3.5.6). While in study #3 vibro-tactile plus visual feedback was used as a base interface and then audio feedback was added, in this study, the base interface starts with visual feedback only, then audio feedback is added to it, followed by the addition of vibro-tactile feedback and smell feedback. We expect that the enhancements of the visual interface with audio, vibro-tactile and olfactory feedback should still lead to improvements in robot navigation performance similar to study #3 and regardless of the feature changes made in the visual ring.

Second, as mentioned above, in previous studies, subjects' performance was enhanced when we added multi-sensory feedback to a visual-only interface by adding both audio and vibro-tactile feedback as CPF interfaces. Following the same reasoning, we believe that adding smell feedback as an interface for facilitating search of red circles will enhance subjects' performance in terms of the number of red circles found because it will enable cognitive load balance to four senses instead of three. If the visual CO bar leads to visual-cognitive burden to subjects, we expect an improvement in the number of spheres found for the interface with smell feedback. This increase is an indication that the visual interface is overloaded, that the user cannot pay enough attention to the CO bar in order to perceive all its variations, and that the smell feedback is improving the basic visual interface. The smell interface is displaying the same feedback in a way where the CO events are less frequently missed by the user because this type of feedback does not require user's visual focus.

Third, in study #3, we concluded that redundant feedback is only useful if it improves subjects' awareness levels for relevant data. In the case of smell feedback, because the bar is reasonably far from the video panel, we believe that this design is going to lead to fewer checks on its state by the operator and, hence, frequent CO alert misses. When the smell feedback is added, and owing to its omni-directional feedback nature, we believe that such redundant feedback might lead to improvements in the search for the circles and therefore in the number of circles found.

Fourth, based on reports of alertness enhancements due to the use of the smell of rosemary (Moss et al., 2003), we believe that users receiving smell feedback will find a larger number of circles. Morevoer, because the use of the smell of rosemary has also been reported to improve one's memory (Moss et al., 2003), it is expected that subjects receiving smell feedback will also better remember the circles' location as well as the environment they have traversed. This improvement will be reflected on the quality of their sketchmaps.

Last, the use of a real robot instead of a simulated one should not affect the performance results obtained by the use of multi-sensory feedback. Improvements caused by the multi-sensory feedback should still be detected regardless of whether the study is using a real or simulated robotic platform.

The statements above may be summarized in the following four hypotheses:

S4H1. The addition of redundant vibro-tactile and audio collision proximity feedback to a visual-only interface should enhance the robot operator navigation performance, regardless of the order with which these are added;

S4H2. The addition of redundant smell feedback to the multi-sensory interface with visual-only CO sensor feedback should enhance operator search performance, leading to an increase in the number of circles found;

S4H3. The addition of redundant smell feedback should lead to improvement in the operator memorization of the environment layout, leading to an increase in the quality of the maps sketched.

S4H4. The performance results obtained with the simulated robot in previous studies should be reproducible with a real robot.

3.5.6. Methodology

To validate the four hypotheses above, a between-subjects study was carried out with 48 subjects. In this study, a real robot was used. Subjects had an average age of 23, with a standard deviation of 6 years and 10 months and median of 21.

3.5.6.1. Independent Variable

The independent variable was the type of multi-sensory feedback interface they were exposed to. The four possible types of interfaces are presented in Table 3.10.

Interface 1 was a visual-only interface. This interface visually presented all the data that came from the robot on the computer screen (Figure 3.31). It used as a basis the visual interface from study #3 and added a tricolored bar in the bottom right corner of the screen to display CO levels in the air. Additionaly, the map blueprint was removed and the graphical ring now displays information for collision (in red) and CPF (in yellow).

Interface 2 is built upon Interface 1. In addition, in this interface, feedback on robot movement and collision was also displayed redundantly through audio in the same way as in study #3 with a difference that now a real robot is being used.

Interface 3 is built upon Interface 2. In this interface, feedback on collision proximity and collision were now also displayed redundantly through touch using the TactaBelt (Figure 3.2a) in Intensity mode as in study #3.

Interface 4 is built upon Interface 3. In this interface, not only was feedback on the levels of CO displayed visually, but it was also displayed as the smell of Rosemary blown through our customized smell device. The higher the emulated level of CO in the air around the remote robot, the more intense was the smell of Rosemary dispersed in the air around the robot operator.

Table 3.10: Four possible interface configurations for study #4.

	Type of Information Displayed			
	Speed	**Collision**	**Collision Proximity**	**CO Levels**
Interface 1	V	V	V	V
Interface 2	V, A	V, A	V	V
Interface 3	V, A	V, A	V, T	V
Interface 4	V, A	V, A	V, T	V, O

V = Visual, A = Aural, T = Tactual, O = Olfactorial

3.5.6.2. Dependent Variables

The dependent variables were chosen with the purpose of measuring how the use of each interface impacted the following factors:

- Robot navigation efficiency and effectiveness;
- Search efficiency and effectiveness;
- Subject work load (Hart & Staveland, 1988; Hart, 2006);
- Subject cognitive load (Gwizdka, 2010);

- Subject situation awareness (SA) (Endsley & Garland, 2000);
- Subject sense of presence (Witmer & Singer, 1998);
- Subject health (Kennedy & Land, 1993; Kennedy et al., 1993);

The dependent variables are listed in the Table 3.11 through Table 3.15, where it is also indicated how each piece of data was collected and what its purpose and description was. An indication of whether the measures are subjective (S) or objective (O) is also present. The variables are categorized into tables as related to the main, Stroop, NASA-TLX, questionnaire and health measures.

Table 3.11: Main experimental measures.

#	Dependent Variable	Collection Method	Type	Purpose/Description
1	Number of collisions	Collision sensors	O	Gives a high level estimate of how well subjects navigated the robot around the task environment. It is also considered a measure of local situation awareness.
2	Number of collisions per minute	Collision sensors	O	A time-normalized version of measure #1 that reduces variation in the data.
3	Task time	Application	O	Measures how efficiently subjects performed the task.
4	Number of circles found as reported by Subjects	Form	S	Measures how effective and attentive users were when searching for circles and reporting and their location.
5	Number of circles found as counted by experimenter	Pictures	O	Number of the circles found excluding subject miscounts. A more accurate measure of the variation in the number of circles found.
6	Number of circles found per minute according to Subjects	Form	S	A time-normalized version of measure #4 with potentially less data variation.
7	Number of circles found per minute as counted by experimenter	Pictures	O	A time-normalized version of measure #5 with potentially less data variation.
8	Error on Reporting the Number of Circles Found	Form + Pictures	O	The difference between the measures #4 and #5 and indicates how much interfaces affected users' understanding of the places they have visited and what circles they have seen.
9	Quality of Sketchmaps	Sketchmaps	S	Measures how well subjects were able to remember the spatial organization of the environment explored. It is also considered a measure of global situation awareness.

Table 3.12: Stroop task measures.

#	Dependent Variable	Collection Mechanism	Type	Purpose/Description
10	Number of Incorrect Answers	Application	O	Measures how cognitively loaded users were.
11	Response Time	Application	O	Measures how cognitively loaded users were.
12	Number of Unanswered Questions	Application	O	Measures how cognitively loaded users were.

Table 3.13: NASA-TLX measures.

#	Dependent Variable	Collection Mechanism	Type	Purpose/Description
13	Mental Workload	Form	S	How much mental and perceptual activity was required
14	Physical Workload	Form	S	How much physical activity was required
15	Temporal Workload	Form	S	How much time pressure one felt
16	Performance Workload	Form	S	How successful about performing the task one felt
17	Effort Workload	Form	S	How hard one had to work
18	Frustration Workload	Form	S	How insecure, discouraged, irritated, stressed or annoyed one felt

Table 3.14: Questionnaire measures.

#	Dependent Variable	Collection Mechanism	Type	Purpose/Description
19	Ease of Learning (Difficulty)	Form	S	How difficult it was to learn how the interface worked.
20	Interface Confusion (Understanding)	Form	S	How confusing the interface was.
21	Distraction (Feedback)	Form	S	How distracting the feedback was.
22	Comfort (Use)	Form	S	How comfortable to use the interface was.
23	Understanding (Impact)	Form	S	How much using the interface impacted one's understanding of the environment.
24	Being There	Form	S	How much one felt as being in person in the remote room. It is considered a measure of presence.
25	Reality	Form	S	To what extent there were times during the experience when the remote room became one's "reality". It is considered a measure of presence.
26	Visited	Form	S	Whether, when thinking back about the experience, whether one thinks of the remote room more as something that one saw, or more as somewhere that one visited. It is considered a measure of presence.
27	Walking	Form	S	Whether, when navigating in the remote room, one felt more like driving through the room or walking in the room. It is considered a measure of presence.

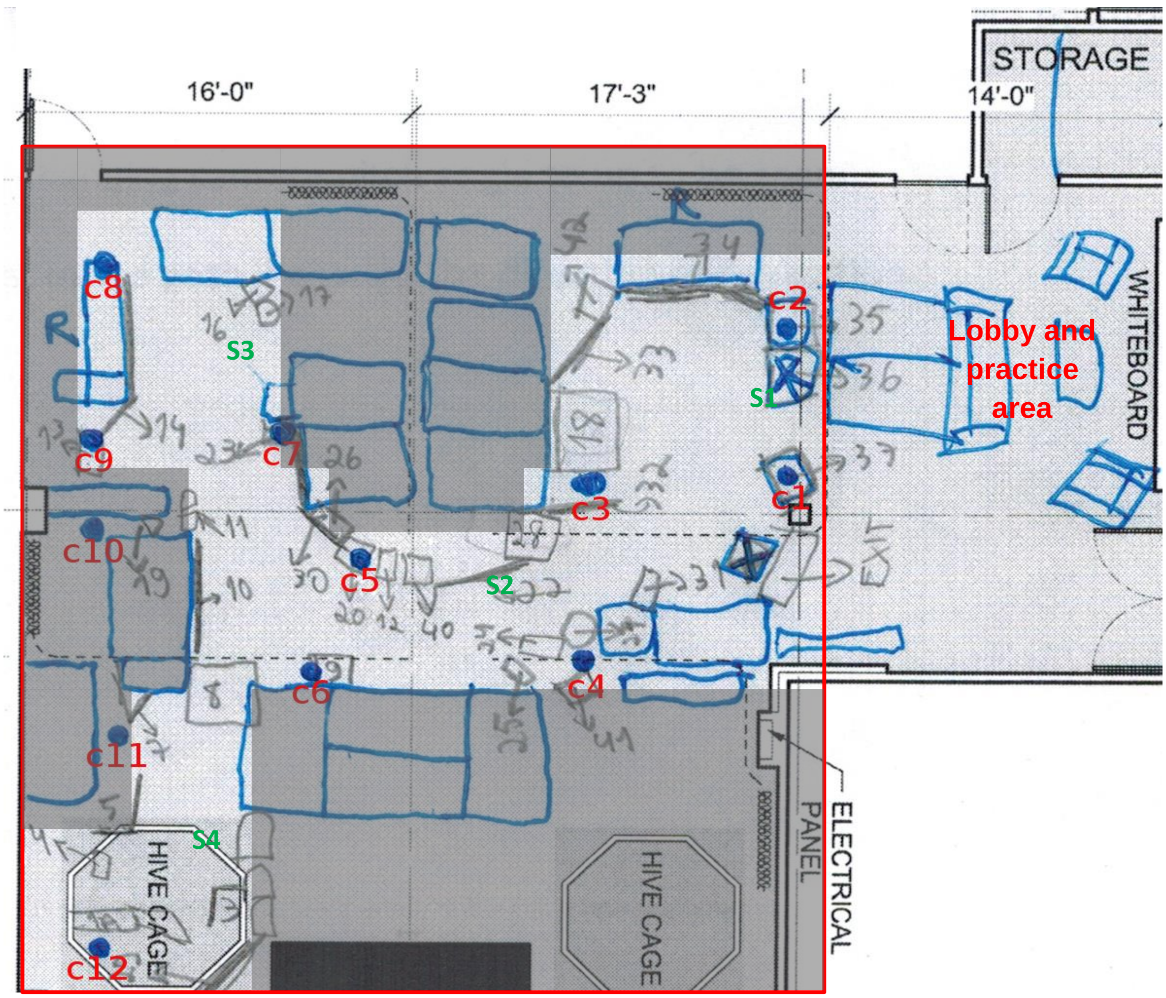
Table 3.15: Health measures.

#	Dependent Variable	Collection Mechanism	Type	Purpose/Description
28	Fatigue	Form	S	How much subject fatigue was caused by study participation
29	Headache	Form	S	How much subject headache was caused by study participation
30	Eyestrain	Form	S	How much subject eyestrain was caused by study participation
31	Difficulty Focusing	Form	S	How much subject focusing was impacted by study participation
32	Increased Salivation	Form	S	How much subject salivation varied because of study participation
33	Sweating	Form	S	How much subject sweating increased by study participation
34	Nausea	Form	S	How much subject nausea was caused by study participation
35	Difficulty Concentrating	Form	S	How much subject concentration was impacted by study participation
36	Fullness of Head	Form	S	How much subject fullness of head was caused by study participation
37	Blurred Vision	Form	S	How much subject vision was blurred due to participation in the study
38	Dizzy (Eyes Open)	Form	S	How much subject dizziness (eyes open) was caused by study participation
39	Dizzy (Eyes Closed)	Form	S	How much subject dizziness (eyes closed) was caused by study participation
40	Vertigo	Form	S	How much subject vertigo was caused by study participation
41	Stomach Awareness	Form	S	How much subject stomach awareness was caused by study participation
42	Burping	Form	S	How much subject burping was caused by study participation

3.5.6.3. Study environment

As mentioned earlier, the study was carried out in a closed lab environment. The laboratory was divided into three areas (Figure 3.32, D.2.4.1):

- A larger area filled with debris and where the red circles were hidden. This was the area where only the robot would go to perform the study task. The subject was not allowed to enter or look at this area in person, but only through the robot during the search task.
- A smaller lobby area where the subject would fill the necessary forms and questionnaires, practice the robot controls, and get accustomed to the different types of feedback he would be exposed to in the real experiment. He would also have the opportunity to examine the robot to be controlled.
- A small closet from where the subject would control the robot (Figure 3.33 below). This area was where the operator computer and the feedback displays were placed. This area was ventilated by two domestic fans, one blowing air in and the other blowing air out. The purpose of this increase in ventilation was to avoid the accumulation of Rosemary smell on the operator room and hence guarantee the intermittence of the smell feedback during the task.



Legend:

- **Blue dots:** Circles to be searched for;
- **c1…c12:** Identification number for the circle close to this label;
- **S1…S4:** different section of the lab accessible by the robot, and illustrated by the pictures below;
- **Black lines:** Lab walls;
- **Blue lines:** Lab objects (tables, chairs, etc.);
- **Gray lines:** Debris added to the lab;
- **Grayed out areas:** Areas visible through the robot camera but inaccessible to the robot;
- **Red Square Line:** lab area used for the experiment.

Figure 3.32: Lab environment sub-areas for study #4.

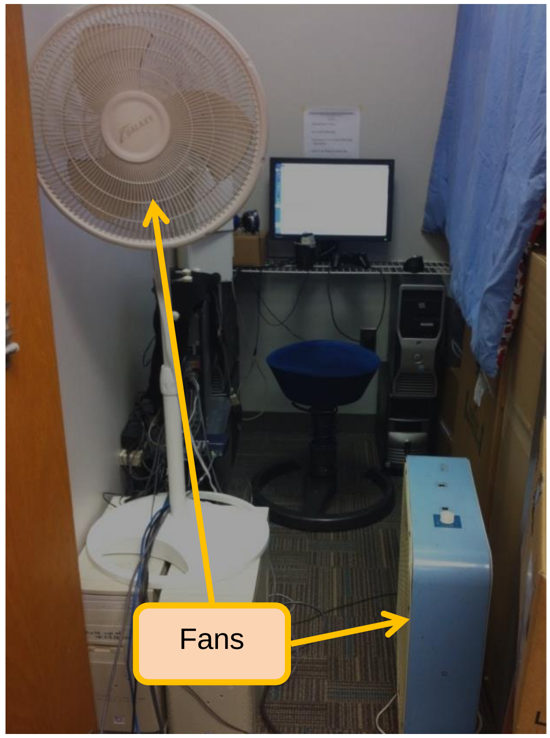


Figure 3.33: Robot operator room. Two fans guaranteed fresh air ventilation.

3.5.6.4. Experimental procedure

As mentioned earlier, the study has a between-subjects design, which means each subject was exposed to only one of the treatment interfaces. The reason behind the decision of running a between-subjects study was because it would not be viable to run each treatment for all subjects. This would require four different physical scenarios, one for each treatment, and physical resources were not available for that. In addition the study would be excessively long for each subject (6 - 8 hours), and would require multiple sessions per subject, which would potentially lead to a smaller pool of volunteers.

Because of the highly perceptual nature of the study, before participating in the study, subjects were asked questions about claustrophobia, color-blindness, hearing or olfactory problems and allergy to any smells or Rosemary.

If the subject was mentally and physiologically qualified for the study, the subject would then come to the lab and participate in the study at a specific two-hour time slot, whose starting time could vary from 8 a.m. to 6 p.m. Subjects were compensated with course credits, if registered at the university. They were also offered snacks after the study was completed.

The experiment steps followed for each subject are listed below:

1. Demographics questionnaire was filled in. This could be done on-line and prior to coming to the lab for the study;
2. Institutional Review Board (IRB) approved consent forms were read and signed;
3. Health questionnaire was filled in;
4. Instructions page was read;
5. Overview of the task and the robot input and output interface would take place, followed by a Q&A session. During that time, the robot was placed in front of the subject so that they would get to know how it looked like;
6. Training session with Q&A. Durign this session, subjects could turn around and see how what the robot situation was directly in nthe environment;
7. Experiment. Subejcts had no access to the robot or the environment it was in. Any information from the robot could only be obtained through the robot feedback interface;
8. Questionnaire with map sketching task;
9. Health questionnaire was filled in again;
10. NASA TLX questionnaire was filled in;
11. Spatial aptitude test was taken.

In order to balance the pool of subjects among treatments, they were distributed among treatments so that each treatment had a similar number of subjects with experience scores of different levels. The experience score was calculated using the information collected in the demographics questionnaire according to Equation 3.1. The scores ranged from 1 to 4, similar to all the sub-scores being used in previous studies. Notice that experience with robots and videogame were given double the weight of the other variables. For the former variable, this decision was made because of the very robotic nature of the study. For the latter, the weight was chosen because it was detected in previous studies that videogame experience did seem to have an impact on subject performance.

$$Total_{XP} = (Videogame_{XP} \times 2 + Robot_{XP} \times 2 + RCV_{XP} + Gamepad_{XP} + Computer_{XP}) / 7$$

Equation 3.1: Equation that associated subjects to a single overall experience score in study #4.

3.5.6.5. Other Materials

Other materials used in this study, such as the script used by the experimenter, the information contained in the user study instruction sheet, and the questions contained in the user study post-task questionnaire, are found in Appendix D.1.

3.5.7. Results

This section presents all the relevant results for study #4. Data for all the data analysis can be found in appendix D.2. Even though the pool per interface treatment was small, the data analysis of this study led to a few interesting results.

Our results were obtained using a single-factor ANOVA with confidence level of $\alpha = 0.05$. Results close to significance had a confidence level of $\alpha = 0.1$ and were described as trends. When a statistically significant difference (SSD) among more than two groups was found, a Tukey test (HSD, 95% confidence level) was performed to reveal the groups that differed from each other. In some cases, ANOVAs were also applied to compare groups in a pair-wise fashion.

For questionnaire ratings, Friedman tests were used to compare all groups together, while Wilcoxon tests were used to compare them in a pair-wise fashion. Sections where SSD results were found have their titles marked with an asterisk (*). If only a trend was found, the title of that section is marked with a plus (+) sign.

3.5.7.1. *Demographics**

A total of 18 females and 30 males participated in the study. Their average age was 23, with standard deviation of 6 years and 9 months and median 21.

A trend was found between the number of circles found by male subjects and female subjects, the former being higher ($F = 2.721$, $p = 0.106$, D.2.1.8.3). It was also noticed that males had more experience with remote-controlled vehicles (RCVs) ($F = 3.166$, $p = 0.082$, D.2.1.8.9).

On the other hand, a SSD was also found for number of collisions per minute, where females had fewer ($F = 4.477$, $p = 0.040$, D.2.1.8.5). Interestingly, females reported a significantly higher level of experience with videogames than males ($F = 7.252$, $p = 0.010$, D.2.1.8.7). In previous studies, higher levels of videogame experience were associated with better navigation performance. If these reports are accurate, these results are a re-validation of such concepts. Nevertheless, the author believes this unexpected result for videogame experience reporting is an artifact caused by differences in social behavior among men and women associated within the area of Computer Science and Robotics.

3.5.7.2. Task Time

A slight reduction in task time was perceived for interfaces 3 and 4 (Figure 3.33, D.2.2), but no SSD was detected. It is believed that the TactaBelt tended to annoy users after prolonged use and that might have pressured them to finish the study faster.

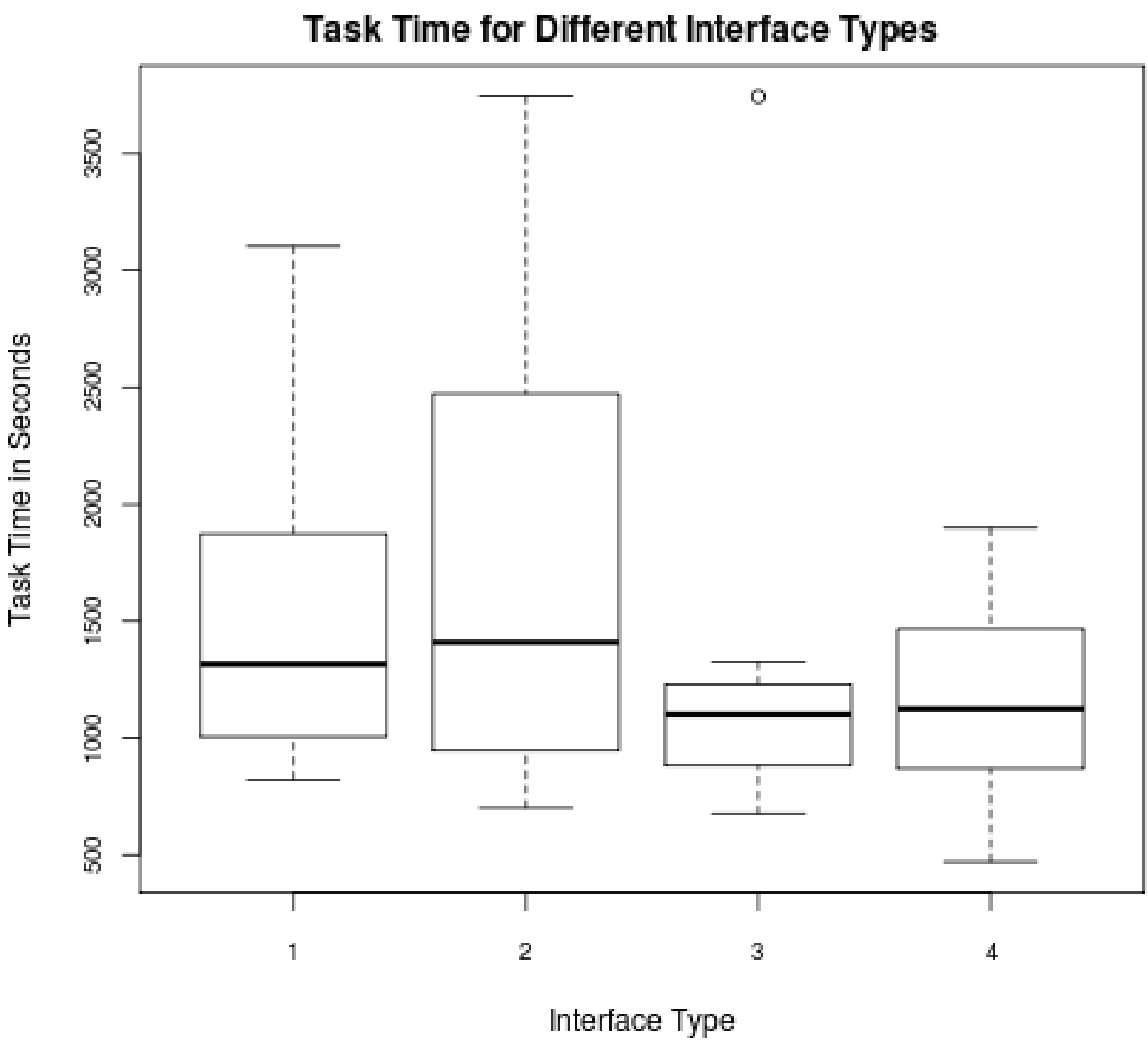


Figure 3.34: Interface 3 seems to have led to a reduction in the task time and its variation.

3.5.7.3. *Number of Circles Found**

For the number of circles found, we considered the analysis for the actual number of circles found, as counted by the experimenter, instead of the number of circles subjects reported they found (Figure 3.34, D.2.4). SSDs were found for the number of circles, but we believe this was caused due to population experience variation and the small sample size considered.

However, for the time-normalized version of the number of circles found, a SSD was detected for the number of circles found per minute between interfaces 1 and 4 (w = 14.0, z = -1.961, p = 0.052, r = -0.200, D.2.4.7). This supports S4H2. It is an indication that having the redundant feedback for CO did help subjects find more circles per minute.

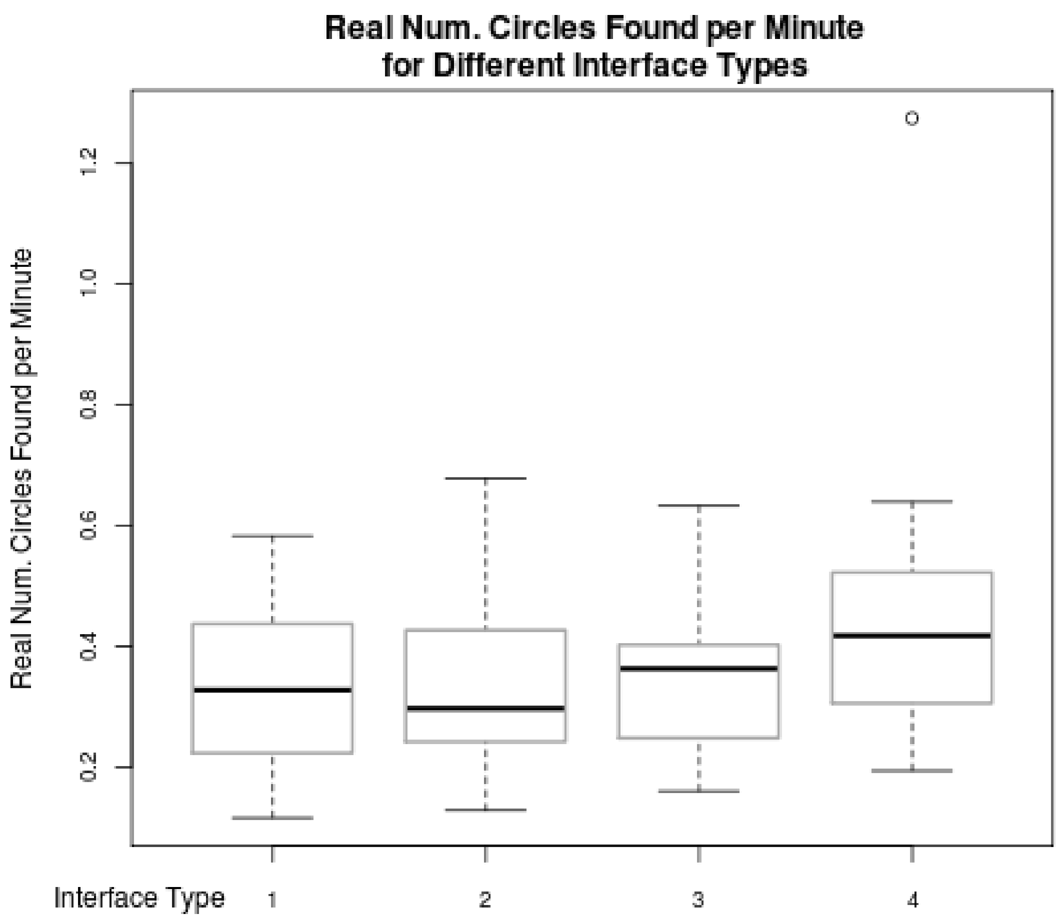


Figure 3.35: The use of smell feedback led to an increase in the number of circles found per minute.

3.5.7.4. Number of Collisions

For the variables related to the number of robot collisions, even though no SSD was found, a visible decrease in the number of collisions and number of collisions per minute was noticed for interfaces 2 and 3 (Figure 3.36, D.2.3). The data seem to follow the same pattern obtained in the third study despite the lack of map blueprint. However, for this study, the vibro-tactile feedback did not seem to have as much of an effect in reducing the number of collisions.

If we look at the results of study #3 (Table 3.16), which had a statistically significant difference when the data was normalized per subject, we see that the addition of audio caused a decrease of about 30% in the median for the number of collisions per minute. The same decrease was detected in study #4 for the median when audio was added, though not with statistical significance. This lead us to believe that study #4 reproduced similar results to study #3 for audio feedback, and that these results would have achieved statistical significance had a larger pool of subjects been used.

Notice that a similar decrease of 30% was detected in study #2 the vibro-tactile belt was added to the visual interface. This variation, however, was not detected in study #4. Notice also that the median for the number of collisions per minute decreased from 4.814 in the second study to 2.242 in the third study. The consistency of the median values between the Intensity interface in study #2 (3.074) and in study #3 (Interface 1, 3.441) show that not only the population used in both studies had similar levels of experience, but also that these studies indeed have used very similar and controlled environments with the only variation being the feedback interface used. One could understand studies #2 and #3 as one large study split into two to avoid subject fatigue. By doing so, the accumulated benefit of adding multi-sensory feedback is much clearer. In study #2, a 30% decrease was obtained for the number of collisions per minute. In study #3 a further

30% decrease was obtained. Adding both audio and vibro-tactile feedback has then decreased the number of collisions from 100% to ((100% * 0.7) * 0.7) = 49%. Naturally, even with such similar median values for the Intensity interface, this claim would only be valid if the studies had used the same population of subjects. These results, however, are a good indication of the benefits of multi-sensory interfaces.

Table 3.16: Comparison of median value decay for number of collisions per minute across studies #2, #3 and #4.

Number of Collisions per Minute for Study #2

Interface	*Mean*	*Std. Dev.*	*Median*	
None	4.982	2.893	4.814	-30%
Intensity	3.854	3.286	3.074	
Frequency	4.032	2.981	3.243	

Number of Collisions per Minute for Study #3

Interface #	*Mean*	*Std. Dev.*	*Median*	
1 = Intensity	3.819	2.394	3.441	-30%
2 = (1) + audio	2.844	2.015	2.242	
3 = (2) + redundant visuals	3.063	2.479	2.221	

Number of Collisions per Minute for Study #4

Interface #	*Mean*	*Std. Dev.*	*Median*	
1: visuals	1.286	0.816	1.177	-30%
2: (1) + audio	0.957	0.487	0.824	
3: (2) + vibration	1.196	0.685	0.853	
4: (3) + smell	1.472	0.848	1.358	

By looking at the median values and comparing it with the ones obtained in previous studies, the result of study #4 seems to partially confirm S4H1 at least in terms of the audio-enhanced Interface 2, although no SSD was found. Because the study had a between subjects design, the data could not be normalized across treatments on a per-subjects basis as in preivous studies. This lack of normalization led to results that were much noisier statistically than for study #3. In addition, from a treatment's perspective, the pool of subjects per treatment was smaller. Had the results been normalized on a per subject basis, we might have obtained significance in the collision improvements made by interfaces 2 and 3.

Interestingly, the group exposed to the smell feedback display (Interface 4) had the worse collision performance levels of all groups. This was unexpected, since the smell display does not provide any collision related information, but instead emphasizes the response to robot closeness to the red circles. Therefore, it would be expected that it should not impact the number of collisions. However, as visibly noticeable in Figure 3.36, Interface 4 did cause an increase in the number of collisions to a point that it even led to more collisions than the control case, countering any collision improvements made by the use of the other types of multi-sensory feedback defined in interfaces 2 and 3.

This increase in collisions could be an indication of subject cognition overload. However, another possible explanation, and perhaps a more plausible one, is that smell feedback affected subject's behavior during the task, increasing his or her attention to circle finding. Since the smell interface led to more circles being found, as reported in section 3.5.7.3, subjects might have had to maneuver the robot around more frequently solely based on this feedback and visual CO bar. They assumed a "sniffing" behavior when in search for a yet unseen circle, similar to what a dog does when using its sense of smell to search for objects of its own interest. Since the smell feedback provided did not contain any directional information on where the circle could be relative to the robot, the extra effort put into navigating around and looking for the circles led to an increase in the number of collisions. In fact, such change in subject behavior was perceived by the experimenter in a few subjects. When they passed through an area where smell was detected, subjects tended to either back up more often to reassess the area, or they would get closer to objects around that area in search for the hidden circle.

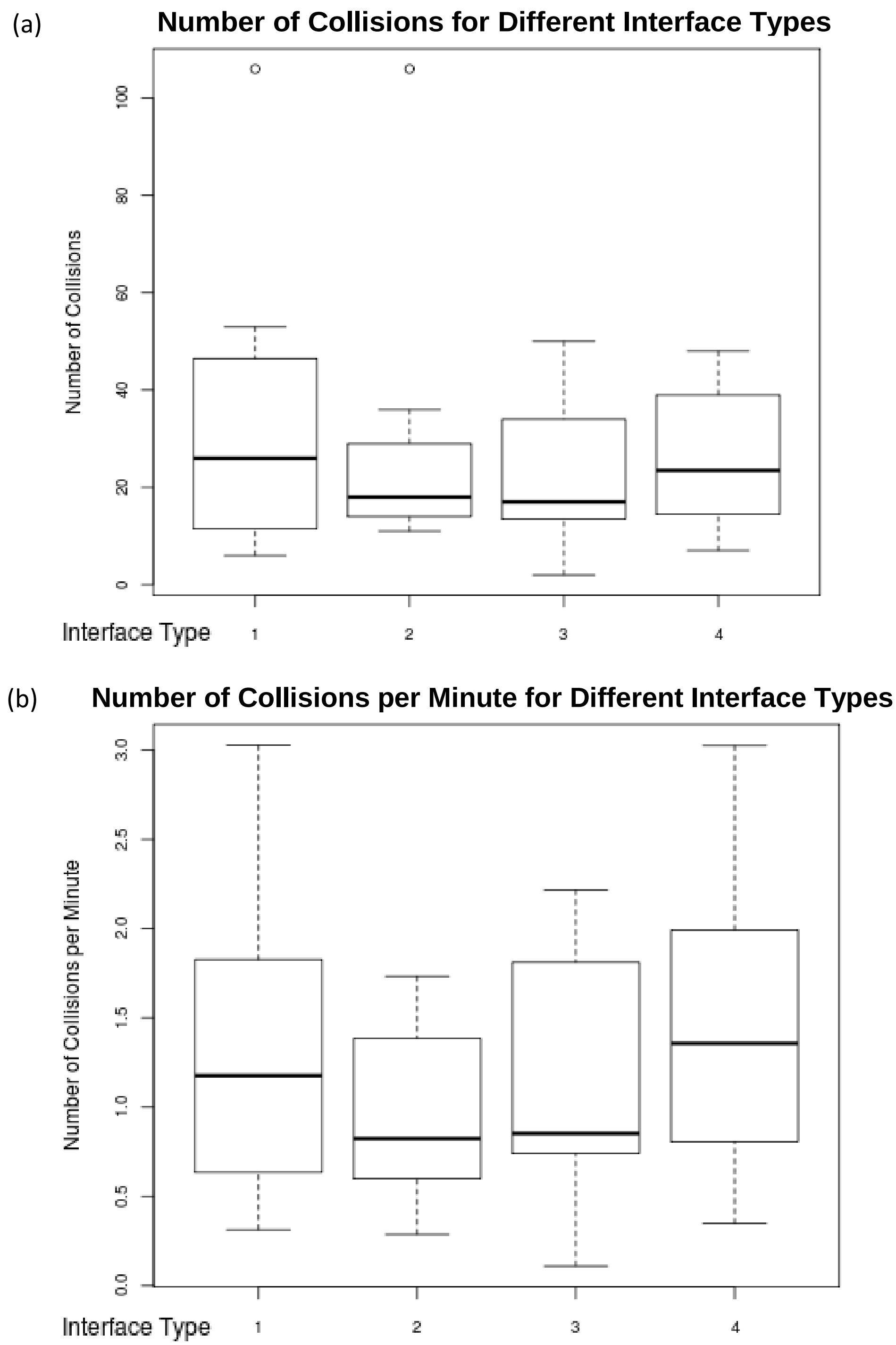


Figure 3.36: (a) Number of collisions and (b) collisison per minute for diffferent interface types.

3.5.7.5. Map Quality+

In the analysis of the sketchmap quality results (Figure 3.37, D.2.5), trends were detected between interfaces 1 and 2 (w = 11.0, z = -1.616, p = 0.111, r = -0.165), which partially confirms S4H4, and interfaces 1 and 4 (w = 13.0, z = -1.633, p = 0.109, r = -0.167), which partially confirms S4H3.

For interface 2, the improvement seems to be an indication of the lowering subjects' cognitive load, which might have enabled subjects to pay more attention about the robot's orientation relative to landmarks in the remote environment which in turn led to an increase in their global situation awareness (SA). For interface 4, the improvement over Interface 1 could also be related to a decrease in cognitive load and increase in global SA, but it could also be related to an improvement in subjects' memorization capacity. If the latter is the case, the results here would be in accordance with the results obtained from other researchers (Moss et al., 2003).

Interface 3, where vibro-tactile feedback was added, however, caused a slight degradation in the quality of the sketchmaps drawn, which was enough to undermine the improvement in the sketchmaps caused by the use of the interface 2 enhancements. The reason behind this is probably because of the annoyance and itchiness caused by the prolonged used of the belt. However, considering the results of the Wilcoxon test for Interfaces 1 and 3 (w = 14.0, z = -1.550, p = 0.139, r = -0.158, D.2.5), it is probable that an SSD would have been obtained for this interface had a larger pool of subjects been used.

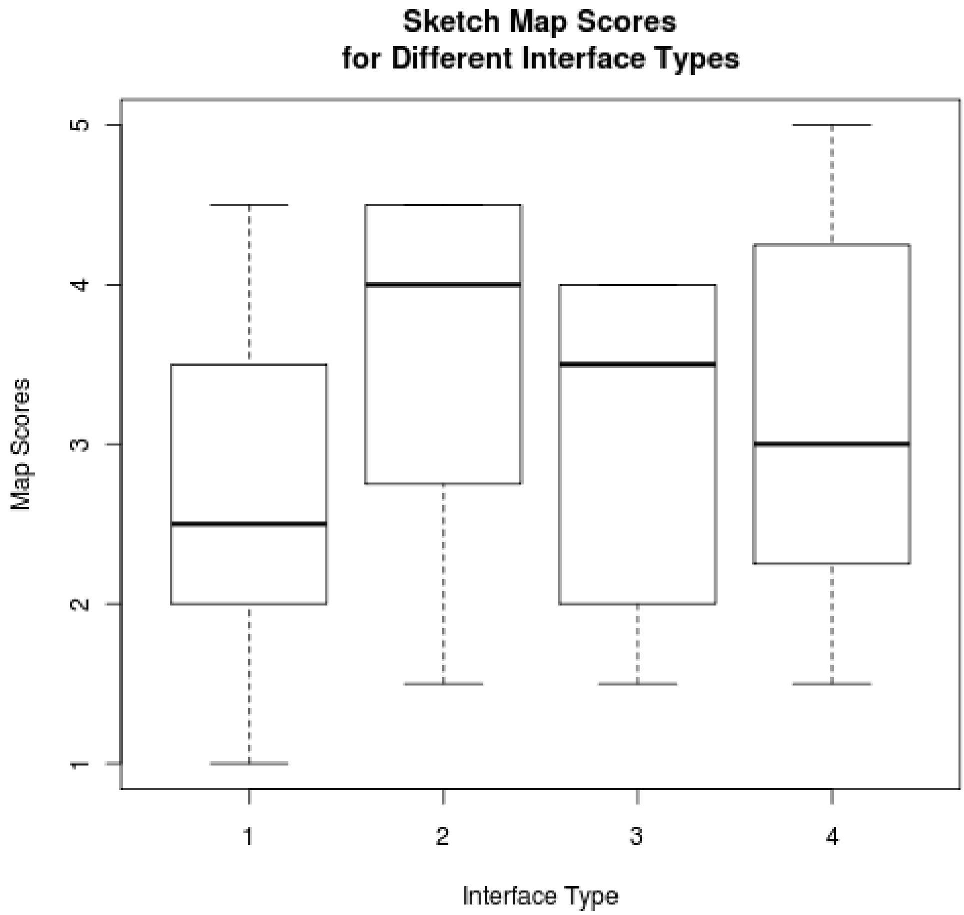


Figure 3.37: In general, multi-sensory interfaces led to an increase in the quality of sketchmaps in study #4.

*3.5.7.6. Stroop Task Cognitive Load**

For the Stroop task, specifically for the percentual number of incorrect responses (Figure 3.38a, D.2.6.1), a SSD was detected between the pairs of interfaces (1, 4) (w = 53.0, z = 2.638, p = 0.006, r = 0.269) and (2, 4) (w = 44.0, z = 1.772, p = 0.084, r = 0.181). In this case, interface 4 performed better than all others.

Notice also in Figure 3.38 the gradual decrease in the median number of incorrect answers as more multi-sensory feedback is added. This is a good indication that the multi-sensory feedback is having a small but positive effect on subjects' cognition. It may be that offloading data display from vision to other senses reduces subjects' visual cognitive load.

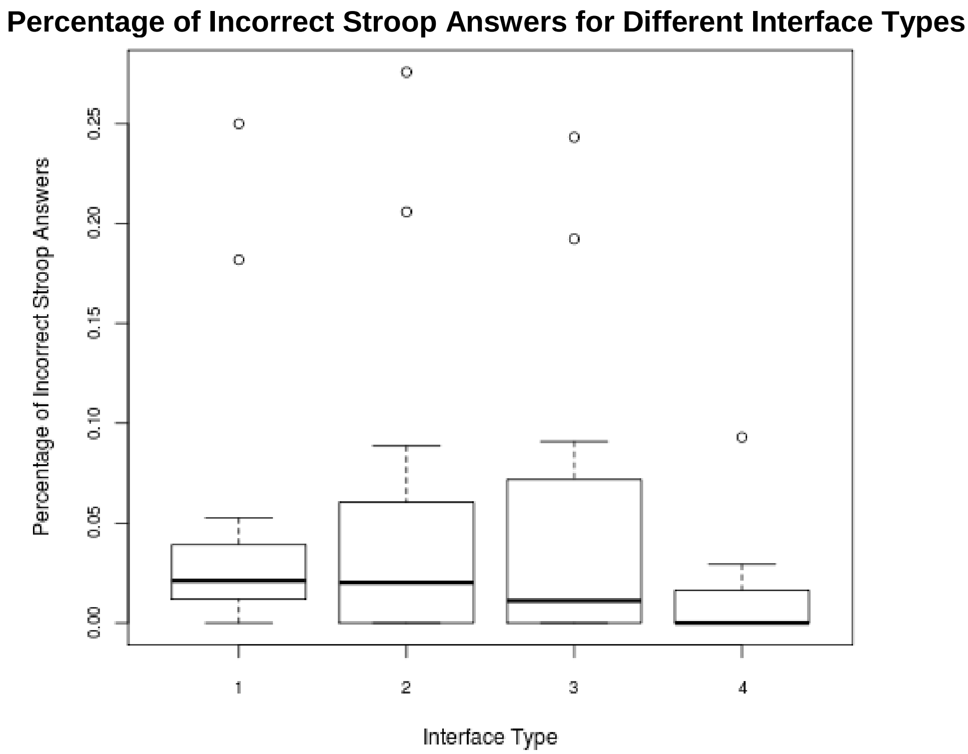
Another interesting fact is that, when the Stroop questions where split between those in which color and text description matched and those where color and text description mismatched, this difference was only detected in the group where the color and text description matched. Since the number of questions in each group was randomly balanced, this result seems to show that matched questions are more sensitive to variations in cognitive load than mismatched questions, probably due to their *stimulus-response compatibility*. That is, they were easier to notice, required less cognitive load, and hence could better measure small cognitive load variations. Although this fact is not of much relevance to validate our hypotheses, it is an interesting result from the point of view of experimental measurement.

In terms of response time, a visible increase in response time was detected for Interface 4 compared to the other interfaces (Figure 3.38b, D.2.6.2). This difference was significant when interface 4 was compared to interface 3 (χ^2 = 3.853, p = 0.050). In addition, this difference was even more statistically significant for questions where color and text matched, in this case being close to significant when interface 4 was compared with all other three interfaces. It is believed that the reason for such a drastic increase for interface 4 was the fact that, out of curiosity, subjects were diverting their attention from the computer screen to the smell feedback device from time to time whenever they smelled rosemary to see if they could see the device at work. They were asked by the experimenter not to do so before the experimenter, but the behavior was not enforced during the study. Such behavior was observed during treatments by the experimenter, and might have been the reason behind the increase in response time.

For interfaces 2 and 3, however, a slight decrease in response time was noticed, but it was not statistically significant due in part to the increase in response time variation for these interfaces. For questions with color mismatch, a trend indicated that interface 3 had better response time than interface 1 (χ^2 = 2.803, p = 0.094, D.2.6.2.2).

In terms of the number of unanswered questions, interfaces 2 and 3 led to a small reduction in the number of unanswered questions. This is an indication of lowering in subjects' visual cognitive load. A SSD was detected between interfaces 1 and 3 (χ^2 = 4.083, p = 0.043, D.2.6.3). This supports S4H1. Interface 4, on the other hand, led to an increase in the number of unanswered questions. A trend indicated that this increase had a close to significant difference when compared to interface 3 (χ^2 = 2.613, p = 0.106, D.2.6.3). It is believed the same cause for the increase in response time for Interface 4 has also impacted the number of unanswered questions for this interface.

(a)



(b)

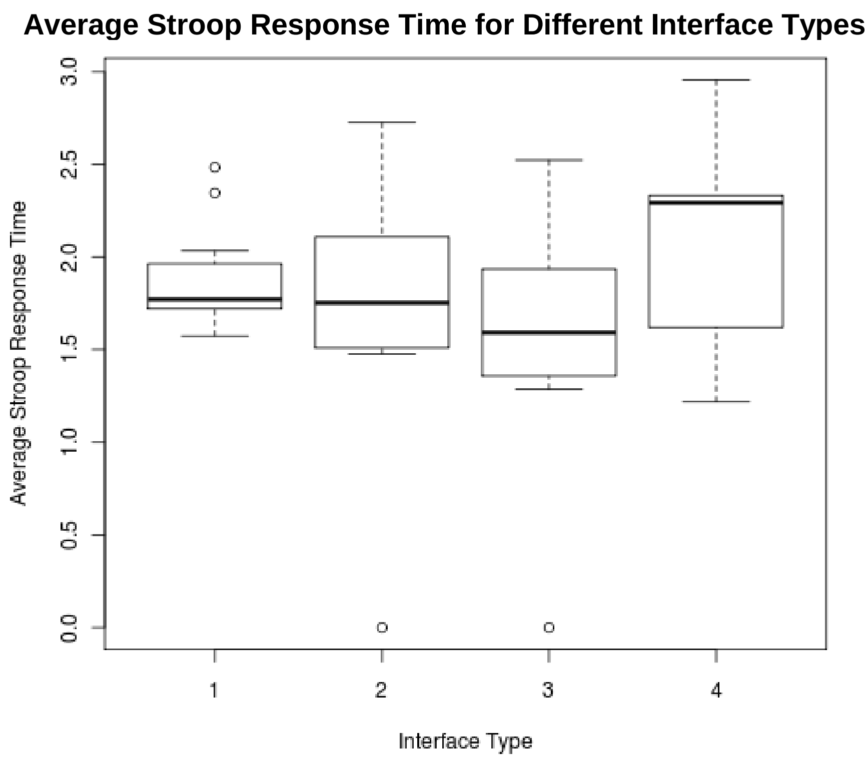


Figure 3.38: Interface 4 led to (a) a decrease in the number of incorrect Stroop task responses and (b) an increase in response time.

*3.5.7.7. NASA-TLX Workload**

In terms of mental workload, results showed that interface 3 and 4 increased users' mental workload (Figure 3.39), while interface 2 reduced it. A SSD was detected between the results of interfaces 2 and 3 (w = 2.0, z = -2.643, p = 0.008, r = -0.270, D.2.7.1). A SSD was also detected for the mental workload weights between interfaces 2 and 3 (w = 2.0, z = -2.643, p = 0.008, r = -0.270, D.2.7.1). This result seems to indicate that while Interface 2 led to similar results than previous experiments, the same cannot be stated about interface 3. The reasons for such differences are discussed in section 3.5.8.

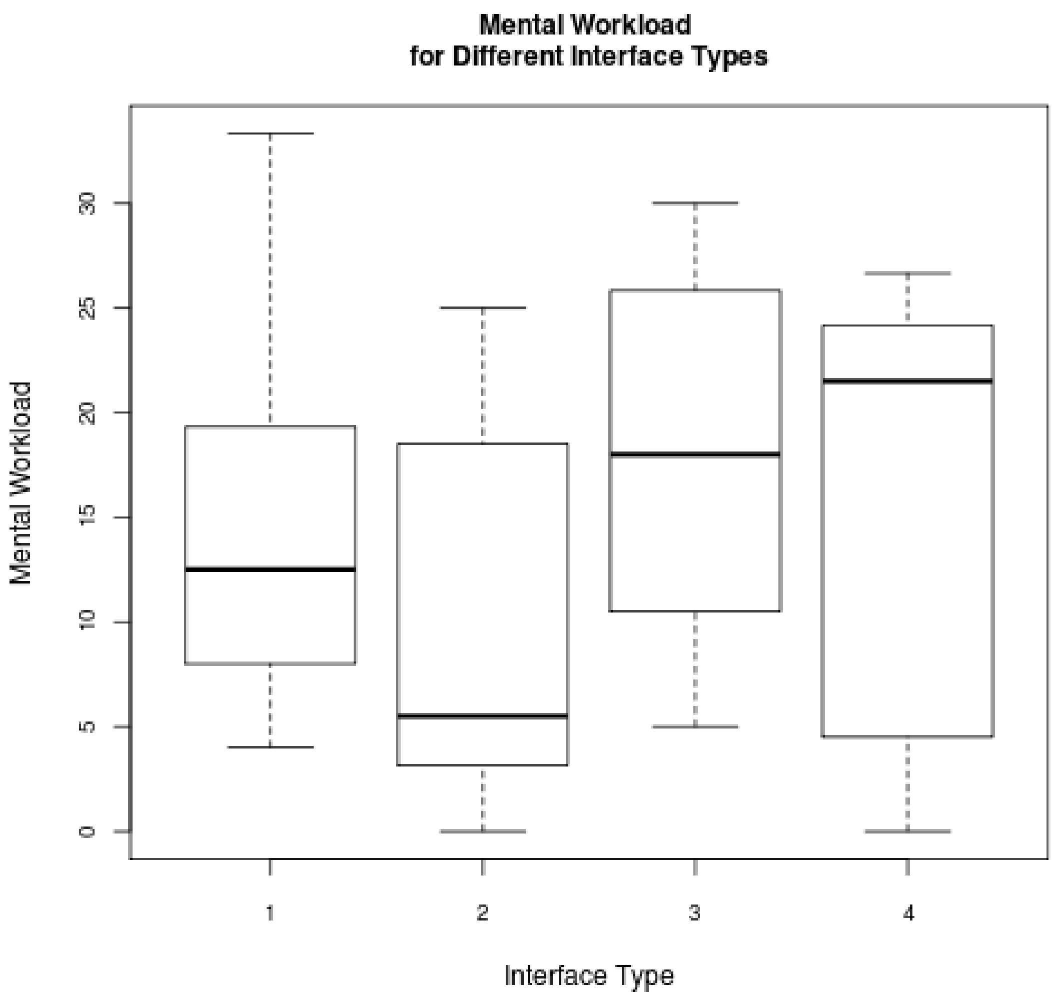


Figure 3.39: An increase in mental workload was detected for Interface 3 and Interface 4.

Physical, temporal, performance, effort, frustration workloads were not affected much by the type of interface used and did not lead to any SSDs.

It is interesting to notice that a similar pattern emerged from the temporal, performance and effort workload graph as well as from the Stroop Task response time graphs (Figure 3.42 and *Figure 3.41*, D.2.7.3, D.2.7.4, D.2.7.5, D.2.6.2). This means interface 4 made subjects feel more rushed during the task, feel that they performed better and that they had to put more effort to accomplish it. They also show that interfaces 2 and 3 led to the opposite effect of Interface 4, that is, they reduced the effort of the task, it made subjects feel as if they performed better, and made them feel less rushed. Even though these were not statistically significant, the similarity in these plots seem to point towards what the expected results would be with a larger pool of subjects. The reason for such an effect will be discussed further in section 3.5.8.

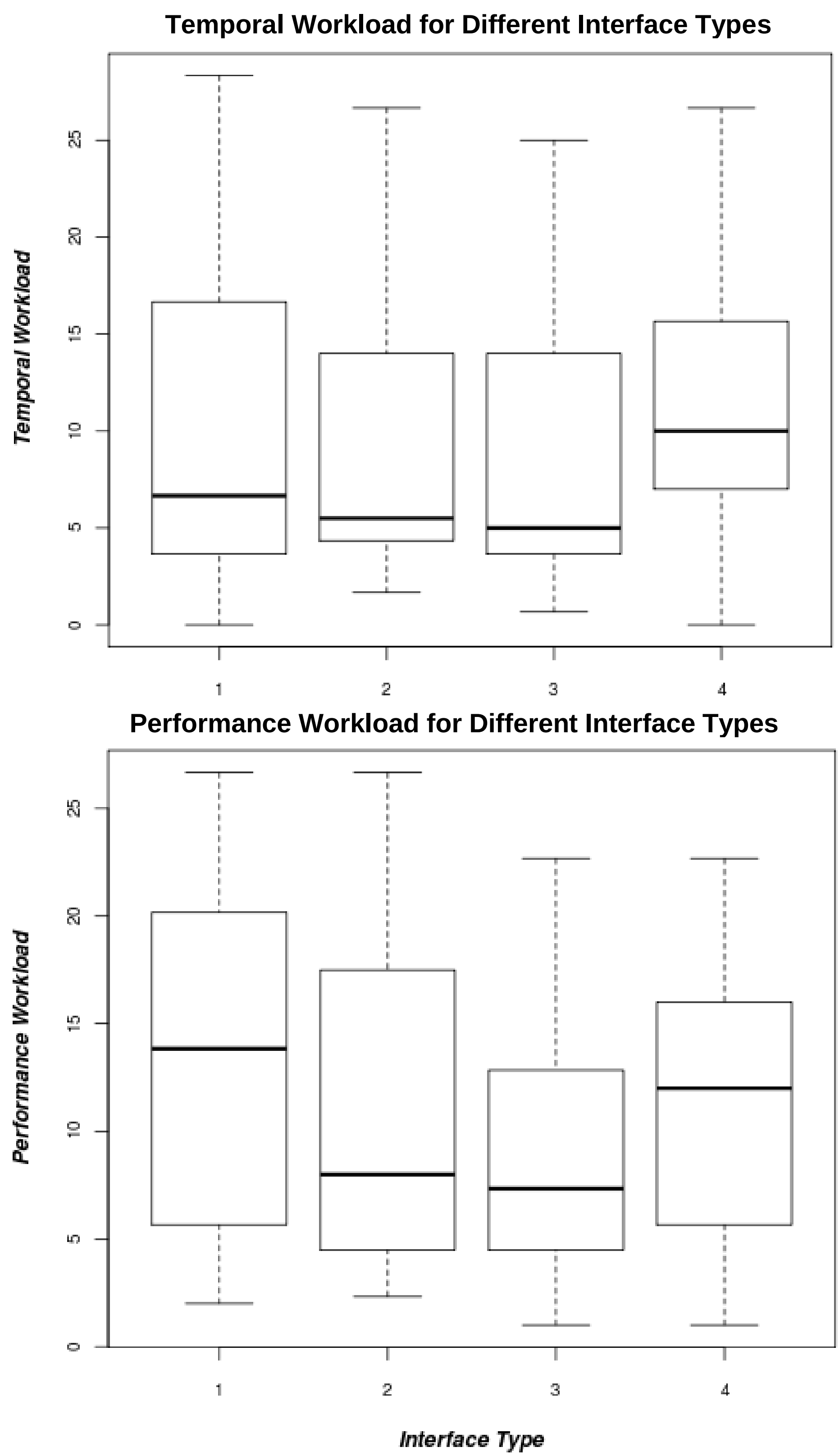


Figure 3.40: Comparison of data patterns among interface types for temporal and performance workload in study #4.

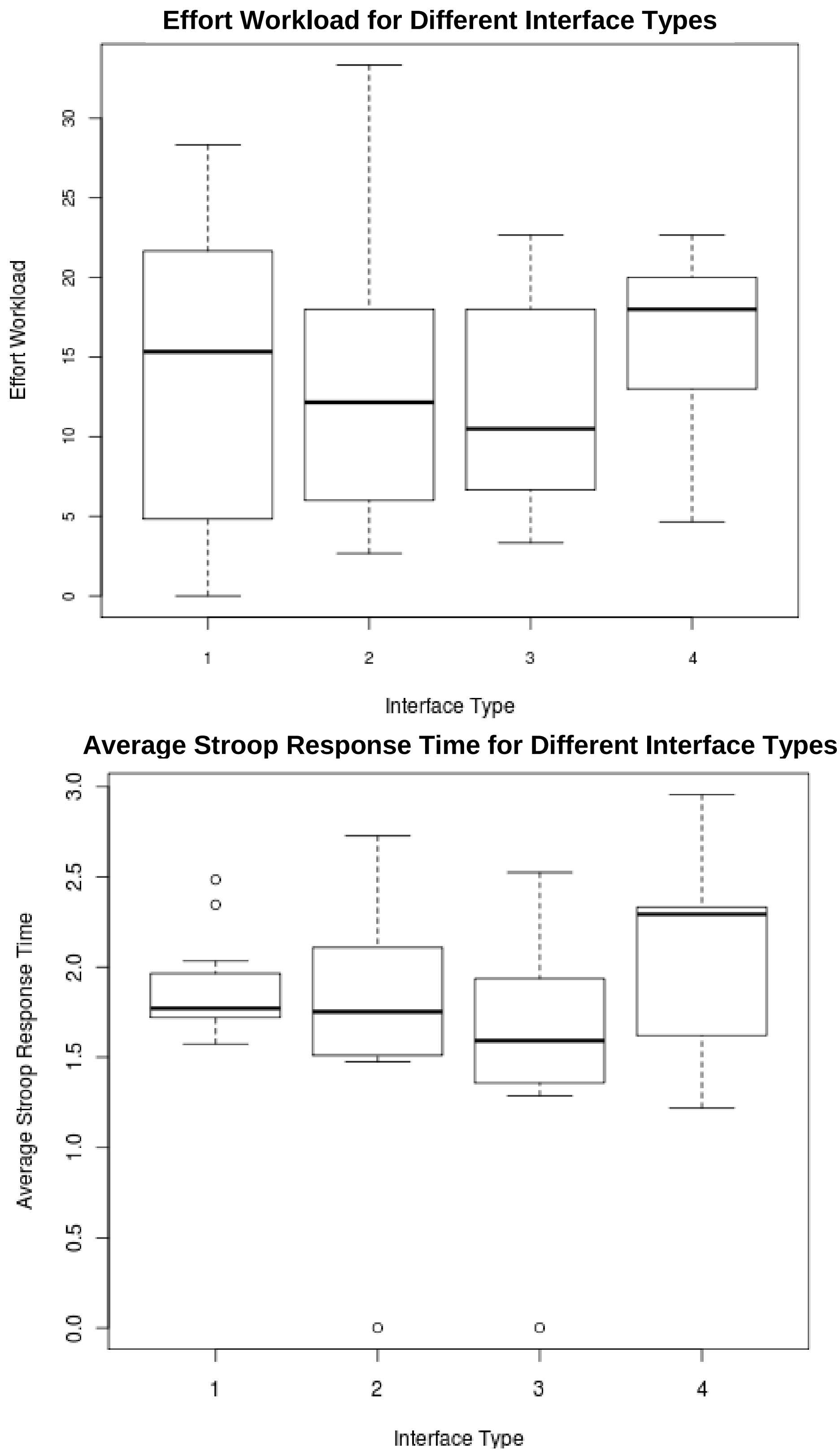


Figure 3.41: Comparison of data patterns among interface types for effort workload and the average Stroop response time in study #4.

When all workload factors were put together, interface 2 was rated as having higher workload than interface 3 with SSD (w = 62.0, z = 1.804, p = 0.077, r = 0.184, D.2.7.7).

*3.5.7.8. Questionnaire**

For the questionnaires, in terms of overall difficulty, no SSDs were detected. However, by looking at the means, interface 2 seemed to have been rated as slightly easier than interface 1 while interfaces 3 and 4 were rated slightly harder. Aural feedback was rated as more difficult to use than the visual feedback with statistical significance in interfaces 2 (F = 6.171, p = 0.021, D.2.8.2.6) and 4 (w = 7.5, z = -2.384, p = 0.020, r = -0.243, D.2.8.2.8). In terms of each individual feedback for all the interfaces, and considering the median, it was noticed that aural feedback was rated the most difficult, sequentially followed by smell, vibro-tactile, and visual feedback.

For understanding, no SSDs were detected. For interface 4 however, the vibro-tactile feedback was rated higher than others while the smell feedback was rated lower than others. A SSD was also detected between the vibro-tactile and smell feedback (w = 55.5, z = 2.060, p = 0.041, r = 0.210, D.2.8.3.8), while a trend was detected between the aural and vibro-tactile feedback (w = 11.0, z = -1.797, p = 0.092, r = -0.183, D.2.8.3.8).

For feedback, a SSD was detected between visuals for interfaces 1 and 2 (w = 4.5, z = -2.265, p = 0.023, r = -0.231, D.2.8.4). For interfaces 2, 3 and 4, aural feedback was rated lower than visual feedback, but with a SSD to interface 1 only for interfaces 2 (w = 57.5, z = 2.291, p = 0.016, r = 0.234, D.2.8.4.6) and 3 (w = 48.0, z = 2.276, p = 0.016, r = 0.232, D.2.8.4.7). Overall, all muti-sensory interfaces improved feedback understanding ratings. However, using pair-wise ANOVA a trend was only detected between interfaces 1 and 2 (F = 3.082, p = 0.088, D.2.8.4.9).

For use, a trend was detected between visuals for interfaces 2 and 3 (w = 8.0, z = -1.775, p = 0.070, r = -0.181, D.2.8.5.1). For interface 3, aural feedback received a lower rating than visual feedback with statistical significance (w = 32.0, z = 2.137, p = 0.062, r = 0.218, D.2.8.5.7). Overall, the interfaces led to improvements in terms of use, but with no SSD.

In terms of impact, aural feedback was rated lower with SSD than other types of feedback for all multi-sensory interfaces (Interface 2: F = 6.744, p = 0.016, D.2.8.6.6; Interface 3: F = 3.983, p = 0.028, D.2.8.6.7; Interface 4: F = 6.613, p = 0.001, D.2.8.6.8). For interface 4, olfactory feedback was also rated lower than visual feedback with SSD (w = 37.5, z = 2.032, p = 0.039, r = 0.207, D.2.8.6.8). Interfaces 2 and 4 led to lower impact ratings, although no SSDs were detected.

For the “being there”, reality, visited and walking ratings, no SSDs were detected.

*3.5.7.9. Health Questionnaire**

In terms of how much each interface impacted users’ health, most variations were related to discomfort, fatigue, headache and eyestrain (Figure 3.42).

For general discomfort, interface 4 led to more discomfort than other interfaces with SSD (F = 6.545, p = 0.065, D.2.9.1.3). For fatigue, interface 3 led to more fatigue compared to interface 2 (χ^2 = 4.571, p = 0.032, D.2.9.1.4). Interface 2 had a decrease in burping with SSD (F = 3.667, p = 0.019, D.2.9.1.8), but we don't believe this was caused by the use of this interface. The author believes this decrease was more likely caused by subjects eating before participating in the study and having their bodies digest the food while in the study.

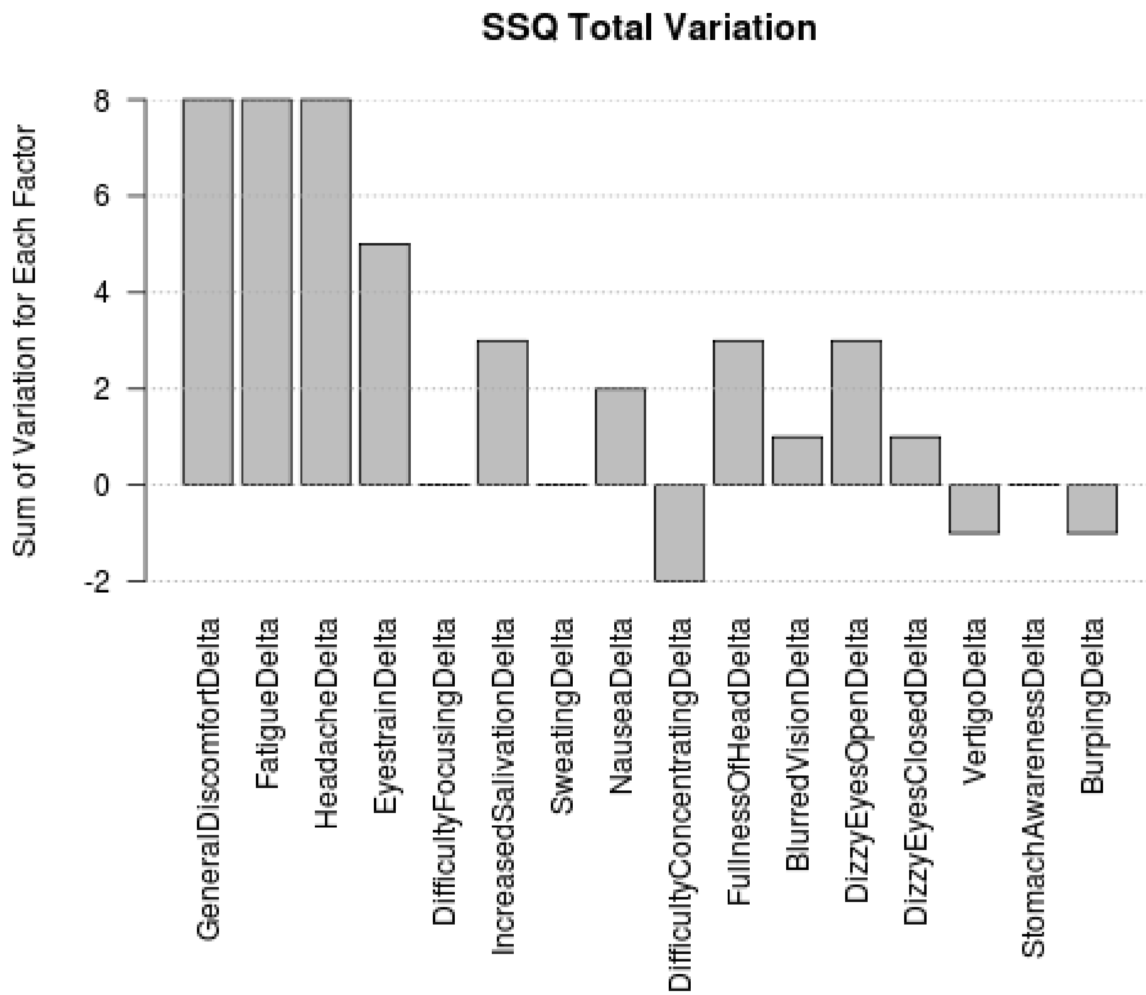


Figure 3.42: Variation in health factors between before and after the experiment.

3.5.7.10. Subjects' Comments

Subject comments reflect in part the analysis already presented in previous sections. They also help us explain some of the results obtained. Notice that comments that were too generic were not categorized and are listed in black in section D.2.10.

Overall, people enjoyed the enhancements on the interface and most of the time reported it to be easy to learn but hard to master, especially for the feedback coming from senses other than vision. In terms of problems operating the robot, it is clear from Figure 3.43 below that delay and movement friction were the main causes of frustration during the experiment. Despite our efforts to minimize both of these, they were still present and were the leading cause of problems with moving the robot around the environment. In addition, the motor batteries discharged over time during each session. Because of that the sensitivity of the robot controls also changed over time and subjects had to adapt to that in order to properly navigate the environment. Some subjects also commented on the robot-turning movement to favor one-side over the other. Despite our efforts to calibrate the motors and mitigate this problem, it still occurred.

There were also complaints related to subjects losing their sense of orientation when either the robot or the camera turned too fast. This problem generally happened either when the camera was reset to point forward or when the robot turned more than what was desired.

Other complaints about the camera referred to the small size of the camera panel. Additionally, in some sessions, due to a physical collision or software error, the robot had to be restarted. This restarting problem happenend with about 20% of the subjects and it was done 2 to 5 time per subject. The robot would be left in plece while restarted, after 2 to 10 minutes, the experiment would continue from the point where it stopped. A few subjects commented on how that prevented them from efficiently accomplishing their task.

If the robot could not recover from the crash, the entire system was restarted. In this case, the study was aborted for that subject and its data was discarded.

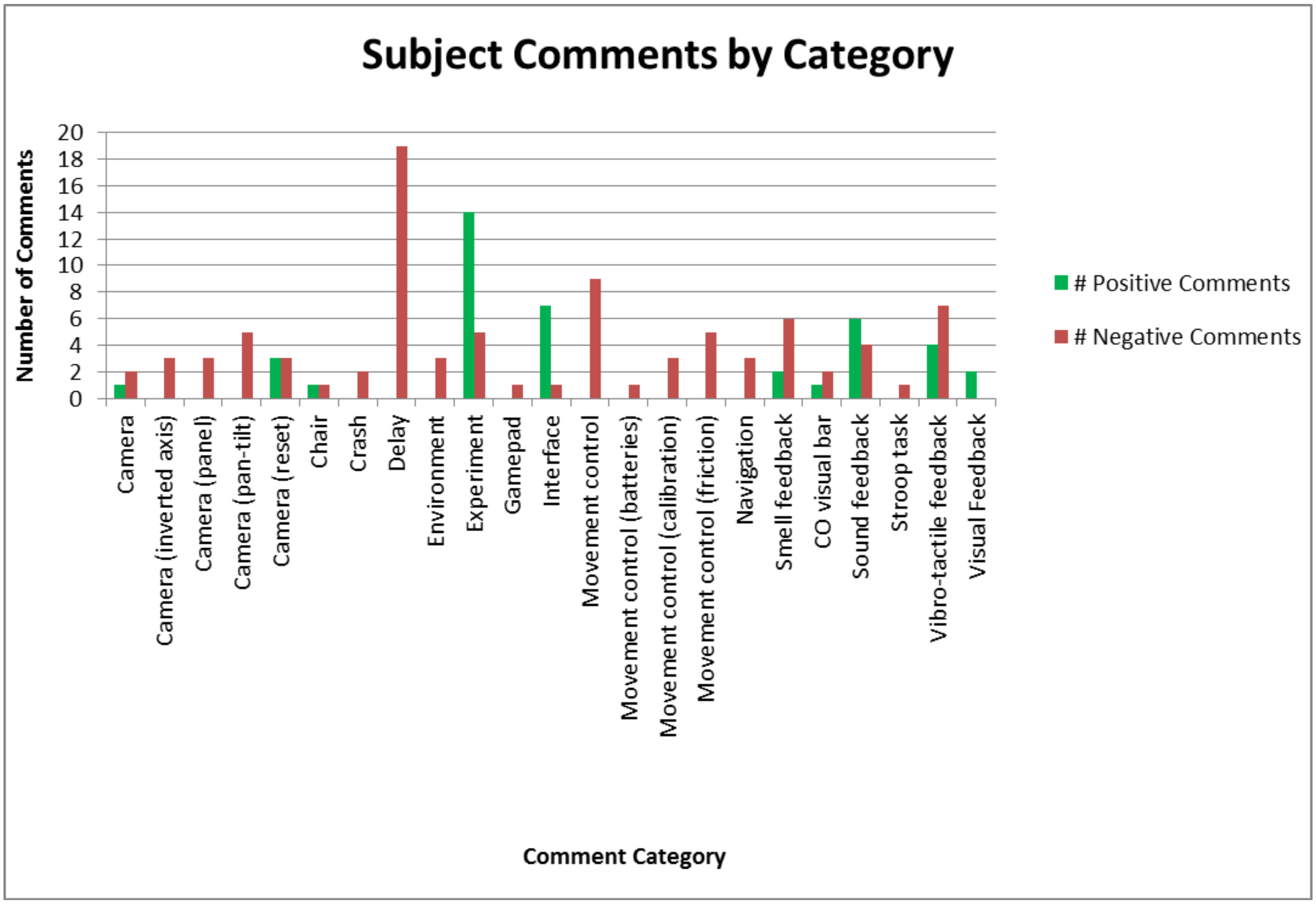


Figure 3.43: Subjects comments organized by category and divided into positive and negative ones.

The type of feedback with most positive comments was the sound feedback, followed by vibro-tactile, visual and smell feedback. If we sort the types of feedback by the ratio *FR* defined in Equation 3.2, then visual feedback (*FR = 1.0*) comes first, followed by sound feedback (*FR* = 0.6), vibro-tactile feedback (*FR = 0.364*) and finally by smell feedback (*FR =0.25*).

FR = (positive comments - negative comments)/ (positive comments + negative comments)

Equation 3.2: Feedback score for an interface based on its number of positive and negative comments made in study #4.

Few comments were really associated with the visual feedback enhancements as can be seen from the first an last columns in Figure 3.43.

For the sound feedback, both the sound of collisions and motor were deemed relevant. However, the latter had more negative comments than the former. These negative comments referred to the delay between the speed sound and the movement of the robot caused by video transmission delay and wheel friction with the floor carpet.

For the vibro-tactile belt, even though subjects commented it was helpful in estimating distance to objects around robots, the interface became annoying when the subject was already aware of the object being reported by the interface. In addition, after prolonged use, subjects commented on having the area of the skin where the belt vibrated become itchy. Because of the constant and sometimes unnecessary feedback by the belt, one suggestion made was to use the belt merely as a collision feedback interface instead of a CPF one.

For the smell feedback, it seemed that the smell indeed could help subjects. However, most complaints related to subjects being unable to detect the smell at all, even when the CO bar was reporting high values of CO in the air. A cause for that could have been that the fans used for air ventilation were too effective and dissipated the smell too quickly. In addition, the expectation that smell would be sensed as soon as the CO bar would go up could also have distracted subjects. This lack of smell feedback might have led subjects to focus their attention more on the smell device than on screen, which distracted the user from the primary and secondary tasks. This could be a possible explanation for the degradation in the Stroop measurements of response time and number of unanswered questions.

3.5.8. Discussion

This study has further explored how multi-sensory interfaces can be used to improve user performance in a USAR scenario. This time, a real robot was used and smell feedback was included in addition to the interfaces previously evaluated in study #3.

In terms of our hypotheses, we have seen that audio and vibro-tactile feedback led to an improvement in navigation performance during the task. This shows that the claims about the benefits of multi-sensory interface are still valid with a real robot. Notice that our pool of subjects per treatment (12 subjects) was smaller than in study #3 (18 subjects) but we were still able to capture similar patterns in the results, even though it was with little statistical significance. Therefore, S4H1 seems to be supported by our results, but a similar study with a larger population would be required to consolidate these results.

Interestingly, the improvements caused by the use of vibro-tactile feedback in this study were much smaller than the ones detected in study #3. Therefore, S4H4 could not be fully confirmed. We believe the reason for that was the fact that, in this study, subjects spent longer periods of time in each section of the environment dealing with navigation control problems than in study #3. In other words, they spent more time coping with overturns and moving too far due to delay and friction issues, problems that only occur in the operation of a real robot. During that time, subjects would already be aware of the surroundings and would be just adjusting their navigation controls. However, during the entire time, they would be continuously receiving feedback from the belt. The belt was on providing the same type of feedback for long periods of time. This might have led subjects to ignore the belt most of the time when it was vibrating for prolonged periods, even if the robot was really close to objects.

Because in study #3 the friction and delay problems were not simulated and therefore did not exist, subjects had better navigation control over the robot. As a consequence the robot movement was more dynamic, that is, the robot would not stay for too long in a certain area of the environment, the belt would change state more frequently, be triggered for shorter periods of time, thus becoming less annoying, less ignored by subjects and a more useful navigation instrument. The lack of map blueprint could have been the cause for this difference in results.

Another justification for the decrease in improvement caused by the TactaBelt was the fact that the visual ring interface was now improved to differentiate collisions (ring dots would turn red) from collision proximity (dots would assume shades of yellow). Such an improvement might have made the ring a more useful interface than the belt, and led users to lean more towards its use to the detriment of the belt. However, none of the subjects' comments supported this explanation.

Additionally, during the experiment, it was noticed after the fact that for a few subjects two of the belt tactors had their positions accidentally swapped in the belt. This might have affected their responses for this interface for some subjects and added noise to this interface results.

We believe that, had we used a robotic platform that provided more fluid navigation to the operator, and collected data from a larger pool of subjects, the results obtained from study #3 would be likely reproduced with a real robot with increased fidelity. Nevertheless, this difference in results shows that it is important to implement in HRI simulation all the issues related to a real HRI scenario in detail. The design of an interface using a simulation that is inconsistent with the real world scenario may lead to interface designs that are not applicable to the real world. In the case of the vibro-tactile feedback, however, we believe that with proper recalibration and an improved robotic platform, such feedback could still lead to improved navigation.

Regarding S4H2, the sense of smell did lead to an improvement in the number of circles found. Nevertheless, this does not mean that a multi-sensory interface with four senses (such as Interface 4) is always necessarily more effective than a multi-sensory interface without smell feedback (such as Interface 3). It could mean that the current design of the CO visual bar was unable to convey information as effectively as the smell feedback. However, perhaps a better visual bar design would be as effective as the smell feedback provided. For example, one could attach the CO bar to the video panel or the robot, so that it would now be closer to the user's main focus area. This would make it more likely that he would notice changes in the level of this visual bar. The lateral design used in this study was the one found to be currently used in other USAR interfaces (Yanco et al., 2007), but it is not necessarily the optimal one. Having the bar show up only when a certain CO threshold is reached or have it blink or become highlighted to call the user's attention when that happened could also have improved its effectiveness.

The important point to take away from the increase in the number of circles found due to the smell feedback is that the use of smell feedback helped further maximize the user's omni-directional awareness of the remote environment. This means that the redundant feedback was not distracting, but supplementary to the CO visual bar and therefore useful. This goes in hand with claim CL1 described in section 3.4.8.

With respect to S4H3, we have also obtained improvements in the quality of the sketchmaps for the smell interface. However, similar improvements were detected for interface 2 due to the addition of audio and interface 3, although the latter with more data variation and therefore no SSD.

Hence, the improvements in the quality of the maps are not caused merely by physiological effects due to the dispersion of the smell of rosemary around the user. There must be another factor that is causing such an improvement. We believe that the use of redundant feedback through other senses is leading subjects to offload part of the cognitive demand of the visual interface related to navigating the robot and monitoring controls to other senses. However, this transference only happens when these types of feedback are indeed readable and useful. This cognitive offload frees up some of the subjects' visual cognition resources that can now be reallocated into paying better attention to the video stream and the surrounding environment. This effect is visually perceptible in the graphs for effort and performance workload (Figure 3.40), where a decrease in workload occurs, especially for Interface 3.

Therefore, in terms of S4H3, to say that the addition of smell feedback improved map quality is a valid claim. However, the reason behind it was not only the use of the physiological effects of rosemary on subjects in the case of Interface 4, but also the effect a redundant multi-sensory interface has on user workload as in the case of Interface 2 and 3.

3.5.9. Conclusions

The results obtained in this study have confirmed the results obtained in previous studies despite the problems with transitioning to a real robotic platform. Most of the improvements caused by the use of multi-sensory interfaces in a simulated USAR task environment in previous studies were also present in a real-world USAR environment. We have seen that the use of audio and vibro-tactile feedback led to similar improvements in navigation performance, although this occurred to a lesser degree due to the small sample size and the navigation issues involved in a real robot application. These issues led to larger degradations in performance related to vibro-tactile feedback than for the audio feedback.

In addition to that, we have also shown that increasing the number of senses to distribute data display could further enhance robot operator performance. In this study, we have added the sense of smell to enhance the user's search for red circles compared to using only visual feedback. We have shown that the visual feedback provided (CO sensor bar), although helpful in finding the spheres, was not optimal. The addition of the smell feedback for redundant CO level display covered any deficiencies of the visual feedback with minimal effects on workload. This led to improvements in search performance measured as an increase in the number of circles found by subjects.

Problems using the smell feedback interface were also found nevertheless. The ventilation system for the smell devices needs to be enhanced so that the correct smell can be more accurately displayed to the user's nose. This might involve the utilization of a completely different approach to smell display, such as the smell projecting cannon (Yanagida et al., 2004), smell transmission tubes (Yamada et al., 2006), or simply the adjustment of the refresh rate of air in the operator room. The novelty of the smell device led subjects to be distracted by the device itself. We believe that with a better display system and more extensive subject training, both of these problems could be easily resolved.

Using the results from this and previous studies we can now restate claim CL1 in section 3.4.8 as follows:

CL2: Redundant data displays, through one or multiple-senses, are only beneficial to the user of an interactive system if they help further enhance the user's omni-directional perception and understanding of the data that is relevant to the task at hand.

Please, notice that redundancy in *CL2* refers to the simultaneous presentation of the same data through different senses. Notice also that *CL2* is not saying that the display needs to be omni-directional from a physical point-of-view, but instead that it needs to improve the omni-directional perception and understanding of the user. Additionally, in some occasions, redundancy may be beneficial if different kinds of users exist. Some users may perform better with visual information while others do better with data displayed in tables or played as sound. Additionally, different ways of perceiving omni-directional data may be needed for different tasks and situations. In that case, versions of the interface displaying omni-directional information in different ways should be devised on a per-user or per-task basis. This idea will be further discussed in chapter 4 as future work.

We have seen two opposing examples in our studies that support *CL2*. In studies #3 and #1, the addition of the visual ring did not bring much enhancement to the user's omni-directional awareness and sometimes served as a visual distraction to users, hindering their performance. In this study, however, the use of smell feedback as a supplement to the visual CO sensor bar led to an increase in user awareness of CO data, and therefore an improvement in his omni-directional awareness of the circles nearby the robot, ultimately leading to an improvement in his task performance.

Moreover, the addition of sound feedback in this study has also led to improvements in navigation performance, despite the fact that similar data was also being displayed through the visual ring (red dots) and speedometer. This shows that redundancy of feedback has once again helped improve the user's perception and understanding of omni-directional robot-sensed data.

Furthermore, an increase in the quality of shetchmaps was detected for two of the three multi-sensory interfaces implemented. Additionally, different interfaces led to improvements in certain factors of the Stroop task. Some led to a lower number of unanswered questions (Interface 3) while others led to an improvement in the number of correct questions (Interface 4). A small decrease in response time was also noticed for some of these interfaces. Again, we believe that with the corrections to the smell projection device, improvements to the robotics platform and the use of a slightly larger and more specialized subject pool, the benefits of having multi-sensory interfaces would be even more evident.

This study has shown that the use of multi-sensory feedback can benefit the robot operator. This time, not only navigation performance benefits were detected, but also benefits in search performance. This means that the benefits associated with multi-sensory displays are not limited to navigation, or any other subtask for that matter, but can rather be extended to other activities as long as the display interface is designed well enough to make the user feel natural interaction with it.

The author believes that the methodology used in this study is solid enough to be reused in future multi-sensory interface studies. It has been able to measure subject health, workload, cognitive load, presence, situation awareness and task-related performance effects caused by the evaluated interfaces. It was a comprehensive set of measures that could be used as a starting point for future research in the area. Other bio-physical measures (Ikehara & Crosby, 2005), such as heart-rate and pupil dilation, could be added as a means to verify some of the results obtained by the other approaches described in this work.

One important point of future discussion related to the methodology employed here regards deciding which multi-sensory interface, among a set of experimentally pre-designed ones, is ultimately the best interface for performing a specifc task, based on the results obtained by the multiple experimental variables analyzed. In other words, each variable or factor must be weighted with a level of importance according to the task and other relevant factors. For example, depending on the risk level of a USAR task environment, having an interface with the lowest collision rate to avoid structural collapse as much as possible might become more important than having an interface with the highest victim-finding rate. After all, if there is a collapse, many victims might suffer, and even the robot might become incapable to further assist in the rescue. The weighing of these variables is a very important issue to be considered in future research on multi-sensory feedback interfaces.

The author belives that, at the end of the day, adjustable multi-sensory interfaces will be one of the tools to help resolve this issue. The operator will have a set of interface configuration profiles, each of which can be used during a certain task or situation. In fact, different operators may have different profiles for the same situation, depending on their skill set and physiological sensibility. Some people are more aural than others and prefer audio feedback configurations, while others might be more smell-sensitive and be very effective in using olfactory interfaces.

Not only the user's skill set, but also the task, the HRI system in use, the environment the robot is immersed in, and the benefits of each available feedback interface should be among the defining factors in choosing the right interface configuration. For that to be possible, however, researchers still need to have a much better understanding of how to employ the naturalness with which humans use their senses when performing daily tasks and apply such knowledge to the design of multi-sensory interfaces.

Despite the results achieved by this study, there is still much to be explored in the area of multi-sensory interfaces. We need to enhance our smell display system, as well as better fine-tune the TactaBelt so that it becomes less distracting on a real-world robot scenario. Additionally, it would be interesting to measure the individual benefits of adding each of the extra sound, touch and smell types of feedback instead of measuring their accumulated effect. This will enable us to evaluate the differences in performance between the case when each of them is used by itself with the help of visuals only in a bi-sensory interface, and the case when they are integrated together with multiple types of feedback not coming from visuals. In other words, it would enable the detection of how feedback provided by each sense interferes or interacts with the others. These individual effects have already partially been measured for visual + touch as treatment 2 of study #3 and visual + audio as treatment 2 in study #4. The conjunction effects have also been measured in studies #3 and #4. However, many combinations are still to be explored. For example, no interface with audio and smell only has yet been tested.

In conclusion, we have seen that indeed multi-sensory interfaces contribute to the enhancement of user performance. This verification was done in the context of USAR robotics. But we believe that similar interfaces could also bring benefits to other types of interactive robotic and non-robotic systems. More general conclusions on this topic will be presented in chapter 4 where a summary of the findings for all the four studies is presented.

4. Conclusions

The work presented here explored different types of multi-sensory feedback interfaces, their effect on a robot operator, and the performance in an urban search-and-rescue (USAR) task. Three studies involved a simulated robot and environment, but were followed by a study with a real robot and environment for validation of the results.

This work started by reviewing the related work in the areas of HRI, HCI, VR and 3DUI, the current techniques used for approaching USAR interface issues and the areas where more research work still needs to be done. We then described a set of four studies involving multi-sensory interfaces in the context of USAR robot teleoperation.

In study #1, a comparison between visual, vibro-tactile and both types of feedback was presented. The type of feedback displayed was robot collision proximity feedback (CPF). Results indicated that the combined use of both types of feedback improved the operator global awareness. One type of feedback seemed to supplement the other's deficiencies. When put together, they helped the robot operator acquire a better understanding of the remote environment surrounding the robot. This study has shown that a sub-optimally designed visual interface can leverage from other types of feedback with redundant data to enhance the robot operator perception and task performance.

In study #2, a comparison was made between two types of vibro-tactile CPF interfaces and a control case where no direct CPF interface data was given. The results showed significant improvements when either the Intensity or Frequency vibro-tactile feedback interfaces were used. Users' preference leaned towards the Intensity interface. This study showed that performance can indeed be improved by using vibro-tactile CPF feedback even if such interface is not optimally designed. It also showed that care must be taken when selecting how information should be displayed, so that the novel interface does not add a high cognitive burden to the operator.

Study #3 attempted to evaluate how complex multi-sensory interfaces can become before they cognitively overwhelm the robot operator. The best-rated, bi-sensory feedback interface from study #2 (Intensity) was used as a control case. It was compared against a second interface which consisted of the Intensity interface enhanced with audio feedback for collisions and robot speed. These two interfaces were also compared against a third interface which consisted of the second audio-enhanced interface with the addition of redundant visual feedback for robot collision and speed. Results showed that adding audio feedback still enhanced operator performance in terms of number of collisions. However, adding the visual redundant feedback did not improve performance. In fact, some subjects reported that the extra visual feedback was distracting or annoying. This study showed that it is possible to design multi-sensory interfaces for three senses and further improve operator performance as long as there is balance of the data distribution among the senses. It also showed that redundant feedback is not always beneficial to the robot operator.

Study #4 used a real robot and added smell feedback to extend the multi-sensory interfaces in study #3. The real robot helped validate the simulated results from previous experiments while the smell feedback further explored the idea of how complex multi-sensory feedback interfaces can become and still be usable and useful. In this study, a visual-only interface was compared to multi-sensory interfaces with different levels of complexity: audio-visual, audio-visual-tactile, and audio-visual-tactile-olfactory interfaces.

Despite differences in the simulated versus real robot experimental scenarios and the small subject pool considered, results still showed performance enhancements as multi-sensory interfaces were gradually added. In addition, it has shown that the benefits of using multi-sensory feedback interfaces are not restricted to specific functionalities of the interface, such as providing collision proximity feedback. In this study, multi-sensory interfaces were used to enhance both navigation and search tasks. Last, since all the data was already displayed visually in the experimental control-case, this study also showed, by the use of redundant feedback through smell, that multi-sensory interfaces can be used to provide redundant feedback to supplement suboptimal visual data display, and to enhance the robot operator's perception and performance.

This work has also been able to measure the isolated benefits of adding a specific type of sensory feedback to the interface for at least two of the senses for our experimental scenario. Study #1 showed the benefit of adding vibration when redundant visual feedback was present. The benefits of adding vibration without redundant visual feedback was shown in study #2. In study #4 we have shown the same effect with redundant visual feedback for audio, since audio was the first interface added to the control case. In study #3, we have shown that even without the visually redundant feedback, the audio feedback also brought benefits. Because the smell feedback was added last in the study #4, however, its isolated impact could not be measured.

Through these studies, this work was able to verify how beneficial multi-sensory interfaces can be to a user, specifically to a robot operator. It has also been able to show that, if well designed, even multi-sensory interfaces involving four of the human senses could be used to improve performance with minor effects on cognitive load. Overall, our empirical evidence shows that multi-sensory redundant interfaces are beneficial to the user only if they allow the enhancement of the users' omni-directional perception and understanding of task-relevant data. Last, by the end of study #4, we have built a comprehensive methodology to evaluate multi-sensory interfaces. The author believes that these contributions should provide further guidance to the HRI and USAR research communities, but also other interface research communities in designing more user-friendly robot interfaces.

As a last contribution, we have introduced the concept of omni-directional user perception. The idea of omni-directionality has been explored in robotic locomotion (Rojas & Föster, 2006; West, 2013) and also robotic vision (Nieuwenhuisen et al., 2013). Even though omni-directional vision has even been extended to encompass multiple robot sensors, such as laser range finders and video cameras (Gaspar et al., 2007), it has never been extended to non-visual-geometrical types of environmental data. More importantly, the notion of omni-directionality is often associated with machine vision only, and it has never been extended to involve multiple senses or sensors that are not part of the robot AI perception system. In this work we have extended the notion of omni-directional perception to the final system user. Defining this notion is only possible because user sensing is no longer restricted by the pixel area on a computer screen. With multi-sensory interfaces, feedback can now come from any direction and through any sense, mimicking as naturally as the user desires the data generated or sensed by a machine or system. This concept was introduced as a measure that represents the effectiveness of multi-sensory interfaces. Variations It was indirectly investi

Overall, the results from this work point to the conclusion that, when properly designed, multi-sensory interfaces can encompass multiple senses and be used as complementary or supplementary feedback interfaces to enhance the user perception and understanding of relevant data. At some point, however, the excessive use of multi-sensory feedback must lead to the user's cognitive overload. Nonetheless, this point has not been reached during the use of the interfaces associated with the studies presented in this work.

Another important comment to make is that it is known that some people are more kinesthetic while others are more sensitive to sound or visuals. Because of that fact, it would be useful to have multi-sensory interfaces to users in order to reduce their cognitive load based on their preferred subjective perception channels. As mentioned, the user should be able to either disable or re-channel flow of specific data from one type of feedback interface to another, constantly adapting the interface to his or her current needs. When doing so, nonetheless, it is important to also elauate how much the switch time between interface configurations impacts task performance.

Another way to reduce such load is by splitting tasks among users. For example, in the USAR scenario explored here, it is common to have a robot operator and a supervisor for an individual robotic unit. The multi-sensory interface could be respectively split into navigation and search multi-sensory interfaces for these users to reduce load and distraction by task-irrelevant data for each user.

A logical extension of this work is the further exploration of more complex multi-sensory interfaces in USAR robotics. This work could also be extended to other areas of mission robotics, such as space exploration and HAZMAT operations. They could also be applied to interfaces for other types of automated and controlled machines and systems such as military drones, jet pilots, and submarines. Furthermore, it could be extended to any type of interface that demands high cognitive load from a user and that could have its data mapped to other senses. Obviously, and realistically, many interfaces are better off as simply being mono-sensory. Over-selling multi-sensory feedback would be a grave mistake.

Another important area of future work is enabling the user to configure multi-sensory feedback to match his personal needs. A toolkit could be devised where the user would have a set of sensor data channels. Filters and data modifiers could be applied to each of these channels, and then be mapped to the available multi-sensory feedback interface displays. The toolkit would also allow the user or an HCI expert to bookmark interface feedback configurations that are associated with specific tasks or user strengths and abilities. The user can then retrieve each of these configuration when necessary.

This concept of multi-sensory customizable channels could also be applied to system input. Multisensory input is still in its infancy. The ideal input interface would not only allow the user to use his limbs to interact with the computerized system, but also use body gestures, voice, and even facial expressions. Again, the same toolkit mentioned above would also allow the user to apply functions and filters to the input channel and customize the user control of the system. In fact, input channels could be directly mapped to output channels so that the user could receive direct feedback from his actions and more accurately perform input.

Multi-sensory interfaces are still realtively unexplored. Through the use of the scientific method, this work contributed by pointing in directions that might bear fruit. The author hopes that the HRI and HCI research communities will make good use of these initial directions to facilitate their search for more effective human-machine interfaces.

Glossary

This section contains a list of terms commonly used in the HRI area that may be unfamiliar to the reader. They are defined in the HRI context, although some may also assume a broader meaning.

Abstraction: in robot autonomy, abstraction consists of varying the autonomy complexity or abstraction level of the task to be performed. For example, a task called moveToPoint (x,y) would have a lower level of abstraction than a task collectObjectsNearby().

Accident: a serious event that may have led to hazard to the HRI system, to the people involved with it or to the environment with which it interacted. It is generally caused by a consequence of the occurrence of a series of errors or incidents during the operation of such HRI system (Parasuraman et al., 2008; DW04; DW02).

Affordance: is the concept of how an interface allows the user to interact with it. Affordable interfaces allow the user to understand the affordances, that is, what they allow the user to do with them, just by having the user look at (touch, listen to, smell) them.

Aggregation: in robot autonomy, aggregation defines the magnitude of the number of robotic agents to which a particular task is assigned. For example, a task done by a single robot has a lower level of aggregation than a task delegated to a team of robots.

Automation: in the context of human-machine interaction (HMI), it can be defined as "a device or system that accomplishes (partially or fully) a function that has previously been, or conceivably could be, carried out (partially or fully) by a human *operator*" (Parasuraman et al., 2000).

Bots: a robot whose existence is limited to a software *application* or a virtual world.

Choice: the ability of choosing among known available options.

Coalition: a team of robots that works with a certain *objective* in common (Adams, 2005).

Cognitive load or overhead: originally defined as a Web-related term (Conklin, 1987), it can be defined in HRI as the extra effort and concentration required from the user to perform a task using an HRI system interface when compared to the same task being performed using a default system interface.

Complacency: Relying on the fact that a (sub)system will keep behaving the same way it has been during the previous operator system checks, the operator reduces the *state* monitoring rate for such a (sub)system to a lower rate generally below optimal, which may lead to the missing of important events in the state of the (sub)system. Complacency is generally associated as being a consequence of overreliance (Parasuraman et al., 2008) (Moray, 2003).

Compliance: is taking the correct action without hesitation in response to an event or request from the system. Compliance is generally associated with the operator and not with the robot part of an HRI system (Sheridan & Parasuraman, 2006).

Degrees-of-freedom: In HRI and automation, it is the minimum number of variables that must be sampled in order to effectively assume a function or role in a system, that is, the amount of information necessary in order for the system to be of some purpose. However, a system with *N* degrees-of-freedom could also perform tasks that require less than the available *N* such degrees.

The concept can also be associated with the total number of different spatial displacements and rotations in different axes that all robot joints have together.

Similarly to the previous concept, in Virtual Reality and 3D User Interaction, it is the number of different spatial displacements and rotations in different axes that an object can assume or that an input device can provide that data for.

Display device: any device that provides the user with sensorial feedback for any of the five senses, not just for vision.

Encoders: encoders consist of sensors that detect variations of either transparency or electrical-conductivity around a disk. As the disk turns, the count of alternating detection and non-detection of signals is used to discretely determine the amount of rotation of the disk itself. They are used in robot wheels to help estimate robot speed, position and orientation. The sensors could be optical or electrical sensors depending on the purpose of the encoder.

Error (Machine or Human): a software or hardware fault or a human mistake.

Eutactic behavior: this is an intermediate and optimal behavior between complacency and skepticism. It happens when the user monitors the *HRI* system just as frequently as necessary to guarantee optimal performance (Moray, 2003).

Fan out: the number of robots being controlled or monitored *by* an operator.

Feasibility: "The projected plan's ability to achieve the declared goal state within resource limitations" (Miller & Parasuraman, 2007).

Flow: from an interface standpoint, flow is a mind-body state where there is a continuous stream of complex interactions through a device, where the device interface becomes transparent to its user, and the conscious mind is free to concentrate on higher goals and feelings rather than the stream of control actions needed to operate the device. For example, a virtuoso musician experiences flow while playing his instrument. Playing it becomes as natural as using his own body and does not distract him from expressing the necessary emotions through music.

General Knowledge: long term memory for facts, procedures or *mental* models.

Human-computer Interaction: the area of Computer Science that deals with improving computer interfaces to facilitate interactions between humans and computers.

Human-robot ratio: the ratio between the number *H* of humans over the number *R* of robots in and HRI system (Yanco & Drury, 2002; Yanco & Drury, 2004).

Interaction time: the amount of time spent by the operator in assisting each robot.

Incident: an unexpected event that may have led to a problem in the completion or performance of a task.

Neglection: the measure of lack of attention a robot receives from an operator.

Out-of-the-loop: refers to activities or decisions in a system in which operator or humans in general are not involved.

Overreliance: the act of putting more trust into the hardware / software part of an HRI system than one actually should.

Performance: how good the results are of a user or system during a task. Parameters used for measuring performance may drastically vary from one HRI system to another. A common parameter is task-completion time;

Proprioception: The sense of knowing your current body pose and the forces applied to it (*e.g.*, knowing where your limbs are without looking at them);

Reliance: it consists of how reliable the HRI system is in terms of status and alert reporting. If the operator cannot rely on the tools used for monitoring a system, (s)he cannot operate the system in an optimal manner (Sheridan & Parasuraman, 2006).

Risk: In HRI, it is generally related to an activity or performance of a system. It is a subjective estimate of the negative impact caused by a problem or failure of that specific system. It can be defined as the cost of an error times the probability of occurrence of that error (Parasuraman et al., 2008).

Robustness: quality attributed to systems that can still operate despite abnormal internal (e.g., algorithmic errors) or external (e.g., unexpected input values) behavior.

Skepticism: is the opposite of complacency. In this case the user spends more time monitoring the system or monitors it more frequently than it is necessary to obtain optimal performance (Moray, 2003).

Switch time: the amount of time it takes for an operator to switch from monitoring and controlling one robot to another.

Synoptic: in the context of HCI interfaces and human cognition, it identifies the capacity of a human sense to come up with a broad view of multiple data points that are presented simultaneously.

Task capacity: defines the amount of work per time unit that a system or operator can handle.

Transparency: is a quality generally attributed to the interface of a system. A transparent interface allows its user to interact with the system without hinderance, hence the idea of transparency. The idea is that the user should interact "through the interface and not with the interface". This concept is also associated with the concept of *direct manipulation*, whereby a user can manipulate objects on the interface in loosely the same way physical objects are manipulated in the real world.

Bibliography

Adams, 2005 — Adams, J.A. "Human-Robot Interaction Design: Understanding User Needs and Requirements," *Proc. of the 2005 Human Factors and Ergonomics Soc. 49th Annu. Meeting*, Orlando, FL, 2005.

Adams, 2006 — Adams, J.A. "Supporting Human Supervision on Multiple Robots," J. of the Robotics Society of Japan, vol.24, no. 5, pages 579-581, 2006.

Adams et al., 2009 — Adams, J.A., Humphrey, C.M., Goodrich, M.A., Cooper, J.L., and Morse, B.S. "Cognitive Task Analysis for Developing Unmanned Aerial Vehicle Wilderness Search Support", vol. *3*, *no.* 1, pp. 1–26, 2009.

Adams & Skubic, 2005 — Adams, J.A. and Skubic, M. "Introduction to the Special Issue on Human-Robotic Interaction," *IEEE Trans. on Systems, Man and Cybernetics (SMC)*, part A, Special Issue on Human-Robotic Interaction, vol. 12, issue 2, pp. 27-30, Mar.-Apr. 2005.

Atherton *et al.*, 2006 — Atherton, J.A., Hardin, B. and Goodrich, M.A. "Coordinating a Multi-Agent Team Using a Mulitple Perspective Interface Paradigm," *Proc. of the AAAI 2006 Spring Symp.: To Boldly Go Where No Human-Robot Team Has Gone Before,* Stanford University, California, pp. 47-51, 2006.

Aubrey *et al.*, 2008 — Aubrey, A.D., Chalmers, J.H., Bada, J.L., Grunthaner, F.J., Amashukeli, X., Willis, P., Skelley, A.M., Mathies, R.A., Quinn, R.C., Zent, A.P., Ehrenfreund, P., Amundson, R., Glavin, D.P., Botta, O., Barron, L., Blaney, D.L., Clark, B.C., Coleman, M., Hoffmann, B.A., Josset, J-L., Rettberg, P., Ride, S., Robert, R., Sephton, M.A. and Yen, A. "The Urey Instrument: An Advanced In Situ Organic and Oxidant Detector for Mars Exploration," *Astrobiology*, vol. *8*, pp. 583-595, 2008.

Barrass, 2005 — Barrass, S. "A Perceptual Framework for the Auditory Display of Scientific Data," *ACM Trans. on Applied Perception* vol. 2, no. 4, pp. 389-402, 2005.

Berkelman & Ma, 2009 — Berkelman, P. and Ma, J., "A Compact Modular Teleoperated Robotic System for Laparosocpic Surgery," *The Intl. J. of Robotics Research*, vol. 28, pp. 1198-1215, Sept. 2009.

Bien & Lee, 2007 — Bien, Z.Z. and Lee, H.-E. “Effective learning system techniques for human-robot interaction in service environment,” *Knowledge-Based Systems*, vol. 20, no. 5, pp. 439-456, Jun. 2007.

Billinghurst & Weghorst, 1995 — Billinghurst, M. and Weghorst, S. “The use of sketch maps to measure cognitive maps of virtual environments,” *Virtual Reality Annu. Int. Symp.*, pp. 40-47, 1995.

Blom & Beckhaus, 2010 — Blom, K.J. and Beckhaus, S. “Virtual collision notification,” *Proc. of IEEE Symp. on 3D User Interfaces (3DUI)*, pp. 35-38, 2010.

Bloomfield & Badler, 2007 — Bloomfield, A. and Badler, N. “Collision awareness using vibrotactile arrays,” *Proc. of the IEEE Virtual Reality Conf.*, pp. 163–170, 2007.

Bowman et al., 2005 — Bowman, D., Kruijff, E., LaViola Jr., J. and Poupyrev, I. *3D User Interfaces: Theory and Practice*, parts 2 and 3, pp. 27-310, Addison-Wesley, Boston, 2005, ISBN: 0-201-75867-9.

Brazil, 2009 — Brazil, E. “A Review of Methods and Frameworks for Sonic Interaction Design: Exploring Existing Approaches,” CMMR/ICAD – LNCS, Copenhagen, 2009, pp. 41-67, 2009.

Burke et al., 2004 — Burke, J.L., Murphy, R.R., Rogers, E., Lumelsky, V.J. and Scholtz, J. “Final report for the DARPA/NSF interdisciplinary study on human-robot interaction,” *IEEE Trans. on Systems, Man, and Cybernetics (SMC)*, Part C: Applications and Reviews, vol. 34, issue 2, pp. 103-112, 2004.

Burke et al., 2006 — Burke, J.L., Prewett, M.S., Gray, A.A., Yang, L., Stilson, F.R.B., Coovert, M.D., Elliot, L.R., and Redden, E. “Comparing the effects of visual-auditory and visual-tactile feedback on user performance: a meta-analysis,” *Proc. of the 8th Int. Conf. on Multimodal Interfaces*. ACM, New York, NY, pp. 108–117, 2006.

Burns et al., 2005 — Burns, E., Panter, A. T., McCallus, M. R., and Brooks, F. P. “The Hand is Slower than the Eye: A Quantitative Exploration of Visual Dominance over Proprioception,” *Proc. of the 2005 IEEE Conf. 2005 on Virtual Reality*, Washington, DC, Mar. 12-16, pp. 3-10, 2005.

C4 Game Engine, 2012. C4 Game Engine, *Terathon Software*, 2012, URL: www.terathon.com. Last visited: 4/12/2014.

Calhoun et al., 2003 Calhoun, G., Draper, M., Ruff, H., Fontejon, J. and Guilfoos, B. "Evaluation of Tactile Alerts for Control Station Operation," *Proc. of the Human Factors and Ergonomics Soc. (HFES) 47th Annu. Meeting*, Santa Monica, CA, USA, pp. 2118-2122, 2003.

Casper & Murphy, 2002 Casper, J. and Murphy, R. "Workflow study on human-robot interaction in USAR," *Proc. of the IEEE Int. Conf. on Robotics and Automation (ICRA)*, vol. 2, pp. 1997-2003, 2002.

Casper et al., 2000 Casper, J., Murphy, R. and Micire, M. "Issues in intelligent robots for search and rescue," *SPIE Ground Vehicle Technology II*, Orlando, Florida, vol. 4024, pp. 292-302, 2000.

Calefato et al., 2008 Calefato, C., Montanari, R. and Tesauri, F. "The Adaptive Automation Design," *Human Computer Interaction: New Developments*, Kikuo Asai, 2008, ISBN: 978-953-7619-14-5.

Chen *et al.*, 2006 Chen, J.Y.C., Haas, E.C., Pillalamarri, K. and Jacobson, C.N. "Human-Robot Interface: Issues in Operator Performance, Interface Design, and Technologies," *Army Research Labs Technical Report: ARL-TR-3834*, U.S. Army Research Laboratory, Human Research and Engineering Directorate, Aberdeen Proving Ground, MD 21005-5425, USA, 2006.

Conklin, 1987 Conklin, J. "Hypertext: An Introduction and Survey," *IEEE Computer*, vol. 20, no. 9, pp. 17-41, 1987.

Cooper & Goodrich, 2008 Cooper, J. and Goodrich, M. A. "Towards Combining UAV and Sensor Operator Roles in UAV-Enabled Visual Search," *Proc. of ACM/IEEE Int. Conf. on Human-Robot Interaction*, Amsterdam, The Netherlands, Mar. 2008, pp. 351-358.

Correa et al., 2010 Correa, A., Walter, M.R., Fletcher, L., Glass, J., Teller, S. and Davis, R. "Multimodal Interaction with an Autonomous Forklift," *Proc. of HRI,* pp. 243-250, 2010.

CRA, 2003 CRA. "Grand Research Challenges in Information Systems", *Computing Research Association*, Washington, DC, 2003.

Crandall & Cummings, 2007 — Crandall, J.W. and Cummings, M.L. “Developing performance metrics for the supervisory control of multiple robots,” *Proc. of the ACM/IEEE Int. Conf. on Human-robot Interaction*, Arlington, VA, USA, pp. 33-40, 2007.

Crandall & Goodrich, 2002 — Crandall, J. and Goodrich, M.A. “Principles of adjustable interactions,” in *Human-Robot Interaction*, 2002 AAAI Fall Symp., AAAI Press, pp. 29-38, 2002.

Cassinelli et al., 2006 — Cassinelli, A., Reynolds, C., and Ishikawa, M. “Augmenting spatial awareness with haptic radar,” *10th Int. Symp. on Wearable Computers (ISWC)*, Montreux, Switzerland, pp. 61-64, 2006.

Dautenhahn, 2007 — Dautenhahn, K. “Methodology & Themes of Human-Robot Interaction: A Growing Research Field,” *Int. J. of Advanced Robotic Systems*, Special Issue on Human-Robot Interaction, vol.4, pp. 103-108, Mar. 2007, ISSN: 1729-8806-4114.

de Barros & Lindeman, 2012 — de Barros, P.G. and Lindeman, R.W. “Poster: Comparing Vibro-tactile Feedback Modes for Collision Proximity Feedback in USAR Virtual Robot Teleoperation,” *Proc. of IEEE Symp. on 3D User Interfaces (3DUI)*, pp. 137- 138, 2012.

de Barros & Lindeman, 2014 — de Barros, P.G., Lindeman, R.W. “Multi-sensory interfaces for Robot Teleoperation”, Research project Official website, WPI HIVE Lab, March 2014. URL: http://web.cs.wpi.edu/~gogo/hive/Teleoperation/. Last visited: 4/12/2014.

de Barros et al., 2009 — de Barros, P.G., Lindeman, R.W. and Ward, M.O. “A multi-sensorial HRI interface for teleoperated robots,” *Technical Report Series*, Computer Science Department, Worcester Polytechnic Institute, 2009.

de Barros et al., 2011 — de Barros, P.G., Lindeman, R.W. and Ward, M.O. “Enhancing robot teleoperator situation awareness and performance using vibro-tactile and graphical feedback,” *Proc. of IEEE Symp. on 3D User Interfaces (3DUI)*, pp. 47-54, 2011.

De Campo, 2007 — De Campo, A. “A Data Sonification Design Space Map,” Proc. of the 2nd Int. Workshop on Interactive Sonification, York, UK, pp. 1-4, Feb. 2007.

DeJong et al., 2006 DeJong, B.P., Faulring, E.L., Colgate, J.E., Peshkin, M.A., Kang, H., Park, Y.S. and Ewing, T.F. “Lessons Learned from a Novel Teleoperation Testbed,” *Industrial Robot*, vol. 33, no. 3, pp. 187- 193, 2006.

Dekker & Woods, 2002 Dekker, S.W.A. and Woods, D.D. “MABA-MABA or abracadabra? Progress on human automation coordination,” *Cognition, Technology, and Work*, vol. 4, pp. 240–244, 2002.

Dekker & Hollnagel, 2004 Dekker, S.W.A., and Hollnagel, E. “Human factors and folk models,” *Cognition, Technology and Work*, vol. 6, pp. 79–86, 2004.

Dell, 2013 Dell XPS 360i Manuals and Documents, URL: http://www.dell.com/support/Manuals/us/en/19/product/xps-630. Last visited: 4/12/2014.

Desai et al., 2013a Desai M., Kaniarasu P., Medvedev M., Steinfeld A. and Yanco H. “Impact of robot failures and feedback on real-time trust,” *Proc. of the 8th ACM/IEEE Int. Conf. on Human-Robot Interaction (HRI)*, IEEE Press, Piscataway, NJ, USA, pp. 251-258, 2013.

Desai et al., 2013b Desai M., Medvedev M., Vazquez M., McSheehy S., Gadea-Omelchenko S., Bruggeman C., Steinfeld A. and Yanco H. “Influence of Situation Awareness on Control Allocation for Remote Robots,” *IEEE Int. Conf. on Technologies for Practical Robot Applications (TePRA)*, Woburn, MA,USA, pp.1-6, 2013.

Dewhurst, 2010 Dewhurst, D. “Creating And Accessing Audiotactile Images With “Hfve” Vision Substitution Software,” *Interactive Sonification Workshop*, Stockholm, Sweden, pp. 101-104, 2010.

Difilippo & Pai, 2000 Difilippo, D. and Pai, D.K. “The AHI : An Audio And Haptic Interface For Contact Interactions,” *Proc. of ACM Symp. on User Interface Software and Technology (UIST)*, pp. 10, 2000.

Dury et al., 2003 Drury, J., Riek, L., Christiansen, A., Eyler-Walker, Z., Maggi, A. and Smith, D. "Evaluating Human-Robot Interaction in a Search-and-Rescue Context," *Performance Metrics for Intelligent Systems (PerMIS)*, 2003.

Drury et al., 2006a	Drury, J. L., Riek, L. and Rackliffe, N. “A Decomposition of UAV-Related Situation Awareness,” *Proc. of the First Annu. Conf. on Human-Robot Interaction*, Salt Lake City, UT, pp. 88-94, Mar. 2006.
Drury et al., 2006b	Drury, J.L., Yanco, H.A., Howell, W., Minten, B. and Casper, J. "Changing Shape: Improving Situation Awareness for a Polymorphic Robot," *Proc. of the 1st ACM SIGCHI/SIGART Conf. on Human-Robot Interaction (HRI)*, Salt Lake City, Utah, USA, Mar. 2-3, 2006.
Dubus & Bresin, 2011	Dubus, G. and Bresin, R. “Sonification of Physical Quantities Throughout History: A Meta-Study of Previous Mapping Strategies,” *Int. Conf. on Auditory Display*, Budapest, Hungary, 2011.
Eclipse, 2013	The Eclipse Foundation Open Source Comunity Website, URL: http://www.eclipse.org/. Last visited: 4/12/2014.
Edworthy & Hellier, 2000	Edworthy, J. and Hellier, E. “Auditory warnings in noisy environments,” *Noise & health*, vol. 2, no. 6, pp. 27-40, Jan. 2000.
Endsley & Garland, 2000	Endsley, M.R. and Garland, D. J. "Theoretical Underpinning of Situation Awareness: A Critical Review," *Situation Awareness Analysis and Measurement*, Lawrence Erlbaum Associates, Mahwah, NJ, 2000.
Endsley et al., 1998	Endsley, M.R., Selcon, S.J., Hardiman, T.D. and Croft, D.G. “A Comparative Evaluation of SAGAT and SART for Evaluations of Situation Awareness,” *Proc. of the Human Factors and Ergonomics Soc. (HFES) Annu. Meeting*, pp. 82-86, 1998.
Fallon, 2010	Fallon, E.F. “Allocation of Functions: Past, Present, and Future Perspectives,” *Int. Encyclopedia of Ergonomics and Human Factors*, W. Karwowski, 2nd ed., vol. 1, pp. 581-589, Dec. 2010.
Fontaine, 1992	Fontaine, G. “The Experience of a Sense of Presence in Intercultural and International Encounters,” *Presence: Teleoperators and Virtual Environments*, vol. 1, no. 4, pp. 482 – 490, 1992.
Freedman & Adams, 2007	Freedman, S.T. and Adams, J.A. "The inherent components of unmanned vehicle situation awareness," *Proc. of IEEE Int. Conf. on Systems, Man and Cybernetics (SMC)*, pp. 973-977, 2007.

Gaspar et al., 2007 Gaspar, J., Winters, N., Grossmann, E.and Santos-Victor, J. “Toward Robot Perception through Omnidirectional Vision,” *Studies in Computational Intelligence (SCI),* vol. 70, pp. 223–270, 2007.

Ghinea et al., 2011 Ghinea, G., Andres, F. Gulliver S. “Multiple Sensorial Media Advances and Applications: New Developments in Mulsemedia,” *IGI Global*, 2011, ISBN-13: 9781609608217.

Goodrich & Olsen, 2003 Goodrich, M.A. and Olsen, D.R. “Seven Principles of Efficient Human Robot Interaction,” *Proc. of the IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC)*, pp. 3943-3948, 2003.

Goodrich et al., 2001 Goodrich, M.A., Olsen, D., Crandall, J. and Palmer, T. “Experiments in adjustable autonomy,” *Proc. of IJCAI Workshop on Autonomy, Delegation and Control: Interacting with Intelligent Agents*, pp. 1624-1629, 2001.

Golledge, 2011 Golledge, R.G. “Reflections on Procedures for Learning Environments Without the Use of Sight,” *J. of Geography*, vol. 104, no. 3, pp. 37-41, 2011.

Goodrich & Schultz, 2007 Goodrich, M.A., and Schultz, A. C. “Human-Robot Interaction: A Survey”. *Foundations and Trends® in Human-Computer Interaction*, vol. 1, no. 3, pp. 203–275, 2007.

Goodrich et al., 2005 Goodrich, M.A., Quigley, M., and Cosenzo, K. “Task Switching and Multi-Robot Teams,” *Proc. of the Third Int. Multi-Robot Systems Workshop,* Washington, DC, pp. 14-16, Mar. 2005.

Gonot et al., 2007 Gonot, A., Natkin, S., Emerit, M. and Chateau, N. “The Roles of Spatial Auditory Perception and Cognition in the Accessibility of a Game Map with a First Person View,” *Int. J. of Intelligent Games & Simulation*, vol. 4, no. 2, pp. 23-39, 2007.

Griffin et al., 2005 Griffin, W.B., Provancher, W.R., and Cutkosky, M.R. “Feedback Strategies for Telemanipulation with Shared,” *Presence,* vol. 14 no. 6, pp. 720–731, 2005.

Gröhn et al., 2005	Gröhn, M., Lokki, T. and Takala, T. "Comparison of auditory, visual, and audiovisual navigation in a 3D space," *ACM Trans. Appl. Percept.*, vol. 2, no. 4, 564-570, Oct. 2005.
Größhauser & Hermann, 2010	Größhauser, T. and Hermann, T. "Wearable Multi-Modal Sensor System For Embedded Audio-Haptic Feedback," *Workshop on Interactive Sonification*, Stockholm, Sweden, pp. 75-79, 2010.
Gunther et al., 2004	Gunther, R., Kazman, R. and MacGregor, C. "Using 3D sound as a navigational aid in virtual environments," *Behaviour & Information Technology*, vol. 23, no. 6, pp. 435-446, Nov. 2004.
Gwizdka, 2010	Gwizdka, J. "Using Stroop Task to Assess Cognitive Load". *Proc. of the 28th Annu. European Conf. on Cognitive Ergonomics (ECCE),* pp. 4 , 2010.
Hart, 2006	Hart, S. G. "NASA-Task Load Index (NASA-TLX): 20 Years Later," *Proc. of the Human Factors and Ergonomics Society (HFES) 50th Annual Meeting*, pp. 904-908, 2006.
Hart & Staveland, 1988	Hart, S.G. and Staveland, L.E. "Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research," *Human Mental Workload*, North Holland Press, Amsterdam, 1988.
Hashimoto et al., 2006	Hashimoto, Y., Nagaya, N. and Kojima M. "Straw-like user interface: virtual experience of the sensation of drinking using a straw," *Proc. of the 2006 ACM SIGCHI Int. Conf. on Advances in Computer Entertainment Technology*, pp. 50, 2006.
Henry & Furness, 1993	Henry, D. and Furness, T. "Spatial Perception in Virtual Environments: Evaluating an Architectural Application," *IEEE Virtual Reality Ann. Int. Symp.*, Seattle, WA, USA, pp. 33–40, Sept. 1993.
Herbst & Stark, 2005	Herbst, I. and Stark, J. "Comparing force magnitudes by means of vibro-tactile, auditory and visual feedback," *IEEE Int. Workshop on Haptic Audio Visual Environments and their Applications (HAVE)*, pp. 67–71, 2005.
Hermann & Hunt, 2005	Hermann, T. and Hunt, A. "An Introduction to Interactive Sonification," *IEEE Multimedia*, pp.20-24, 2005.

Hermann & Ritter, 1999 — Hermann, T. and Ritter, H. “Listen to your Data : Model-Based Sonification for Data Analysis,” *Advances in intelligent computing and multimedia systems*, Int. Institute for Advanced Studies in System Research and Cybernetics, Baden-Baden, Germany, pp.189-194, 1999.

Herz, 2009 — Herz, R.S. “Aromatherapy facts and fictions: a scientific analysis of olfactory effects on mood, physiology and behavior,” *The Int. J. of Neuroscience*, vol. 119, no. 2, pp.263–90, 2009.

Hill & Bodt, 2007 — Hill, S.G. and Bodt, B. “A Field Experiment of Autonomous Mobility: Operator Workload for One and Two Robots,” *Proc. of the ACM/IEEE Int. Conf. on Human-Robot Interaction*, Arlington, Virginia, USA, pp. 169-176, Mar. 2007.

Höferlin et al., 2011 — Höferlin B., Höferlin M., Raschke M., Heidemann G., Weiskopf D. “Interactive Auditory Display to Support Situational Awareness in Video Surveillance”. *Proc. of the 17th Int. Conf. on Auditory Display (ICAD)*, Budapest, Hungary, Jun. 2011.

Humphrey et al., 2008 — Humphrey, C.M., Henk, C., Sewell, G., Williams, B.W. and Adams, J.A. “Assessing Scalability of a Multiple Robot Interface,” *Proc. of the 3rd ACM/IEEE Int. Conf. on Human Robot Interaction*, pp. 89-96, ISBN:978-1-60558-017-3, 2008.

Ikehara & Crosby, 2005 — Ikehara, C.S. and Crosby, M.E., "Assessing Cognitive Load with Physiological Sensors," *2005. Proc. of the 38th Annual Hawaii International Conference on System Sciences (HICSS)*, pp. 295a, 2005.

Insko, 2003 — Insko, B.E. “Measuring Presence: Subjective, Behavioral and Physiological Methods,” *Being There - Concepts, Effects and Measurements of User Presence in Synthetic Environments*, IOS Press, Amsterdam, pp. 109-120, 2003, ISBN 1586033018, 9781586033019.

Interrante et al., 2007 — Interrante, V., Ries, B., Lindquist, J. and Anderson, L. “Elucidating Factors that can Facilitate Veridical Spatial Perception in Immersive Virtual Environments,” *Proc. of IEEE Virtual Reality (VR)*, pp. 11-18, 2007.

Iwata et al., 2004 — Iwata, H., Yano, H., Uemura, T., and Moriya, T., “Food simulator: a haptic interface for biting,” *Proc. of IEEE VR 2004*, pp. 51–57, 2004.

Jacoff et al., 2003 — Jacoff, A., Messina, E., Weiss, B.A., Tadokoro, S., and Nakagawa, Y. "Test arenas and performance metrics for urban search and rescue," *Proc. of IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS)*, vol. 3, pp. 3396-3403, 2003.

Johannes et al., 2013 — Johannes, M.S., Armiger, R.S., Zeher, M.J., Matthew, V., Bigelow, J.D., and Harshbarger, S.D. "Human Capabilities Projection : Dexterous Robotic Telemanipulation with Haptic Feedback". *Johns Hopkins APL Technical Digest*, vol. 31 no. 4, pp. 315–324, 2013.

Johnson et al., 2003 — Johnson, C.A., Adams, J.A. and Kawamura, K. "Evaluation of an enhanced human-robot interface," *Proc. of the IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC)*, pp. 900-905, 2003.

Kaber et al., 2006 — Kaber, D.B., Wright, M.C. and Sheik-Nainar, M.A. "Investigation of multi-modal interface features for adaptive automation of a human–robot system," Int. J. of Human-Computer Studies, vol. 64, no. 6, pp. 527-540, Jun. 2006.

Kadous et al., 2006 — Kadous, M. W., Sheh, R. K. and Sammut, C. "Effective User Interface Design for Rescue Robotics," *Proc. of the ACM SIGCHI/SIGART Conf. on Human-Robot Interaction*, ACM, New York, NY, USA, pp. 250-257, 2006.

Kennedy & Land, 1993 — Kennedy, R.S., and Land, N.E. "Simulator sickness questionnaire: an enhanced method for quantifying simulator sickness," *The Int. J. of Aviation Psychology*, vol. 3, no. 3, pp. 203-220, 1993.

Kennedy et al., 1993 — Kennedy, R.S., Lane, N.E., Berbaum, K.S. and Lilienthal, M.G. "Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness," *The Int. J. of Aviation Psychology*, vol. 3, no. 3, pp. 203-220, 1993.

Kobayashi et al., 2005 — Kobayashi, M., O'Brien, S., Pyrzak, G., Ratterman, C., Wong, K. and Vassallo, G. "Building an Interface for Robotic In-Situ Re-Tasking," *Final Report*, Sep. 28th, 2005.

Koh et al., 2001 Koh, K.C., Choi, H.J., Kim, J.S., Ko, K.W. and Cho, H. "Sensor-based Navigation of Air-duct Inspection Mobile Robots," *Proc. of Society of Photo-optical Instrumentation Engineers (SPIE)*, vol. 4190, pp. 202-211, 2001.

Kontarinis & Howe, 1995 Kontarinis, D.A. and Howe, R.D. "Tactile display of vibratory information in teleoperation and virtual environments," *Presence: Teleoperators and Virtual Environments*, vol. 4, no. 4, pp. 387-402, 1995.

Larssen et al., 2006 Larssen, A.T., Robertson, T. and Edwards, J. "How it Feels, Not just How it looks: When Bodies Interact with Technology," *Proc. of the 18th Australia Conf. on Computer-Human Interaction: Design: Activities, Artefacts and Environments*, pp. 329-332, 2006.

Larsson, 2009 Larsson, P. "EARCONSAMPLER: A Tool for Designing Emotional Auditory Driver-Vehicle Interfaces," *Proc. of the 15th Int. Conf. on Auditory Display (ICAD)*, pp. 9-11, 2009.

Larsson et al., 2006 Larsson, P., Opperud A., Fredriksson, K. and Västfjäll, D. "Emotional and Behavioral Response to Auditory Icons and Earcons in Driver-Vehicle Interfaces," *Proc. of the 21st Int. Technical Conf. on the Enhanced Safety of Vehicles (ESV)*, paper #09-0104, 2006.

Lewis et al., 2003 Lewis, M., Sycara, K., and Nourbakhsh, I. "Developing a Testbed for Studying Human-Robot Interaction in Urban Search and Rescue," *Proc. of 10th Int. Conf. on Human Computer Interaction (HCII)*, pp. 22-27. 2003.

Lindeman, 1999 Lindeman, R.W. "Bimanual Interaction, Passive-Haptic Feedback, 3D Widget Representation, and Simulated Surface Constraints for Interaction in Immersive Virtual Environments," Unpublished doctoral dissertation, The George Washington Univ., Dept. of EE & CS, Washington, DC 20052, May 16, 1999.

Lindeman, 2003 Lindeman, R.W. "Virtual contact: the continuum from purely visual to purely physical," *Proc. of the 47th Annu. Meeting of the Human Factors and Ergonomics Society (HFES)*, pp. 2103-2107, 2003.

Lindeman et al., 2003 Lindeman, R.W., Yanagida, Y., Sibert, J.L., Lavine, R. "Effective Vibrotactile Cueing in a Visual Search Task," *Proc. of the 9th IFIP TC13 Int. Conf. on Human-Computer Interaction (INTERACT)*, Zürich, Switzerland, pp. 89-96, Sep. 1-5, 2003.

Lindeman et al., 2005 Lindeman, R.W., Sibert, J.L., Mendez-Mendez, E., Patil, S., and Phifer, D. "Effectiveness of directional vibrotactile cueing on a building-clearing task," *Proc. of SIGCHI Conf. on Human Factors in Computing Systems (CHI)*, pp. 271-280, 2005.

Lindeman et al., 2006 Lindeman, R.W., Yanagida, Y., Noma, H. and Hosaka, K. "Wearable Vibrotactile Systems for Virtual Contact and Information Display," *Virtual Reality*, Special Issue on Haptic Interfaces and Applications, vol. 9, no. 2-3, pp. 203-213, 2006.

Lindeman et al., 2008 Lindeman, R.W., Noma, H. and de Barros, P.G. "An Empirical Study of Hear-Through Augmented Reality: Using Bone Conduction to Deliver Spatialized Audio," *Proc. of IEEE Virtual Reality (VR)*, pp. 35-42, 2008.

Lindeman & Yanagida, 2003 Lindeman, R.W. and Yanagida, Y. "Empirical Studies for Effective Near-Field Haptics in Virtual Environments," (Poster) *Proc. of IEEE Virtual Reality (VR)*, pp. 287-288, 2003.

Loomis et al., 1998 Loomis J.M., Klatzky R.L., Philbeck J.W., Golledge R.G. "Assessing auditory distance perception using perceptually directed action," *Perception & Psychophysics*, vol. 60, no. 6, pp. 966-980, Aug. 1998.

Lindeman et al., 1999 Lindeman, R.W., Sibert, J.L. and Hahn, J.K. "Towards usable VR: An empirical study of user interfaces for immersive virtual environments," *Proc. of SIGCHI Conf. on Human Factors in Computing Systems (CHI)*, pp. 64-71, 1999.

Maes et al., 2010 Maes, P.-J., Leman, M., Lesaffre, M. "A Model-Based Sonification System For Directional Movement Behavior," *Interactive Sonification Workshop*, Stockholm, Sweden, pp. 91-94, 2010.

Mantovani & Riva, 2001	Mantovani, G. and Riva G. "Building a Bridge between Different Scientific Communities: On Sheridan's Eclectic Ontology of Presence," *Presence: Teleoperators and Virtual Environments*, vol. 10, no. 5, pp. 537-543, 2001.
Maynes-Aminzade, 2005	Maynes-Aminzade, D. "Edible bits: Seamless interfaces between people, data and food," *Proc. of SIGCHI Conf. on Human Factors in Computing Systems (CHI)*, Extended Abstracts, pp. 2207-2210, 2005.
Meehan et al., 2002	Meehan, M., Insko, B., Whitton, M. and Brooks Jr., F.P. "Physiological measures of presence in stressful virtual environments," *Proc. of the 29th Annu. Conf. on Computer Graphics and Interactive Techniques (SIGGRAPH)*, pp. 645-652, 2002.
Merriam-Webster, 2009	Merriam-Webster, "delegation," *Merriam-Webster Online Dictionary*. Retrieved: Sep. 23, 2009.
Micire et al., 2011	Micire, M., Desai, M., Drury, J.L., McCann, E., Norton, A., Tsui, K.M. and Yanco, H.A. "Design and Validation of Two-Handed Multi-Touch Tabletop Controllers for Robot Teleoperation," *Proc. of the Int. Conf. on Intelligent User Interfaces (IUI)*, Palo Alto, CA, pp. 145-154, Feb. 2011.
Miller & Parasuraman, 2007	Miller, C. and Parasuraman, R. "Designing for flexible interaction between humans and automation: Delegation interfaces for supervisory control," *Human Factors*, vol. 49, pp. 57-75, 2007.
Miller et al., 2005	Miller, C., Funk, H., Wu, P., Goldman, R., Meisner and Wu, P. "Implications of adaptive vs. adaptable uis on decision making: Why "automated adaptiveness" is not always the right answer," *Proc. of the 1st Int. Conf. on Augmented Cognition*, Las Vegas, NV, Jul. 2005.
Mine et al., 1997	Mine, M., Brooks Jr., F.P. and Sequin, C. "Moving Objects in Space: Exploiting Proprioception in Virtual-Environment Interaction," *Proc. of the Annu. Conf. on Computer Graphics and Interactive Techniques (SIGGRAPH)*, Los Angeles, CA, pp. 19-26, 1997.
Mitra & Niemeyer, 2008	Mitra, P., and Niemeyer, G. "Model-mediated Telemanipulation," *The International Journal of Robotics Research*, vol. 27, no.2, pp. 253–262, 2008.

Moray, 2003 — Moray, N. “Monitoring Complacency, Scepticism and Eutactic Behavior”. *Int. Journal of Industrial Ergonomics*, vol. 31, no. 3, pp. 175-178, 2003.

Moss et al., 2003 — Moss, M., Cook, J., Wesnes, K. and Duckett, P. “Aromas of rosemary and
lavender essential oils differentially affect cognition and mood in healthy adults,”
International Journal of Neuroscience, vol. 113, pp. 15–38, 2003.

Murphy, 2004 — Murphy, R.R. “Human-Robot Interaction in Rescue Robotics,” *Proc. of the IEEE Trans. on System, Man and Cybernetics (SMC)*, Part C: Applications and Reviews, vol. 34, no. 2, pp. 138-153, 2004.

Nakamura & Miyashita, 2012 — Nakamura, H. and Miyashita, H. “Development and evaluation of interactive system for synchronizing electric taste and visual content,” *Proc. of the ACM Annu. Conf. on Human Factors in Computing Systems*, pp. 517-520, 2012.

Narumi et al., 2011 — Narumi, T., Nishizaka, S., Kajinami, T., Tanikawa, T. and Hirose, M. “Augmented reality flavors: gustatory display based on edible marker and cross-modal interaction,” *Proc. of the SIGCHI Conf. on Human Factors in Computing Systems (CHI)*, pp. 93-102, 2011.

Nasir & Roberts, 2007 — Nasir, T. and Roberts, J.C. “Sonification of Spatial Data,” *Proc. of the 13th Int. Conf. on Auditory Display (ICAD)*, Schulich Sch. of Music, McGill Univ., Canada, pp. 112-119, Jun. 2007.

Nehme & Cummings, 2006 — Nehme, C.E. and Cummings, M.L. “Audio Decision Support for Supervisory Control of Unmanned Vehicles,” Literature Review, MIT, MA, 2006.

Neuron Robotics, 2014 — Neuron Robotics, Better Tools for Better Ideas, URL: http://www.neuronrobotics.com/. Last visited: 4/5/2014.

Nielsen & Goodrich, 2006 — Nielsen, C.W. and Goodrich, M.A. “Comparing the usefulness of video and map information in navigation tasks,” *Proc. of the ACM Conference on Human-Robot Interaction (HRI)*, pp. 95-101, 2006.

Nielsen et al., 2007 — Nielsen, C.W., Goodrich, M.A. and Ricks, B. “Ecological interfaces for improving mobile robot teleoperation,” *IEEE Trans. on Robotics*, vol. 23, no. 5, pp. 927-941, 2007.

Nieuwenhuisen et al., 2013 — Nieuwenhuisen, M., Droeschel, D., Holz, D. and Behnke, S. "Omnidirectional Obstacle Perception for Collision Avoidance for Lightweight UAVs," *Resource-Efficient Integration of Perception, Control and Navigation for Micro Air Vehicles (MAVs)*, Contributed Talk, Tech. Univ. Berlin, Berlin, Germany, Jun. 2013.

Noguchi et al., 2009 — Noguchi, D., Ohtsu, K., Bannai, Y. and Okada, K. “Scent presentation expressing two smells of different intensity simultaneously,” *Proc. of the 15th Joint Virtual Reality Eurographics Conf. on Virtual Environments (JVRC)*, pp. 53-60, 2009.

NRC, 2002 — NRC. “Making the Nation Safer: The Role of Science and Technology in Countering Terrorism,” Cover and Executive Summary, *Comm. on Sci. and Tech. for Countering Terrorism*, National Academies Press, 2002. URL: http://cryptome.org/scitech-role.htm. Last visited: 4/5/2014

Osuka et al., 2002 — Osuka, K., Murphy, R. and Schultz, A.C. “USAR competitions for physically situated robots,” *IEEE Robotics & Automation Magazine*, vol.9, no. 3, pp. 26-33, 2002.

Parasuraman et al., 2000 — Parasuraman, R., Sheridan, T., and Wickens, C.D. “A Model for Types and Levels of Human Interaction with Automation,” *IEEE Trans. on Systems, Man, and Cybernetics (SMC)*. Part A: Systems and Humans, vol. 30, pp. 286–297, 2000.

Parasuraman et al., 2003 — Parasuraman R., Galster S. and Miller, C. “Human Control of Multiple Robots in the RoboFlag Simulation Environment,” *Proc. of the IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC)*, USA, pp. 3232-3237, 2003.

Parasuraman et al., 2005 — Parasuraman, R., Galster, S., Squire, P., Furukawa, H. and Miller, C. “A flexible delegation interface enhances system performance in human supervision of multiple autonomous robots: Empirical studies with RoboFlag,” *IEEE Trans. on Systems, Man, and Cybernetic*, Part A: Systems and Humans, vol. 35, no. 4, pp. 481-493, 2005.

Parasuraman et al., 2008 — Parasuraman, R., Sheridan, T.B. and Wickens, C.D. "Situation awareness, mental workload, and trust in automation: Viable, empirically supported cognitive engineering constructs," *J. of Cognitive Engineering and Decision Making*, vol. 2, pp. 141-161, 2008.

Pauletto & Hunt, 2004 — Pauletto, S. and Hunt, A. "A Toolkit for Interactive Sonification," *Proc. of the Int. Conf. on Auditory Display (ICAD)*, Sydney, Australia, 2004.

Phantom, 2014 — Phantom Desktop Haptic Device. Sensable Inc. URL: http://www.sensable.com/haptic-phantom-desktop.htm. Last visited: 4/5/2014.

Pielot & Boll, 2010 — Pielot, M. and Boll, S. "Tactile Wayfinder: Comparison of Tactile Waypoint Navigation with Commercial Pedestrian Navigation Systems," *Prof of the 8th Int.Conf. on Pervasive Computing (Pervasive)*, Helsinki, Finland, pp. 76–93, May 2010.

Poupyrev et al., 2000 — Poupyrev, I., Weghorst, S., Fels, S. "Non-isomorphic 3D Rotational Techniques," *Proc. of the SIGCHI Conf. on Human Factors in Computing Systems (CHI)*, The Hague, The Netherlands, pp. 540-547, 2000.

Poupyrev et al., 1999 — Poupyrev I, Weghorst S, Otsuka T and Ichikawa T. "Amplifying spatial rotations in 3d interfaces," *Proc. of the SIGCHI Conf. on Human Factors in Computing Systems (CHI)*, pp. 256–257, 1999.

Rojas & Föster, 2006 — Rojas, R. and Föster, A.G. "Holonomic Control of a robot with an omnidirectional Drive," *Künstliche Intelligenz (KI)*, vol. 20, no. 2, BöttcherIT Verlag, 2006.

Rinott, 2004 — Rinott, M. "Sonified Interactions with Mobile Devices," *Proc. of Int. Workshop on Interacctive Sonification*, pp. 1-5, 2004.

Ryu & Kim, 2004 — Ryu, J. and Kim, G.J. "Using a vibro-tactile display for enhanced collision perception and presence," *Proc. of the ACM* Symp.*on Virtual Reality Software and Technology (VRST)*, pp. 89-96, 2004.

Ranasinghe et al., 2012 — Ranasinghe, N., Nakatsu, R., Nii, H. and Gopalakrishnakone, P., "Tongue Mounted Interface for Digitally Actuating the Sense of Taste," *Proc. of the16th Int. Symp. on Wearable Computers*, pp. 80–87, Jun. 2012.

Rocchesso et al., 2004 — Rocchesso, D., Avanzini, F., Rath, M., Bresin, R. And Serafin, S. "Contact Sounds for Continuous Feedback," *Proc. of Int. Workshop on Interacctive Sonification*, pp. 1-6, 2004.

Roborealm, 2014 — Roborealm, Vision for Machines, URL: http://www.roborealm.com/. Last visited: 4/5/2014.

Rowe et al., 1998 — Rowe, D.W., Sibert, J. and Irwin, D. "Heart Rate Variability: Indicator of User State as an aid to Human-Computer Interaction," *Proc. of the SIGCHI Conf. on Human Factors in Computing Systems (CHI)*, pp. 480-487, 1998.

Razzaque et al., 2002 — Razzaque, S., Swapp, D., Slater, M., Whitton, M. C. and Steed, A. "Redirected walking in place," *Proc. of the Workshop on Virtual Environments*, Barcelona, Spain, vol. 23, pp. 123-130, May 2002.

Scholtz et al., 2004 — Scholtz, J., Antonishek, B. and Young, J. "Evaluation of a Human-Robot Interface: Development of a Situational Awareness Methodology," *Proc. of the 37th Annu. Hawaii Int. Conf. on System Sciences (HICSS)*. track 5, pp.1-9, Jan. 2004.

Scholtz, 2002 — Scholtz, J. "Evaluation methods for human-system performance of intelligent systems," *Proc. of the Performance Metrics for Intelligent Systems (PerMIS'02) Workshop*, National Institute of Standards and Technology, Gaithersburg, MD, USA, 2002.

Scholtz, 2003 — Scholtz, J. "Theory and Evaluation of Human Robot Interactions," *Hawaii Int. Conf. on System Science (HICSS)*, tr. 5, vol.5, pp. 125.1, 2003.

Sciavicco & Siciliano, 2000 — Sciavicco, L. and Siciliano, B., "Modelling and Control of Robot Manipulators," Advanced Textbooks in Control and Signal Processing Series, 2nd Edition, Springer-Verlag, chapter 8, 2000.

Senders, 1964	Senders, J. "The human operator as a monitor and controller of multidegree of freedom systems," IEEE Trans. on Human Factors in Electronics (HFES), vol. 5, pp. 2–6, 1964.
Sheridan, 1999	Sheridan, T.B. "Descartes, Heidegger, Gibson, and God: Towards an eclectic ontology of presence," *Presence: Teleoperators and Virtual Environments*, vol. 8, no. 5, pp. 551-559, 1999.
Sheridan & Parasuraman, 2006	Sheridan, T. and Parasuraman, R. "Human-automation interaction," *Reviews of Human Factors and Ergonomics*, vol.1, pp. 89-129, 2006.
Sheridan & Verplank, 1978	Sheridan, T. B. and Verplank, W. "Human and Computer Control of Undersea Teleoperators," Technical report, Cambridge, MA. Man-Machine Systems Lab., Dep. of Mech. Eng., MIT, 1978.
Shinn-Cunningham et al., 2005	Shinn-Cunningham, B.G., Streeter, T. and Gyss, J.-F. "Perceptual plasticity in spatial auditory displays," *ACM Trans. Appl. Percept.*, vol. 2, no. 4, pp. 418-425, Oct. 2005.
Sibert et al., 2006	Sibert, J., Cooper, J., Covington, C., Stefanovski, A., Thompson, D. and Lindeman, R.W. "Vibrotactile feedback for enhanced control of urban search and rescue robots," *Proc. of the IEEE Symp. on Safety, Security and Rescue Robots*, demonstration, Gaithersburg, MD, USA, Aug. 2006.
Skubic et al., 2006	Skubic, M., Anderson, D., Blisard, S., Perzanowski, D. and Schultz, A. "Using a qualitative sketch to control a team of robots," *Proc. IEEE Int. Conf. on Robotics and Automation (ICRA)*, pp. 3595-3601, 2006.
Slater, 1999	Slater, M. "Measuring Presence: A Response to the Witmer and Singer Presence Questionnaire," *Presence: Teleoperators and Virtual Environments*, vol. 8, no. 5, pp. 560-565, 1999.
Slater et al., 1994	Slater, M., Usoh, M. and Steed, A. "Depth of Presence in Virtual Environments," *Presence: Teleoperators and Virtual Environments*, vol. 3, no. 2, pp. 130-144, 1994.
Slater & Usoh, 1994	Slater, M. and Usoh, M. "Body Centred Interaction in Immersive Virtual Environments," *Artificial Life and Virtual Reality*, John Wiley and Sons, pp. 125-148, 1994.

Song et al., 2010 — Song, M., Tao, D., Liu, Z., Li, X. and Zhou, M. “Image ratio features for facial expression recognition application,” *Trans. on System, Man and Cybernetics (SMC)*, Part B, vol. 40, no. 3, pp. 779-788, Jun. 2010.

Spath et al., 2007 — Spath, D., Peissner, M., Hagenmeyer, L. and Ringbauer, B. “New Approaches to Intuitive Auditory User Interfaces,” *Proc. of the Conf. on Human interface (HCII)*, Part 1, pp. 975-984, 2007.

Steinfeld et al., 2006 — Steinfeld, A., Fong, T., Kaber, D., Lewis, M., Scholtz, J., Schultz, A., and Goodrich, M. "Common Metrics for Human-Robot Interaction," Proc. of the 1st ACM SIGCHI/SIGART Conf. on Human-Robot Interaction (HRI), Salt Lake City, Utah, USA, pp 33-40, Mar. 2006.

Steuer, 1992 — Steuer, J. “Defining Virtual Reality: Dimensions Determining Telepresence,” *J. of Communication*, vol. 42, no. 4, pp. 73-93, 1992.

Suarez & Murphy, 2012 — Suarez, J., Murphy, R.R. “Using the Kinect for search and rescue robotics,” *IEEE Int. Symp. on Safety, Security, and Rescue Robotics (SSRR)*, College Station, TX, pp. 1-2, 2012, ISBN: 978-1-4799-0164-7.

Tachi, 1992 — Tachi, S. “Tele-Existence”. *Journal of Robotics and Mechatronics*, vol. 4, no. 1, pp. 7 – 12, 1992.

Tanaka et al., 2011 — Tanaka, H., Koizumi, N., Uema, Y. and Inami, M., “Chewing Jockey: Augmented Food Texture by using sound based on the cross-modal effect,” *Proc. the Annu. Conf. on Computer Graphics and Interactive Techniques (SIGGRAPH) Asia*, pp. 18, 2011.

Taylor II et al., 2001 — Taylor II, R.M., Hudson, T.C., Seeger, A., Weber, H., Juliano, J. and Helser, A.T. “VRPN: A Device-Independent, Network-Transparent VR Peripheral System,” *Proc. of the ACM Symp. on Virtual Reality Software & Technology (VRST)*, pp. 55-61, 2001.

Usoh et al., 1999 — Usoh, M., Arthur, K., Whitton, M. C., Bastos, R., Steed, A. and Slater, M. “Walking > Walking-in-Place > Flying in Virtual Environments,” *Proc. the Annu. Conf. on Computer Graphics and Interactive Techniques (SIGGRAPH)*, pp. 359-364, 1999.

Usoh et al., 2000 Usoh, M., Catena, E., Arman, S. and Slater, M. "Using presence questionnaires in reality," *Presence: Teleoperators and Virtual Environments*, vol. 9, no. 5, pp. 497-503, 2000.

Van Erp & Van Veen, 2004 Van Erp, J.B.F. and Van Veen, H.A.H.C. "Vibrotactile in-vehicle navigation system," *Transportation Research*, vol. 7, pp. 247–256, 2004.

Walker & Kramer, 2005 Walker, B.N. and Kramer, G. "Mappings and Metaphors in Auditory Displays : An Experimental Assessment," *ACM Trans. on Applied Perception*, vol. 2, no. 4, pp. 407-412, 2005.

Wersényi, 2009 Wersényi, G. "Auditory Representations of a Graphical User Interface for a better Human-Computer Interaction," *Proc. of the Int. Conf. on Auditory Display (ICAD)*, Springer-Verlag, Berlin, Heidelberg, pp. 80-102, 2009. URL: http://dx.doi.org/10.1007/978-3-642-12439-6_5. Last visited: 4/12/2014.

West, 2013 West, M.T. "The Design and Control of a Singularity Drive System for an Omni-Directional Vehicle," Master thesis, Dep. of Mech. Eng., Bradley Univ., 2013.

Wickens, 2008 Wickens, C.D., "Multiple Resources and Mental Workload," *Human Factors*, vol. 50, no. 3, pp. 449–45, June 2008.

Witmer & Singer, 1998 Witmer, B.G. and Singer, M.J. "Measuring Presence in Virtual Environments: A Presence Questionnaire," *Presence: Teleoperators and Virtual Environments*, vol. 7, no. 3, pp. 225–240, 1998.

Woods et al., 2004 Woods, D.D., Tittle, J., Feil, M. and Roesler, A. "Envisioning Human–Robot Coordination in Future Operations," *Proc. of the IEEE Trans. on System, Man and Cybernetics (SMC)*, Part C: Applications and Reviews, vol. 34, no. 2, pp. 210-218, 2004.

Yamada et al., 2006 Yamada, T., Yokoyama, S., Tanikawa, T., Hirota, K. and Hirose, M. "Wearable olfactory display: Using odor in outdoor environments," *Proc. of IEEE Virtual Reality (VR)*, Charlotte, NC, USA, pp. 199–206, 2006.

Yanagida et al., 2004 Yanagida, Y., Kawato, S., Noma, H., Tomono, A. and Tetsutani, N. "Projection-based olfactory display with nose tracking," *Proc. of IEEE Virtual Reality (VR)*, pp. 43–50, 2004.

Yanco & Drury, 2002 Yanco, H.A. and Drury, J.L. “A Taxonomy for Human-Robot Interaction,” *Proc. of the AAAI Fall Symp. on Human-Robot Interaction*, AAAI Tech. Report FS-02-03, Falmouth, MA, USA, pp. 111-119, Nov. 2002.

Yanco & Drury, 2004 Yanco, H. A. and Drury, J. L. “Classifying Human-Robot Interaction: An Updated Taxonomy,” *Proc. of the IEEE Conf. on Systems, Man and Cybernetics (SMC)*, vol. 3, pp. 2841- 2846, 2004.

Yanco et al., 2004 Yanco, H.A., Drury, J.L. and Scholtz, J. "Beyond Usability Evaluation: Analysis of Human-Robot Interaction at a Major Robotics Competition," *Human-Computer Interaction*, vol. 19, nos.1-2, pp.117-149, 2004.

Yanco et al., 2006 Yanco, H.A., Baker, M., Casey, R., Keyes, B. Thoren, P., Drury, J.L., Few, D., Nielsen, C. and Bruemmer, D. “Analysis of human-robot interaction for urban search and rescue,” *Proc. of the IEEE Symp. on Safety, Security and Rescue Robots*, Gaithersburg, MD, USA, Aug. 2006.

Yanco et al., 2007 Yanco, H.A., Keyes, B., Drury, J. L., Nielsen, C.W., Few, D. A. and Bruemmer, D. J. “Evolving interface design for robot search tasks”. *Journal of Field Robotics*, vol. *24, nos.*8-9, pp. 779–799, 2007.

Zanbaka et al., 2005 Zanbaka, C., Lok, B., Babu, S., Ulinski, A. and Hodges, L. F. “Comparison of Path Visualizations and Cognitive Measures Relative to Travel technique in a Virtual Environment,” *IEEE Trans. on Visualization and Computer Graphics*, vol. 11, no. 6, pp. 694-705, 2005.

Zelek & Asmar, 2003 Zelek, J.S. and Asmar, D. "A Robot's Spatial Perception Communicated via Human Touch," *Proc. of the IEEE Int. Conf. on Systems, Man, and Cybernetics (SMC)*, Washington, DC, USA, pp. 454-461, Oct. 2003.

Zeltzer, 1992 Zeltzer, D. "Autonomy, Interaction, and Presence," *Presence: Teleoperators and Virtual Environments*, vol. 1, no. 1, pp. 127-132, 1992.

Zhang et al., 2013 Zhang, Z., Liu, A., Gao, Z., Liu, C. “A Kinect-based 3D sensing and human action recognition solution for urban search and rescue environments”. *Proc. The IEEE Int. Symp. on Robot and Human Interactive Comm. (RO-MAN),* pp. 344 – 345, ISSN: 1944-9445.

Zhao et al., 2005 Zhao, H., Smith, B.K, Norman, K., Plaisant, C., Shneiderman, B. “Interactive Sonification of Choropleth Maps,” *IEEE Multimedia*, vol. 12, no. 2, pp. 26-35, Apr. 2005.

Appendix A: Study 1 Material

This appendix contains all the forms used and data analysis done for user study #1. Source code, videos and images can be found on-line (de Barros & Lindeman, 2014).

A.1 Forms

The forms used in study #1 are contained in this section. The text listed is presented as it was originally was given to subjects, with the exception of the removal of watermarks and institutional logotypes.

A.1.1 Instructions Sheet

This experiment aims at evaluating the effect of a tactile interface on robot teleoperation.

Task: You will be asked to enter a closed virtual environment, search for red spheres by remotely operating a robot and, then safely exit the environment. You will have to do this as fast and effectively as possible.

You will be presented with a house-like virtual environment. The house will have objects spread around in a chaotic manner, so as to reproduce a catastrophic situation. Among the objects there will be red spheres. You will have to locate them by navigating a robot through the debris. **Please try to memorize the location of the spheres so that you can report them later by sketching a map of the place and the spheres' location.** You will be able to take pictures of the location of the spheres that you will be able to refer to while you are sketching.

The world will be seen by using the robot camera present in the virtual robot interface. The camera will display the simulated remote environment. Other information obtained from the simulated environment will be displayed to you through the robot interface. You will be asked to perform the search task once. A timer will count the amount of time spent during task. The task will be over once you exit the house through the exit door, identified by an emergency exit symbol.

The interface of the program contains a virtual representation of the robot and a virtual representation of the robot camera that displays images from the simulated real world. Additionally, a ring may be around the robot. If it is present, it will change color in different directions according to whether the robot is moving towards a direction that will cause imminent collision. In addition, you are wearing a belt with eight tactors. They may provide you with feedback on imminent collision situations with the robot. If the tactors are active, the closer the robot is to colliding, the more intensely or frequently they will vibrate in the approximate direction of the imminent collision. The proximity collision range of the robot sensors can be adjusted. The teleoperation interface therefore provides **you** with collision proximity detection, robot orientation and position, robot-camera orientation, and identification of nearby objects.

It is important to notice that if you are trying to **move** the robot and it does not move, it is because the robot is colliding with objects in the remote environment.

Please sit comfortably during the experiment, but pay attention to the search task. After reading this, the instructor will present you with the controls for the robot and give you time to get accustomed to the controls in a training room. If you have questions about how to proceed in the experiment, please, ask during the training session.

After that, feel free to ask the instructor to **start** the experiment whenever you are ready. Further information about the project can be given by the experiment instructor after you have finished the experiment. **Please do not ask the instructor question about the environment during the task performance.**

A.1.2 Consent Form

Primary Investigator:

Robert W. Lindeman

Contact Information:

WPI / Department of Computer Science

100 Institute Road

Worcester, MA 01609

Tel: 508-831-6712

E-Mail: gogo@wpi.edu

Title of Research Study:

Evaluation of Tactile Feedback for Teleoperated Robots

Sponsor: None.

Introduction

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you make a fully informed decision regarding your participation.

Purpose of the study:

This study is designed to assess the effect of using vibrotactile interfaces in robot teleoperation.

Procedures to be followed:

You will be asked to move a robot through a third-person virtual environment using a gamepad with two thumb-joysticks and monitor. The task is a simulated search task in a collapsed building. Your control of the robot movement will make it move forward and backward by moving a thumbstick to the front and to the back respectively. Moving the thumbstick to the left or to the right will make the robot turn left or right respectively. Releasing the thumbstick at its central static position will bring the robot to a stop. In addition, another thumbstick will give you control over the robot's pan-and-tilt camera. Moving this thumbstick to the left or right will turn the camera to the left or right respectively. Moving it forward or backward will turn the camera down or upward respectively. Releasing this second thumbstick at its central static position will bring the robot camera to a stop.

The robot may have a graphical ring displayed around its virtual representation that changes color to alert you on imminent robot collision in specific directions. You will also be wearing a belt with eight vibration units (called *tactors*) distributed in cardinal directions that may provide you with feedback on imminent collisions. If the tactors are active, the higher the intensity or frequency of a tactor's vibration, the closer you are to having the robot collide along the tactor's direction. The proximity detection range can be increased or decreased by consecutively pressing the buttons "□" and "×" respectively. The range is bound by minimum and maximum values.

After a familiarization period in a special virtual environment, you will be asked to move through another virtual environment and search for red spheres ("victims"). You will be asked to memorize their locations and report them later on. You will have to move in a closed space through an entrance and exit the environment through an exit door. You will be asked to perform this task only once and as fast and effectively as you can. A timer will count the time you have spent on your search task. The search task will last about 10 minutes. Following the search task you will be asked to identify the number and location of each of the red spheres. Finally, you will be given the opportunity to provide any additional comments on the experiment and the application.

Risks to study participants:

The risks to you in participating in this study are minimal.

Benefits to research participants and others:

There is no direct benefit to you.

Record keeping and confidentiality:

Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. No data identifying you by name will be collected, and any publication or presentation of the data will not identify you.

You will be given a copy of this consent form for your records; it contains the contact information for the investigator. The investigator's copy will be stored in a locked file cabinet, and retained for a period of 3 years.

Compensation or treatment in the event of injury:

This study will put you at minimal risk. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact me using the information at the top of this page. In addition, you may contact the IRB Chair (Professor Kent Rissmiller, Tel: 508-831-5019, E-Mail: kjr@wpi.edu) and the University Compliance Officer (Michael J. Curley, Tel. 508-831-5519, E-Mail: mjcurley@wpi.edu).

Your participation in this research is voluntary.

Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

______________________________ Date: ___________________

Study Participant Signature

Study Participant Name (Please print)

Date:

Signature of Person who explained this study

A.1.3 Demographics Collection Form

TactaBelt	Subject #	Gender	Age	Play videogames?	Use robots?
Off	0	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never
Off	1	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never
On	2	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never
On	3	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never
Off	4	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never
On	5	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never
On	6	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never
Off	7	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never
On	8	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never
On	9	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never
Off	10	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never
Off	11	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never
On	12	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never
Off	13	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never
Off	14	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never
On	15	M F		Daily Weekly Seldom Never	Daily Weekly Seldom Never

A.1.4 Post-Questionnaire

1) Please answer the questions in the empty space following them.

2) How many red spheres did you find?

3) Using the pictures taken as a reference, could you draw a map locating them with respect to the house in the space below?

4) Please provide any comments about the robot interface.

5) Do you have any comments about the experiment in general?

6) If you wish to know about the final results of this experiment, please, provide us with your e-mail address: ____.

A.1.5 Instructor Script

Hello. My name is AAAAAA.

Welcome to the HIVE lab. Please, have a seat here.

Please, read the consent form and, if you agree, sign it at the bottom of the second page.

{ Subject reads and signs the consent form }

We are going to start with a few demographic questions:

How old are you?

How often do you play video-games: daily, weekly, seldom or never?

How often do you use or work with robots: daily, weekly, seldom or never?

Now, please carefully read these instructions, and let me know if you have any questions.

{ Subject reads the instruction sheet }

Any questions?

The overall task you will perform simulates a search for victims after a building collapse.

I am now going to show you how to control the robot.

Using the left-hand analog stick on the controller, you can control the robot direction, making it move forward or backwards, or making it turn left or right.

Using the right-hand analog stick you can tilt and pan the robot camera, whose movement is reflected on the video panel in front of the robot.

In order to take a picture, you first zoom in by pressing trigger button #2 on the right side of the controller. You can adjust the picture by moving either the camera or the robot, but be careful with collisions.

When you are satisfied with the picture and while still pressing the zoom button, you press the trigger button #2 on the left side of the controller. This will take a screen shot of the robot camera current view. After that, you can simply release both trigger buttons and move on with your task.

You can also increase or decrease the range of the collision proximity sensors using the “□” and “x” buttons. These are limited to minimum and maximum values however.

You will have some time now to practice robot control in a training room. The task here is to take a picture of a single red sphere, just like the ones you will have to locate in the real task, and which is hidden somewhere in this room. After that, you can keep practicing with the robot controls. Feel free to ask me questions about how to proceed with the study during this training session.

When you feel ready to start the search task, let me know and I will activate it for you. You will not be allowed to ask questions once the experiment starts, so please do so now and during the practice session.

{

Start chronometer for measuring training session time. Training task is run until user requests to move on to the real task.

Instructions during training session:

"The robot is represented by this red box in the middle of the screen. The blue lines represent the surfaces of objects that are close to the robot and that are detected by its sensors (only if a map is present). Remember, if you try to move the robot and the robot does not move, it is because it is colliding with some object in the environment."

- If subject interface contains graphical feedback ring: "The ring around the robot gives feedback on potential collisions that may occur in certain directions. The more red a ring cylinder gets, the closer you are to colliding in its direction. The indicators are not completely precise, so be careful."

- If subject interface (also) has the TactaBelt activated: "The belt around your waist provides you with feedback on potential collisions in certain directions. The more it vibrates in a certain direction, the closer you are to colliding with an object in that direction. (Once again,) The indicators are not completely precise, so be careful."

"Do you have any questions on how to operate the robot?"

Stop chronometer.

}

Now I am going to start the real task. The objective of the task is to find as many red spheres ("victims") as you can in as little time as possible and colliding as little as you can with the robot. Once you are done with your search, you should move out of the house by passing through the exit door, which is identified by an exit sign on top of it, much like the one we have here in the lab. So please try to pay attention to that. Once you pass through the door, the task will be over. After the task, you will be asked to draw a sketch of the environment, and especially the location of each of the spheres. Pay attention to the sphere locations and take pictures at any time. I will start the task now, ok?

{

Start chronometer for measuring task time.

Task is run, no questions allowed.

Stop chronometer when task is over.

}

Now, please fill in this questionnaire. You can browse this document here with the pictures you have taken to help you with the description of the location of the red spheres you found. Feel free to use either pen or pencil.

{

Start chronometer for measuring sketching time.

Subject fills-in post-questionnaire.

Stop chronometer when sketching is over.

}

Do you have any other questions about this study or the lab?

Since other colleagues from your class might come to participate in this study, please avoid discussing what you did with others in order to avoid bias in our results, ok? Thank you very much for your participation.

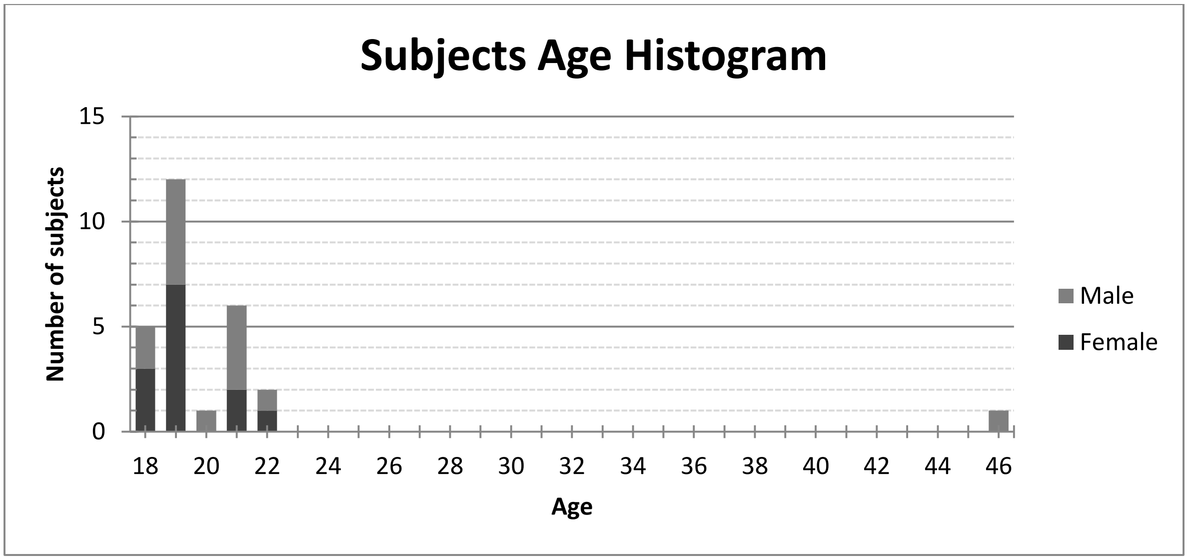
A.2 Data Analysis

The section contains all the data collected for study #1 as well as the statistical analysis performed on it. In the section, subsections whose title is marked with an asterisk (*) contain statistically significant differences (SSD) in the data analysis. If the title of a subsection is marked with a plus sign (+) after it, it means trends are present in its data analysis.

A.2.1 Population

Tactabelt	Group	Subject #	Gender	Age	Videogame XP	Robot XP
Off	0	0	m	19	4	4
Off	1	1	f	18	3	4
On	2	2	m	46	4	4
On	3	3	f	19	3	4
Off	1	4	f	19	4	4
On	2	5	f	19	3	4
On	3	6	f	19	2	4
Off	0	7	m	21	1	4
On	2	8	m	18	1	4
On	3	9	m	20	2	4
Off	0	10	f	18	2	4
Off	1	11	m	18	4	3
On	3	12	m	22	3	3
Off	0	13	f	19	3	4
Off	1	14	m	19	3	3
On	2	15	m	19	3	4
Off	0	16	f	21	3	4
Off	1	17	m	19	2	3
On	2	18	f	19	3	4
On	3	19	m	21	2	3
Off	1	20	f	21	4	4
On	2	21	m	19	3	4
On	3	22	m	21	1	4
Off	0	23	f	19	3	4
On	2	24	f	22	4	4
On	3	25	m	21	2	4
Off	0	26	f	18	4	4

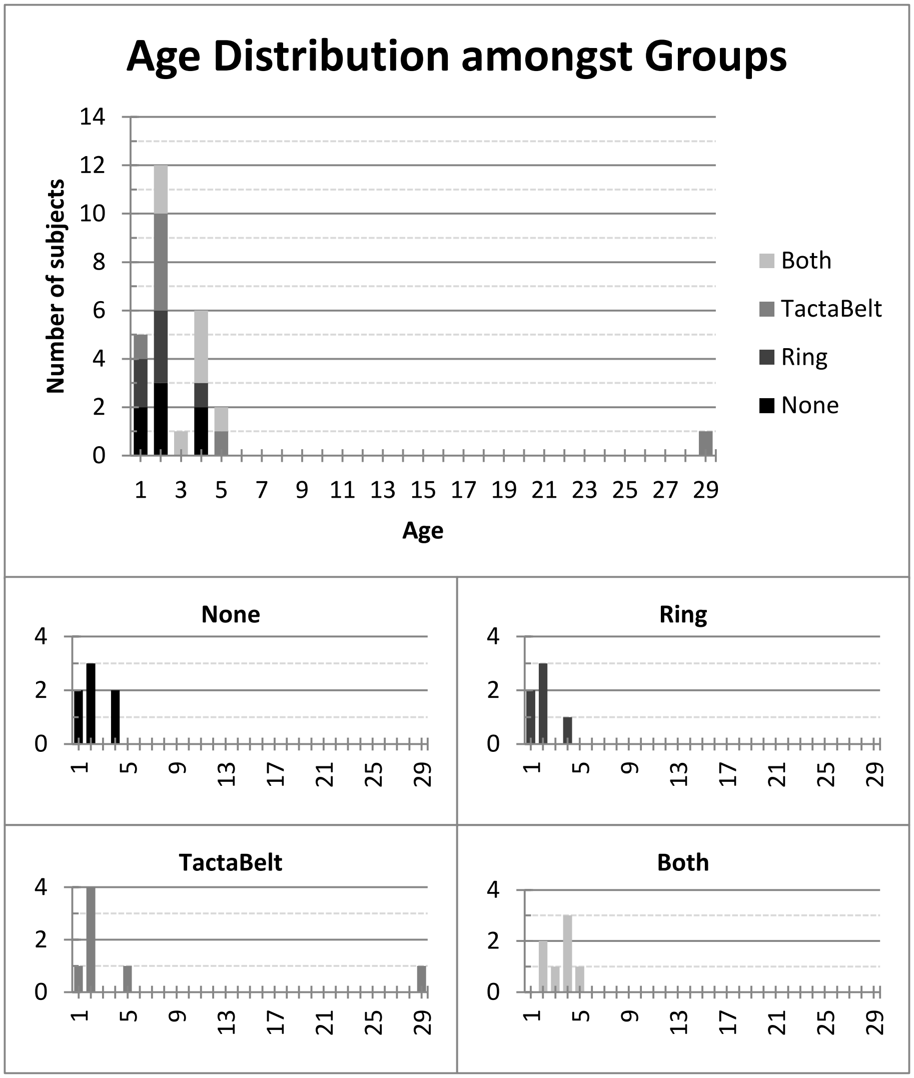
A.2.1.1 Age Histogram



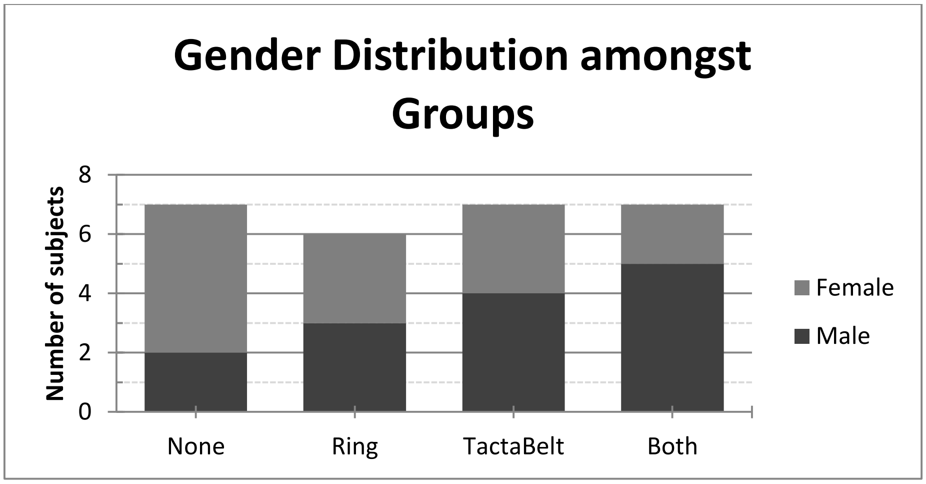
A.2.1.2 Age Distribution for Different Groups

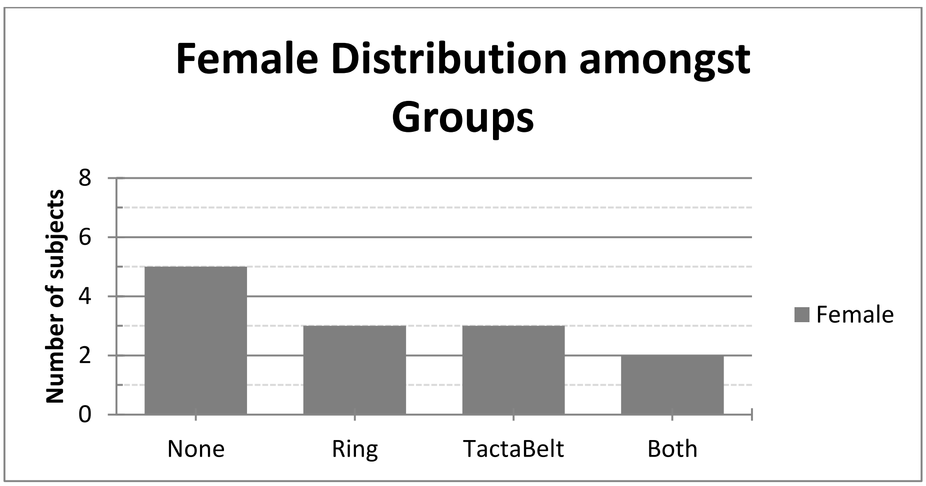
None	Ring	TactaBelt	Both
19	18	46	19
21	19	19	19
18	18	18	20
19	19	19	22
21	19	19	21
19	21	19	21
18		22	21

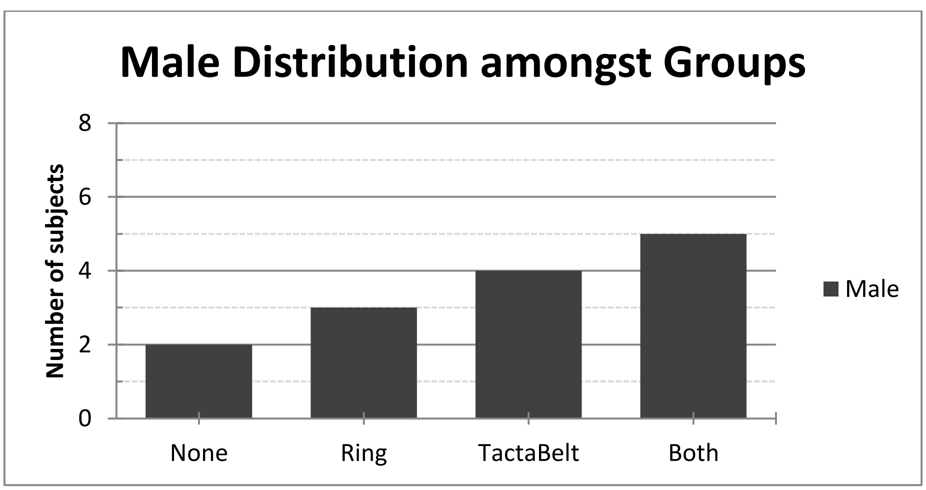
ANOVA: Age vs. Interface Type						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	72.741	3	24.247	0.869	0.472	3.028
Within Groups	642.000	23	27.913			
Total	714.741	26				


Age Distribution amongst Groups
Number of subjects
Age
Both
TactaBelt
Ring
None
None
Ring
TactaBelt
Both

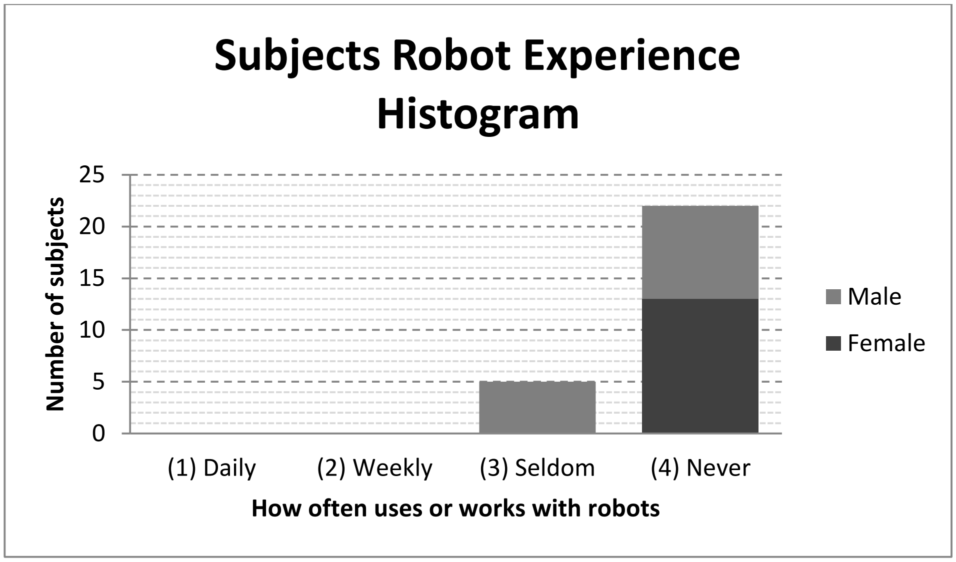
A.2.1.3 Gender Distribution for Different Groups

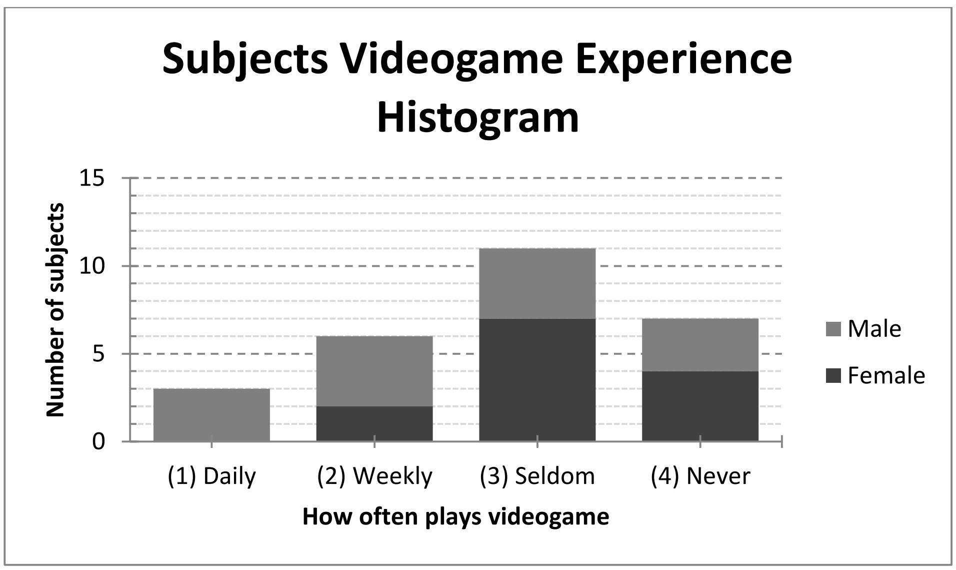






A.2.1.4 Robot and Videogame Experience Histograms

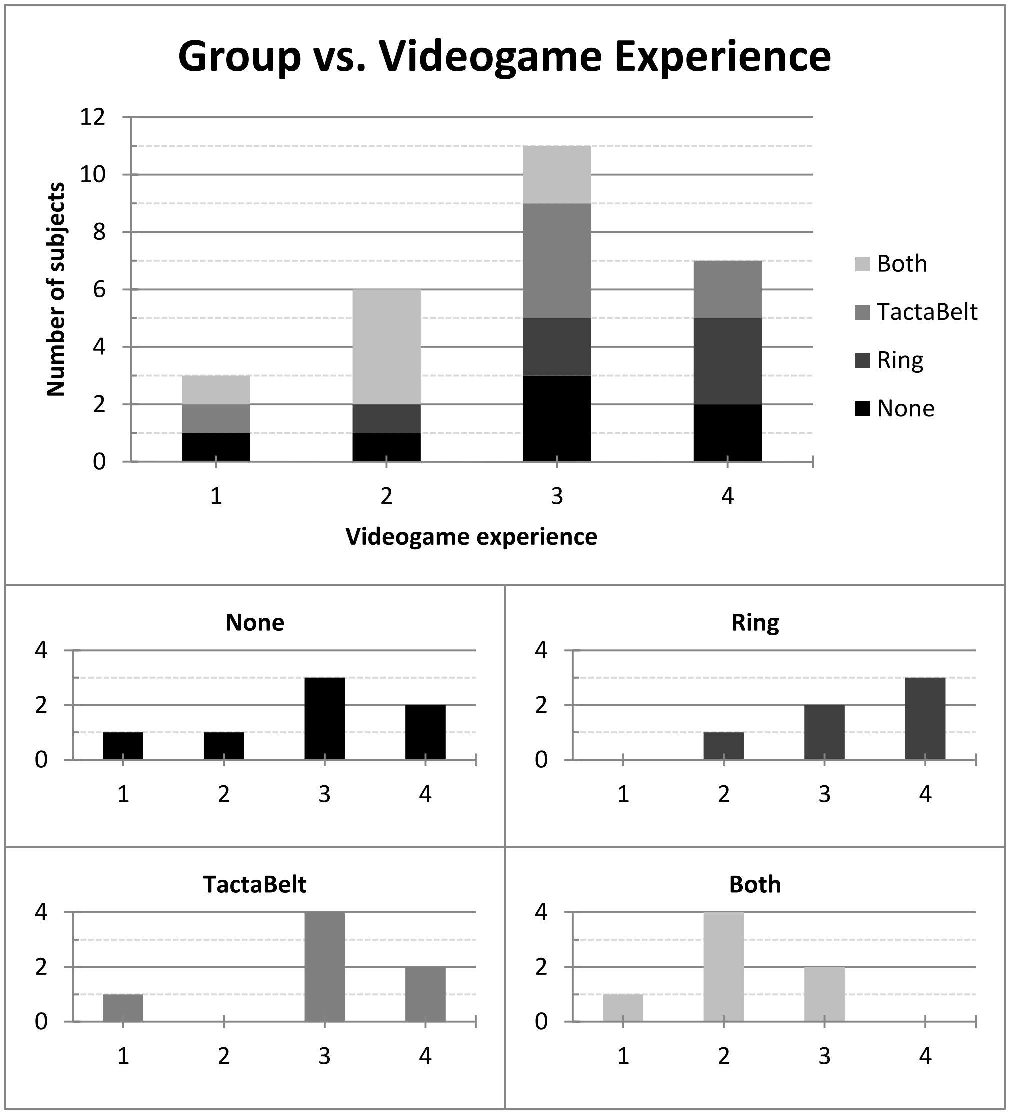




A.2.1.5 Videogame Experience Distribution for Different Groups

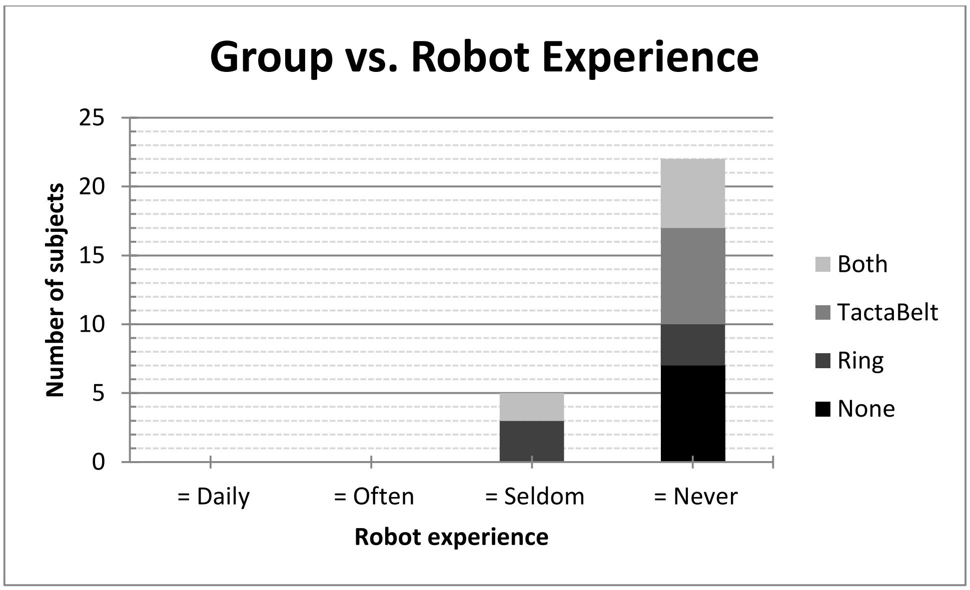
None	Ring	TactaBelt	Both	Legend
4	3	4	3	**1 = Daily**
1	4	3	2	**2 = Often**
2	4	1	2	**3 =Seldom**
3	3	3	3	**4 = Never**
3	2	3	2	
3	4	3	1	
4		4	2	
2.857	3.333	3.000	2.143	**Mean**
3.000	3.500	3.000	2.000	**Median**
1.069	0.816	1.000	0.690	**Std. Dev.**

ANOVA: Videogame Experience for All Groups						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	5.026	3	1.675	2.023	0.139	3.028
Within Groups	19.048	23	0.828			
Total	24.074	26				


Group vs. Videogame Experience
Number of subjects
Videogame experience
Both
TactaBelt
Ring
None
None
Ring
TactaBelt
Both

A.2.1.6 Robot Experience Distribution for Different Groups

None	Ring	TacataBelt	Both	Legend
4	4	4	4	**1 = Daily**
4	4	4	4	**2 = Often**
4	3	4	4	**3 = Seldom**
4	3	4	3	**4 = Never**
4	3	4	3	
4	4	4	4	
4		4	4	
4.00	3.50	4.00	3.71	**Mean**
4.00	3.50	4.00	4.00	**Median**
0.00	0.55	0.00	0.49	**Std. Dev.**

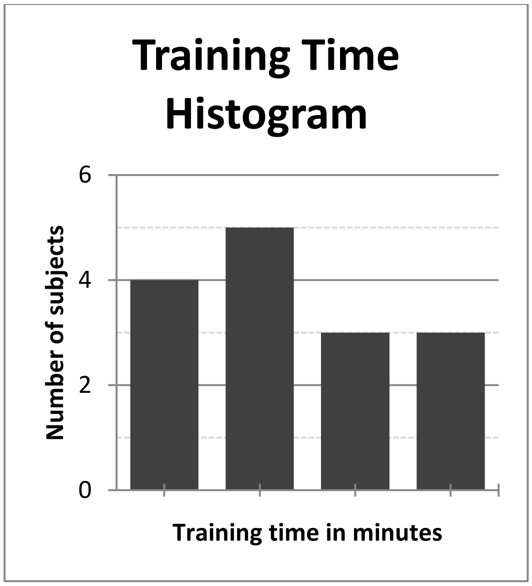


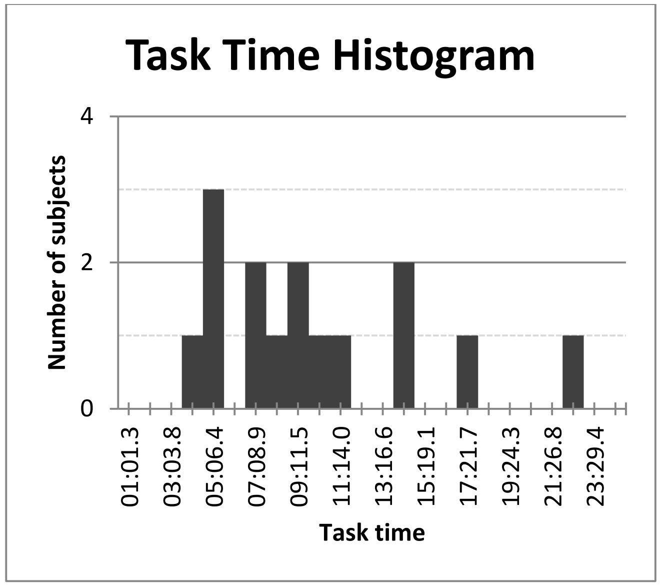
A.2.2 Subjects Comments

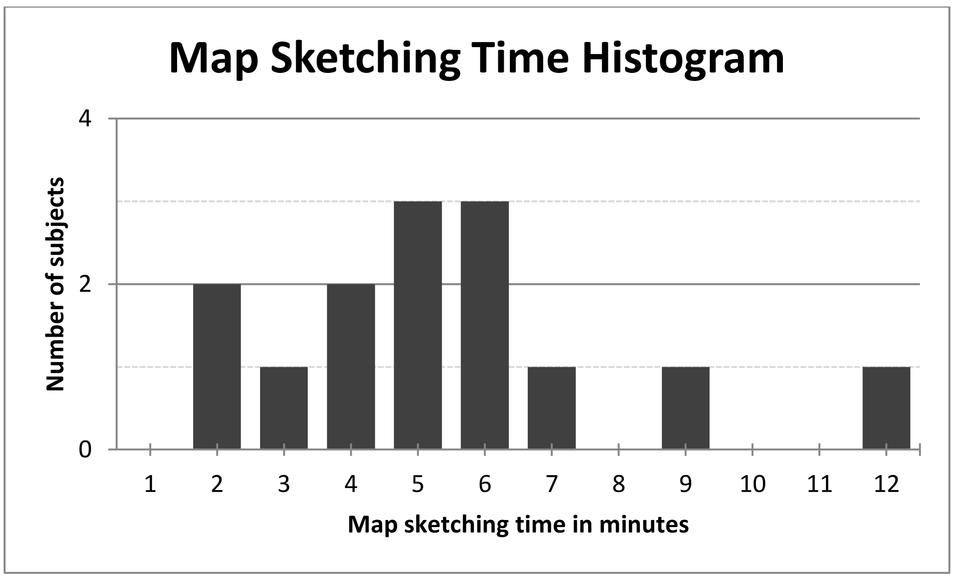
Comments	Number of Mentions
Did not like camera panel	1
Robot was slow	10
Wanted to know the amount of spheres ahead of time	1
TactaBelt vibrates too much and ends up being helpful	4
Option to switch axis of robot camera	1
Vibration sensitivity radius should be smaller	2
Blue lines were the very useful	4
Camera cannot see front of robot	1
Hard to know when robot would be able to pass	4
Did not move camera much	1
Camera view did not match sensor feedback	1
Imprecision of blueprints	4
Camera view was strange	3
Thought having more videogame experience would have helped	2
Space was too tight	1
Hard to turn left and right while moving robot	1

A.2.3 Experimental Time

Subject#	Training Time	Experiment Time	Post-questionnaire Time
10	05:40.8	04:45.9	03:01.9
11	03:49.1	13:29.0	05:46.4
12	04:25.7	04:28.8	02:00.8
13	04:02.6	09:06.2	04:06.1
14	03:07.6	21:45.0	12:01.0
15	02:56.3	04:47.1	02:47.4
16	02:41.4	03:44.1	06:32.9
17	04:26.0	06:58.3	05:40.9
18	03:37.5	08:20.1	03:10.7
19	04:27.0	07:03.2	04:51.1
20	05:30.8	16:39.9	03:35.3
21	03:49.9	13:36.5	04:05.7
22	02:48.5	10:45.7	08:34.2
23	03:01.0	07:53.9	01:50.6
25	05:11.8	09:14.3	05:51.0
AVG:	**03:58.4**	**09:30.5**	**04:55.7**
Median:	**03:49.9**	**08:20.1**	**04:06.1**
Std. dev.	**00:58.5**	**05:02.3**	**02:40.9**

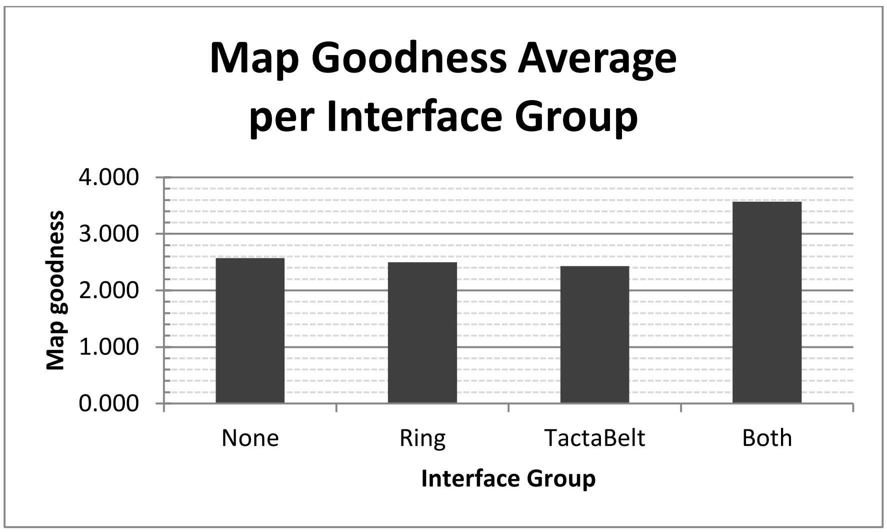

Training Time Histogram
6
4
2
0
Number of subjects
Training time in minutes

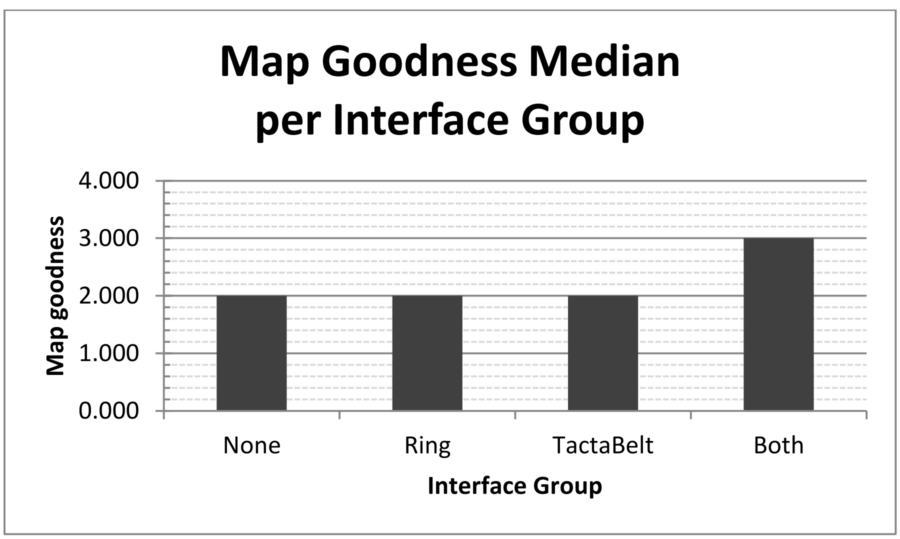

Task Time Histogram
4
2
0
Number of subjects
01:01.3
03:03.8
05:06.4
07:08.9
09:11.5
11:14.0
13:16.6
15:19.1
17:21.7
19:24.3
21:26.8
23:29.4
Task time

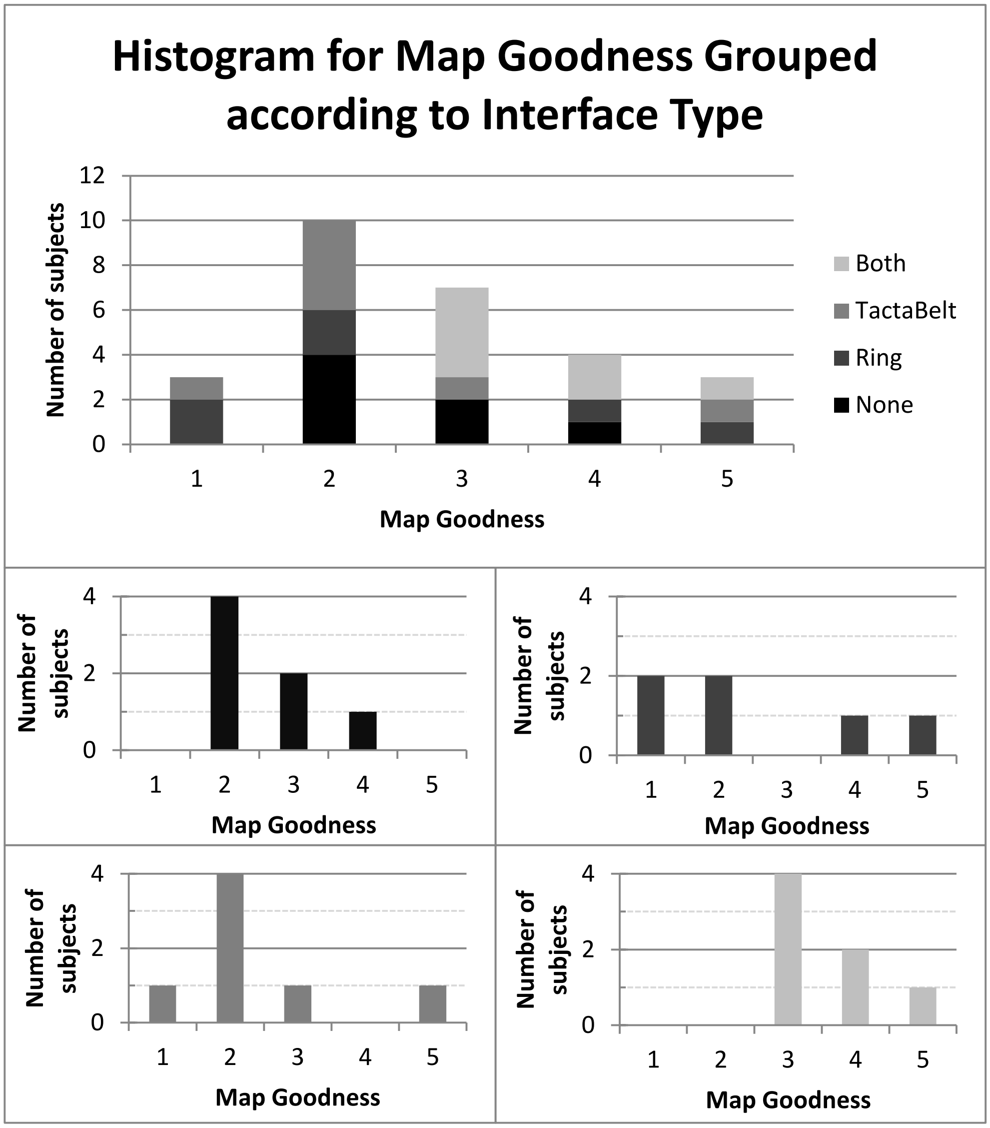

Map Sketching Time Histogram
4
2
0
Number of subjects
1
2
3
4
5
6
7
8
9
10
11
12
Map sketching time in minutes

A.2.4 Sketchmap Evaluation*

Map Quality Ratings for Each Group				
None	**Ring**	**TactaBelt**	**Both**	**Legend**
2	1	3	3	**1 = poor**
3	2	2	4	**and**
3	5	5	3	**5 = excellent**
4	2	2	5	
2	4	2	3	
2	1	2	3	
2		1	4	
2.571	2.500	2.429	3.571	**Mean**
2.000	2.000	2.000	3.000	**Median**
0.787	1.643	1.272	0.787	**Std. Dev.**







ANOVA: Map Quality for All Groups						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	6.024	3	2.008	1.507	0.239	3.028
Within Groups	30.643	23	1.332			
Total	36.667	26				

ANOVA: None vs. Ring						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.016	1	0.016	0.011	0.920	4.844
Within Groups	17.214	11	1.565			
Total	17.231	12				

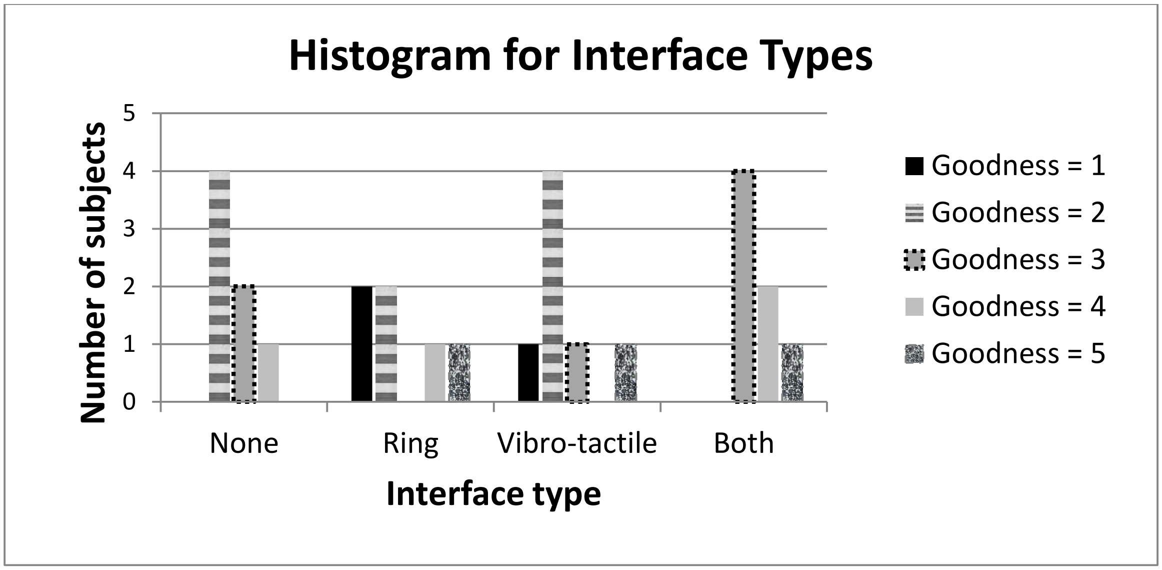
ANOVA: None vs. TactaBelt						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.071	1	0.071	0.064	0.805	4.747
Within Groups	13.429	12	1.119			
Total	13.500	13				

ANOVA: None vs. Both						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	3.500	1	3.500	5.654	0.035	4.747
Within Groups	7.429	12	0.619			
Total	10.929	13				

ANOVA: Ring vs. TactaBelt						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.016	1	0.016	0.008	0.931	4.844
Within Groups	23.214	11	2.110			
Total	23.231	12				

ANOVA: Ring vs. Both						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	3.709	1	3.709	2.370	0.152	4.844
Within Groups	17.214	11	1.565			
Total	20.923	12				

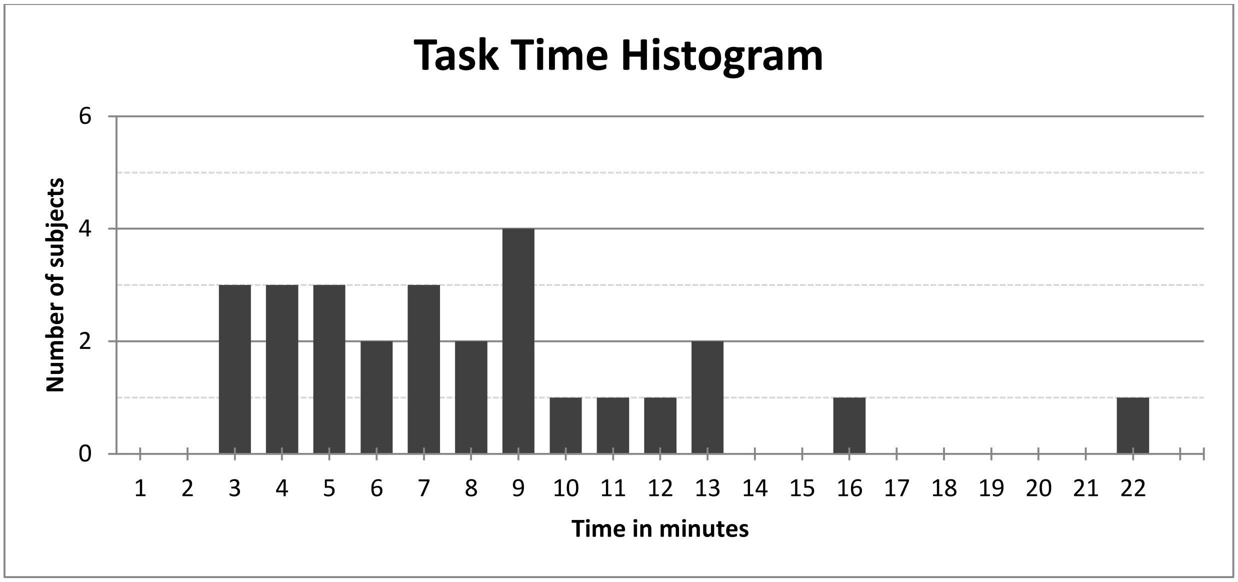
ANOVA: TactaBelt vs. Both						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	4.571	1	4.571	4.085	0.066	4.747
Within Groups	13.429	12	1.119			
Total	18.000	13				


Histogram for Interface Types
Number of subjects
5
4
3
2
1
0
None
Ring
Vibro-tactile
Both
Interface type
Goodness = 1
Goodness = 2
Goodness = 3
Goodness = 4
Goodness = 5

A.2.5 Task Time[+]

Subject#	Start Time	End Time	Delta (seconds)
0	1238789454	1238789644	190
1	1239365659	1239365837	178
2	1239367637	1239368384	747
3	1239370022	1239370570	548
4	1239371417	1239371989	572
5	1239372994	1239373310	316
6	1239374867	1239375304	437
7	1239390502	1239390734	232
8	1239394176	1239394450	274
9	1239396449	1239396936	487
10	1239631811	1239632074	263
11	1239633581	1239634344	763
12	1239635666	1239635895	229
13	1239637131	1239637675	544
14	1239638989	1239640294	1305
15	1239642457	1239642732	275
16	1239712960	1239713155	195
17	1239714638	1239715022	384
18	1239718669	1239719181	512
19	1239729005	1239729402	397
20	1239738055	1239739022	967
21	1239740112	1239740916	804
22	1239887560	1239888204	644
23	1240328382	1240328830	448
24	1240340934	1240341271	337
25	1240513994	1240514545	551
26	1240515896	1240516392	496

Task Time	
AVG:	485.00
Median:	448.00
Std. dev.	263.32



A.2.5.1 Task Time per Group

Task Time in Seconds per Group			
None	**Ring**	**TactaBelt**	**Both**
190	178	747	548
232	572	316	437
263	763	274	487
544	1305	275	229
195	384	512	397
448	967	804	644
496		337	551

Group vs. Time (sec.)	Mean	Median	Std. Dev.
None	338.286	263	152.049
Ring	694.833	667.5	407.393
TactaBelt	466.429	337	226.497
Both	470.429	487	133.982

ANOVA: All Groups					
Source of Variation	*SS*	*MS*	*F*	*P-value*	*F crit*
Between Groups	418756.3	139585.437	2.320	**0.102**	3.028
Within Groups	1384074	60177.117			
Total	1802830				

ANOVA: None vs. Ring						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	410715.430	1	410715.430	4.665	0.054	4.844
Within Groups	968560.262	11	88050.933			
Total	1379275.692	12				

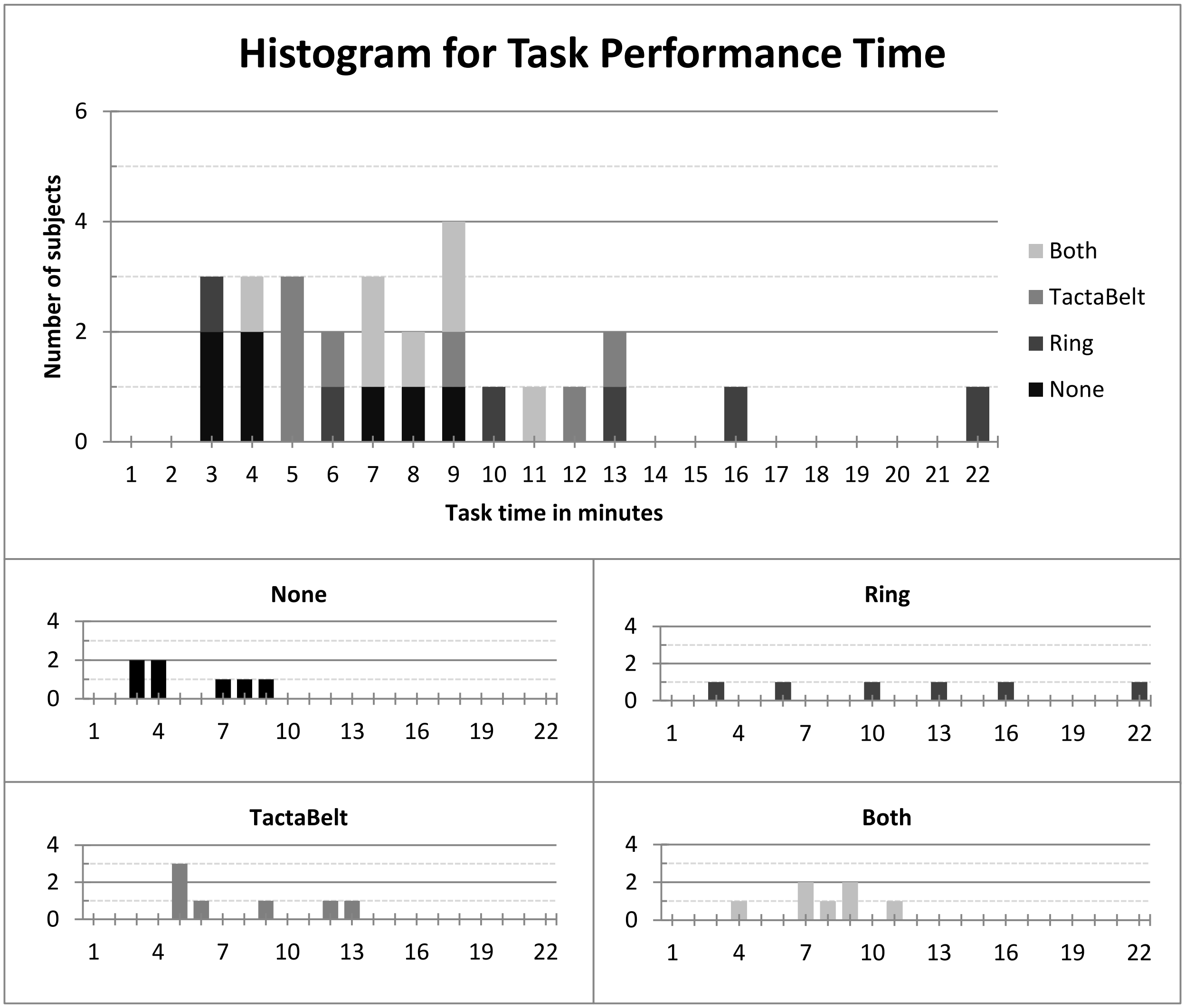
ANOVA: None vs. TactaBelt						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	57472.071	1	57472.07143	1.544536	0.23768	4.747225
Within Groups	446519.143	12	37209.92857			
Total	503991.214	13				

ANOVA: None vs. Both						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	61116.071	1	61116.071	2.976	0.110	4.747
Within Groups	246421.143	12	20535.095			
Total	307537.214	13				

ANOVA: Ring vs. TactaBelt						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	168545.145	1	168545.145	1.630	0.228	4.844
Within Groups	1137652.548	11	103422.959			
Total	1306197.692	12				

ANOVA: Ring vs. Both						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	162693.452	1	162693.452	1.909	0.195	4.844
Within Groups	937554.548	11	85232.232			
Total	1100248.000	12				

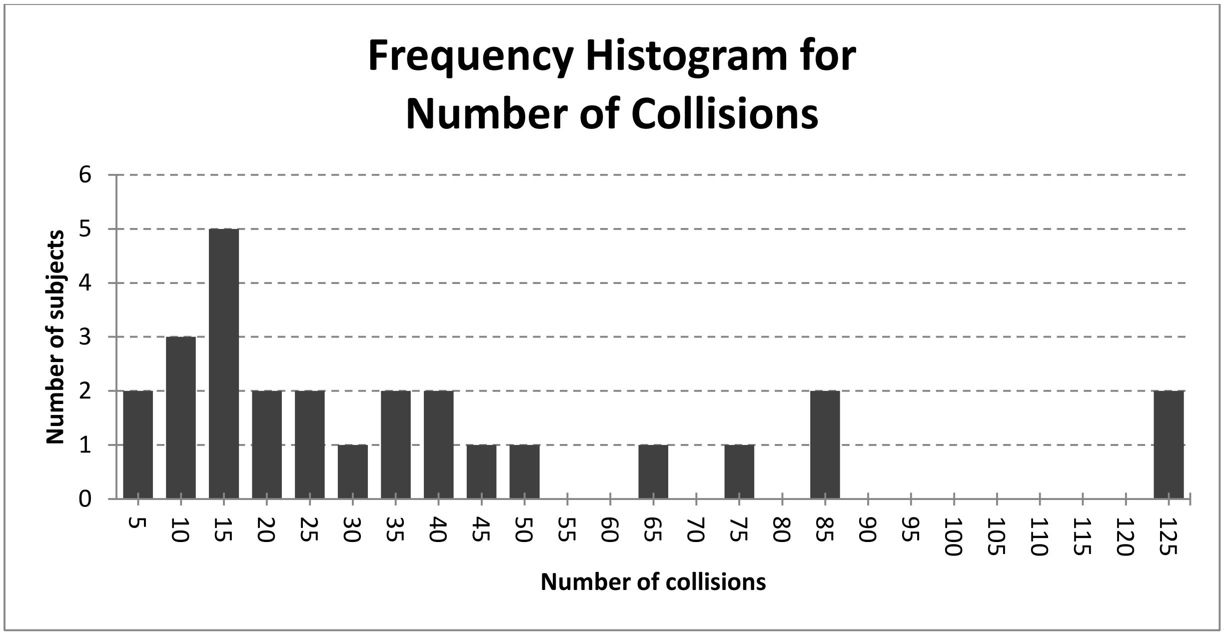
ANOVA: TactaBelt vs. Both						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	56.000	1	56.000	0.002	0.969	4.747
Within Groups	415513.429	12	34626.119			
Total	415569.429	13				


Histogram for Task Performance Time
Number of subjects
Task time in minutes
Both
TactaBelt
Ring
None
None
Ring
TactaBelt
Both

A.2.6 Number of Collisions*

Subject#	Num. Collisions
0	15
1	12
2	37
3	81
4	122
5	38
6	11
7	12
8	7
9	9
10	13
11	71
12	1
13	2
14	122
15	27
16	16
17	18
18	31
19	7
20	85
21	43
22	49
23	62
24	22
25	33
26	23

Number of Collisions	
AVG:	35.89
Median:	23.00
Std. dev.	34.02



A.2.6.1 Number of Collisions per Group

Group 0	Group 1	Group 2	Group 3
15	12	37	81
12	122	38	11
13	71	7	9
2	122	27	1
16	18	31	7
62	85	43	49
23		22	33

Group vs. Num Collisions	Mean	Median	Std. Dev.
None	20.429	13	5.595
Ring	71.667	78	48.343
TactaBelt	29.286	9	12.802
Both	27.286	9	33.305

ANOVA: All groups

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10176.762	3	3392.254	3.919	0.021	3.028
Within Groups	19907.905	23	865.561			
Total	30084.667	26				

ANOVA: None vs. Ring

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8481.875	1	8481.875	6.695	0.025	4.844
Within Groups	13935.048	11	1266.823			
Total	22416.923	12				

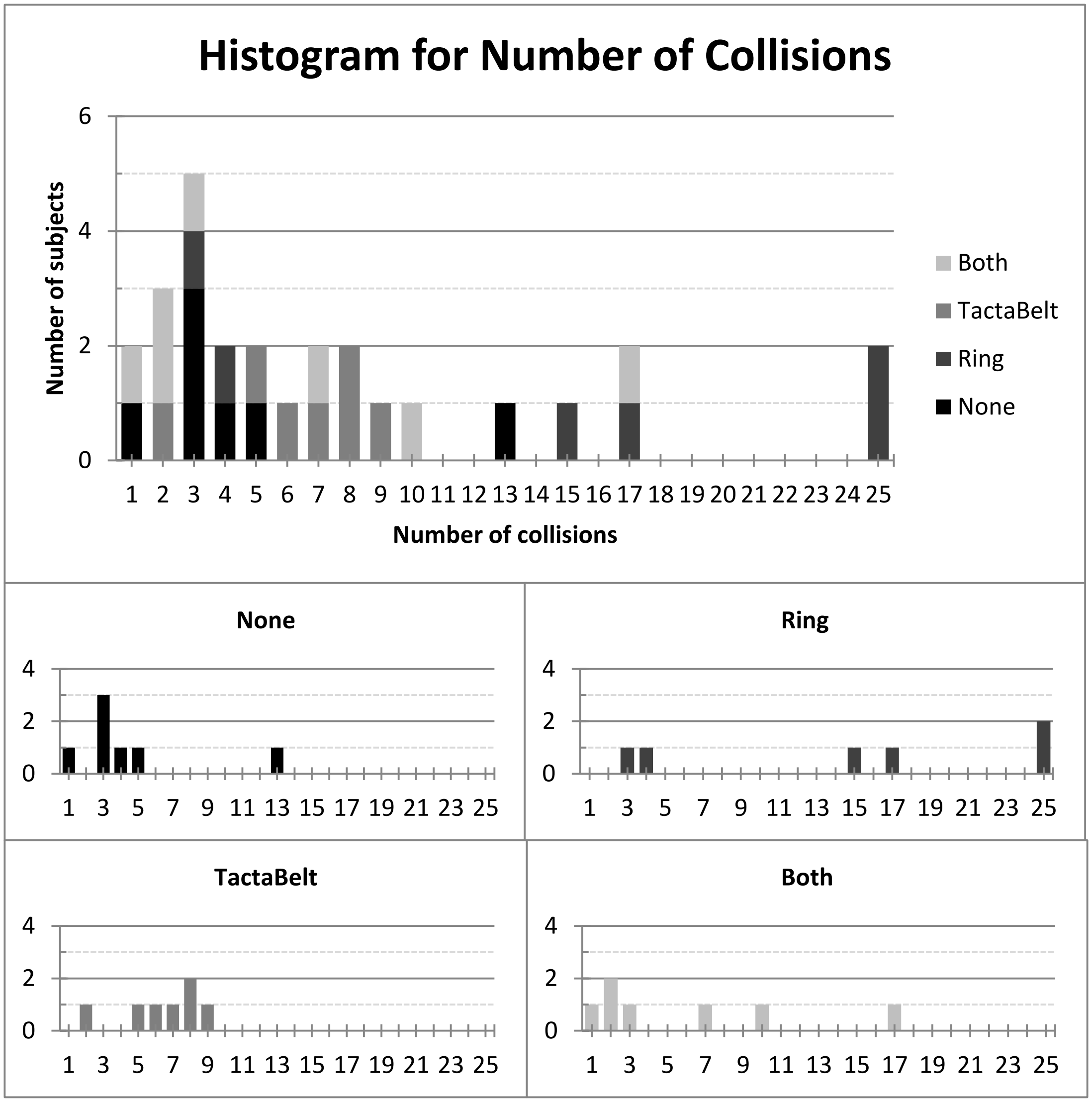
ANOVA: None vs. TactaBelt						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	274.571	1	274.571	1.052	0.325	4.747
Within Groups	3131.143	12	260.929			
Total	3405.714	13				

ANOVA: None vs. Both						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	164.571	1	164.571	0.269	0.613	4.747
Within Groups	7341.143	12	611.762			
Total	7505.714	13				

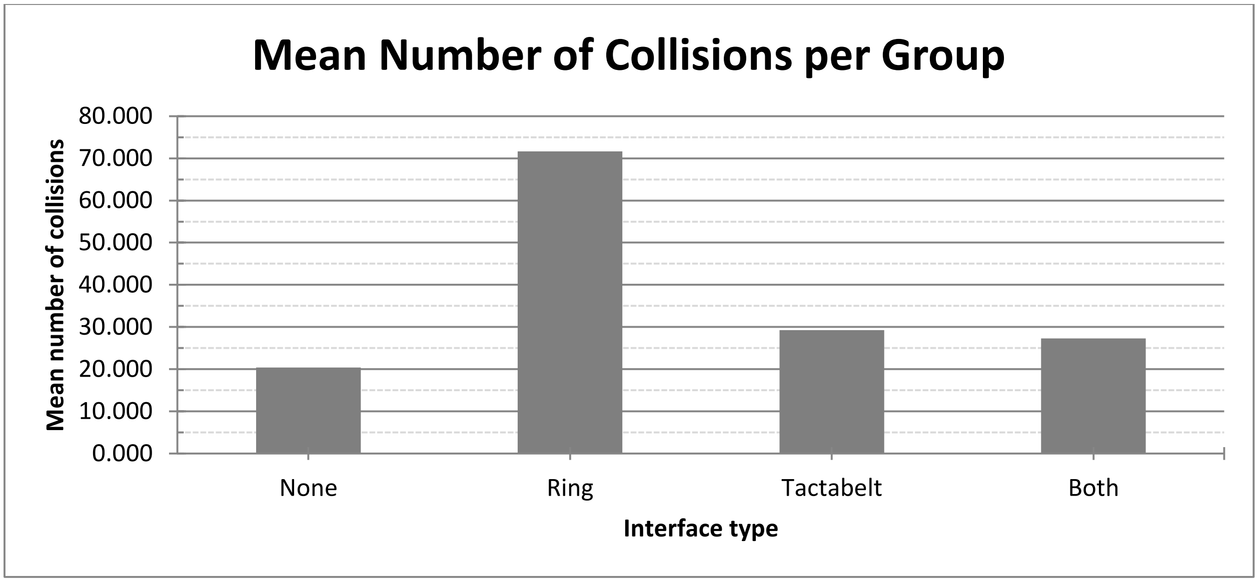
ANOVA: Ring vs. TactaBelt						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	5802.930	1	5802.930	5.079	0.046	4.844
Within Groups	12566.762	11	1142.433			
Total	18369.692	12				

ANOVA: Ring vs. Both						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	6363.546	1	6363.546	4.172	0.066	4.844
Within Groups	16776.762	11	1525.160			
Total	23140.308	12				

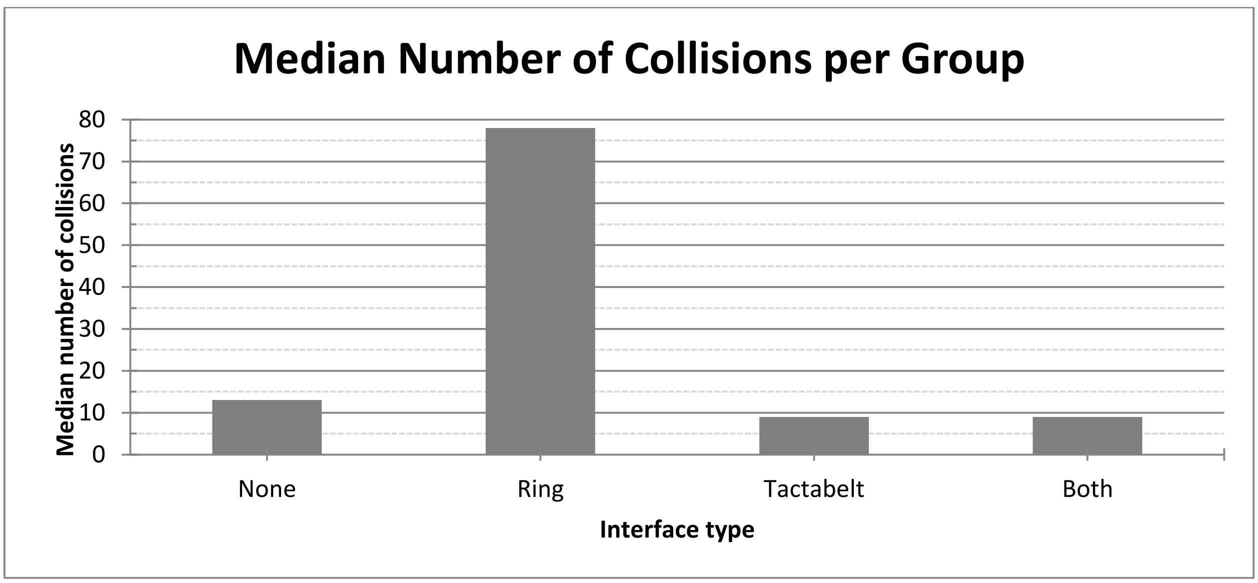
ANOVA: TactaBelt vs. Both						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	14.000	1	14.000	0.028	0.870	4.747
Within Groups	5972.857	12	497.738			
Total	5986.857	13				



Histogram for Number of Collisions
Number of subjects
Number of collisions
Both
TactaBelt
Ring
None
0
2
4
6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
None
Ring
TactaBelt
Both
1 3 5 7 9 11 13 15 17 19 21 23 25



Mean Number of Collisions per Group
Mean number of collisions
80.000
70.000
60.000
50.000
40.000
30.000
20.000
10.000
0.000
None
Ring
Tactabelt
Both
Interface type



Median Number of Collisions per Group
Median number of collisions
80
70
60
50
40
30
20
10
0
None
Ring
Tactabelt
Both
Interface type

A.2.7 Number of Collisions per Minute

Subject Number	Group	Num. Collisions	Time (Mins)	Num. Col. Per Min.
1	0	15	3	5.000
2	1	12	3	4.000
3	2	37	12	3.083
4	3	81	9	9.000
5	1	122	10	12.200
6	2	38	5	7.600
7	3	11	7	1.571
8	0	12	4	3.000
9	2	7	5	1.400
10	3	9	8	1.125
11	0	13	4	3.250
12	1	71	13	5.462
13	3	1	4	0.250
14	0	2	9	0.222
15	1	122	22	5.545
16	2	27	5	5.400
17	0	16	3	5.333
18	1	18	6	3.000
19	2	31	9	3.444
20	3	7	7	1.000
21	1	85	16	5.313
22	2	43	13	3.308
23	3	49	11	4.455
24	0	62	7	8.857
25	2	22	6	3.667
26	3	33	9	3.667
27	0	23	8	2.875

Number of Collisions per Minute per Group				
	None	**Ring**	**TactaBelt**	**Both**
	0.222	3.000	1.400	0.250
	2.875	4.000	3.083	1.000
	3.000	5.313	3.308	1.125
	3.250	5.462	3.444	1.571
	5.000	5.545	3.667	3.667
	5.333	12.200	5.400	4.455
	8.857		7.600	9.000
Median	3.250	5.387	3.444	1.571
Mean + Std. Dev.	6.767	9.156	5.962	6.056
Mean - Std. Dev.	1.386	2.684	2.010	-0.037
Mean	4.077	5.920	3.986	3.010
Std. Dev.	2.690	3.236	1.976	3.046

ANOVA: None vs. Ring						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	10.975	1	10.975	1.260	0.286	4.844
Within Groups	95.799	11	8.709			
Total	106.774	12				

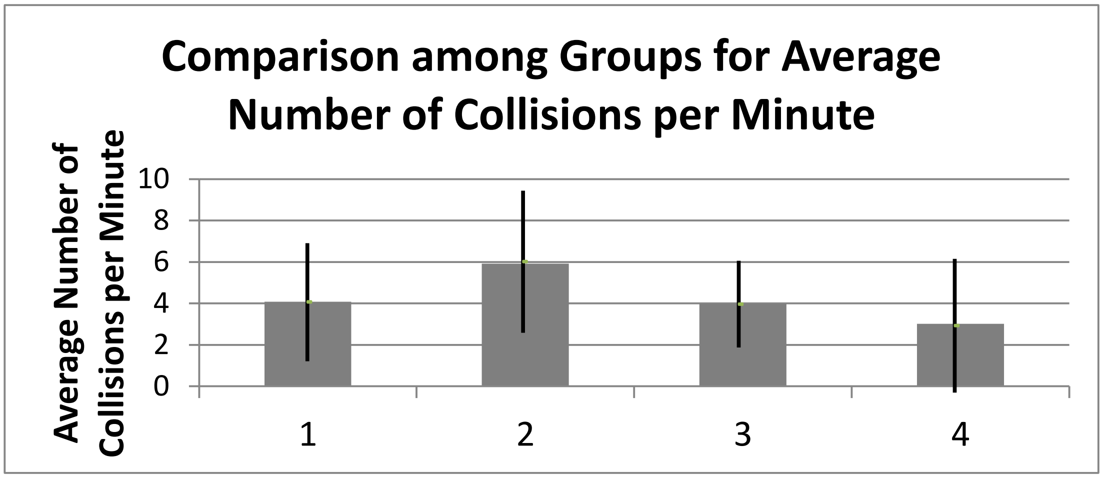
ANOVA: None vs. TactaBelt						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.029	1	0.029	0.005	0.944	4.747
Within Groups	66.846	12	5.570			
Total	66.875	13				

ANOVA: None vs. Both						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	3.986	1	3.986	0.483	0.500	4.747
Within Groups	99.106	12	8.259			
Total	103.092	13				

ANOVA: Ring vs. TactaBelt						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	12.083	1	12.083	1.754	0.212	4.844
Within Groups	75.789	11	6.890			
Total	87.872	12				

ANOVA: Ring vs. Both						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	27.363	1	27.363	2.786	0.123	4.844
Within Groups	108.049	11	9.823			
Total	135.412	12				

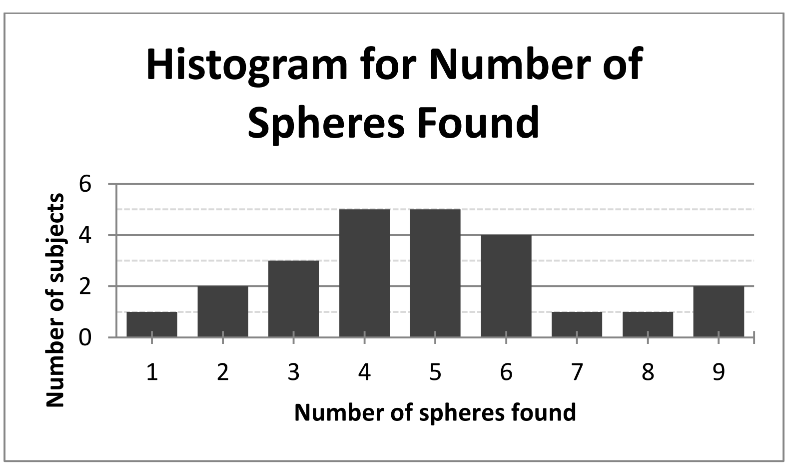
ANOVA: TactaBelt vs. Both						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	3.336	1	3.336	0.506	0.490	4.747
Within Groups	79.096	12	6.591			
Total	82.433	13				


Comparison among Groups for Average Number of Collisions per Minute
Average Number of Collisions per Minute
10
8
6
4
2
0
1
2
3
4

A.2.8 Number of Spheres Found

Subject #	Num. Spheres Found Reported:	Num. Spheres Actually Found:
0	2	2
1	1	1
2	6	5
3	5	5
4	2	2
5	1	1
6	6	6
7	3	3
8	6	6
9	5	5
10	2	2
11	6	6
12	3	3
13	6	6
14	8	8
15	4	4
16	4	4
17	4	4
18	4	4
19	5	5
20	4	4
21	9	7
22	5	5
23	3	3
24	2	2
25	9	9
26	9	9

Number of Spheres Found	
AVG:	4.481481481
Median:	4
Std. dev.	2.207859569



A.2.8.1 Number of Spheres Found per Group

Group 0	Group 1	Group 2	Group 3
2	1	5	5
3	2	1	6
2	6	6	5
6	8	4	3
4	4	4	5
3	4	7	5
9		2	9

Group vs. Num. Spheres	**Mean**	**Median**	**Std. Dev.**
None	4.143	3	2.545
Ring	4.167	4	2.563
Vibro-tactile	4.143	4	2.116
Both	5.429	5	1.813

ANOVA: All Groups					
Source of Variation	***SS***	***MS***	***F***	***P-value***	***F crit***
Between Groups	8.479	2.826	0.550	0.653	3.028
Within Groups	118.262	5.142			
Total	126.741				

ANOVA: None vs. Ring						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.002	1	0.002	0.000	0.987	4.844
Within Groups	71.690	11	6.517			
Total	71.692	12				

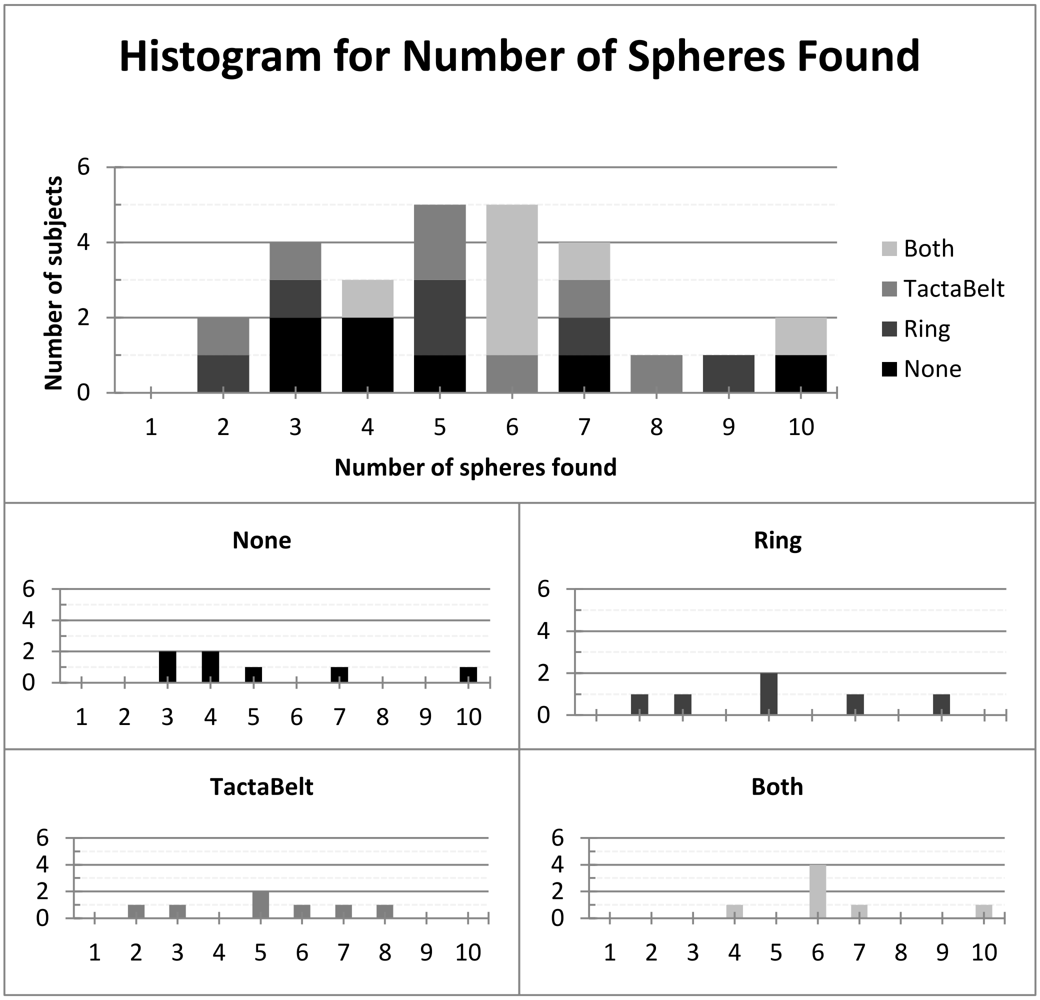
ANOVA: None vs. TactaBelt						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.000	1	0.000	0.000	1.000	4.747
Within Groups	65.714	12	5.476			
Total	65.714	13				

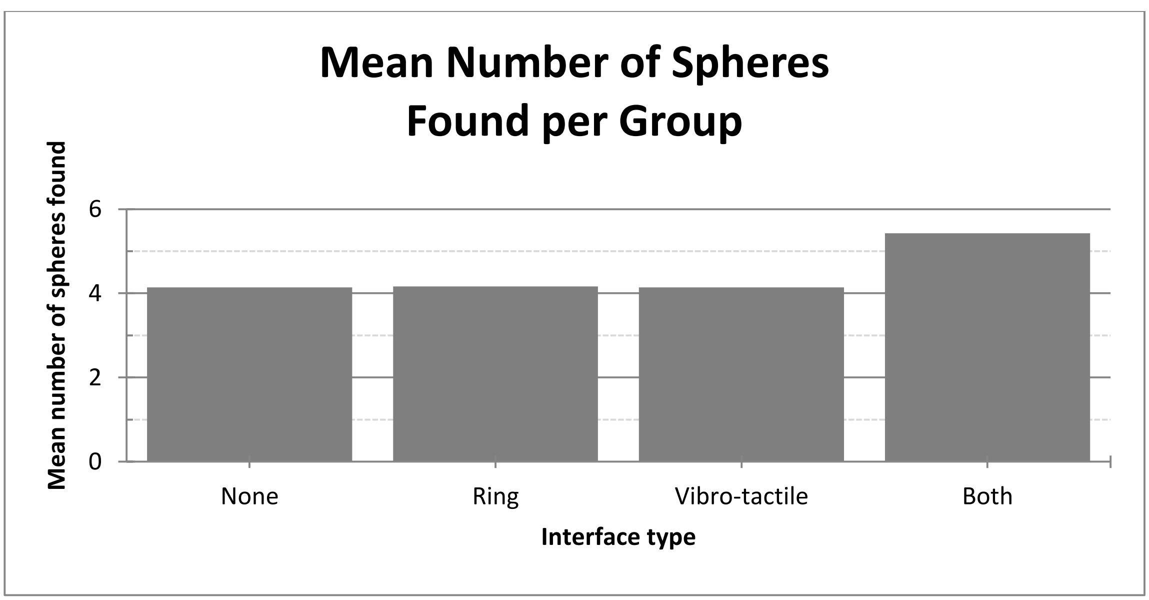
ANOVA: None vs. Both						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	5.786	1	5.786	1.185	0.298	4.747
Within Groups	58.571	12	4.881			
Total	64.357	13				

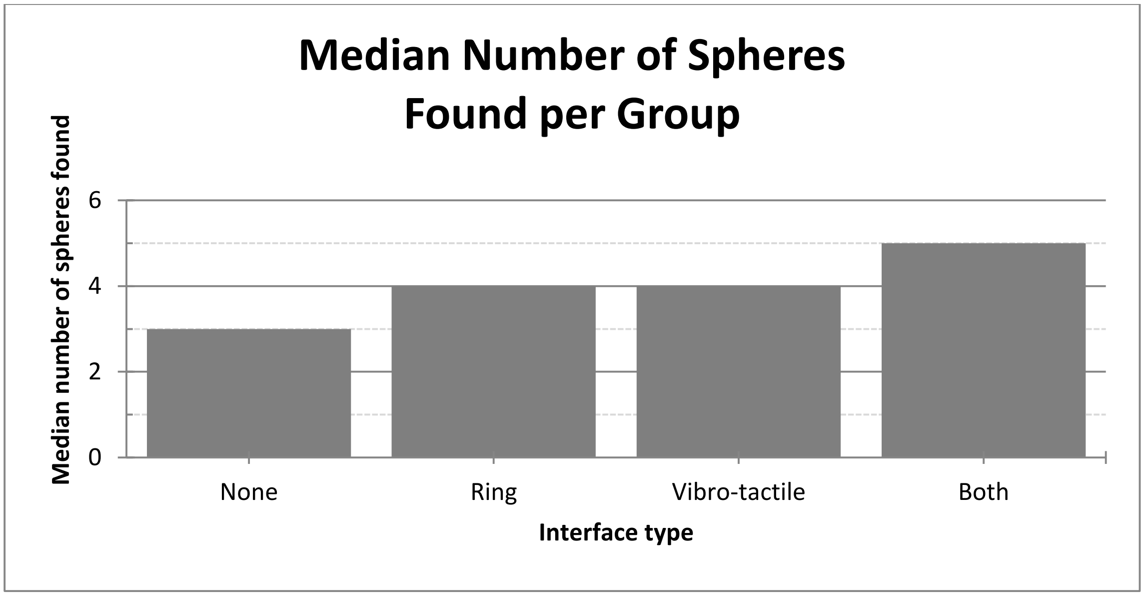
ANOVA: Ring vs. TactaBelt						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.002	1	0.002	0.000	0.986	4.844
Within Groups	59.690	11	5.426			
Total	59.692	12				

ANOVA: Ring vs. Both						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	5.145	1	5.145	1.077	0.322	4.844
Within Groups	52.548	11	4.777			
Total	57.692	12				

ANOVA: TactaBelt vs. Both						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	5.786	1	5.786	1.491	0.246	4.747
Within Groups	46.571	12	3.881			
Total	52.357	13				


Histogram for Number of Spheres Found
Number of subjects
0
2
4
6
1
2
3
4
5
6
7
8
9
10
Number of spheres found
Both
TactaBelt
Ring
None
None
Ring
TactaBelt
Both


Mean Number of Spheres
Found per Group
Mean number of spheres found
0
2
4
6
None
Ring
Vibro-tactile
Both
Interface type


Median Number of Spheres
Found per Group
Median number of spheres found
6
4
2
0
None
Ring
Vibro-tactile
Both
Interface type

A.2.9 Number of Spheres Found per Minute*

Subject Number	Group	Num. Spheres Actually Found	Time (Mins)	Num. Spheres Found per Min.
1	0	2	3	0.667
2	1	1	3	0.333
3	2	5	12	0.417
4	3	5	9	0.556
5	1	2	10	0.200
6	2	1	5	0.200
7	3	6	7	0.857
8	0	3	4	0.750
9	2	6	5	1.200
10	3	5	8	0.625
11	0	2	4	0.500
12	1	6	13	0.462
13	3	3	4	0.750
14	0	6	9	0.667
15	1	8	22	0.364
16	2	4	5	0.800
17	0	4	3	1.333
18	1	4	6	0.667
19	2	4	9	0.444
20	3	5	7	0.714
21	1	4	16	0.250
22	2	7	13	0.538
23	3	5	11	0.455
24	0	3	7	0.429
25	2	2	6	0.333
26	3	9	9	1.000
27	0	9	8	1.125

A.2.9.1 Number of Spheres Found per Minute per Group

Number of Spheres Found per Minute per Group				
	None	**Ring**	**TactaBelt**	**Both**
	0.667	0.333	0.417	0.556
	0.750	0.200	0.200	0.857
	0.500	0.462	1.200	0.625
	0.667	0.364	0.800	0.750
	1.333	0.667	0.444	0.714
	0.429	0.250	0.538	0.455
	1.125		0.333	1.000
Median	0.667	0.348	0.444	0.714
Mean + Std. Dev.	1.112	0.547	0.899	0.892
Mean - Std. Dev.	0.451	0.212	0.225	0.524
Mean	0.781	0.379	0.562	0.708
Std. Dev.	0.330	0.168	0.337	0.184

ANOVA: None vs. Ring						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.075	1	0.075	1.013	0.334	4.747
Within Groups	0.886	12	0.074			
Total	0.961	13				

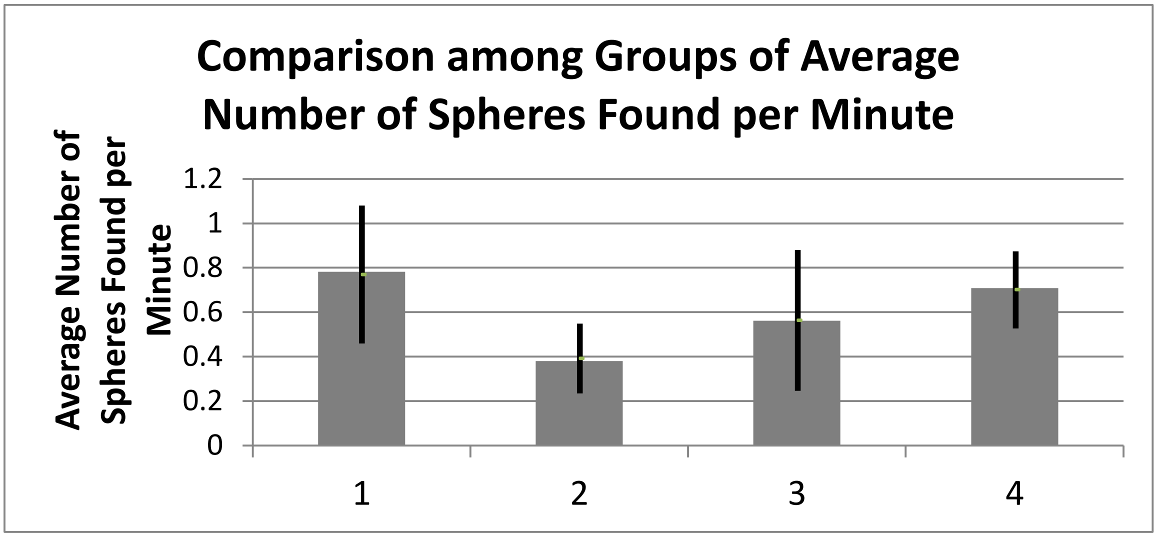
ANOVA: None vs. TactaBelt						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.169	1	0.169	1.516	0.242	4.747
Within Groups	1.336	12	0.111			
Total	1.505	13				

ANOVA: None vs. Both						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.019	1	0.019	0.264	0.617	4.747
Within Groups	0.857	12	0.071			
Total	0.876	13				

ANOVA: Ring vs. TactaBelt						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.108	1	0.108	1.440	0.255	4.844
Within Groups	0.823	11	0.075			
Total	0.931	12				

ANOVA: Ring vs. Both						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.349	1	0.349	11.166	0.007	4.844
Within Groups	0.344	11	0.031			
Total	0.694	12				

ANOVA: TactaBelt vs. Both						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.075	1	0.075	1.013	0.334	4.747
Within Groups	0.886	12	0.074			
Total	0.961	13				



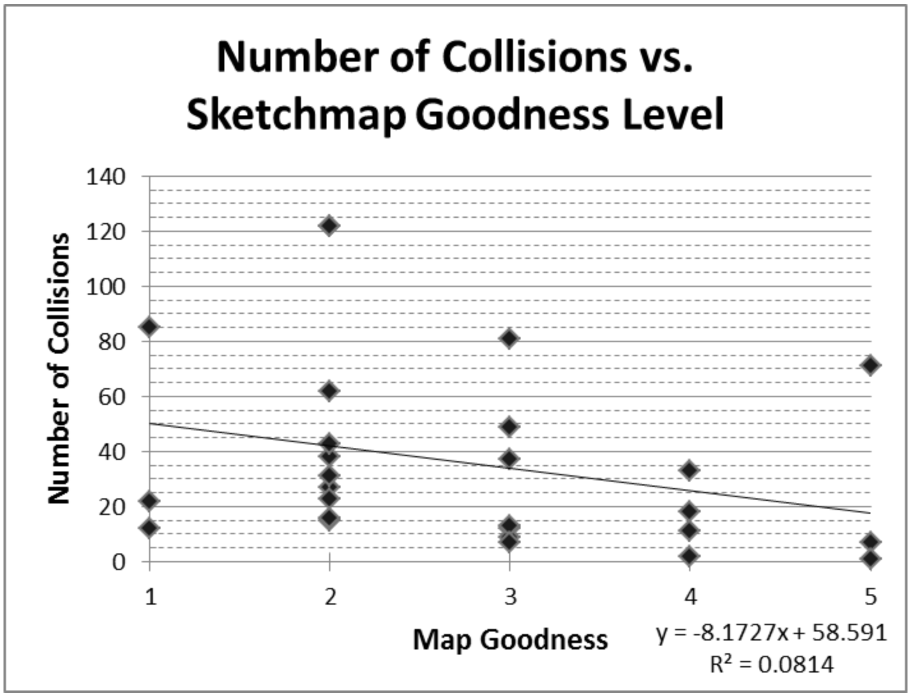
Comparison among Groups of Average Number of Spheres Found per Minute
Average Number of Spheres Found per Minute
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4

A.2.10 Error on Reporting Number of Spheres Found

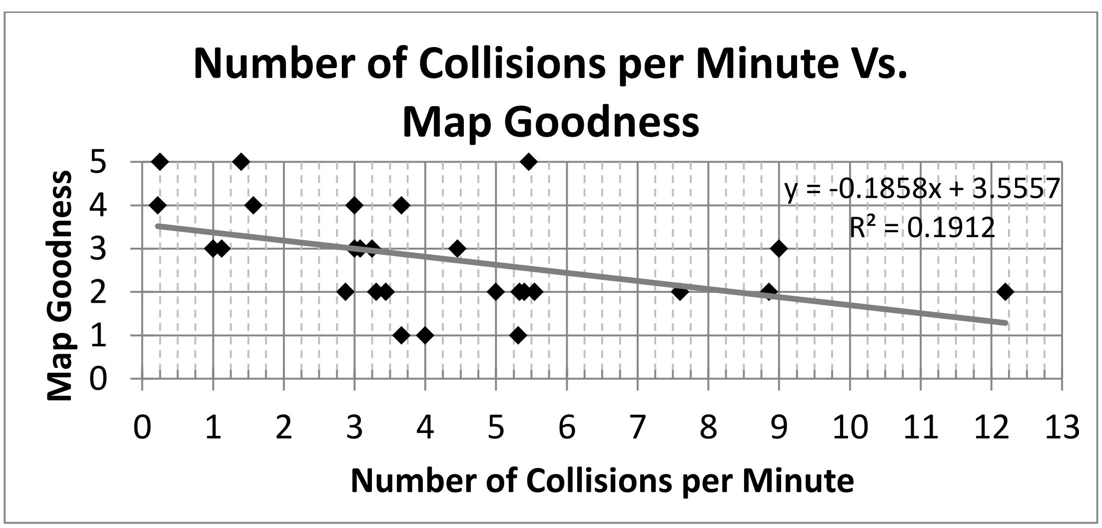
Errors in reporting the number of spheres found only happened for the TactaBelt group. For all of these cases, subjects reported a number of spheres higher than what was actually found.

Group	Num. Spheres Found Reported:	Num. Spheres Actually Found:	Error
0	2	2	0
1	1	1	0
2	6	5	**-1**
3	5	5	0
1	2	2	0
2	1	1	0
3	6	6	0
0	3	3	0
2	6	6	0
3	5	5	0
0	2	2	0
1	6	6	0
3	3	3	0
0	6	6	0
1	8	8	0
2	4	4	0
0	4	4	0
1	4	4	0
2	4	4	0
3	5	5	0
1	4	4	0
2	9	7	**-2**
3	5	5	0
0	3	3	0
2	2	2	0
3	9	9	0
0	9	9	0

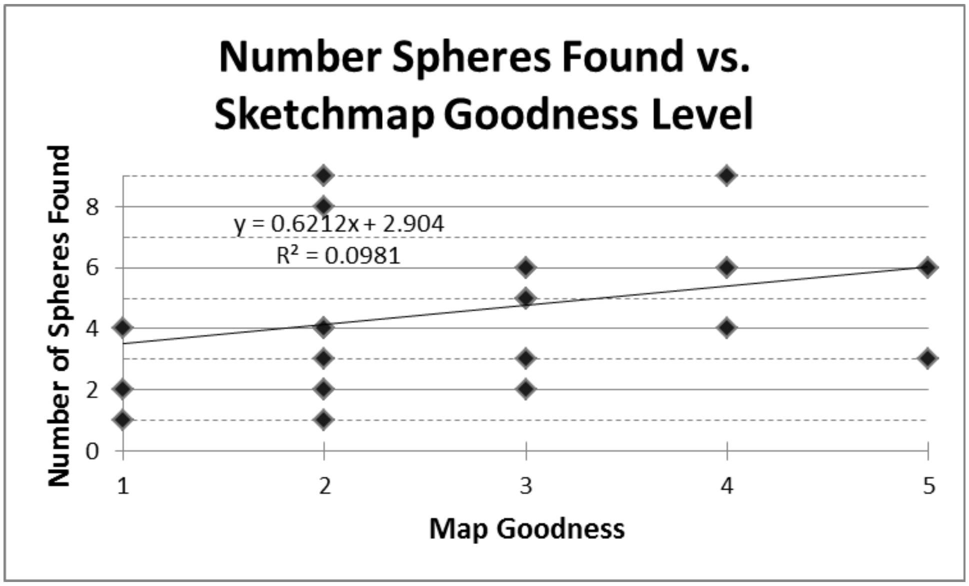
A.2.11 Correlation between Sketchmap Quality and Number of Collisions



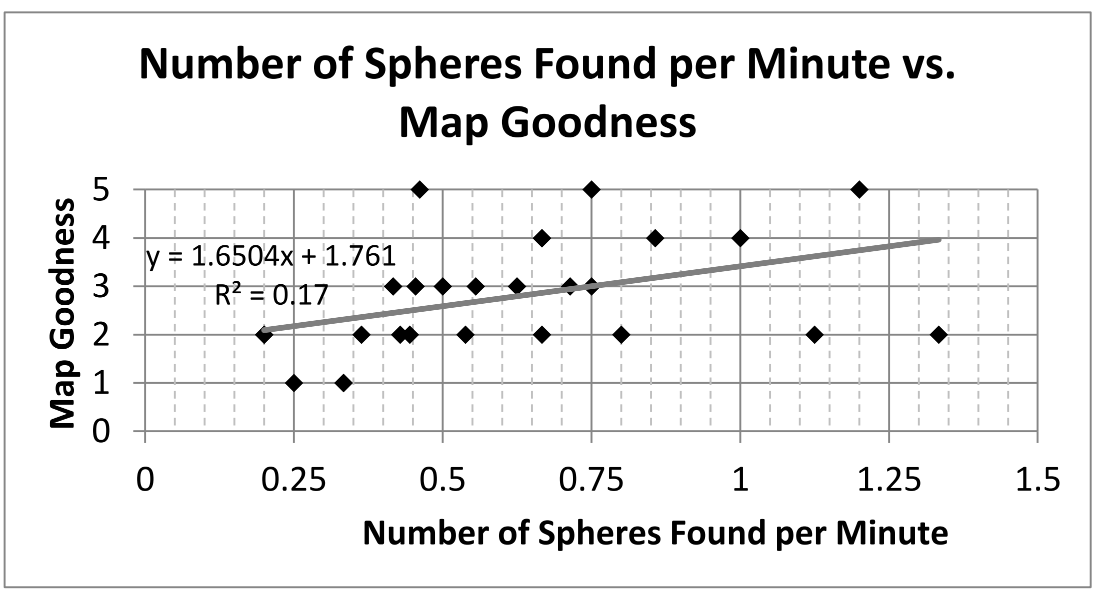
A.2.12 Correlation between Sketchmap Quality and Number of Collisions per Minute



A.2.13 Correlation between Sketchmap Quality and Number of Spheres Found



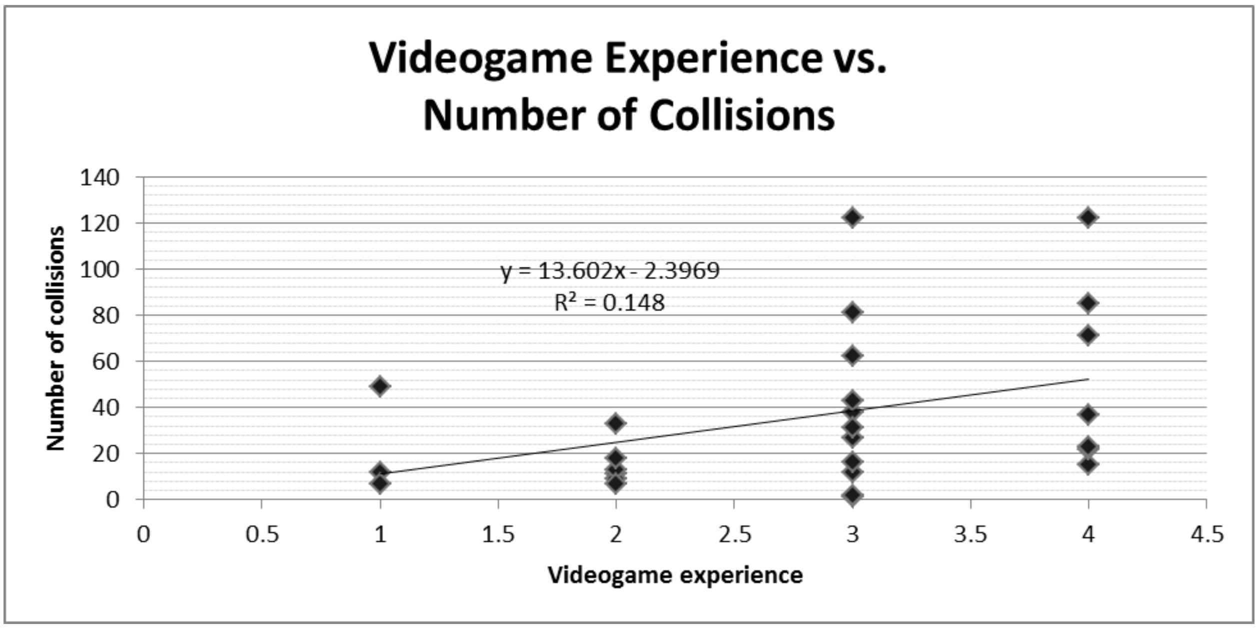
A.2.14 Correlation between Sketchmap Quality and Number of Spheres Found per Minute

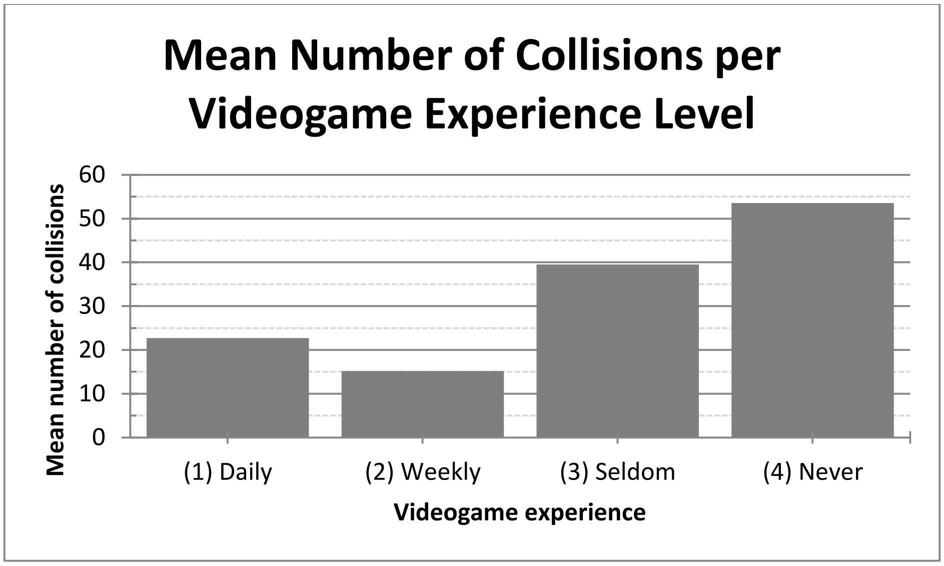


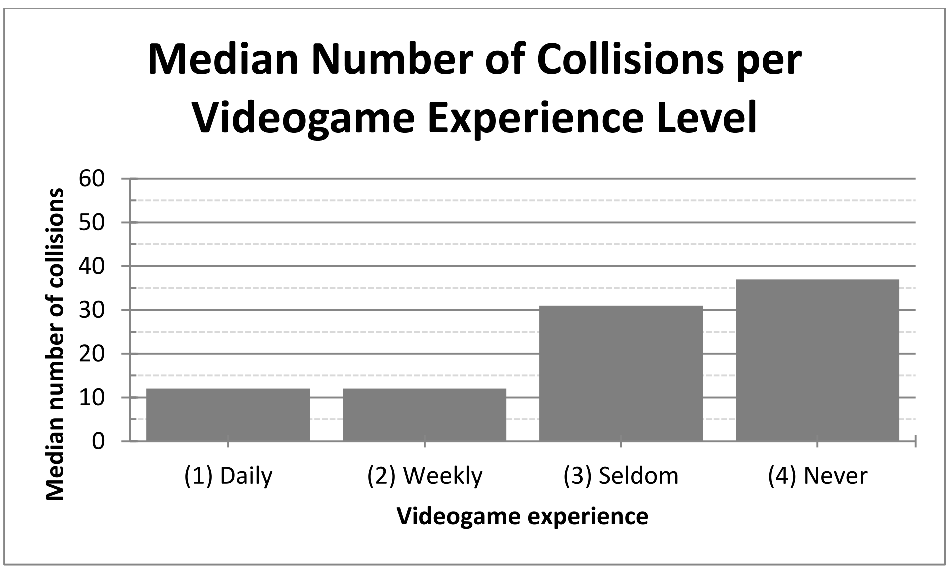
A.2.15 Correlation between Videogame Experience vs. Number of Collisions

A SSD for the number of collisions was found between groups with videogame experience of levels weekly and never. Daily gamers collided less with the virtual robot.

SSD in Number of Collisions between Groups with Different Levels of Videogame Experience				
	Daily	**Weekly**	**Seldom**	**Never**
Daily	x	no	no	no
Weekly	x	x	no	yes
Seldom	x	x	x	no

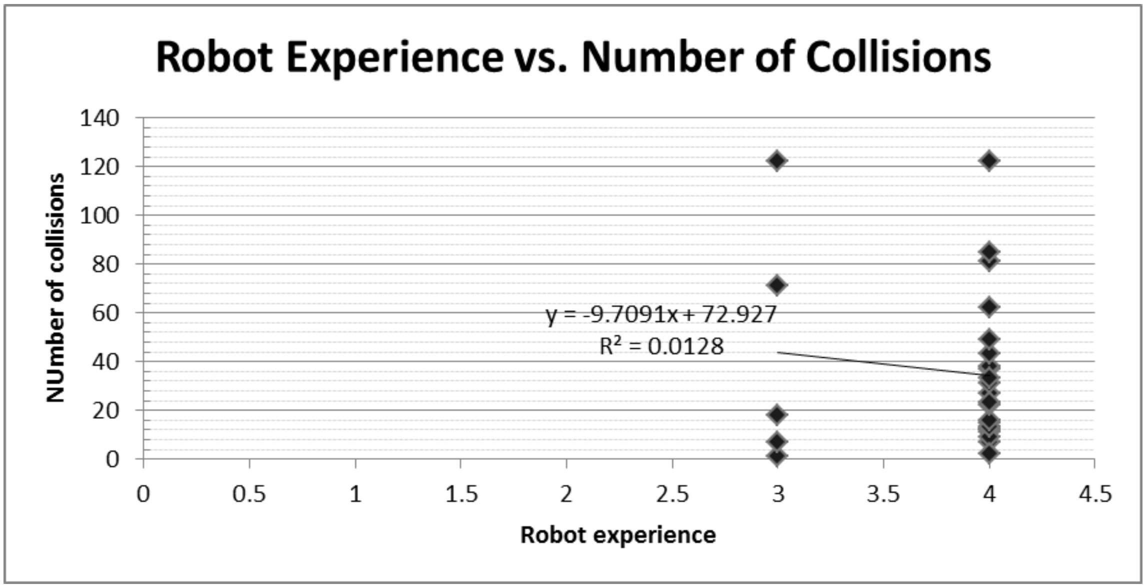


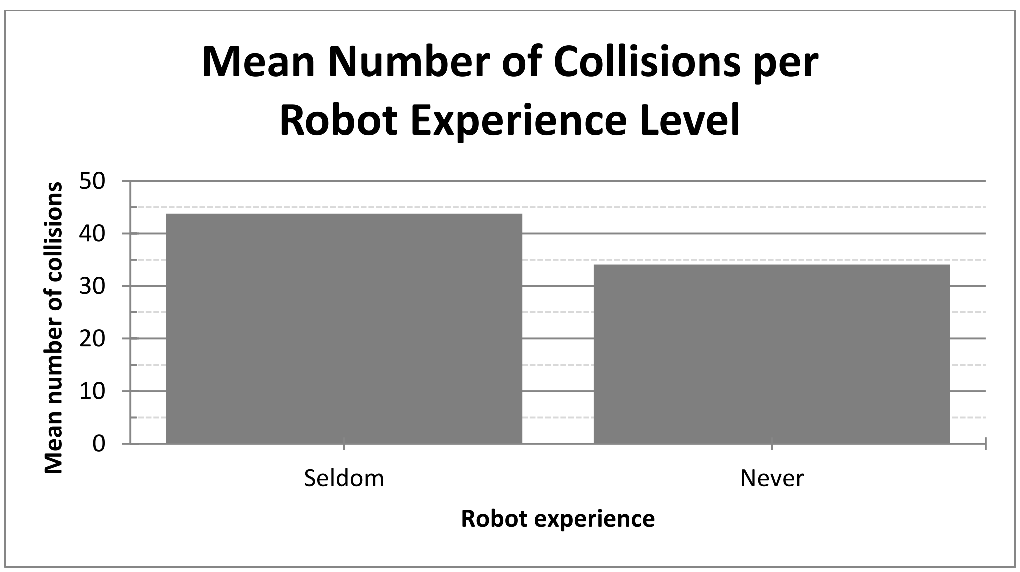

Mean Number of Collisions per Videogame Experience Level
Mean number of collisions
60
50
40
30
20
10
0
(1) Daily
(2) Weekly
(3) Seldom
(4) Never
Videogame experience

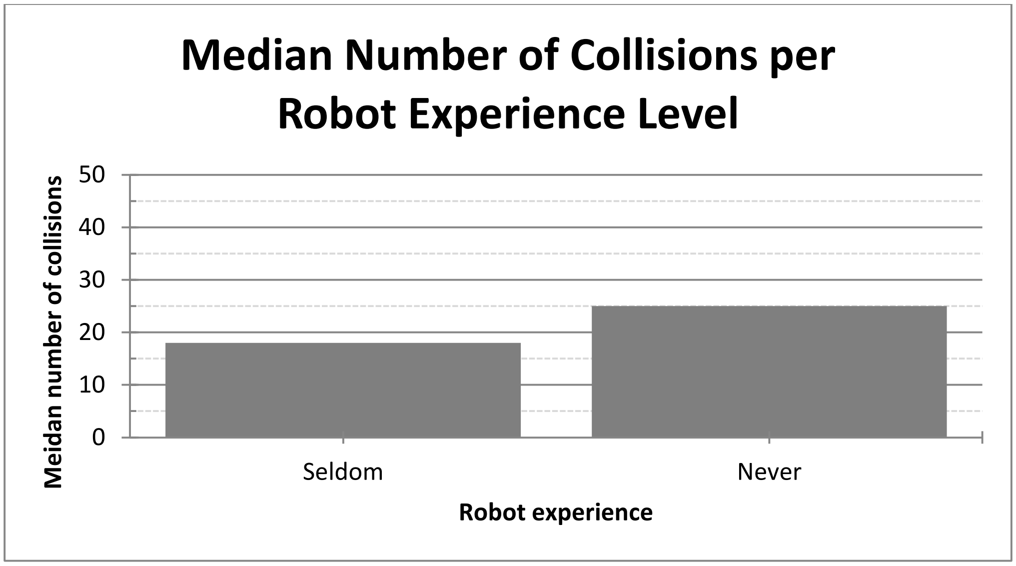

Median Number of Collisions per Videogame Experience Level
Median number of collisions
60
50
40
30
20
10
0
(1) Daily
(2) Weekly
(3) Seldom
(4) Never
Videogame experience

A.2.16 Correlation between Videogame Experience vs. Number of Collisions

No SSD was found between groups with different levels of robot experience. Only two of the four groups had subjects with any robot experience.

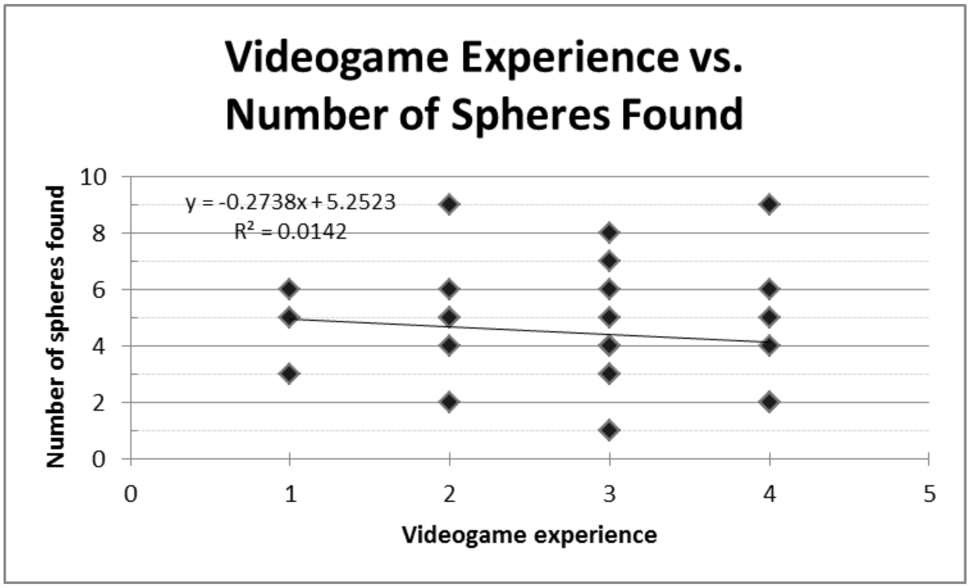


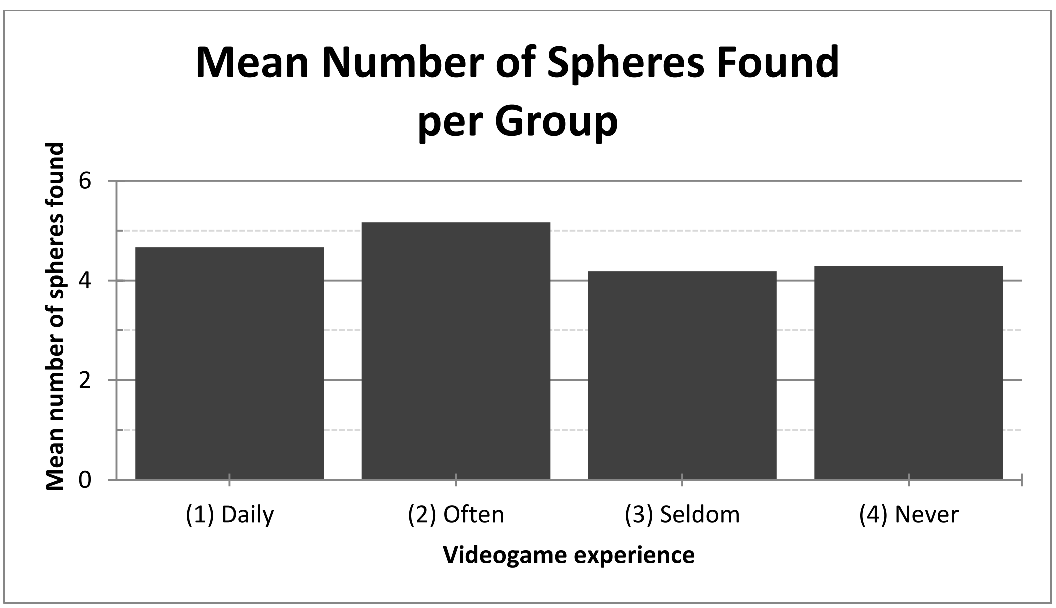


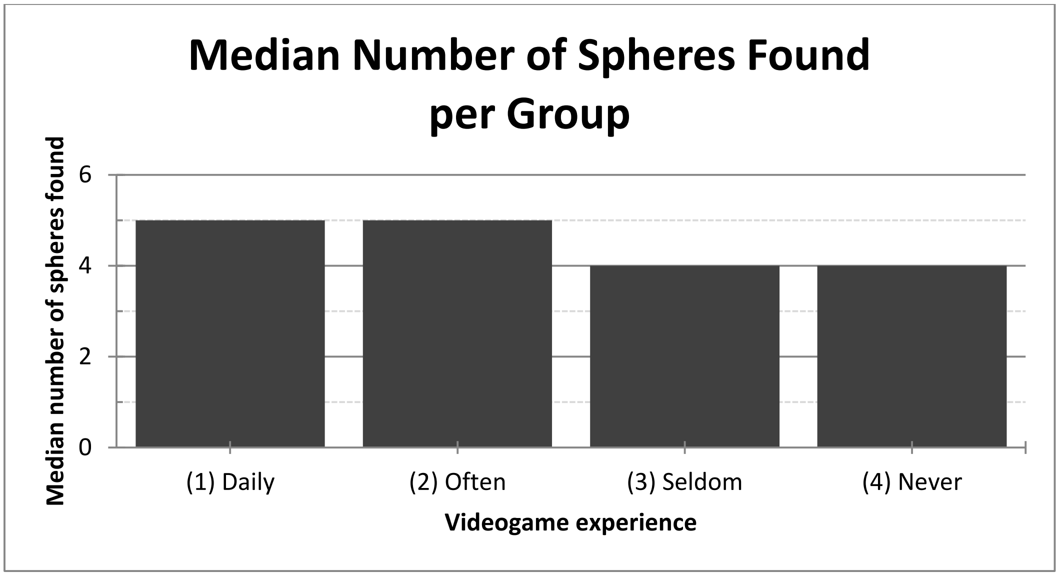

Median Number of Collisions per Robot Experience Level
Meidan number of collisions
50
40
30
20
10
0
Seldom
Never
Robot experience

A.2.17 Correlation between Videogame Experience vs. Number of Spheres Found

No SSD was found between groups with different levels of videogame experience.

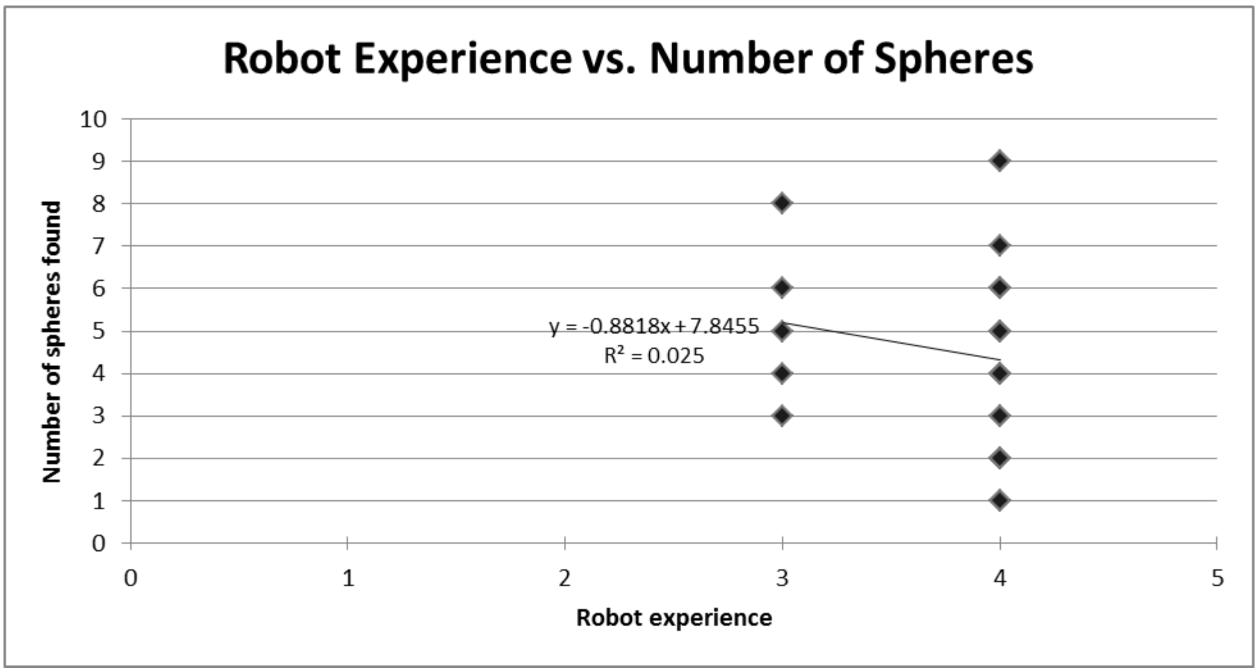


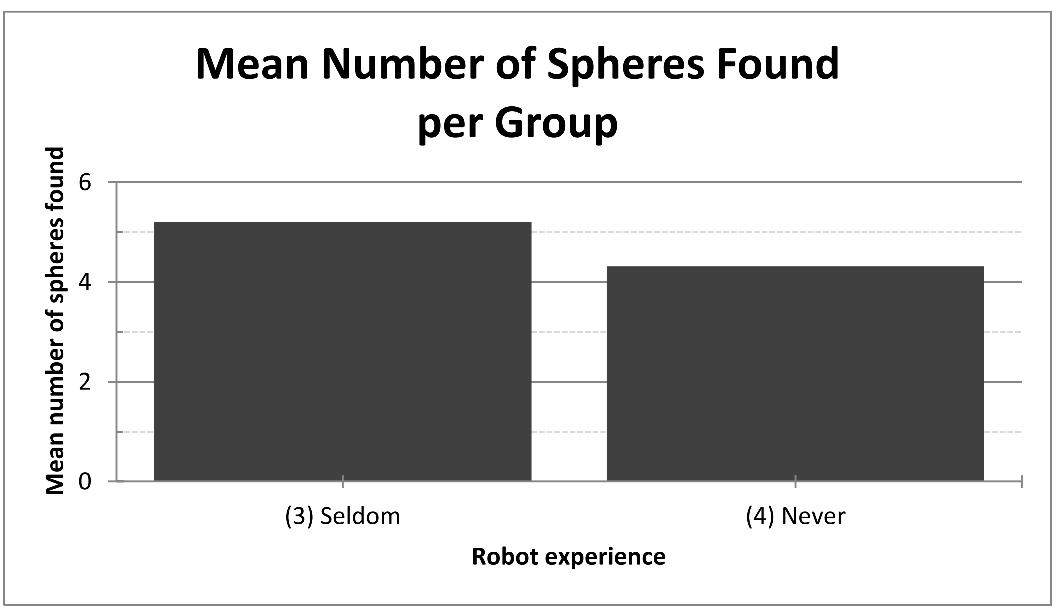


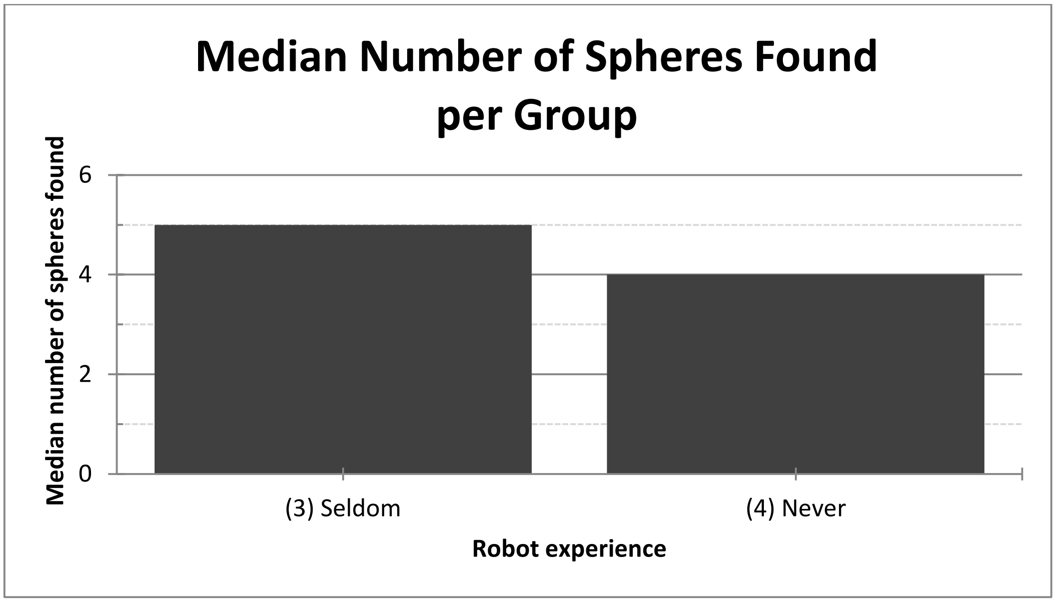

Median Number of Spheres Found per Group
Median number of spheres found
6
4
2
0
(1) Daily
(2) Often
(3) Seldom
(4) Never
Videogame experience

A.2.18 Correlation between Robot Experience vs. Number of Spheres Found

No SSD was found between groups with different levels of robot experience. Only two of the four groups had subjects with any robot experience.



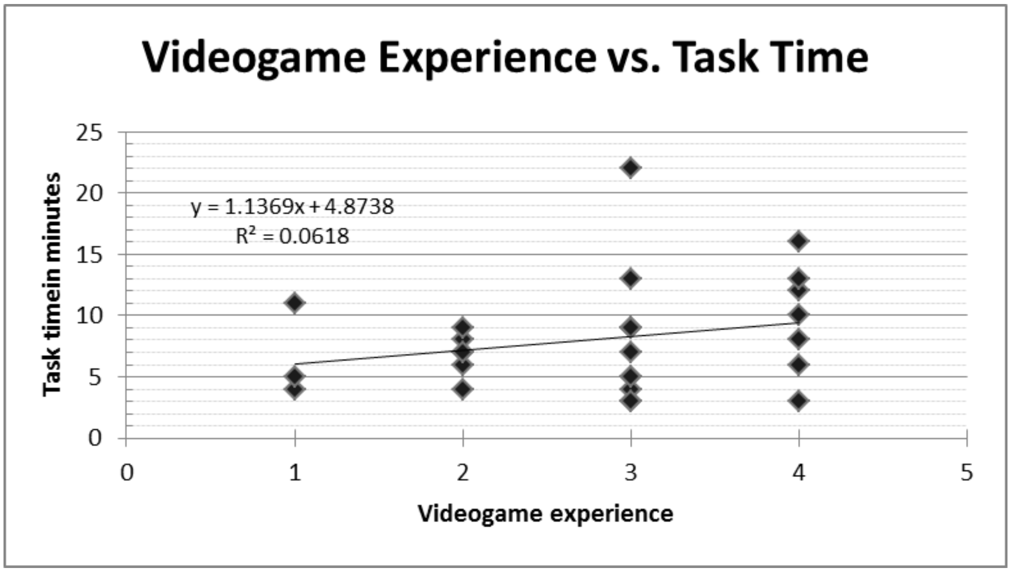


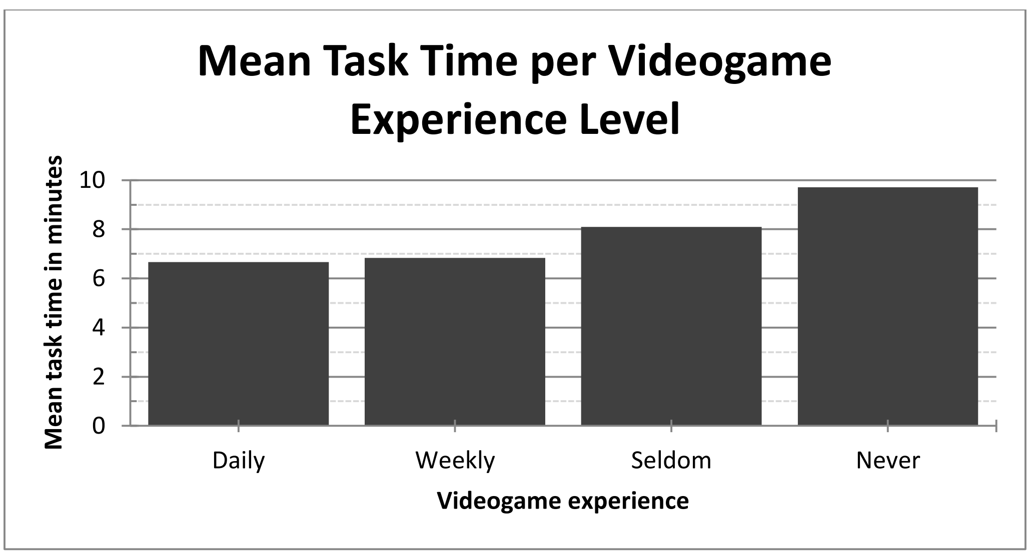


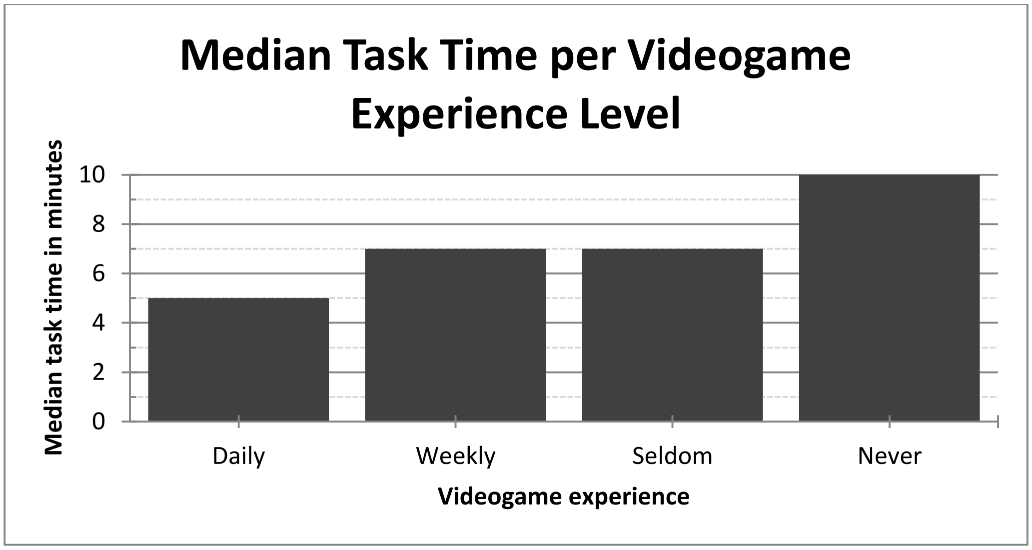
Median Number of Spheres Found per Group
Median number of spheres found
6
4
2
0
(3) Seldom
(4) Never
Robot experience

A.2.19 Correlation between Videogame Experience vs. Task Time

No SSD was found between groups with different levels of videogame experience.

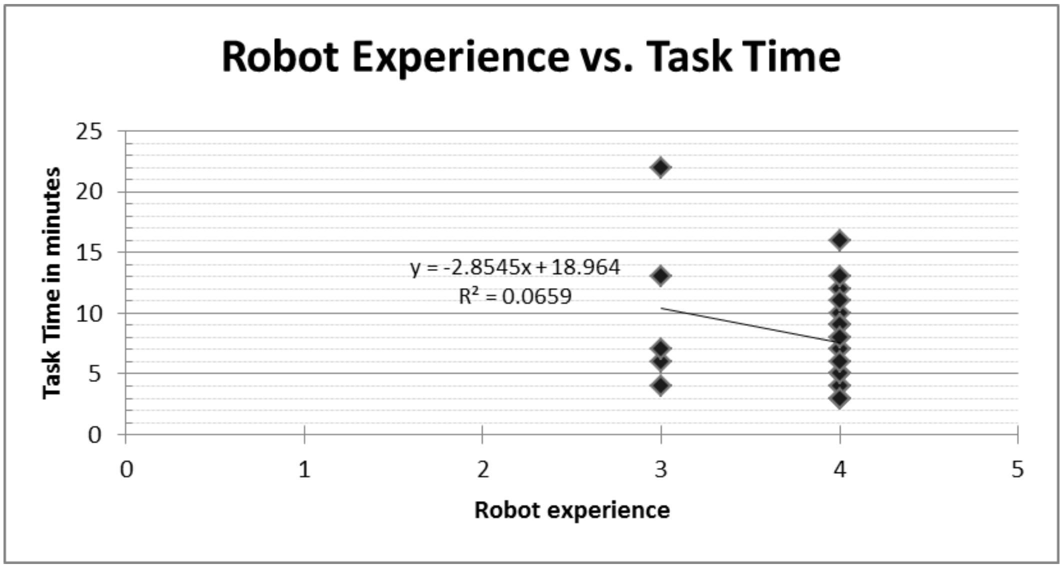


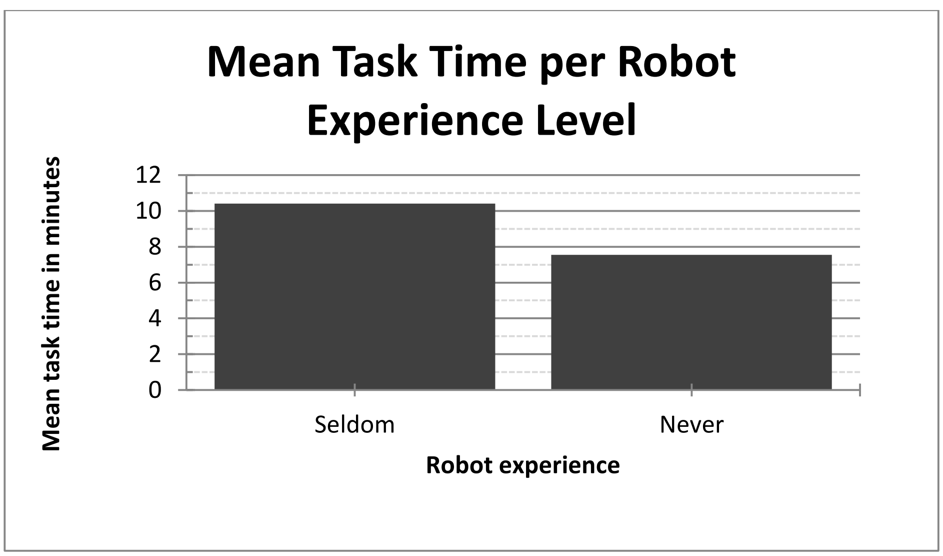


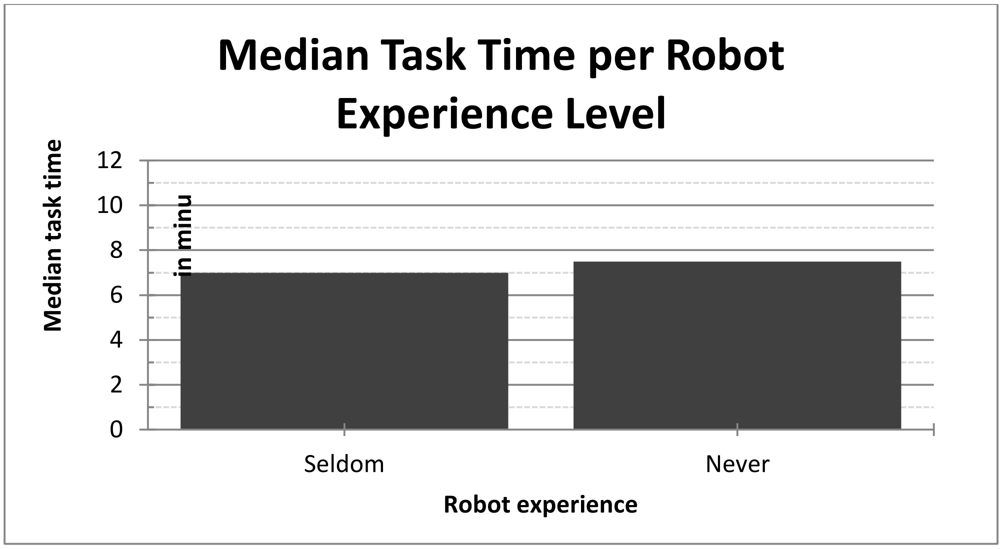

Median Task Time per Videogame Experience Level
Median task time in minutes
0
2
4
6
8
10
Daily
Weekly
Seldom
Never
Videogame experience

A.2.20 Correlation between Robot Experience vs. Task Time

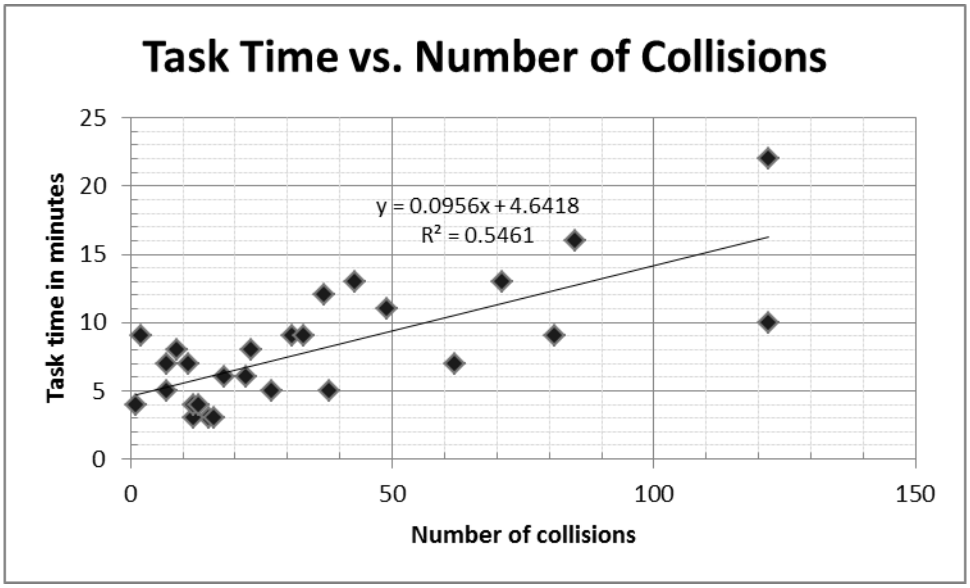
No SSD was found between groups with different levels of robot experience. Only two of the four groups had subjects with any robot experience.



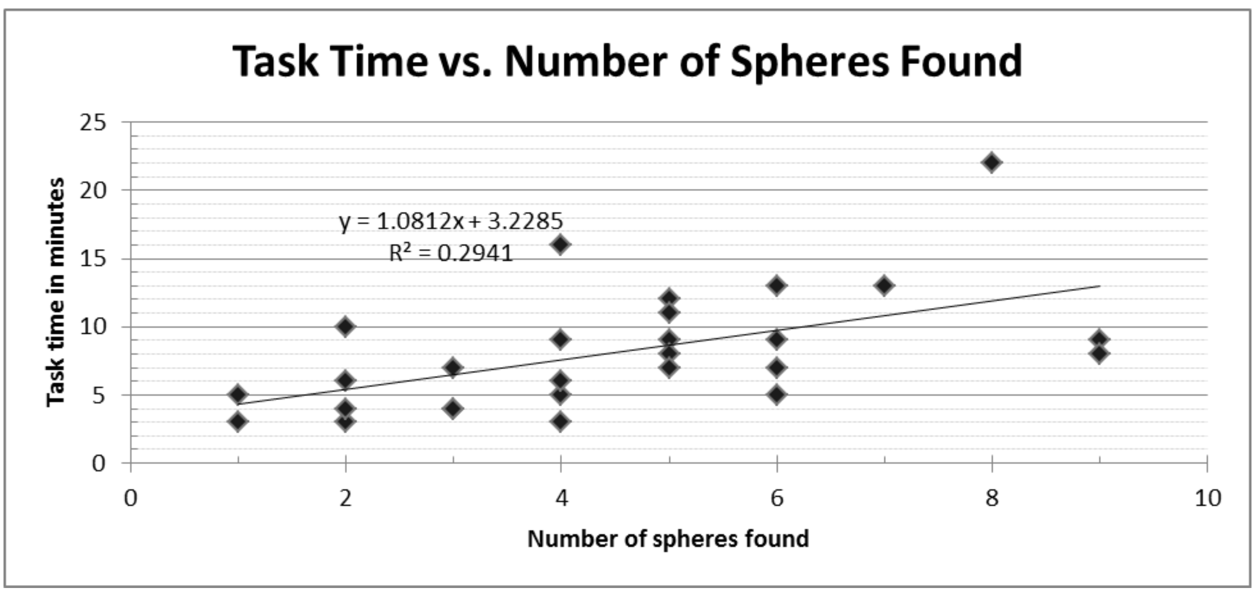



Median Task Time per Robot Experience Level
Median task time
in minu
12
10
8
6
4
2
0
Seldom
Never
Robot experience

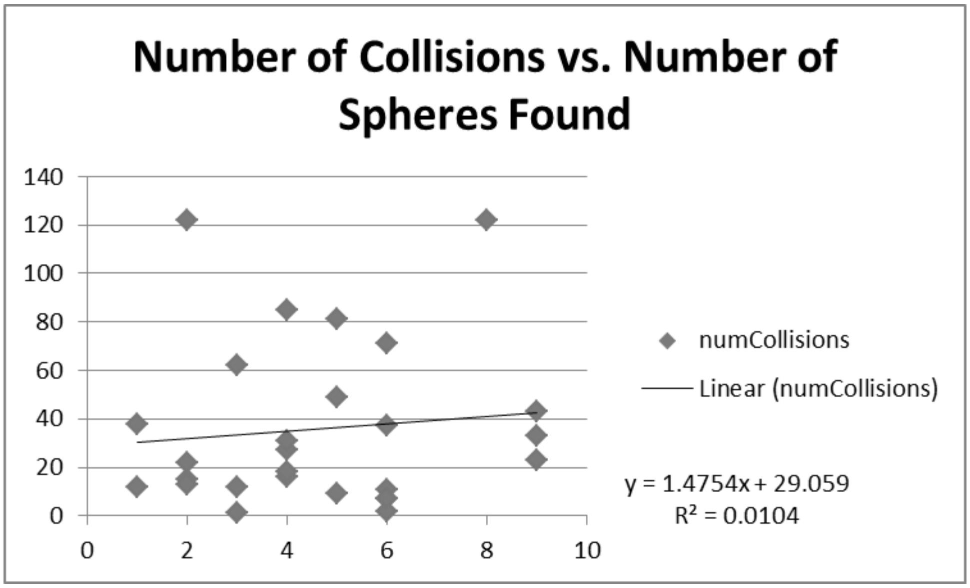
A.2.21 Correlation between Number of Collisions vs. Task Time



A.2.22 Correlation between Num. of Spheres Found vs. Task Time



A.2.23 Correlation between Num. of Spheres Found and Num. of Collisions



A.2.24 Effect of Gender on Search Success+

Num. Spheres Found per Gender		
Male	**Female**	
2	1	
6	5	
3	2	
6	1	
5	6	
6	2	
3	6	
8	4	
4	4	
4	4	
6	3	
9	2	
5	9	
9		
5.429	3.769	**Mean**
5.5	4	**Median**
2.174	2.315	**Std. Dev.**

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	18.560	1	18.560	3.690	0.066	4.242
Within Groups	125.736	25	5.029			
Total	144.296	26				

A.2.25 Effect of Gender on Task Time

Task Time per Gender		
Female	**Male**	
3	3	
9	12	
10	4	
5	5	
7	8	
4	13	
9	4	
3	22	
9	5	
16	6	
7	7	
6	13	
8	11	
	9	
7.385	8.714	**Mean**
7	7.5	**Median**
3.501	5.150	**Std. Dev.**

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	11.918	1	11.918	0.606	0.444	4.242
Within Groups	491.934	25	19.677			
Total	503.852	26				

A.2.26 Effect of Gender on Num. of Collisions

Num. Collisions per Gender		
Female	**Male**	
12	15	
81	37	
122	12	
38	7	
11	9	
13	71	
2	1	
16	122	
31	27	
85	18	
62	7	
22	43	
23	49	
	33	
39.846	32.214	**Mean**
23	22.5	**Median**
36.499	32.471	**Std. Dev.**

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	392.617	1	392.617	0.331	0.570	4.242
Within Groups	29692.049	25	1187.682			
Total	30084.667	26				

A.2.27 Effect of Gender on Sketchmap Quality

Sketchmap Quality per Gender		
Female	**Male**	
18	20	
3	27	
7	16	
9	12	
2	24	
10	13	
26	17	
25	5	
22	1	
19	8	
23	6	
15	11	
21	14	
	4	
15.385	12.714	**Mean**
18	12.5	**Median**
8.322	7.640	**Std. Dev.**

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	48.066	1	48.066	0.756	0.393	4.242
Within Groups	1589.934	25	63.597			
Total	1638.000	26				

Appendix B: Study 2 Material

This appendix contains all the forms used and data analysis done for user study #2. Source code, videos and images can be found on-line (de Barros & Lindeman, 2014).

B.1 Forms

The forms used in study #2 are contained in this section. The text listed is presented as it was originally was given to subjects, with the exception of the removal of watermarks and institutional logotypes.

B.1.1 Instructions Sheet

This experiment aims at evaluating the effect of a tactile interface on robot teleoperation.

Task: You will be asked to enter a closed virtual environment, search for red spheres by remotely operating a robot and, then safely exit the environment. You will have to do this as fast and effectively as possible. You will perform this task three times, each with a different level of feedback.

You will be presented with a house-like virtual environment. For each of the three trials, a small house with 3 different rooms will have objects spread around in a chaotic manner, so as to reproduce a catastrophic situation. Among the objects there will be red spheres. You will have to locate them by navigating a robot through the debris around the entire area. **Please try to memorize the location of the spheres so that you can report them later by sketching a map of the place and the spheres' location.** You will be able to take pictures of the location of the spheres. You will be able to refer these pictures while you are sketching.

The world will be seen by using the robot camera present in the virtual robot interface. The camera will display the simulated remote environment. Other information obtained from the simulated environment may also be displayed to you through the robot interface. You will be asked to perform the search task once. A timer will count the amount of time spent during task. The task will be over once you exit the house through the exit door, identified by an emergency exit symbol.

The interface of the program contains a virtual representation of the robot and a virtual representation of the robot camera that displays images from the simulated real world. You are wearing a belt with eight tactors. They may provide you with feedback on imminent collision situations with the robot. If the tactors are active, the closer the robot is to colliding, the more intensely or frequently they will vibrate in the approximate direction of the imminent collision. The teleoperation interface therefore provides you with collision proximity detection, robot orientation and position, robot-camera orientation, and identification of nearby objects.

It is important to notice that if you are trying to move the robot and it does not move, it is because the robot is colliding with objects in the remote environment.

Please sit comfortably during the experiment, but pay attention to the search task. After reading this, you will be presented with the controls for the robot and given time to get accustomed to the controls in a training room. If you have questions about how to proceed in the experiment, please, ask during the training session.

After that, feel free to ask the instructor to start the experiment whenever you are ready. Further information about the project can be given by the experiment instructor after you have finished the experiment. **Please do not ask the instructor question about the environment during the task performance.**

B.1.2 Consent Form

Primary Investigator: Robert W. Lindeman

Contact Information:

WPI / Department of Computer Science

100 Institute Road

Worcester, MA 01609

Tel: 508-831-6712

E-Mail: gogo@wpi.edu

Title of Research Study:

Evaluation of Tactile Feedback for Teleoperated Robots

Sponsor: None.

Introduction

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you make a fully informed decision regarding your participation.

Purpose of the study:

This study is designed to assess the effect of using vibrotactile interfaces in robot teleoperation.

Procedures to be followed:

You will be asked to move a robot through a third-person virtual environment using a gamepad with two thumb-joysticks and monitor. The task is a simulated search task in a collapsed building. Your control of the robot movement will make it move forward and backward by moving a thumbstick to the front and to the back respectively. Moving the thumbstick to the left or to the right will make the robot turn left or right respectively. Releasing the thumbstick at its central static position will bring the robot to a stop. In addition, another thumbstick will give you control over the robot's pan-and-tilt camera. Moving this thumbstick to the left or right will turn the camera to the left or right respectively. Moving it forward or backward will turn the camera down or upward respectively. Releasing this second thumbstick at its central static position will bring the robot camera to a stop.

You will also be wearing a belt with eight vibration units (called *tactors*) distributed in cardinal directions that may provide you with feedback on imminent collisions in specific directions. If the tactors are active, the higher the intensity or frequency of a tactor's vibration, the closer you are to having the robot collide along the tactor's direction.

You will have to perform a search task three times each time with a different feedback interface. Each of these three search trials will be preceded by an interface familiarization period in a special virtual environment. After the familiarization period, the real search task will be performed in another virtual environment. You will have to search for red spheres ("victims"). You will be asked to perform the search *as fast and effectively as you can*. You will also be asked to memorize their locations and report them later on. You will have to move in a closed space through an entrance and exit the environment through an exit door. A timer will count the time you have spent on each search task. The search task will last about 10 minutes. Following each search task you will be asked to identify the number and location of each of the red spheres. Finally, after the three search tasks are performed, you will be given the opportunity to provide any additional comments on all the interfaces, the experiment and the application.

Risks to study participants:

The risks to you in participating in this study are minimal.

Benefits to research participants and others:

There is no direct benefit to you apart from class half-credit.

Record keeping and confidentiality:

Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. No data identifying you by name will be collected, and any publication or presentation of the data will not identify you.

You will be given a copy of this consent form for your records; it contains the contact information for the investigator. The investigator's copy will be stored in a locked file cabinet, and retained for a period of 3 years.

Compensation or treatment in the event of injury:

This study will put you at minimal risk. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact me using the information at the top of this page. In addition, you may contact the IRB Chair (Professor Kent Rissmiller, Tel: 508-831-5019, E-Mail:

kjr@wpi.edu) and the University Compliance Officer (Michael J. Curley, Tel. 508-831-5519, E-Mail: mjcurley@wpi.edu).

Your participation in this research is voluntary.

Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

_____________________________ Date: ____________________

Study Participant Signature

____

Study Participant Name (Please print)

______________________________________ Date: ____________________

Signature of Person who explained this study

B.1.3 Demographics Collection Form

Subject #: ______

Gender: ______

How old are you? _________

1) How often do you play video-games?

Please tick against your answer.

Daily	Weekly	Seldom	Never
□	□	□	□

2) How often do you use or work with robots: daily, weekly, seldom or never?

Please tick against your answer.

Daily	Weekly	Seldom	Never
□	□	□	□

B.1.4 Post-Treatment Questionnaire

Subject #: ______

Please answer the questions in the empty space following them.

- How many red spheres did you find?

- Using the pictures taken as a reference, could you draw a map locating them with respect to the house and debris in the space below?

- How difficult was it to perform the task compared to actually performing it yourself (if the remote environment was real)? Please answer on the following 1 to 7 scale.

  Please tick against your answer.

Very easy						Very difficult
1	2	3	4	5	6	7
□	□	□	□	□	□	□

- Please rate *your sense of being there* in the computer generated world on the following 1 to 7 scale.

  In the computer generated world I had a sense of "being there" ...

  Please tick against your answer.

Not at all						Very much
1	2	3	4	5	6	7
□	□	□	□	□	□	□

- To what extent were there times during the experience when the computer generated world became the "reality" for you, and you almost forgot about the "real world" outside? Please answer on the following 1 to 7 scale.

  There were times during the experience when the computer generated world became more real or present for me compared to the "real world"...

  Please tick against your answer

At no time						Almost all of the time
1	2	3	4	5	6	7
□	□	□	□	□	□	□

- When you think back about your experience, do you think of the computer generated world more as *something that you saw*, or more as *somewhere that you visited*? Please answer on the following 1 to 7 scale.

  The computer generated world seems to me to be more like…

  Please tick against your answer.

Something I saw						Somewher e I visited
1	2	3	4	5	6	7
□	□	□	□	□	□	□

- When navigating in the environment did you feel more like *driving* through the environment or *walking* in the environment? Please answer on the following 1 to 7 scale.

  Moving around the computer generated world seems to me to be more like…

  Please tick against your answer.

Driving						Walking
1	2	3	4	5	6	7
□	□	□	□	□	□	□

- During this task trial how nauseated did you feel? Please answer on the following 1 to 7 scale.

  While performing this task I felt...

  Please tick against your answer.

Fine						Very nauseated
1	2	3	4	5	6	7
□	□	□	□	□	□	□

- During this task trial how dizzy did you feel? Please answer on the following 1 to 7 scale.

  While performing this task I felt...

  Please tick against your answer.

Fine						Very dizzy
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

- Please provide any comments about the robot interface.

B.1.5 Final Questionnaire

Subject #: ______

During the experiment you were exposed to three types of interfaces, two of which provided you with vibro-tactile feedback. One vibro-tactile feedback interface varied the vibration *intensity* while the other varied the *frequency* with which a pulsing vibration would occur. The third provided no vibration feedback. For each of the following questions grade the three interfaces and use the 1 to 7 scale.

- How easy was it for you to learn how to use the interface?

  Learning how the interface worked was…

  Make your selection for each of the three interfaces.

Type of Interface	Very easy 1	2	3	4	5	6	Very difficult 7
Vibration Intensity	☐	☐	☐	☐	☐	☐	☐
Vibration Frequency	☐	☐	☐	☐	☐	☐	☐
No vibration	☐	☐	☐	☐	☐	☐	☐

- How confusing was the interface?

  Understanding the information the interface was presenting was…

  Make your selection for each of the three interfaces.

Type of Interface	Confusing 1	2	3	4	5	6	Straightforward 7
Vibration Intensity	☐	☐	☐	☐	☐	☐	☐
Vibration Frequency	☐	☐	☐	☐	☐	☐	☐
No Vibration	☐	☐	☐	☐	☐	☐	☐

- How distracting was the feedback provided by the interface?

  The feedback provided by the interface…

  Make your selection for each of the three interfaces.

Type of Interface	Caused distraction 1	2	3	4	5	6	Did not distract me 7
Vibration Intensity	☐	☐	☐	☐	☐	☐	☐
Vibration Frequency	☐	☐	☐	☐	☐	☐	☐
No vibration	☐	☐	☐	☐	☐	☐	☐

- How comfortable was using the interface?

Using the interface was...

Make your selection for each of the three interfaces.

Type of Interface	Very uncomfortable 1	2	3	4	5	6	Very comfortable 7
Vibration Intensity	☐	☐	☐	☐	☐	☐	☐
Vibration Frequency	☐	☐	☐	☐	☐	☐	☐
No vibration	☐	☐	☐	☐	☐	☐	☐

- How much did the interface helped you understand the environment?

Using the interface impacted my understanding of the environment in a…

Make your selection for each of the three interfaces.

Type of Interface	Negative way 1	2	3	4	5	6	Positive way 7
Vibration Intensity	☐	☐	☐	☐	☐	☐	☐
Vibration Frequency	☐	☐	☐	☐	☐	☐	☐
No vibration	☐	☐	☐	☐	☐	☐	☐

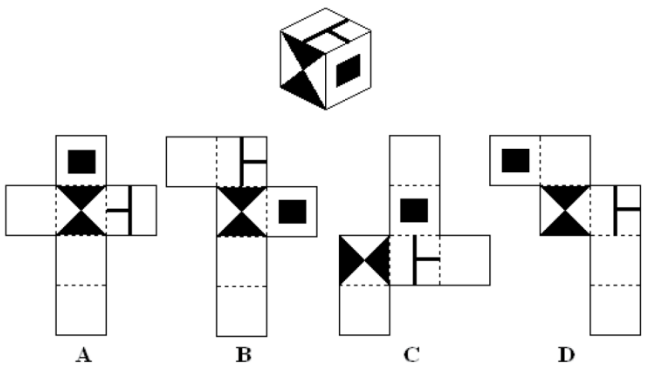
- Do you have any comments about the experiment in general?

- If you wish to know about the final results of this experiment, please, provide us with your e-mail address: ____.

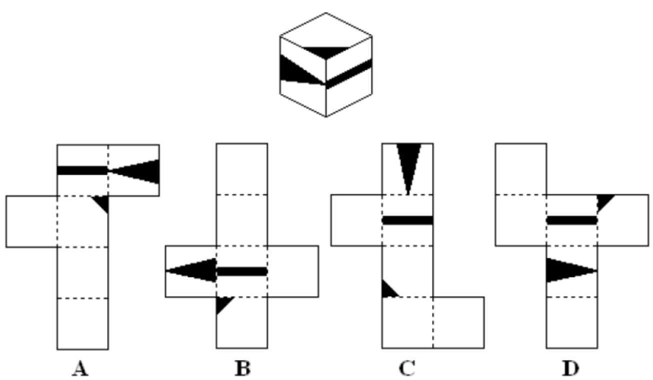
B.1.6 Spatial Aptitude Test

Please, answer as many questions as you can in the 5 minutes provided to you. For each of the three set of pictures on this page, answer the following question:

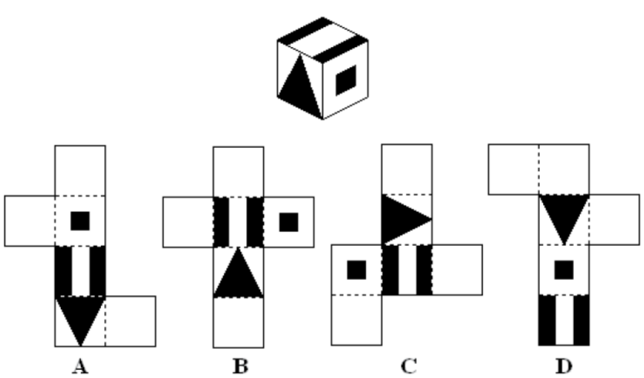
Which pattern can be folded to make the cube shown?



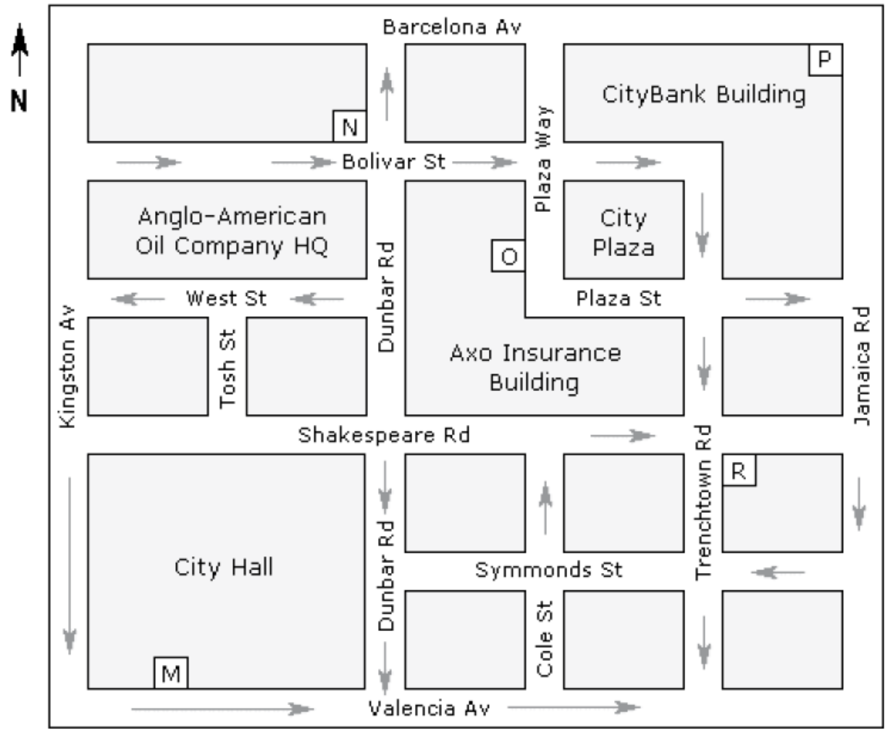
- Answer:
  - ☐ A
  - ☐ B
  - ☐ C
  - ☐ D



- Answer:
  - ☐ A
  - ☐ B
  - ☐ C
  - ☐ D



- Answer:
  - ☐ A
  - ☐ B
  - ☐ C
  - ☐ D



- Officer Perez is on Tosh St with City Hall to her right. What direction is she facing?

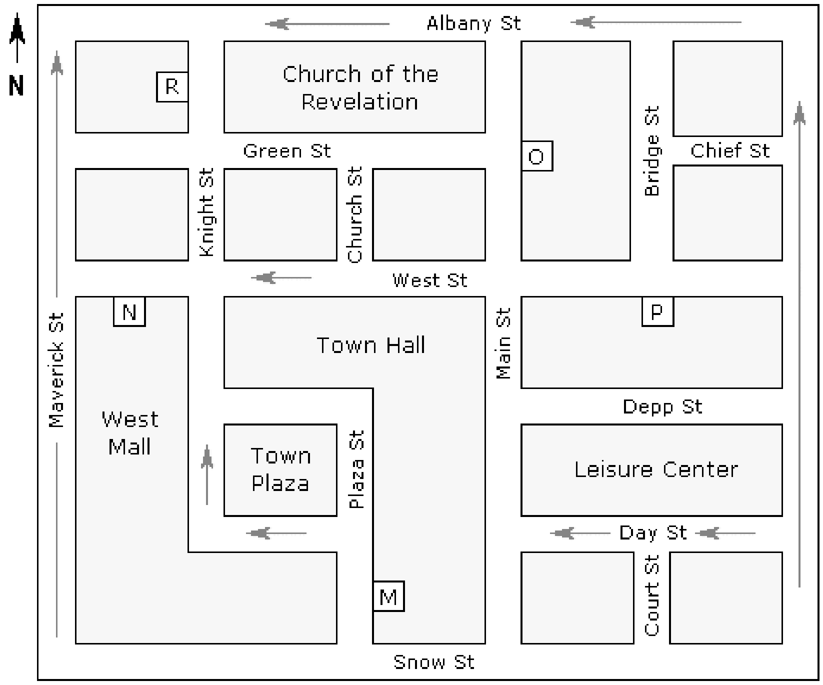
☐ North ☐ South ☐ East ☐ West

- She turns and walks to the junction with West St. She then turns right and walks to the next junction before turning left. Where is the 'O' in relation to her position?

☐ North ☐ South ☐ East ☐ West

- Officer Martinez starts from location 'M' and proceeds as follows: left onto Valencia Av-heading East, second left – heading North, second right – heading East, second left-heading North. He proceeds North for two blocks. What is his location?

☐ N ☐ O ☐ R ☐ P



- Officer Wilkinson is on Depp St and can see the Town Hall to her right. What direction is she facing?

  □ North □ South □ East □ West

- She turns and walks to the junction with Main St. She turns left and proceeds two blocks before turning right, then taking the next right, and walking half a block. Which location is nearest to her current position?

  □ M □ N □ R □ P

- Officer Garcia starts from location 'N' and proceeds as follows: right onto West St - heading East, fourth left - heading North, first right - heading East, first right - heading South, third right – heading West. He proceeds West for one block. Where is location 'P' in relation to his current position?

  □ North □ South East □ North East □ North West

Answers to spatial test questions:

5) B
6) A
7) B
8) C
9) C
10) D
11) B
12) A
13) A

B.1.7 Instructor Script

Hello. My name is AAAAAA.

Welcome to the HIVE lab. Please, have a seat here.

Please, read the consent form and, if you agree, sign it at the bottom of the second page.

{

Subject reads and signs the consent form

}

We are going to start with a few demographic questions:

How old are you?

How often do you play video-games: daily, weekly, seldom or never?

How often do you use or work with robots: daily, weekly, seldom or never?

Let me now ask you to answer the spatial aptitude test. You will have five minutes to do it. Try to answer as many question as you can in these five-minutes. I will take the exam from you when the five minutes are over.

Now, please carefully read these instructions, and let me know if you have any questions.

{

Subject reads the instruction sheet

}

Any questions?

First, let me ask you to wear this belt.

The overall task you will perform simulates a search for victims after a building collapse.

I am now going to show you how to control the robot.

Using the left-hand analog stick on the controller, you can control the robot direction, making it move forward or backwards, or making it turn left or right.

Using the right-hand analog stick you can tilt and pan the robot camera, whose movement is reflected on the video panel in front of the robot.

In order to take a picture, you first zoom in by pressing trigger button #2 on the right side of the controller. You can adjust the picture by moving either the camera or the robot, but be careful with collisions.

When you are satisfied with the picture and while still pressing the zoom button, you press the trigger button #2 on the left side of the controller. This will take a screen shot of the robot camera current view. After that, you can simply release both trigger buttons and move on with your task.

You can also increase or decrease the range of the collision proximity sensors using the “□” and “x” buttons. These are limited to minimum and maximum values however.

The robot is represented by this red box in the middle of the screen. There is a chance that you are also presented with blue dots on the ground to represent the surfaces of objects that are close to the robot and that are detected by its sensors. Remember, if you try to move the robot and the robot does not move, it is because it is colliding with some object in the environment.

† The belt around your waist may provide you with feedback on potential collisions in certain directions. If so, the more intensely or frequently it vibrates in a certain direction, the closer you are to colliding with an object in that direction. . The indicators are not completely accurate, so be careful.(The feedback you will receive now, if any exists, is going to be different from the one you had in the last trial)

You will have some time now to practice robot control in a training room. The task here is to take a picture of a single red sphere, just like the ones you will have to locate in the real task, and which is hidden somewhere in this room. After that, you can keep practicing with the robot controls. Feel free to ask me questions about how to proceed with the study during this training session.

When you feel ready to start the search task, let me know and I will activate it for you. You will not be allowed to ask questions once the experiment starts, so please do so now and during the practice session.

{

Training task is run until user requests to move on to the real task.

"Do you have any questions on how to operate the robot?"

}

Now I am going to start the real task. The objective of the task is to find as many red spheres ("victims") as you can in as little time as possible and colliding as little as you can with the robot. **The house has 3 rooms. Make sure you cover as much as area in the rooms as possible.** Once you are done with your search, you should move out of the house by passing through the exit door, which is identified by an exit sign on top of it. So please try to pay attention to that. Once you pass through the door, the task will be over. After the task, you will be asked to draw a sketch of the environment, and especially the location of each of the spheres. Pay attention to the sphere locations and take pictures at any time. I will start the task now, ok?

{

Task is run, no questions allowed.

}

Now, please fill in this questionnaire. You can browse this document here with the pictures you have taken to help you with the description of the location of the red spheres you found. Feel free to use either pen or pencil.

{

Start chronometer for measuring sketching time.

Subject fills-in post-questionnaire.

Stop chronometer when sketching is over.

}

(After the third trials only:

Please, fill-in this questionnaire now giving your opinion about all three interfaces.

)

Feel free to take a 5-minute break and we will start with the second task after that.

***Repeat steps starting from † for interfaces 2 and 3.

Do you have any other questions about this study or the lab?

Since other colleagues from your class might come to participate in this study, please avoid discussing what you did with others in order to avoid bias in our results, ok? Thank you very much for your participation.

B.2 Data Analysis

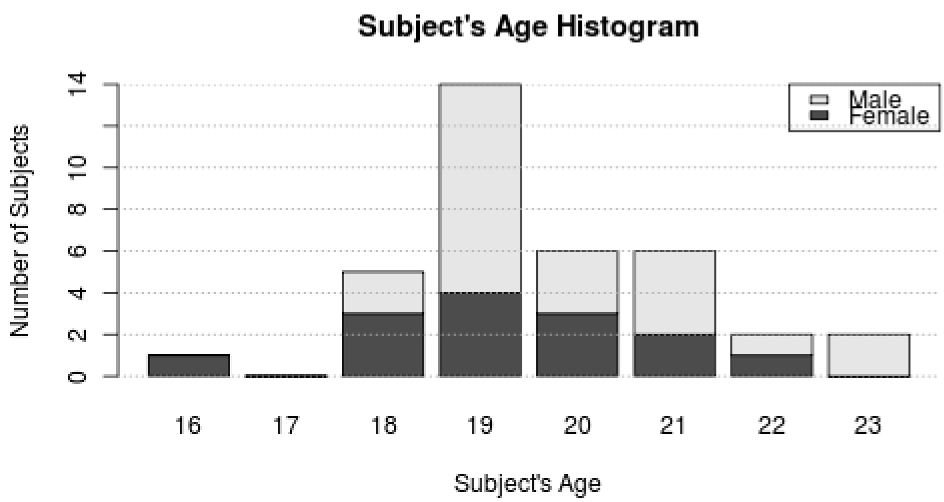
The section contains all the data collected for study #2 as well as the statistical analysis performed on it. In the section, subsections whose title is marked with an asterisk (*) contain statistically significant differences (SSD) in the data analysis. If the title of a subsection is marked with a plus sign (+) after it, it means trends are present in its data analysis.

B.2.1 Population

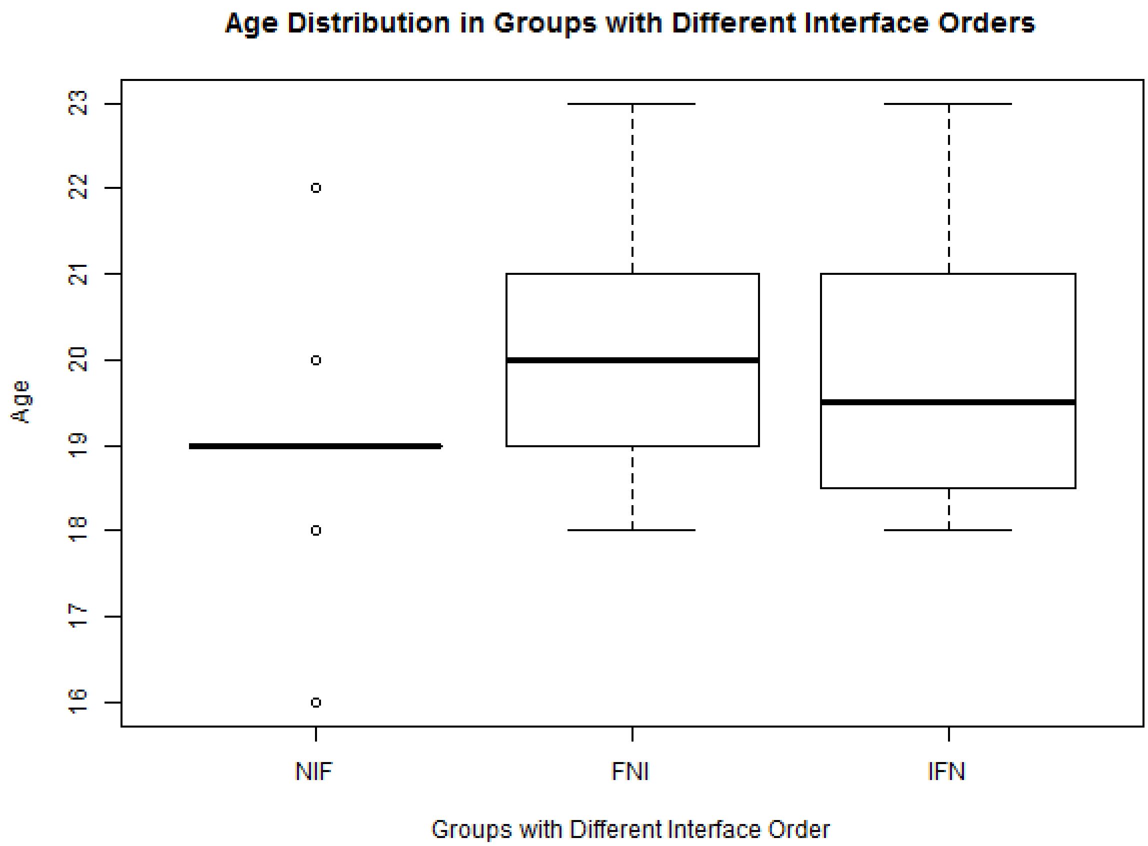
This section contains demographics information. It includes subjects' age, gender distributions and well as videogame experience, robot experience and their scores on the spatial aptitude test.

Subject #	Trial Sequence	VE Sequence	Gender	Age	Videogame XP	Robot XP
0	nif	xyz	m	18.00	3	4
1	fni	xyz	f	18.00	2	4
2	ifn	xyz	m	21.00	1	3
3	nif	zxy	m	19.00	2	4
4	fni	zxy	f	21.00	4	4
5	ifn	zxy	m	19.00	2	4
6	nif	yzx	m	22.00	3	4
7	fni	yzx	f	20.00	3	4
8	ifn	yzx	f	19.00	3	4
9	nif	xyz	m	19.00	1	4
10	fni	xyz	m	21.00	2	2
11	ifn	xyz	f	20.00	3	3
12	nif	zxy	f	19.00	4	4
13	fni	zxy	f	19.00	3	4
14	ifn	zxy	f	18.00	3	4
15	nif	yzx	m	20.00	1	3
16	fni	yzx	m	20.00	3	4
17	ifn	yzx	f	22.00	3	4
18	nif	xyz	m	19.00	3	4
19	fni	xyz	m	21.00	3	3
20	ifn	xyz	m	19.00	1	3
21	nif	zxy	f	19.00	3	3
22	fni	zxy	m	20.00	3	3
23	ifn	zxy	m	21.00	2	4
24	nif	yzx	m	19.00	3	4
25	fni	yzx	m	19.00	3	4
26	ifn	yzx	f	18.00	4	3
27	nif	xyz	m	19.00	3	3
28	fni	xyz	m	23.00	2	4
29	ifn	xyz	f	21.00	4	4
30	nif	zxy	f	16.00	4	3
31	fni	zxy	f	20.00	4	4
32	ifn	zxy	m	18.00	1	3
33	nif	yzx	m	19.00	3	4
34	fni	yzx	m	19.00	3	3
35	ifn	yzx	m	23.00	1	1

B.2.1.1 Age Histogram



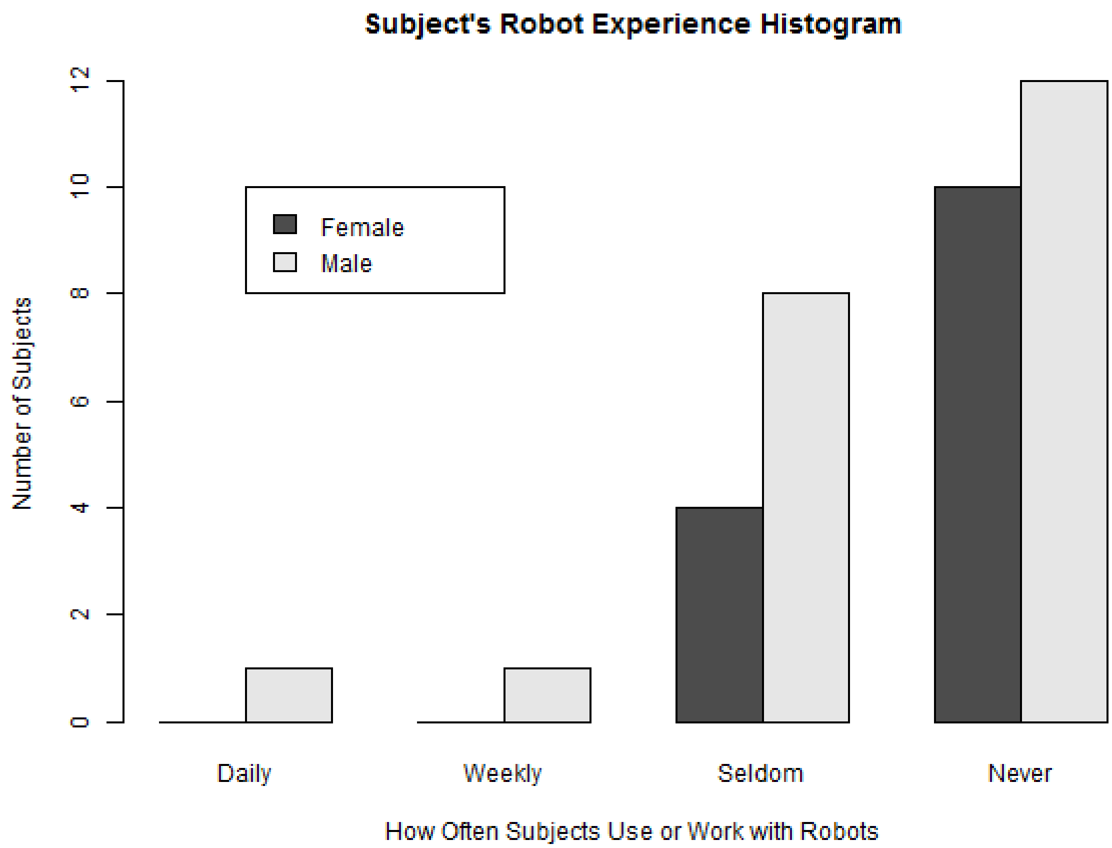
B.2.1.2 Age Distribution for Groups with Different Interface Orders



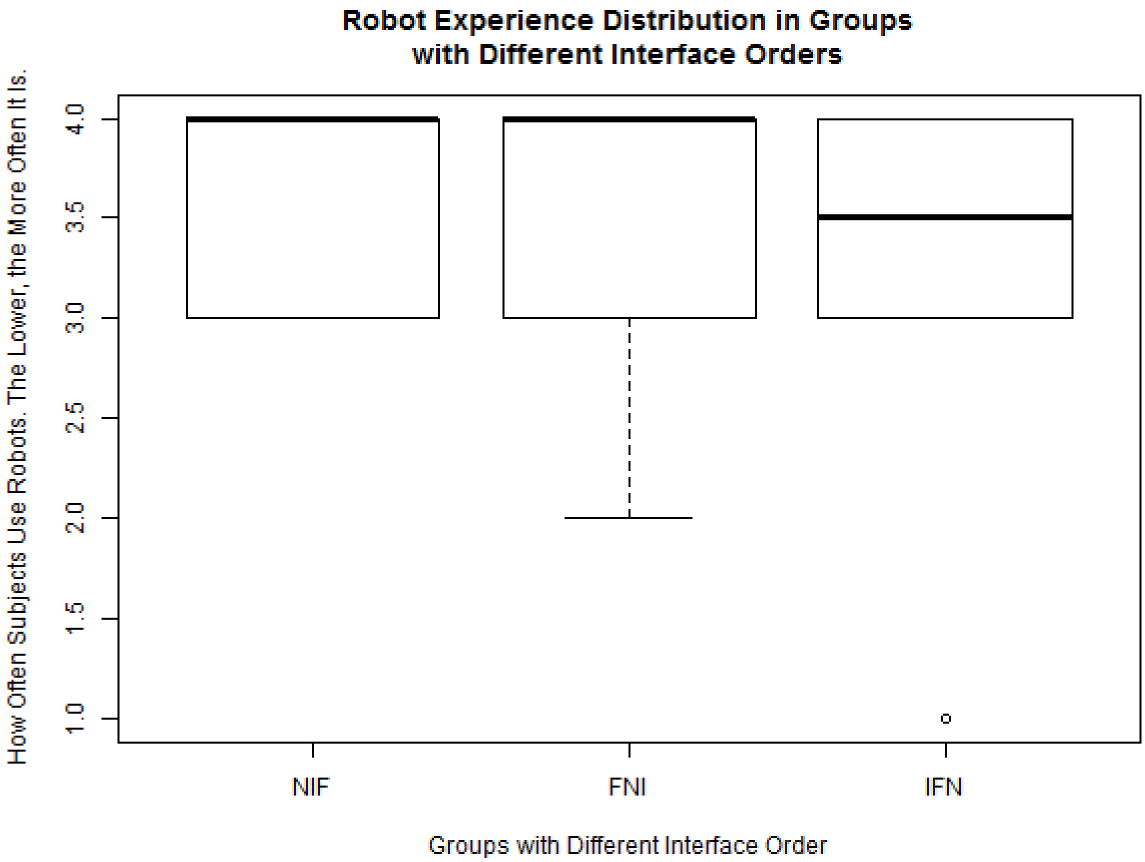
	NIF	FNI	IFN
Mean	19	20.08	19.92
Median	19	20	19.5
Std. deviation	1.348	1.311	1.677

B.2.1.3 Robot Experience

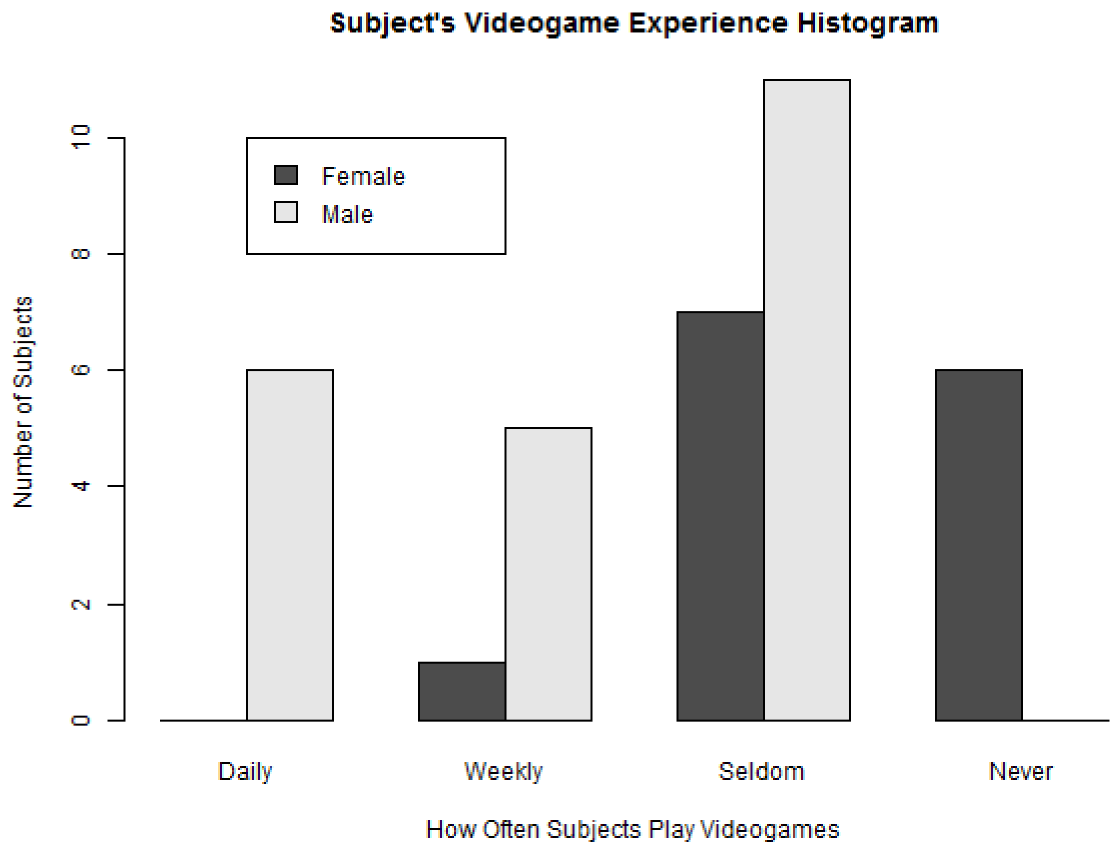
Most subjects had no experience with robots. No SSDs was detected for groups with different interface orders.



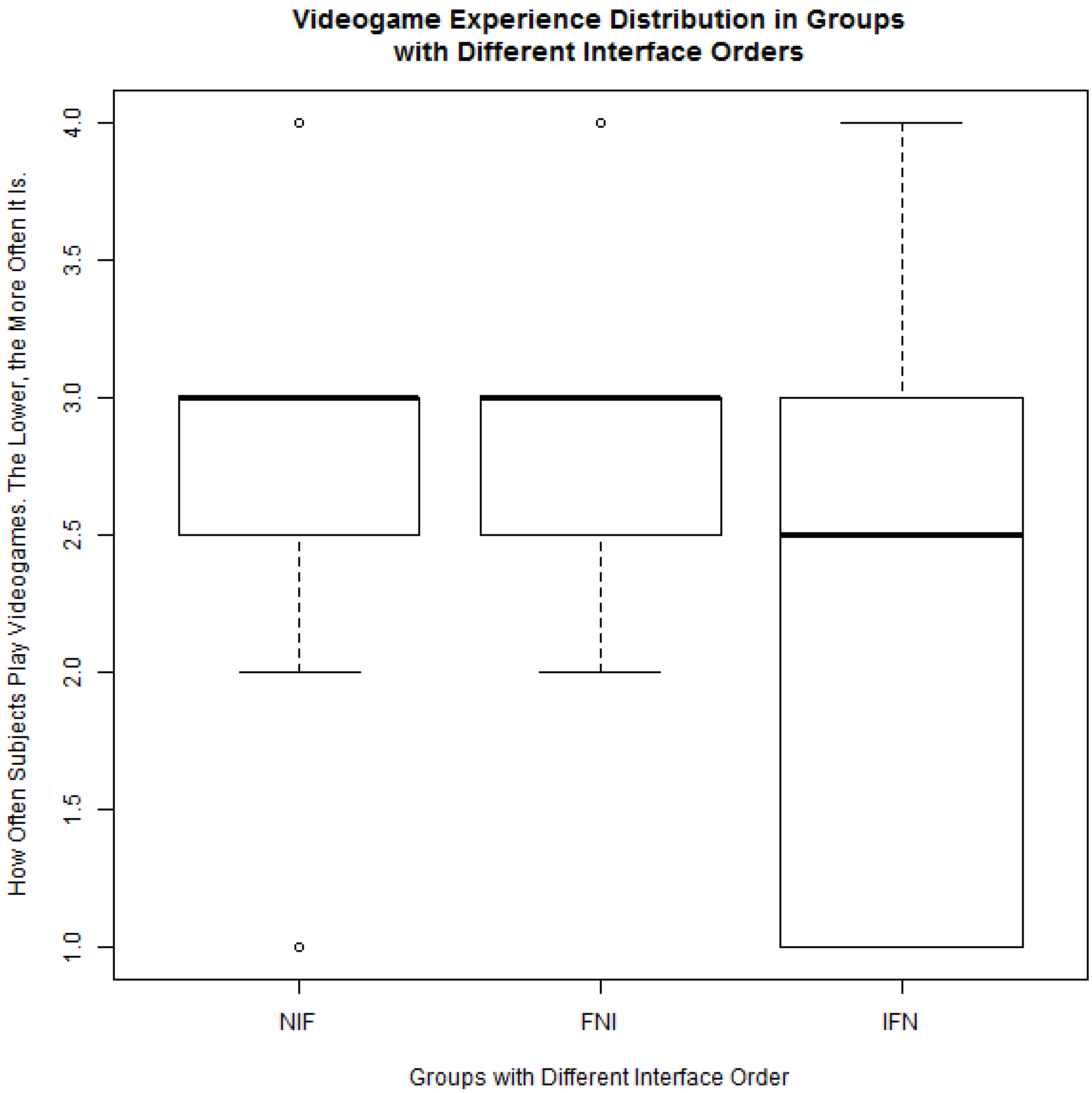
ANOVA: Robot Experience for Groups With Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.722	0.361	0.733	0.488
Residuals	33	16.250	0.492		


Robot Experience Distribution in Groups
with Different Interface Orders
How Often Subjects Use Robots. The Lower, the More Often It Is.
1.0
1.5
2.0
2.5
3.0
3.5
4.0
NIF
FNI
IFN
Groups with Different Interface Order

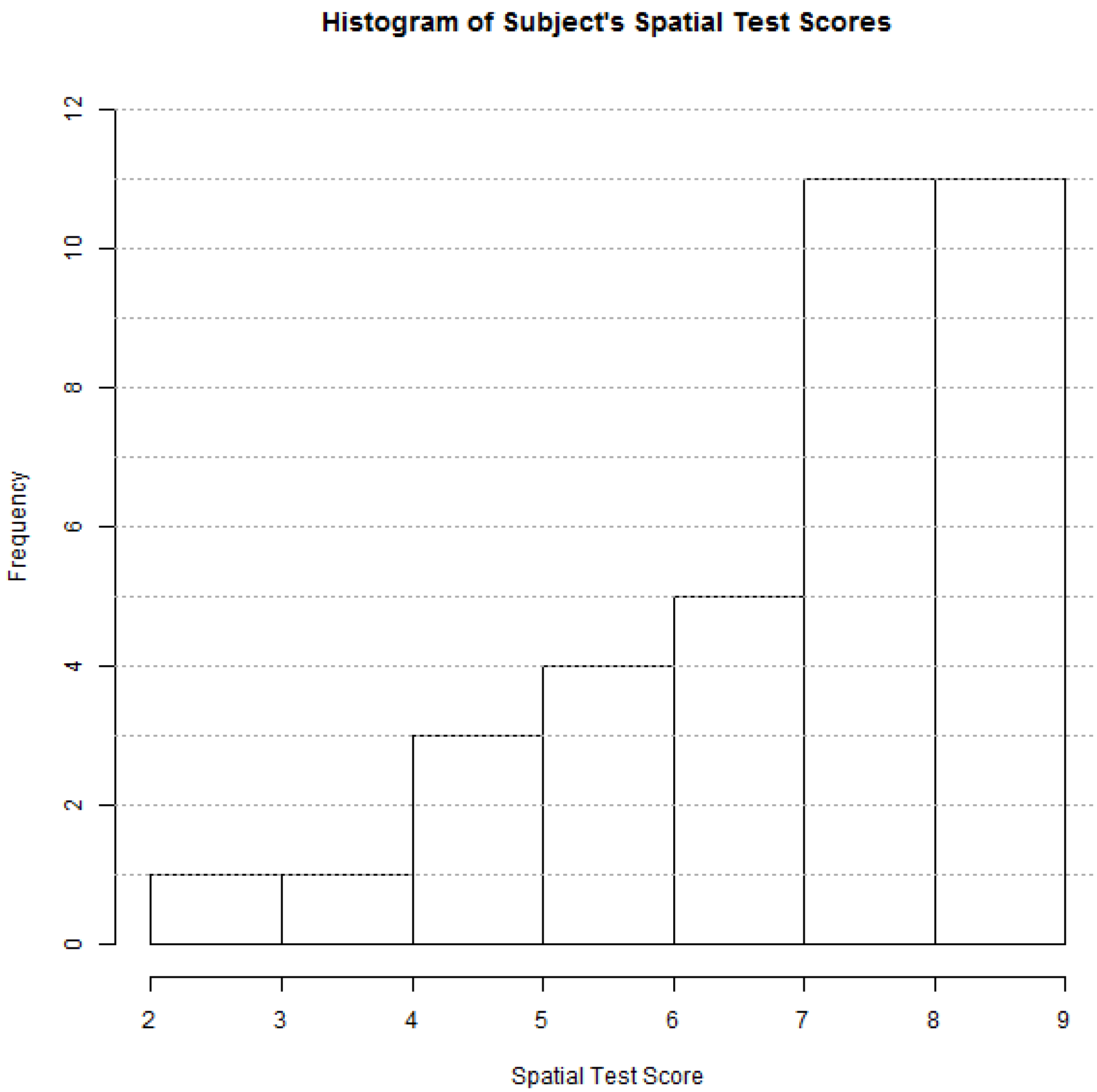
B.2.1.4 Videogame Experience



ANOVA: Videogame Experience for Groups With Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	2.167	1.083	1.198	0.314
Residuals	33	29.833	0.904		

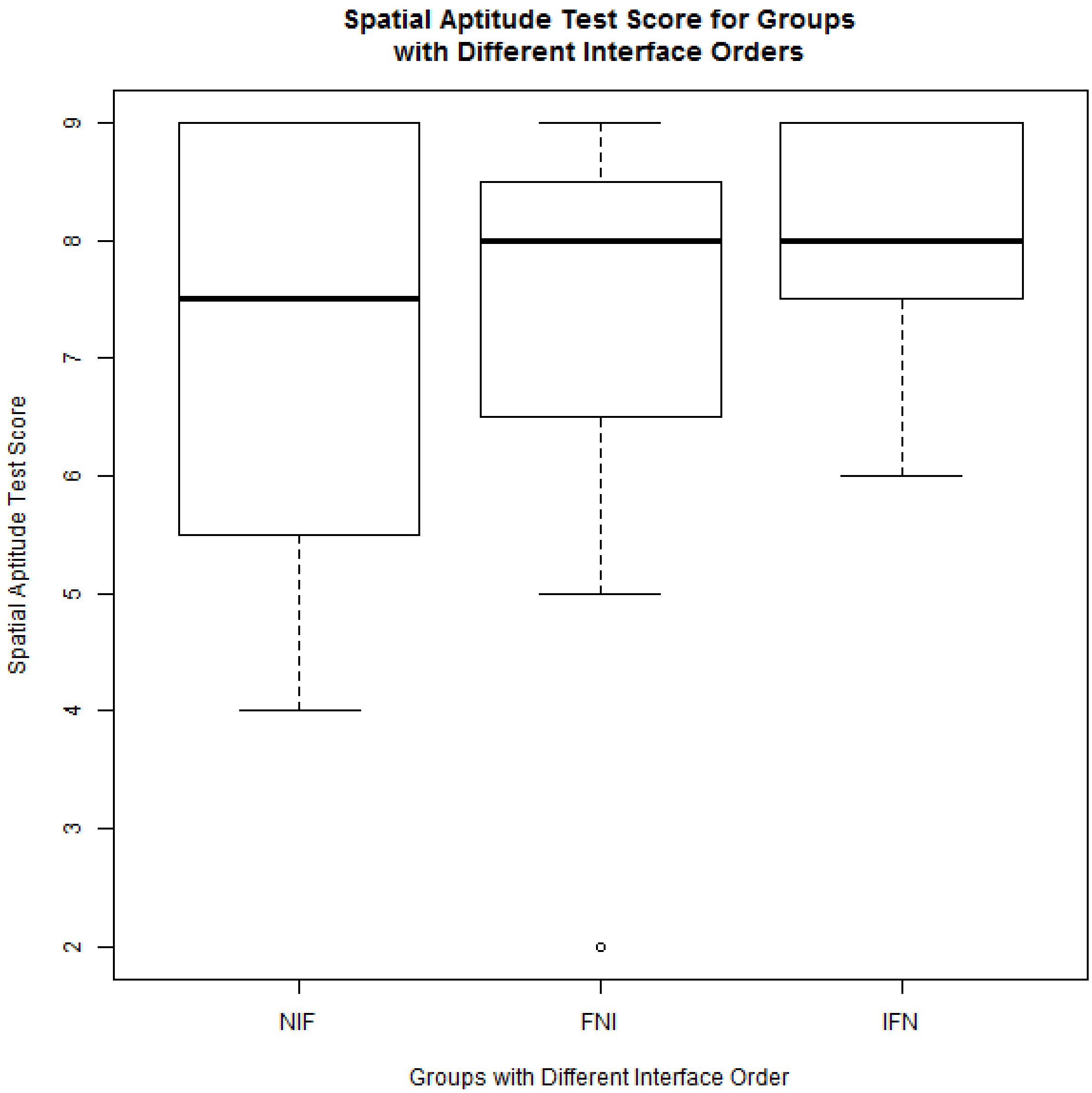

Videogame Experience Distribution in Groups
with Different Interface Orders
How Often Subjects Play Videogames. The Lower, the More Often It Is.
4.0
3.5
3.0
2.5
2.0
1.5
1.0
NIF
FNI
IFN
Groups with Different Interface Order

B.2.1.5 Spatial Aptitude



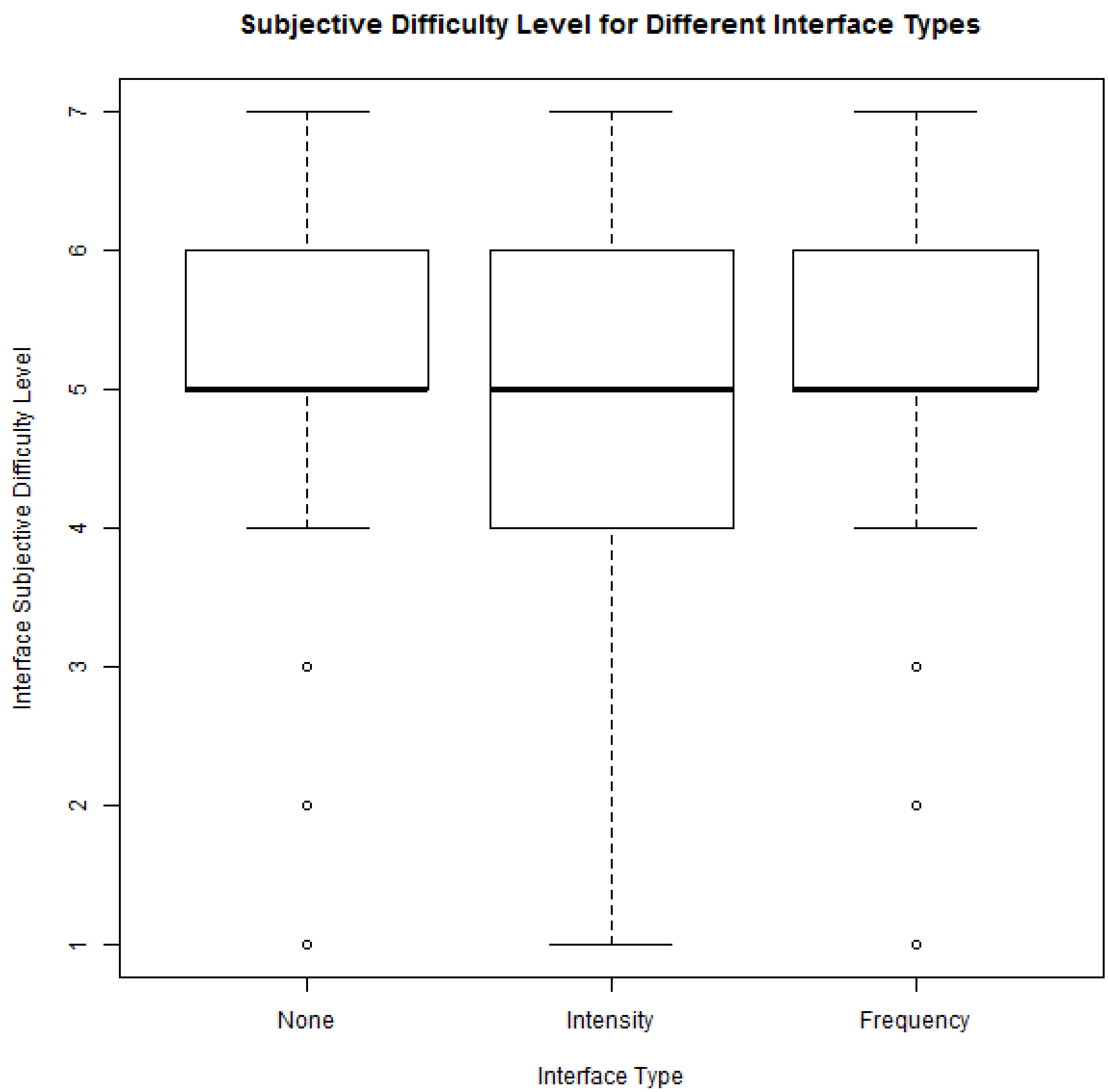
ANOVA: Spatial Aptitude Scores for Groups With Different Interface Order

Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	6,170	3.083	1.099	0.345
Residuals	33	92.580	2.806		


Spatial Aptitude Test Score for Groups
with Different Interface Orders
Spatial Aptitude Test Score
9
8
7
6
5
4
3
2
NIF
FNI
IFN
Groups with Different Interface Order

B.2.2 Treatment Questionnaire

B.2.2.1 Difficulty



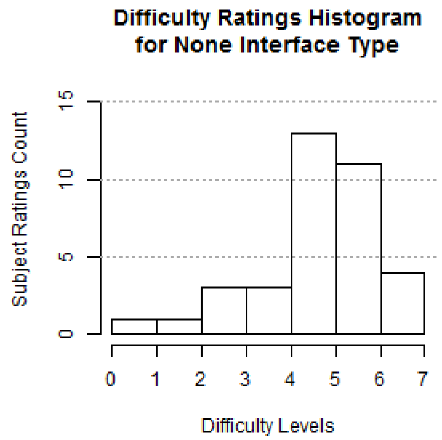
ANOVA: Difficulty Levels for Groups With Different Interface Types

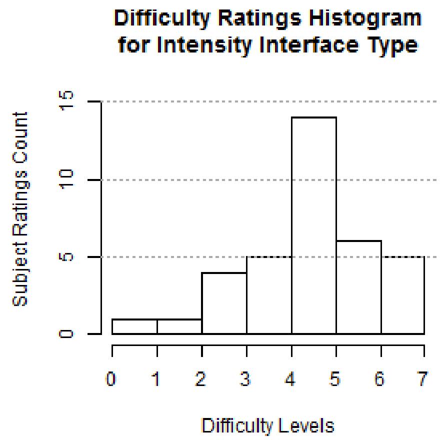
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.91	0.454	0.228	0.797
Residuals	105	209.06	1.991		

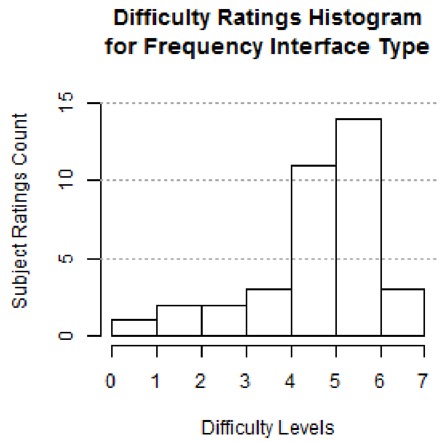
Difficulty vs. Interface Used - Friedman Test	
X^2	1.299
p	0.522
DoF	2.000

Difficulty vs. Interface Used – Wilcoxon Test			
	N – I	***N – F***	***I – F***
W	181.500	140.000	82.500
Z	1.093	-0.284	-0.916
p	0.285	0.809	0.403
R	0.129	-0.033	-0.108

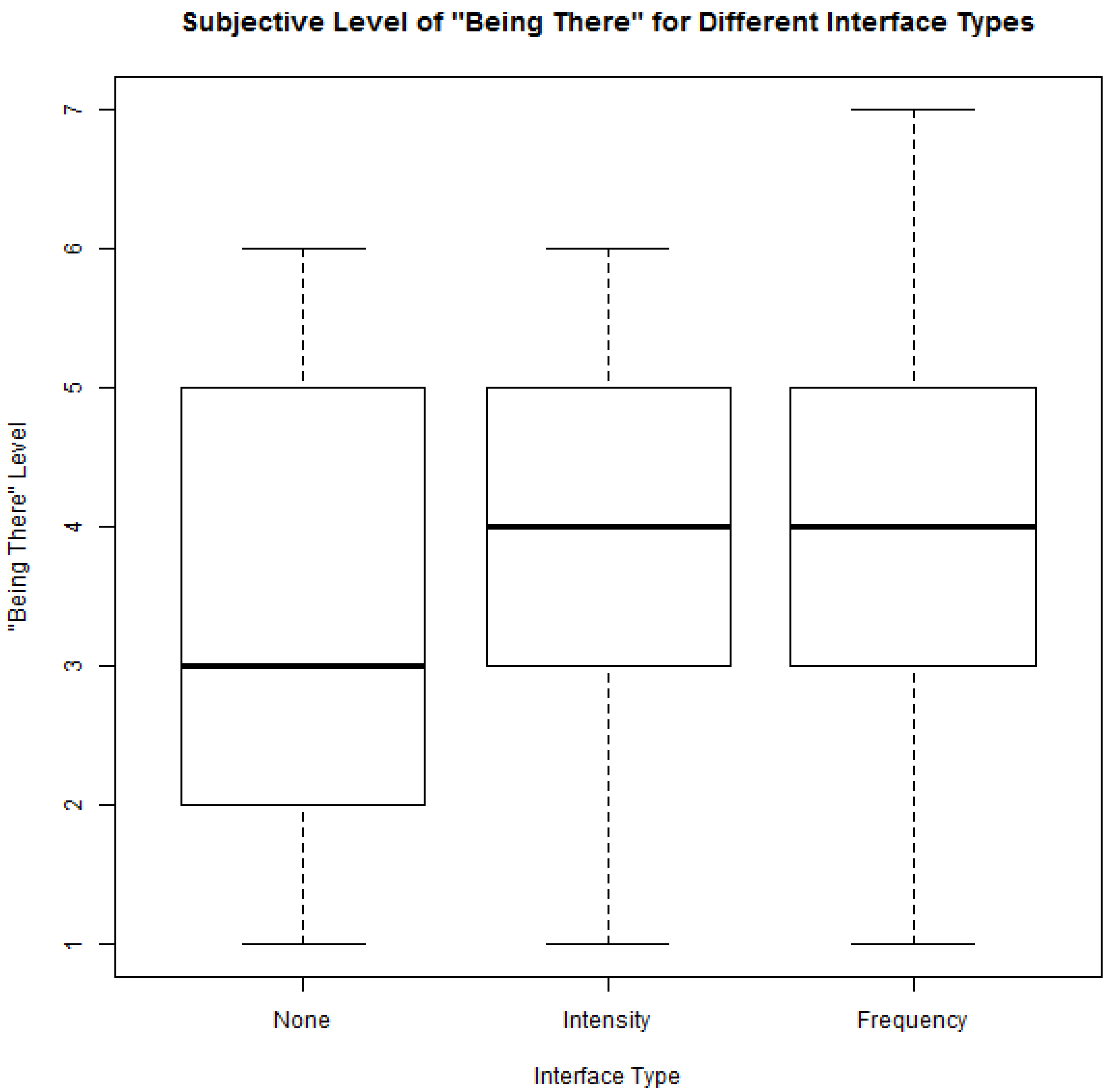
Difficulty vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	5.083	1.381	5.000
Intensity	4.899	1.430	5.000
Frequency	5.083	1.422	5.000







B.2.2.2 Being There+

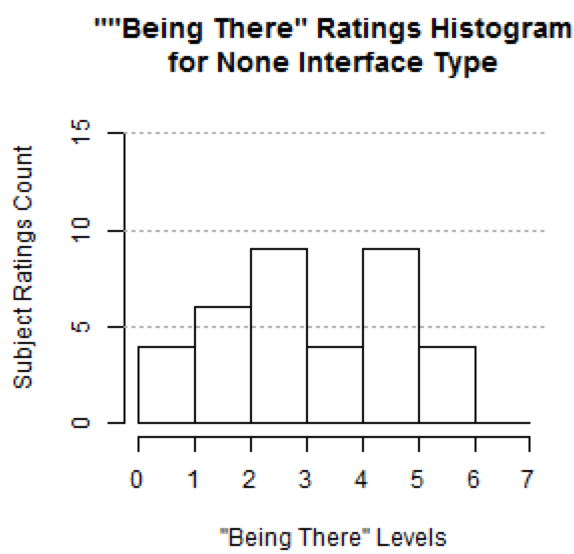


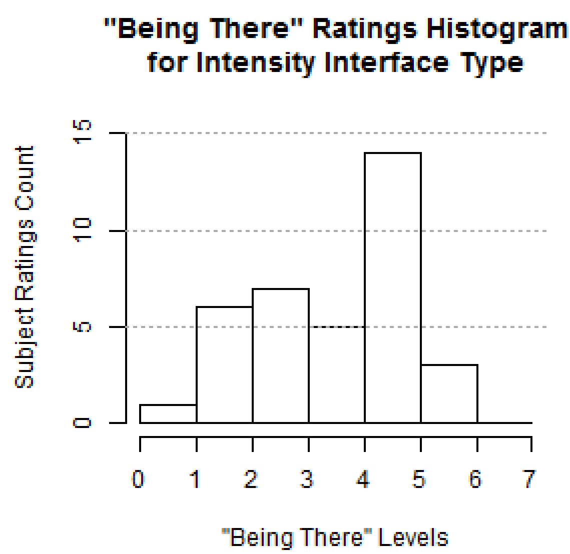
ANOVA: Being There Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	3.39	1.694	0.768	0.466
Residuals	105	231.53	2.205		

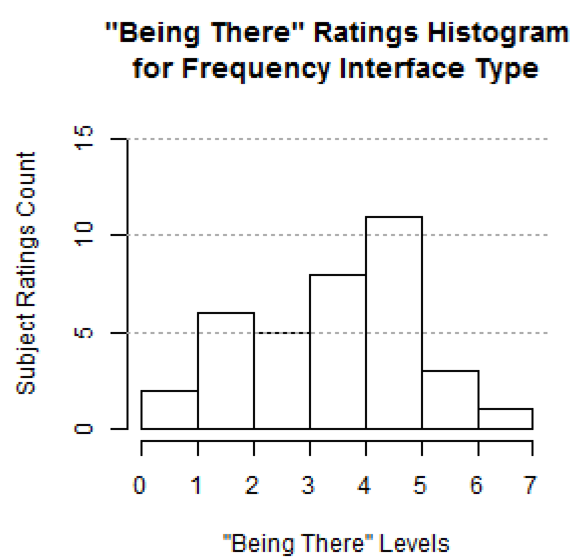
Being There vs. Interface Used - Friedman Test	
X^2	3.515
p	0.173
DoF	2.000

Being There vs. Interface Used – Wilcoxon Test			
	N – I	***N – F***	***I – F***
W	129.000	96.5000	97.500
Z	-1.703	-1.691	0.468
p	0.087	0.095	0.661
R	-0.201	-0.199	0.055

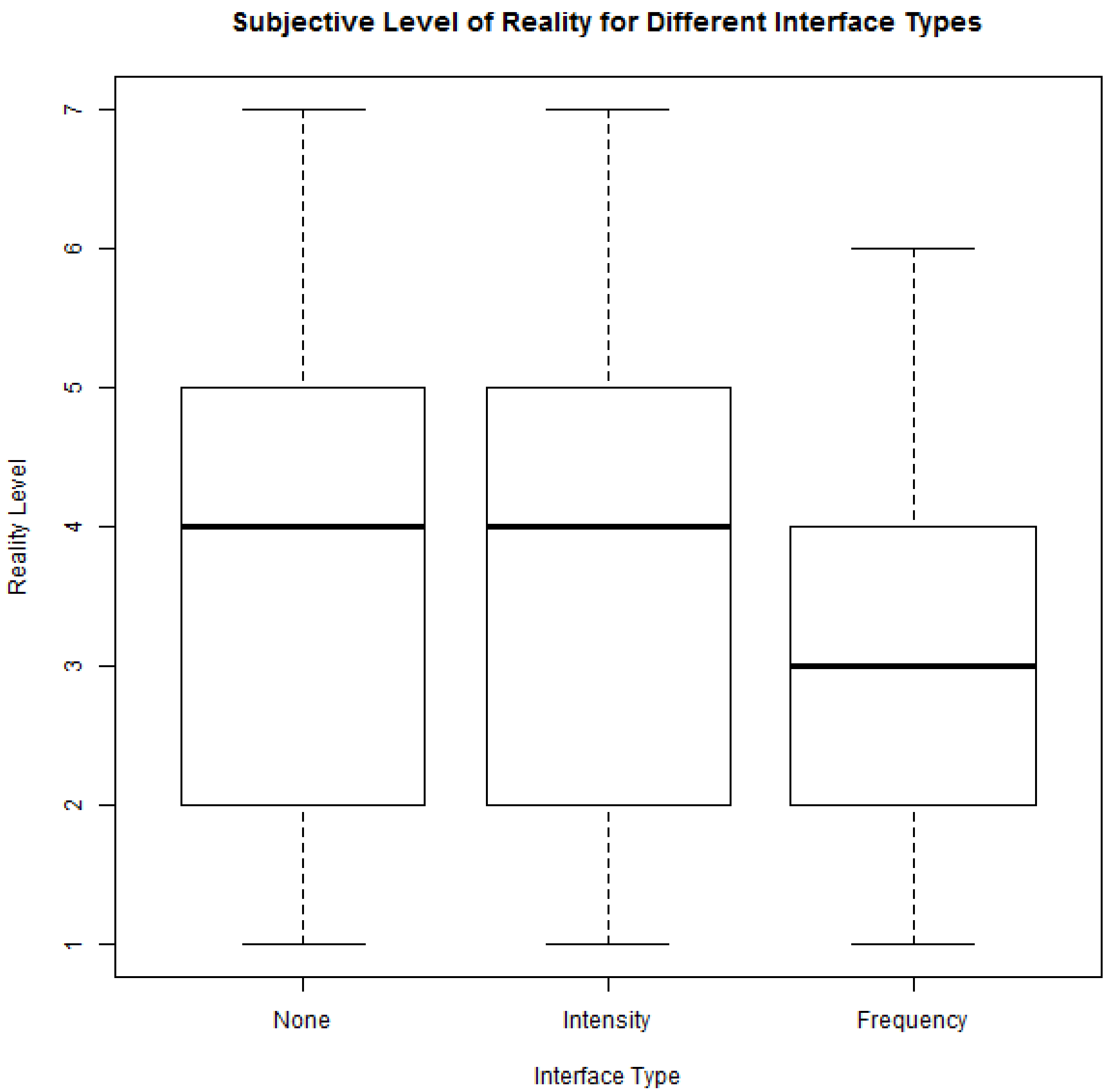
Being There vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	3.556	1.576	3.000
Intensity	3.994	1.372	4.000
Frequency	3.917	1.500	4.000







B.2.2.3 Reality+

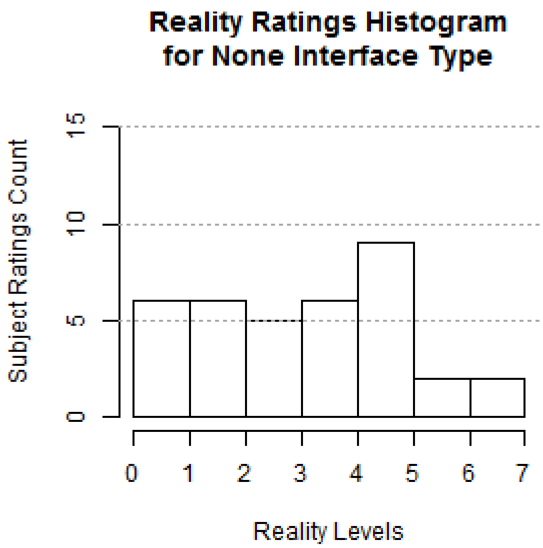


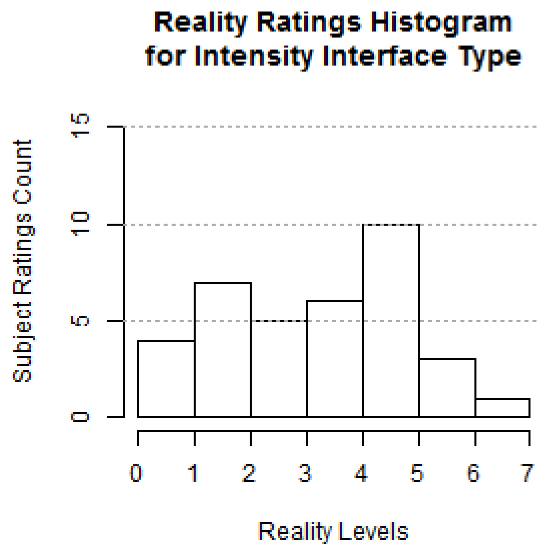
ANOVA: Being There Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	3.35	1.676	0.643	0.528
Residuals	105	273.64	2.606		

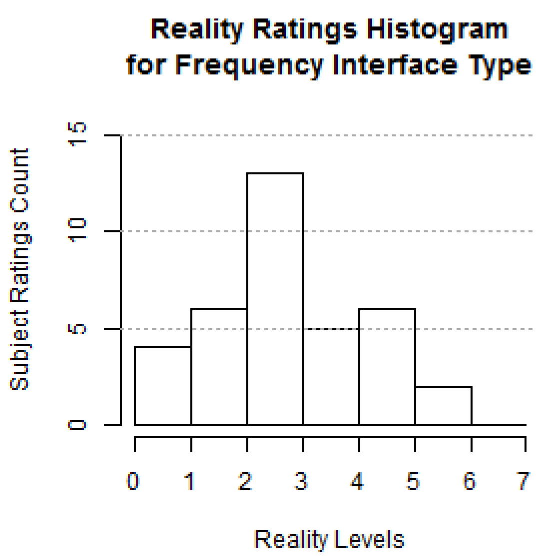
Being There vs. Interface Used - Friedman Test	
X^2	1.787
p	0.409

DoF		2.000	
Being There vs. Interface Used – Wilcoxon Test			
	N – I	***N – F***	***I – F***
W	101.500	209.500	172.500
Z	-0.355	1.022	1.802
p	0.752	0.321	0.074
R	-0.042	0.120	0.212

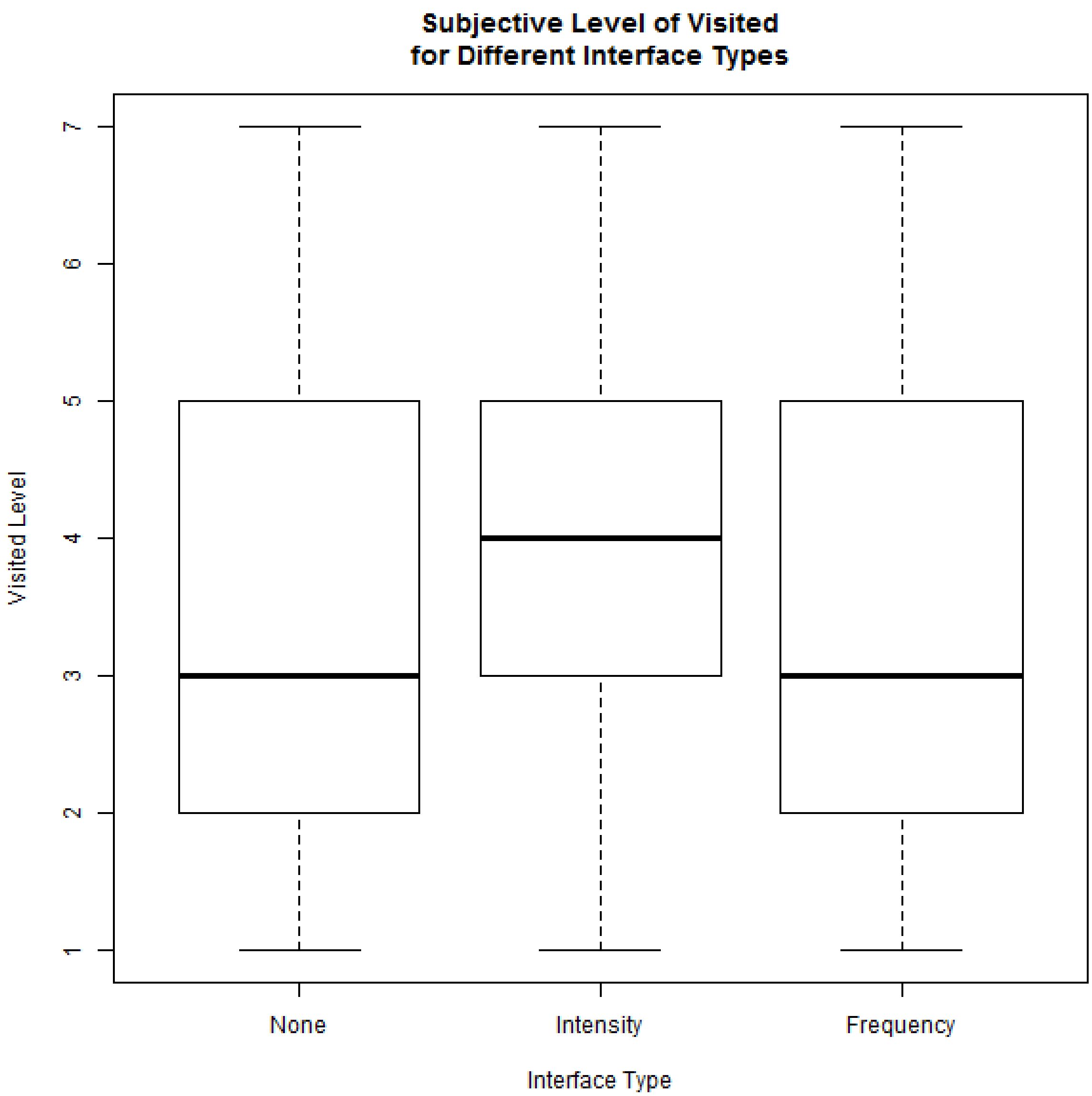
Being There vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	3.556	1.780	4.000
Intensity	3.667	1.656	4.000
Frequency	3.250	1.381	3.000







*B.2.2.4 Visited**

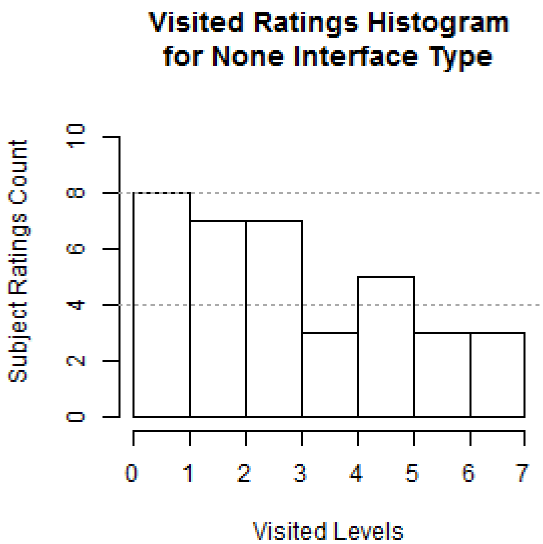


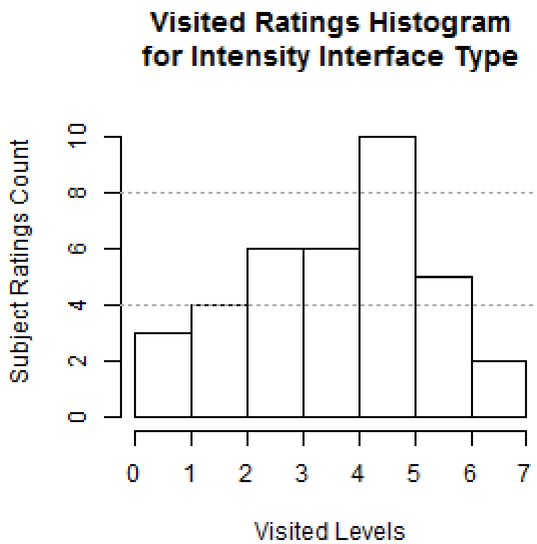
ANOVA: Visited Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	10.9	5.444	1.597	0.207
Residuals	105	358.0	3.410		

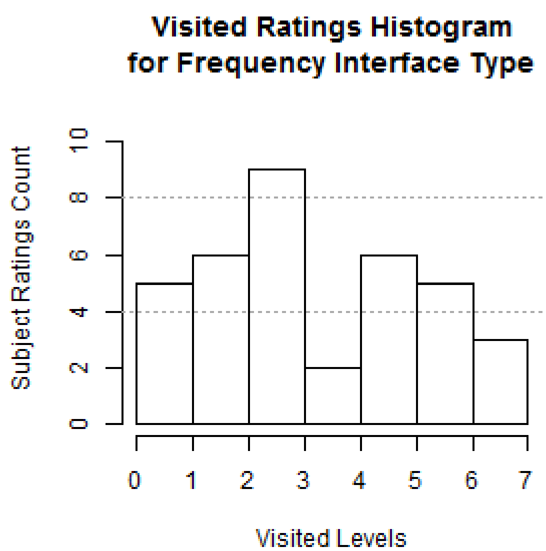
Visited vs. Interface Used - Friedman Test	
X^2	9.407
p	0.009
DoF	2.000

Visited vs. Interface Used – Wilcoxon Test			
	N – I	***N – F***	***I – F***
W	18.000	44.000	148.000
Z	-3.135	-1.692	1.507
p	0.001	0.092	0.141
R	-0.370	-0.199	0.178

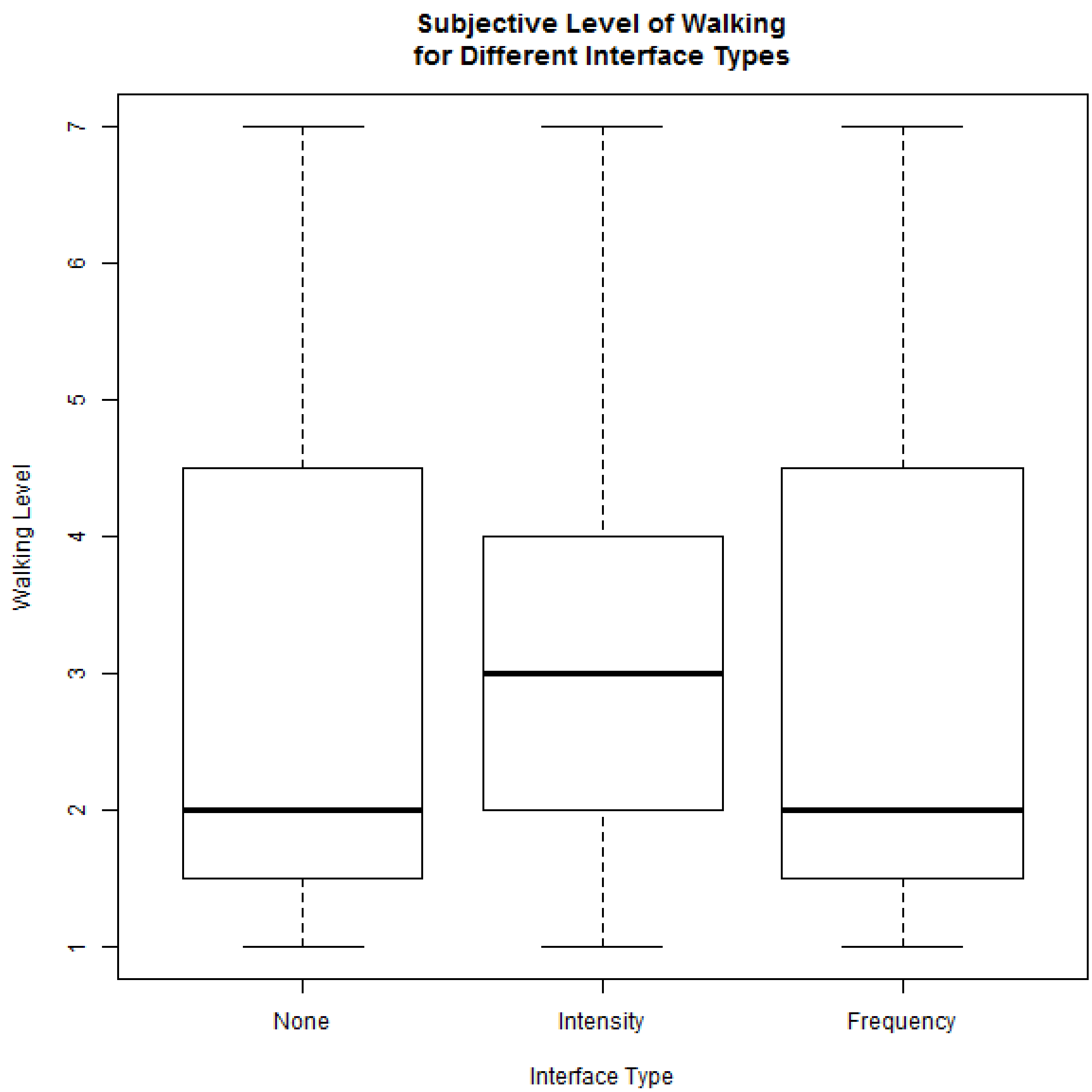
Visited vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	3.306	1.954	3.000
Intensity	4.083	1.663	4.000
Frequency	3.694	1.910	3.000







B.2.2.5 Walking

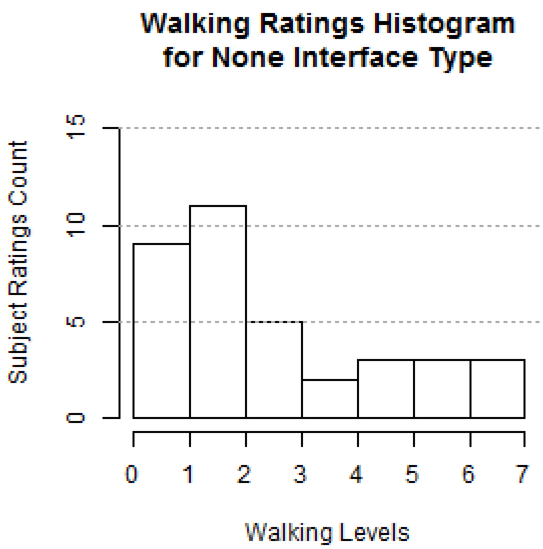


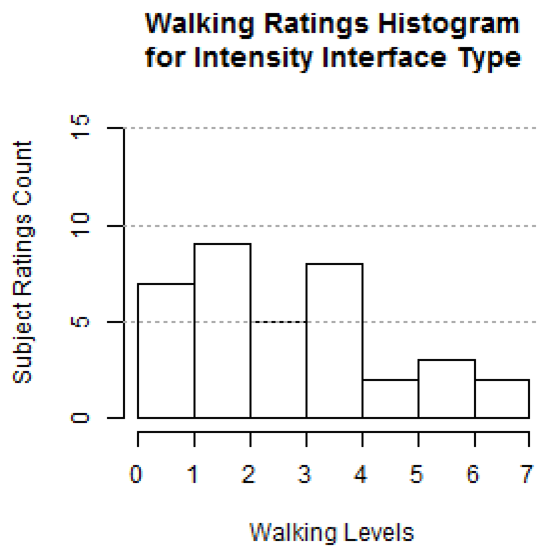
ANOVA: Walking Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	1.7	0.843	0.246	0.782
Residuals	105	359.3	3.422		

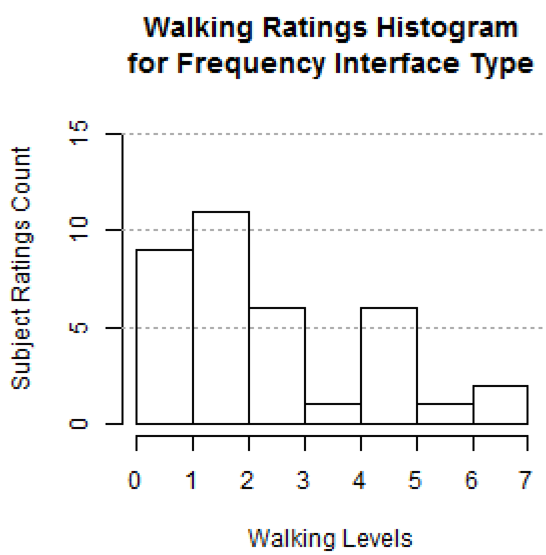
Walking vs. Interface Used - Friedman Test	
X^2	1.238
p	0.538
DoF	2.000

Walking vs. Interface Used – Wilcoxon Test			
	N – I	***N – F***	***I – F***
W	110.500	74.000	159.500
Z	-0.488	0.104	1.222
p	0.631	0.901	0.231
R	-0.057	0.012	0.144

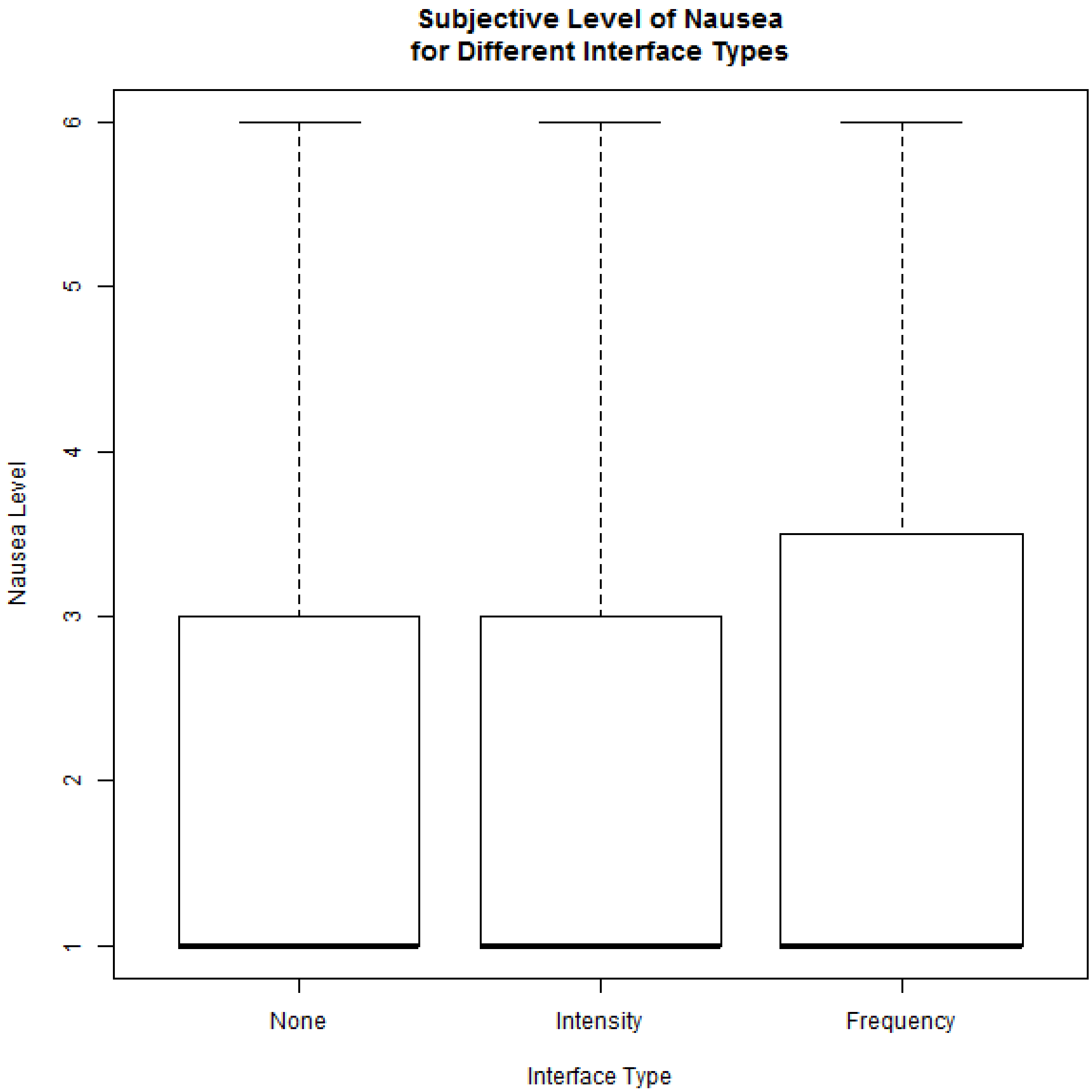
Walking vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	3.000	1.971	2.000
Intensity	3.167	1.781	3.000
Frequency	2.861	1.791	2.000







B.2.2.6 Nausea+

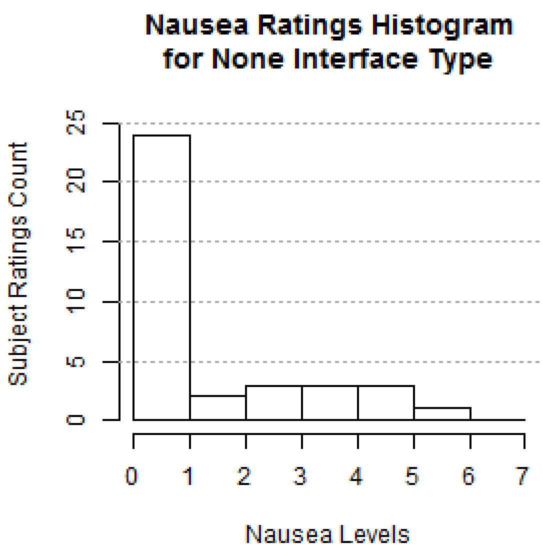


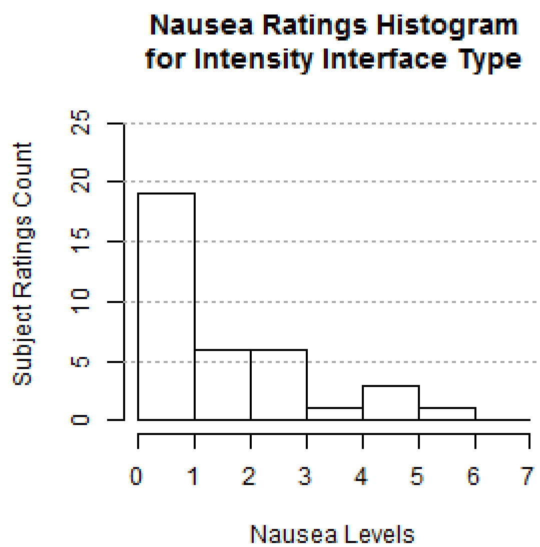
ANOVA: Nausea Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	2.046	1.232	0.506	0.604
Residuals	105	255.42	2.433		

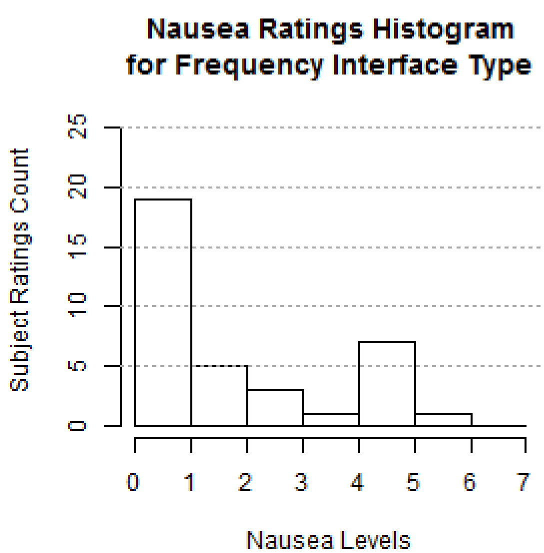
Nausea vs. Interface Used - Friedman Test	
X^2	3.964
p	0.138
DoF	2.000

Nausea vs. Interface Used – Wilcoxon Test			
	N – I	***N – F***	***I – F***
W	45.5000	27.000	27.500
Z	-0.916	-1.818	-0.967
p	0.401	0.084	0.328
R	-0.108	-0.214	-0.114

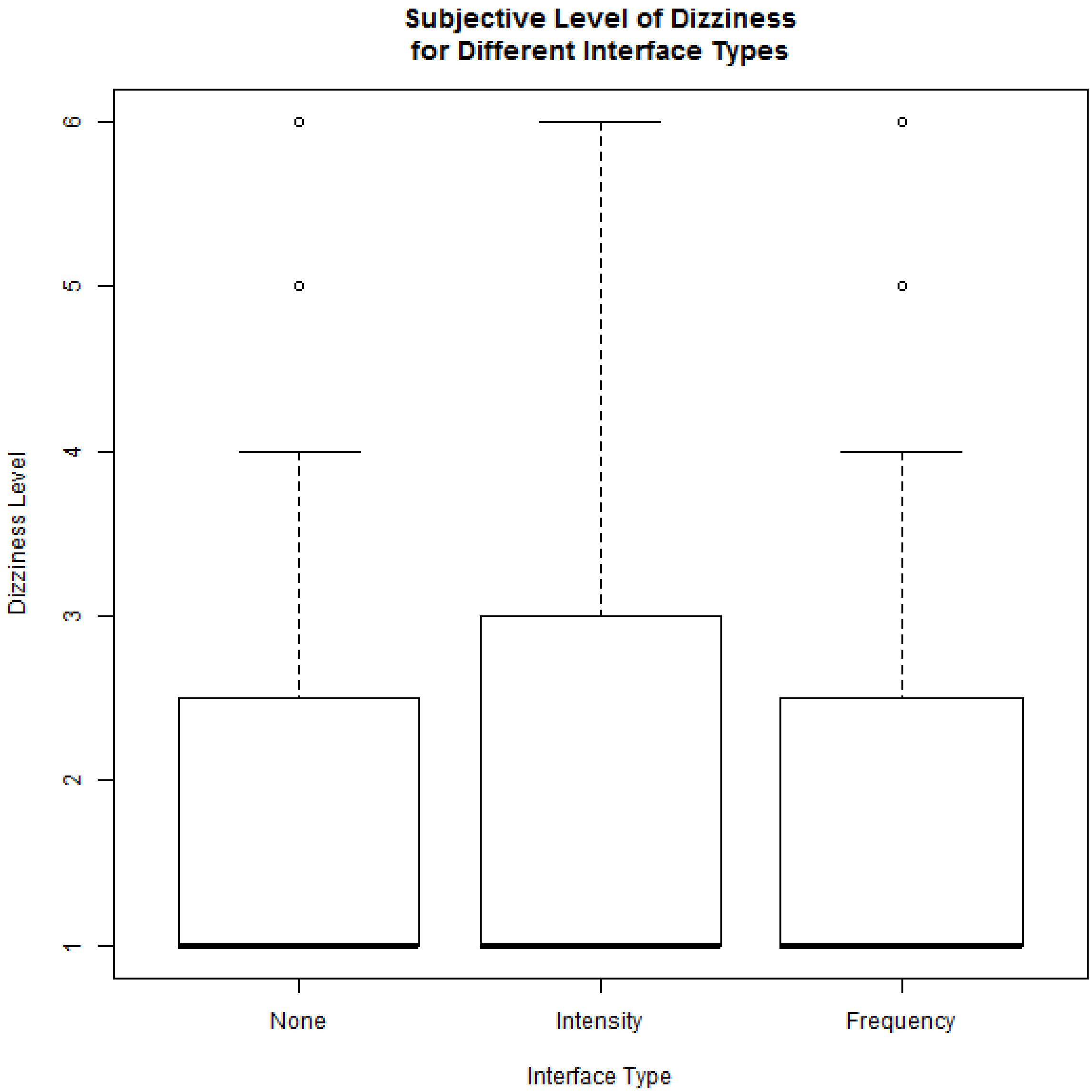
Nausea vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	1.944	1.530	1.000
Intensity	2.056	1.433	1.000
Frequency	1.306	1.704	1.000







B.2.2.7 Dizziness

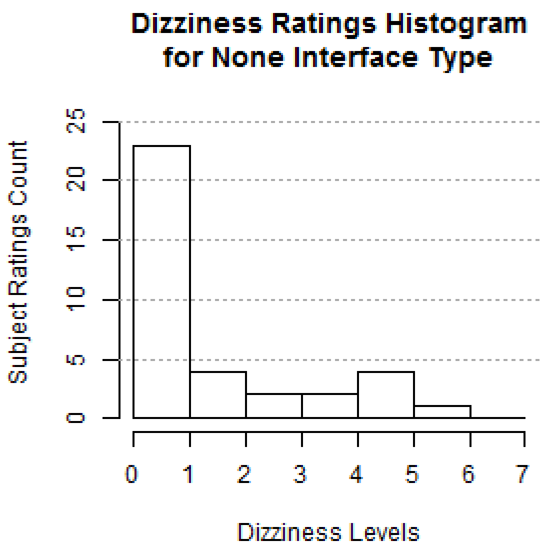


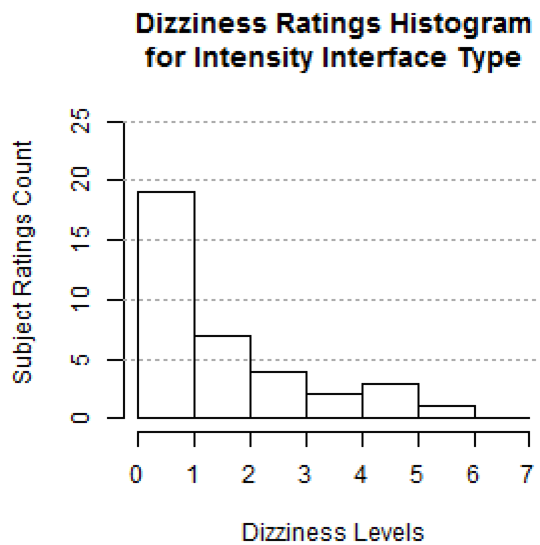
ANOVA: Dizziness Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.5	0.250	0.104	0.902
Residuals	105	253.2	2.411		

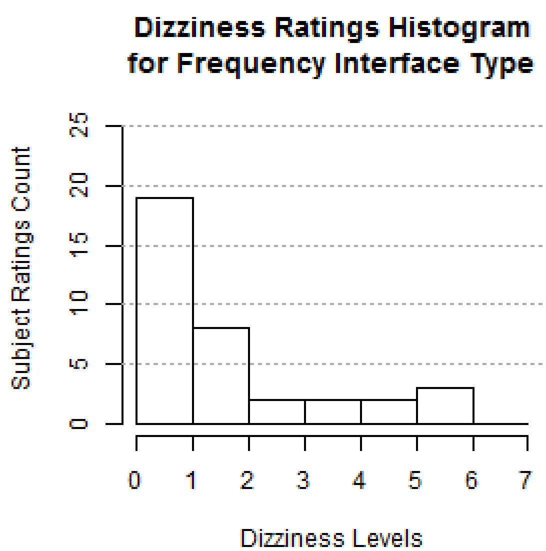
Dizziness vs. Interface Used - Friedman Test	
X^2	1.088
p	0.581
DoF	2.000

Dizziness vs. Interface Used – Wilcoxon Test			
	N – I	***N – F***	***I – F***
W	51.500	34.000	32.500
Z	-0.706	-0.845	-0.574
p	0.537	0.426	0.637
R	-0.083	-0.100	-0.068

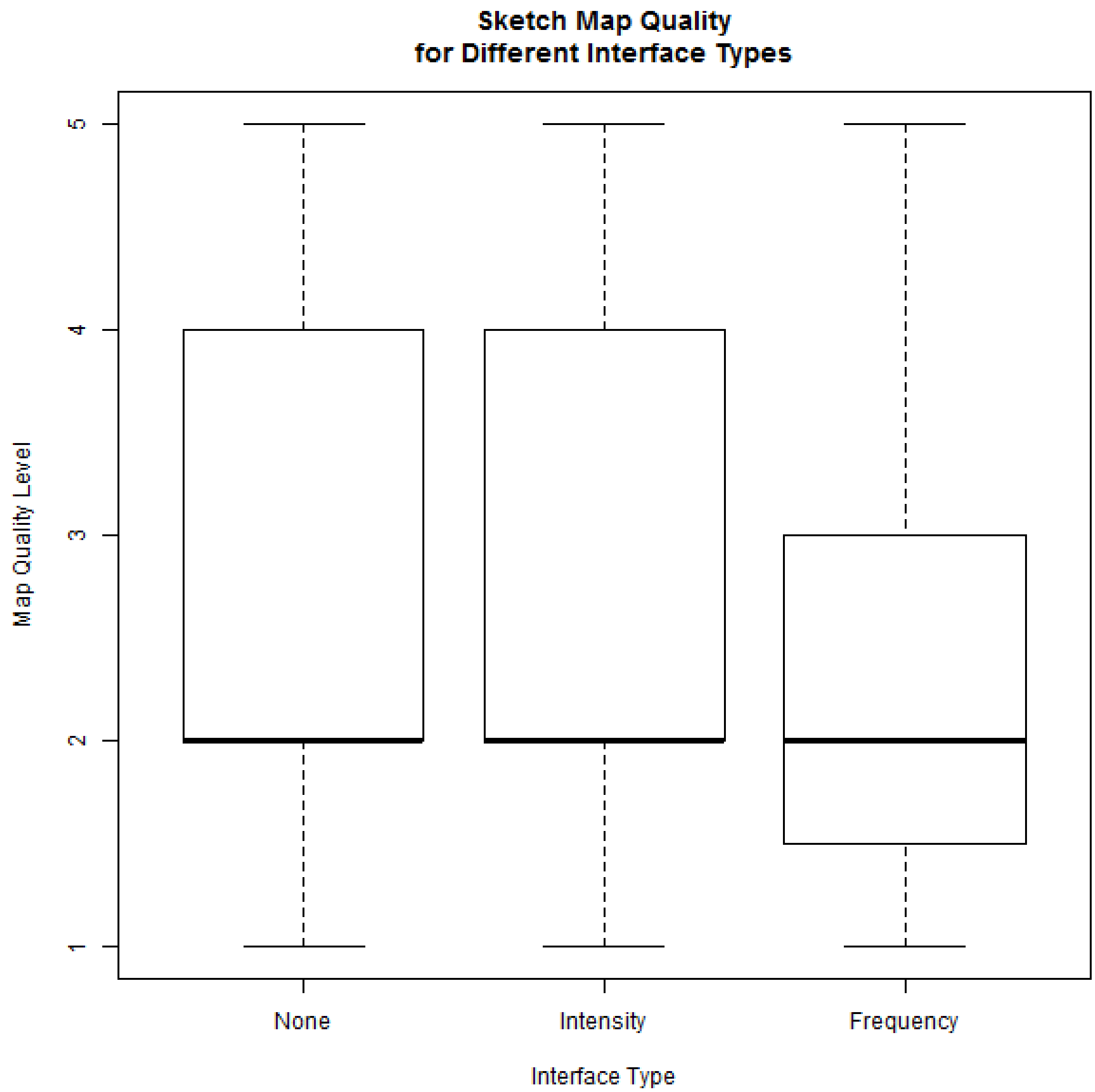
Dizziness vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	1.972	1.558	1.000
Intensity	2.056	1.453	1.000
Frequency	2.139	1.641	1.000







B.2.3 Map Quality

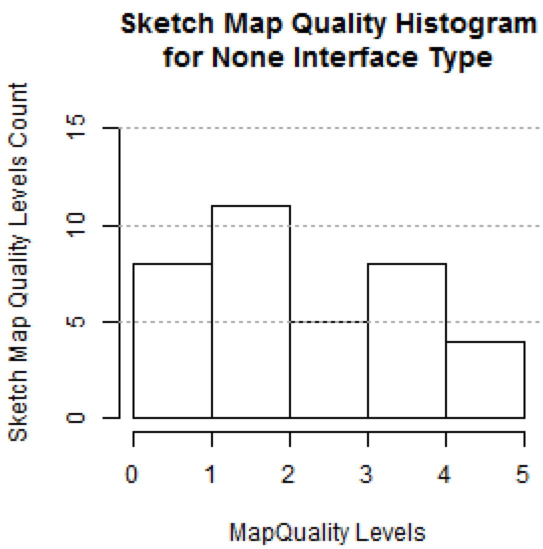


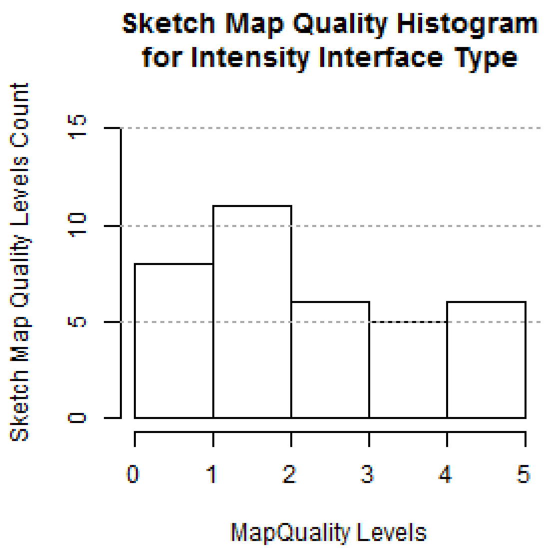
ANOVA: Map Quality Scores for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	1.35	0.676	0.378	0.686
Residuals	105	187.83	1.789		

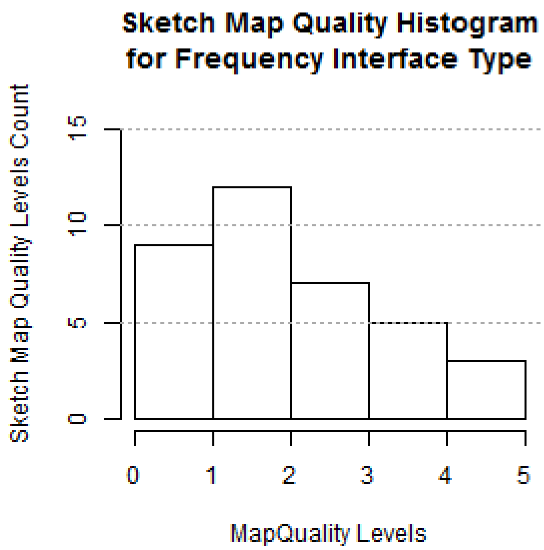
Map Quality vs. Interface Used - Friedman Test	
X^2	3.176
p	0.204
DoF	2.000

Map Quality vs. Interface Used – Wilcoxon Test			
	N – I	***N – F***	***I – F***
W	64.000	96.000	76.500
Z	-0.070	1.540	1.621
p	1.000	0.168	0.127
R	-0.008	0.182	0.191

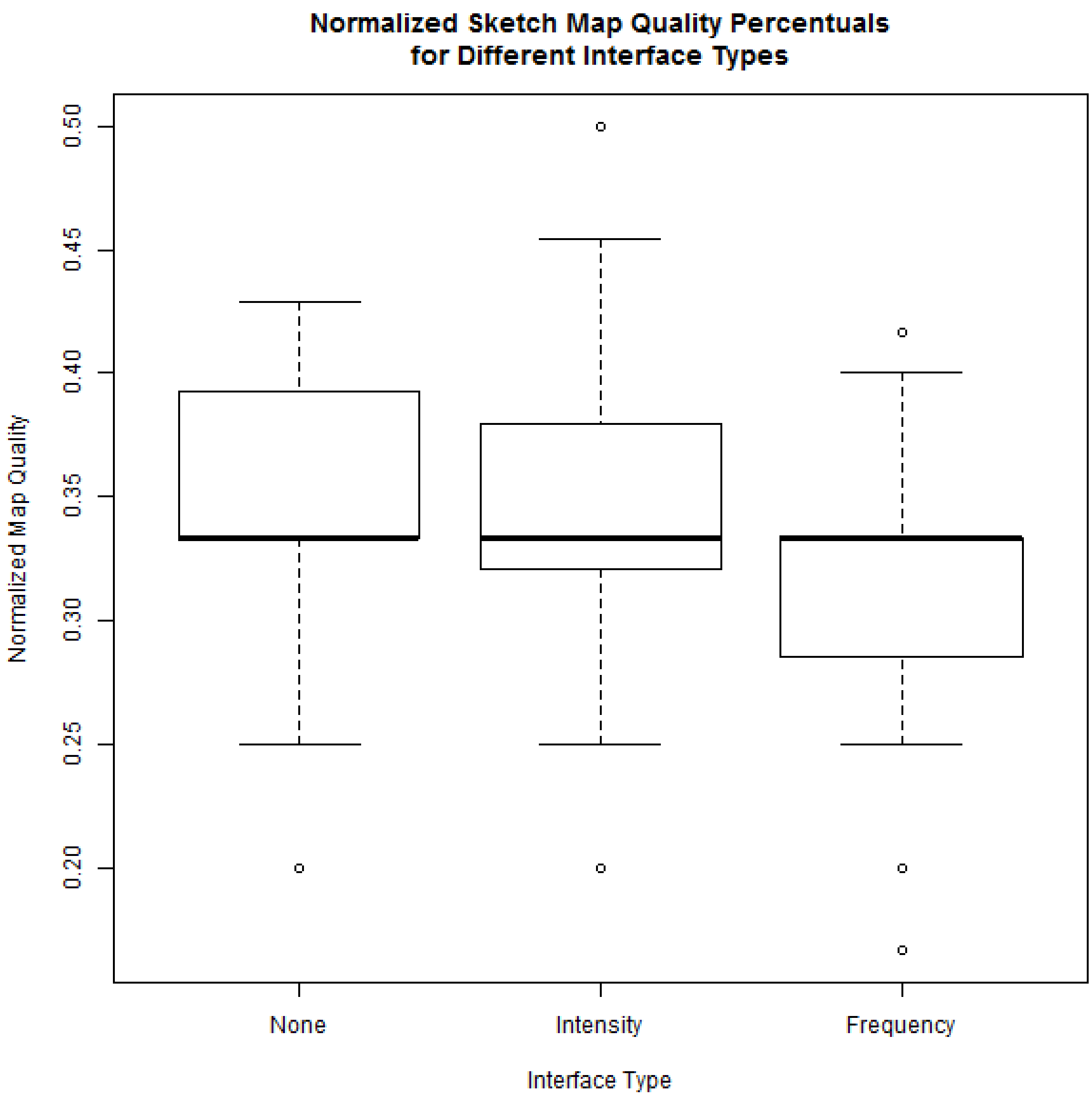
Map Quality vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	2.694	1.348	2.000
Intensity	2.722	1.406	2.000
Frequency	2.472	1.253	2.000







B.2.3.1 Normalized Map Quality+



ANOVA: Normalized Map Quality Scores for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.016	0.008	2.397	0.096
Residuals	105	0.357	0.004		

ANOVA: Normalized Map Quality Scores for Groups None and Intensity					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.000	0.000	0.037	0.847
Residuals	70	0.240	0.003		

ANOVA: Normalized Map Quality Scores for Groups None and Frequency					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.011	0.011	3.442	0.068
Residuals	70				

ANOVA: Normalized Map Quality Scores for Groups Intensity and Frequency					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.013	0.013	3.725	0.057
Residuals	70				

B.2.3.2 Interface Order Effect on Quality of Maps

B.2.3.2.1 None Interface

ANOVA: None Interface Map Quality in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	1.72	0.861	0.459	0.636
Residuals	33	61.92	1.876		

None Interface Map Quality vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (1st)	2.500	1.446	2.000
FNI (2nd)	2.583	1.379	2.000
IFN (3rd)	3.000	1.279	3.000

ANOVA: None Interface Normalized Map Quality in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.009	0.005	1.531	0.231
Residuals	33	0.096	0.003		

None Interface Map Quality vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (1st)	0.318	0.054	0.333
FNI (2nd)	0.348	0.053	0.333
IFN (3rd)	0.354	0.054	0.333

B.2.3.2.2 Intensity Interface*

ANOVA: Intensity Interface Map Quality in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.22	0.111	0.053	0.948
Residuals	33	69.00	2.091		

Intensity Interface Map Quality vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	2.833	1.697	2.500
FNI (3rd)	2.667	1.371	2.000
IFN (1st)	2.667	1.231	2.500

ANOVA: Intensity Interface Normalized Map Quality in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.020	0.010	2.872	0.071
Residuals	33	0.115	0.003		

ANOVA: Intensity Interface Normalized Map Quality for Interface Orders NIF (2nd) and FNI (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.002	0.002	0.465	0.502
Residuals	33	0.084	0.004		

ANOVA: Intensity Interface Normalized Map Quality for Interface Orders NIF (2nd) and IFN (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.009	0.009	2.861	0.105
Residuals	33	0.071	0.003		

ANOVA: Intensity Interface Normalized Map Quality for Interface Orders FNI (3rd) and IFN (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.019	0.019	5.546	0.028
Residuals	33	0.076	0.003		

Intensity Interface Map Quality vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.351	0.060	0.348
FNI (3rd)	0.368	0.063	0.333
IFN (1st)	0.311	0.053	0.320

B.2.3.2.3 Frequency Interface

ANOVA: Frequency Interface Map Quality in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	5.06	2.528	1.671	0.204
Residuals	33	49.92	1.513		

Frequency Interface Map Quality vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (3rd)	2.500	1.243	2.5
FNI (1st)	2.000	0.953	2.000
IFN (2nd)	2.916	1.443	2.500

ANOVA: Frequency Interface Normalized Map Quality in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.019	0.009	3.157	0.056
Residuals	33	0.098	0.003		

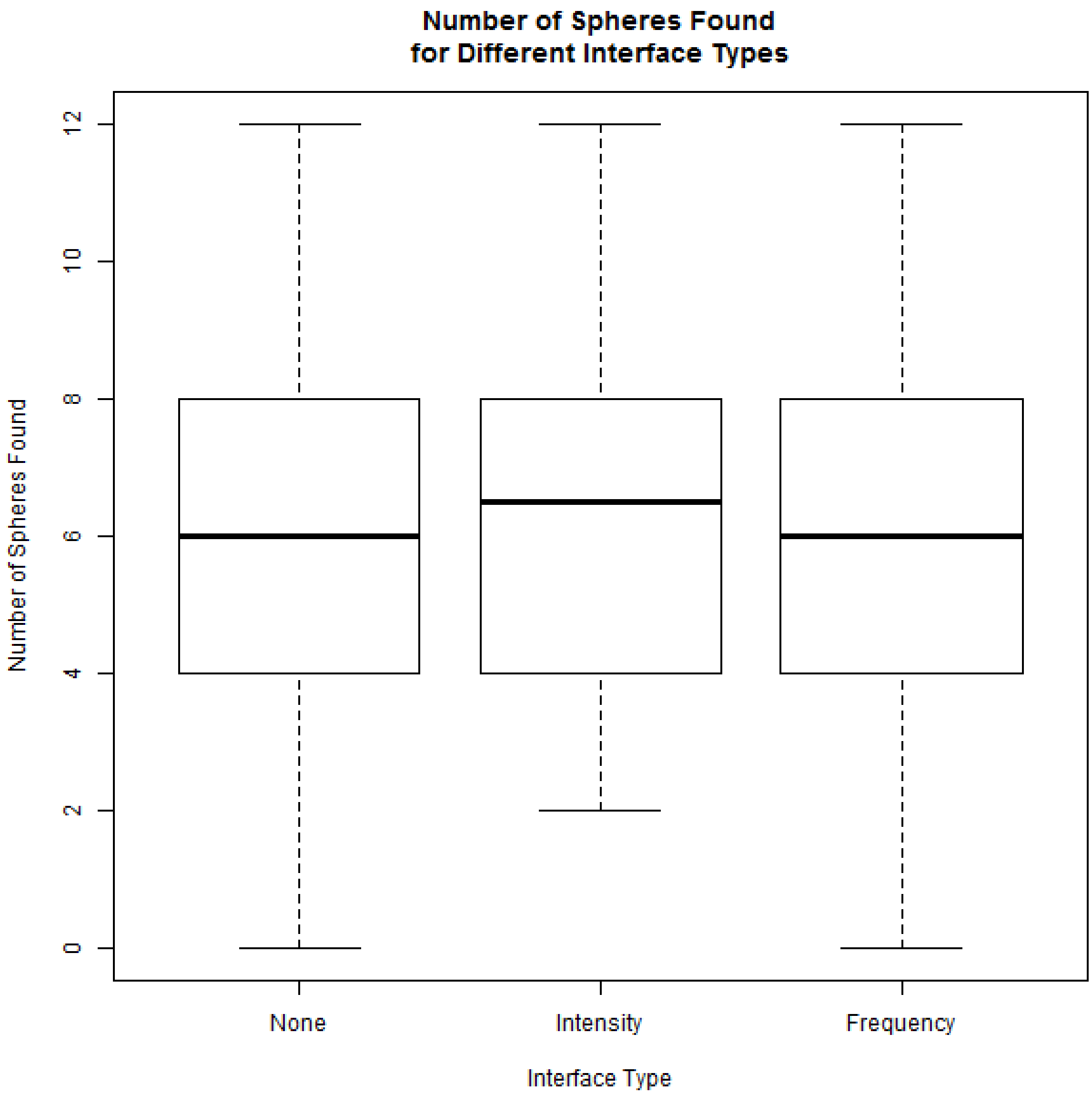
ANOVA: Frequency Interface Normalized Map Quality for Interface Orders NIF (3rd) and FNI (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.013	0.013	5.025	0.035
Residuals	33	0.058	0.003		

ANOVA: Frequency Interface Normalized Map Quality for Interface Orders NIF (3rd) and IFN (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.000	0.000	0.02	0.89
Residuals	33	0.063	0.003		

ANOVA: Frequency Interface Normalized Map Quality for Interface Orders FNI (1st) and IFN (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.015	0.015	4.327	0.049
Residuals	33	0.076	0.003		

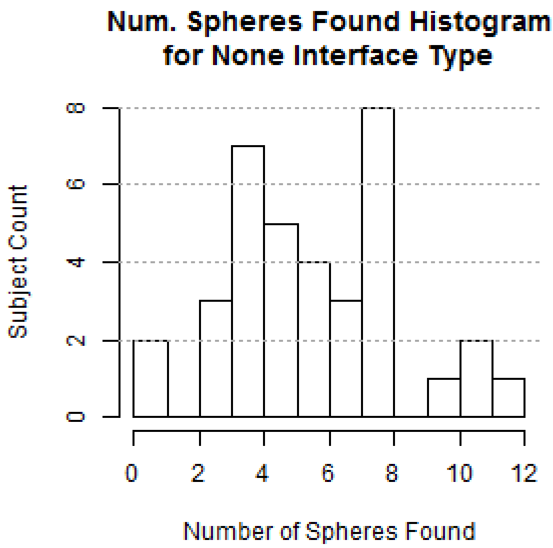
Frequency Interface Map Quality vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (3rd)	0.331	0.045	0.333
FNI (1st)	0.283	0.056	0.293
IFN (2nd)	0.334	0.061	0.333

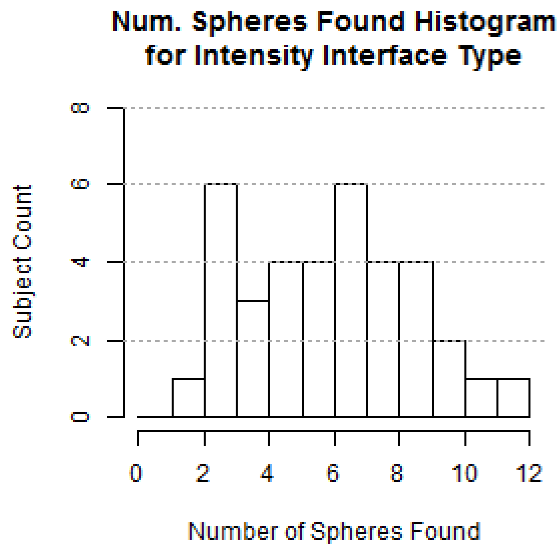
B.2.4 Number of Spheres Found

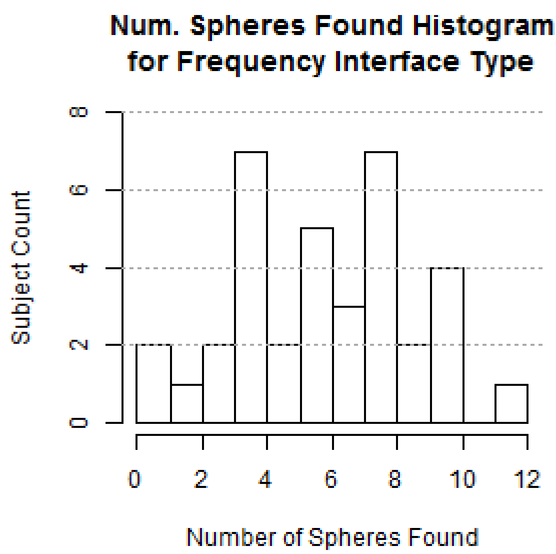


ANOVA: Number of Spheres Found for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	2.7	1.370	0.183	0.833
Residuals	105	784.9	7.475		

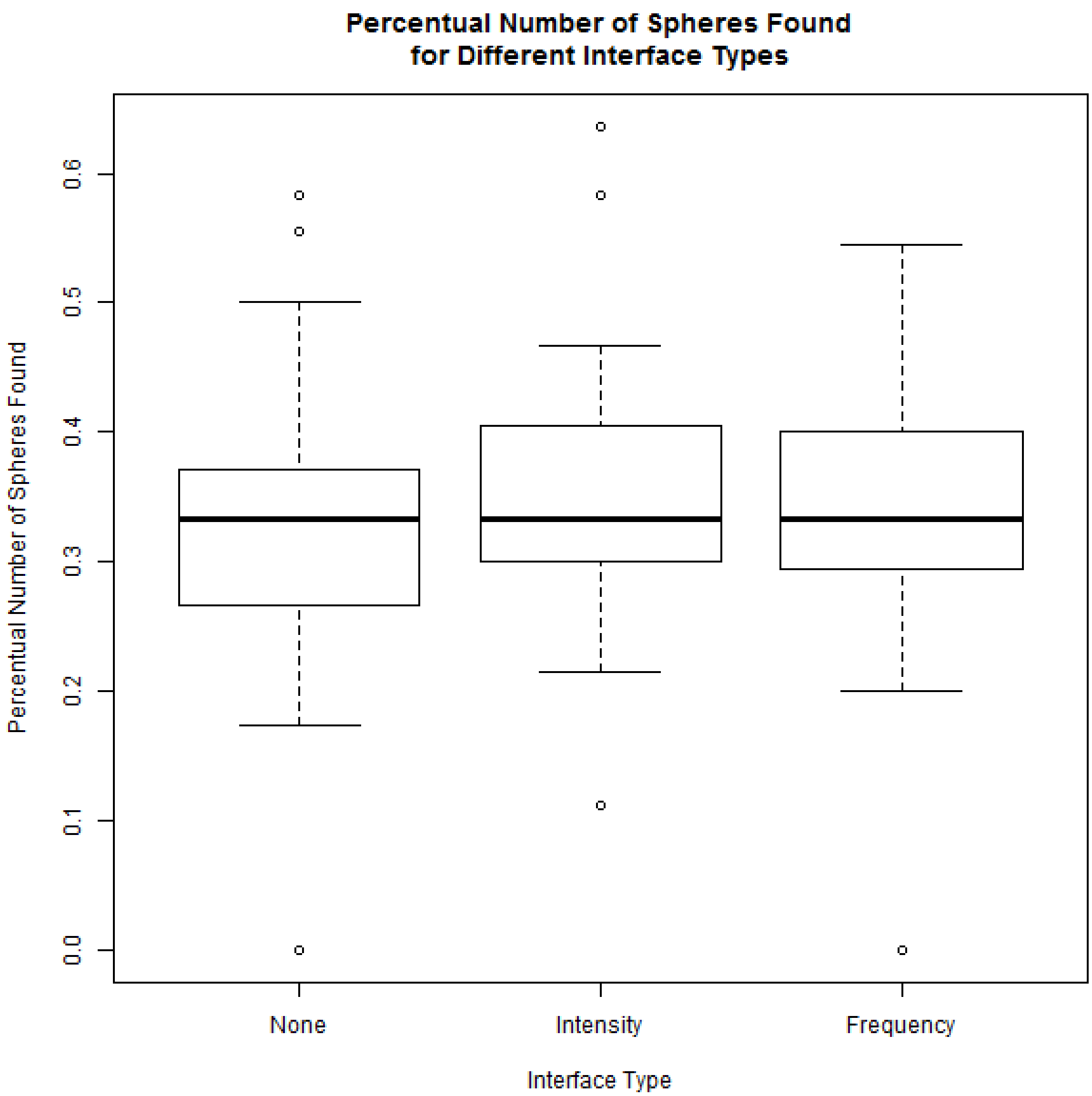
Number of Spheres Found vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	5.972	2.772	6.000
Intensity	6.361	2.576	6.500
Frequency	6.194	2.847	6.000


Num. Spheres Found Histogram
for None Interface Type
Subject Count
0
2
4
6
8
0
2
4
6
8
10
12
Number of Spheres Found


Num. Spheres Found Histogram
for Intensity Interface Type
Subject Count
0
2
4
6
8
0
2
4
6
8
10
12
Number of Spheres Found


Num. Spheres Found Histogram
for Frequency Interface Type
Subject Count
0
2
4
6
8
0
2
4
6
8
10
12
Number of Spheres Found

B.2.4.1 Normalized Number of Spheres Found



ANOVA: Normalized Number of Spheres Found for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	02013	02006	0.549	0.579
Residuals	105	1.216	0.011		

Normalized Number of Spheres Found vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	0.323	0.119	0.333
Intensity	0.348	0.097	0.333
Frequency	0.328	0.106	0.333

B.2.4.2 Interface Order Effect on Number of Spheres Found

B.2.4.2.1 None Interface

ANOVA: None Interface Number of Spheres Found in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	20.39	10.194	1.353	0.272
Residuals	33	248.58	7.533		

None Interface Number of Spheres Found vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	5	2.923	4.500
FNI (3rd)	6.083	2.193	6.000
IFN (1st)	6.833	3.040	6.500

ANOVA: None Interface Normalized Number of Spheres Found in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.144	0.072	6.759	0.003
Residuals	33	0.351	0.011		

ANOVA: None Interface Normalized Number of Spheres Found for Interface Orders NIF(1st) and FNI (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.092	0.092	7.652	0.011
Residuals	33	0.265	0.012		

ANOVA: None Interface Normalized Number of Spheres Found for Interface Orders NIF (1st) and IFN (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.121	0.121	10.42	0.004
Residuals	33	0.256	0.011		

ANOVA: None Interface Normalized Number of Spheres Found for Interface Orders FNI (2nd) and IFN (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.002	0.002	0.241	0.628
Residuals	33	0.180	0.008		

Frequency Interface Normalized Number of Spheres Found vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.234	0.124	0.262
FNI (3rd)	0.358	0.092	0.333
IFN (1st)	0.376	0.088	0.371

B.2.4.2.2 Intensity Interface *

ANOVA: Intensity Interface Number of Spheres Found in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	20.22	10.111	1.573	0.223
Residuals	33	212.08	6.427		

Intensity Interface Number of Spheres Found vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	7.250	2.050	7.000
FNI (3rd)	6.417	2.843	7.000
IFN (1st)	5.417	2.644	5.000

ANOVA: Intensity Interface Normalized Number of Spheres Found in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.046	0.023	2.708	0.081
Residuals	33	0.282	0.008		

ANOVA: Intensity Interface Normalized Number of Spheres Found for Interface Orders NIF(2nd) and FNI (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.002	0.002	0.166	0.688
Residuals	33	0.218	0.009		

ANOVA: Intensity Interface Normalized Number of Spheres Found for Interface Orders NIF (2nd) and IFN (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.041	0.041	5.564	0.027
Residuals	33	0.163	0.007		

ANOVA: Intensity Interface Normalized Number of Spheres Found for Interface Orders FNI (3rd) and IFN (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.026	0.026	3.189	0.088
Residuals	33	0.182	0.008		

Intensity Interface Normalized Number of Spheres Found vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.381	0.095	0.365
FNI (3rd)	0.365	0.104	0.340
IFN (1st)	0.298	0.076	0.311

B.2.4.2.3 Frequency Interface

ANOVA: Frequency Interface Number of Spheres Found in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	29.56	14.778	1.919	0.163
Residuals	33	254.08	7.699		

Frequency Interface Number of Spheres Found vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	7.417	2.234	7.500
FNI (3rd)	5.250	3.414	5.500
IFN (1st)	5.917	2.539	5.000

ANOVA: Frequency Interface Normalized Number of Spheres Found in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.070	0.035	3.546	0.040
Residuals	33	0.324	0.010		

ANOVA: Frequency Interface Normalized Number of Spheres Found for Interface Orders NIF(3rd) and FNI (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.069	0.069	5.143	0.033
Residuals	33	0.297	0.013		

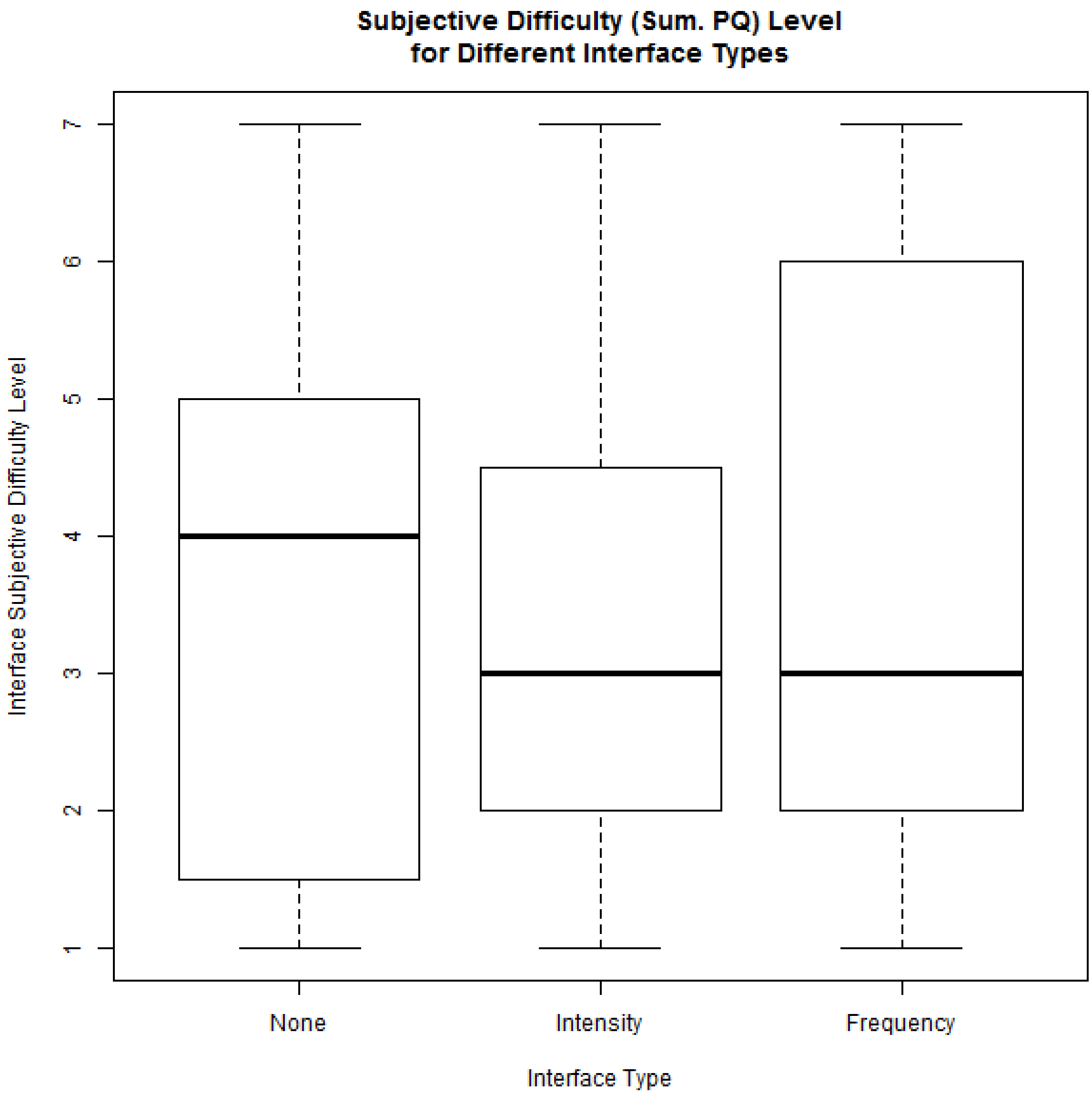
ANOVA: Frequency Interface Normalized Number of Spheres Found for Interface Orders NIF (3^{rd}) and IFN (2^{nd})					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.021	0.021	5.044	0.035
Residuals	33	0.092	0.004		

ANOVA: Frequency Interface Normalized Number of Spheres Found for Interface Orders FNI (1^{st}) and IFN (2^{nd})					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.014	0.014	1.186	0.288
Residuals	33	0.259	0.012		

Frequency Interface Normalized Number of Spheres Found vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2^{nd})	0.384	0.077	0.396
FNI (3^{rd})	0.276	0.145	0.311
IFN (1^{st})	0.325	0.050	0.304

B.2.5 Final Questionnaire

B.2.5.1 Difficulty+

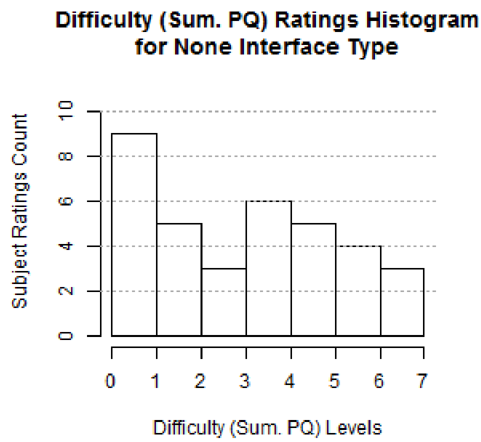


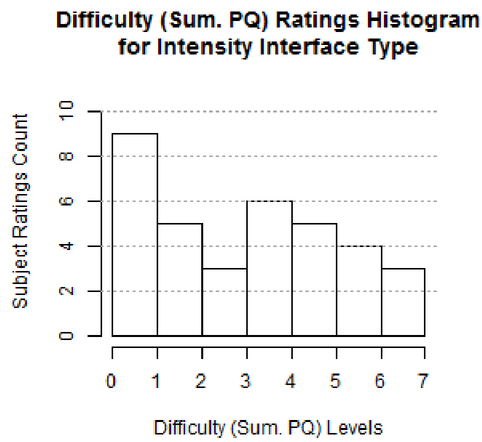
ANOVA: Difficulty Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	5.8	2.895	0.797	0.453
Residuals	102	370.4	3.631		

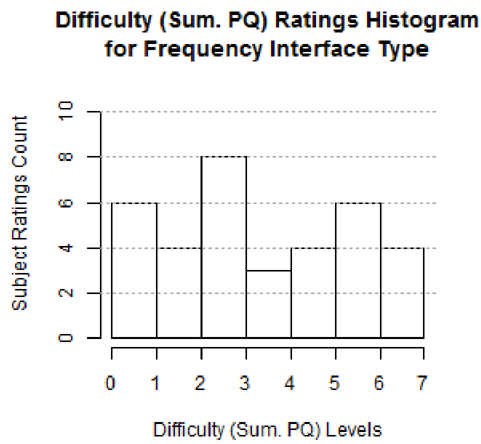
Difficulty vs. Interface Used - Friedman Test	
X^2	2.243
P	0.326
DoF	2.000

Difficulty vs. Interface Used – Wilcoxon Test			
	N – I	***N – F***	***I – F***
W	245.500	196.000	93.500
Z	0.513	-0.850	-1.737
p	0.618	0.402	0.082
R	0.060	-0.100	-0.205

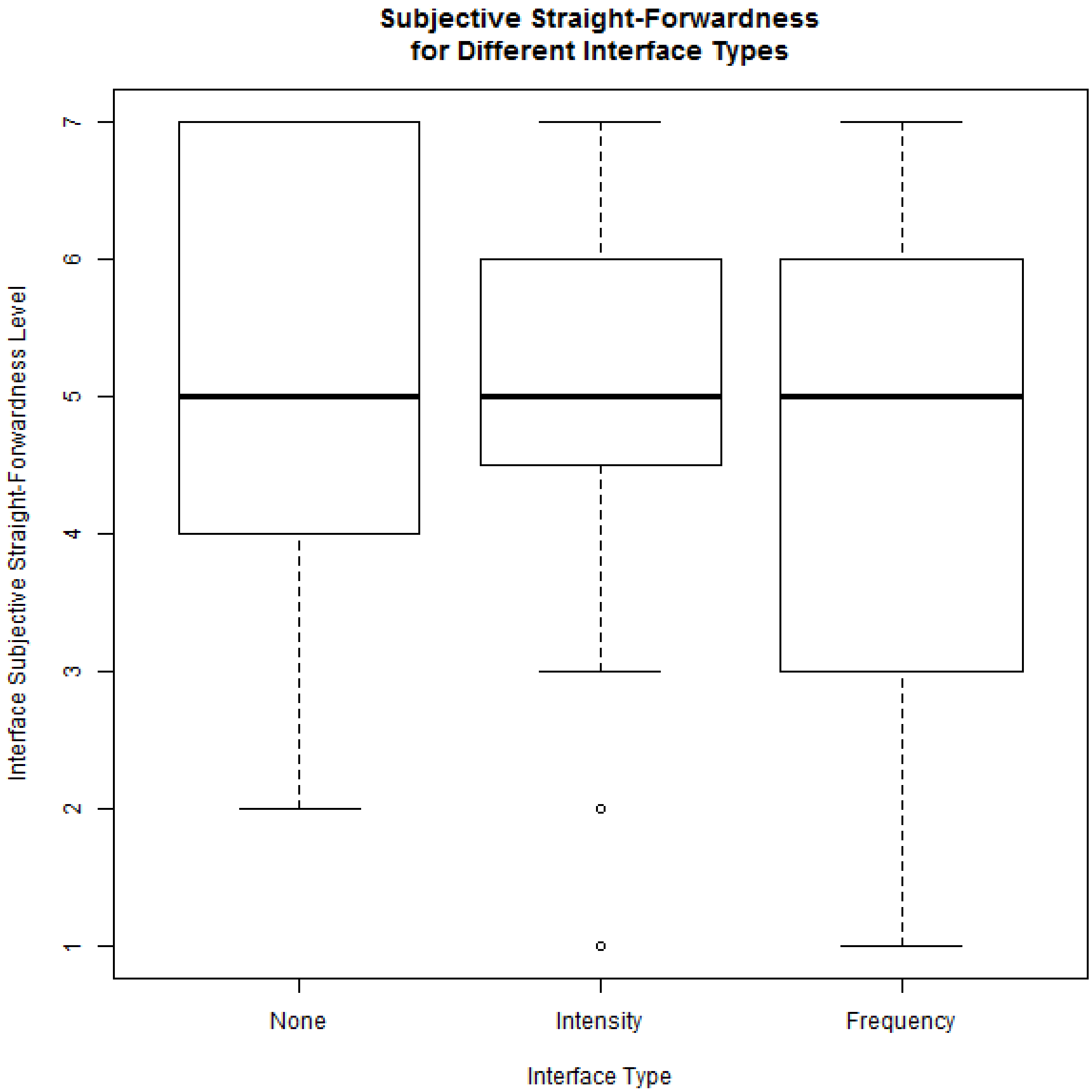
Difficulty vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	3.486	2.049	4.000
Intensity	3.257	1.597	3.000
Frequency	3.829	2.036	3.000







B.2.5.2 Straight-Forwardness+

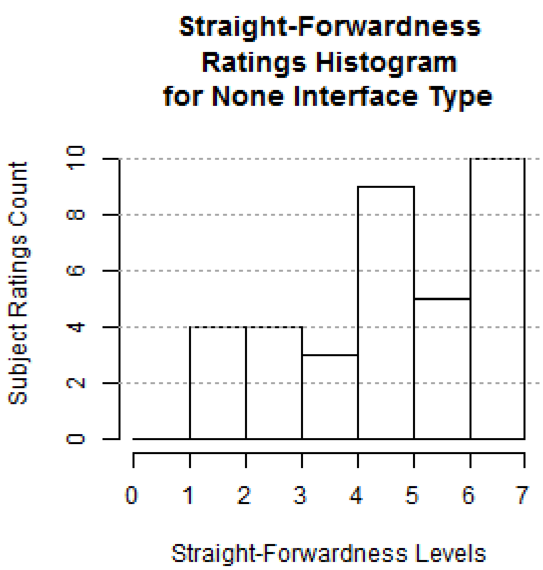


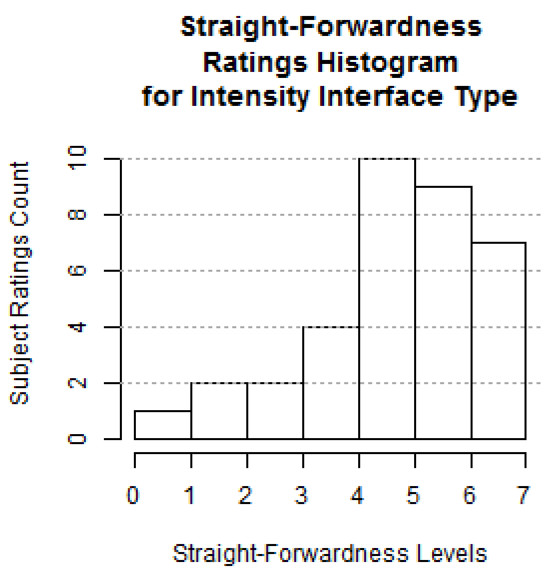
ANOVA: Straight-Forwardness Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	4.7	2.352	0.81	0.447
Residuals	102	296.1	2.902		

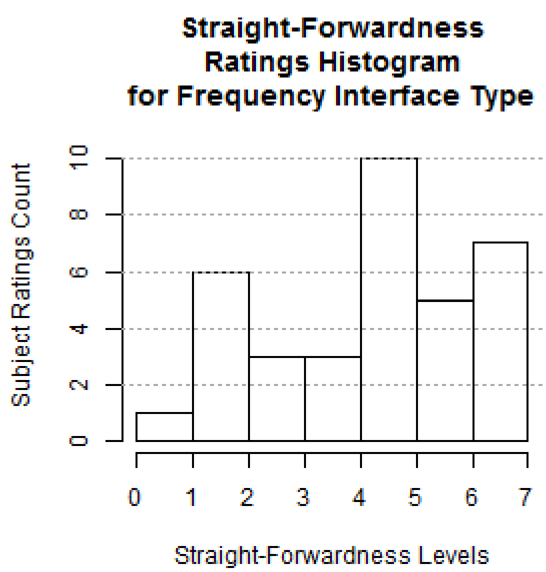
Straight-Forwardness vs. Interface Used - Friedman Test	
X^2	3.857
p	0.145
DoF	2.000

Straight-Forwardness vs. Interface Used – Wilcoxon Test			
	N – I	***N – F***	***I – F***
W	157.500	147.000	203.500
Z	-0.598	1.368	1.634
p	0.556	0.175	0.105
R	-0.070	0.161	0.193

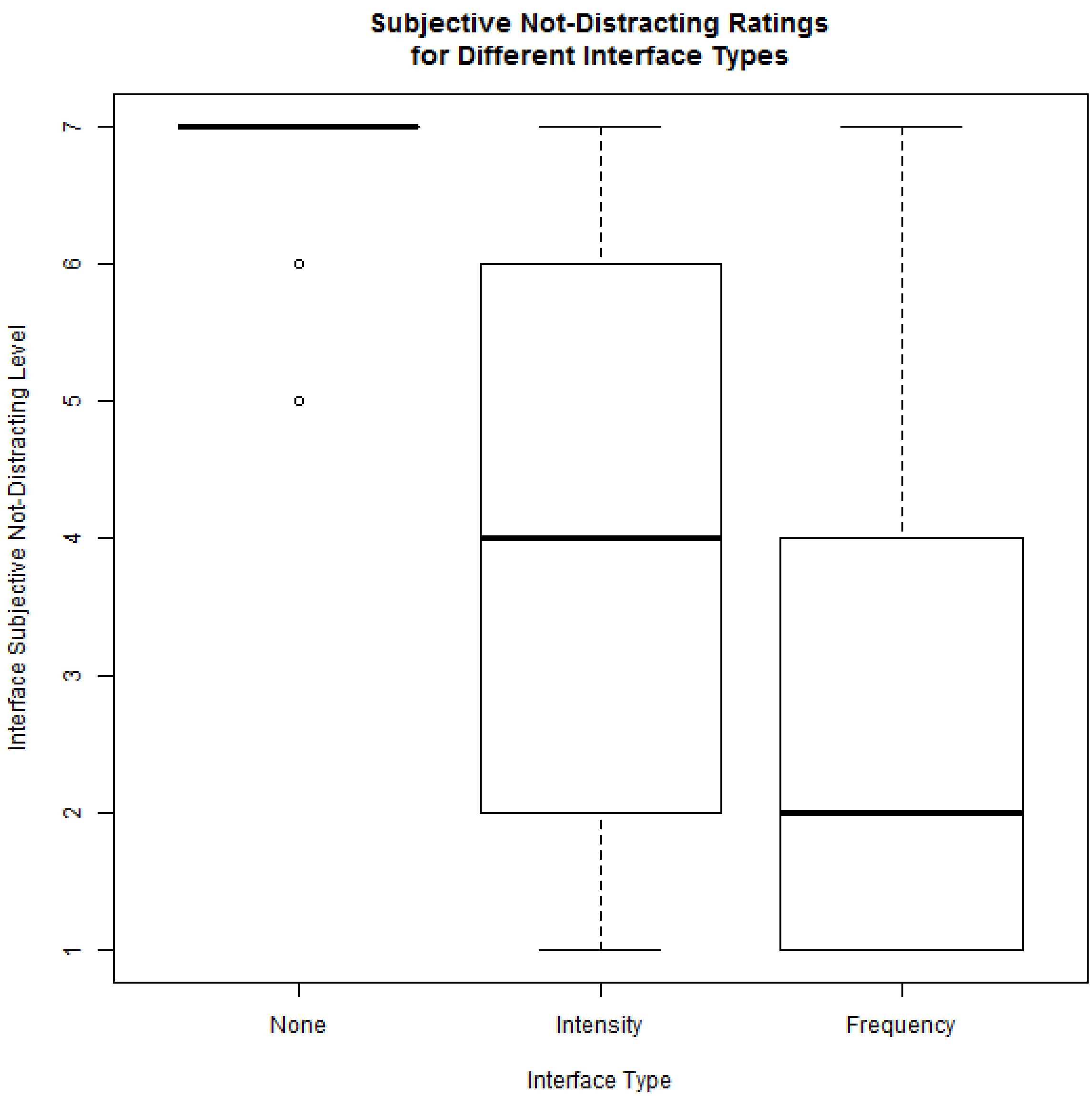
Straight-Forwardness vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	5.057	1.714	5.000
Intensity	5.143	1.556	5.000
Frequency	4.657	1.830	5.000







*B.2.5.3 Not-distracting**

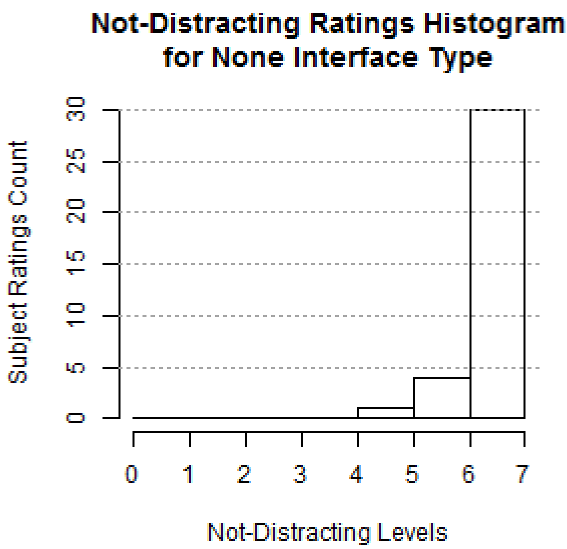


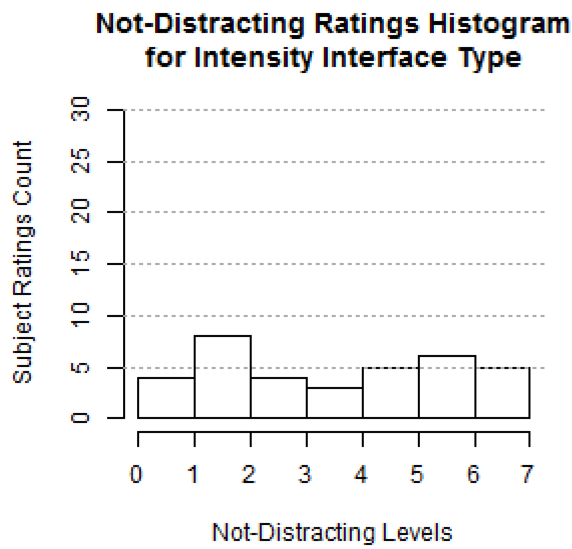
ANOVA: Not-Distracting Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	303.0	151.50	56.57	< 0.001
Residuals	102	273.1	2.68		

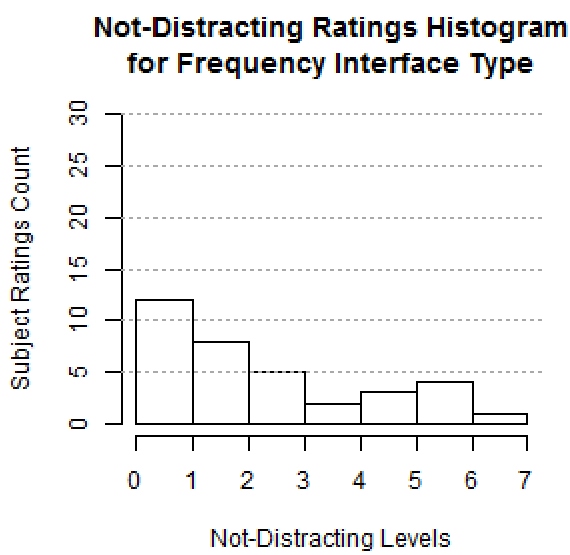
Not-Distracting vs. Interface Used - Friedman Test	
X^2	54.496
p	0.000
DoF	2.000

Not-Distracting vs. Interface Used – Wilcoxon Test			
	N – I	***N – F***	***I – F***
W	465.000	595.000	237.500
Z	5.060	5.178	2.982
p	0.000	0.000	0.002
R	0.596	0.610	0.351

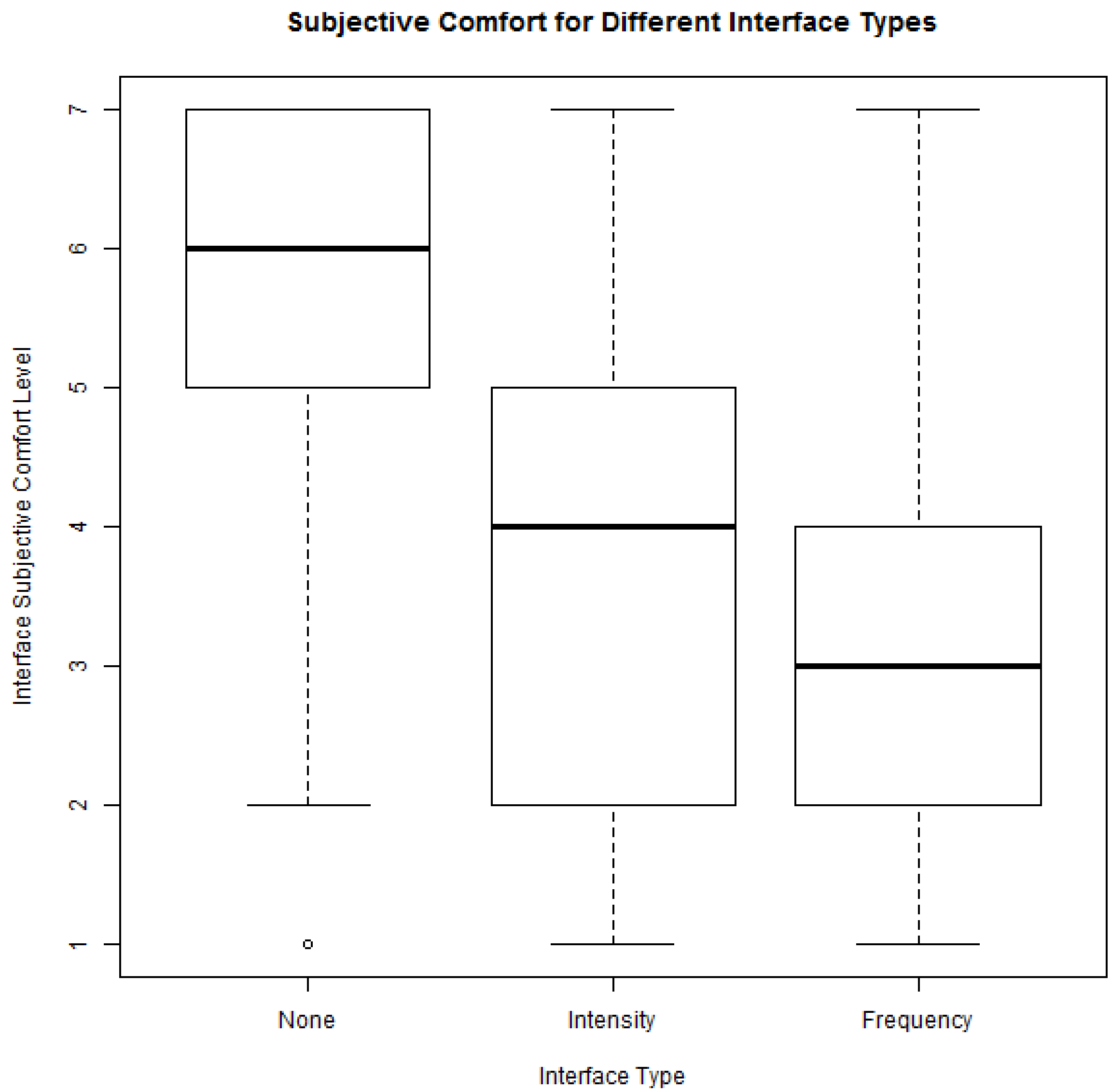
Not-Distracting vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	6.829	0.453	7.000
Intensity	4.000	2.072	4.000
Frequency	2.771	1.880	2.000







*B.2.5.4 Comfort**

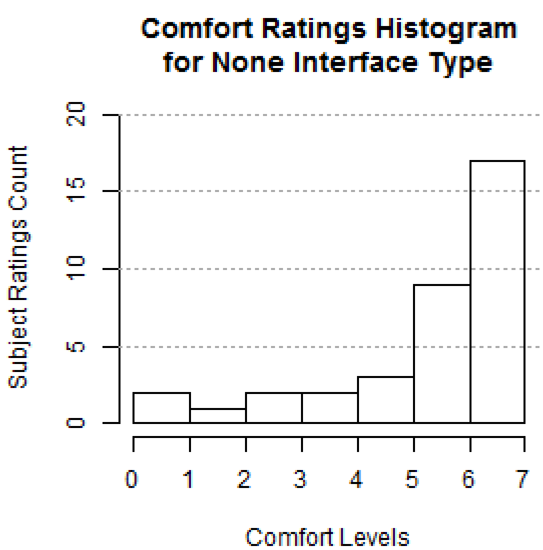


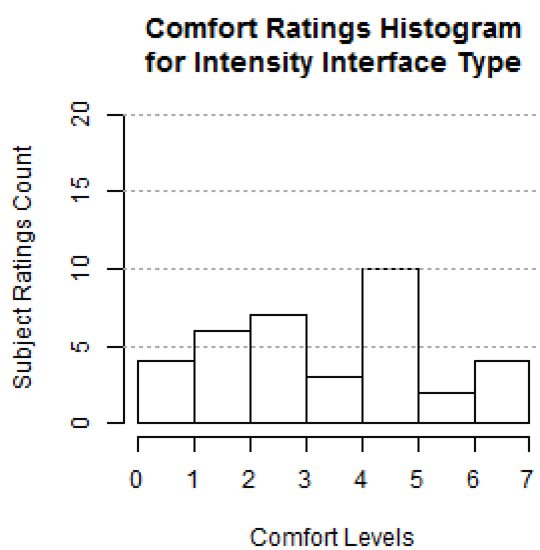
ANOVA: Comfort Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	125.7	62.86	19.97	< 0.001
Residuals	105	330.5	3.15		

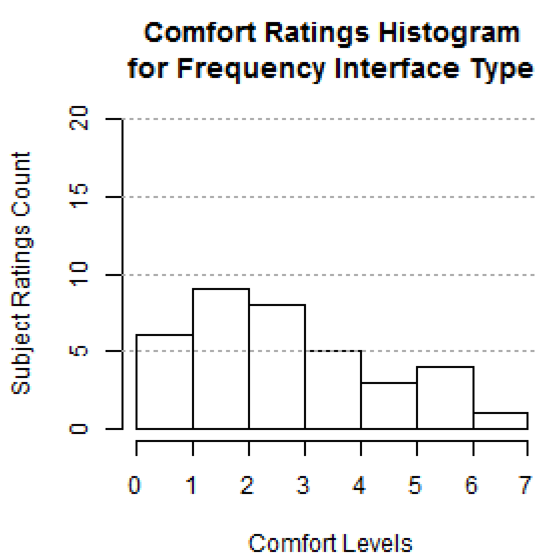
Comfort vs. Interface Used - Friedman Test	
X^2	27.133
p	0.000
DoF	2.000

Comfort vs. Interface Used – Wilcoxon Test			
	N – I	***N – F***	***I – F***
W	417.000	484.000	152.500
Z	3.867	4.224	1.954
p	0.000	0.000	0.053
R	0.456	0.498	0.230

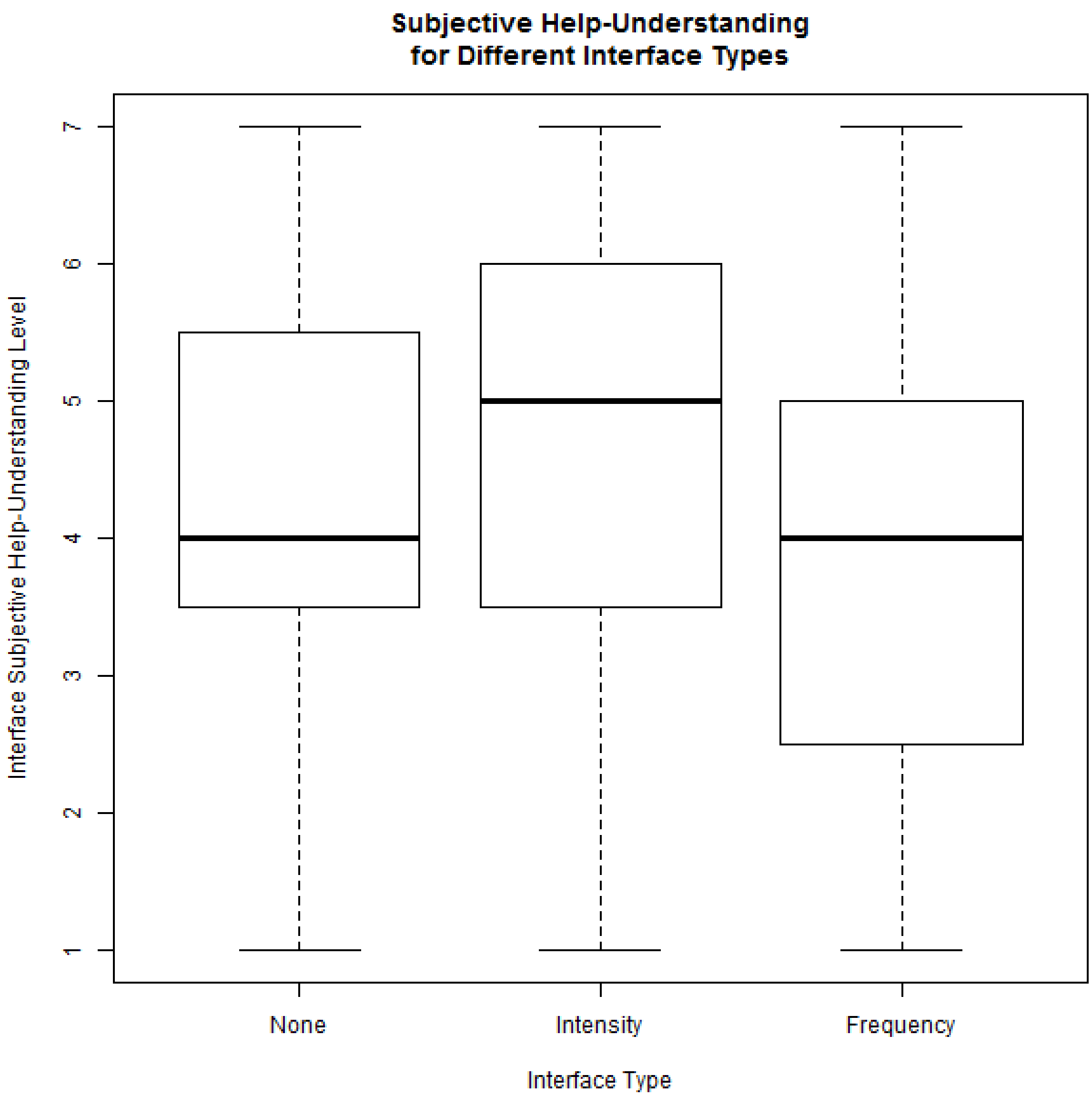
Comfort vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	5.722	1.767	6.000
Intensity	3.861	1.854	4.000
Frequency	3.167	1.699	3.000







B.2.5.5 Help in Understanding

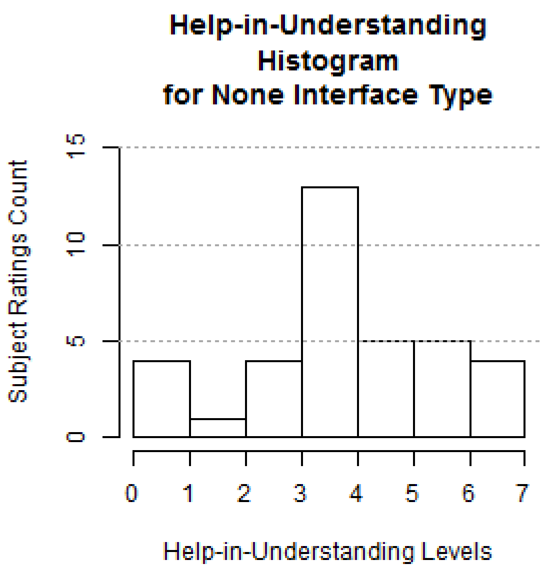


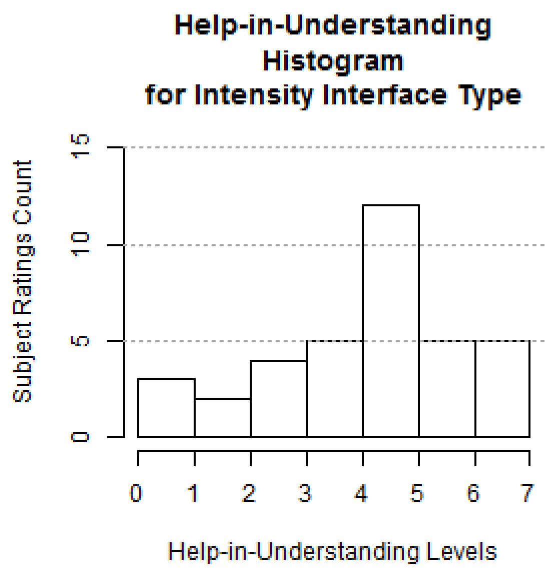
ANOVA: Help-in-Understanding Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	5.6	2.787	0.91	0.406
Residuals	105	321.6	3.063		

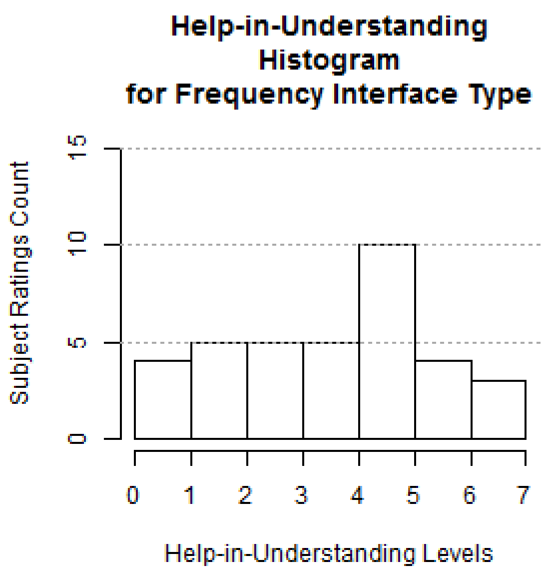
Help-in-Understanding vs. Interface Used - Friedman Test	
X^2	0.295
p	0.523
DoF	2.000

Help-in-Understanding vs. Interface Used – Wilcoxon Test			
	N – I	***N – F***	***I – F***
W	213.500	339.000	174.500
Z	-0.822	0.657	0.907
p	0.412	0.518	0.373
R	-0.097	0.077	0.107

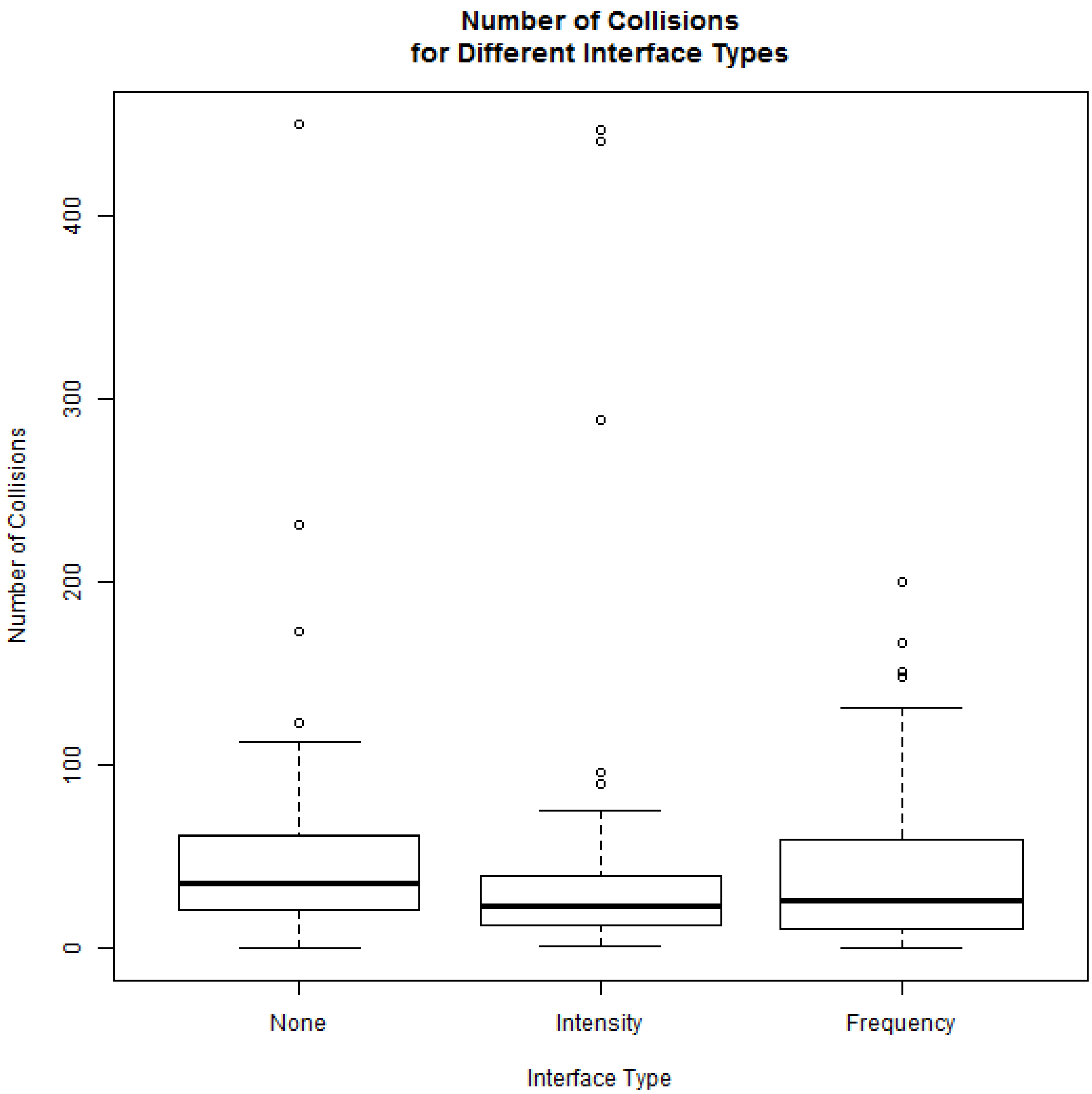
Help-in-Understanding vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	4.250	1.713	4.000
Intensity	4.556	1.731	5.000
Frequency	4.000	1.805	4.000





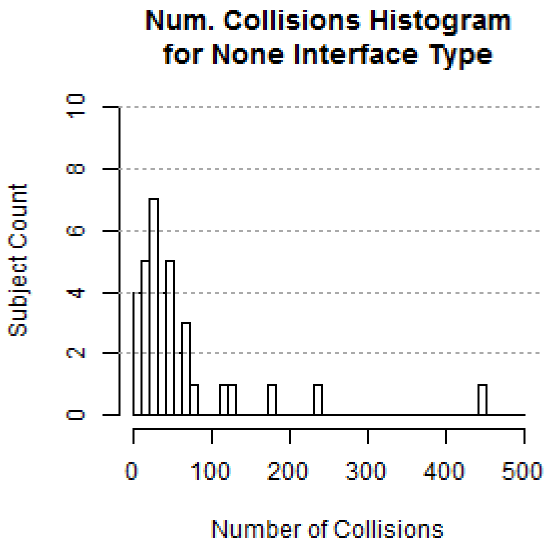


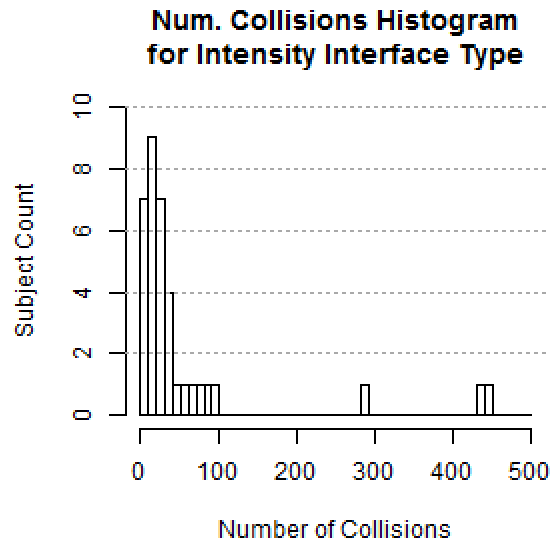
B.2.6 Number of Collisions

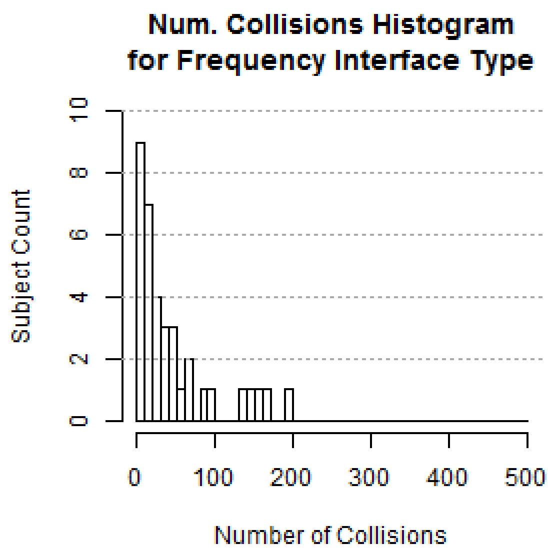


ANOVA: Number of Collisions for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	3946	1973	0.283	0.754
Residuals	105	731303	6965		

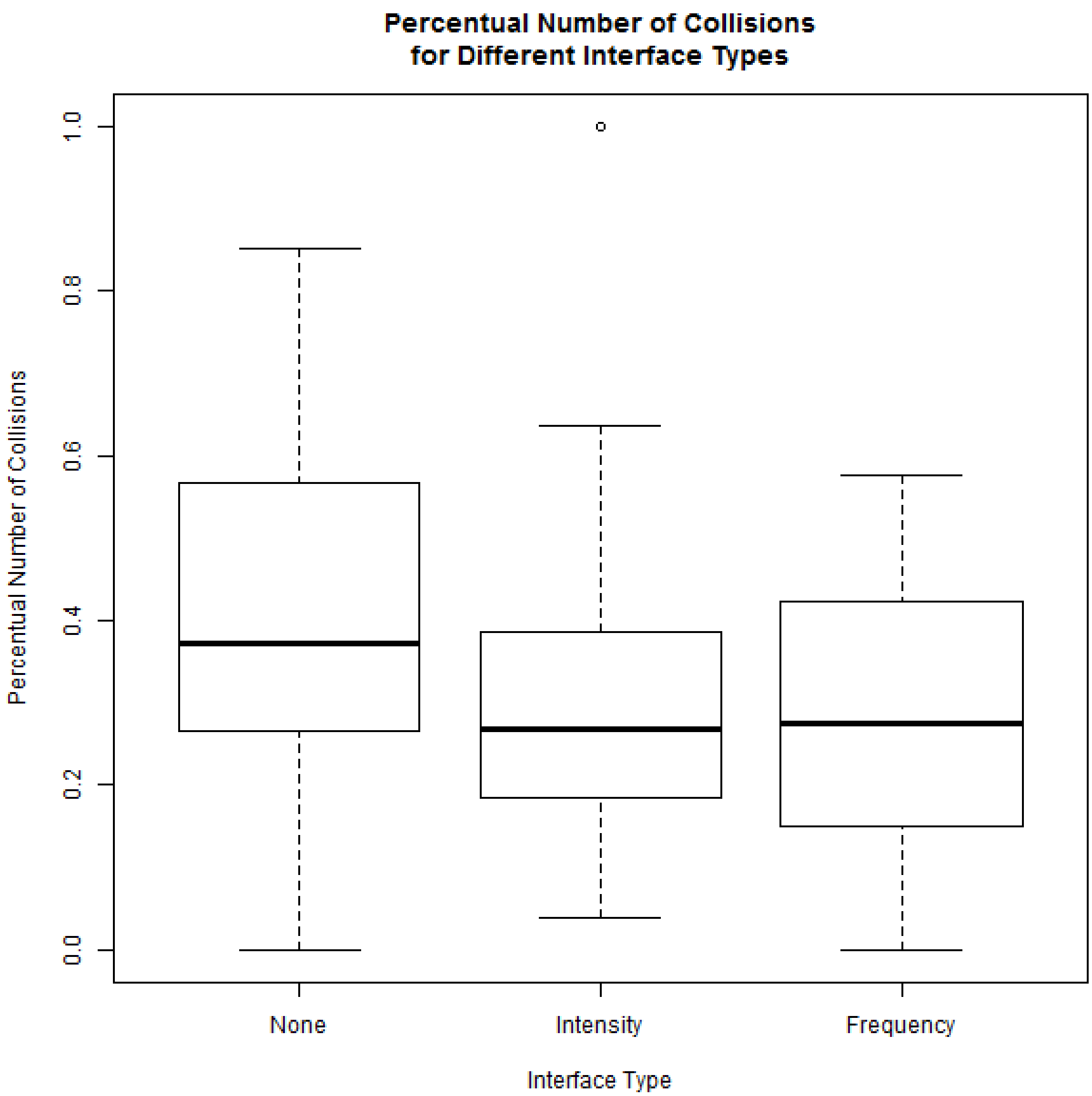
Number of Collisions vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	58.994	82.121	35.500
Intensity	57.907	106.802	22.500
Frequency	45.639	52.382	25.500


Num. Collisions Histogram
for None Interface Type
Subject Count
0
2
4
6
8
10
0
100
200
300
400
500
Number of Collisions

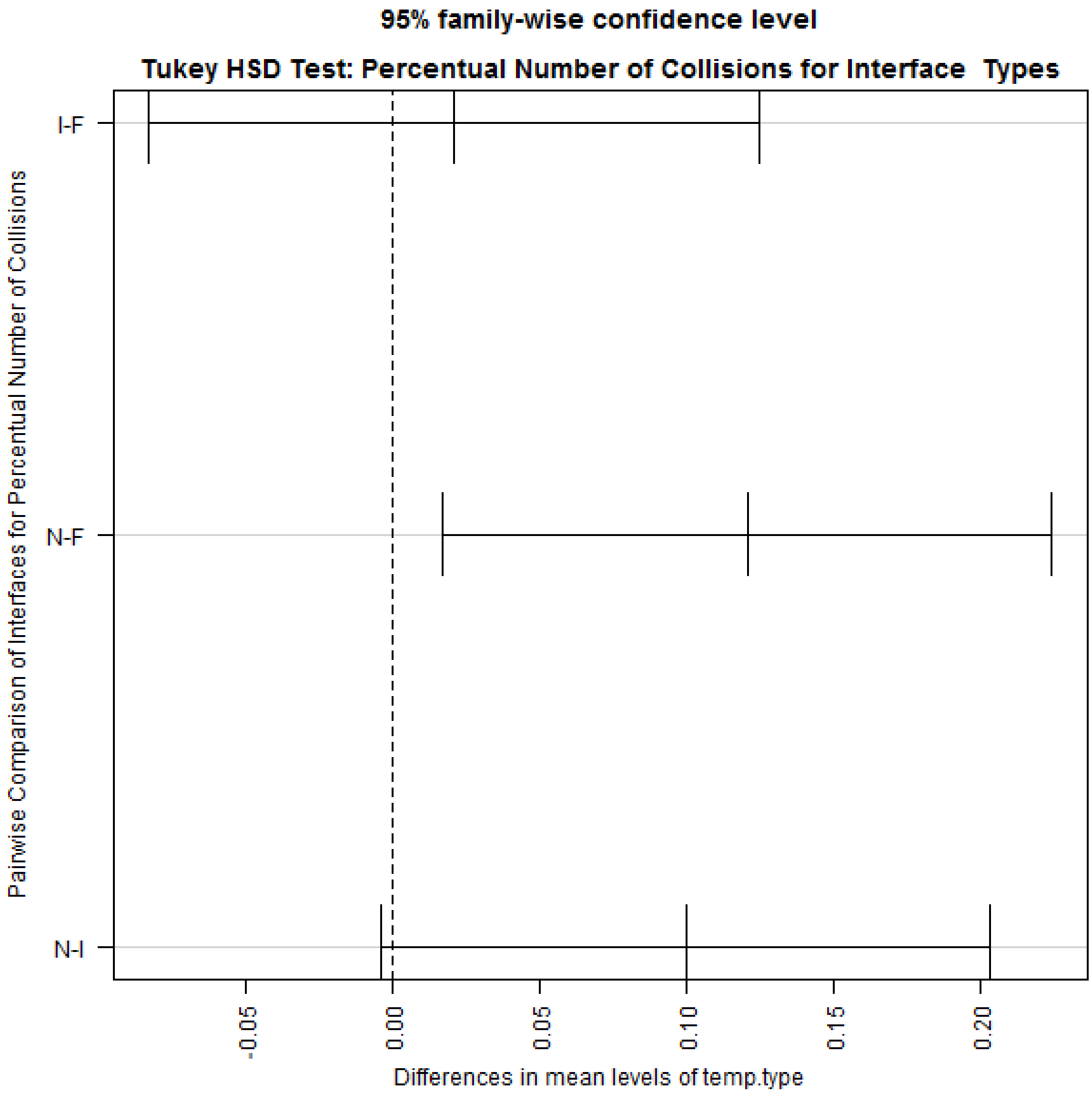

Num. Collisions Histogram
for Intensity Interface Type
Subject Count
0
2
4
6
8
10
0
100
200
300
400
500
Number of Collisions


Num. Collisions Histogram
for Frequency Interface Type
Subject Count
0
2
4
6
8
10
0
100
200
300
400
500
Number of Collisions

*B.2.6.1 Normalized Number of Collisions**



ANOVA: Normalized Number of Collisions for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.299	0.149	4.373	0.015
Residuals	105	3.587	0.034		



ANOVA: Normalized Number of Collisions for Groups With Interface Types None and Frequency					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.261	0.261	7.481	0.008
Residuals	70				

ANOVA: Normalized Number of Collisions for Groups With Interface Types None and Intensity					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.178	0.178	4.808	0.032
Residuals	70	2.604	0.037		

ANOVA: Normalized Number of Collisions for Groups With Interface Types Intensity and Frequency					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.008	0.008	0.258	0.613
Residuals	70	2.124	0.030		

Normalized Number of Collisions vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	0.407	0.204	0.372
Intensity	0.307	0.180	0.267
Frequency	0.286	0.168	0.275

*B.2.6.2 Interface Order Effect on Number of Collisions**

B.2.6.2.1 None Interface

ANOVA: None Interface Number of Collisions in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	20993	10497	1.611	0.215
Residuals	33	215040	6516.		

None Interface Number of Collisions vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	93.083	126.280	48.000
FNI (3rd)	41.083	27.178	31.000
IFN (1st)	42.667	53.513	19.500

ANOVA: None Interface Normalized Number of Collisions in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.324	0.162	4.688	0.016
Residuals	33	1.140	0.034		

ANOVA: None Interface Normalized Number of Collisions for Interface Orders NIF(1st) and FNI (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.094	0.094	2.567	0.123
Residuals	22	0.807	0.037		

ANOVA: None Interface Normalized Number of Collisions for Interface Orders NIF (1st) and IFN (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.323	0.323	9.85	0.005
Residuals	22	0.722	0.033		

ANOVA: None Interface Normalized Number of Collisions for Interface Orders FNI (2nd) and IFN (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.068	0.068	2.005	0.171
Residuals	22	0.751	0.034		

Frequency Interface Normalized Number of Collisions vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.526	0.188	0.531
FNI (3rd)	0.400	0.195	0.354
IFN (1st)	0.294	0.174	0.280

B.2.6.2.2 Intensity Interface

ANOVA: Intensity Interface Number of Collisions in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	20803	10402	0.907	0.414
Residuals	33	378432	11468		

Intensity Interface Number of Collisions vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	63.500	121.588	22.500
FNI (3rd)	26.083	18.422	20.500
IFN (1st)	84.167	138.852	29.500

ANOVA: Intensity Interface Normalized Number of Collisions in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.379	0.190	8.233	0.001
Residuals	33	0.761	0.023		

ANOVA: Intensity Interface Normalized Number of Collisions for Interface Orders NIF(2nd) and FNI (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.001	0.001	0.149	0.703
Residuals	22	0.235	0.011		

ANOVA: Intensity Interface Normalized Number of Collisions for Interface Orders NIF (2nd) and IFN (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.263	0.263	9.129	0.006
Residuals	22	0.633	0.029		

ANOVA: Intensity Interface Normalized Number of Collisions for Interface Orders FNI (3rd) and IFN (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.305	0.305	10.27	0.004
Residuals	22	0.653	0.030		

Intensity Interface Normalized Number of Collisions vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.243	0.099	0.235
FNI (3rd)	0.226	0.108	0.235
IFN (1st)	0.452	0.219	0.416

B.2.6.2.3 Frequency Interface

ANOVA: Frequency Interface Number of Collisions in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	52	25.9	0.009	0.991
Residuals	33	95983	2908.6		

Frequency Interface Number of Collisions vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	46.083	62.710	20.500
FNI (3rd)	44.000	37.723	36.500
IFN (1st)	46.833	58.051	22.000

ANOVA: Frequency Interface Normalized Number of Collisions in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.138	0.069	2.707	0.082
Residuals	33	0.845	0.026		

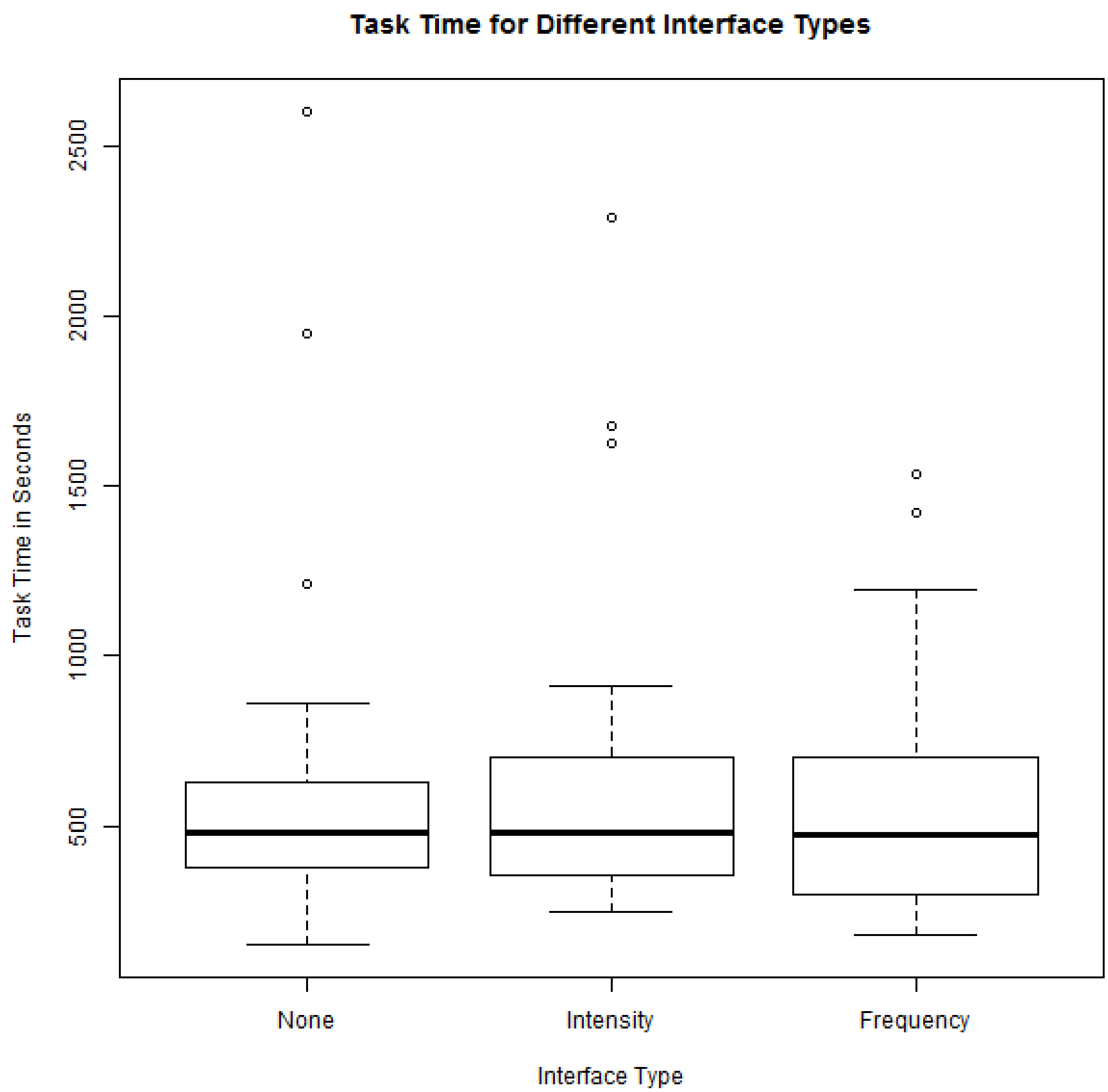
ANOVA: Frequency Interface Normalized Number of Collisions for Interface Orders NIF(3rd) and FNI (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.120	0.120	5.398	0.030
Residuals	22	0.490	0.022		

ANOVA: Frequency Interface Normalized Number of Collisions for Interface Orders NIF (3rd) and IFN (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.003	0.003	0.132	0.72
Residuals	22	0.523	0.024		

ANOVA: Frequency Interface Normalized Number of Collisions for Interface Orders FNI (1st) and IFN (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.084	0.084	2.747	0.112
Residuals	22	0.677	0.030		

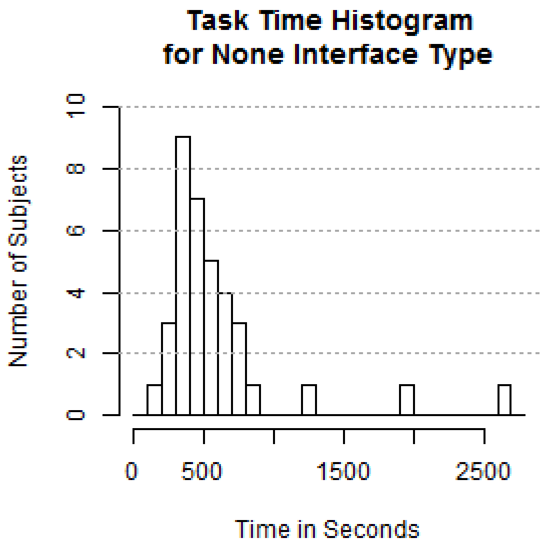
Frequency Interface Normalized Number of Collisions vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.231	0.123	0.202
FNI (3rd)	0.373	0.171	0.438
IFN (1st)	0.254	0.180	0.241

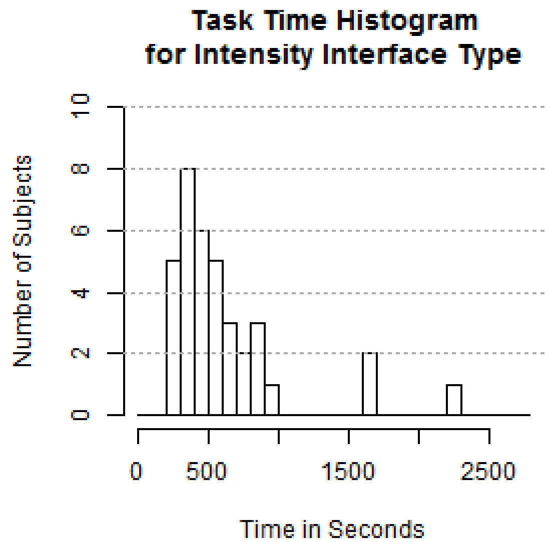
B.2.7 Task Time

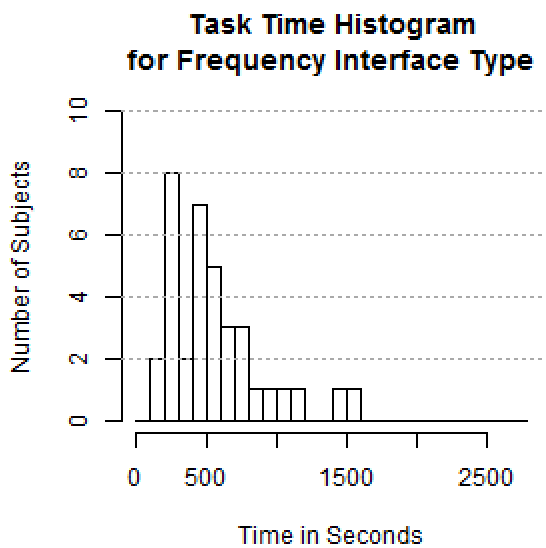


ANOVA: Task Time for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	46676	23338	0.135	0.874
Residuals	105	18177709	173121		

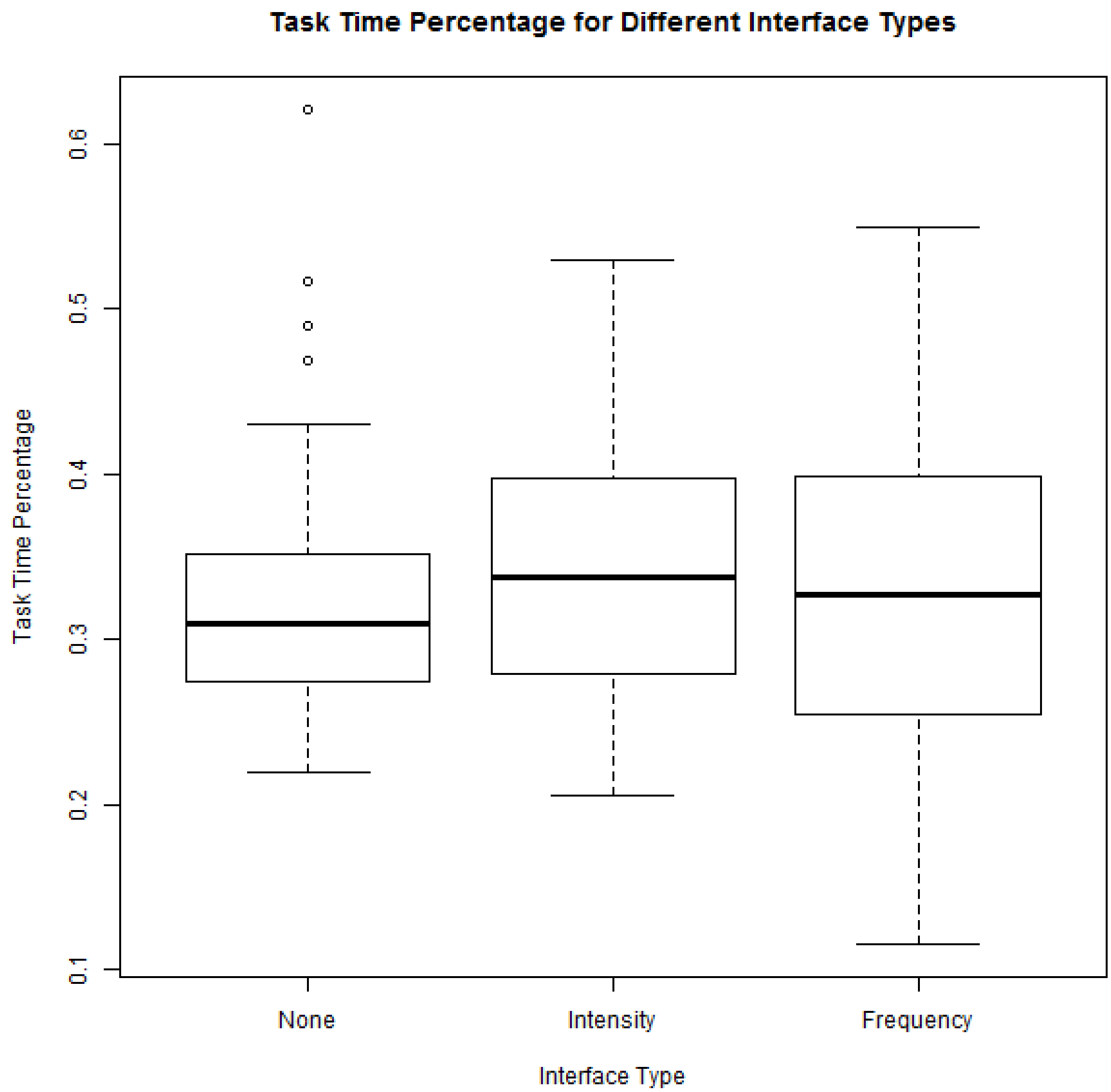
Task Time vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	594.722	466.919	478.000
Intensity	613.917	434.875	479.000
Frequency	563.472	335.013	475.000


Task Time Histogram
for None Interface Type
Number of Subjects
0
2
4
6
8
10
0
500
1500
2500
Time in Seconds


Task Time Histogram
for Intensity Interface Type
Number of Subjects
0
2
4
6
8
10
0
500
1500
2500
Time in Seconds


Task Time Histogram
for Frequency Interface Type
Number of Subjects
0
2
4
6
8
10
0
500
1500
2500
Time in Seconds

B.2.7.1 Normalized Task Time



ANOVA: Normalized Task Time for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.007	0.003	0.471	0.626
Residuals	105	0.799	0.008		

Normalized Task Time vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	0.331	0.089	0.310
Intensity	0.344	0.078	0.338
Frequency	0.325	0.094	0.327

*B.2.7.2 Interface Order Effect on Task Time**

B.2.7.2.1 None Interface

ANOVA: None Interface Task Time in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	670293	335146	1.589	0.219
Residuals	33	696160	210914		

None Interface Task Time vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	785.667	728.775	533.500
FNI (3rd)	523.417	248.994	420.000
IFN (1st)	475.083	199.075	434.500

ANOVA: None Interface Normalized Task Time in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.048	0.024	3.512	0.041
Residuals	33	0.227	0.007		

ANOVA: None Interface Normalized Task Time for Interface Orders NIF(1st) and FNI (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.017	0.017	1.848	0.188
Residuals	22	0.207	0.009		

ANOVA: None Interface Normalized Task Time for Interface Orders NIF (1st) and IFN (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.047	0.047	6.207	0.021
Residuals	22	0.207	0.008		

ANOVA: None Interface Normalized Task Time for Interface Orders FNI (2nd) and IFN (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.007	0.007	2.098	0.162
Residuals	22	0.078	0.003		

Frequency Interface Normalized Task Time vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.378	0.116	0.347
FNI (3rd)	0.325	0.073	0.309
IFN (1st)	0.289	0.042	0.291

B.2.7.2.2 Intensity Interface

ANOVA: Intensity Interface Task Time in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	353101	176550	0.93	0.405
Residuals	33	6265966	189878		

Intensity Interface Task Time vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	642.917	561.362	437.500
FNI (3rd)	480.750	142.769	482.500
IFN (1st)	718.083	483.862	536.000

ANOVA: Intensity Interface Normalized Task Time in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.054	0.027	5.557	0.008
Residuals	33	0.161	0.005		

ANOVA: Intensity Interface Normalized Task Time for Interface Orders NIF(2nd) and FNI (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.001	0.001	0.227	0.638
Residuals	22	0.101	0.005		

ANOVA: Intensity Interface Normalized Task Time for Interface Orders NIF (2nd) and IFN (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.034	0.034	8.193	0.009
Residuals	22	0.091	0.004		

ANOVA: Intensity Interface Normalized Task Time for Interface Orders FNI (3rd) and IFN (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.047	0.047	7.867	0.010
Residuals	22	0.130	0.006		

Intensity Interface Normalized Task Time vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.324	0.053	0.335
FNI (3rd)	0.310	0.080	0.300
IFN (1st)	0.399	0.074	0.407

B.2.7.2.3 Frequency Interface

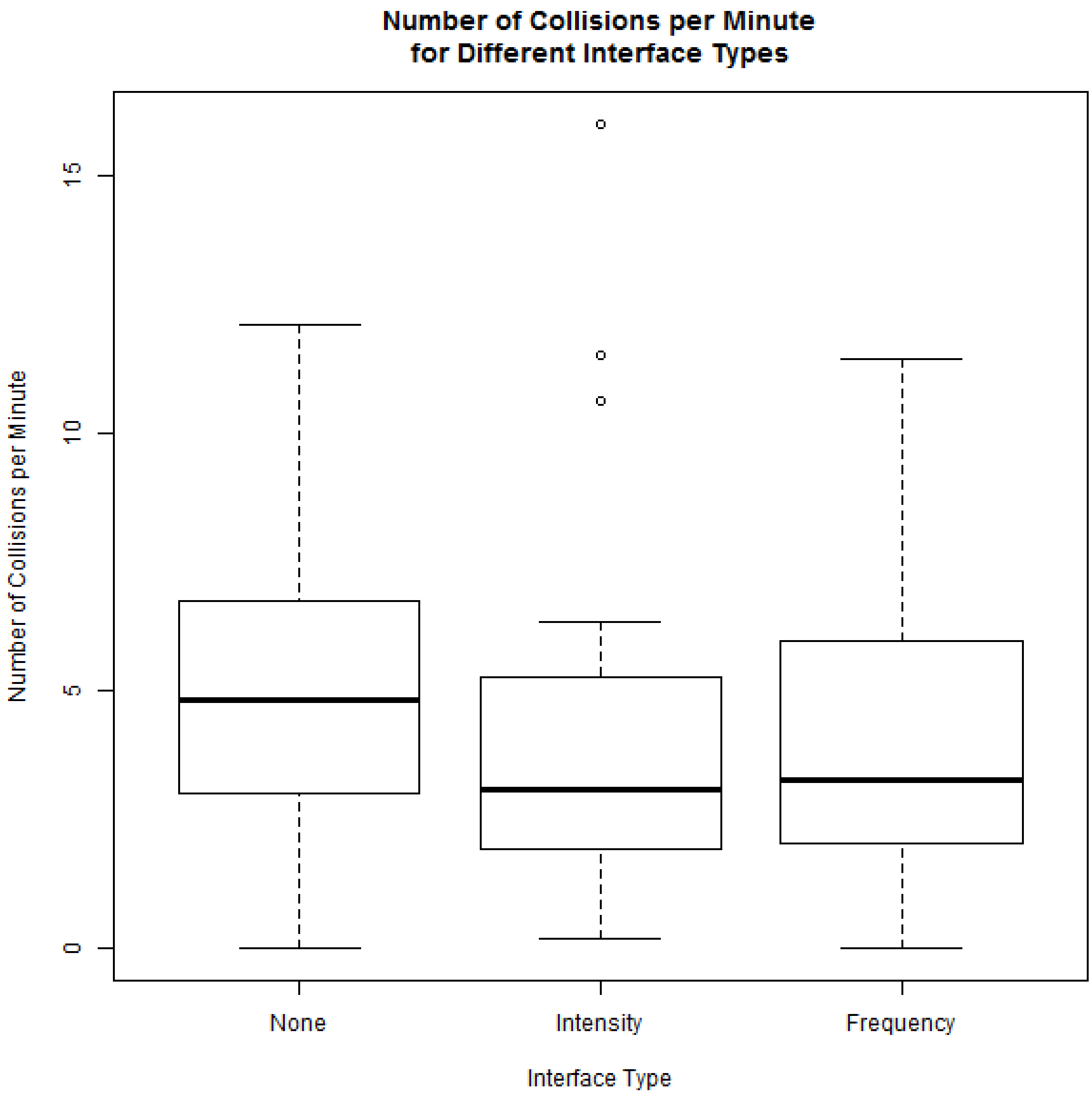
ANOVA: Frequency Interface Task Time in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	62894	31447	0.268	0.766
Residuals	33	3865295	117130		

Frequency Interface Task Time vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	541.917	354.792	448.500
FNI (3rd)	621.917	387.722	573.000
IFN (1st)	526.583	274.197	502.000

ANOVA: Frequency Interface Normalized Task Time in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.030	0.015	1.779	0.185
Residuals	33	0.278	0.008		

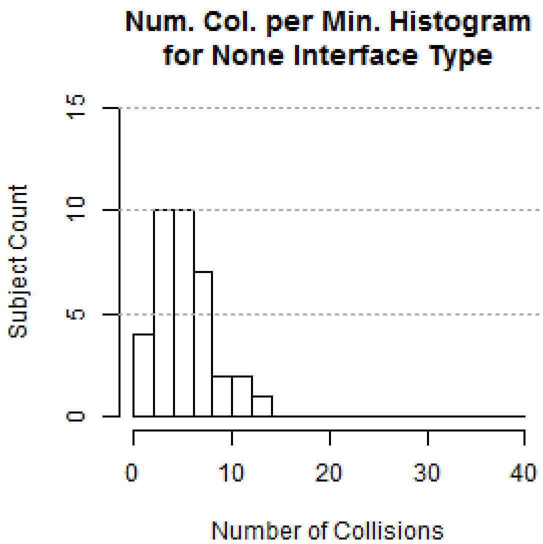
Frequency Interface Normalized Task Time vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.298	0.075	0.314
FNI (3rd)	0.365	0.129	0.417
IFN (1st)	0.312	0.054	0.308

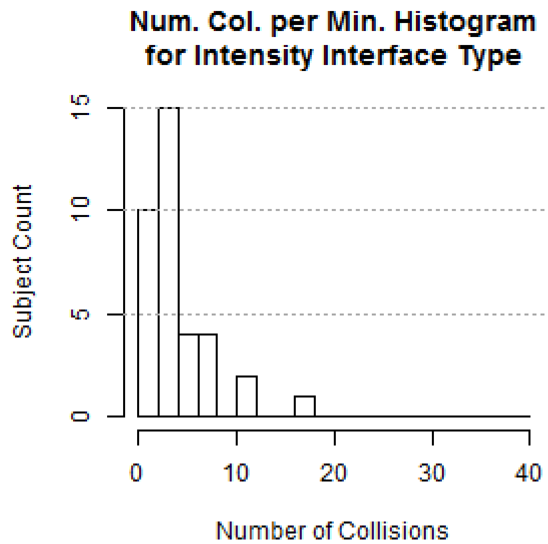
B.2.8 Number of Collisions per Minute

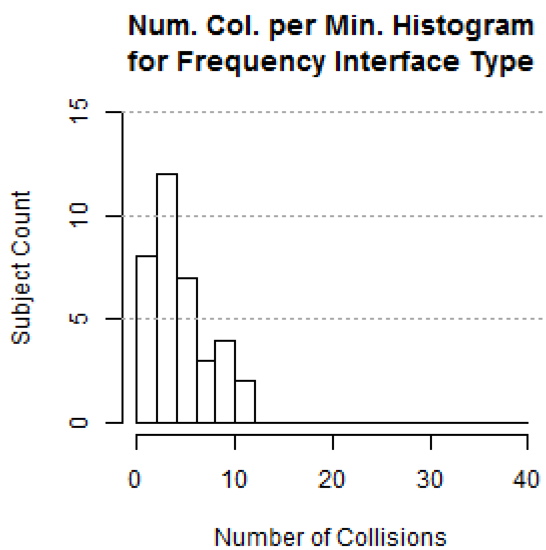


ANOVA: Number of Collisions per Minute for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	26.5	12.241	1.416	0.247
Residuals	105	982.0	9.352		

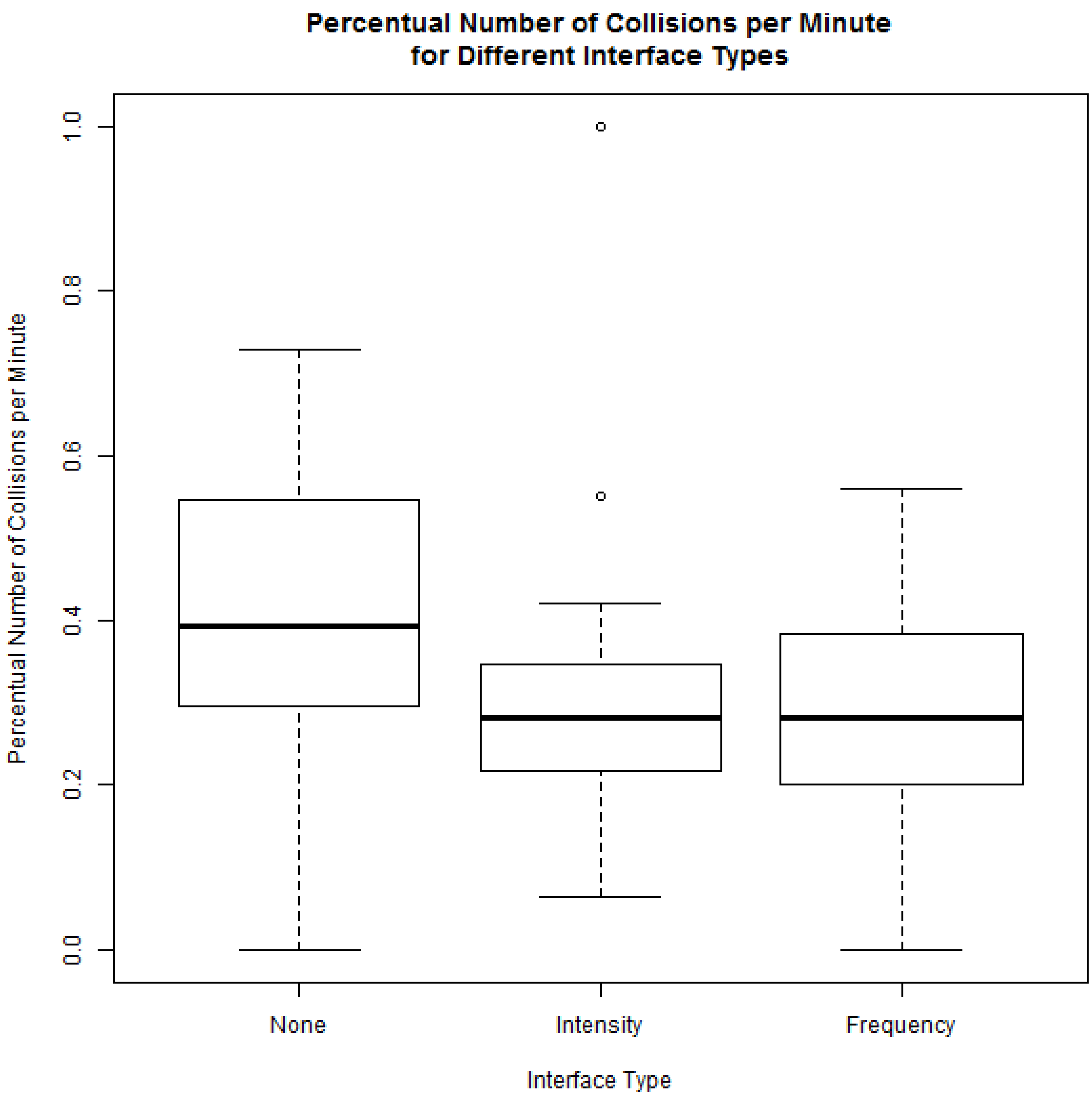
Number of Collisions per Minute vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	4.982	2.893	4.814
Intensity	3.854	3.286	3.074
Frequency	4.032	2.981	3.243


Num. Col. per Min. Histogram
for None Interface Type
Subject Count
0
5
10
15
0
10
20
30
40
Number of Collisions

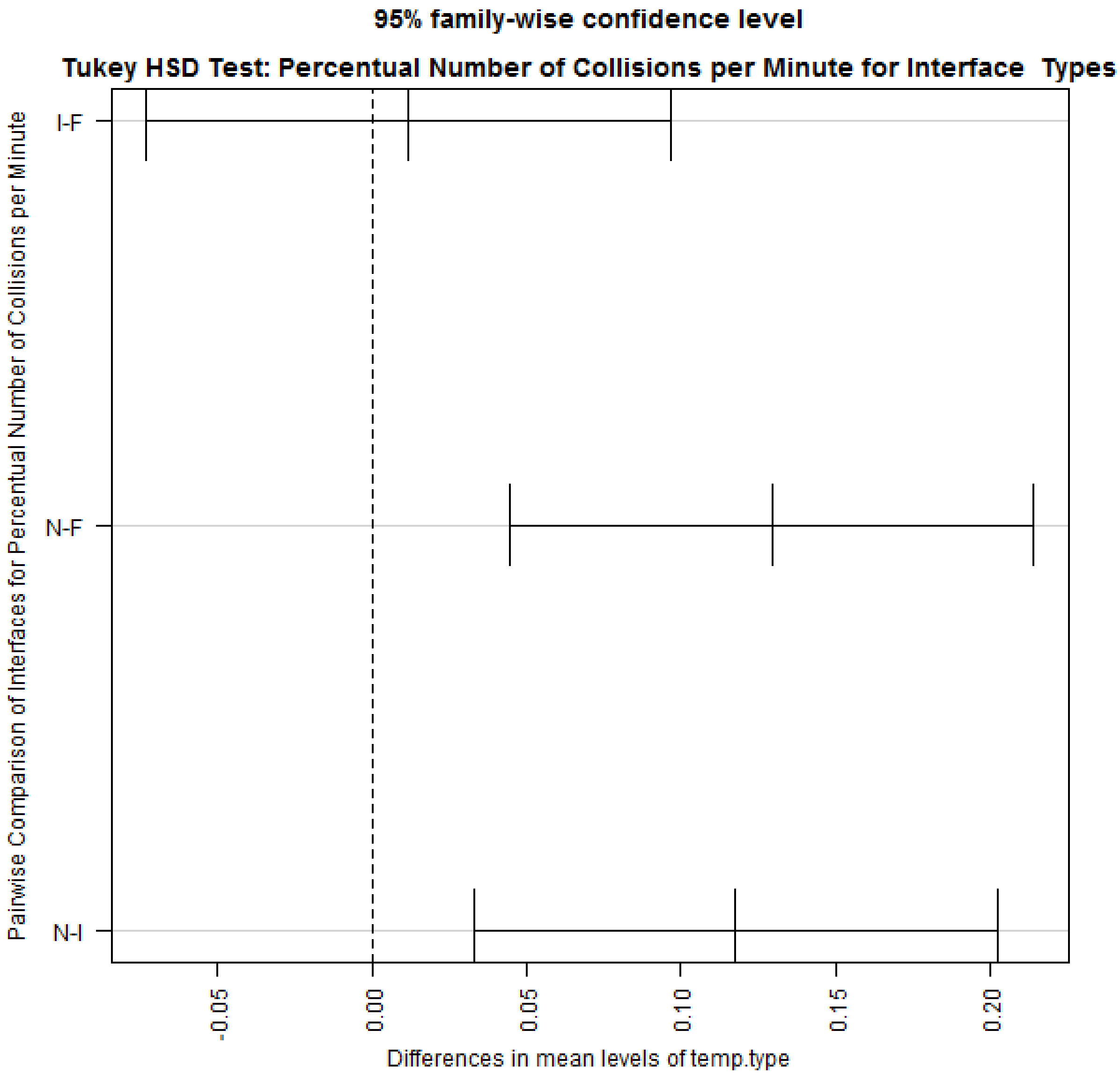

Num. Col. per Min. Histogram
for Intensity Interface Type
Subject Count
0
5
10
15
0
10
20
30
40
Number of Collisions


Num. Col. per Min. Histogram
for Frequency Interface Type
Subject Count
0
5
10
15
0
10
20
30
40
Number of Collisions

*B.2.8.1 Normalized Number of Collisions per Minute**



ANOVA: Normalized Number of Collisions per Minute for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.368	0.184	8.067	< 0.001
Residuals	105	2.398	0.023		



ANOVA: Normalized Number of Collisions per Minute for Groups With Interfaces “None” and “Intensity”					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.249	0.249	9.672	0.003
Residuals	70	1.801	0.025		

ANOVA: Normalized Number of Collisions per Minute for Groups With Interfaces “None” and “Frequency”					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.301	0.301	13.28	< 0.001
Residuals	70	1.588	0.023		

ANOVA: Normalized Number of Collisions per Minute for Groups With Interfaces “Intensity” and “Frequency”					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.002	0.002	0.125	0.725
Residuals	70	1.407	0.020		

Normalized Number of Collisions per Minute vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	0.416	0.168	0.393
Intensity	0.298	0.152	0.283
Frequency	0.286	0.131	0.281

*B.2.8.2 Interface Order Effect on Number of Collisions per Minute**

B.2.8.2.1 None Interface

ANOVA: None Interface Number of Collisions per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	19.58	9.791	1.182	0.319
Residuals	33	273.29	8.281		

None Interface Number of Collisions per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	5.999	2.311	5.918
FNI (3rd)	4.675	1.968	4.321
IFN (1st)	4.272	3.954	3.418

ANOVA: None Interface Normalized Number of Collisions per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.143	0.072	2.792	0.076
Residuals	33	0.848	0.026		

ANOVA: None Interface Normalized Number of Collisions per Minute for Interface Orders NIF(1st) and FNI (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.029	0.029	1.335	0.260
Residuals	22	0.484	0.022		

ANOVA: None Interface Normalized Number of Collisions per Minute for Interface Orders NIF (1st) and IFN (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.143	0.143	5.236	0.032
Residuals	22	0.601	0.027		

ANOVA: None Interface Normalized Number of Collisions per Minute for Interface Orders FNI (2nd) and IFN (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.043	0.043	1.542	0.227
Residuals	22	0.611	0.028		

Frequency Interface Normalized Number of Collisions per Minute vs. Interface Order Used Summary			
	Mean	*Std. Dev.*	*Median*
NIF (2nd)	0.490	0.147	0.480
FNI (3rd)	0.420	0.150	0.368
IFN (1st)	0.336	0.182	0.322

B.2.8.2.2 Intensity Interface

ANOVA: Intensity Interface Number of Collisions per Minute in Different Interface Order					
Source of Variation	*DoF*	*SS*	*MS*	*F*	*P-value*
Interface Type	2	16.4	8.218	0.75	0.48
Residuals	33	361.6	10.957		

Intensity Interface Number of Collisions per Minute vs. Interface Order Used Summary			
	Mean	*Std. Dev.*	*Median*
NIF (2nd)	3.711	2.980	2.800
FNI (3rd)	3.107	1.761	2.783
IFN (1st)	4.743	4.570	3.151

ANOVA: Intensity Interface Normalized Number of Collisions per Minute in Different Interface Order					
Source of Variation	*DoF*	*SS*	*MS*	*F*	*P-value*
Interface Type	2	0.165	0.082	4.208	0.024
Residuals	33	0.645	0.019		

ANOVA: Intensity Interface Normalized Number of Collisions per Minute for Interface Orders NIF(2nd) and FNI (3rd)					
Source of Variation	*DoF*	*SS*	*MS*	*F*	*P-value*
Interface Type	1	0.000	0.000	0.038	0.848
Residuals	22	0.158	0.007		

ANOVA: Intensity Interface Normalized Number of Collisions per Minute for Interface Orders NIF (2nd) and IFN (1st)					
Source of Variation	*DoF*	*SS*	*MS*	*F*	*P-value*
Interface Type	1	0.118	0.117	4.551	0.044
Residuals	22	0.568	0.026		

ANOVA: Intensity Interface Normalized Number of Collisions per Minute for Interface Orders FNI (3rd) and IFN (1st)					
Source of Variation	*DoF*	*SS*	*MS*	*F*	*P-value*
Interface Type	1	0.129	0.129	5.028	0.035
Residuals	22	0.565	0.026		

Intensity Interface Normalized Number of Collisions per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.254	0.085	0.235
FNI (3rd)	0.247	0.084	0.251
IFN (1st)	0.394	0.210	0.342

B.2.8.2.3 Frequency Interface

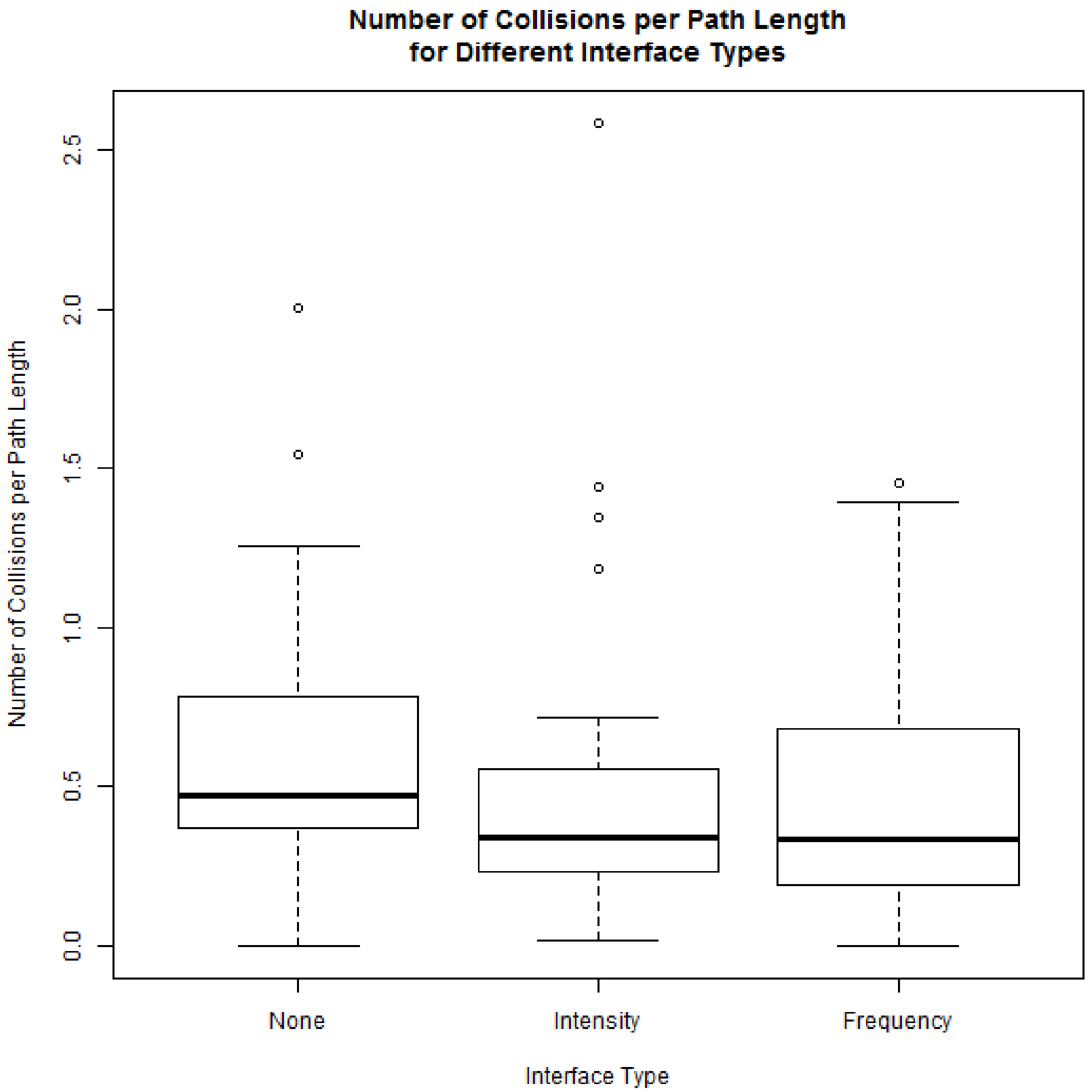
ANOVA: Frequency Interface Number of Collisions per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	3.63	1.813	0.195	0.824
Residuals	33	307.46	9.317		

Frequency Interface Number of Collisions per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	3.638	2.600	2.469
FNI (3rd)	4.043	2.372	3.367
IFN (1st)	4.415	3.944	4.125

ANOVA: Frequency Interface Normalized Number of Collisions per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.040	0.020	1.18	0.32
Residuals	33	0.557	0.017		

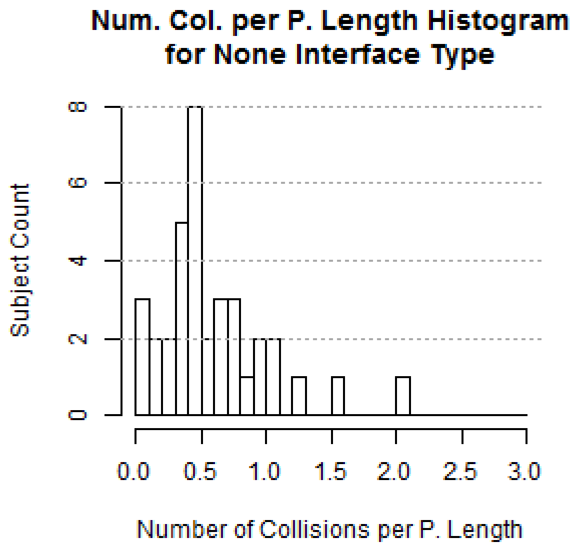
Frequency Interface Normalized Number of Collisions per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.256	0.087	0.239
FNI (3rd)	0.332	0.103	0.370
IFN (1st)	0.270	0.180	0.277

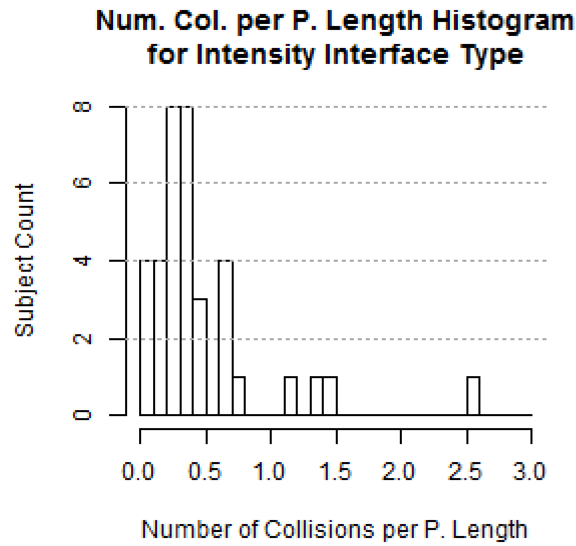
B.2.9 Number of Collisions per Path Length

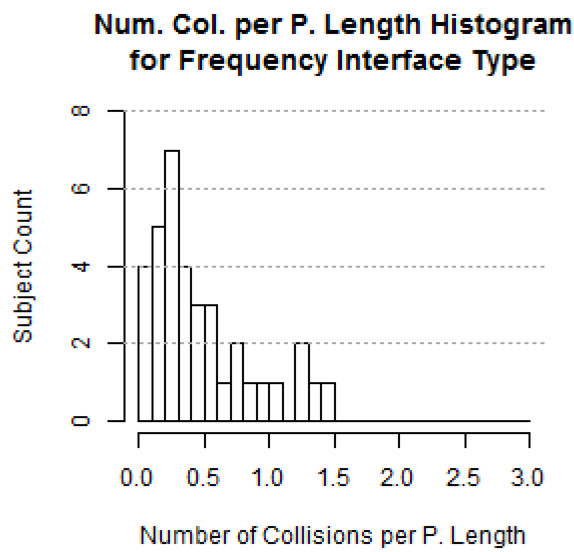


ANOVA: Number of Collisions per Path Length for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.336	0.168	0.875	0.42
Residuals	105	20.179	0.192		

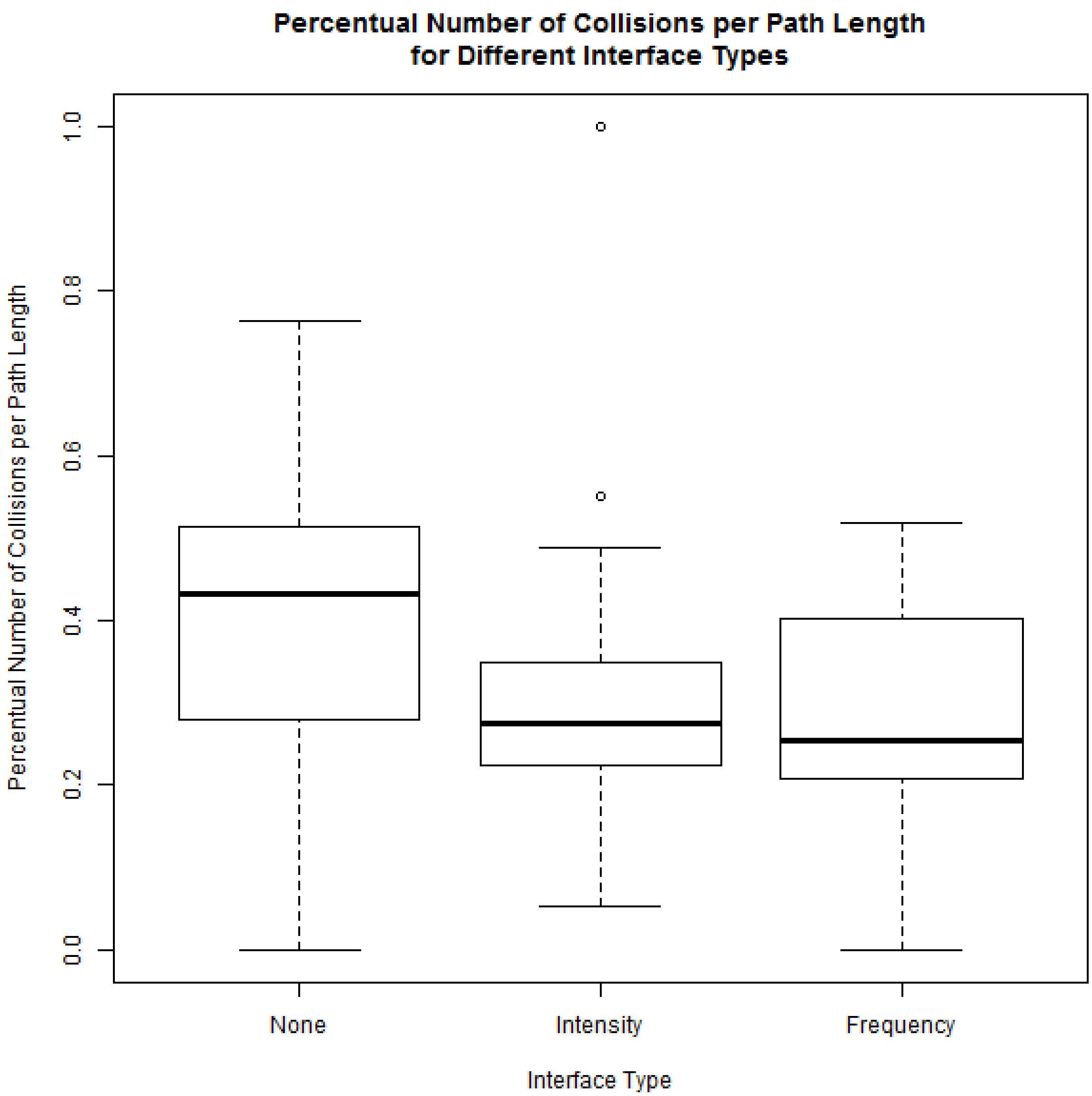
Number of Collisions per Path Length vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	0.593	0.419	0.469
Intensity	0.474	0.491	0.342
Frequency	0.475	0.400	0.337


Num. Col. per P. Length Histogram
for None Interface Type
Subject Count
0
2
4
6
8
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Number of Collisions per P. Length

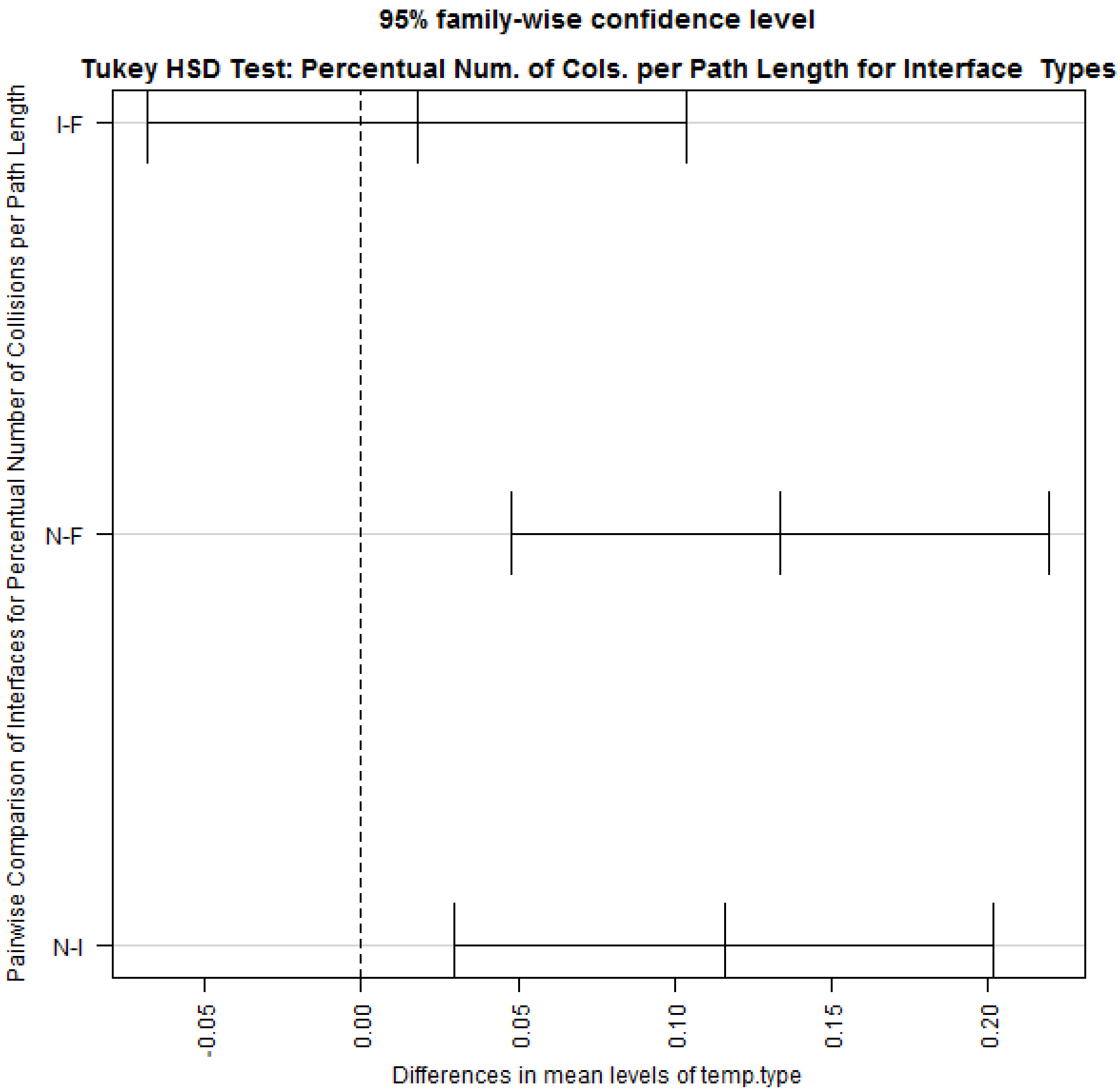

Num. Col. per P. Length Histogram
for Intensity Interface Type
Subject Count
0
2
4
6
8
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Number of Collisions per P. Length


Num. Col. per P. Length Histogram
for Frequency Interface Type
Subject Count
0
2
4
6
8
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Number of Collisions per P. Length

*B.2.9.1 Normalized Number of Collisions per Path Length**



ANOVA: Normalized Number of Collisions per Path Length for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.379	0.189	8.072	< 0.001
Residuals	105	2.463	0.023		



ANOVA: Normalized Number of Collisions per Path Length for Groups With Interfaces “None” and “Intensity”					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.241	0.241	9.172	0.003
Residuals	70	1.840	0.026		

ANOVA: Normalized Number of Collisions per Path Length for Groups With Interfaces “None” and “Frequency”					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.321	0.321	13.82	< 0.001
Residuals	70	1.627	0.023		

ANOVA: Normalized Number of Collisions per Path Length for Groups With Interfaces “Intensity” and “Frequency”					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.006	0.006	0.275	0.601
Residuals	70	1.460	0.021		

Normalized Number of Collisions per Path Length vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	0.416	0.169	0.432
Intensity	0.301	0.155	0.275
Frequency	0.283	0.133	0.254

*B.2.9.2 Interface Order Effect on Number of Collisions per Path Length**

B.2.9.2.1 None Interface

ANOVA: None Interface Number of Collisions per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.303	0.152	0.859	0.433
Residuals	33	5.831	0.177		

None Interface Number of Collisions per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.720	0.375	0.722
FNI (3rd)	0.508	0.213	0.447
IFN (1st)	0.550	0.587	0.428

ANOVA: None Interface Normalized Number of Collisions per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.123	0.061	2.305	0.116
Residuals	33	0.881	0.027		

ANOVA: None Interface Normalized Number of Collisions per Path Length for Interface Orders NIF(1st) and FNI (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.020	0.020	0.886	0.357
Residuals	22	0.487	0.022		

ANOVA: None Interface Normalized Number of Collisions per Path Length for Interface Orders NIF (1st) and IFN (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.121	0.121	4.324	0.049
Residuals	22	0.618	0.028		

ANOVA: None Interface Normalized Number of Collisions per Path Length for Interface Orders FNI (2nd) and IFN (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.043	0.043	1.457	0.24
Residuals	22	0.656	0.030		

Frequency Interface Normalized Number of Collisions per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.483	0.143	0.472
FNI (3rd)	0.426	0.154	0.374
IFN (1st)	0.341	0.189	0.327

B.2.9.2.2 Intensity Interface

ANOVA: Intensity Interface Number of Collisions per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.636	0.318	1.343	0.275
Residuals	33	7.811	0.237		

Intensity Interface Number of Collisions per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.435	0.367	0.335
FNI (3rd)	0.333	0.189	0.315
IFN (1st)	0.652	0.734	0.372

ANOVA: Intensity Interface Normalized Number of Collisions per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.208	0.104	5.474	0.009
Residuals	33	0.628	0.019		

ANOVA: Intensity Interface Normalized Number of Collisions per Path Length for Interface Orders NIF(2nd) and FNI (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.000	0.000	0.057	0.813
Residuals	22	0.144	0.006		

ANOVA: Intensity Interface Normalized Number of Collisions per Path Length for Interface Orders NIF (2nd) and IFN (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.148	0.148	5.959	0.023
Residuals	22	0.548	0.025		

ANOVA: Intensity Interface Normalized Number of Collisions per Path Length for Interface Orders FNI (3rd) and IFN (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.164	0.164	6.388	0.019
Residuals	22	0.564	0.026		

Intensity Interface Normalized Number of Collisions per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.251	0.076	0.234
FNI (3rd)	0.243	0.085	0.254
IFN (1st)	0.408	0.210	0.355

B.2.9.2.3 Frequency Interface

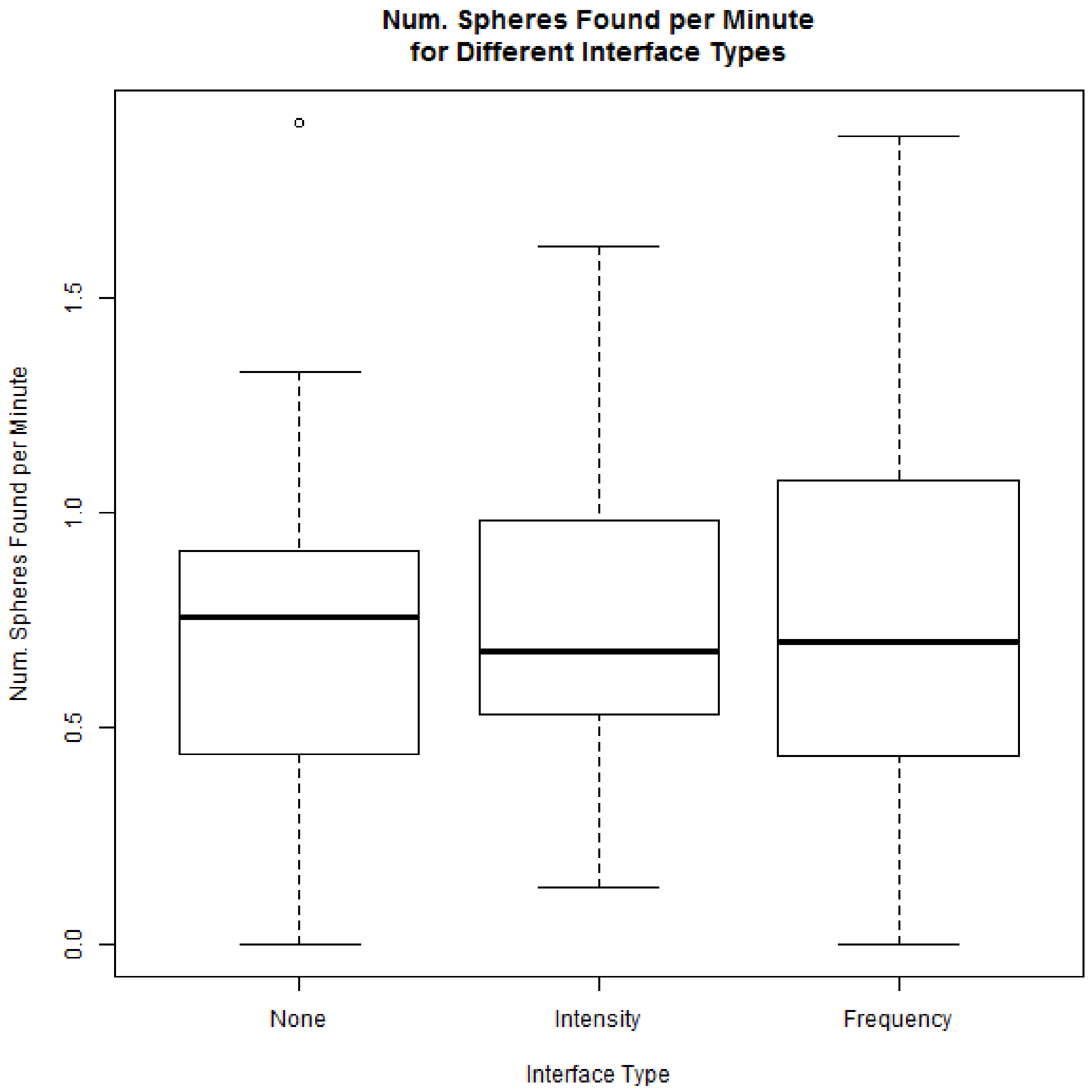
ANOVA: Frequency Number of Collisions per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.015	0.007	0.043	0.958
Residuals	33	5.584	0.169		

Frequency Interface Number of Collisions per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.468	0.373	0.308
FNI (3rd)	0.455	0.331	0.332
IFN (1st)	0.503	0.508	0.399

ANOVA: Frequency Interface Normalized Number of Collisions per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.043	0.022	1.238	0.303
Residuals	33	0.580	0.017		

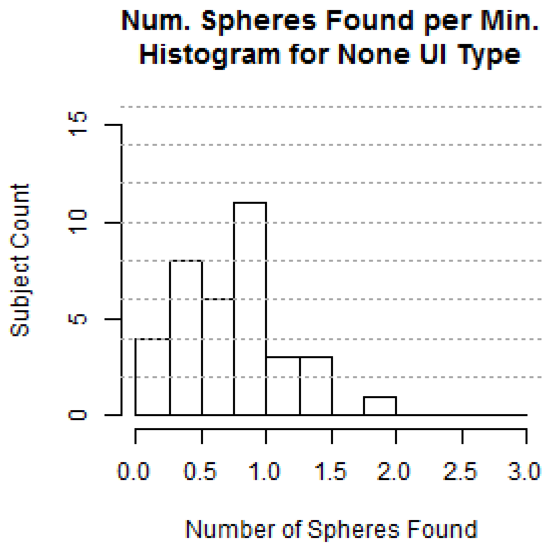
Frequency Interface Normalized Number of Collisions per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.266	0.093	0.245
FNI (3rd)	0.331	0.120	0.361
IFN (1st)	0.251	0.172	0.236

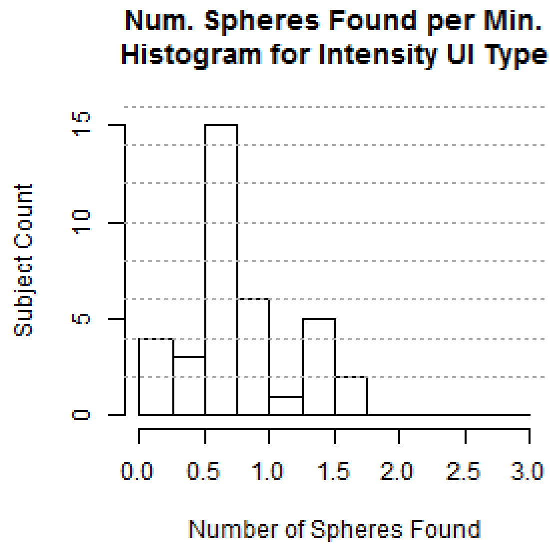
B.2.10 Number of Spheres Found per Minute

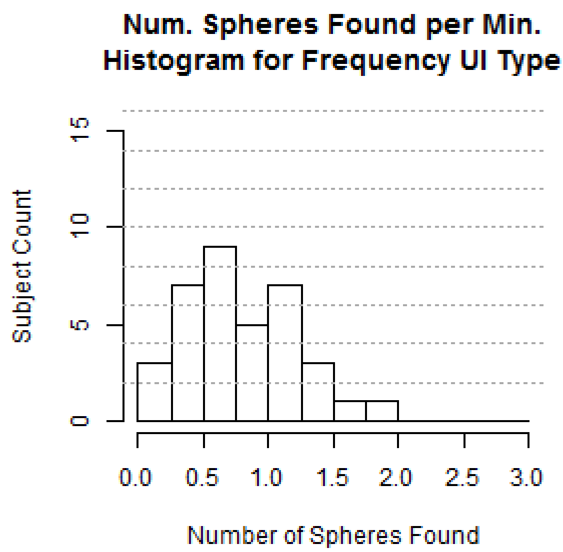


ANOVA: Number of Spheres Found per Minute for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.056	0.028	0.16	0.852
Residuals	105	18.235	0.174		

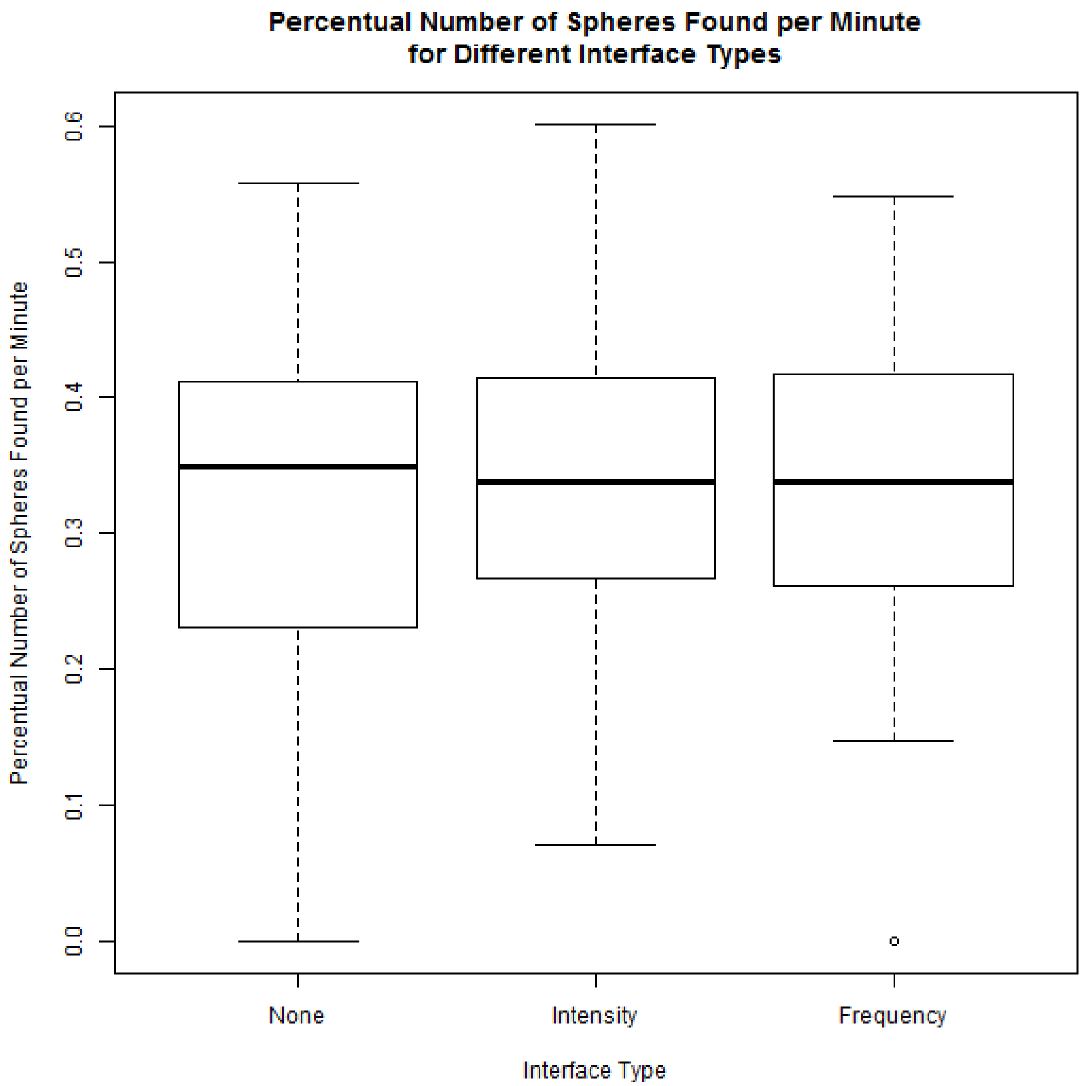
Number of Spheres Found per Minute vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	0.727	0.410	0.758
Intensity	0.775	0.395	0.677
Frequency	0.775	0.443	0.698


Num. Spheres Found per Min.
Histogram for None UI Type
Subject Count
0
5
10
15
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Number of Spheres Found


Num. Spheres Found per Min.
Histogram for Intensity UI Type
Subject Count
0
5
10
15
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Number of Spheres Found


Num. Spheres Found per Min.
Histogram for Frequency UI Type
Subject Count
0
5
10
15
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Number of Spheres Found

B.2.10.1 Normalized Number of Spheres Found per Minute

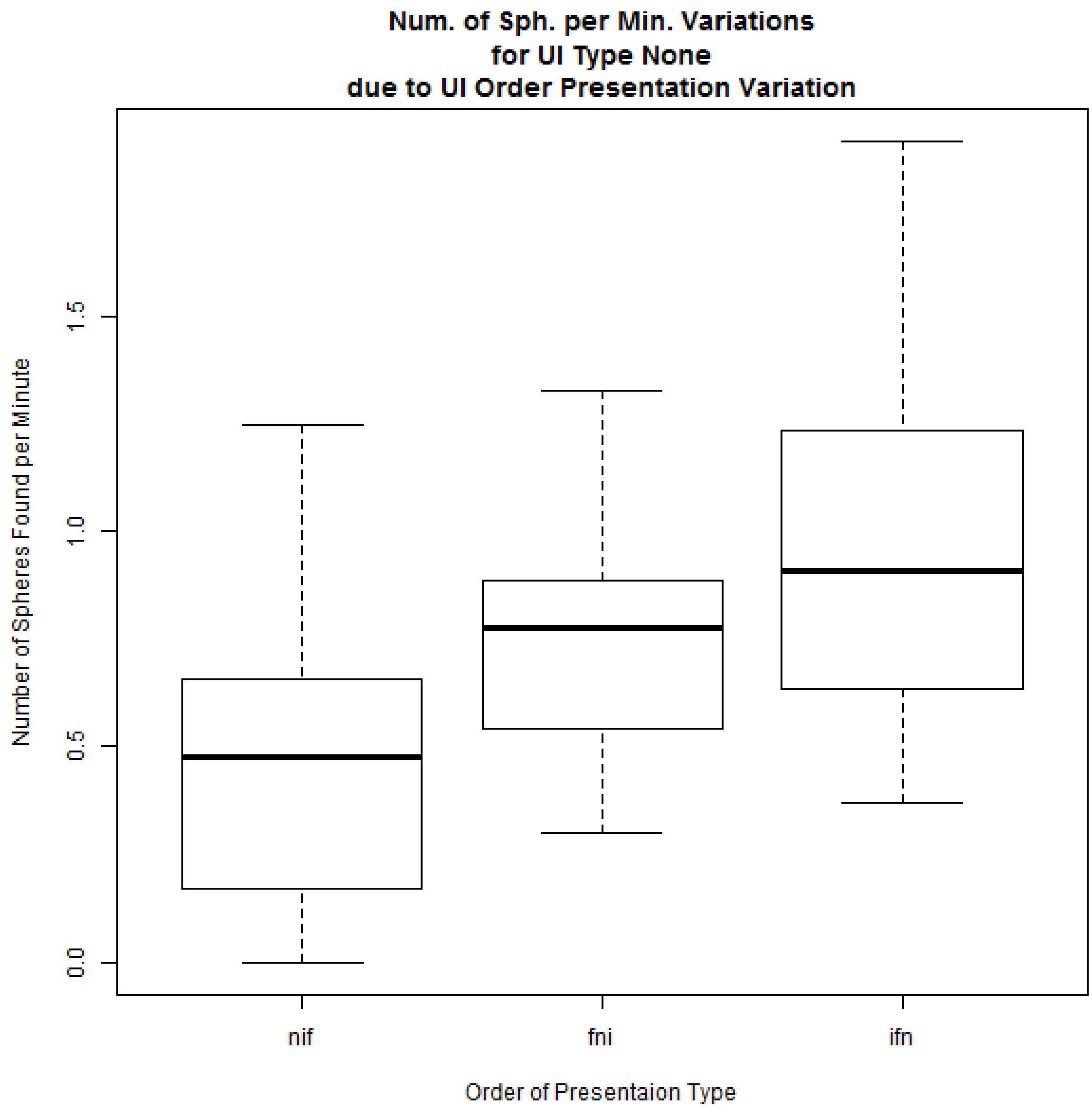


ANOVA: Normalized Number of Spheres Found per Minute for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.005	0.002	0.161	0.852
Residuals	105	1.674	0.016		

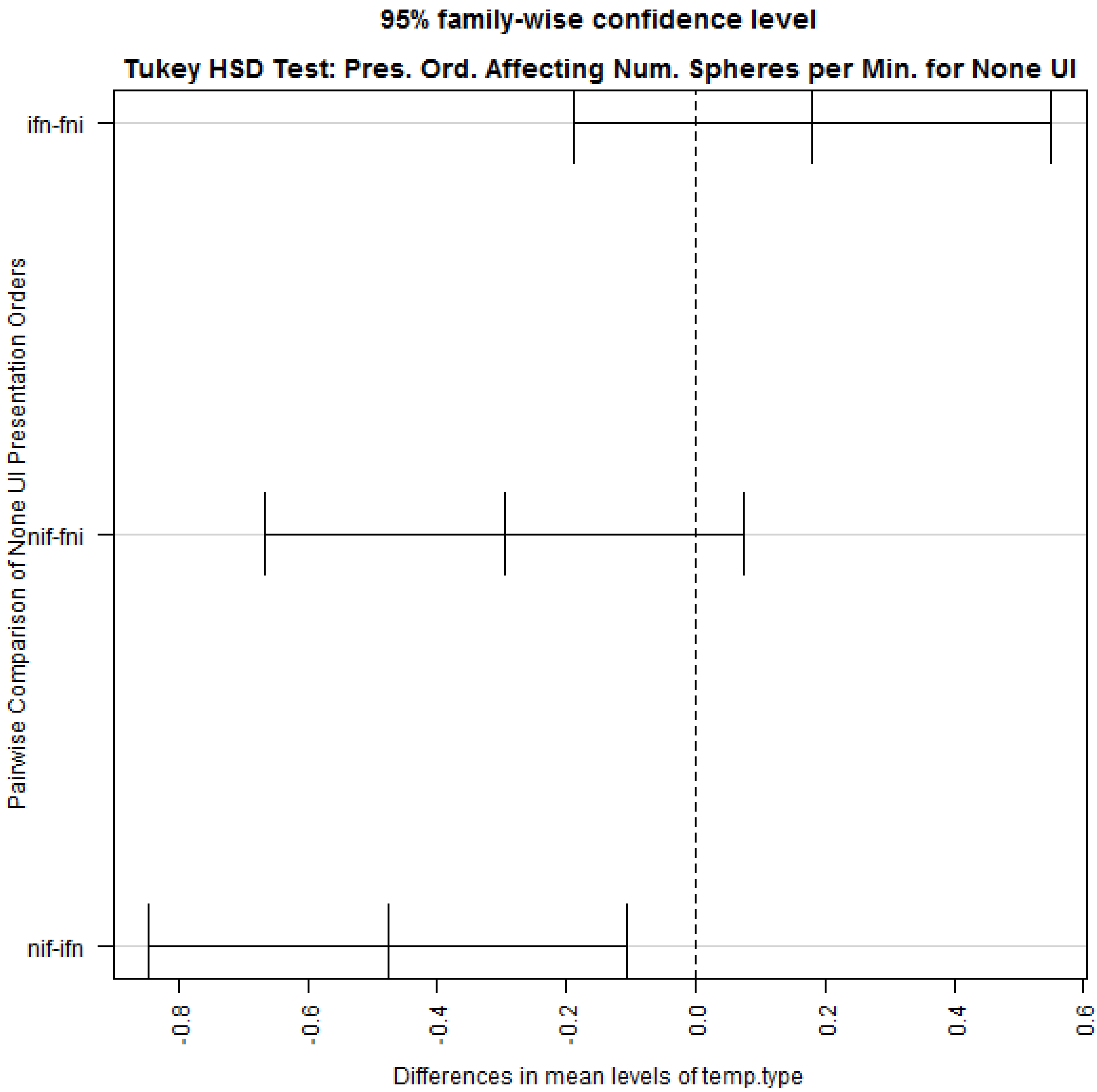
Normalized Number of Spheres Found per Minute vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	0.325	0.134	0.349
Intensity	0.342	0.112	0.339
Frequency	0.333	0.132	0.337

*B.2.10.2 Interface Order Effect on Number of Spheres Found per Minute**

B.2.10.2.1 None Interface



ANOVA: None Interface Number of Spheres Found per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	1.384	0.692	5.075	0.012
Residuals	33	4.499	0.136		



None Interface Number Spheres Found per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.470	0.358	0.475
FNI (3rd)	0.765	0.299	0.774
IFN (1st)	0.945	0.438	0.909

ANOVA: None Interface Normalized Number of Spheres Found per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.341	0.171	19.87	< 0.001
Residuals	33	0.284	0.009		

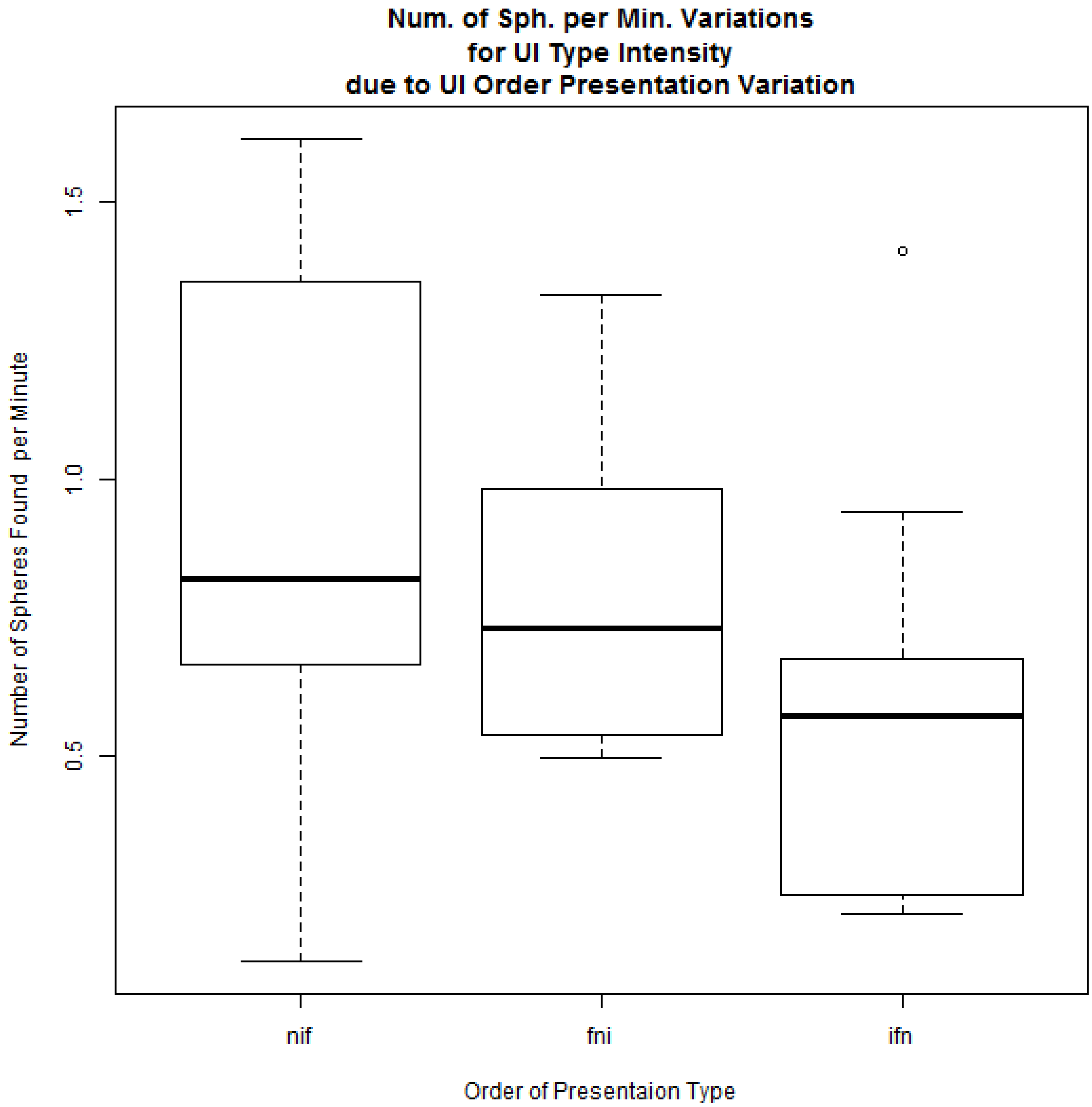
ANOVA: None Interface Normalized Number of Spheres Found per Minute for Interface Orders NIF(1st) and FNI (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.199	0.199	21.37	< 0.001
Residuals	22	0.205	0.009		

ANOVA: None Interface Normalized Number of Spheres Found per Minute for Interface Orders NIF (1st) and IFN (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.303	0.302	32.92	< 0.001
Residuals	22	0.202	0.009		

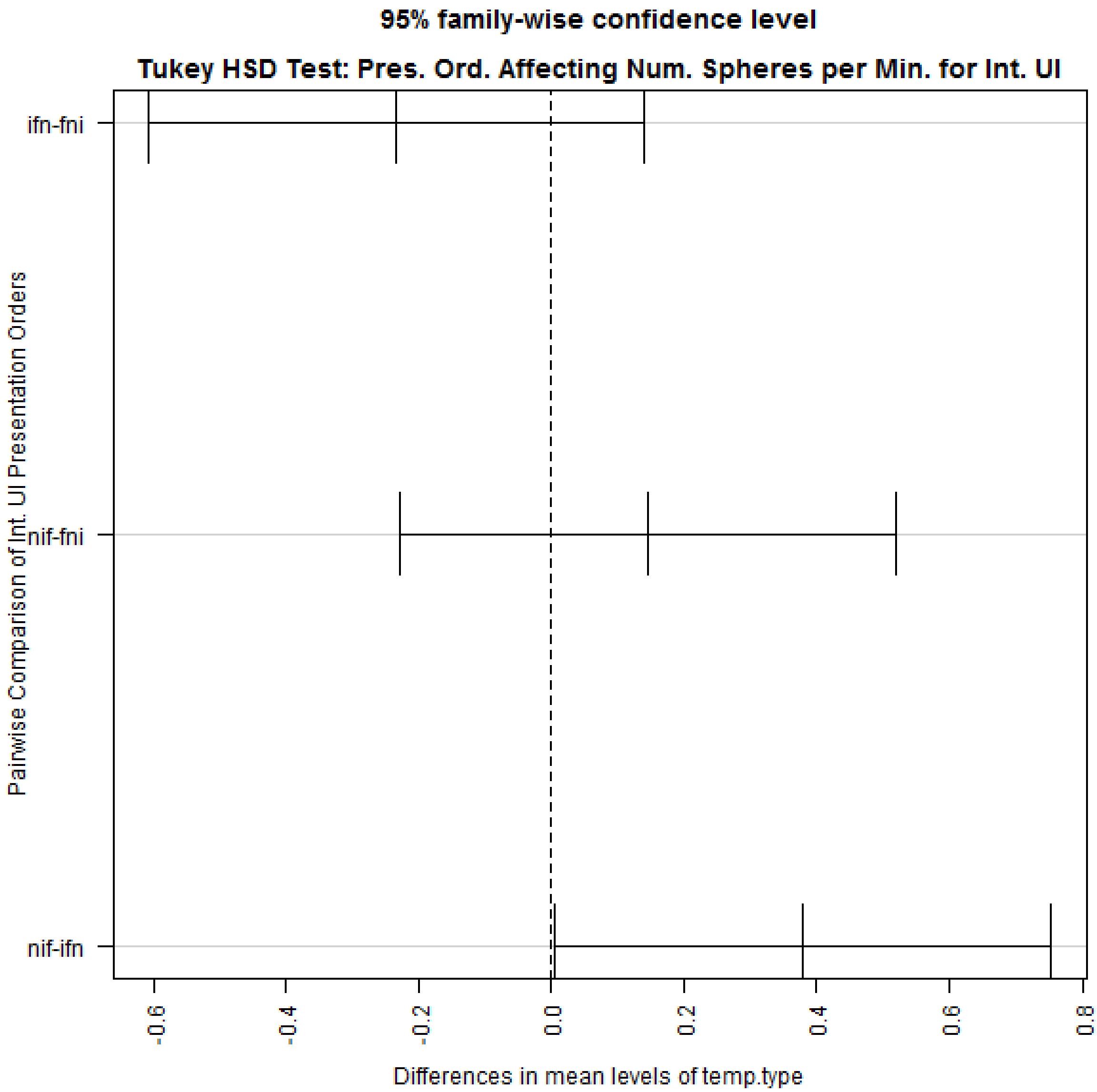
ANOVA: None Interface Normalized Number of Spheres Found per Minute for Interface Orders FNI (2nd) and IFN (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.011	0.011	1.486	0.236
Residuals	22	0.160	0.007		

Frequency Interface Normalized Number of Spheres Found per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.190	0.106	0.207
FNI (3rd)	0.372	0.086	0.381
IFN (1st)	0.414	0.085	0.394

B.2.10.2.2 Intensity Interface



ANOVA: Intensity Interface Number of Spheres Found per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.880	0.440	3.161	0.055
Residuals	33	4.593	0.139		



Intensity Interface Number of Spheres Found per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.950	0.455	0.819
FNI (3rd)	0.804	0.296	0.731
IFN (1st)	0.571	0.350	0.575

ANOVA: Intensity Interface Normalized Number of Spheres Found per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.169	0.085	10.23	< 0.001
Residuals	33	0.273	0.008		

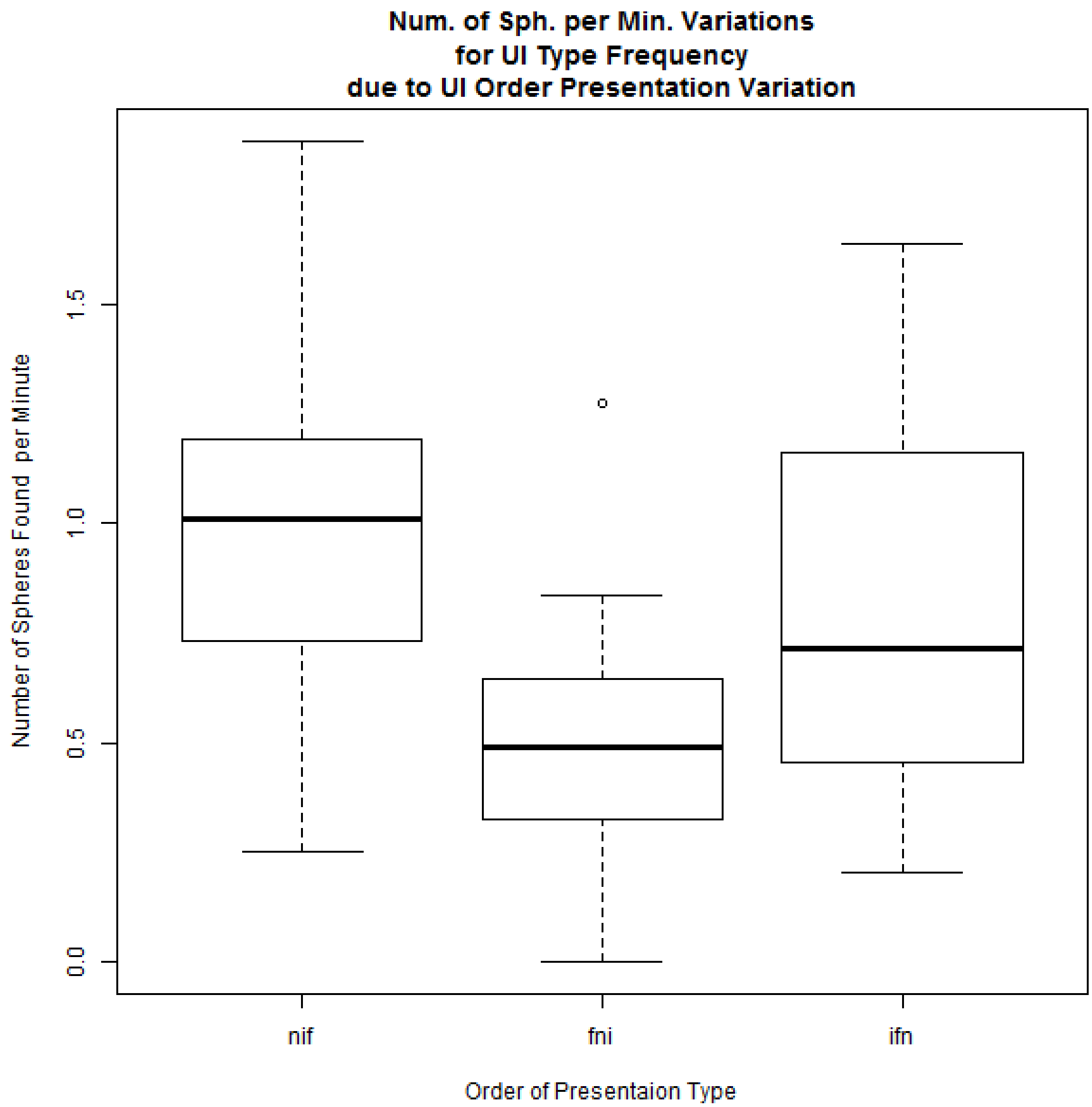
ANOVA: Intensity Interface Normalized Number of Spheres Found per Minute for Interface Orders NIF(2nd) and FNI (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.001	0.001	0.069	0.795
Residuals	22	0.220	0.010		

ANOVA: Intensity Interface Normalized Number of Spheres Found per Minute for Interface Orders NIF (2nd) and IFN (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.117	0.117	13.68	0.001
Residuals	22	0.189	0.008		

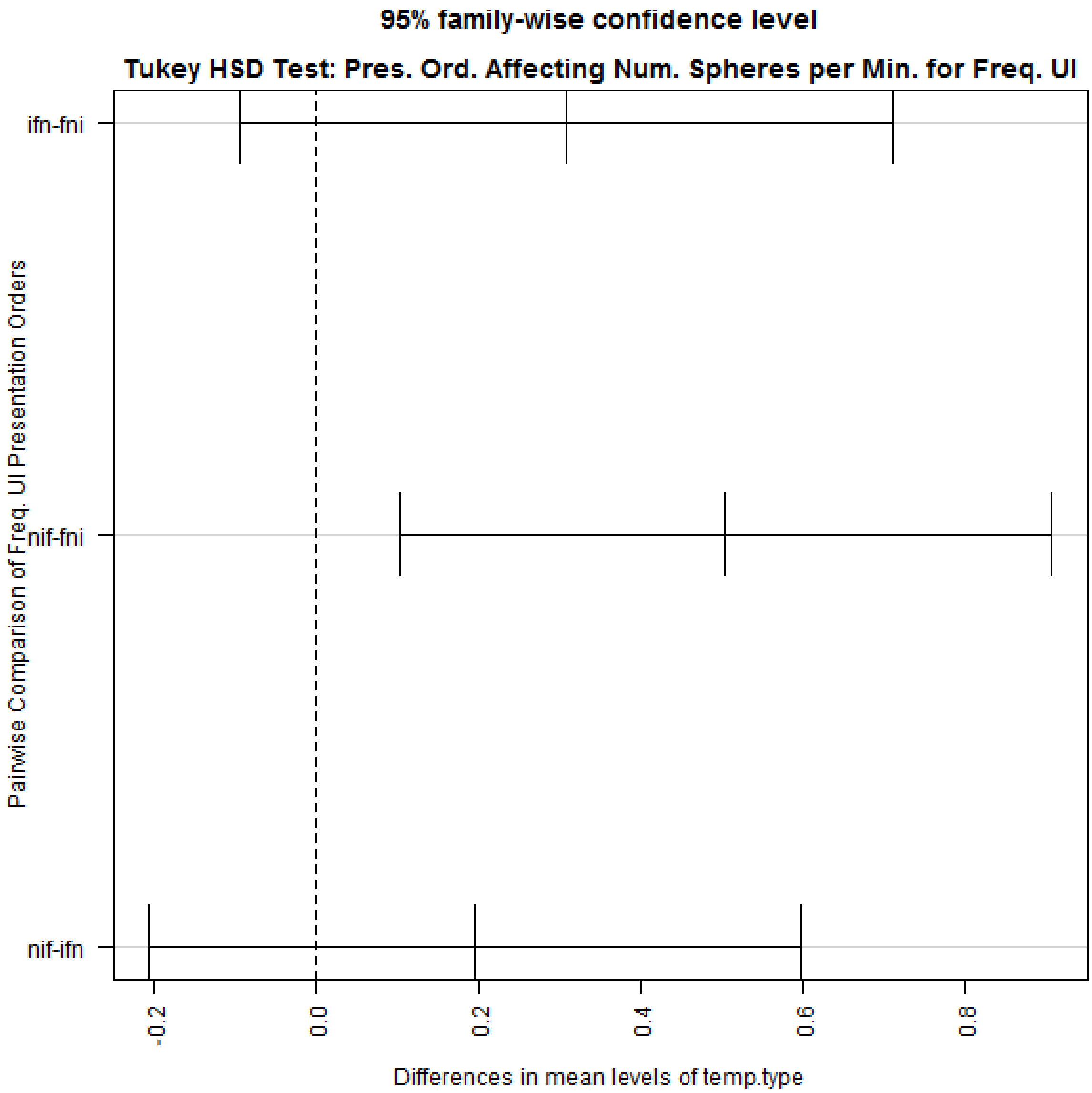
ANOVA: Intensity Interface Normalized Number of Spheres Found per Minute for Interface Orders FNI (3rd) and IFN (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.136	0.136	21.74	< 0.001
Residuals	22	0.138	0.006		

Intensity Interface Normalized Number of Spheres Found per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.385	0.111	0.358
FNI (3rd)	0.396	0.876	0.393
IFN (1st)	0.245	0.069	0.259

B.2.10.2.3 Frequency Interface



ANOVA: Frequency Number of Spheres Found per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	1.555	0.777	4.818	0.015
Residuals	33	5.323	0.161		



Frequency Interface Number Spheres Found per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	1.008	0.409	0.012
FNI (3rd)	0.504	0.350	0.490
IFN (1st)	0.812	0.441	0.714

ANOVA: Frequency Interface Normalized Number of Spheres Found per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.224	0.112	9.672	< 0.001
Residuals	33	0.382	0.116		

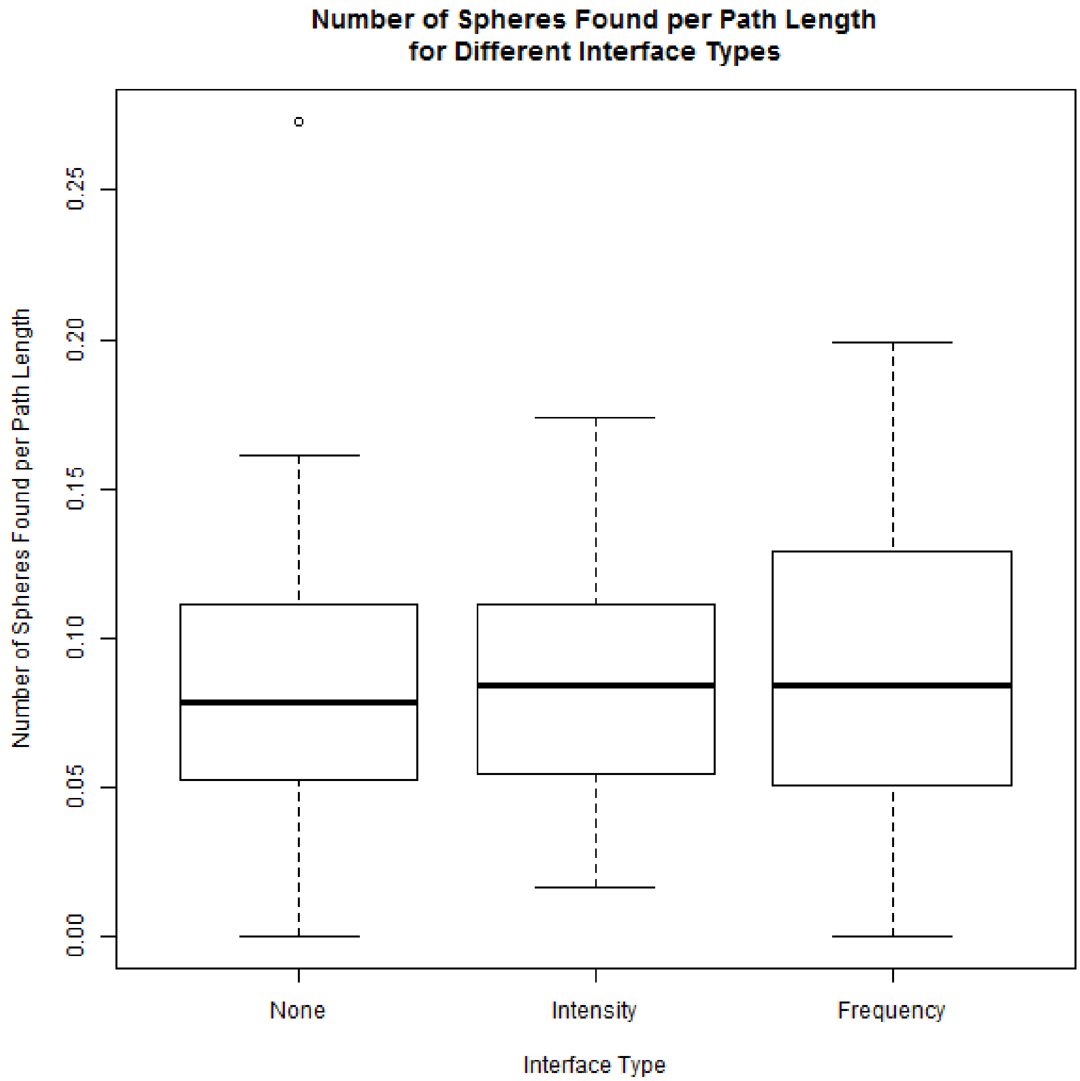
ANOVA: Intensity Interface Normalized Number of Spheres Found per Minute for Interface Orders NIF(2^{nd}) and FNI (3^{rd})					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.223	0.223	15.79	< 0.001
Residuals	22	0.311	0.014		

ANOVA: Intensity Interface Normalized Number of Spheres Found per Minute for Interface Orders NIF (2^{nd}) and IFN (1^{st})					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.043	0.043	6.686	0.017
Residuals	22	0.142	0.006		

ANOVA: Intensity Interface Normalized Number of Spheres Found per Minute for Interface Orders FNI (3^{rd}) and IFN (1^{st})					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.070	0.070	4.938	0.037
Residuals	22	0.312	0.014		

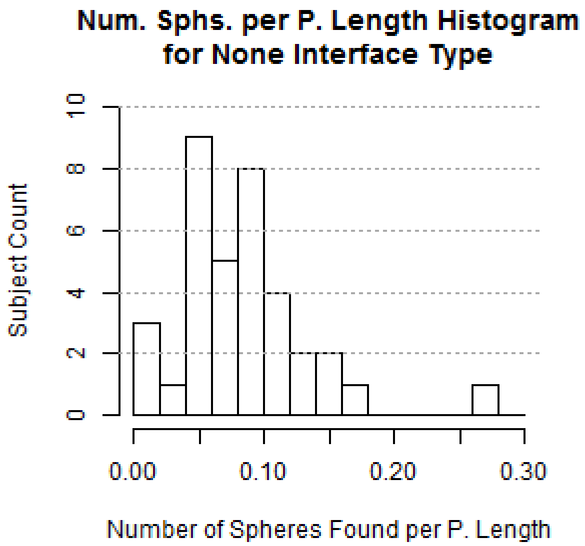
Frequency Interface Normalized Number of Spheres Found per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2^{nd})	0.425	0.080	0.422
FNI (3^{rd})	0.232	0.148	0.245
IFN (1^{st})	0.340	0.081	0.359

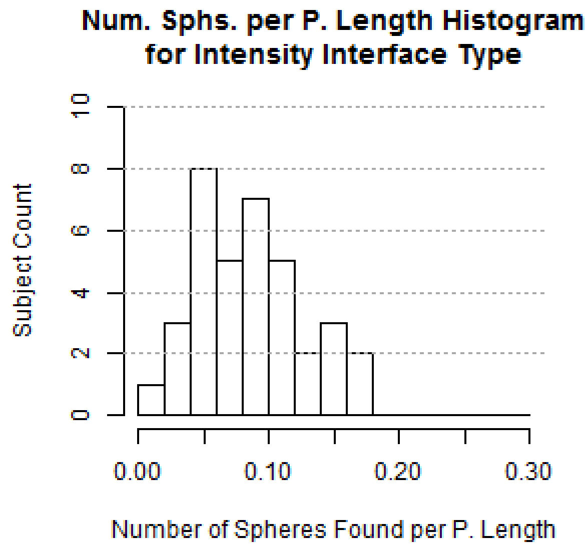
B.2.11 Number of Spheres per Path Length

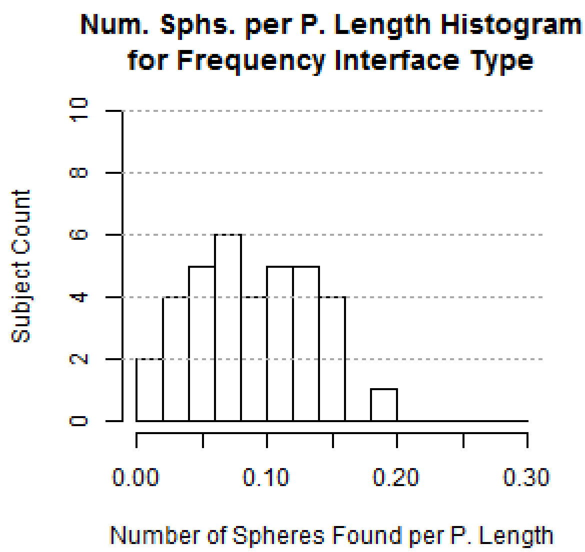


ANOVA: Number of Spheres per Path Length for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.000	0.000	0.084	0.919
Residuals	105	0.226	0.002		

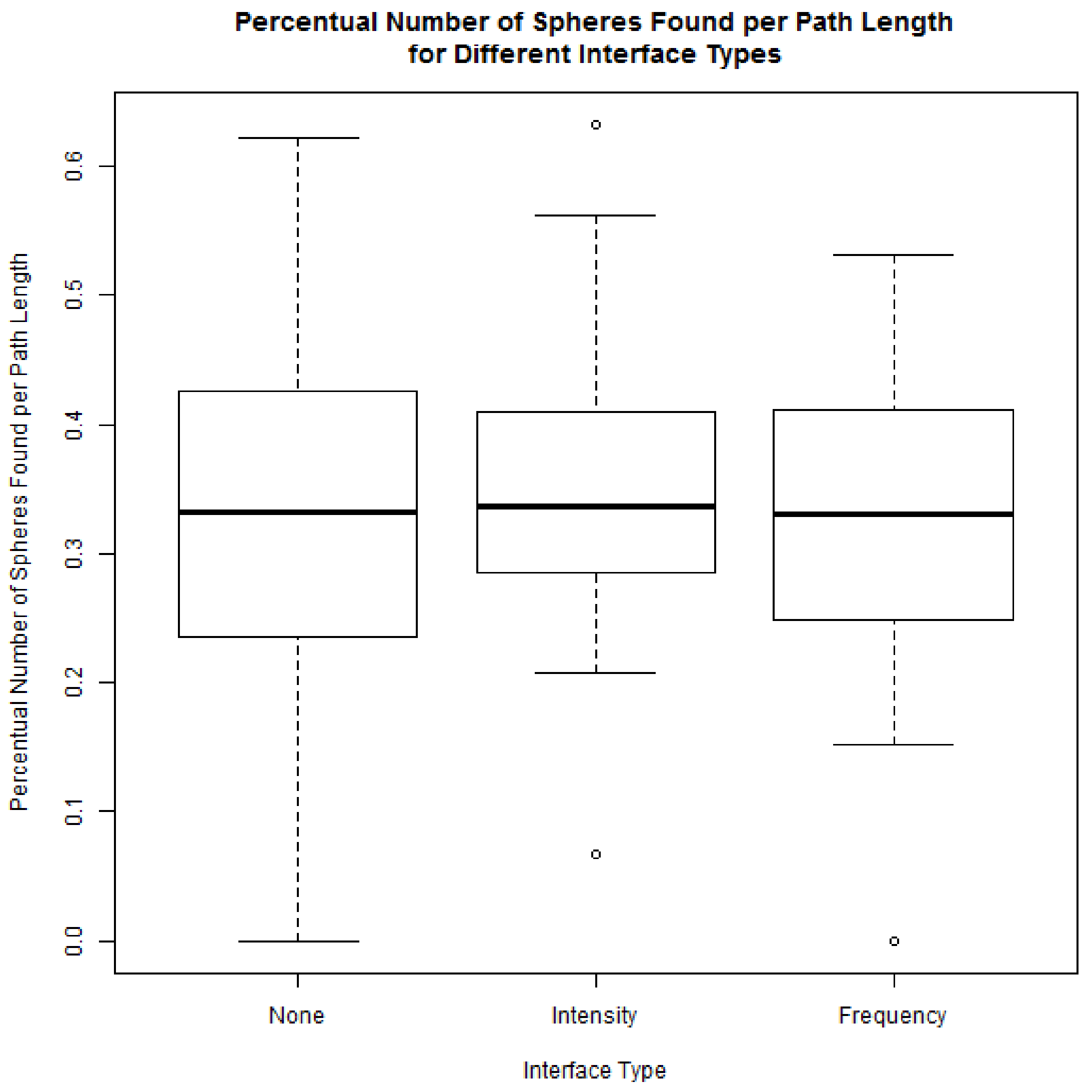
Number of Spheres per Path Length vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	0.083	0.051	0.078
Intensity	0.087	0.040	0.084
Frequency	0.086	0.047	0.084


Num. Sphs. per P. Length Histogram
for None Interface Type
Subject Count
0
2
4
6
8
10
0.00
0.10
0.20
0.30
Number of Spheres Found per P. Length


Num. Sphs. per P. Length Histogram
for Intensity Interface Type
Subject Count
0
2
4
6
8
10
0.00
0.10
0.20
0.30
Number of Spheres Found per P. Length

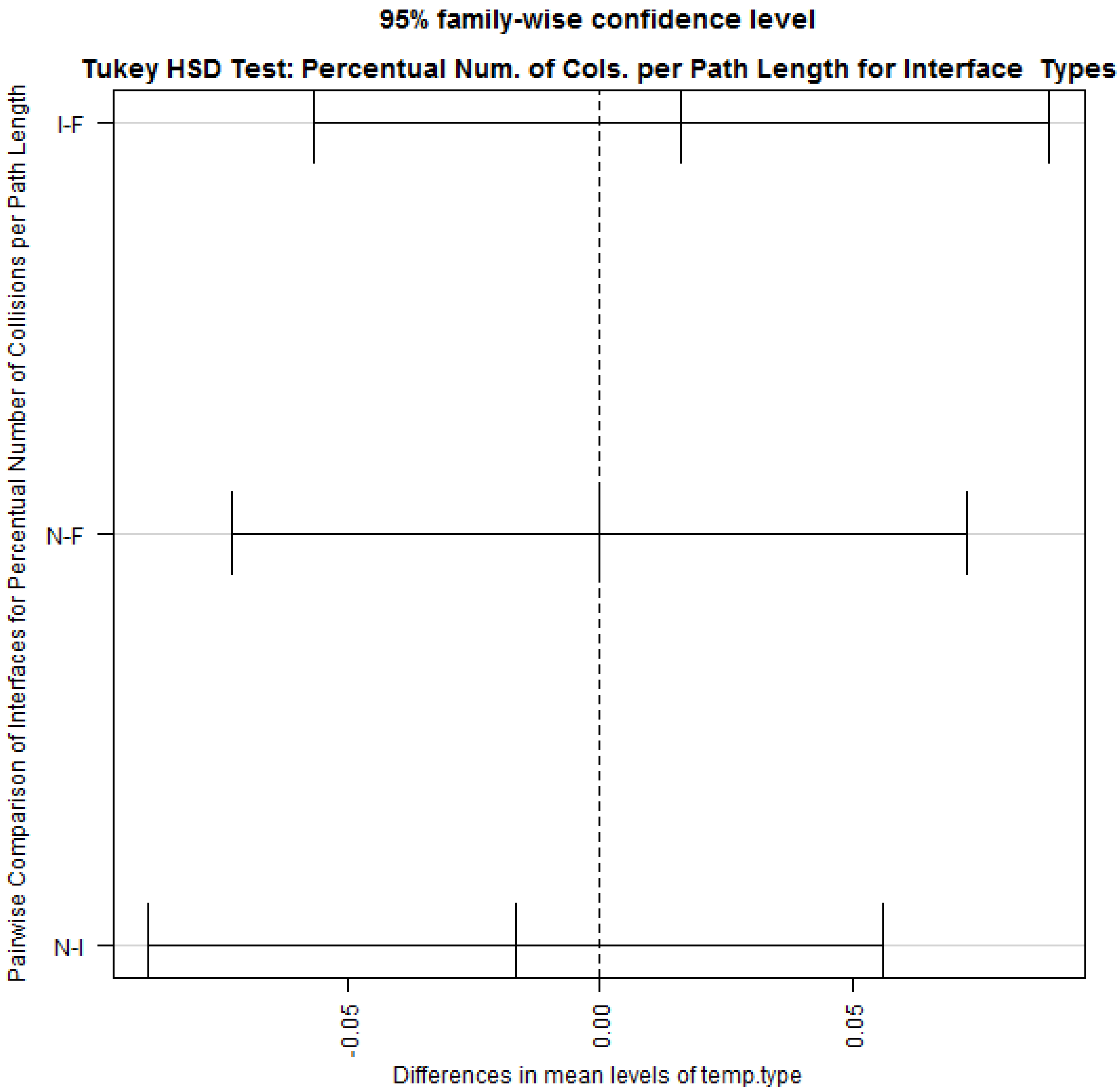

Num. Sphs. per P. Length Histogram
for Frequency Interface Type
Subject Count
0
2
4
6
8
10
0.00
0.10
0.20
0.30
Number of Spheres Found per P. Length

B.2.11.1 Normalized Number of Spheres per Path Length



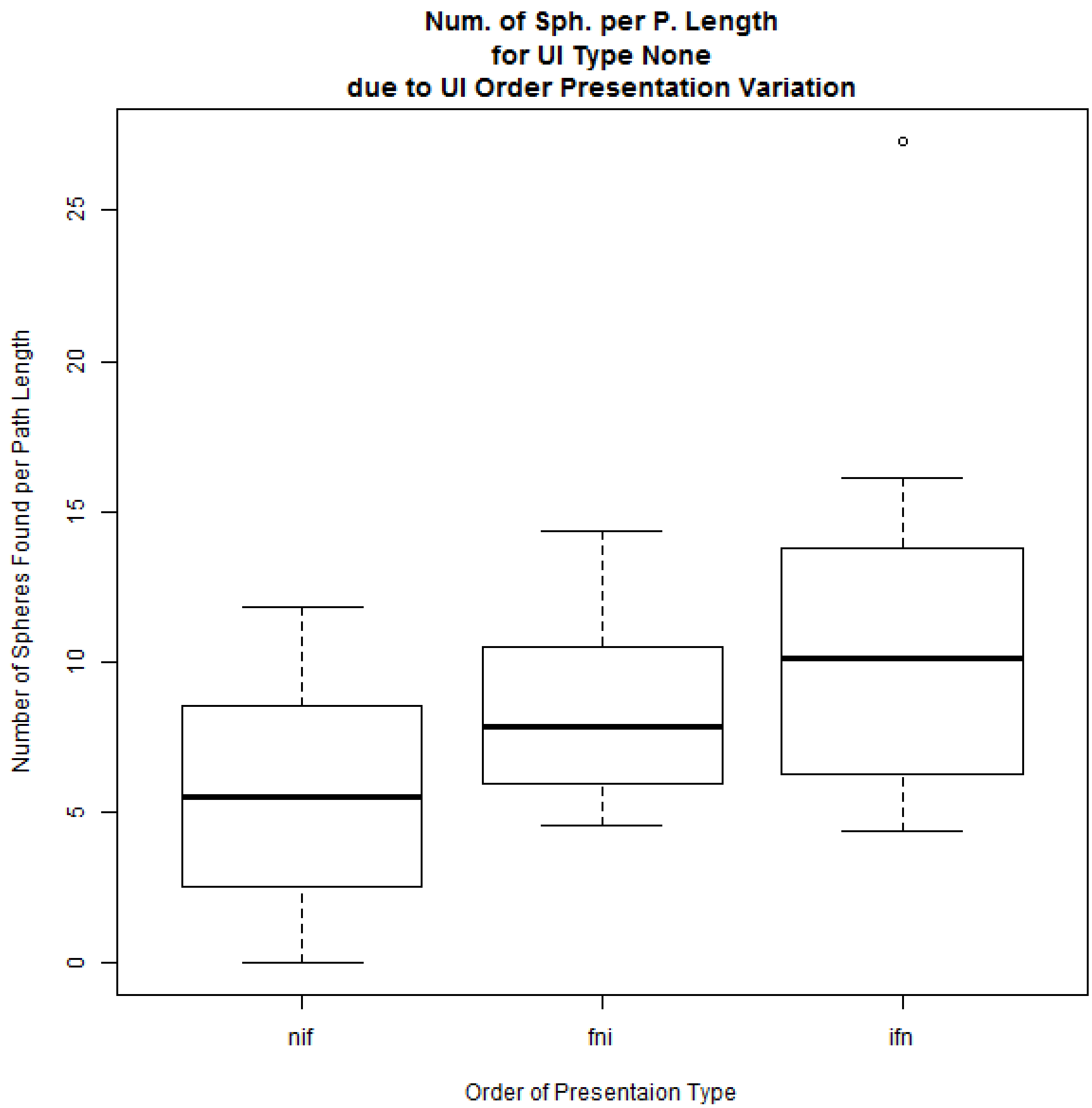
ANOVA: Normalized Number of Spheres per Path Length for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.006	0.003	0.191	0.826
Residuals	105	1.775	0.017		

Normalized Number of Spheres per Path Length vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	0.328	0.145	0.332
Intensity	0.344	0.108	0.337
Frequency	0.328	0.134	0.331

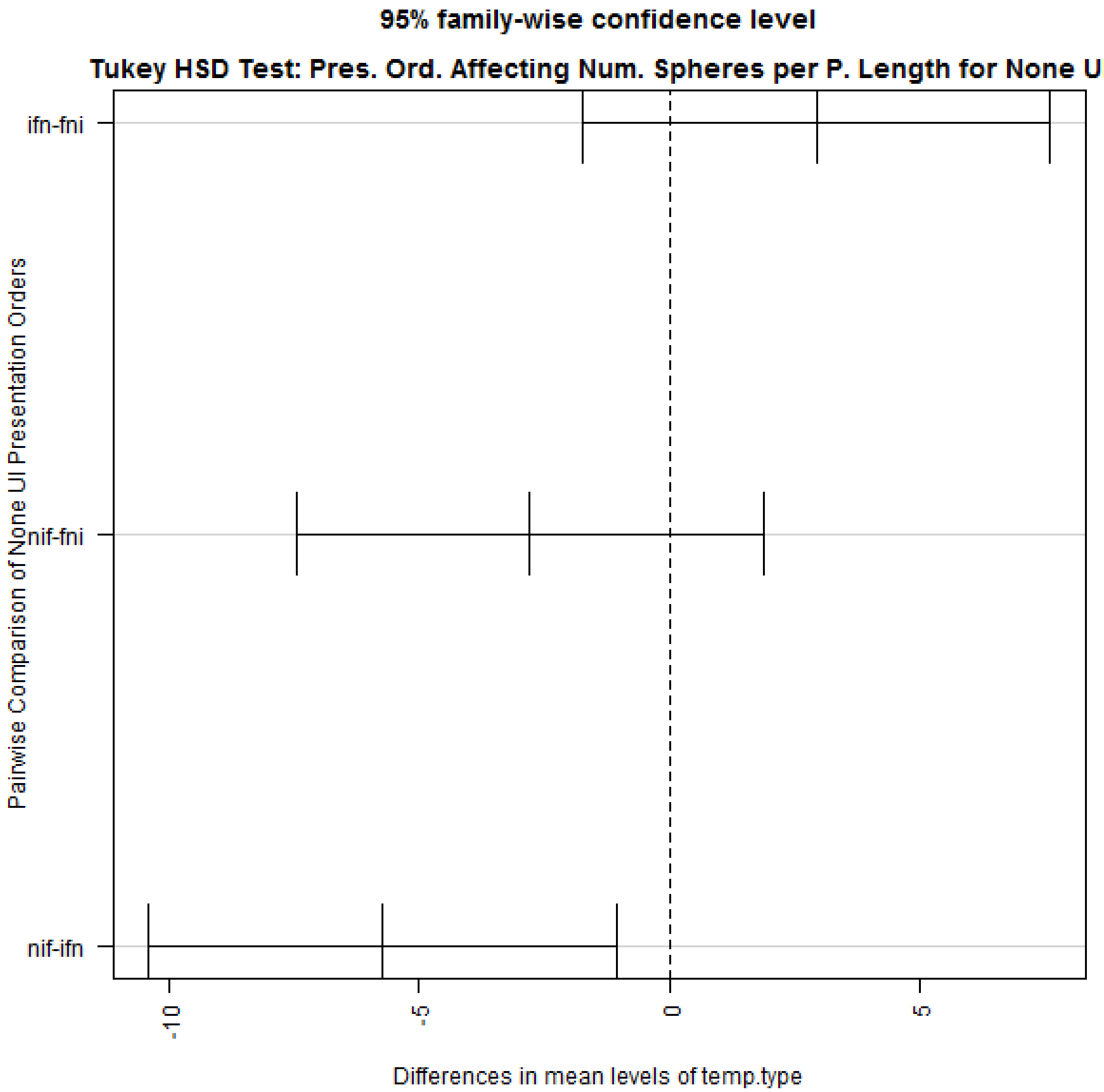

95% family-wise confidence level
Tukey HSD Test: Percentual Num. of Cols. per Path Length for Interface Types
Pairwise Comparison of Interfaces for Percentual Number of Collisions per Path Length
I-F
N-F
N-I
-0.05
0.00
0.05
Differences in mean levels of temp.type

*B.2.11.2 Interface Order Effect on Number of Spheres Found per Path Length**

B.2.11.2.1 None Interface



ANOVA: None Interface Number of Spheres Found per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	196.7	98.37	4.538	0.018
Residuals	33	715.3	21.68		



None Interface Number of Spheres Found per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	5.421	3.815	5.463
FNI (3rd)	8.213	3.142	7.850
IFN (1st)	11.146	6.371	10.097

ANOVA: None Interface Normalized Number of Spheres Found per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.360	0.180	15.66	< 0.001
Residuals	33	0.380	0.011		

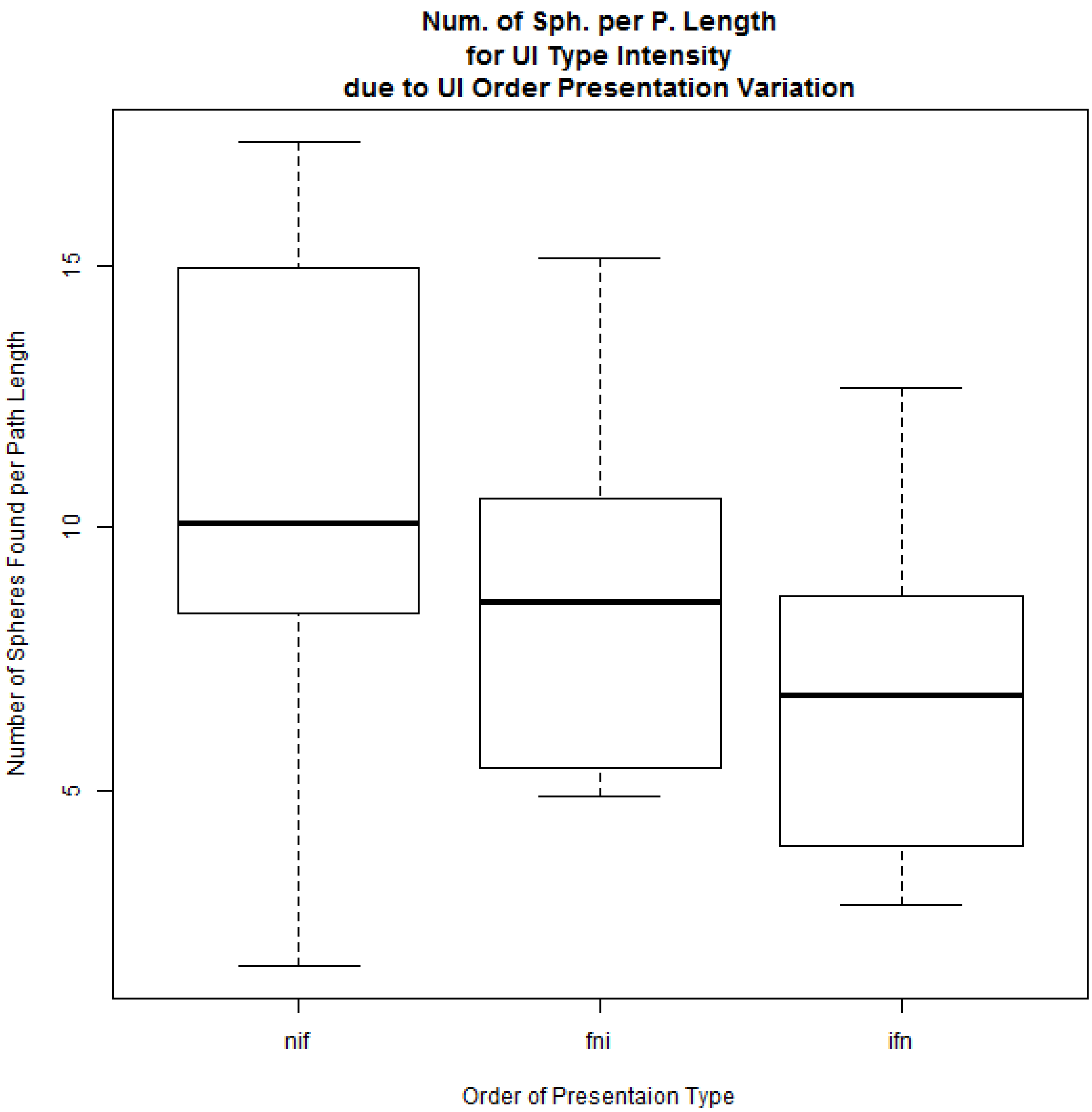
ANOVA: None Interface Normalized Number of Spheres Found per Path Length for Interface Orders NIF(1st) and FNI (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.220	0.220	23.15	< 0.001
Residuals	22	0.209	0.009		

ANOVA: None Interface Normalized Number of Spheres Found per Path Length for Interface Orders NIF (1st) and IFN (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.312	0.312	23.52	< 0.001
Residuals	22	0.292	0.013		

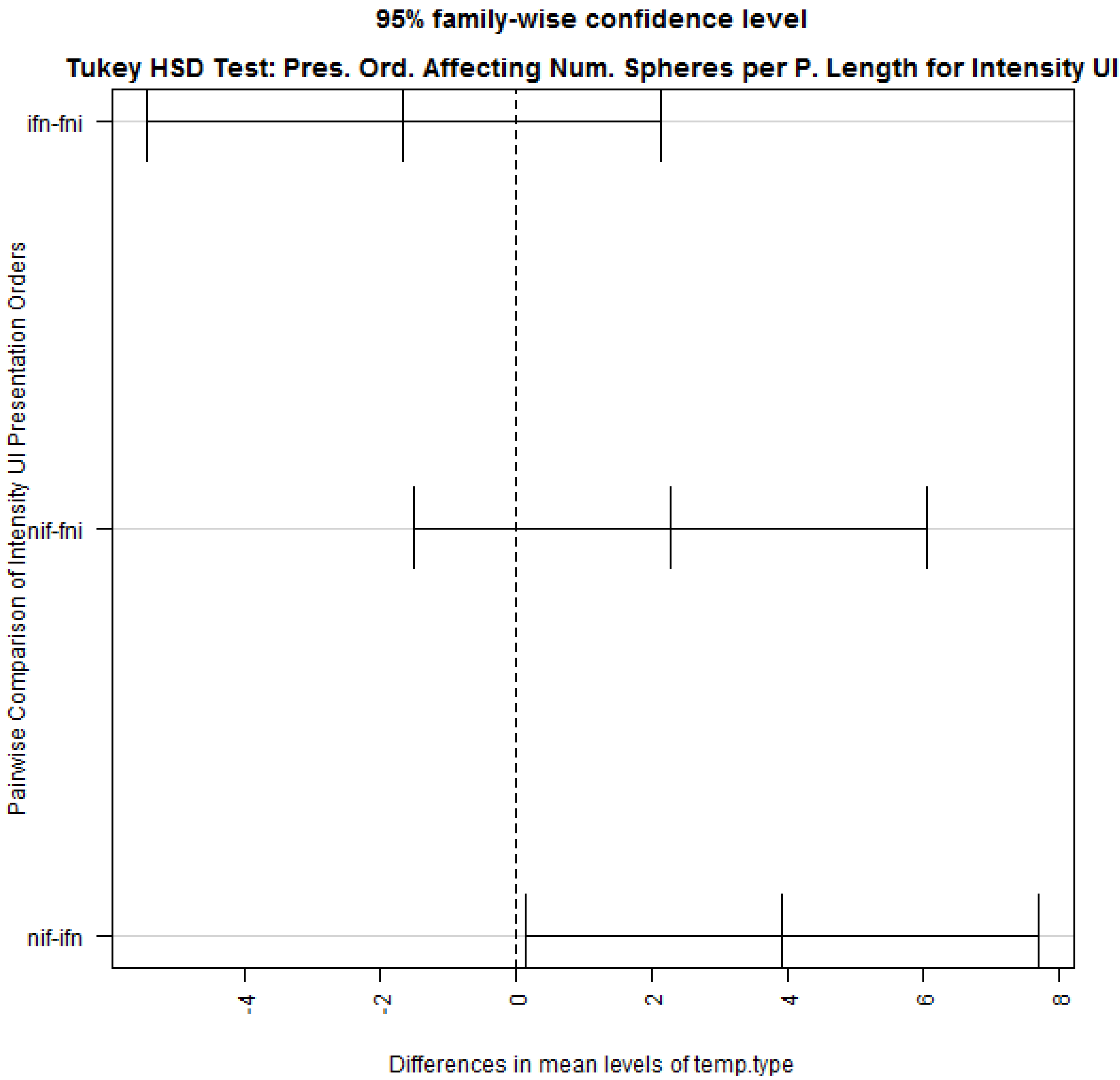
ANOVA: None Interface Normalized Number of Spheres Found per Path Length for Interface Orders FNI (2nd) and IFN (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.008	0.008	0.682	0.418
Residuals	22	0.258	0.012		

Frequency Interface Normalized Number of Spheres Found per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.188	0.105	0.184
FNI (3rd)	0.379	0.089	0.389
IFN (1st)	0.416	0.124	0.397

B.2.11.2.2 Intensity Interface



ANOVA: Intensity Interface Number of Spheres Found per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	93.7	46.87	3.291	0.050
Residuals	33	470.0	14.24		



Intensity Interface Number of Spheres Found per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	10.739	4.611	0.088
FNI (3rd)	8.450	3.233	8.577
IFN (1st)	6.804	3.318	6.807

ANOVA: Intensity Interface Normalized Number of Spheres Found per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.114	0.057	6.339	0.005
Residuals	33	0.296	0.009		

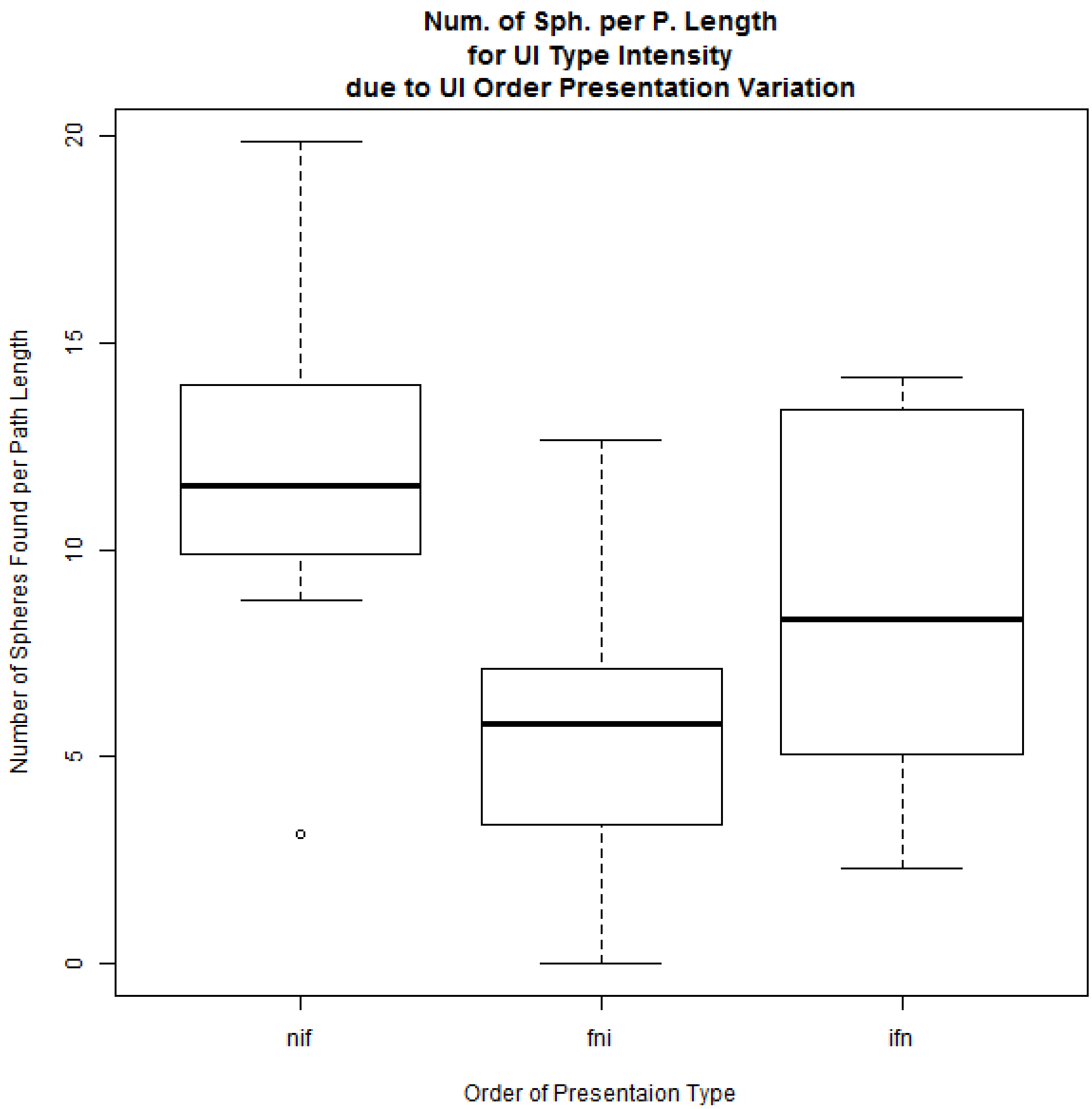
ANOVA: Intensity Interface Normalized Number of Spheres Found per Path Length for Interface Orders NIF(2nd) and FNI (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.000	0.000	0.04	0.843
Residuals	22	0.231	0.010		

ANOVA: Intensity Interface Normalized Number of Spheres Found per Path Length for Interface Orders NIF (2nd) and IFN (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.079	0.079	8.133	0.009
Residuals	22	0.214	0.010		

ANOVA: Intensity Interface Normalized Number of Spheres Found per Path Length for Interface Orders FNI (3rd) and IFN (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.091	0.091	13.59	0.001
Residuals	22	0.147	0.007		

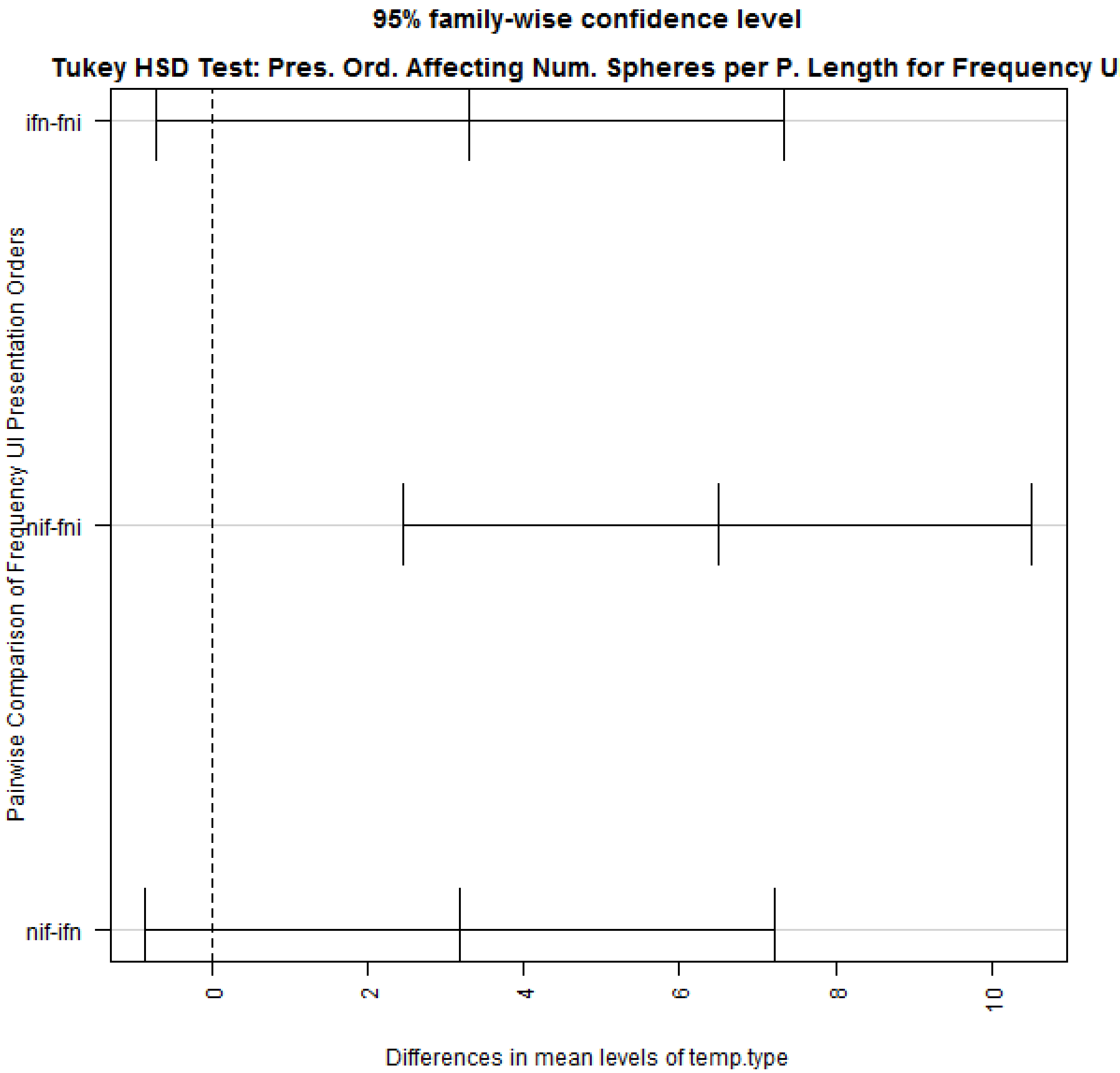
Intensity Interface Normalized Number of Spheres Found per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	0.380	0.116	0.349
FNI (3rd)	0.388	0.086	0.389
IFN (1st)	0.265	0.077	0.288

B.2.11.2.3 Frequency Interface



ANOVA: Frequency Number of Spheres Found per Path Length in Different Interface Order

Source of Variation	*DoF*	*SS*	*MS*	*F*	*P-value*
Interface Type	2	252.6	126.28	7.787	0.002
Residuals	33	535.2	16.22		



Frequency Interface Number of Spheres Found per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2nd)	11.855	4.153	11.544
FNI (3rd)	5.368	3.522	5.784
IFN (1st)	8.675	4.359	8.322

ANOVA: Frequency Interface Normalized Number of Spheres Found per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.241	0.121	10.38	< 0.001
Residuals	33	0.384	0.011		

ANOVA: Frequency Interface Normalized Number of Spheres Found per Path Length for Interface Orders NIF(2^{nd}) and FNI (3^{rd})					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.240	0.240	17.95	< 0.001
Residuals	22	0.294	0.013		

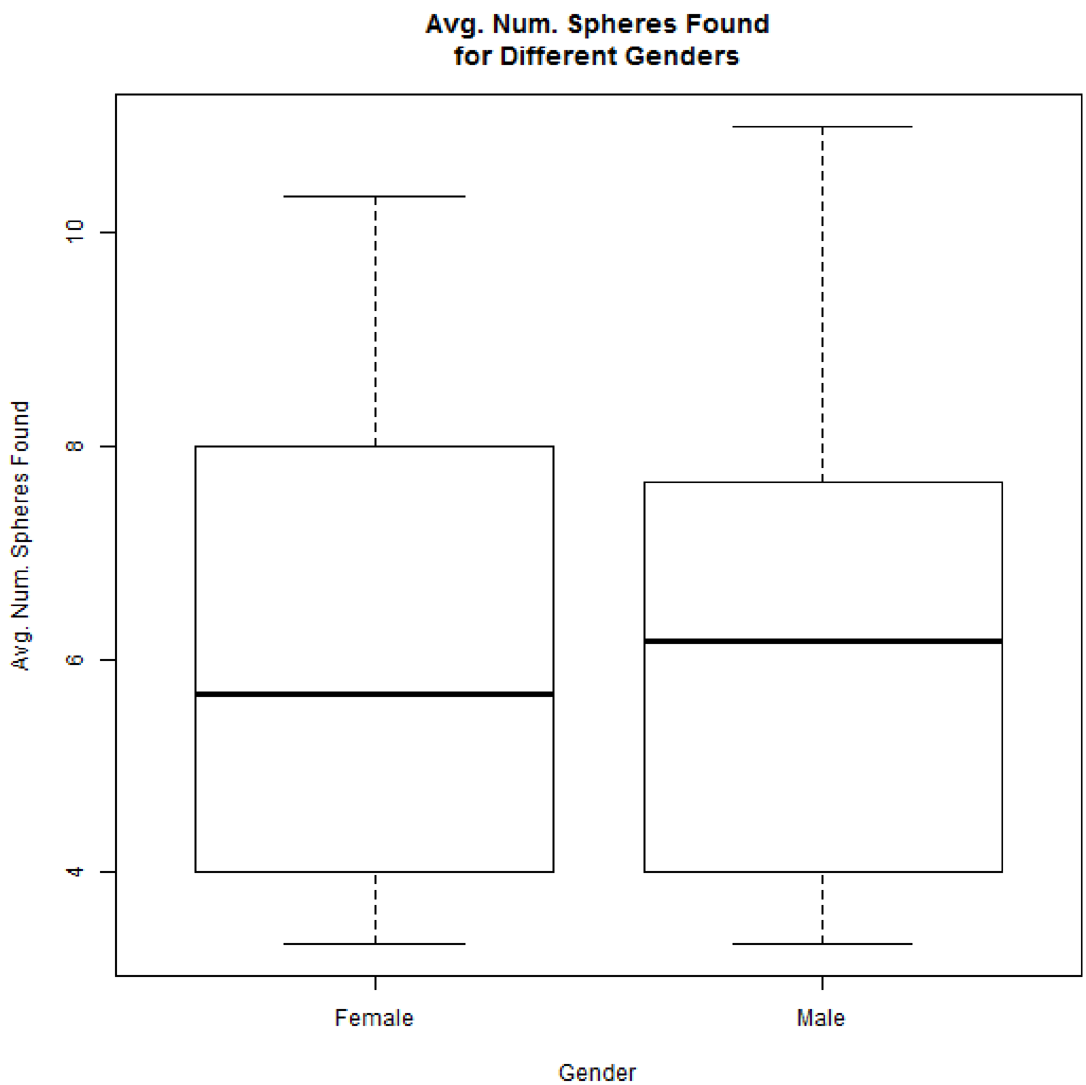
ANOVA: Frequency Interface Normalized Number of Spheres Found per Path Length for Interface Orders NIF (2^{nd}) and IFN (1^{st})					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.077	0.077	11.03	0.003
Residuals	22	0.153	0.007		

ANOVA: Frequency Interface Normalized Number of Spheres Found per Path Length for Interface Orders FNI (3^{rd}) and IFN (1^{st})					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.045	0.045	3.102	0.092
Residuals	22	0.320	0.014		

Frequency Interface Normalized Number of Spheres Found per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
NIF (2^{nd})	0.432	0.076	0.434
FNI (3^{rd})	0.232	0.145	0.252
IFN (1^{st})	0.319	0.090	0.320

B.2.12 Gender Effects to Dependent Variables

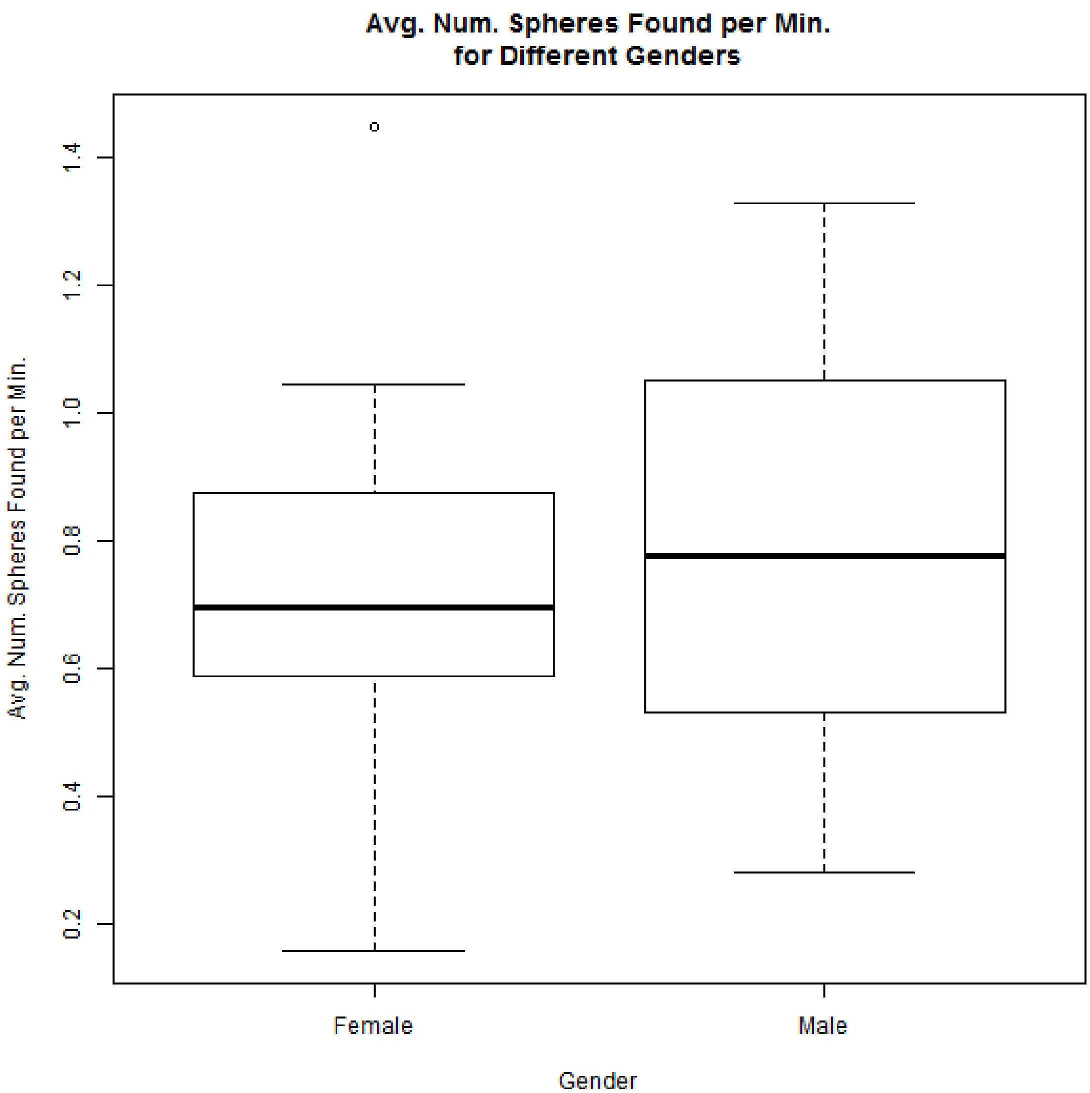
B.2.12.1 Number of Spheres Found



Number of Spheres Found vs. Gender – Kruskal-Wallis Test	
X^2	0.096
p	0.757
DoF	1

Number of Spheres Found vs. Gender Summary			
	Mean	***Std. Dev.***	***Median***
Female	6.071	2.401	5.667
Male	6.242	2.163	6.167

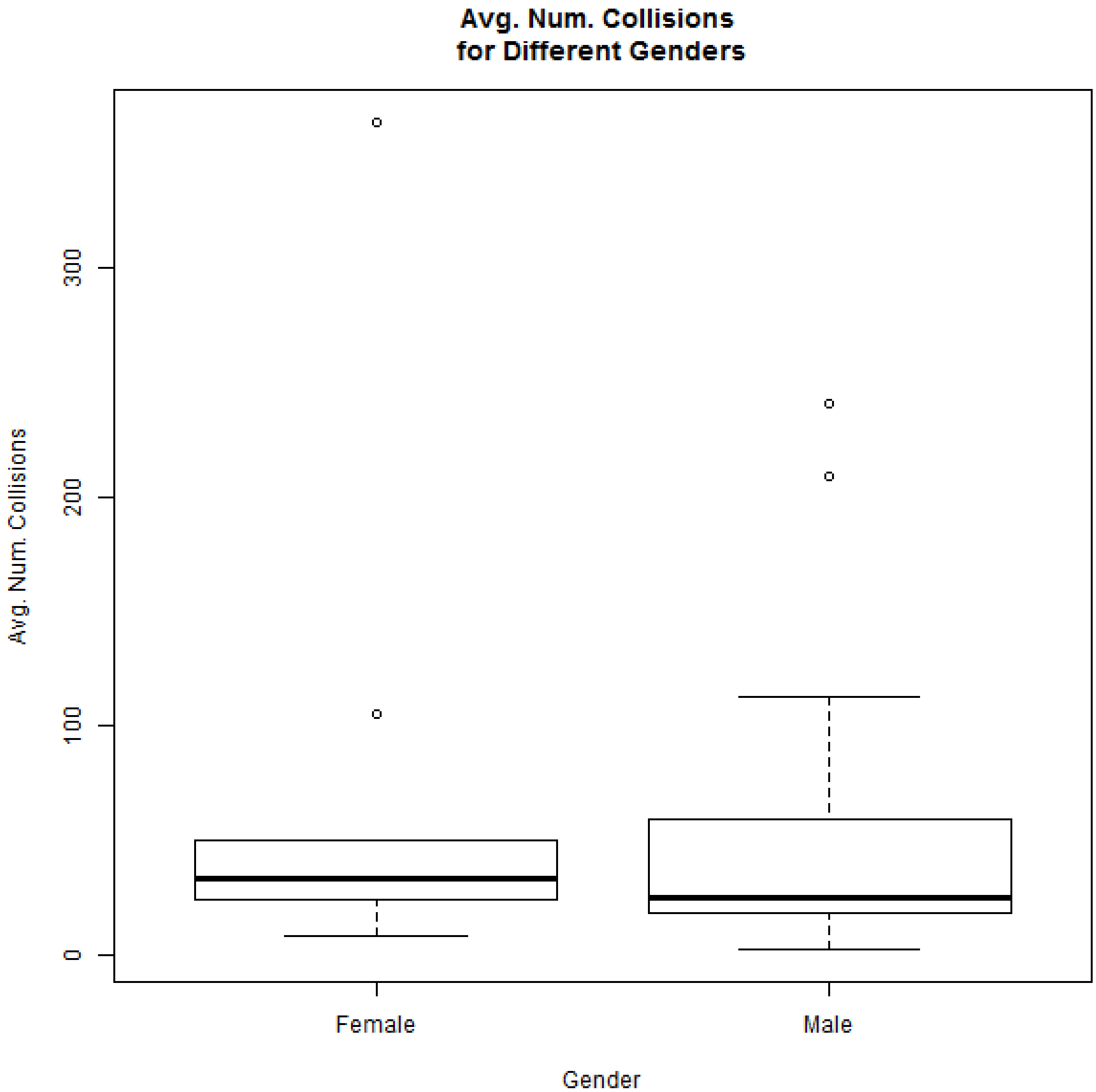
B.2.12.2 Number of Spheres Found per Minute



Number of Spheres Found per Minute vs. Gender – Kruskal-Wallis Test	
X^2	0.127
p	0.721
DoF	1

Number of Spheres Found per Minute vs. Gender Summary			
	Mean	***Std. Dev.***	***Median***
Female	0.746	0.300	0.727
Male	0.767	0.302	0.777

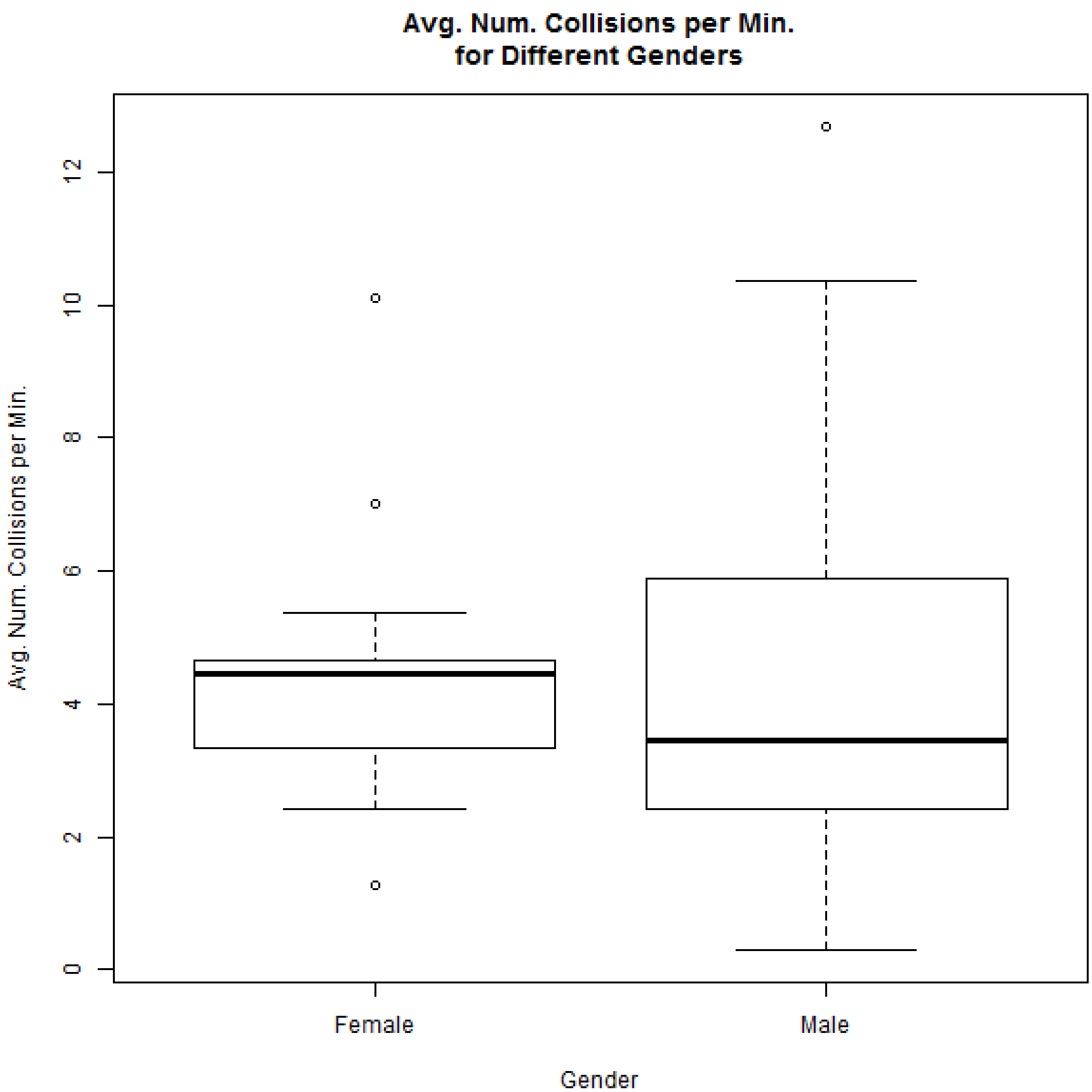
B.2.12.3 Number of Collisions



Number of Collisions vs. Gender – Kruskal-Wallis Test	
X^2	0.400
p	0.527
DoF	1

Number of Collisions vs. Gender Summary			
	Mean	***Std. Dev.***	***Median***
Female	58.786	90.688	31
Male	51.227	63.147	25.333

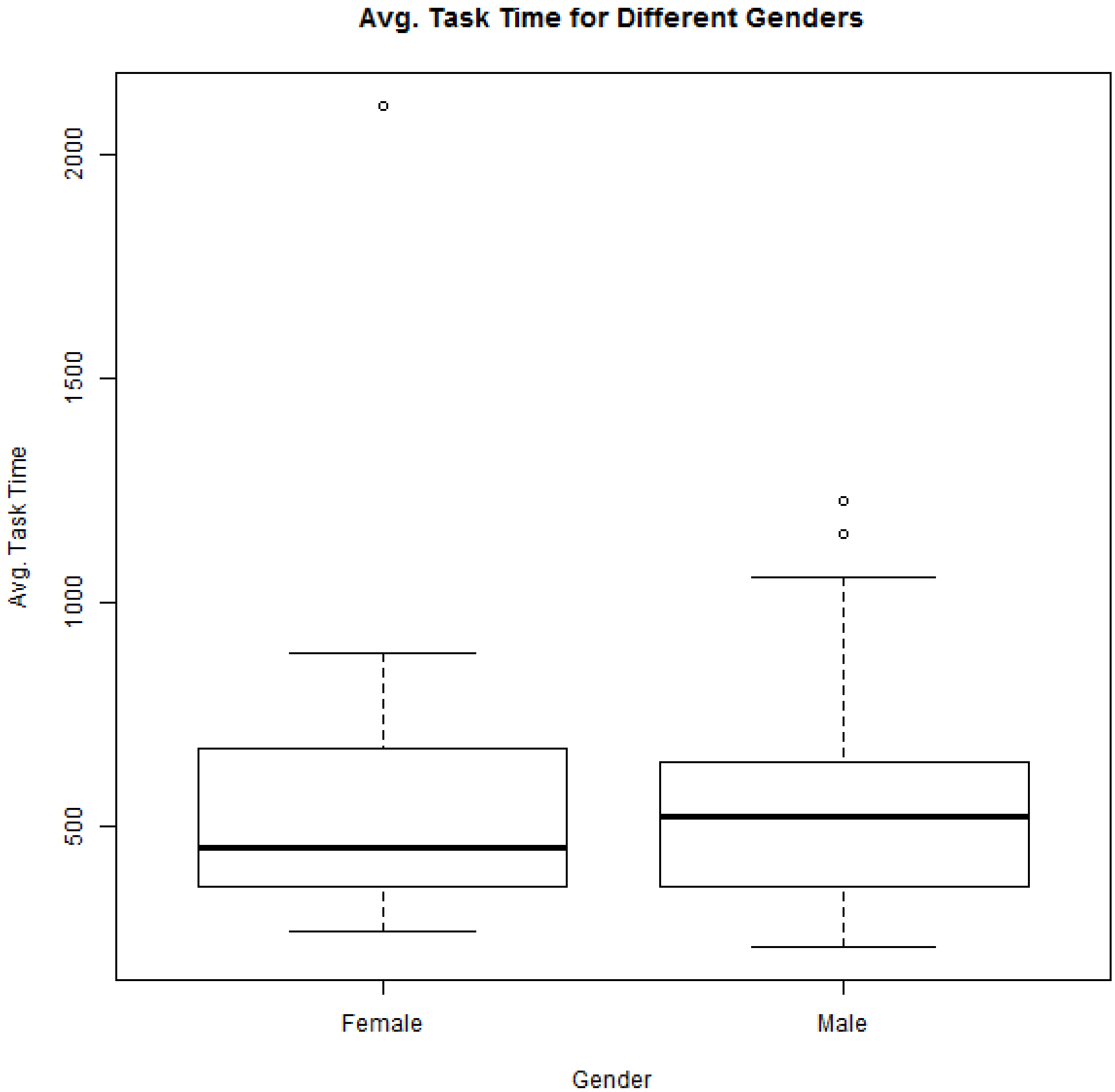
B.2.12.4 Number of Collisions per Minute



Number of Collisions per Minute vs. Gender – Kruskal-Wallis Test	
X^2	0.380
p	0.537
DoF	1

Number of Collisions per Minute vs. Gender Summary			
	Mean	***Std. Dev.***	***Median***
Female	4.356	2.165	4.022
Male	4.246	3.090	3.465

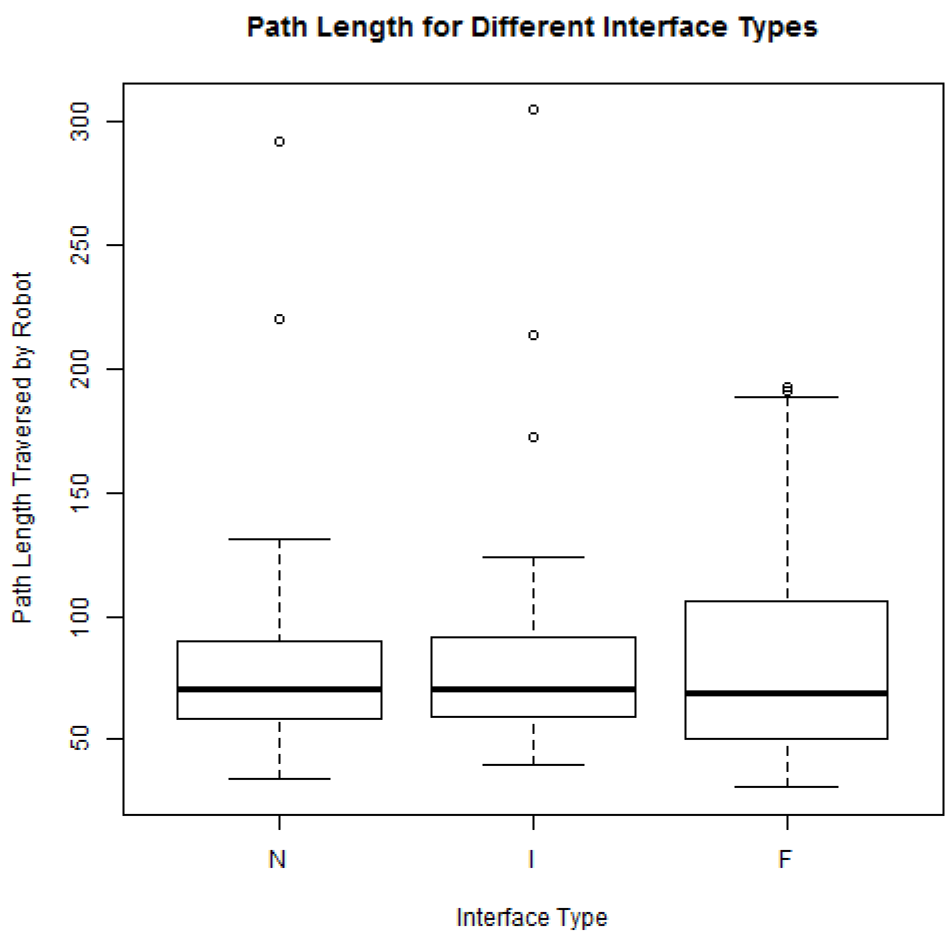
B.2.12.5 Task Time



Task Time vs. Gender – Kruskal-Wallis Test	
X^2	0.085
p	0.770
DoF	1

Task Time vs. Gender Summary			
	Mean	***Std. Dev.***	***Median***
Female	607.452	462.276	451.167
Male	580.045	294.409	522.667

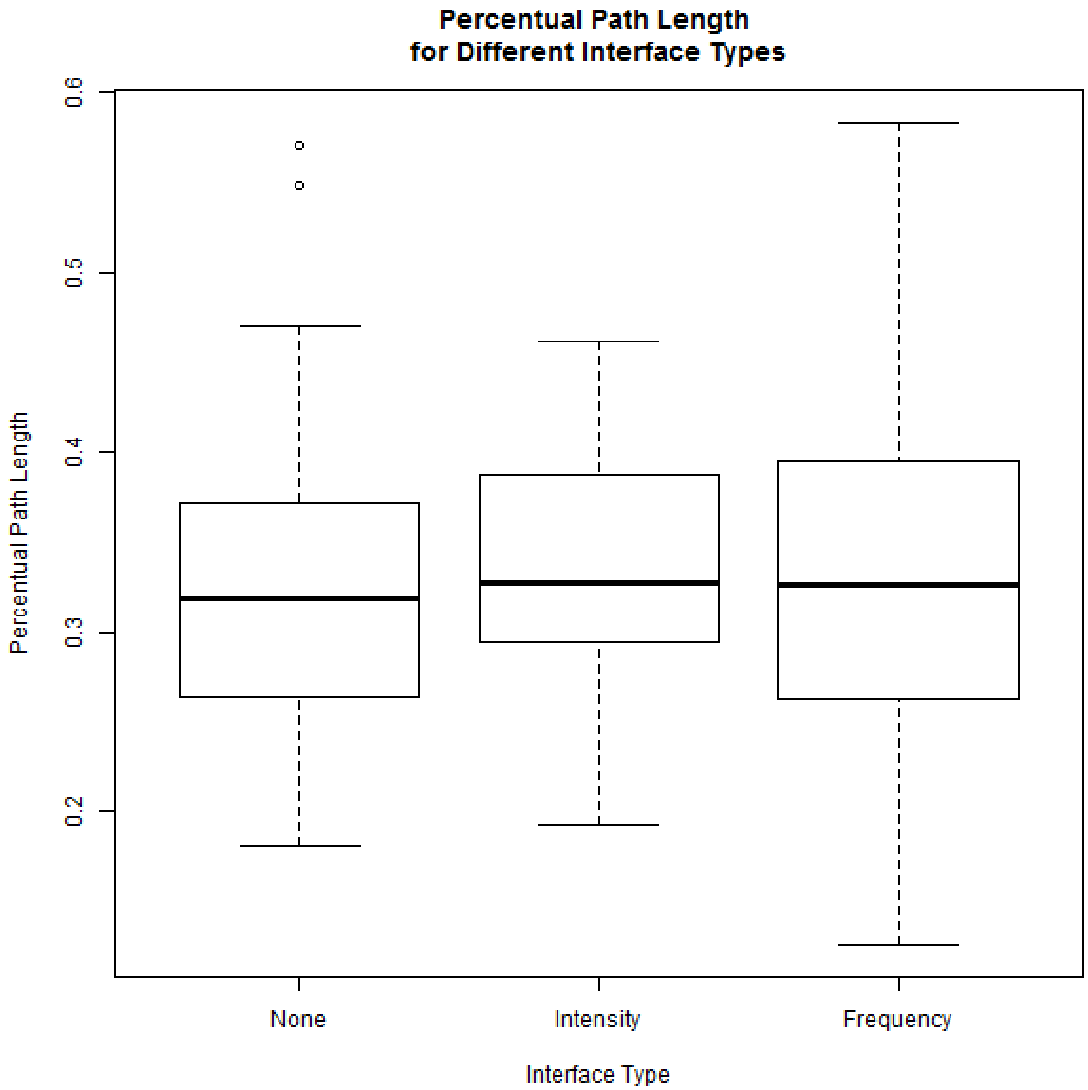
B.2.13 Interface Effects on Path Length



ANOVA: AAA Levels for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	133	66.5	0.028	0.973
Residuals	105	250661	2387.2		

AAA vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	82.830	49.220	70.458
Intensity	84.984	51.654	70.963
Frequency	82.472	45.508	68.983

B.2.14 Interface Effects on Normalized Path Length



ANOVA: AAA Levels for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.000	0.000	0.061	0.941
Residuals	105	0.766	0.007		

AAA vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
None	0.333	0.088	0.319
Intensity	0.337	0.069	0.327
Frequency	0.330	0.096	0.326

B.2.15 Fairness Evaluation of Population Distribution among Groups Exposed to Interfaces in Different Orders

B.2.15.1 Number of Spheres Found

ANOVA: Number of Spheres Found for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	8.1	4.065	0.548	0.58
Residuals	105	779.5	7.424		

B.2.15.2 Quality of Sketchmaps

ANOVA: Quality of Sketchmaps for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	3.57	1.787	1.011	0.367
Residuals	105	185.61	1.768		

B.2.15.3 Number of Collisisons

ANOVA: Number of Collisions for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	17493	8746	1.279	0.282
Residuals	105	717756	6836		

B.2.15.4 Task Time

ANOVA: Task Time for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	253696	126848	0.741	0.479
Residuals	105	17970689	171149		

B.2.15.5 Number of Spheres Found per Minute

ANOVA: Number of Spheres Found per Minute for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.305	0.152	0.507	0.604
Residuals	105	31.525	0.300		

B.2.15.6 Number of Collisions per Minute

ANOVA: Number of Collisions per Minute for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	6.5	3.270	0.343	0.711
Residuals	105	1001.9	9.542		

B.2.15.7 Number of Spheres Found per Path Length

ANOVA: AAA Levels for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	5.2	2.577	0.102	0.903
Residuals	105	2648.7	25.226		

B.2.15.8 Number of Collisions per Path Length

ANOVA: AAA Levels for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	175	87.4	0.03	0.97
Residuals	105	305529	2909.8		

Appendix C: Study 3 Material

This appendix contains all the forms used and data analysis done for user study #3. Source code, videos and images can be found on-line (de Barros & Lindeman, 2014).

C.1 Forms

The forms used in study #3 are contained in this section. The text listed is presented as it was originally was given to subjects, with the exception of the removal of watermarks and institutional logotypes.

C.1.1 Instructions Sheet

This experiment aims at evaluating the effect of an audio and vibro-tactile interface on robot teleoperation.

Task: You will be asked to enter a closed virtual environment, search for red spheres by remotely operating a robot and, then safely exit the environment. You will have to do this as fast and effectively as possible. You will perform this task three times, each with a different type of robot interface.

You will be presented with a house-like virtual environment. For each of the three trials, a small house with 3 different rooms will have objects spread around in a chaotic manner, so as to reproduce a catastrophic situation. Among the objects there will be red spheres. You will have to locate them by navigating a robot through the debris around the entire area. **Please try to memorize the location of the spheres so that you can report them later by sketching a map of the place and the spheres' location.** You will be able to take pictures of the location of the spheres. You will also be able to refer to these pictures while you are sketching.

The world will be seen by using the robot camera present in the virtual robot interface. The camera will display the simulated remote environment. Other information obtained from the simulated environment may also be displayed to you through the robot interface. You will be asked to perform the search task once for each interface. A timer will count the amount of time spent during task. The task will be over once you exit the house through the exit door, identified by an emergency exit symbol.

The interface of the program contains a virtual representation of the robot and a virtual representation of the robot camera that displays images from the simulated real world. You are wearing a belt with eight tactors. They will provide you with feedback on imminent collision situations with the robot. When the tactors are active, the closer the robot is to colliding, the more intensely they will vibrate in the approximate direction of the imminent collision. The teleoperation interface therefore provides you with collision proximity detection, robot orientation and position, robot-camera orientation, and identification of nearby objects.

The top of the robot may light up in the direction the robot is about to collide. The brighter the robot top illuminates, the closer the robot is to an object in that direction. A speedometer displaying the current robot speed may also be visually displayed on its back. In addition, depending on the trial, you may receive sound feedback through the headset you are wearing. Sounds indicating robot speed and collision with objects may be displayed. It is important to notice that if you are trying to move the robot and it does not move, it is because the robot is colliding with objects in the remote environment.

While performing the task, you will also be performing a text-color matching task. You will be presented with text in the middle of the screen with one of the following words: “red”, “green”, “blue”. If the color of the text font matches the string description, you have to press the button with the green triangle. If they do not match, you will have to press the button with a red square to indicate that. Hence, you should respond as soon as you notice the text on screen and as fast as you can. Once you pressed either of these two buttons, the text will disappear. The text also disappears after a while if no button is pressed.

Please sit comfortably during the experiment, but pay attention to the search task. After reading this, you will be presented with the controls for the robot and given time to get accustomed to the controls in a training room. If you have questions about how to proceed in the experiment, please, ask during the training session.

After that, feel free to ask the instructor to start the experiment whenever you are ready. Further information about the project can be given by the experiment instructor after you have finished the experiment. **Please do not ask the instructor question about the environment while performing the main task.**

C.1.2 Consent Form

Primary Investigator: Robert W. Lindeman

Contact Information:

WPI / Department of Computer Science

100 Institute Road

Worcester, MA 01609

Tel: 508-831-6712

E-Mail: gogo@wpi.edu

Title of Research Study:

Evaluation of Multi-sensory Feedback for Teleoperated Robots

Sponsor: None.

Introduction

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you make a fully informed decision regarding your participation.

Purpose of the study:

This study is designed to assess the effect of using audio and vibrotactile interfaces in robot teleoperation.

Procedures to be followed:

You will be asked to move a robot through a third-person virtual environment using a gamepad with two thumb-joysticks and monitor. The task is a simulated search task in a collapsed building. Your control of the robot movement will make it move forward and backward by moving a thumbstick to the front and to the back respectively. Moving the thumbstick to the left or to the right will make the robot turn left or right respectively. Releasing the thumbstick at its central static position will bring the robot to a stop. In addition, another thumbstick will give you control over the robot's pan-and-tilt camera. Moving this thumbstick to the left or right will turn the camera to the left or right respectively. Moving it forward or backward will turn the camera down or upward respectively. Releasing this second thumbstick at its central static position will bring the robot camera to a stop.

You will also be wearing a belt with eight vibration units (called *tactors*) distributed in cardinal directions that will provide you with feedback on imminent collisions in specific directions. If a tactor is active, the higher the intensity of its vibration, the closer the robot is to colliding along the tactor's pointing direction. Similarly, the top of the virtual robot may light up if collision is imminent in the direction the robot top illuminates. A speedometer presenting current robot speed may also be present. Furthermore, you may hear sounds through the speakers that surround you. These sounds represent collisions between the robot and the surrounding environment as well as indicate how fast the robot wheels are moving.

You will have to perform a search task three times, each time with a different feedback interface. Each search trial will be preceded by an interface familiarization period in a special virtual environment. After the familiarization period, the real search task will be performed in a virtual environment. You will have to search for red spheres ("victims"). You will be asked to perform the search *as fast and effectively as you can*. You will also be asked to memorize victim locations and report them later on. You will have to move in a closed space through an entrance and exit the environment through an exit door. A timer will count the time you have spent on each search task. The search task will last about 10 minutes. Following each search task you will be asked to identify the number and location of each of the red spheres. Finally, after all search tasks are performed, you will be given the opportunity to provide any additional comments on all the interfaces, the experiment and the application.

While performing the task, you will also be performing a text-color matching task. You will be presented with text in the middle of the screen with one of the following words: “red”, “green”, “blue”. If the color of the text font matches the string description, you have to press the button with the green triangle. If they do not match, you will have to press the button with a red square to indicate that. Hence, you should respond as soon as you notice the text on screen and as fast as you can. Once you press either of these two buttons, the text will disappear. The text also disappears after a while if no button is pressed.

Before the experiment, a questionnaire will ask you about your videogame, computer and robot experience. You will also take a short spatial test. During the experiment a video will record both you and the computer screen in front of you for the sole purpose of analyzing behavioral changes due to interface use. These videos will be kept confidential and only statistical results derived from them will be directly presented on the research results.

Risks to study participants:

The risks to you in participating in this study are minimal. There is, however, a small chance that you will feel nauseated or dizzy during the experiment. If this happens, please, ask the experimenter for assistance and the experiment will be interrupted.

Benefits to research participants and others:

You will be paid US$20 dollar apart from being provided with refreshments (snacks and beverages).

Record keeping and confidentiality:

Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. No data identifying you by name will be collected, and any publication or presentation of the data will not identify you.

You will be given a copy of this consent form for your records; it contains the contact information for the investigator. The investigator's copy will be stored in a locked file cabinet, and retained for a period of 3 years.

Compensation or treatment in the event of injury:

This study will put you at minimal risk. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact me using the information at the top of this page. In addition, you may contact the IRB Chair (Professor Kent Rissmiller, Tel: 508-831-5019, E-Mail: kjr@wpi.edu) and the University Compliance Officer (Michael J. Curley, Tel. 508-831-5519, E-Mail: mjcurley@wpi.edu).

Your participation in this research is voluntary.

Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

_____________________________ Date: ____________________

Study Participant Signature

____

Study Participant Name (Please print)

______________________________________ Date: ____________________

Signature of Person who explained this study

C.1.3 Demographics Collection Form

Subject#: _____

1. How old are you? _____

2. How many hours per week do you use computers?

   Please click on your answer.

○ 1-10 hours

○ 11-20 hours

○ 21-40 hours

○ More than 40 hours

3. How often do you use or work with robots: daily, weekly, seldom or never?

   Please click on your answer.

○ Daily

○ Weekly

○ Seldom

○ Never

4. How often do you use remote-controlled ground/aerial/aquatic vehicles?

Please click on your answer.

○ Daily

○ Weekly

○ Seldom

○ Never

5. How often do you play video-games?

Please click on your answer.

- ○ Daily
- ○ Weekly
- ○ Seldom
- ○ Never

6. How often do you use joysticks?

Please click on your answer.

- ○ Daily
- ○ Weekly
- ○ Seldom
- ○ Never

C.1.4 Post-Treatment Questionnaire

Subject #:_____

Please answer the questions in the empty space following them.

1. How many red spheres did you find?

2. Using the pictures taken as a reference and using the paper and pencil/pen in front of you, please, draw a map of the building and locate the spheres with respect to the rooms and debris.

3. How difficult was it to perform the task compared to actually performing it yourself (if the remote environment was real)? Please answer on the following 1 to 7 scale.

Please click on your answer.

- ○ 1 (very difficult)
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7 (very easy)

4. Please rate *your sense of being there* in the computer generated world on the following 1 to 7 scale.

In the computer generated world I had a sense of "being there" ...

Please click on your answer.

- ○ 1 (not at all)
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7 (very much)

5. To what extent were there times during the experience when the computer generated world became the "reality" for you, and you almost forgot about the "real world" outside? Please answer on the following 1to 7 scale.

There were times during the experience when the computer generated world became more real or present for me compared to the "real world"...

Please click on your answer

- ○ 1 (at no time)
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7 (almost all the time)

6. When you think back about your experience, do you think of the computer generated world more as *something that you saw*, or more as *somewhere that you visited*? Please answer on the following 1 to 7 scale.

The computer generated world seems to me to be more like…

Please tick against your answer.

- ○ 1 (something I saw)
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7 (somewhere I visited)

7. When navigating in the environment did you feel more like *driving* through the environment or *walking* in the environment? Please answer on the following 1 to 7 scale.

Moving around the computer generated world seems to me to be more like…

Please click on your answer.

- ○ 1 (driving)
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7 (walking)

8. During this task trial how nauseated did you feel? Please answer on the following 1 to 7 scale.

While performing this task I felt...

Please tick against your answer.

- 1 (very nauseated)
- 2
- 3
- 4
- 5
- 6
- 7 (fine)

9. During this task trial how dizzy did you feel? Please answer on the following 1 to 7 scale.

While performing this task I felt...

Please tick against your answer.

- 1 (very dizzy)
- 2
- 3
- 4
- 5
- 6
- 7 (fine)

10. Please provide any comments about the robot interface.

C.1.5 Final Questionnaire

Subject #:

During the experiment you were exposed to three types of interfaces. Some of them provided you with audio and visual feedback in addition to the standard vibro-tactile feedback and visual interface. One interface ("Vibration only") provided you with a default visual display and vibro-tactile feedback . A second interface ("Vibration + Audio") had audio feedback related to collisions with the robot and its speed presented in addition to that. The third interface ("Vibration + Audio + Visual Sensors") visually displayed a speedometer and a ring representing the direction of objects near the robot. For each of the following questions grade the three interfaces and use the 1 to 7 scale.

1. How easy was it for you to learn how to use the interface?

Learning how the interface worked was…

Make your selection for each of the three interfaces.

	Type of Interface		
Difficulty	Vibration Only	Vibration + Audio	Vibration + Audio + Visual Sensors
	○ 1	○ 1	○ 1
Very difficult	○ 2	○ 2	○ 2
	○ 3	○ 3	○ 3
	○ 4	○ 4	○ 4
	○ 5	○ 5	○ 5
Very easy	○ 6	○ 6	○ 6
	○ 7	○ 7	○ 7

2. How confusing was the interface?

Understanding the information the interface was presenting was…

Make your selection for each of the three interfaces.

Type of Interface

Understanding	Vibration Only	Vibration + Audio	Vibration + Audio + Visual Sensors
Confusing	○ 1	○ 1	○ 1
	○ 2	○ 2	○ 2
	○ 3	○ 3	○ 3
	○ 4	○ 4	○ 4
	○ 5	○ 5	○ 5
	○ 6	○ 6	○ 6
Straight-forward	○ 7	○ 7	○ 7

3. How distracting was the feedback provided by the interface?

The feedback provided by the interface…

Make your selection for each of the three interfaces.

Type of Interface

Feedback	Vibration Only	Vibration + Audio	Vibration + Audio + Visual Sensors
Caused distraction	○ 1	○ 1	○ 1
	○ 2	○ 2	○ 2
	○ 3	○ 3	○ 3
	○ 4	○ 4	○ 4
	○ 5	○ 5	○ 5
	○ 6	○ 6	○ 6
Did not distract me	○ 7	○ 7	○ 7

4. How comfortable was using the interface?

Using the interface was...

Make your selection for each of the three interfaces.

Type of Interface

Use	Vibration Only	Vibration + Audio	Vibration + Audio + Visual Sensors
Very uncomfortable	○ 1	○ 1	○ 1
	○ 2	○ 2	○ 2
	○ 3	○ 3	○ 3
	○ 4	○ 4	○ 4
	○ 5	○ 5	○ 5
	○ 6	○ 6	○ 6
Very comfortable	○ 7	○ 7	○ 7

5. How much did the interface helped you understand the environment?

Using the interface impacted my understanding of the environment in a…

Make your selection for each of the three interfaces.

Type of Interface

Impact	Vibration Only	Vibration + Audio	Vibration + Audio + Visual Sensors
Negative way	○ 1	○ 1	○ 1
	○ 2	○ 2	○ 2
	○ 3	○ 3	○ 3
	○ 4	○ 4	○ 4
	○ 5	○ 5	○ 5
	○ 6	○ 6	○ 6
Positive way	○ 7	○ 7	○ 7

6. Do you have any comments about the experiment in general?

7. If you wish to know about the final results of this experiment, please, provide us with your e-mail address:

C.1.6 Spatial Aptitude Test

The same test as in study #2 was used for study #3. Please, see appendix B.1.6 for details.

C.1.7 Instructor Script

A script similar to the one in study#2 was used with small alterations.

C.2 Data Analysis

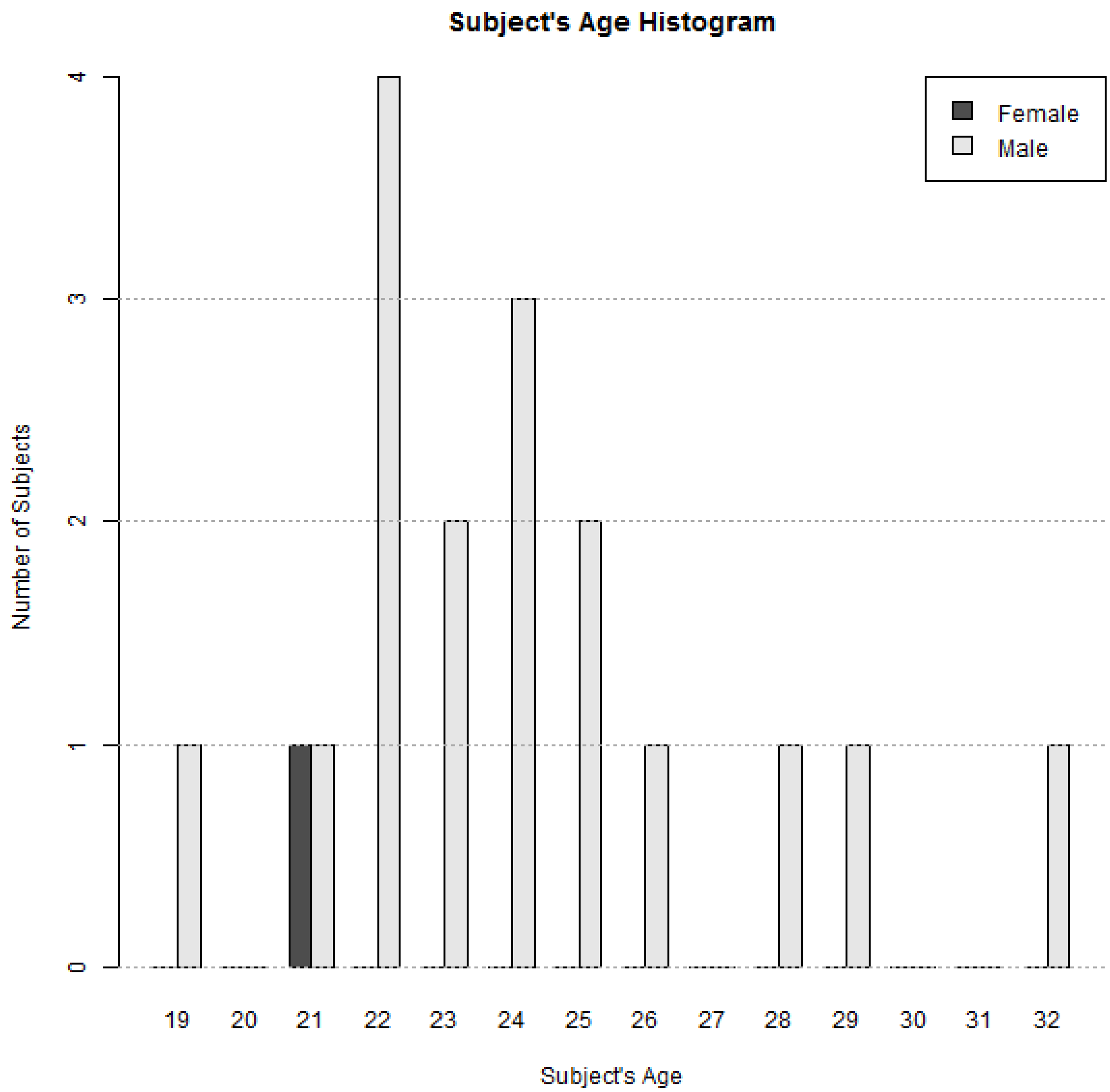
The section contains all the data collected for study #3 as well as the statistical analysis performed on it. In the section, subsections whose title is marked with an asterisk (*) contain statistically significant differences (SSD) in the data analysis. If the title of a subsection is marked with a plus sign (+) after it, it means trends are present in its data analysis.

C.2.1 Population

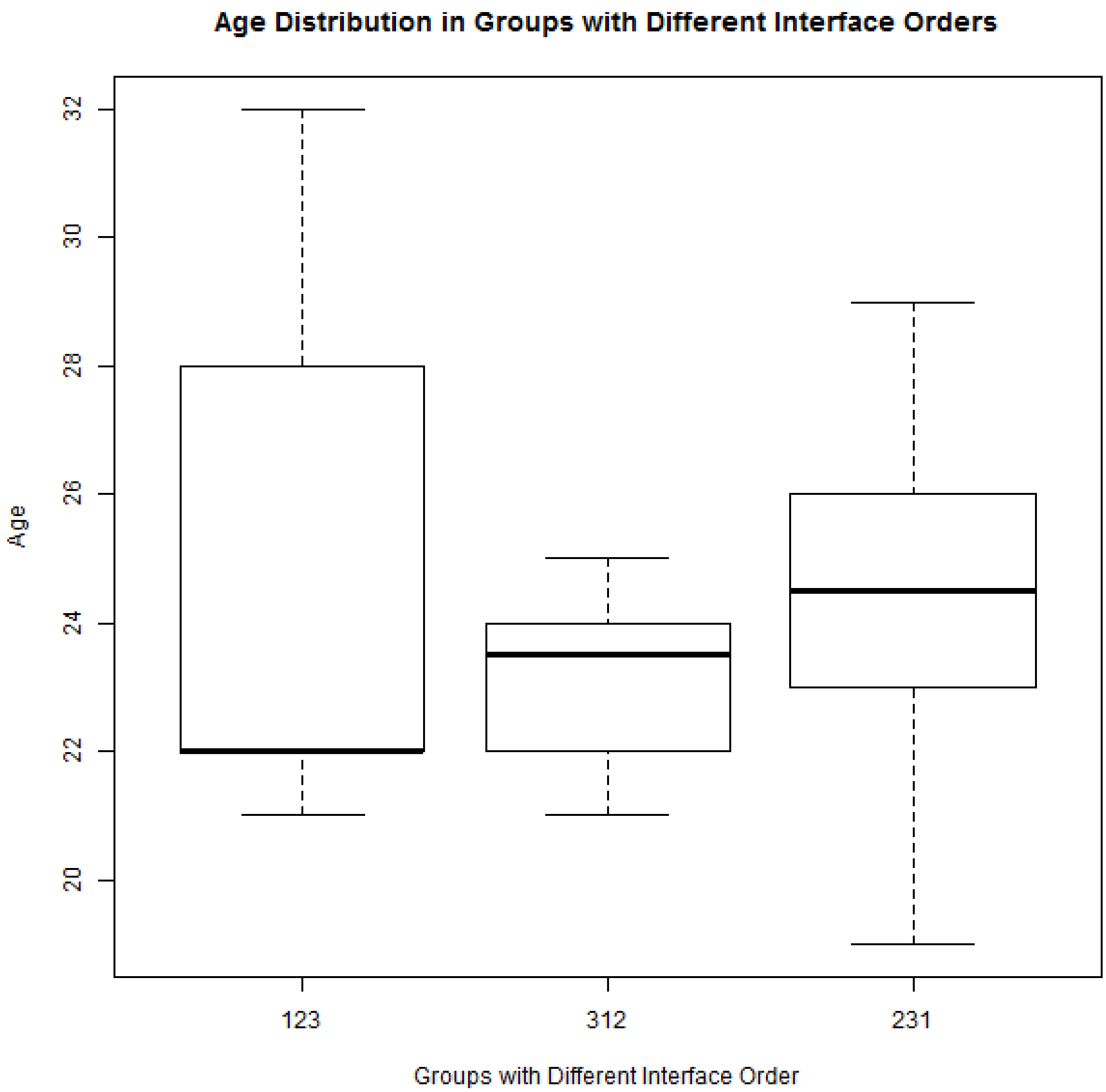
This section statistics about demographics, It includes subjects age, gender distributions and well as videogame experience, robot experience and their scores on the spatial aptitude test.

Subject Number	Trial Sequence	VE Sequence	Gender	Age	PC XP	RCV XP	Videogame XP	Joystick XP	Robot XP
0	123	xyz	m	22	2	4	2	2	4
1	312	xyz	f	21	4	3	3	3	4
2	231	xyz	m	29	4	2	3	2	1
3	123	zxy	m	22	3	4	1	1	4
4	312	zxy	m	25	4	4	2	3	4
5	231	zxy	m	23	4	4	1	3	2
6	123	yzx	m	32	4	4	3	3	2
7	312	yzx	m	24	4	2	2	2	1
8	231	yzx	m	26	3	3	3	4	4
9	123	xyz	m	21	3	3	3	3	3
10	312	xyz	m	24	4	3	2	3	1
11	231	xyz	m	19	4	3	2	1	2
12	123	zxy	m	28	3	4	1	3	3
13	312	zxy	m	23	4	3	2	2	4
14	231	zxy	m	24	4	3	2	2	3
15	123	yzx	m	22	4	3	1	2	1
16	312	yzx	m	22	4	2	1	3	1
17	231	yzx	m	25	4	3	2	2	4

C.2.1.1 Age Histogram



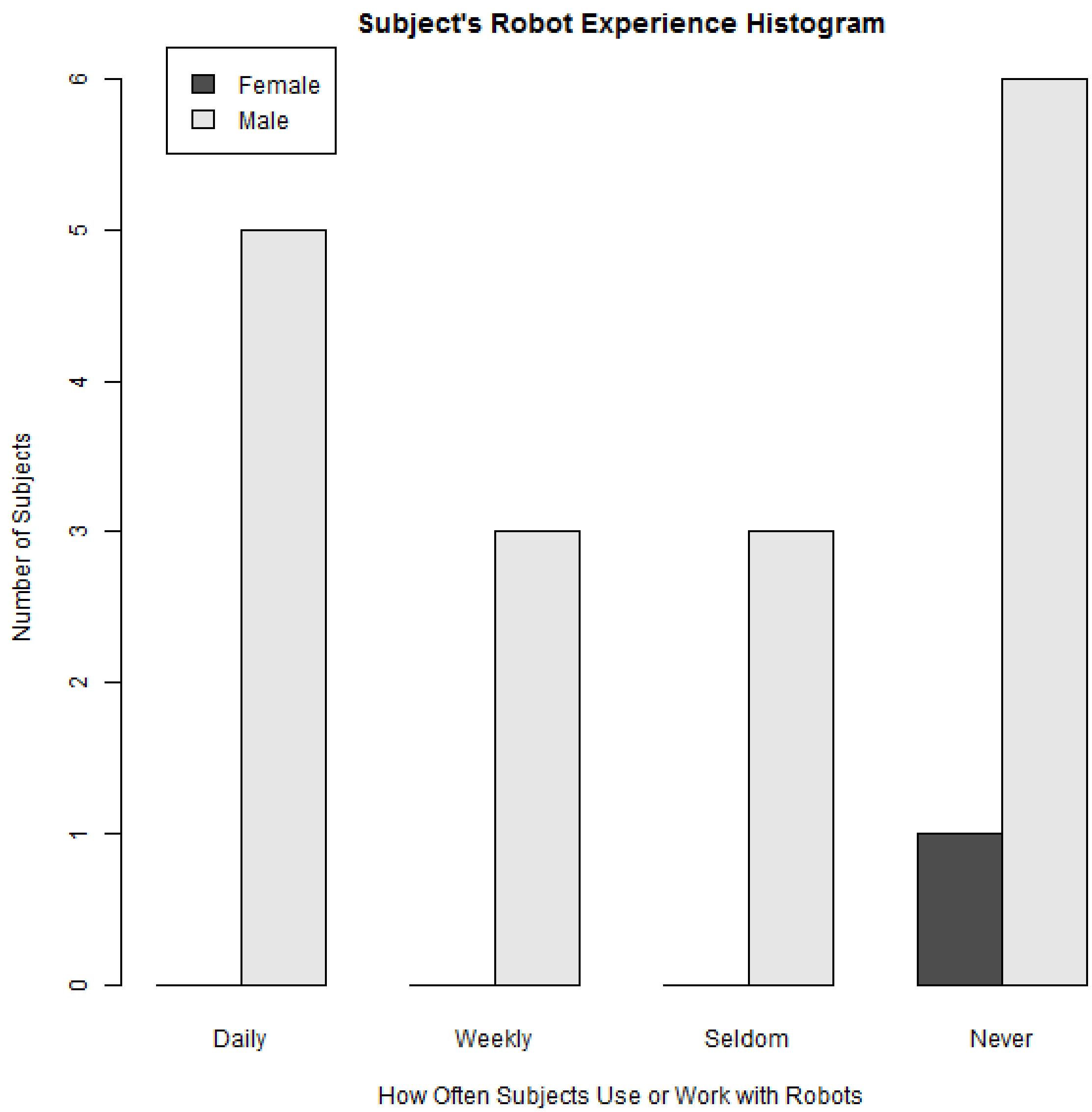
C.2.1.2 Age Distribution for Groups with Different Interface Orders



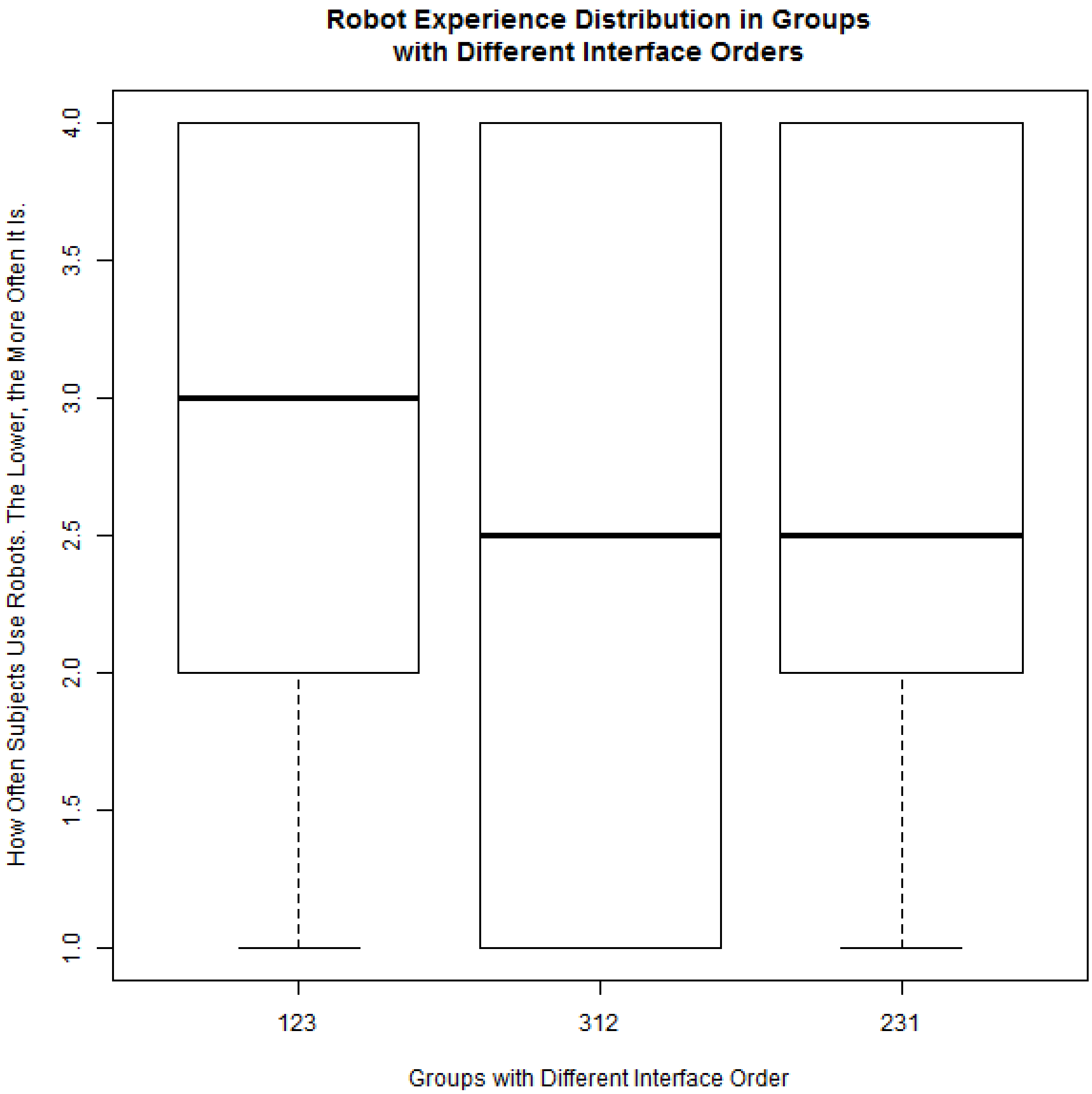
	123	**312**	**231**
Mean	24.500	4.461	22.000
Median	23.167	1.472	23.500
Std. deviation	24.333	3.327	24.500

C.2.1.3 Robot Experience

Most subjects had no experience with robots. No SSDs was detected for groups with different interface orders.



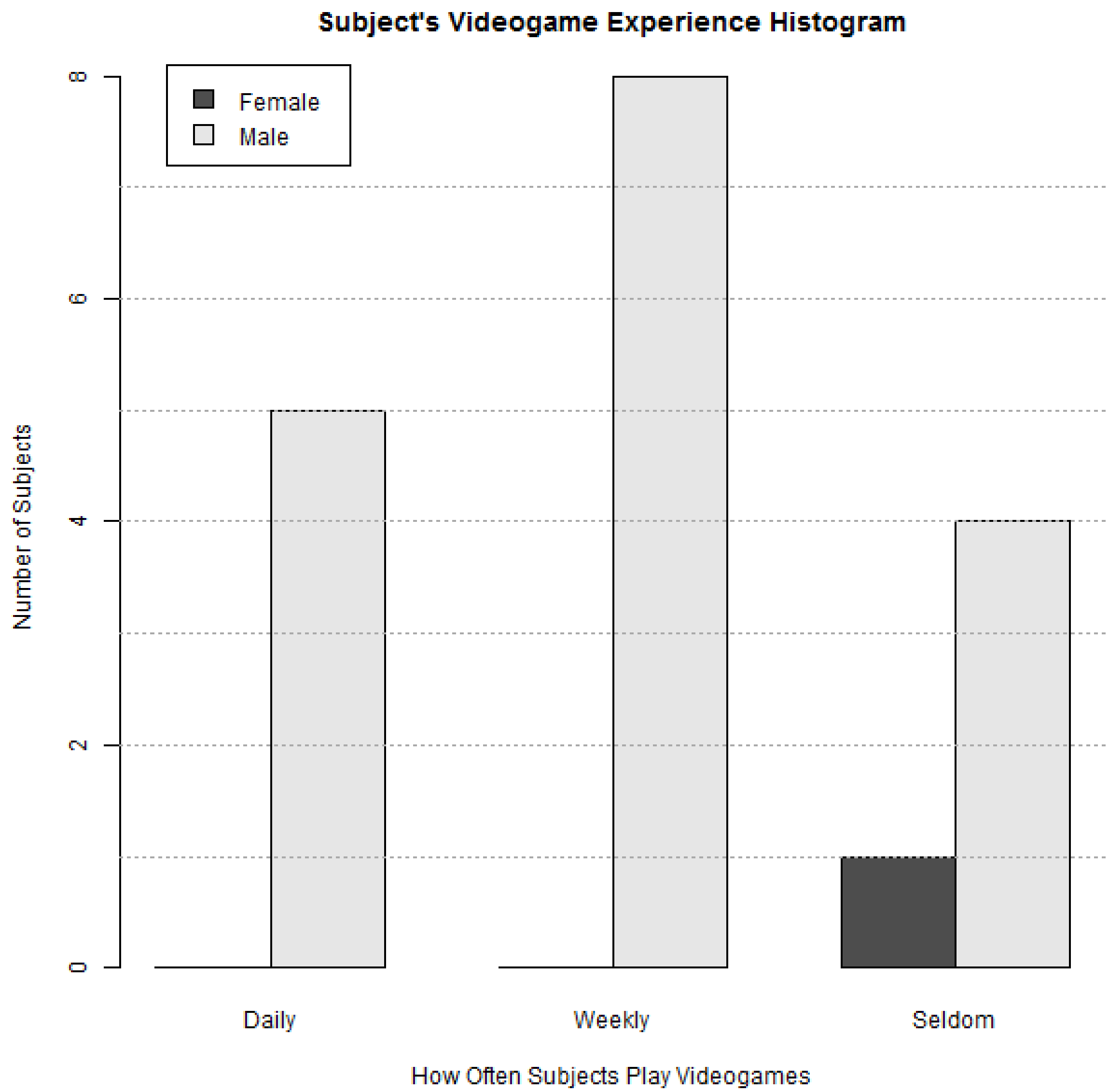
ANOVA: Robot Experience for Groups With Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.333	0.167	0.09	0.914
Residuals	15	27.667	1.844		



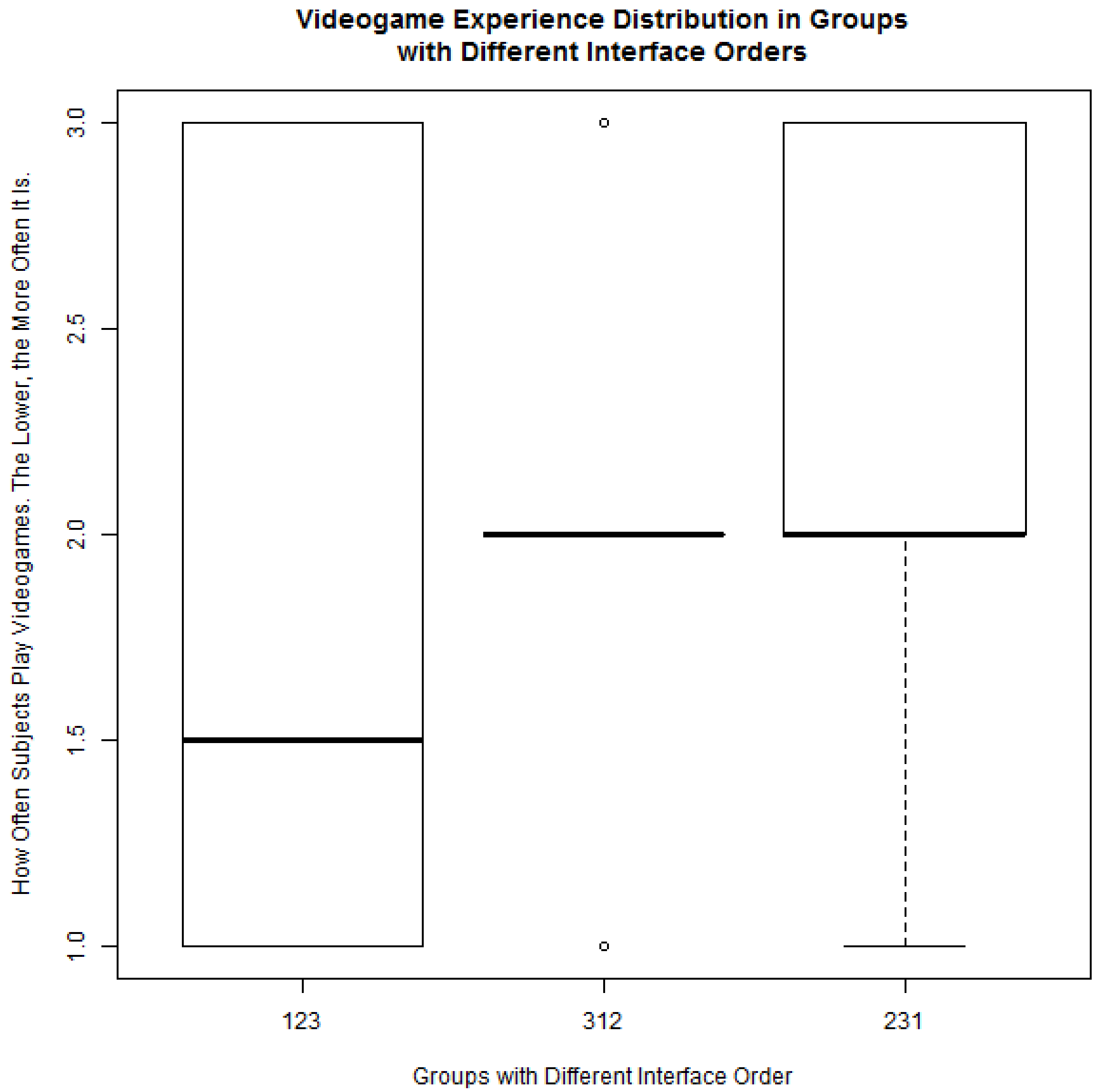
Robot Experience vs. Different Interface Orders - Friedman Test	
X^2	0.300
p	0.861
DoF	2.000

Robot Experience vs. Different Interface Orders Summary			
	Mean	***Std. Dev.***	***Median***
123	3.667	0.516	4.000
312	2.833	0.753	3.000
231	3.000	0.632	3.000

C.2.1.4 Videogame Experience



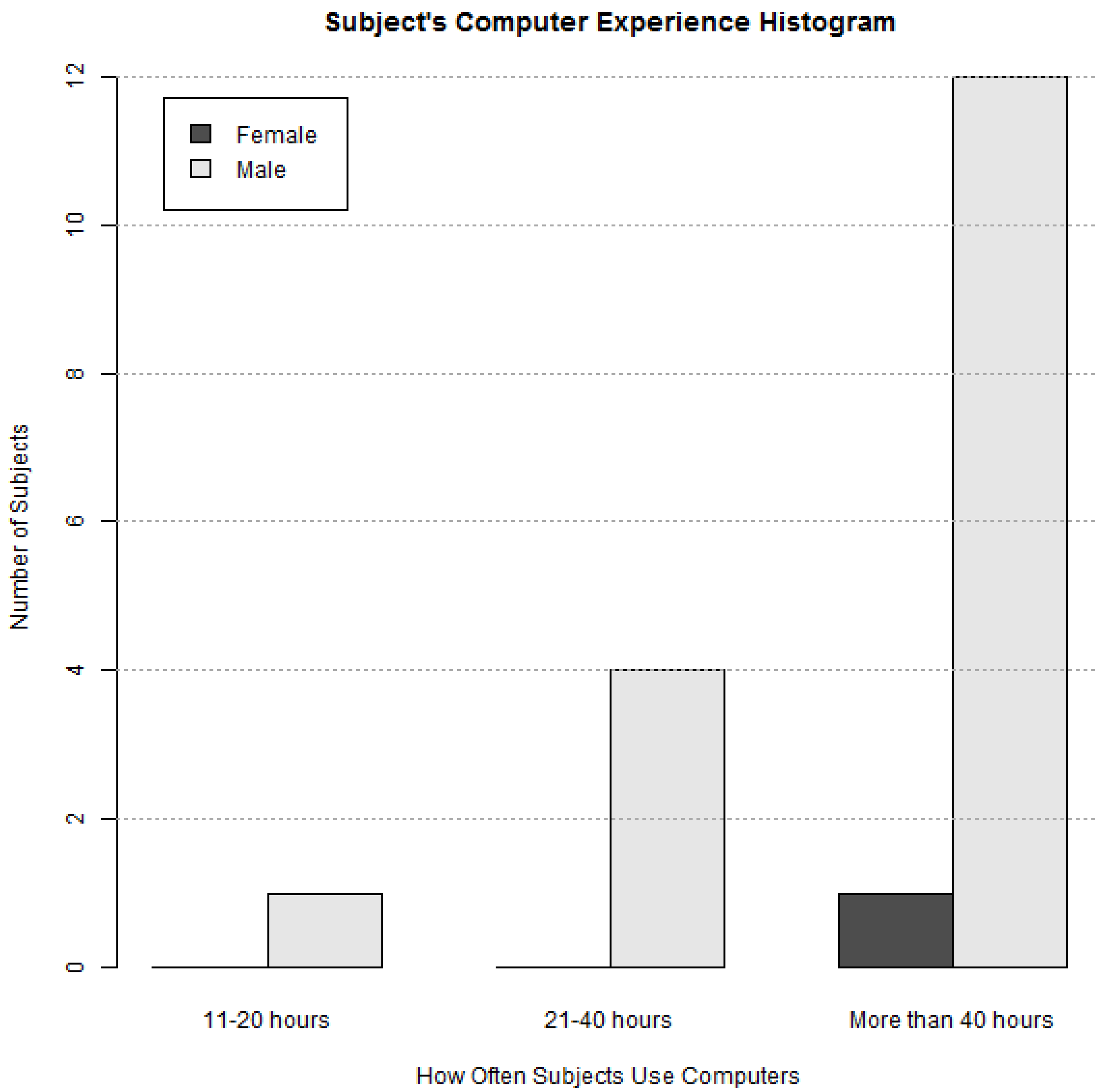
ANOVA: Videogame Experience for Groups With Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.333	0.167	0.259	0.775
Residuals	15	9.667	0.644		



Videogame Experience vs. Different Interface Orders - Friedman Test	
X^2	1.000
p	0.607
DoF	2.000

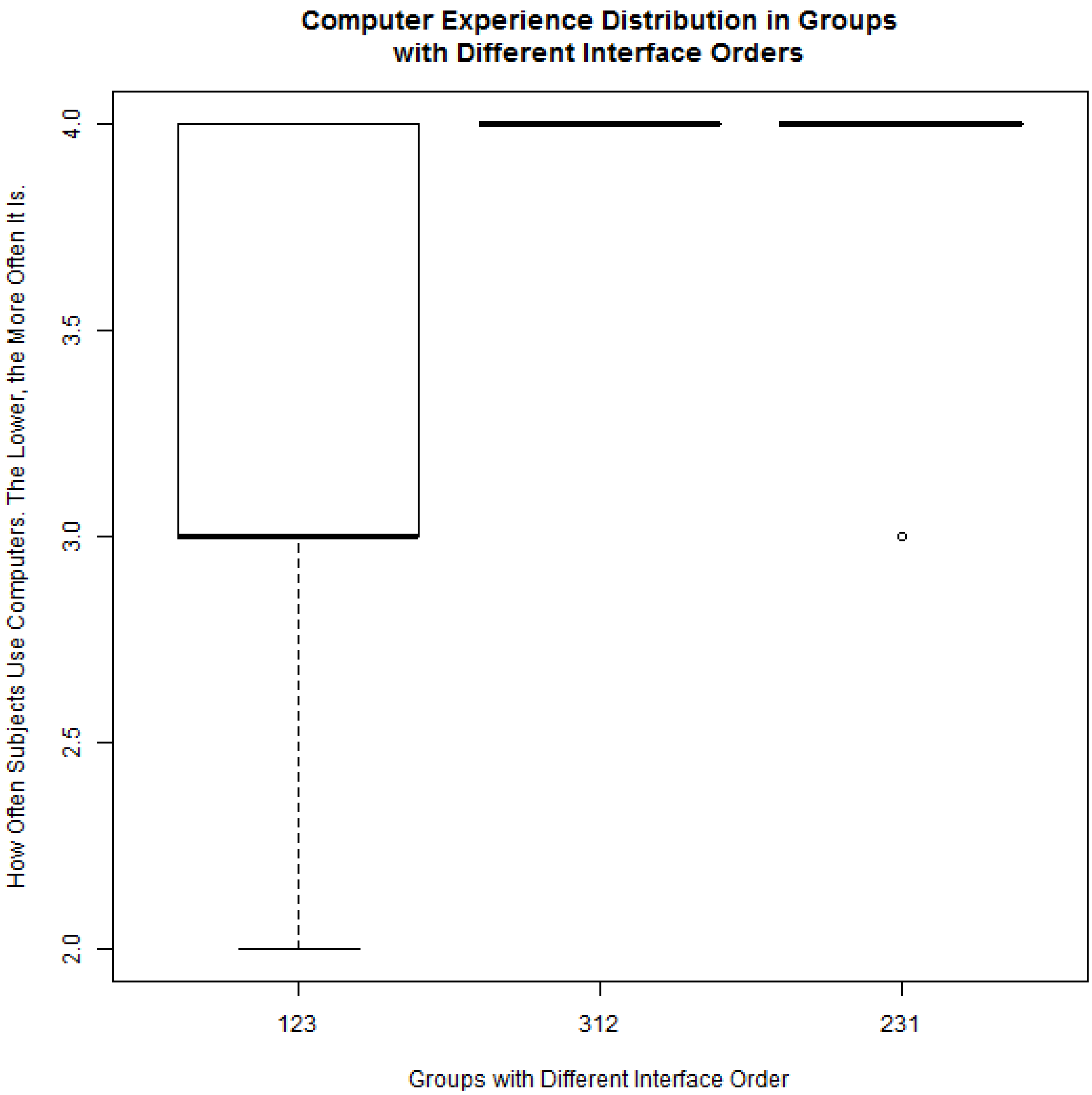
Videogame Experience vs. Different Interface Orders Summary			
	Mean	***Std. Dev.***	***Median***
123	3.667	0.516	4.000
312	2.833	0.753	3.000
231	3.000	0.632	3.000

C.2.1.5 PC Experience*



ANOVA: PC Experience for Groups With Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	2.333	1.167	4.773	0.025
Residuals	15	3.667	0.244		

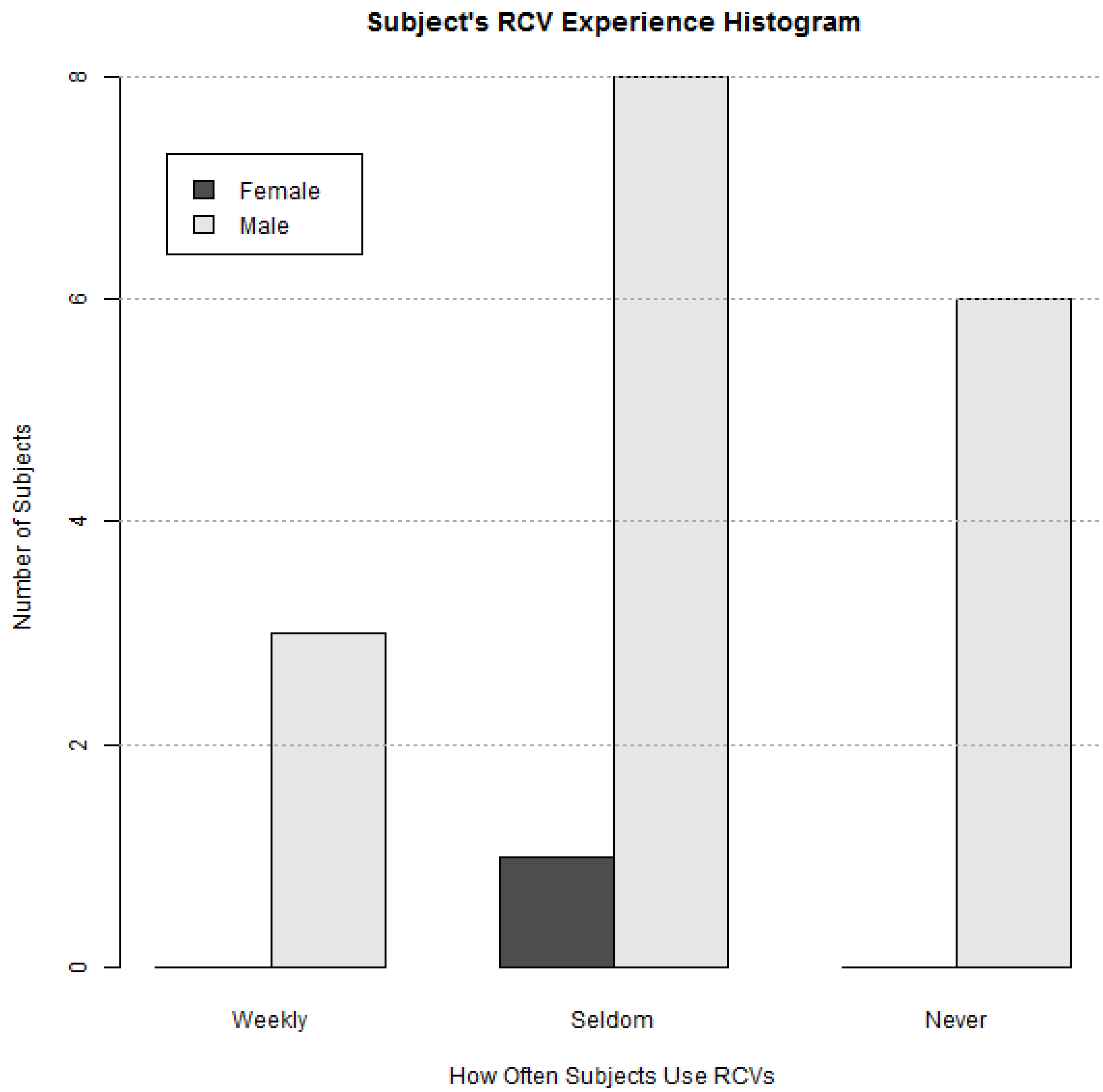
PC Experience vs. Different Interface Orders Summary			
	Mean	***Std. Dev.***	***Median***
123	3.167	0.753	3.000
312	4.000	0.000	4.000
231	3.833	0.408	4.000



PC Experience vs. Different Interface Orders - Friedman Test	
X^2	5.200
p	0.074
DoF	2.000

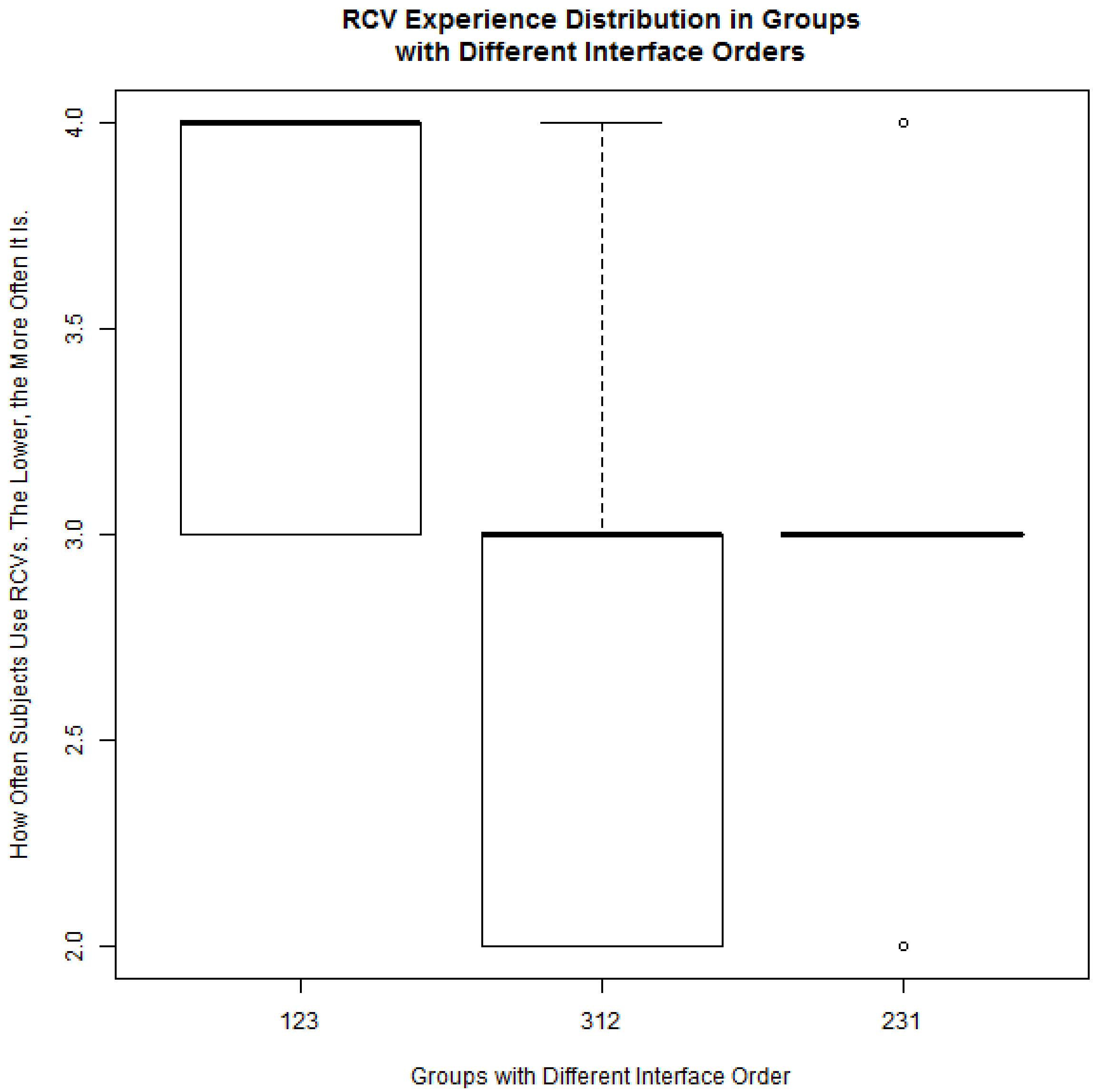
PC Experience vs. Different Interface Orders – Wilcoxon Test			
	123 - 312	***123 - 231***	***312 - 231***
W	0.000	2.500	1.000
Z	-1.964	-1.400	1.000
p	0.125	0.312	1.000
R	-0.327	-0.235	0.167

C.2.1.6 RCV Experience+



ANOVA: RCV Experience for Groups With Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	2.333	1.167	2.838	0.090
Residuals	15	6.167	0.411		

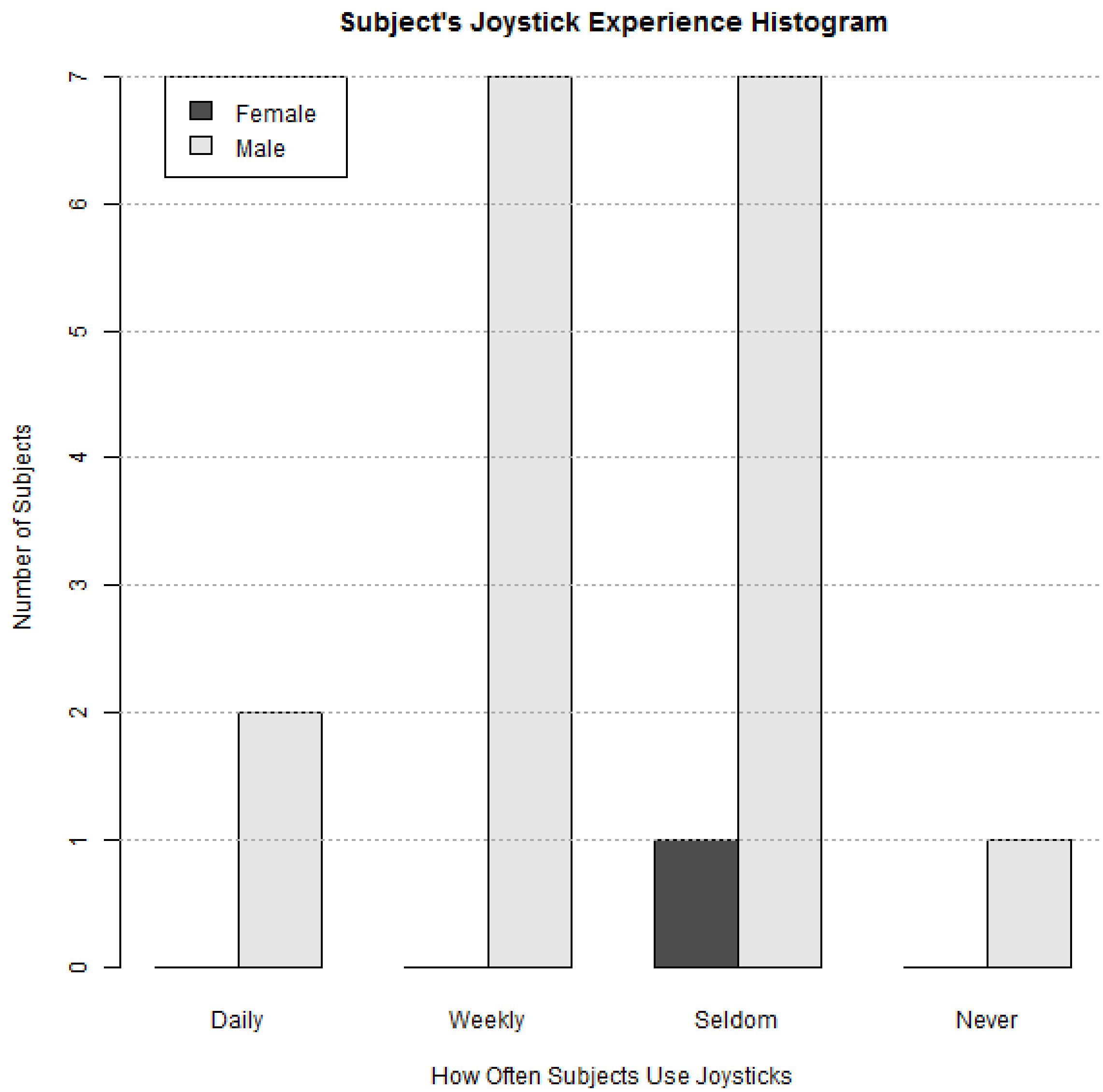
RCV Experience vs. Different Interface Orders Summary			
	Mean	***Std. Dev.***	***Median***
123	3.667	0.516	4.000
312	2.833	0.753	3.000
231	3.000	0.632	3.000



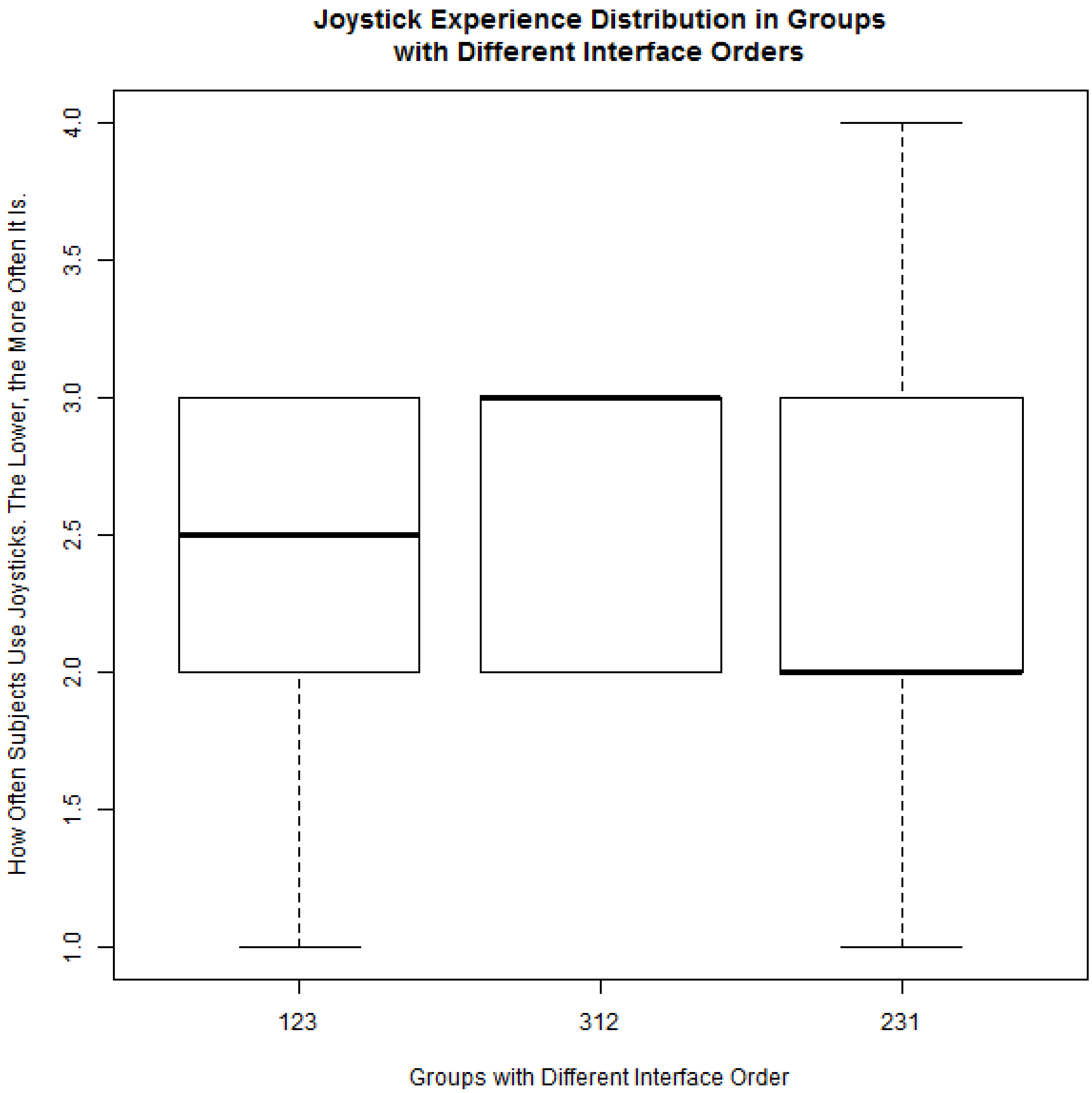
RCV Experience vs. Different Interface Orders - Friedman Test	
X^2	5.571
p	0.062
DoF	2.000

RCV Experience vs. Different Interface Orders – Wilcoxon Test			
	123 - 312	***123 - 231***	***312 - 231***
W	1.000	6.000	2.000
Z	1.964	1.715	-0.577
p	0.125	0.250	1.000
R	0.327	0.286	-0.096

C.2.1.7 Joystick Experience



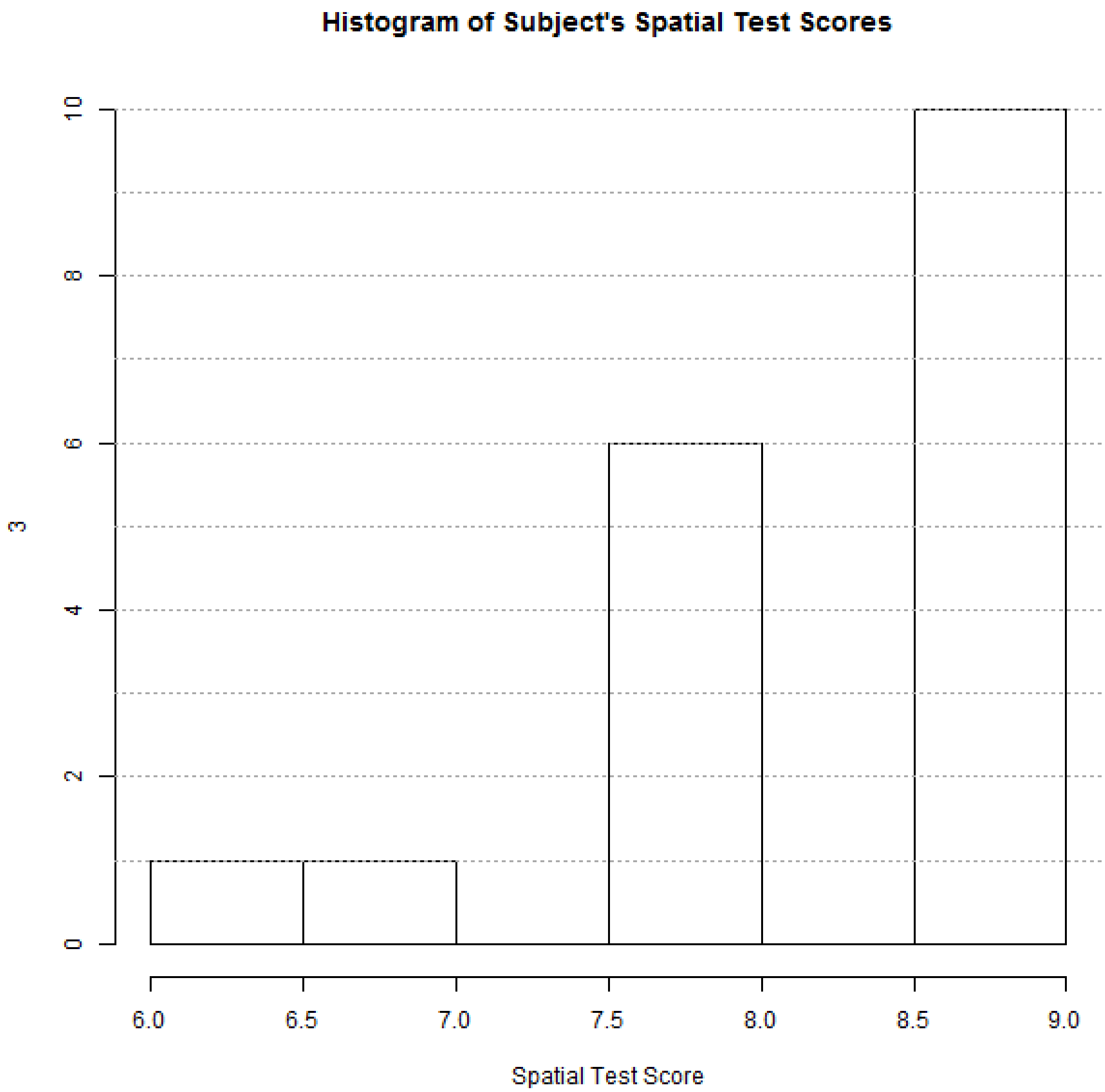
ANOVA: Joystick Experience for Groups With Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.444	0.222	0.333	0.722
Residuals	15	10.000	0.667		



Joystick Experience vs. Different Interface Orders - Friedman Test	
X^2	0.737
p	0.672
DoF	2.000

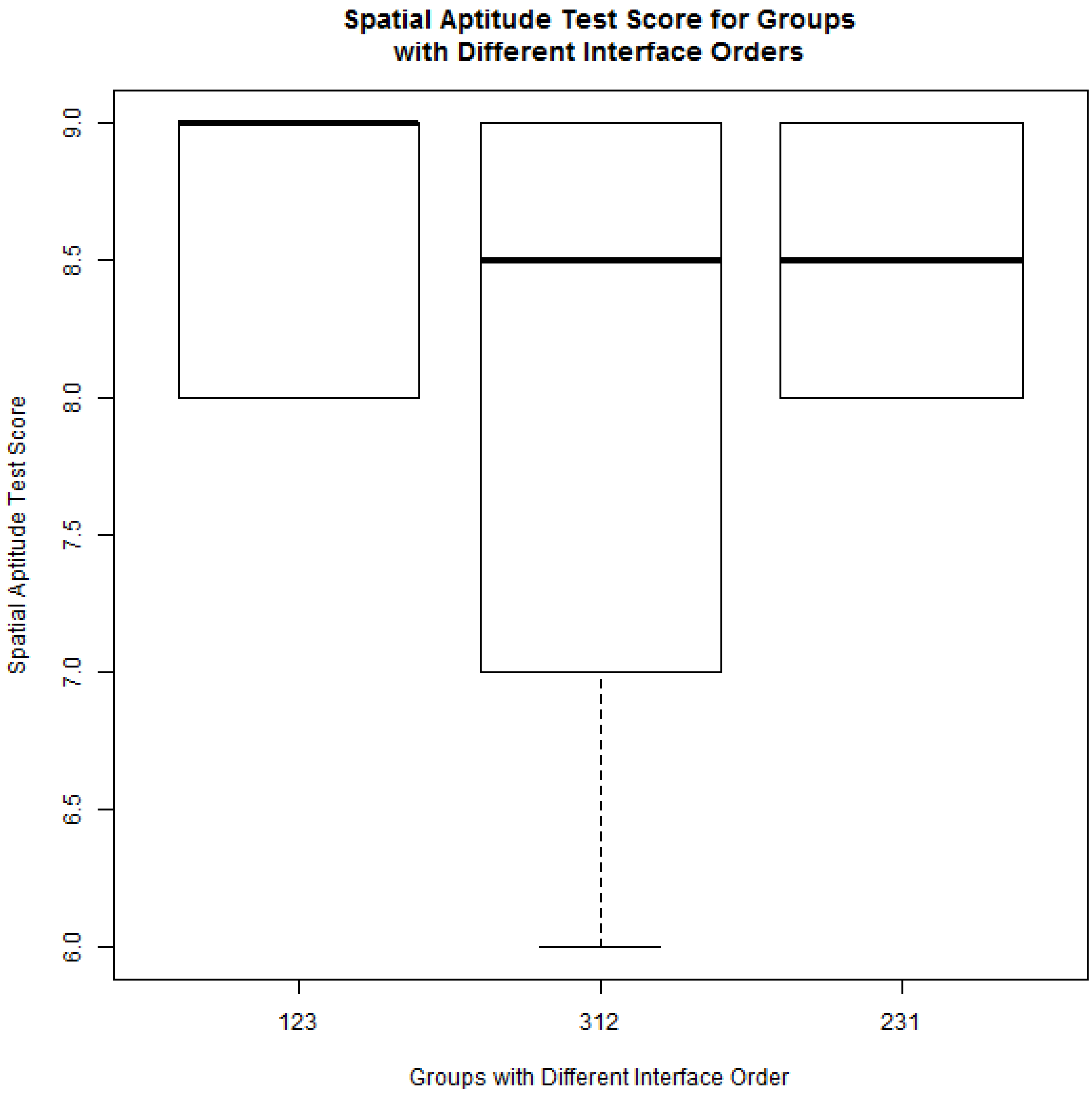
Joystick Experience vs. Different Interface Orders Summary			
	Mean	***Std. Dev.***	***Median***
123	2.333	0.816	2.500
312	2.667	0.516	3.000
231	2.333	1.033	2.000

C.2.1.8 Spatial Aptitude



ANOVA: Spatial Aptitude Scores for Groups With Different Interface Order

Source of Variation	*DoF*	*SS*	*MS*	*F*	*P-value*
Interface Type	2	1.444	0.722	1.000	0.391
Residuals	15	10.833	0.722		

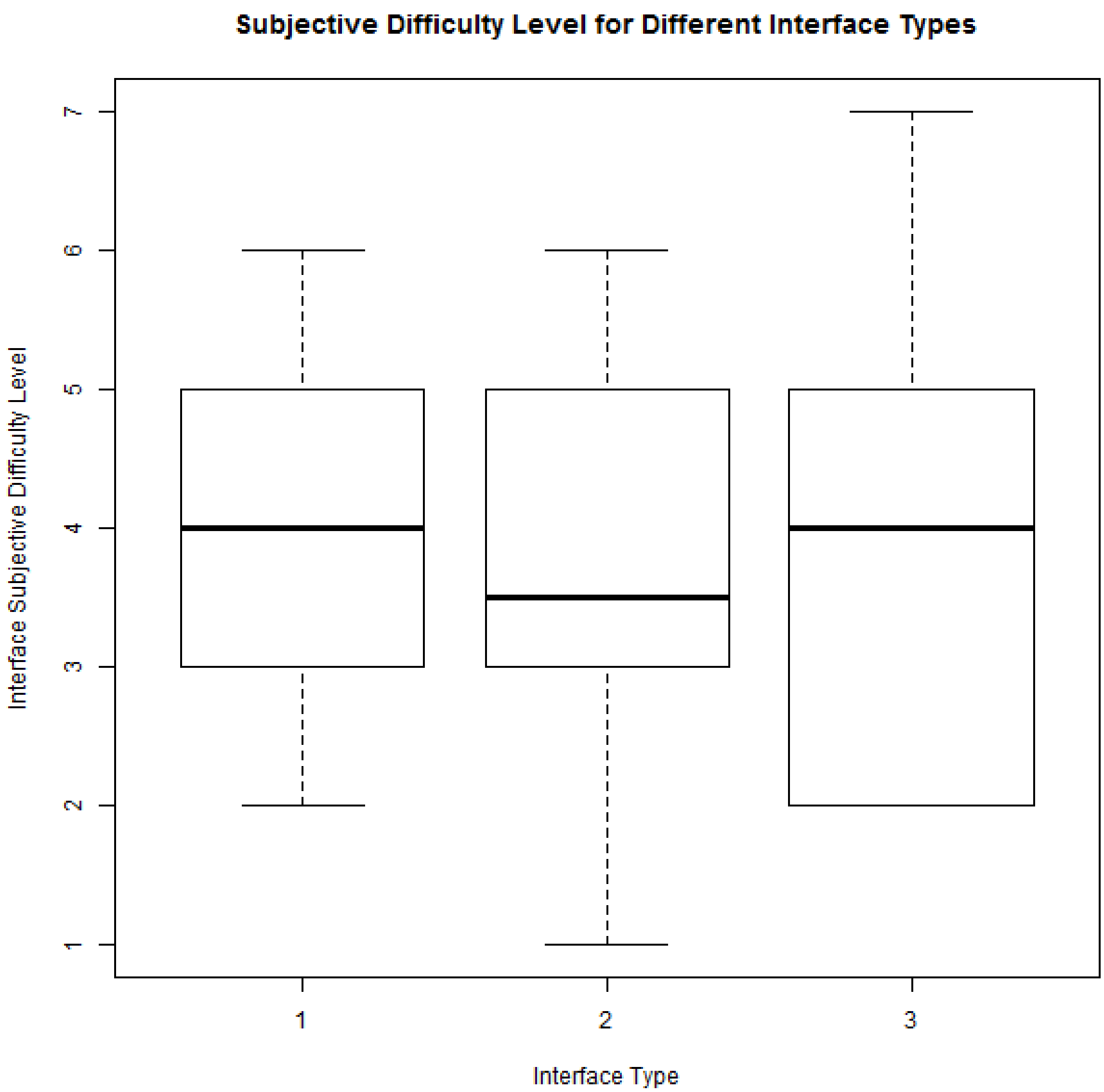


Spatial Aptitude vs. Different Interface Orders - Friedman Test	
X^2	1.636
p	0.441
DoF	2.000

Spatial Aptitude vs. Different Interface Orders Summary			
	Mean	***Std. Dev.***	***Median***
123	8.500	0.837	9.000
312	8.167	1.169	8.500
231	8.500	0.548	8.500

C.2.2 Treatment Questionnaire

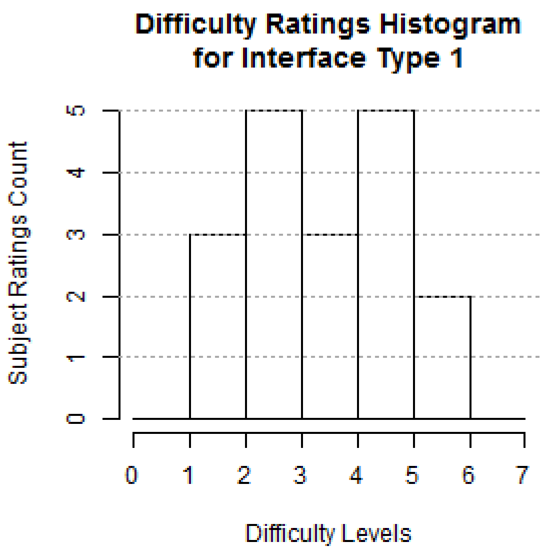
C.2.2.1 Difficulty

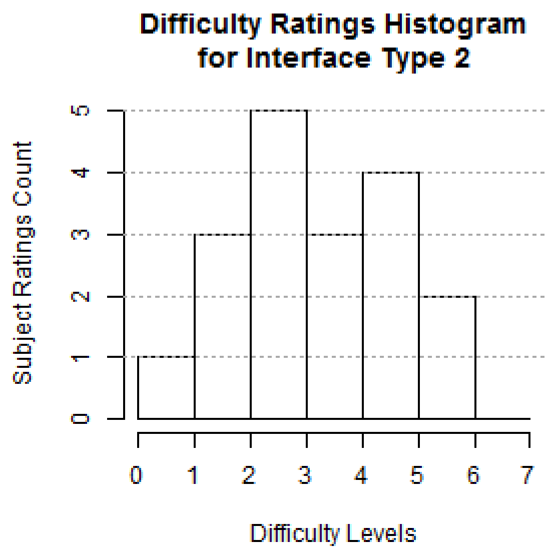


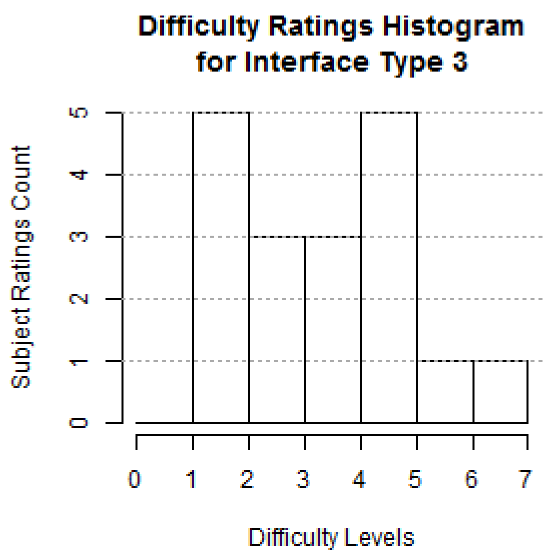
ANOVA: Difficulty Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.48	0.241	0.116	0.891
Residuals	51	106.28	2.084		

Difficulty vs. Interface Used - Friedman Test	
X^2	1.000
p	0.607
DoF	2.000

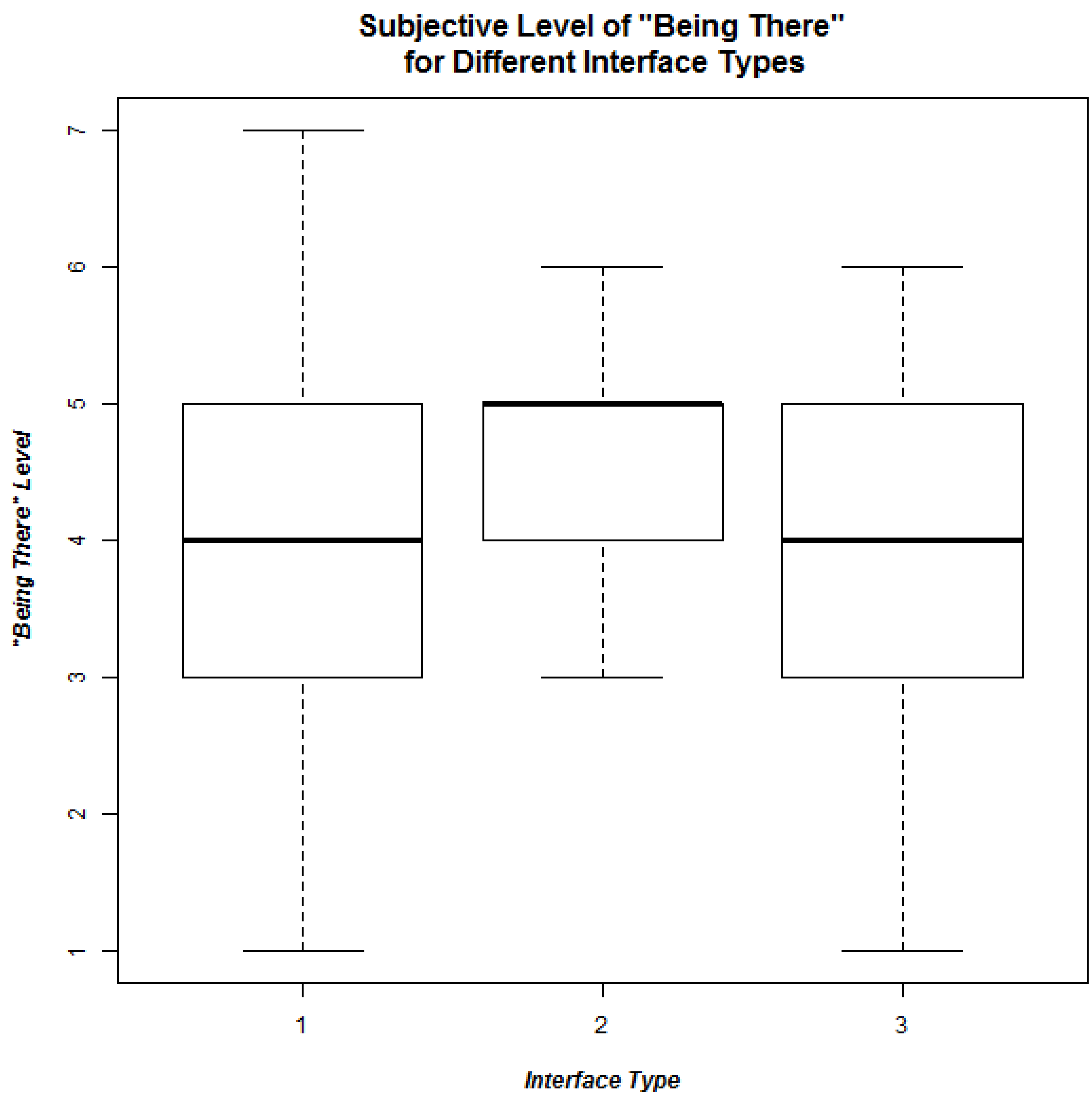
Difficulty vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	3.899	1.323	4.000
2	3.667	1.445	3.500
3	3.883	1.543	4.000







*C.2.2.2 Being There**

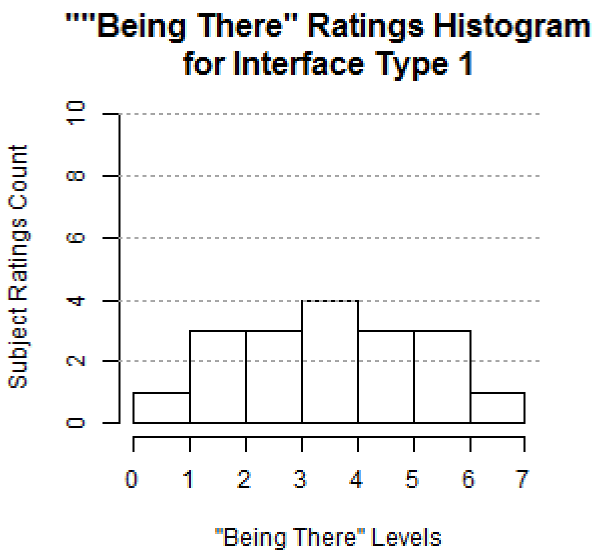


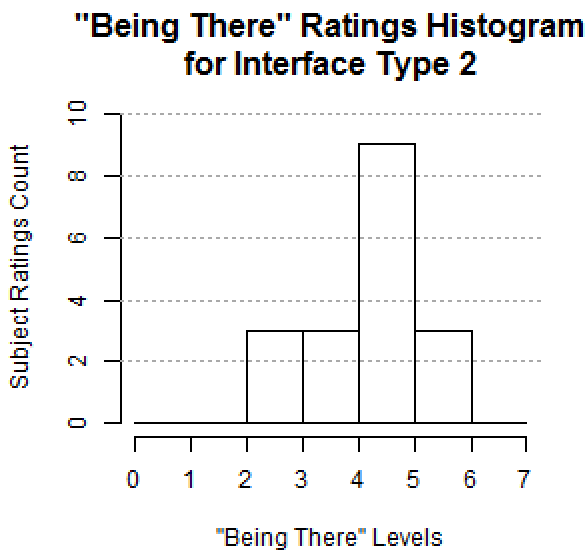
ANOVA: Being There Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	4.59	2.296	1.198	0.31
Residuals	51	97.78	1.917		

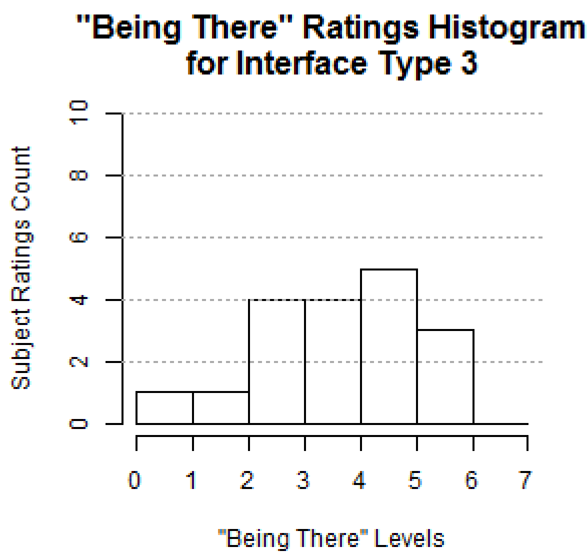
Being There vs. Interface Used - Friedman Test	
X^2	6.280
p	0.043
DoF	2.000

Being There vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	20.500	29.500	37.000
Z	-2.136	-0.965	1.746
p	0.040	0.361	0.121
R	-0.356	-01.161	0.291

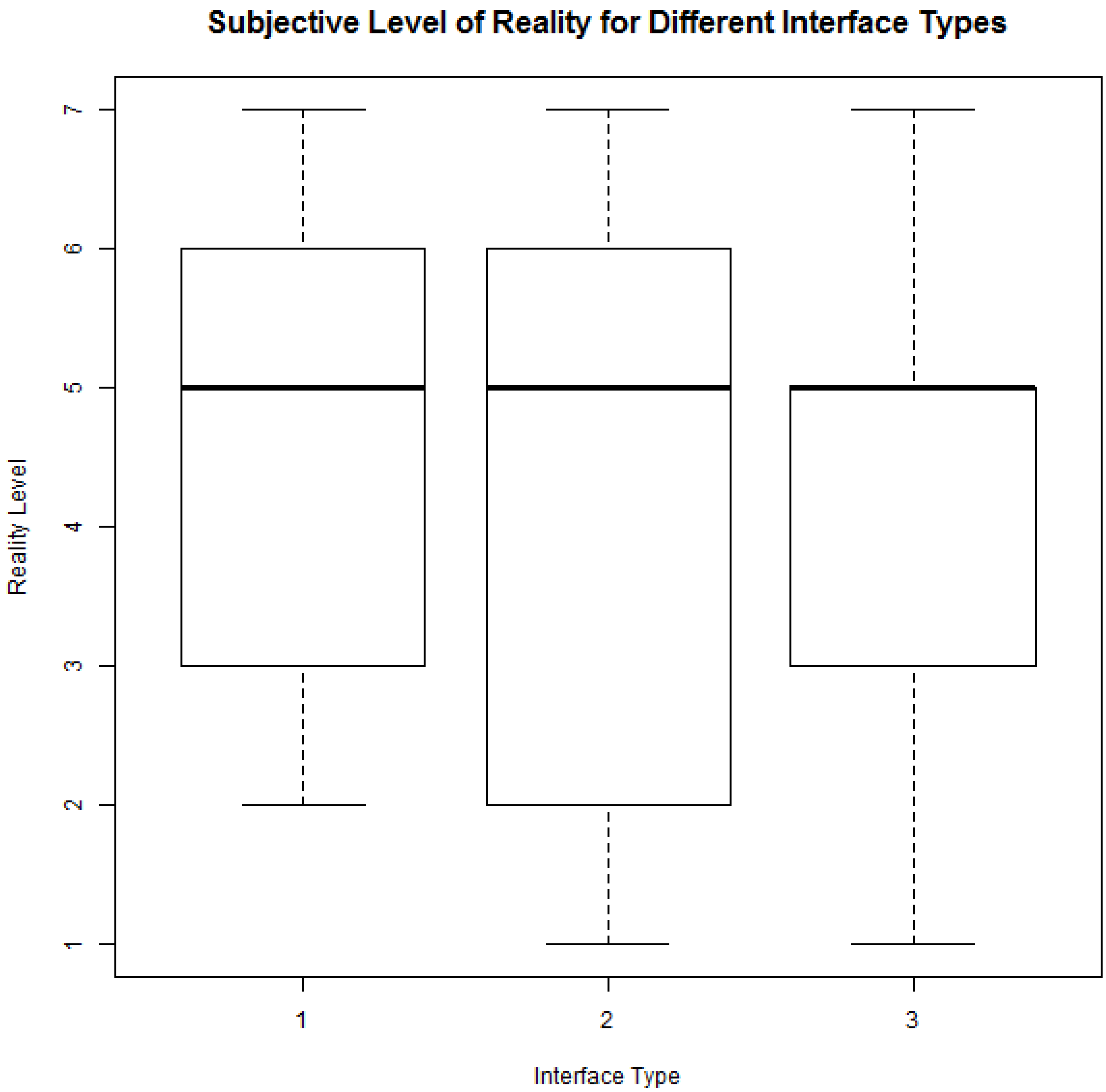
Being There vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	4.000	1.680	4.000
2	4.667	0.970	5.000
3	4.111	1.410	4.000







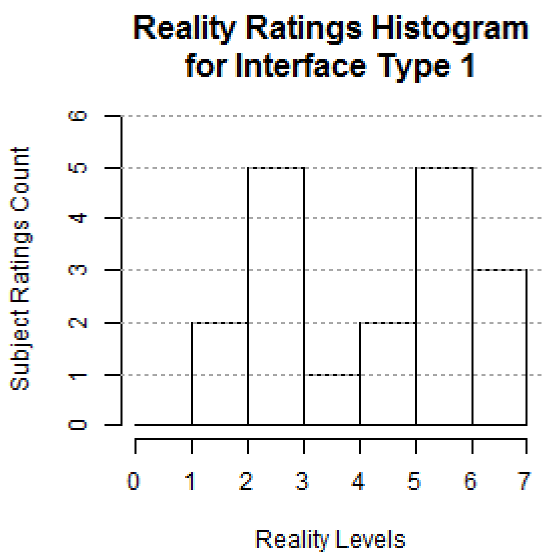
C.2.2.3 Reality

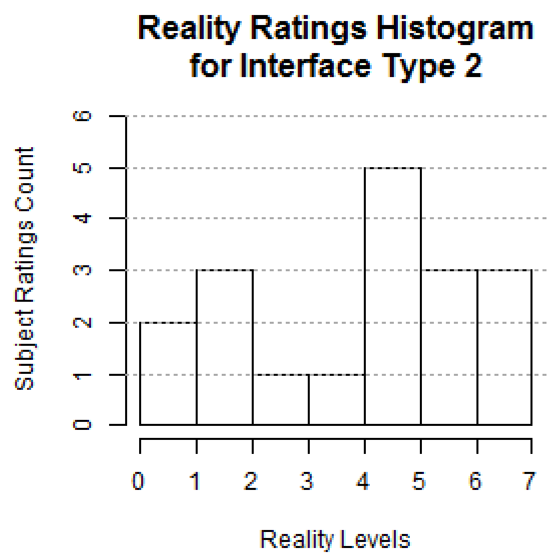


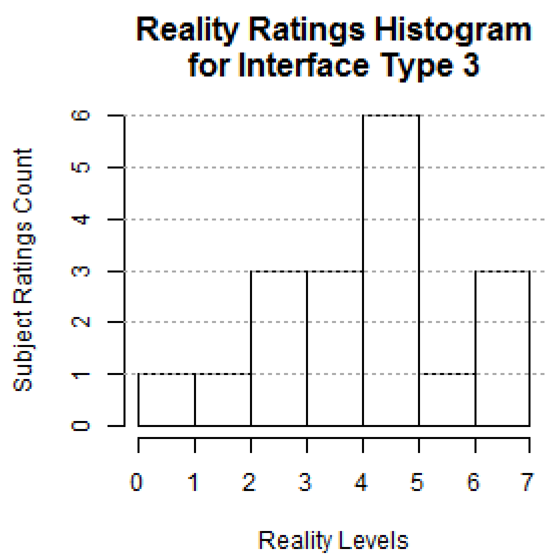
ANOVA: Being There Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.7	0.352	0.103	0.903
Residuals	174.8	3.427			

Being There vs. Interface Used - Friedman Test	
X^2	0.655
p	0.721
DoF	2.000

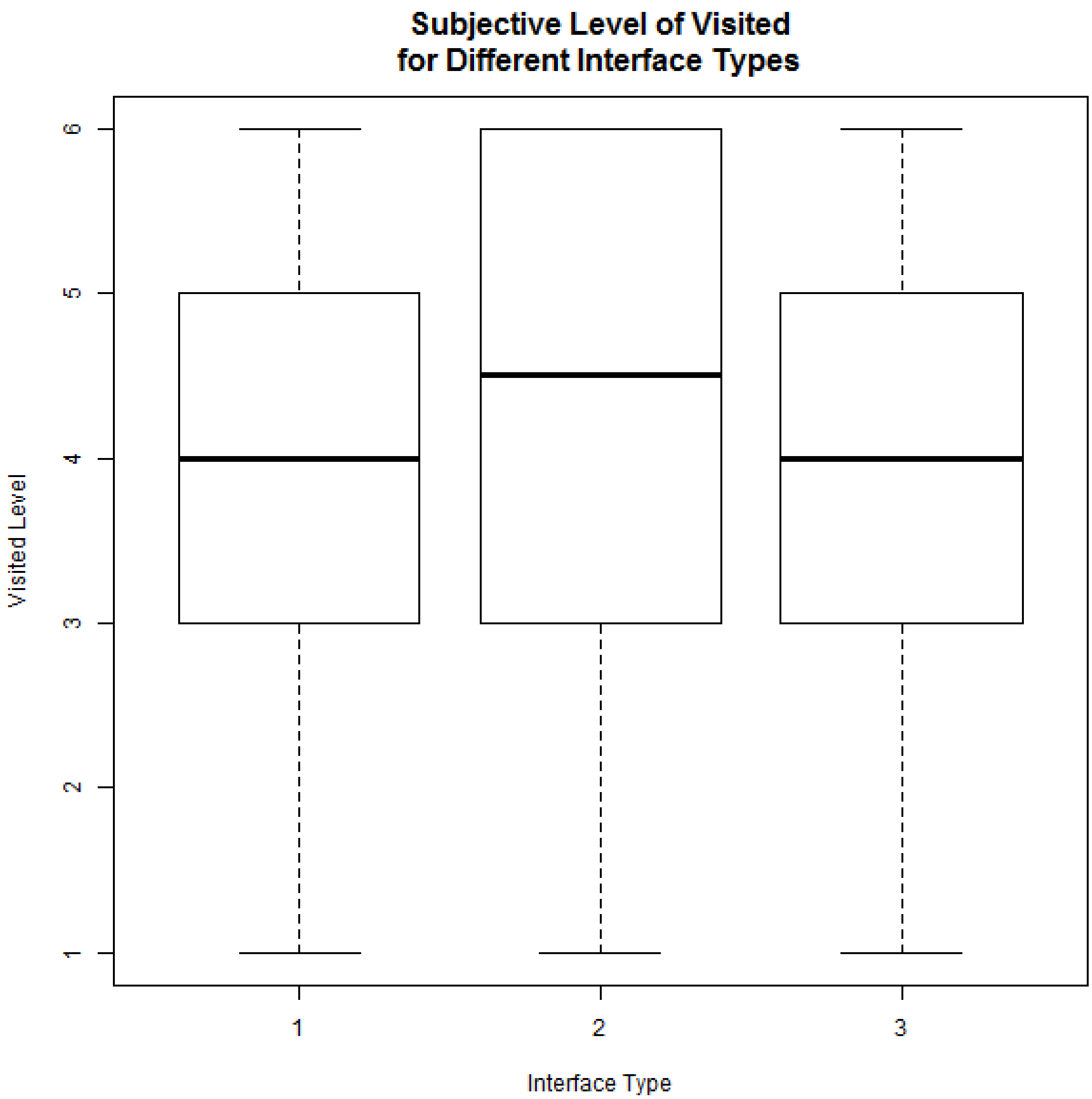
Being There vs. Interface Used Summary			
Interface #	*Mean*	*Std. Dev.*	*Median*
1	4.667	1.782	5.000
2	4.389	2.062	5.000
3	4.500	1.689	5.000







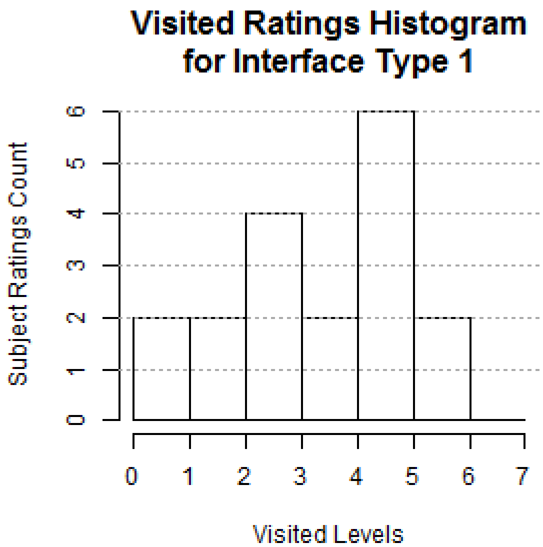
C.2.2.4 Visited

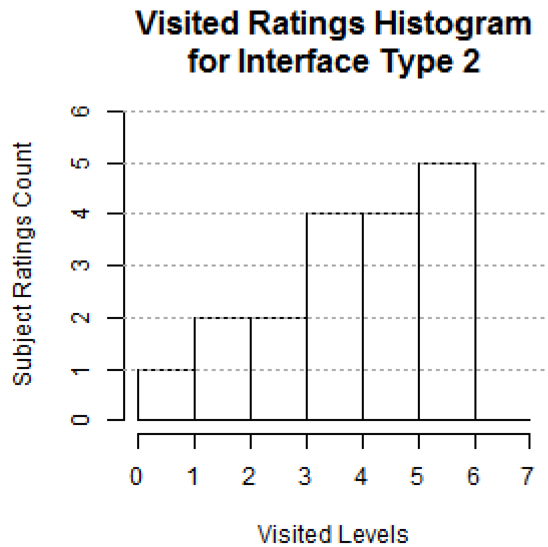


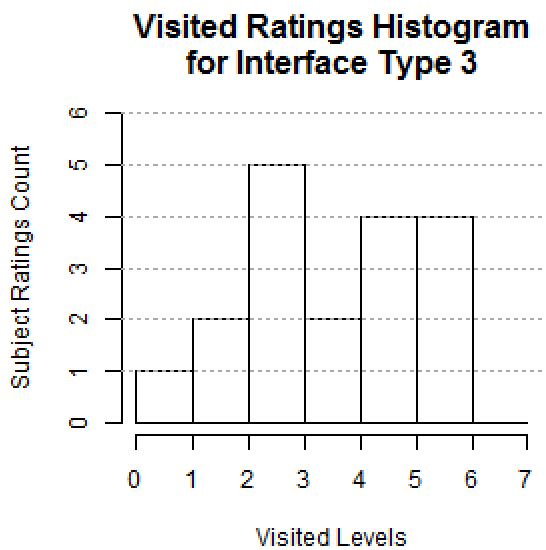
ANOVA: Visited Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	2.26	1.130	0.455	0.637
Residuals	51	126.72	2.485		

Visited vs. Interface Used - Friedman Test	
X^2	1.746
p	0.478
DoF	2.000

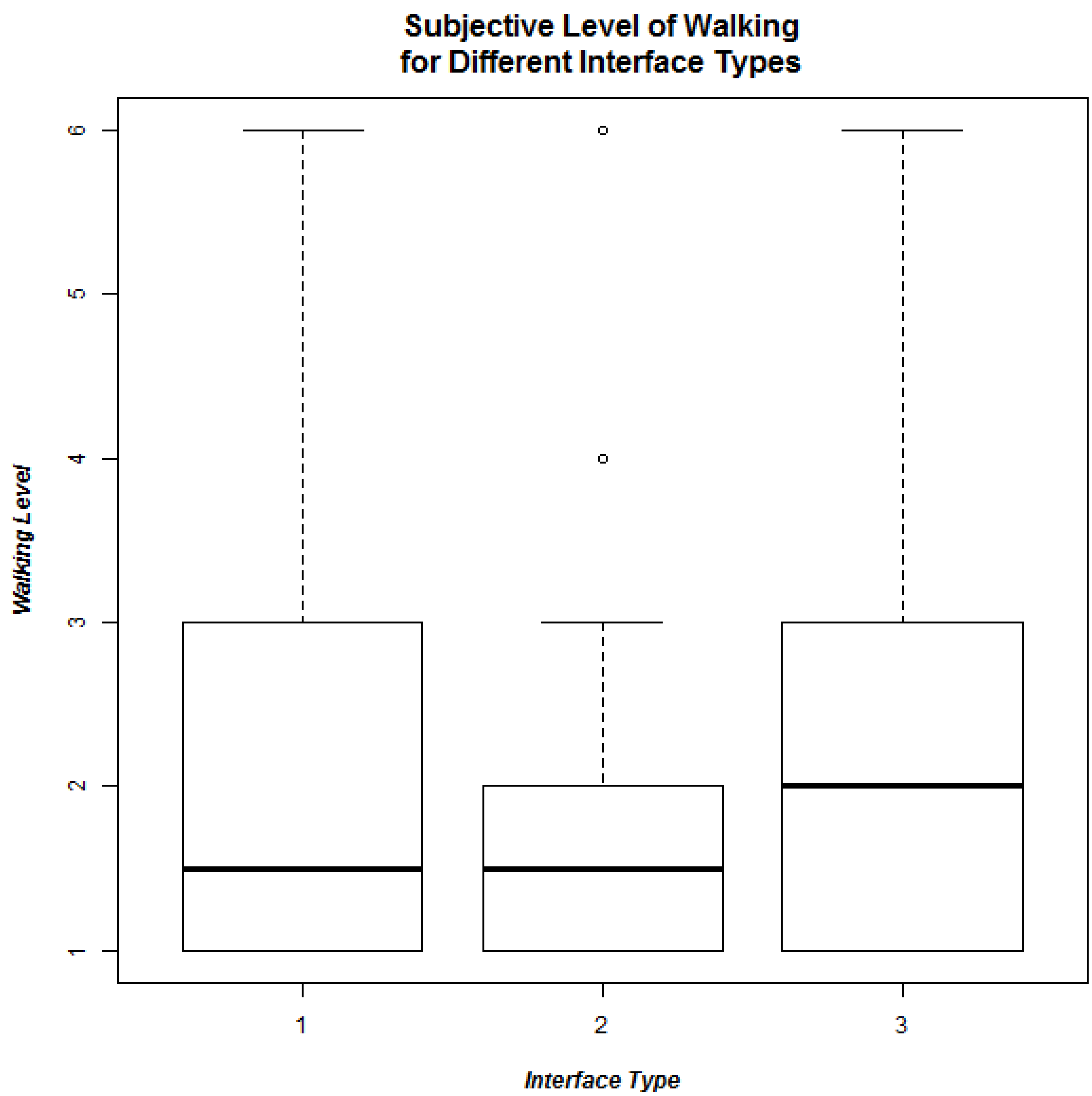
Visited vs. Interface Used Summary			
Interface #	*Mean*	*Std. Dev.*	*Median*
1	3.778	1.592	4.000
2	4.278	1.565	4.500
3	4.000	1.572	4.000







*C.2.2.5 Walking**

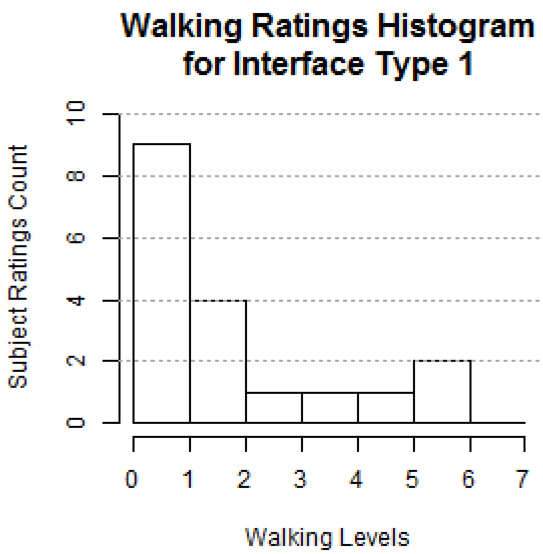


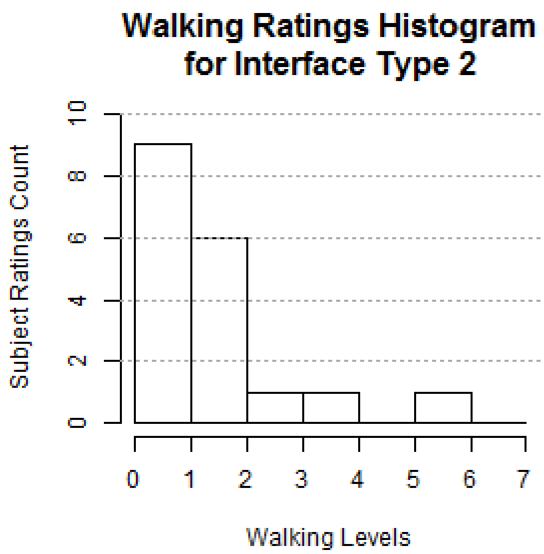
ANOVA: Walking Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	4.04	2.018	0.831	0.441
Residuals	51	123.83	2.428		

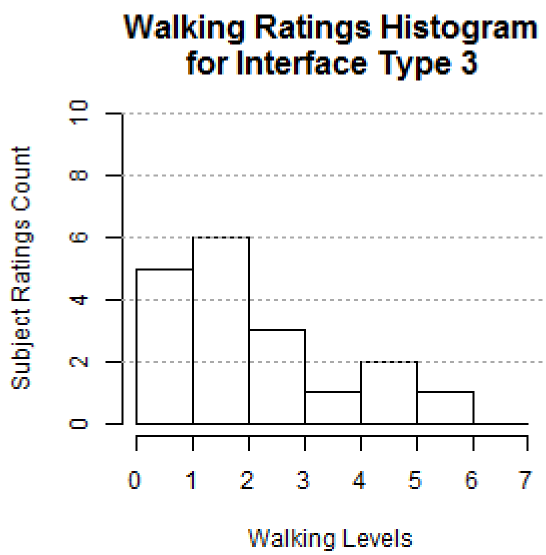
Walking vs. Interface Used - Friedman Test	
X^2	7.824
p	0.020
DoF	2.000

Walking vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	6.000	18.000	4.500
Z	1.731	-1.182	-2.549
p	0.250	0.273	0.018
R	0.288	-0.197	-0.425

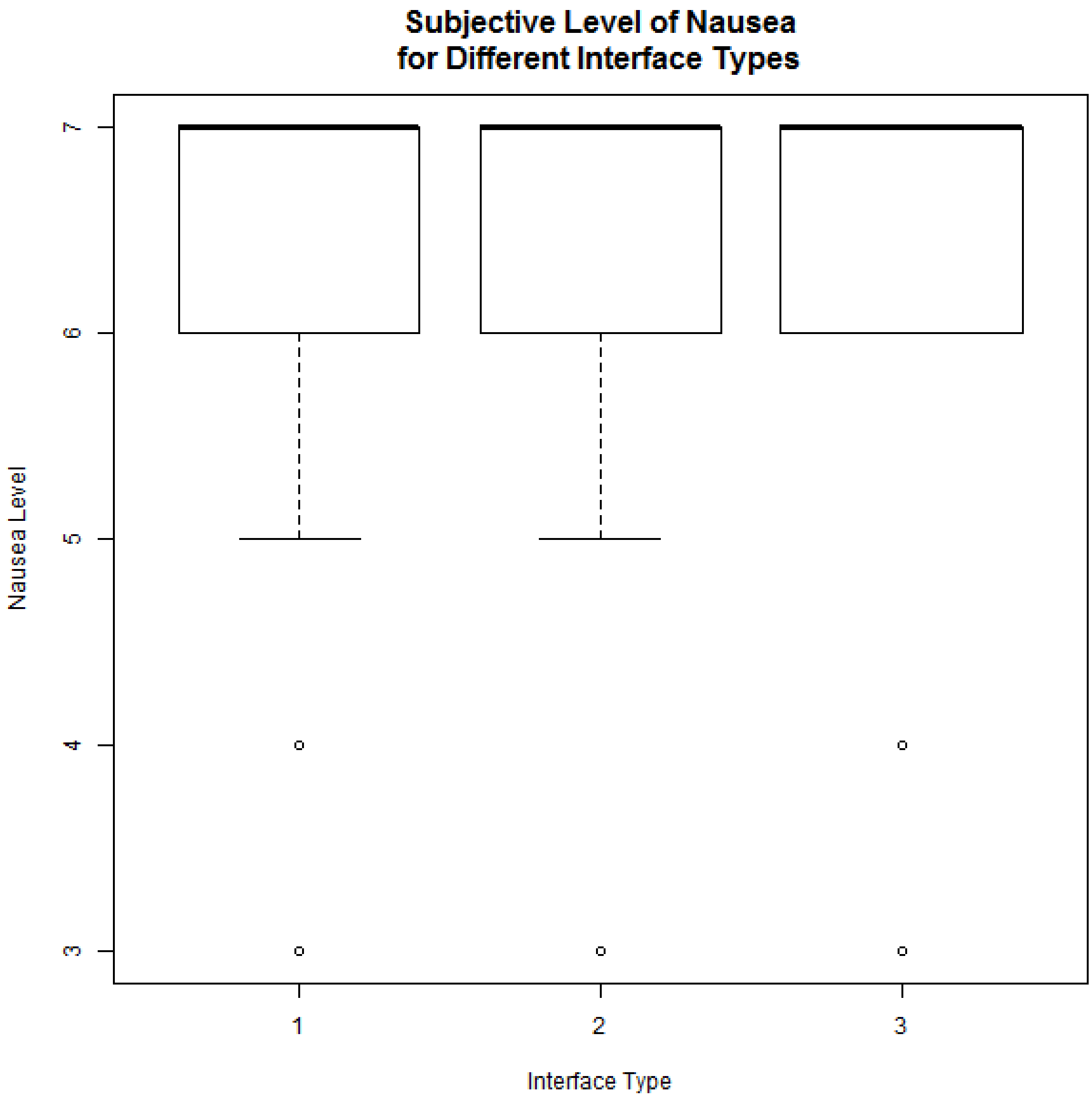
Walking vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	2.278	1.776	1.500
2	1.889	1.323	1.500
3	2.556	1.542	2.000







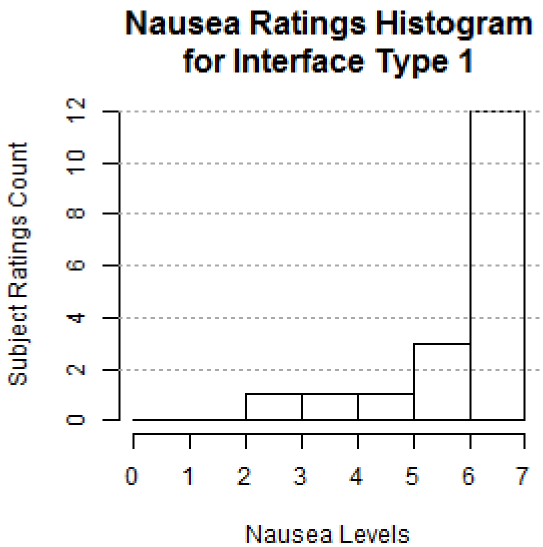
C.2.2.6 Nausea

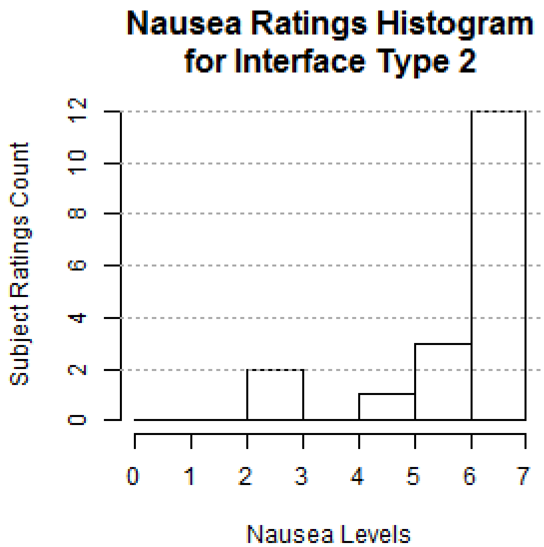


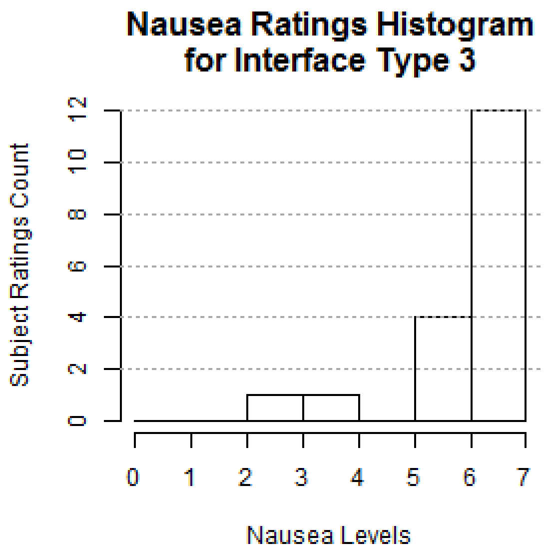
ANOVA: Nausea Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.11	0.056	0.037	0.963
Residuals	51	75.89	1.488		

Nausea vs. Interface Used - Friedman Test	
X^2	1.077
p	0.584
DoF	2.000

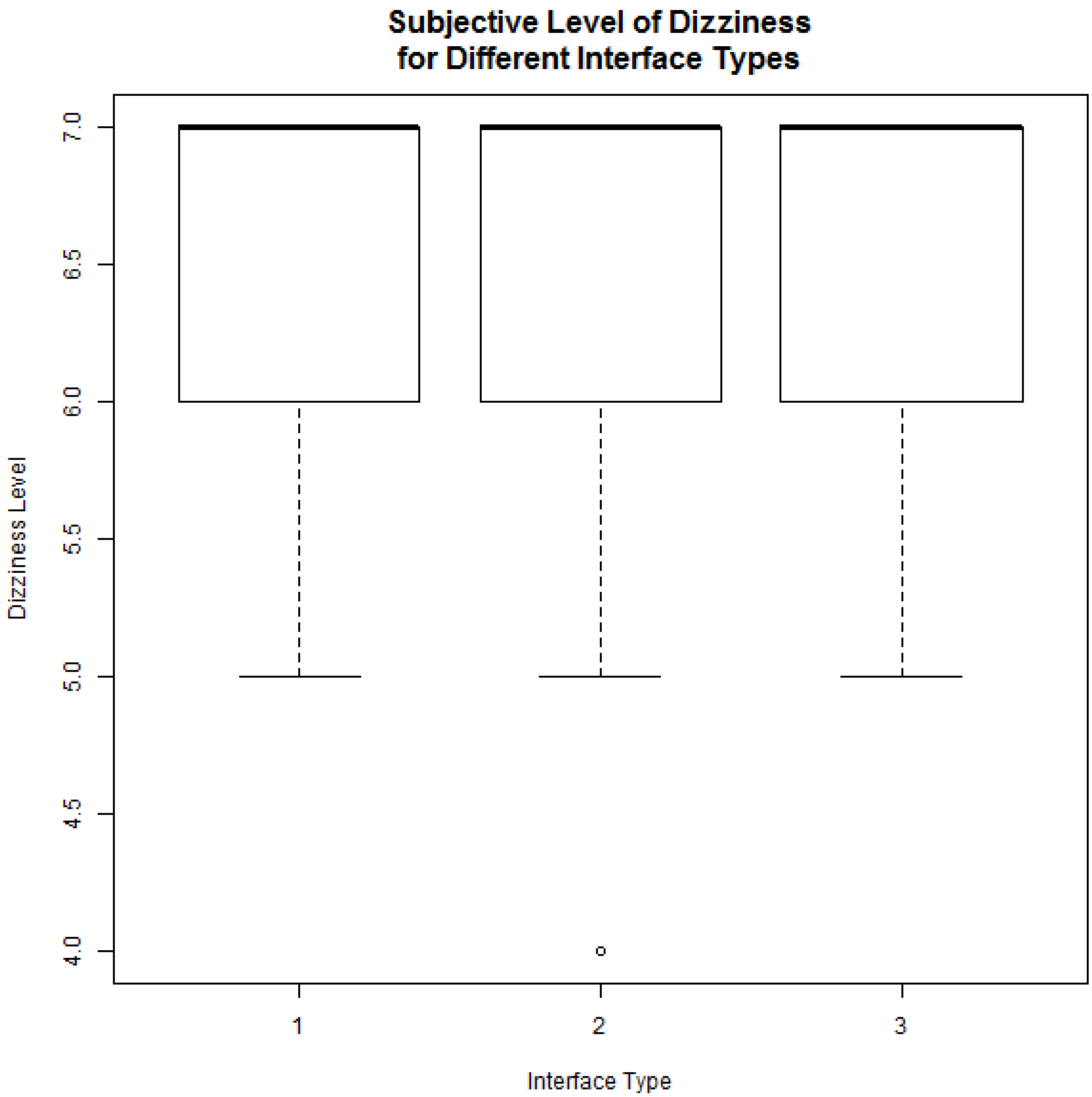
Nausea vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	6.333	1.188	7.000
2	6.278	1.320	7.000
3	6.389	1.145	7.000







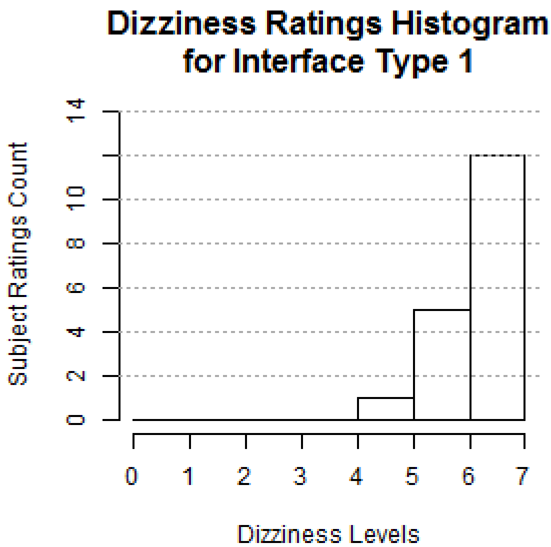
C.2.2.7 Dizziness

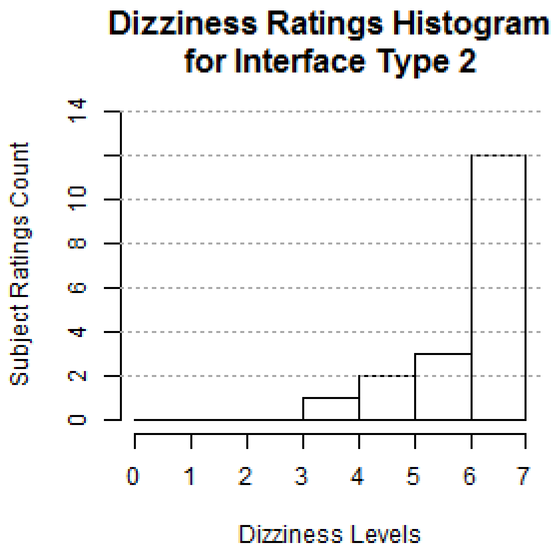


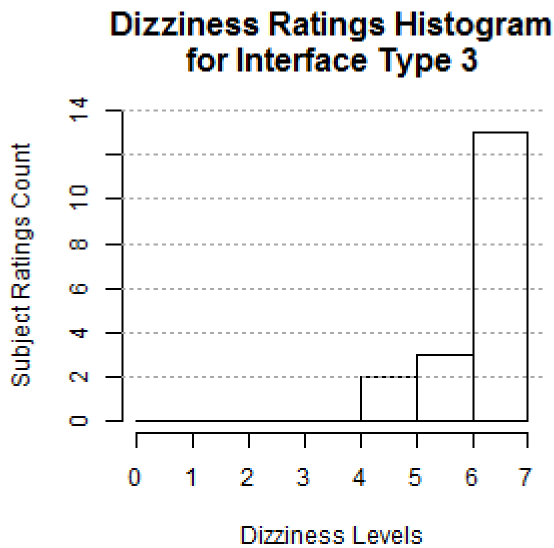
ANOVA: Dizziness Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.333	0.167	0.293	0.747
Residuals	51	29.000	0.569		

Dizziness vs. Interface Used - Friedman Test	
X^2	1.200
p	0.549
DoF	2.000

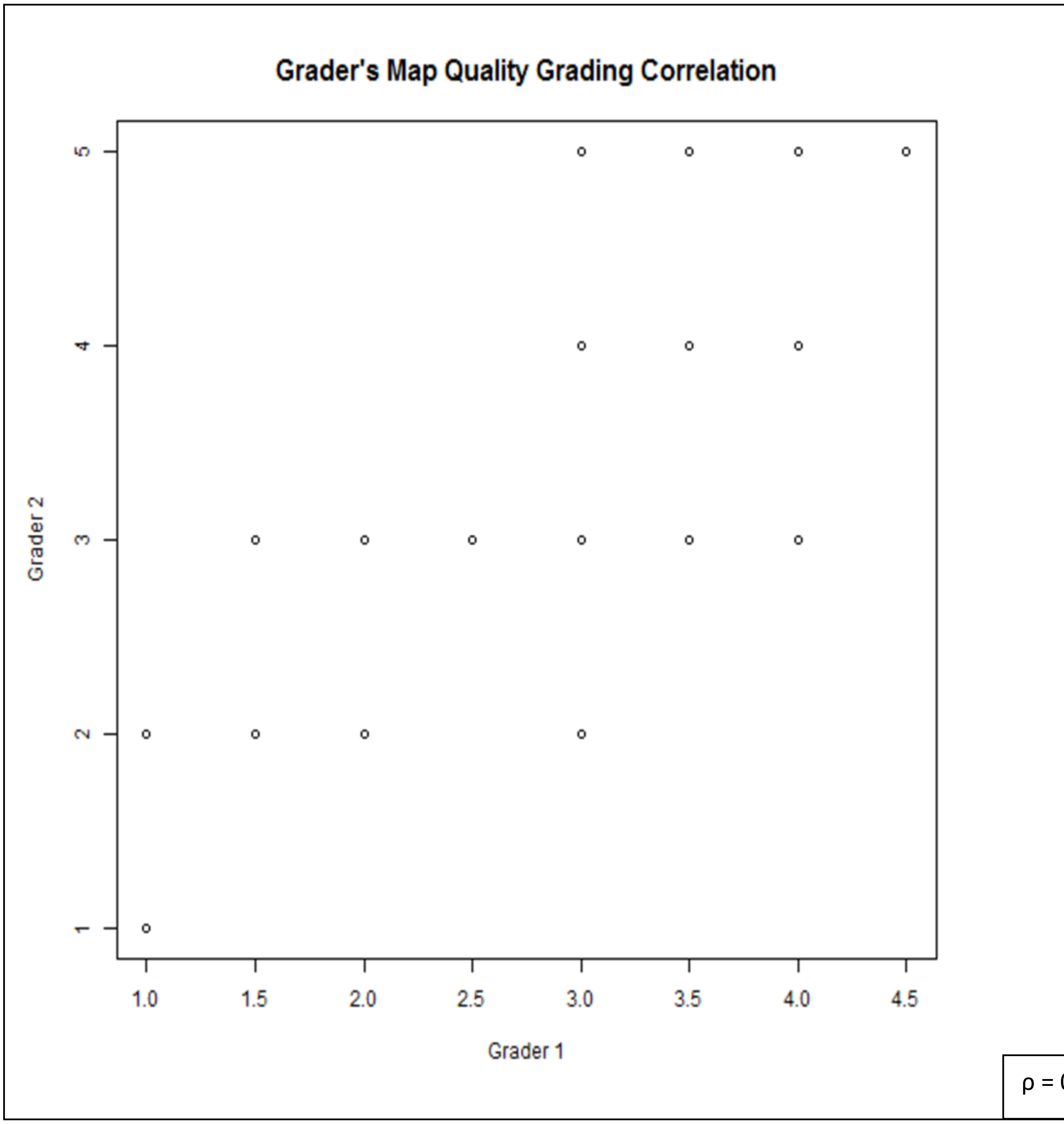
Dizziness vs. Interface Used Summary			
Interface #	*Mean*	*Std. Dev.*	*Median*
1	6.611	0.608	7.000
2	6.444	0.922	7.000
3	6.611	0.698	7.000







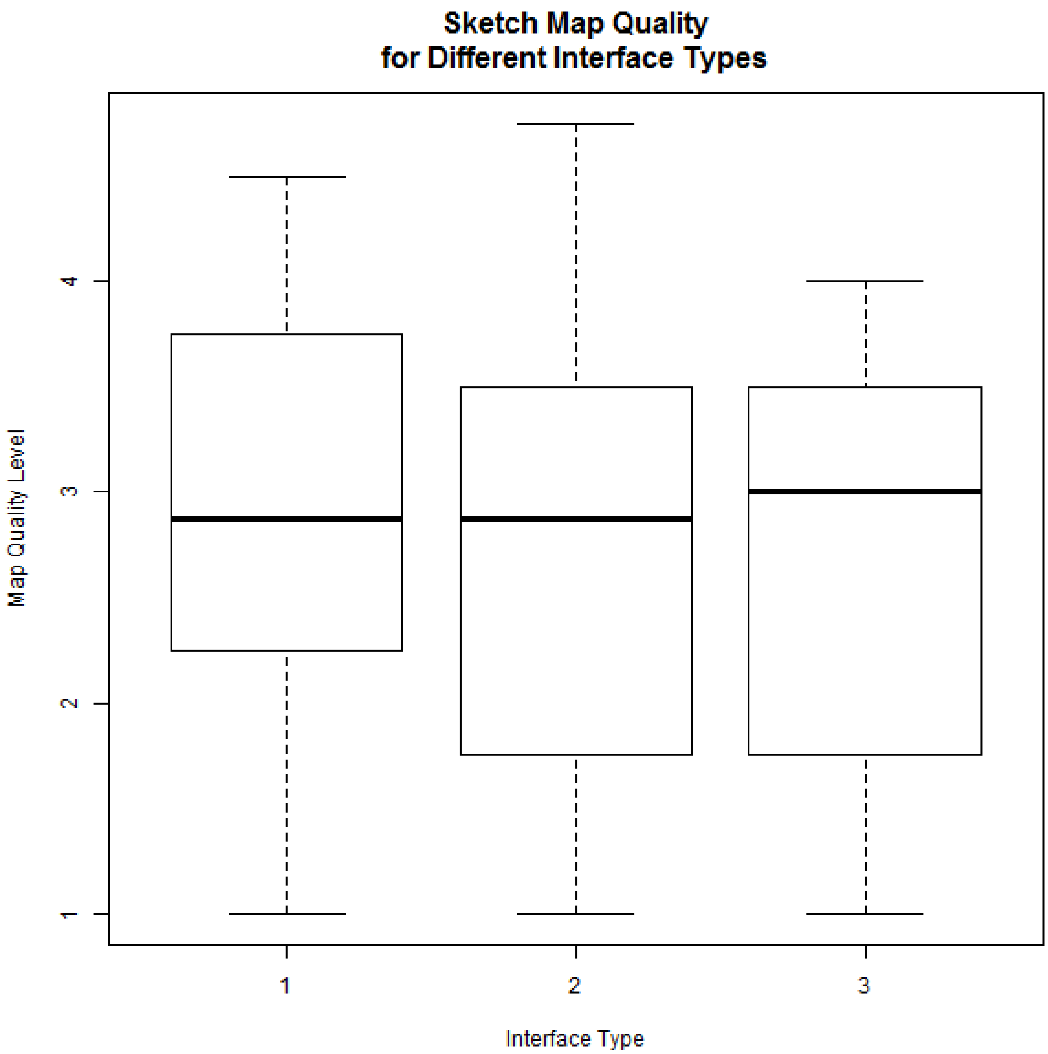
C.2.3 Map Quality



ρ = 0.826

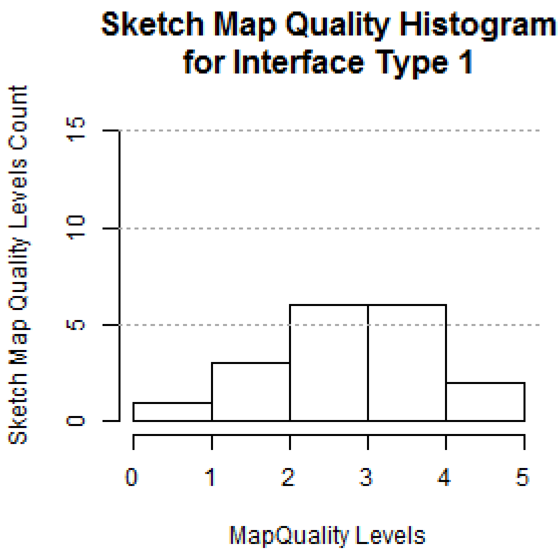
ANOVA: Map Quality Scores for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.21	0.105	0.091	0.913
Residuals	51	58.77	1.152		

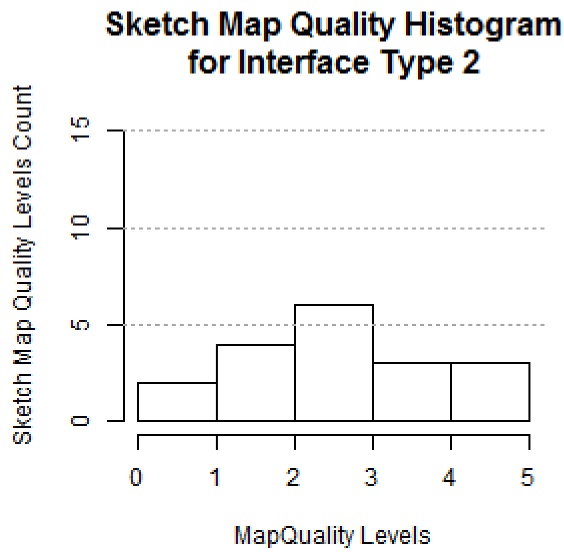
Map Quality vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	2.917	1.033	2.875
2	2.778	1.191	2.875
3	2.792	0.986	3.000

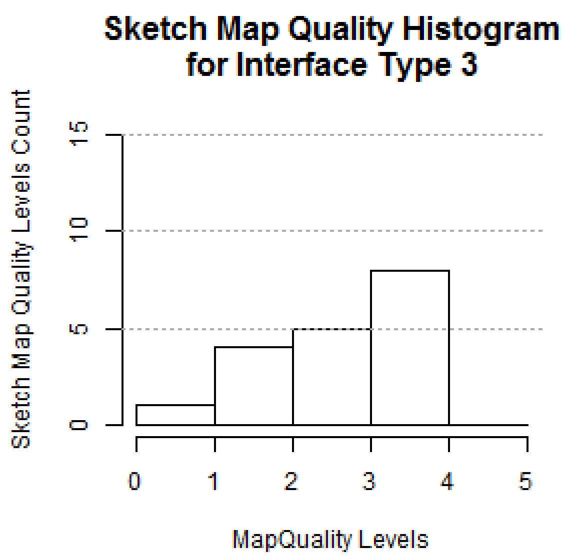


Map Quality vs. Interface Used - Friedman Test	
X^2	1.410
p	0.494
DoF	2.000

Map Quality vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	62.000	74.000	63.000
Z	0.593	0.944	0.197
p	0.566	0.358	0.855
R	0.099	0.157	0.033


Sketch Map Quality Histogram
for Interface Type 1
Sketch Map Quality Levels Count
0
5
10
15
0
1
2
3
4
5
MapQuality Levels


Sketch Map Quality Histogram
for Interface Type 2
Sketch Map Quality Levels Count
0
5
10
15
0
1
2
3
4
5
MapQuality Levels


Sketch Map Quality Histogram
for Interface Type 3
Sketch Map Quality Levels Count
0
5
10
15
0
1
2
3
4
5
MapQuality Levels

C.2.3.1 Normalized Map Quality

ANOVA: Normalized Map Quality Scores for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.006	0.003	0.578	0.564
Residuals	51	0.272	0.005		

Normalized Map Quality vs. Interface Used - Friedman Test	
X^2	1.410
p	0.494
DoF	2.000

Normalized Map Quality vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	61.000	73.000	55.0000
Z	0.548	0.896	-0.153
p	0.607	0.391	0.898
R	0.091	0.149	-0.025

ANOVA: Normalized Map Quality Scores for Interfaces 1 and 2					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.003	0.006	1.003	0.324
Residuals	34	0.199	0.006		

ANOVA: Normalized Map Quality Scores for Interfaces 1 and 3					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.003	0.003	0.526	0.473
Residuals	34	0.182	0.005		

ANOVA: Normalized Map Quality Scores for Interfaces 2 and 3					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.000	0.000	0.117	0.735
Residuals	34	0.163	0.005		

Normalized Map Quality vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.348	0.080	0.345
2	0.322	0.073	0.329
3	0.330	0.065	0.321

*C.2.3.2 Interface Order Effect on Quality of Maps**

C.2.3.2.1 Interface 1

ANOVA: Interface 1 Map Quality in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	4.75	2.375	2.664	0.102
Residuals	15	13.38	0.892		

Interface 1 Map Quality vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (1st)	2.250	0.894	2.375
312 (2nd)	3.500	0.935	3.625
231 (3rd)	3.000	1.000	3.250

ANOVA: Interface 1 Normalized Map Quality in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.023	0.012	2.042	0.164
Residuals	15	0.086	0.006		

Interface 1 Map Quality vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (1st)	0.297	0.075	0.333
312 (2nd)	0.376	0.054	0.384
231 (3rd)	0.371	0.092	0.353

C.2.3.2.2 Interface 2

ANOVA: Interface 2 Map Quality in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	5.007	2.503	1.966	0.175
Residuals	15	19.104	1.274		

Interface 2 Map Quality vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	2.792	1.249	3.000
312 (3rd)	1.417	1.169	3.500
231 (1st)	2.125	0.945	2.000

ANOVA: Interface 2 Normalized Map Quality in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.039	0.020	5.801	0.014
Residuals	15	0.051	0.003		

ANOVA: Interface 2 Normalized Map Quality for Interface Orders 123 (2nd) and 312 (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.000	0.000	0.092	0.768
Residuals	10	0.028	0.028		

ANOVA: Interface 2 Normalized Map Quality for Interface Orders 123 (2nd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.027	0.027	7.007	0.024
Residuals	10	0.038	0.038		

ANOVA: Interface 2 Normalized Map Quality for Interface Orders 312 (3rd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.032	0.032	8.909	0.014
Residuals	10	0.036	0.036		

Interface 2 Map Quality vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.350	0.054	0.352
312 (3rd)	0.360	0.051	0.369
231 (1st)	0.256	0.068	0.274

C.2.3.2.3 Interface 3

ANOVA: Interface 3 Map Quality in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	1.188	0.594	0.58	0.572
Residuals	15	15.344	1.023		

Interface 3 Map Quality vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (3rd)	2.750	1.025	2.875
312 (1st)	2.500	0.790	2.625
231 (2nd)	3.125	1.180	3.750

ANOVA: Interface 3 Normalized Map Quality in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.040	0.020	9.179	0.002
Residuals	15	0.033	0.002		

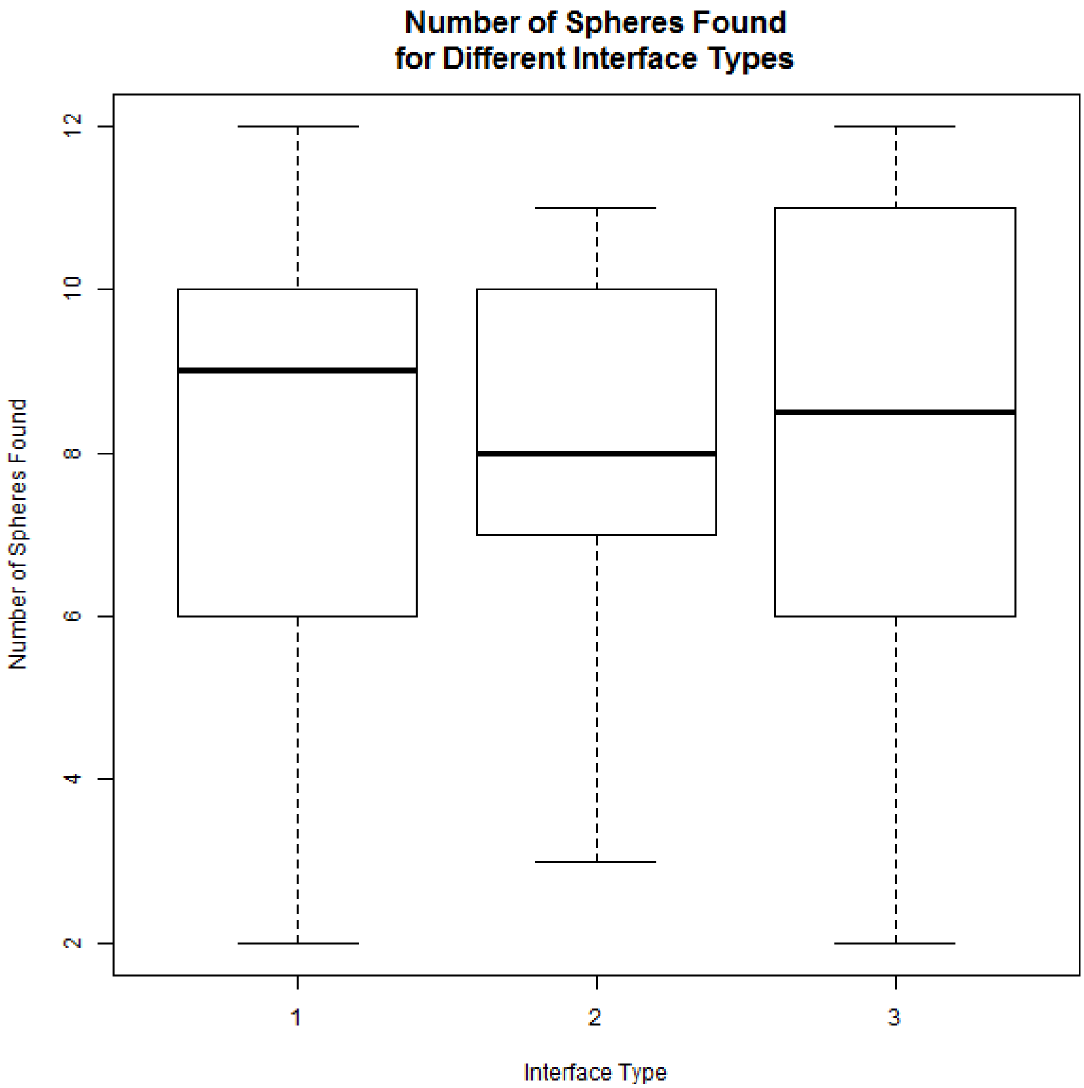
ANOVA: Interface 3 Normalized Map Quality for Interface Orders 123 (3rd) and 312 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.023	0.023	17.48	0.002
Residuals	10	0.013	0.001		

ANOVA: Interface 3 Normalized Map Quality for Interface Orders 123 (3rd) and 231 (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.001	0.001	0.445	0.52
Residuals	10	0.028	0.003		

ANOVA: Interface 3 Normalized Map Quality for Interface Orders 312 (1st) and 231 (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.035	0.035	15.13	0.003
Residuals	10	0.023	0.002		

Interface 3 Map Quality vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (3rd)	0.352	0.043	0.352
312 (1st)	0.264	0.028	0.273
231 (2nd)	0.373	0.062	0.375

C.2.4 Number of Spheres Found

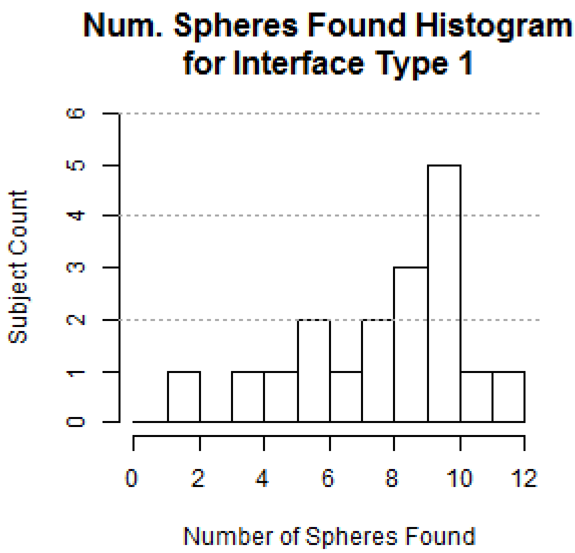


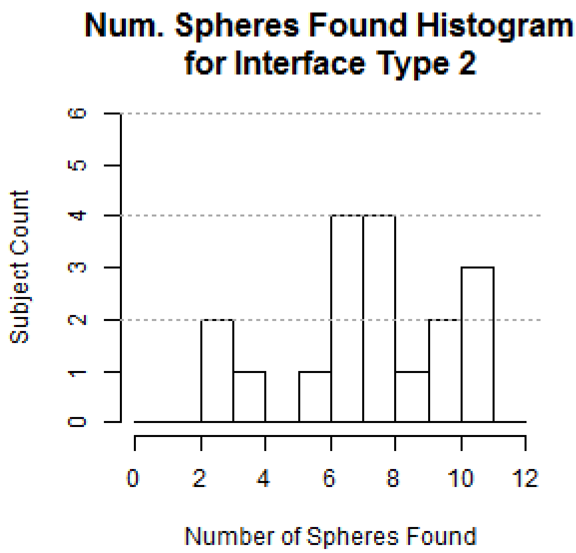
ANOVA: Number of Spheres Found for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	2.8	1.352	0.192	0.826
Residuals	51	358.3	7.025		

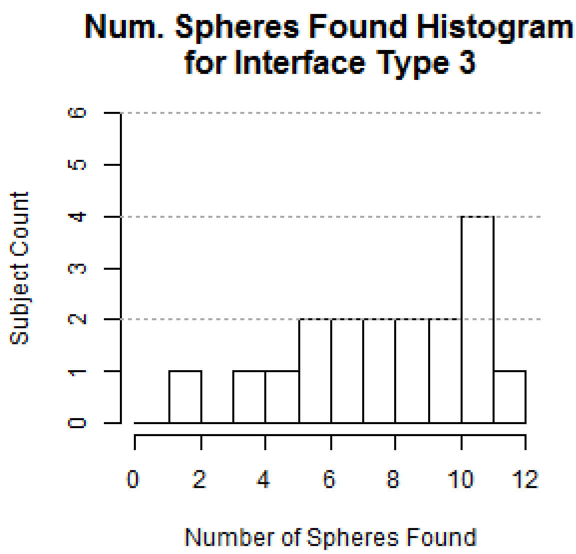
Number of Spheres Found vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	8.111	2.632	9.000
2	7.667	2.521	8.000
3	8.167	2.792	8.500

Number of Spheres Found vs. Interface Used - Friedman Test	
X^2	0.034
p	0.983
DoF	2.000

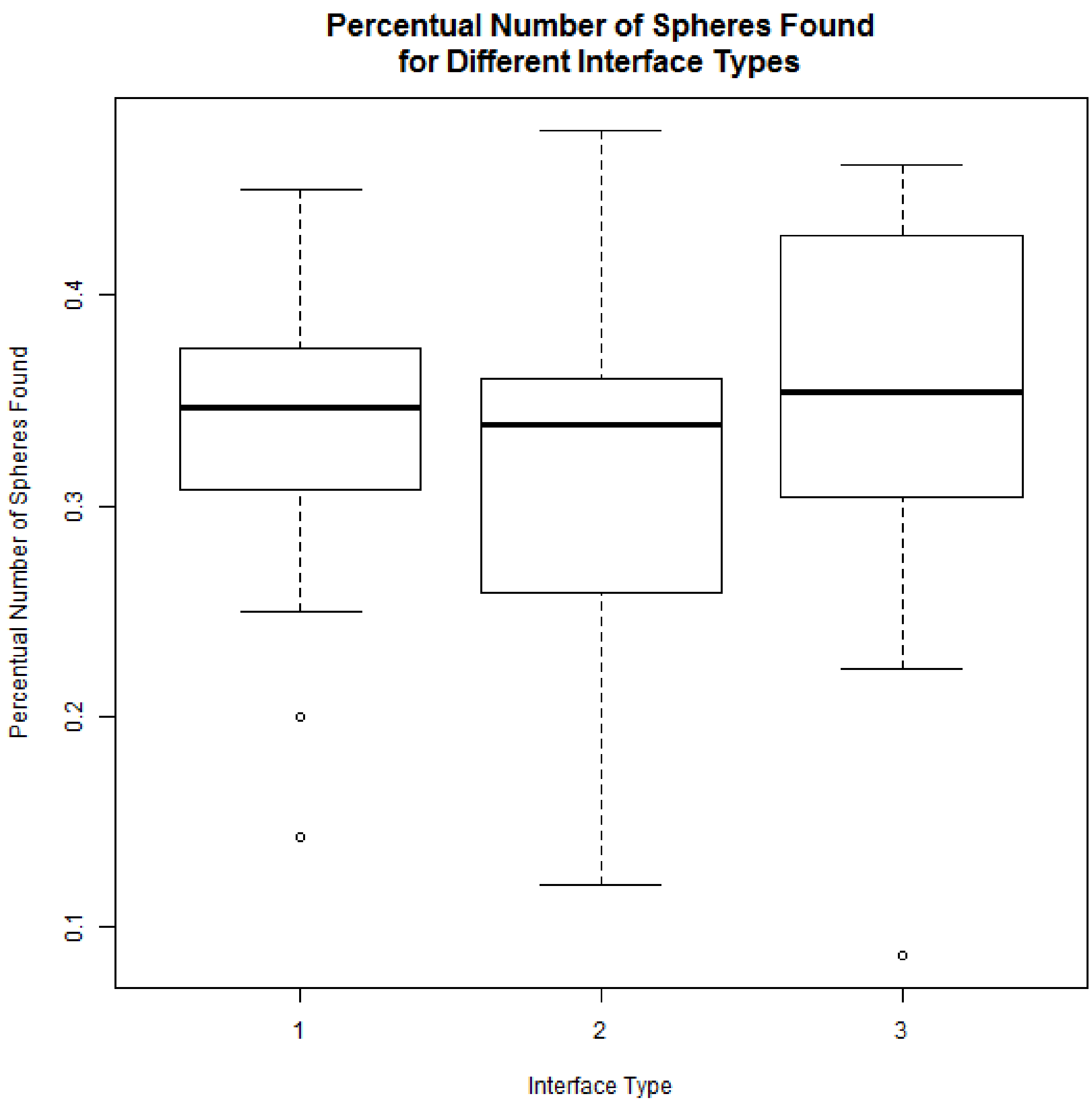
Number of Spheres Found vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	60.000	43.000	44.000
Z	0.330	0.000	-0.767
p	0.755	1.000	0.453
R	0.055	0.000	-0.128





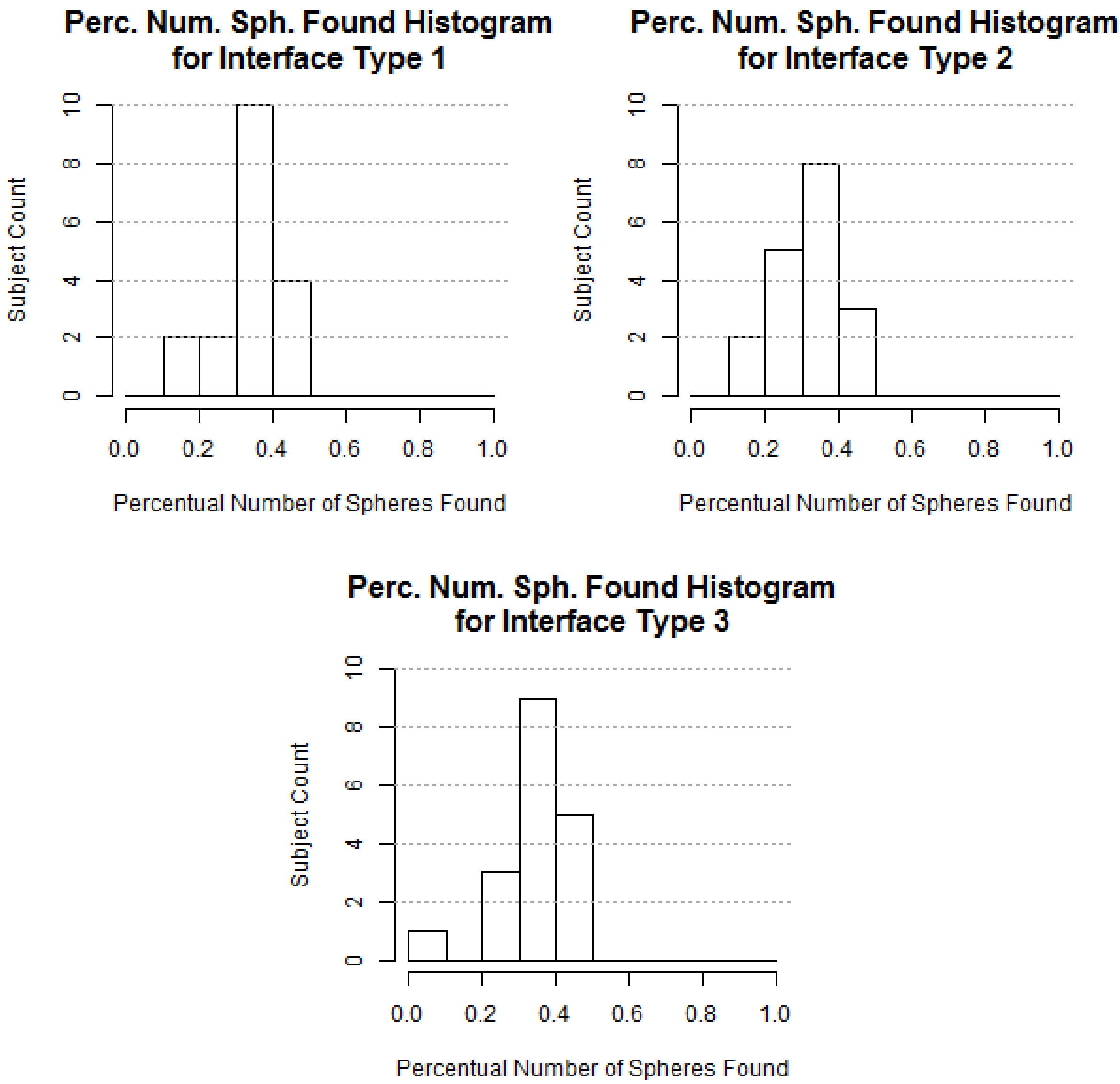


C.2.4.1 Normalized Number of Spheres Found



ANOVA: Normalized Number of Spheres Found for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.004	0.002	0.245	0.783
Residuals	51	0.407	0.008		

Normalized Number of Spheres Found vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.335	0.083	0.346
2	0.322	0.090	0.339
3	0.343	0.095	0.354


Perc. Num. Sph. Found Histogram for Interface Type 1
Subject Count
Percentual Number of Spheres Found
Perc. Num. Sph. Found Histogram for Interface Type 2
Subject Count
Percentual Number of Spheres Found
Perc. Num. Sph. Found Histogram for Interface Type 3
Subject Count
Percentual Number of Spheres Found

*C.2.4.2 Interface Order Effect on Number of Spheres Found**

C.2.4.2.1 Interface 1

ANOVA: Interface 1 Number of Spheres Found in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	20.11	10.056	1.544	0.246
Residuals	15	97.67	6.511		

Interface 1 Number of Spheres Found vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2^{nd})	6.667	2.805	7.500
312 (3^{rd})	9.167	1.602	10.000
231 (1^{st})	8.500	3.016	9.000

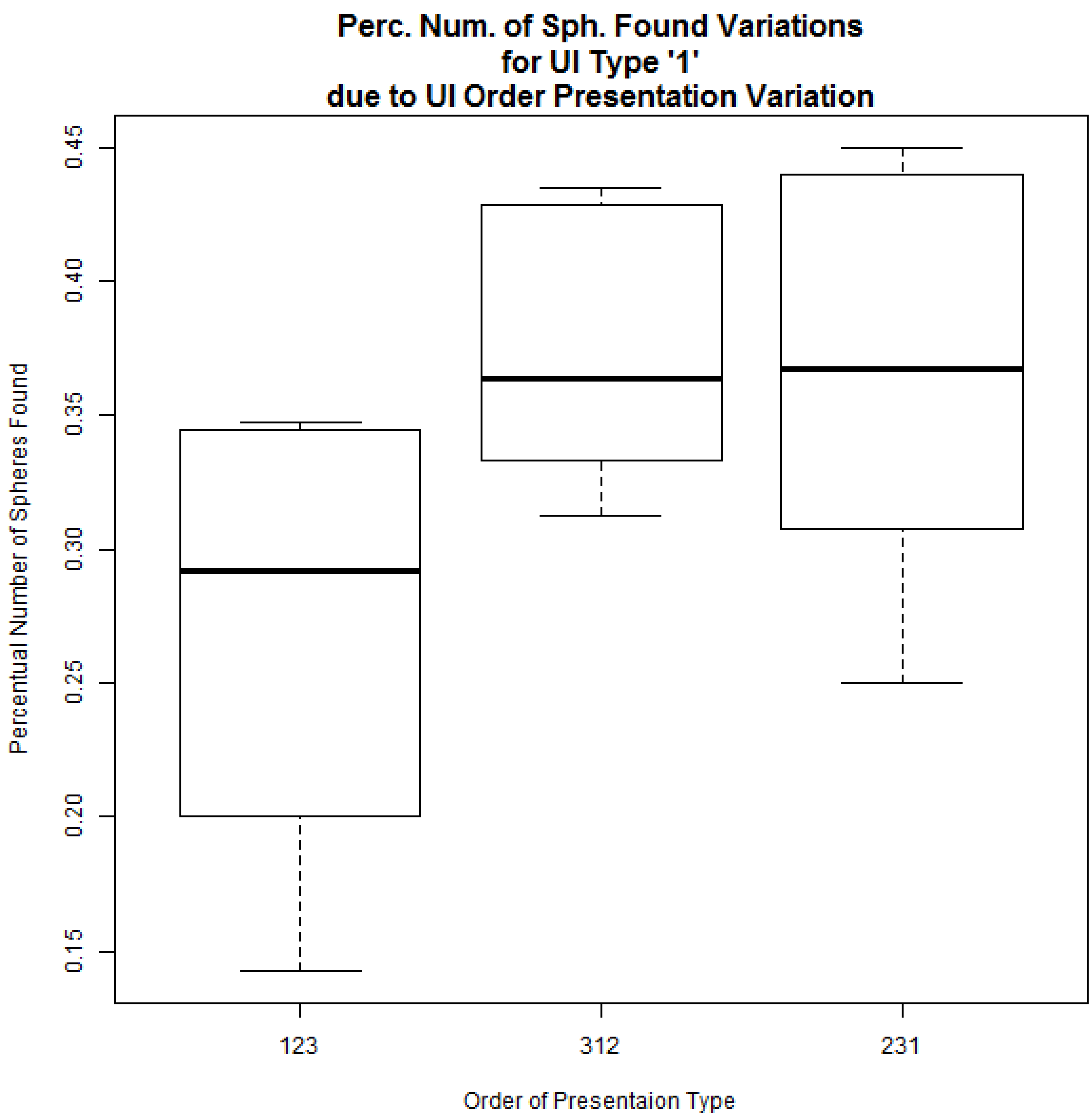
ANOVA: Interface 1 Normalized Number of Spheres Found in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.039	0.019	3.705	0.049
Residuals	15	0.079	0.005		

ANOVA: Interface 1 Normalized Number of Spheres Found for Interface Orders 123(1^{st}) and 312 (2^{nd})					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.032	0.032	6.423	0.029
Residuals	10	0.049	0.005		

ANOVA: Interface 1 Normalized Number of Spheres Found for Interface Orders 123 (1^{st}) and 231 (3^{rd})					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.026	0.026	3.978	0.074
Residuals	10	0.067	0.007		

ANOVA: Interface 1 Normalized Number of Spheres Found for Interface Orders 312 (2^{nd}) and 231 (3^{rd})					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.000	0.000	0.058	0.814
Residuals	10	0.042	0.004		

Interface 3 Normalized Number of Spheres Found vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.270	0.086	0.292
312 (3rd)	0.373	0.050	0.364
231 (1st)	0.364	0.077	0.367



C.2.4.2.2 Interface 2

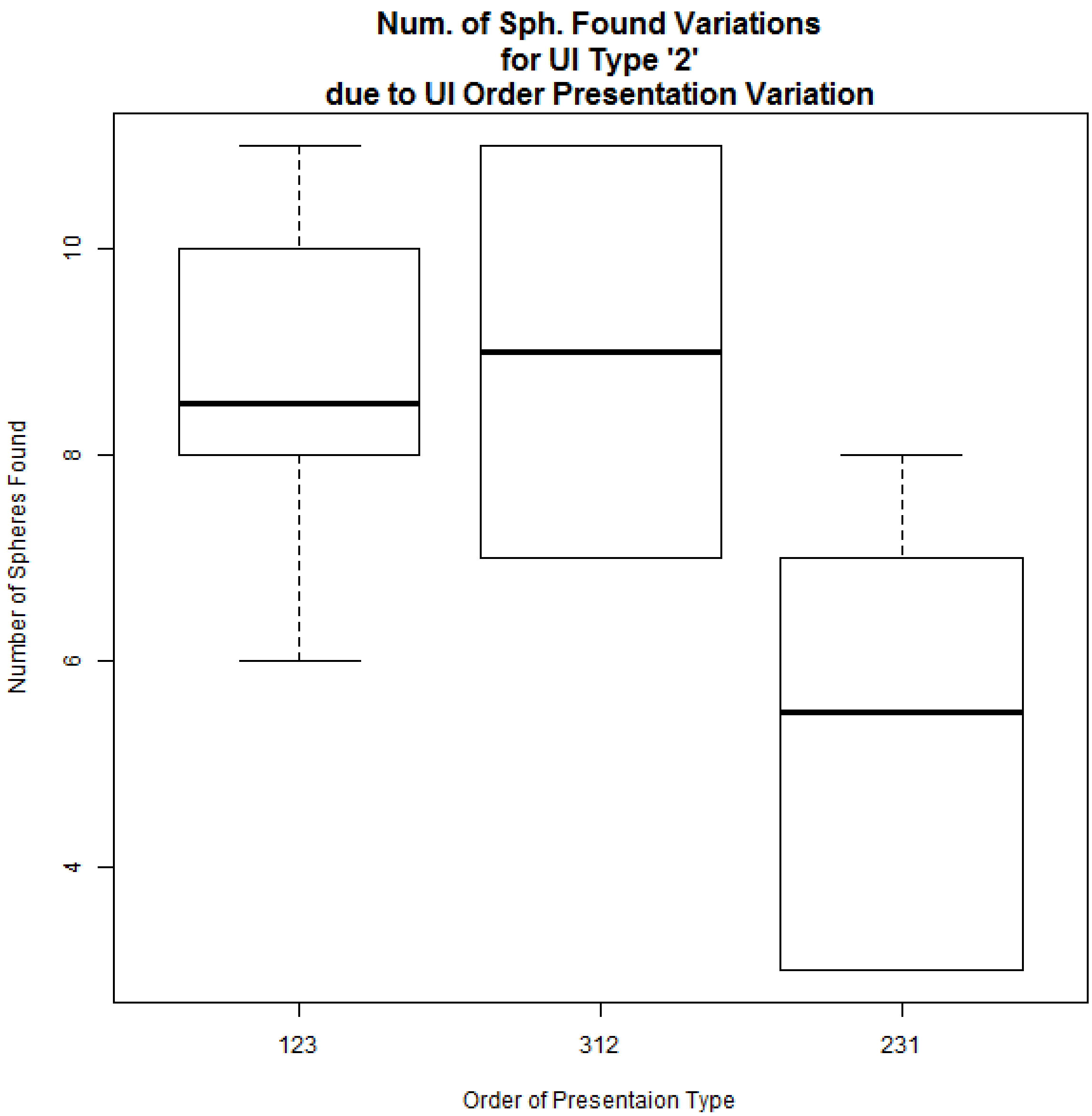
ANOVA: Interface 2 Number of Spheres Found in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	49.33	24.667	6.307	0.010
Residuals	33	58.67	3.911		

ANOVA: Interface 2 Number of Spheres Found for Interface Orders 123(2nd) and 312 (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.33	0.333	0.1	0.758
Residuals	10	33.33	3.333		

ANOVA: Interface 2 Number of Spheres Found for Interface Orders 123 (2nd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	33.33	33.33	8.197	0.017
Residuals	10	40.67	4.07		

ANOVA: Interface 2 Number of Spheres Found for Interface Orders 312 (3rd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	40.33	40.33	9.308	0.012
Residuals	10	43.33	4.33		

Interface 2 Number of Spheres Found vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	8.667	0.751	8.500
312 (3rd)	9.000	1.897	9.000
231 (1st)	5.333	2.250	5.500



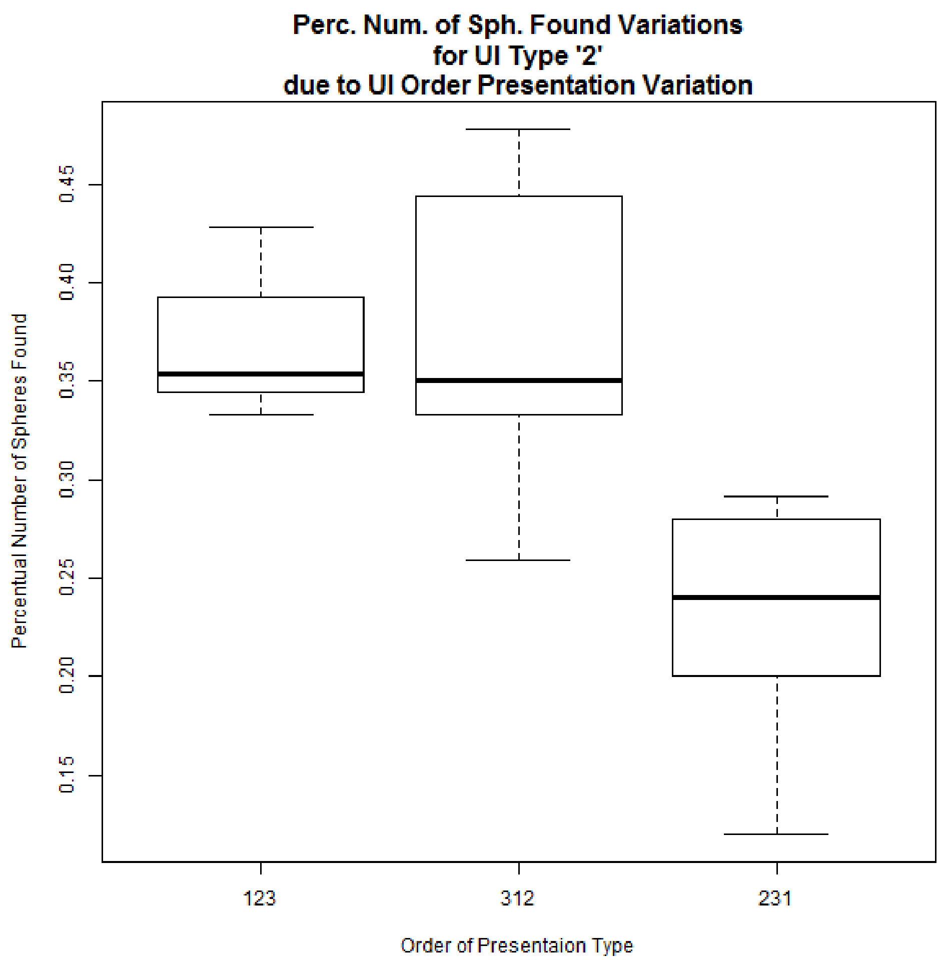
ANOVA: Interface 2 Normalized Number of Spheres Found in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.078	0.039	10.14	0.002
Residuals	15	0.058	0.004		

ANOVA: Interface 2 Normalized Number of Spheres Found for Interface Orders 123(2nd) and 312 (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.000	0.000	0.002	0.968
Residuals	10	0.038	0.004		

ANOVA: Interface 2 Normalized Number of Spheres Found for Interface Orders 123 (2nd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.058	0.058	22.18	0.001
Residuals	10				

ANOVA: Interface 2 Normalized Number of Spheres Found for Interface Orders 312 (3rd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.059	0.059	11.54	0.007
Residuals	10	0.051	0.005		

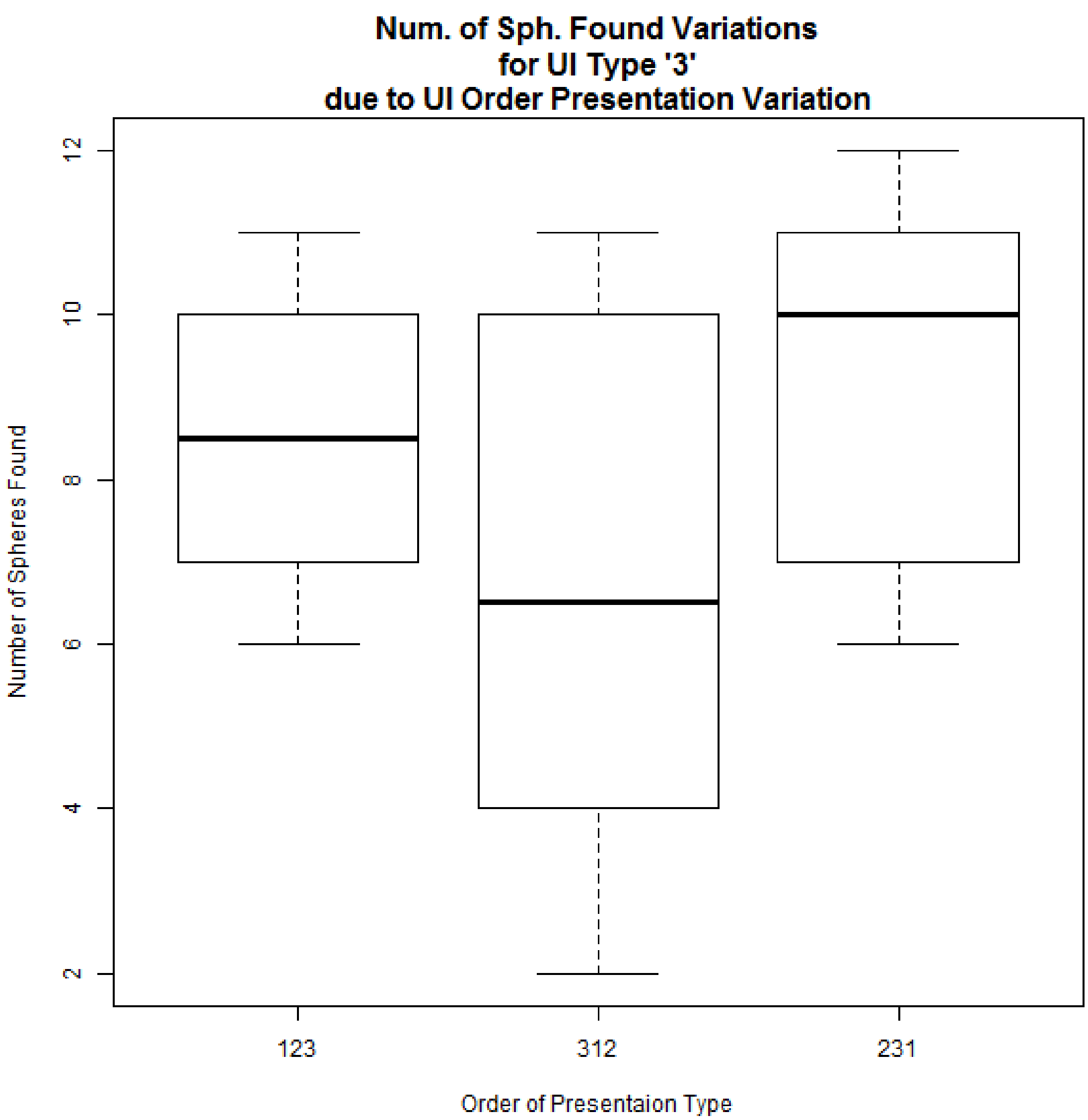
Interface 2 Normalized Number of Spheres Found vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.368	0.036	0.354
312 (3rd)	0.369	0.080	0.350
231 (1st)	0.229	0.063	0.240



C.2.4.2.3 Interface 3

ANOVA: Interface 3 Number of Spheres Found in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	22.33	11.167	1.52	0.25
Residuals	15	110.17	7.344		

Interface 3 Number of Spheres Found vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	8.500	1.871	8.500
312 (3rd)	6.667	3.559	6.500
231 (1st)	9.333	2.422	10.000



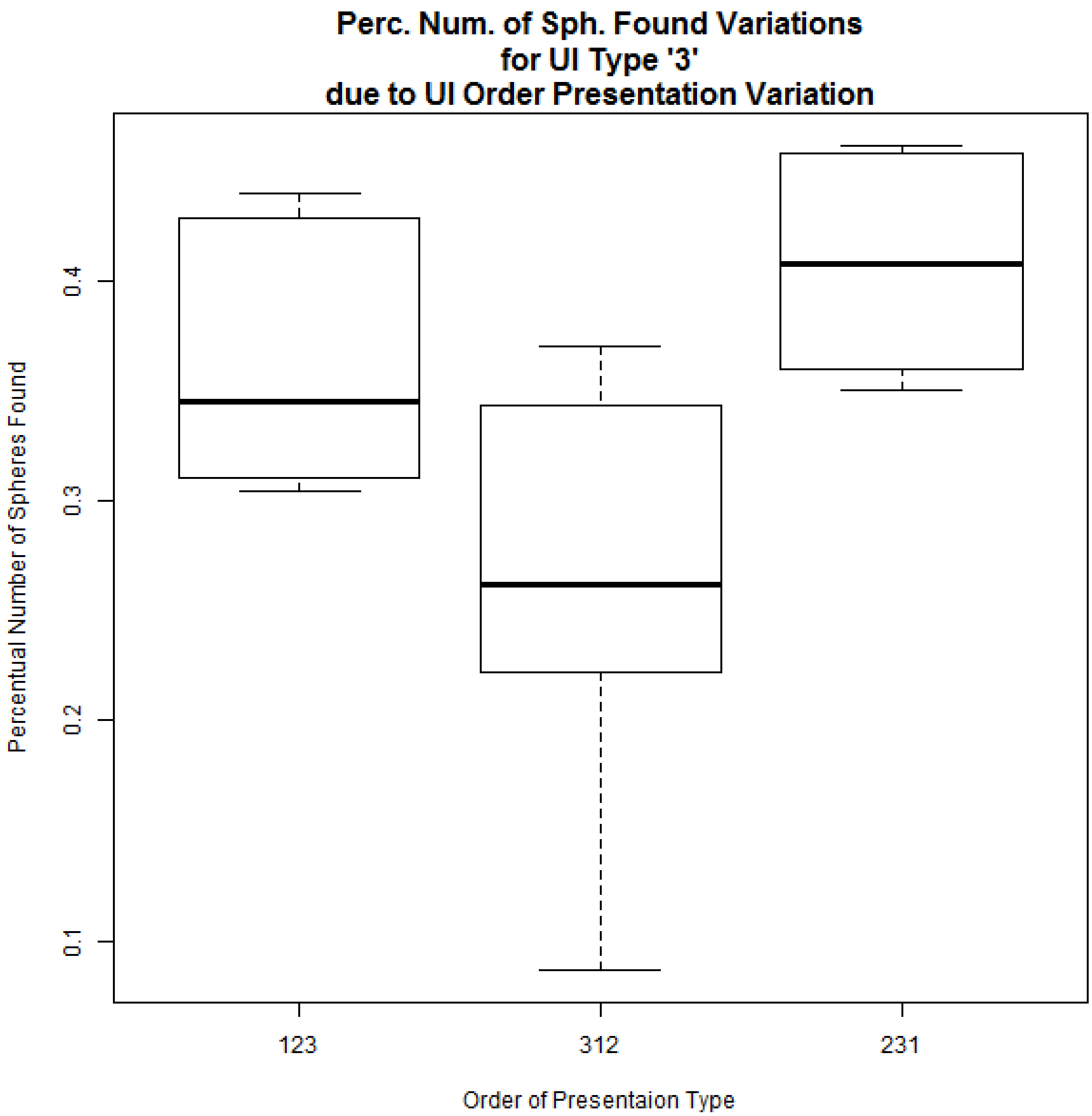
ANOVA: Interface 3 Normalized Number of Spheres Found in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.071	0.035	6.448	0.009
Residuals	15	0.082	0.005		

ANOVA: Interface 3 Normalized Number of Spheres Found for Interface Orders 123(3rd) and 312 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.033	0.033	4.74	0.054
Residuals	10	0.069	0.007		

ANOVA: Interface 3 Normalized Number of Spheres Found for Interface Orders 123 (3rd) and 231 (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.006	0.006	2.006	0.187
Residuals	0.030	0.003			

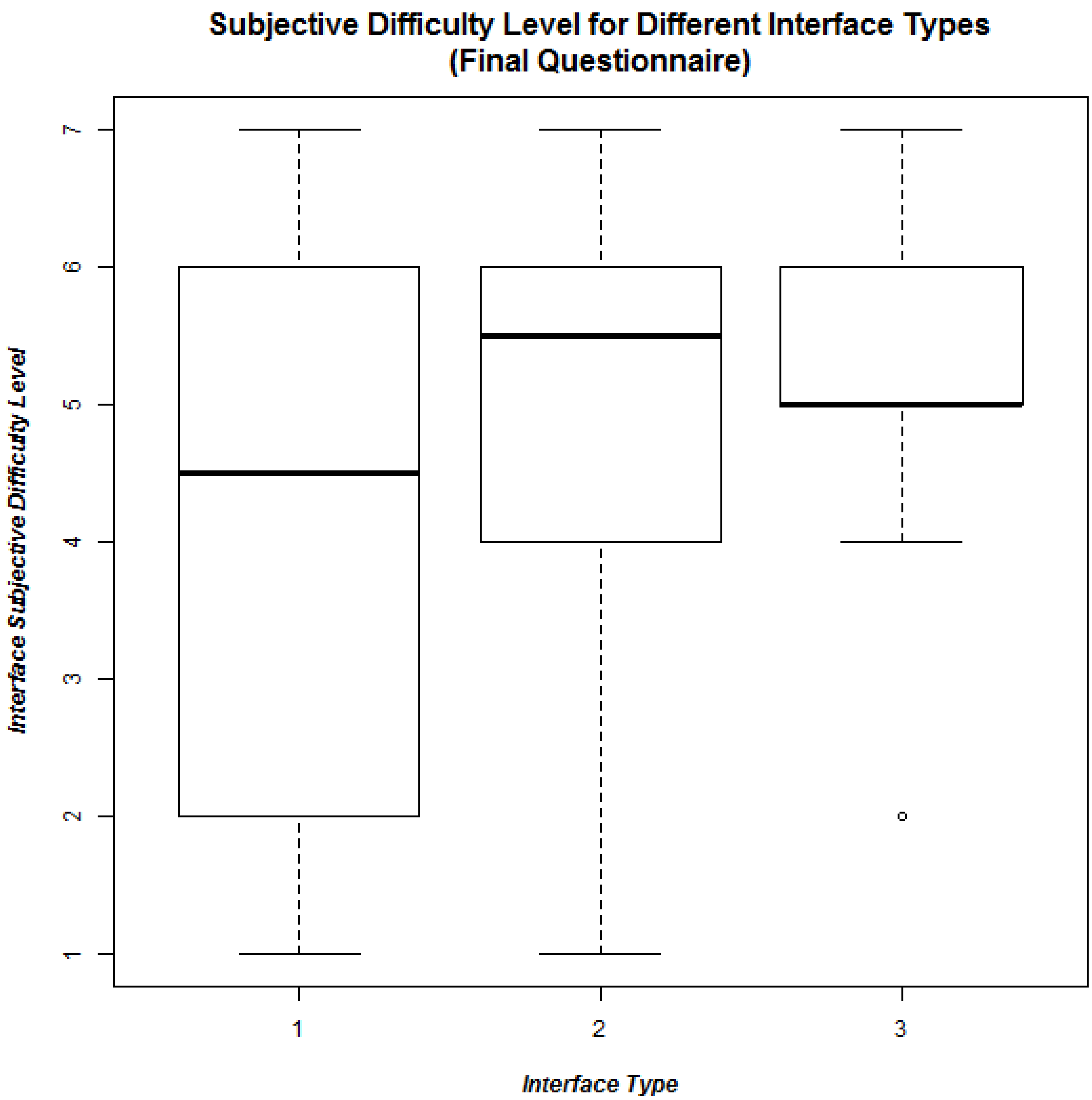
ANOVA: Interface 3 Normalized Number of Spheres Found for Interface Orders 312 (1st) and 231 (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.067	0.067	10.36	0.009
Residuals	10	0.065	0.006		

Interface 3 Normalized Number of Spheres Found vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.362	0.059	0.345
312 (3rd)	0.258	0.101	0.262
231 (1st)	0.407	0.051	0.407


Perc. Num. of Sph. Found Variations
for UI Type '3'
due to UI Order Presentation Variation
Percentual Number of Spheres Found
0.1
0.2
0.3
0.4
123
312
231
Order of Presentaion Type

C.2.5 Final Questionnaire

C.2.5.1 Difficulty+

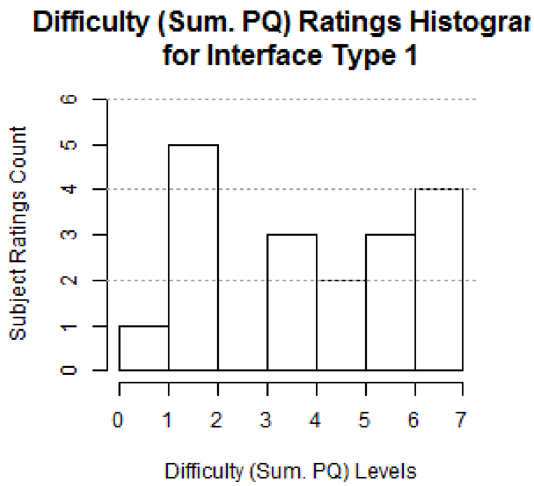


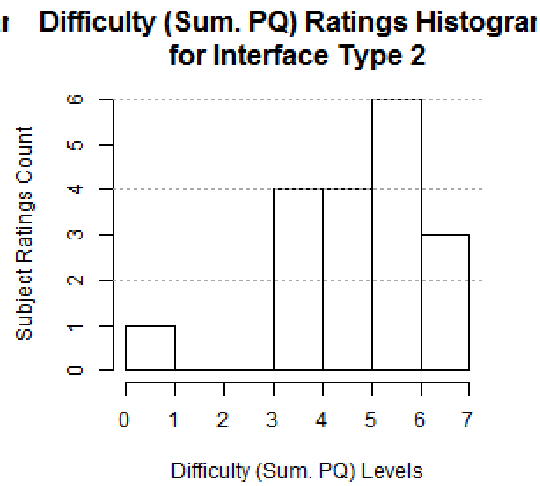
ANOVA: Difficulty Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	7.0	3.500	1.127	0.332
Residuals	51	158.3	3.105		

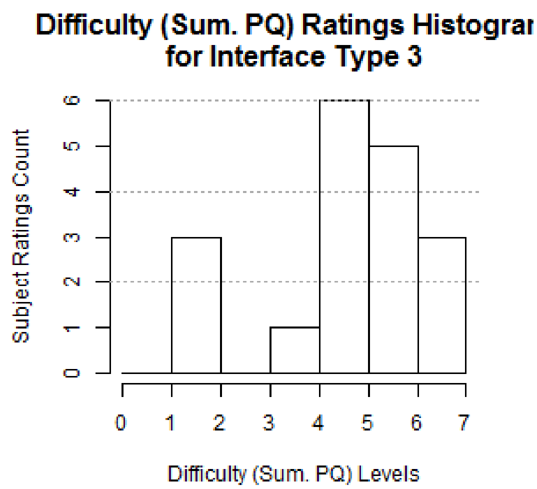
Difficulty vs. Interface Used - Friedman Test	
X^2	1.815
P	0.404
DoF	2.000

Difficulty vs. Interface Used – Wilcoxon Test			
	1 –2I	***1 –3F***	***2 –3F***
W	18.500	41.000	30.500
Z	-1.752	-1.030	0.139
p	0.089	0.323	0.932
R	-0.292	-0.172	0.023

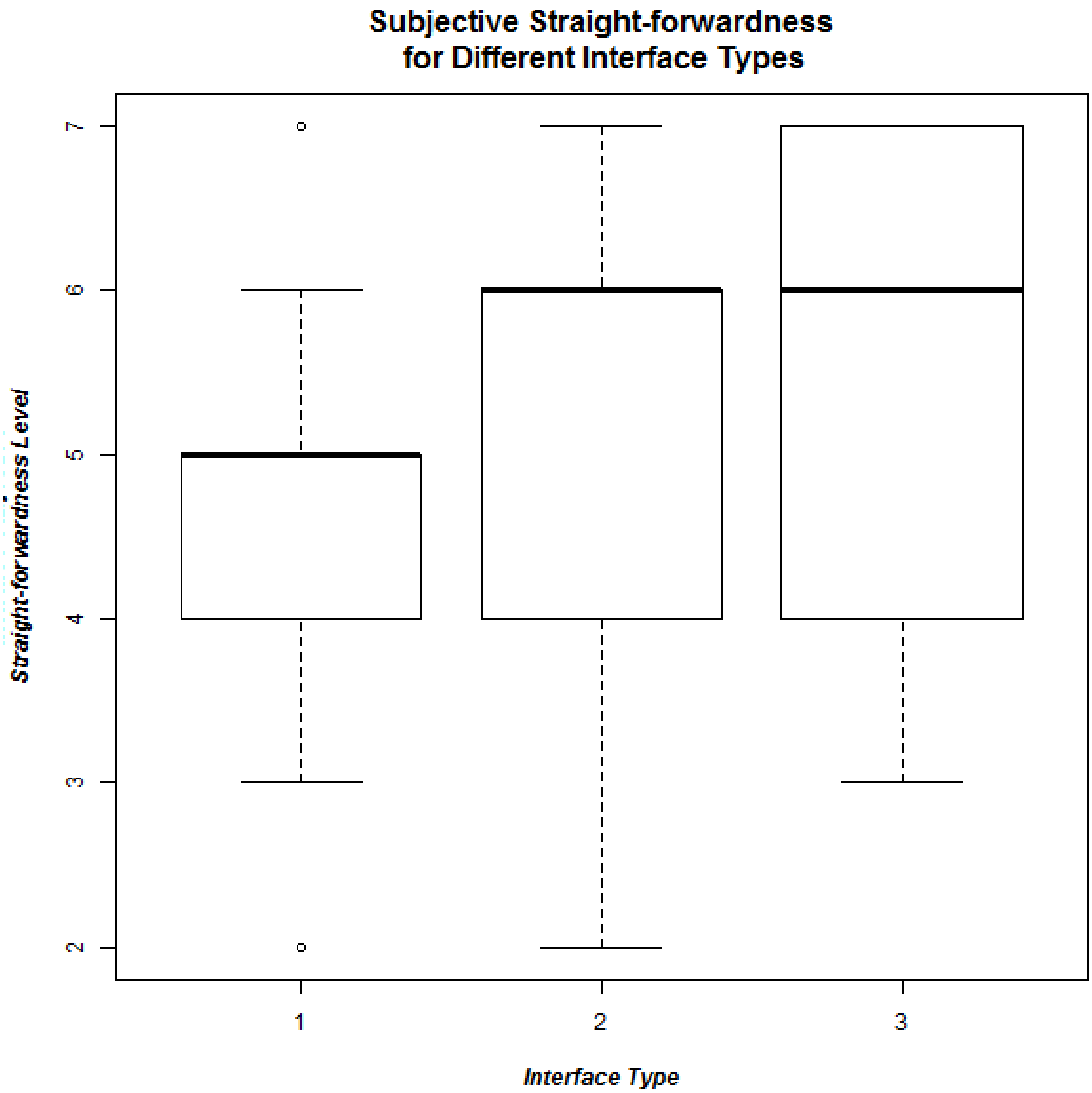
Difficulty vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	4.389	2.118	4.500
2	5.222	1.478	5.500
3	5.056	1.626	5.000







*C.2.5.2 Straight-Forwardness**

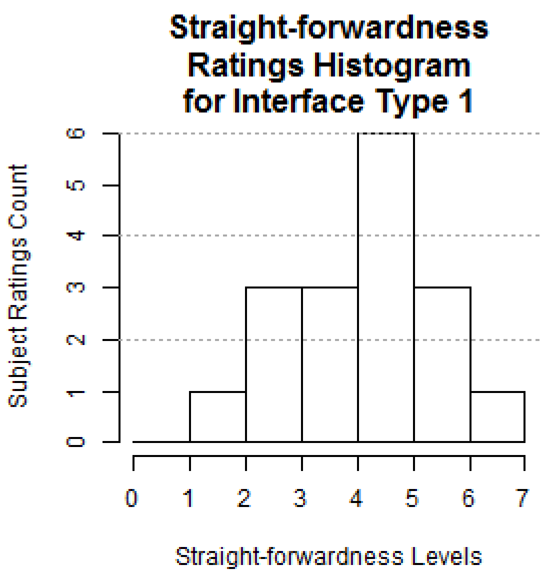


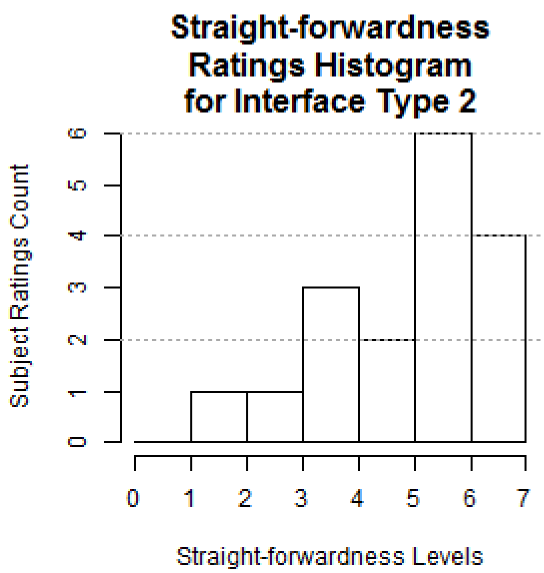
ANOVA: Straight-Forwardness Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	7.8	3.902	1.869	0.165
Residuals	51	100.2	2.088		

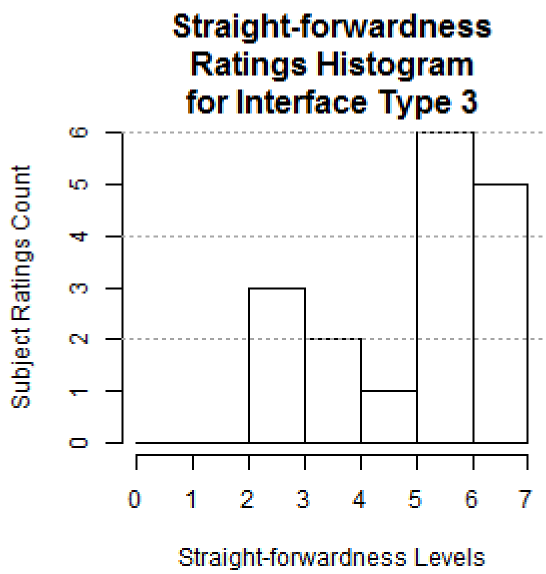
Straight-Forwardness vs. Interface Used - Friedman Test	
X^2	5.522
p	0.063
DoF	2.000

Straight-Forwardness vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	10.000	15.000	21.5000
Z	-2.152	-1.886	-0.252
p	0.041	0.071	0.812
R	-0.359	-0.314	-0.042

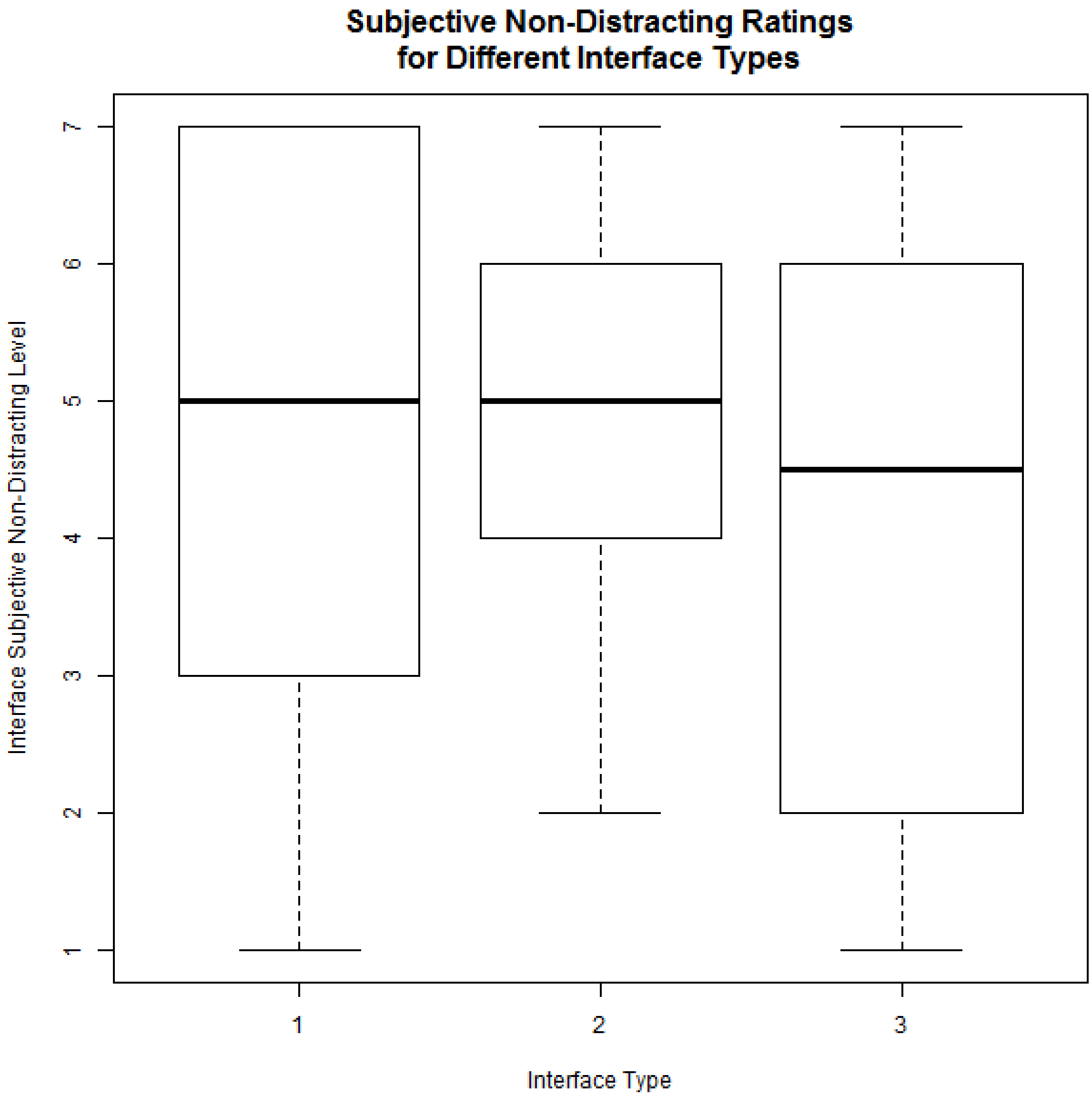
Straight-Forwardness vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	4.588	1.326	5.000
2	1.353	1.498	6.000
3	5.471	1.505	6.000







C.2.5.3 Non-distracting

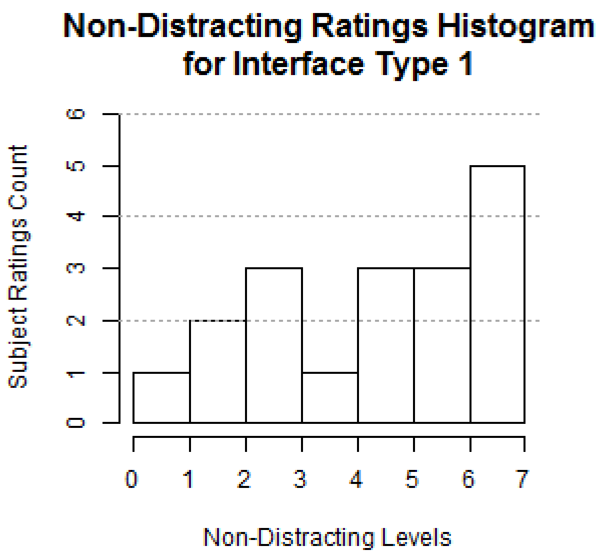


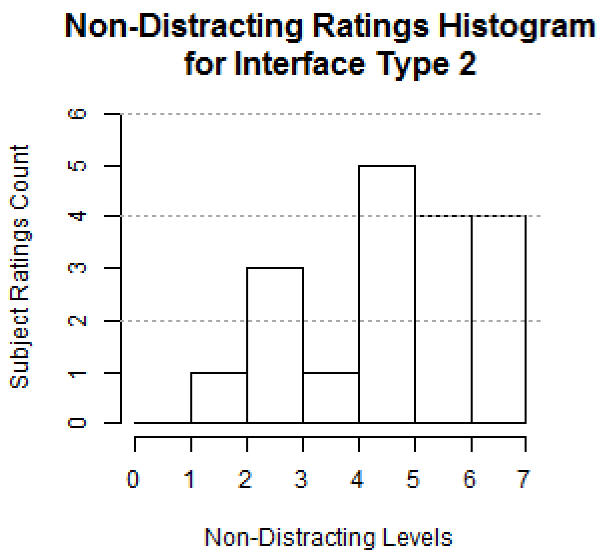
ANOVA: Not-Distracting Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	5.48	2.71	0.764	0.471
Residuals	51	182.89	3.586		

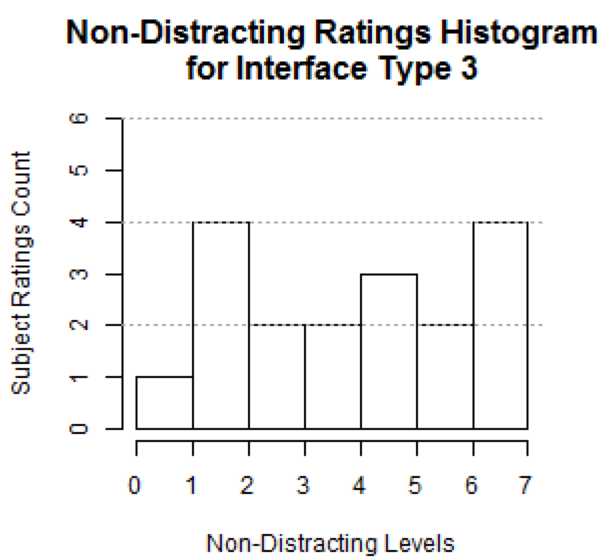
Not-Distracting vs. Interface Used - Friedman Test	
X^2	3.714
p	0.156
DoF	2.000

Not-Distracting vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	27.000	56.500	41.500
Z	-1.075	0.819	1.746
p	0.317	0.419	0.098
R	-0.179	0.136	0.291

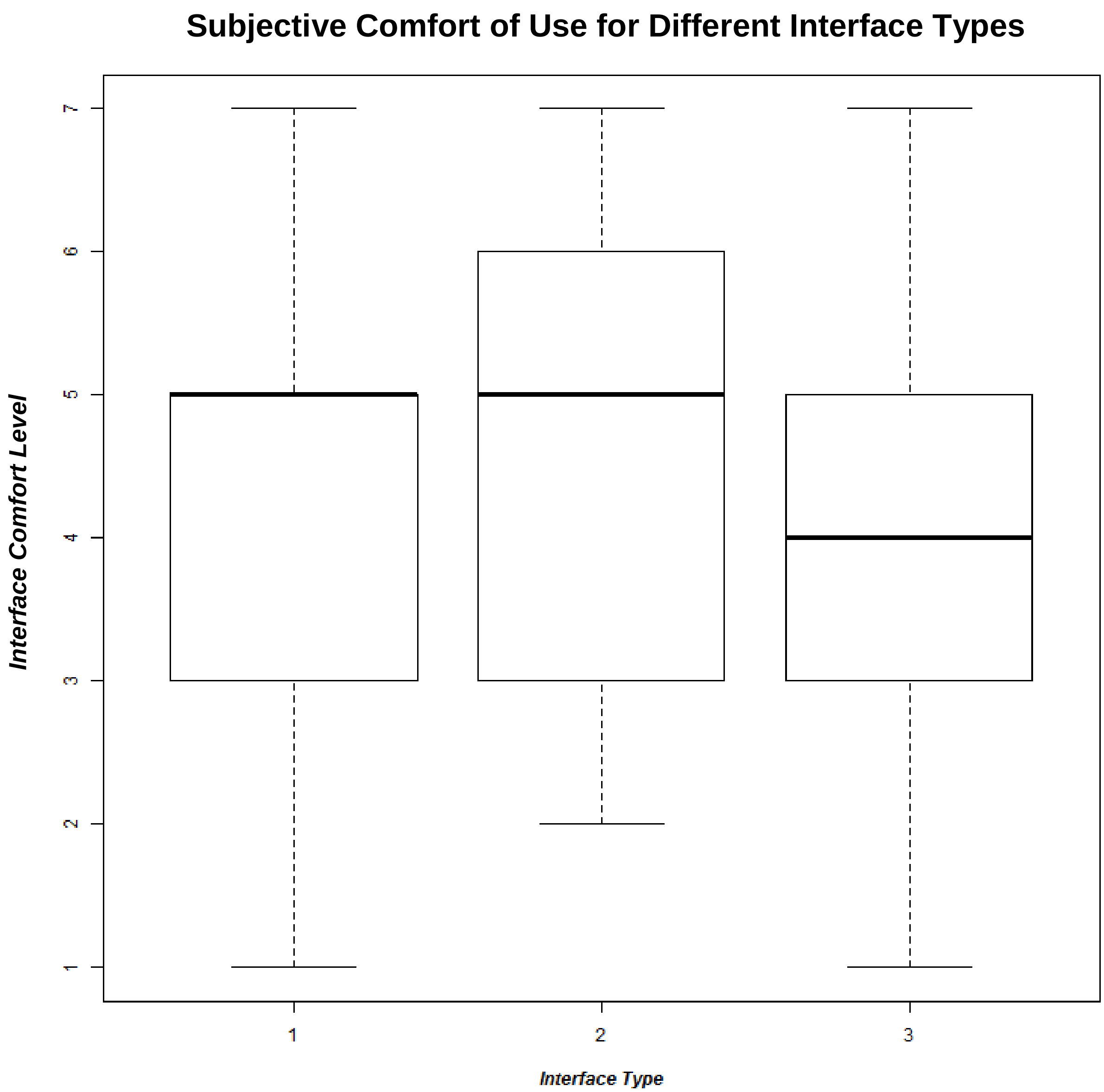
Not-Distracting vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	4.778	2.016	5.000
2	5.111	1.568	5.000
3	4.333	2.058	4.500







*C.2.5.4 Comfort**

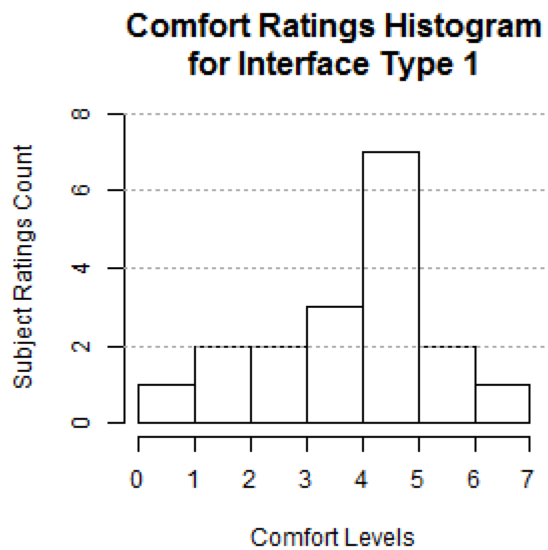


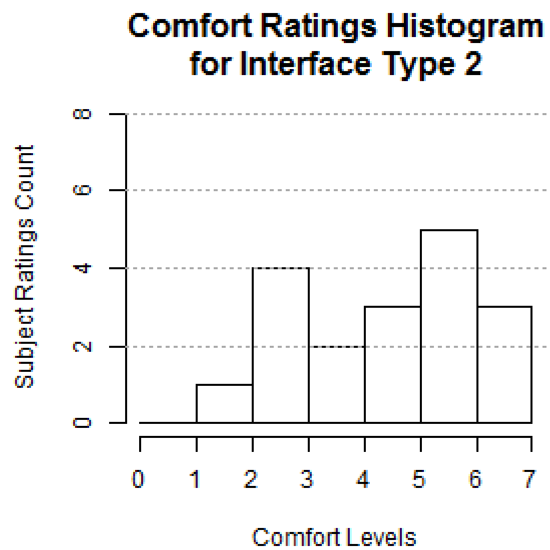
ANOVA: Comfort Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	6.04	3.018	1.23	0.301
Residuals	51	125.17	2.454		

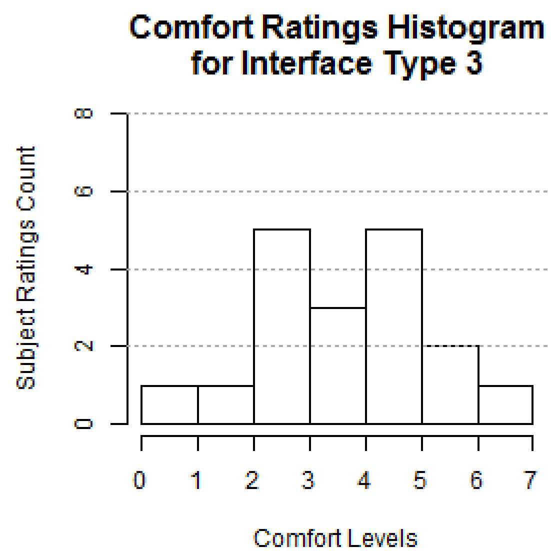
Comfort vs. Interface Used - Friedman Test	
X^2	5.511
p	0.064
DoF	2.000

Comfort vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	14.500	44.000	31.000
Z	-2.183	-0.045	1.592
p	0.032	1.000	0.117
R	-0364	-0.007	0.265

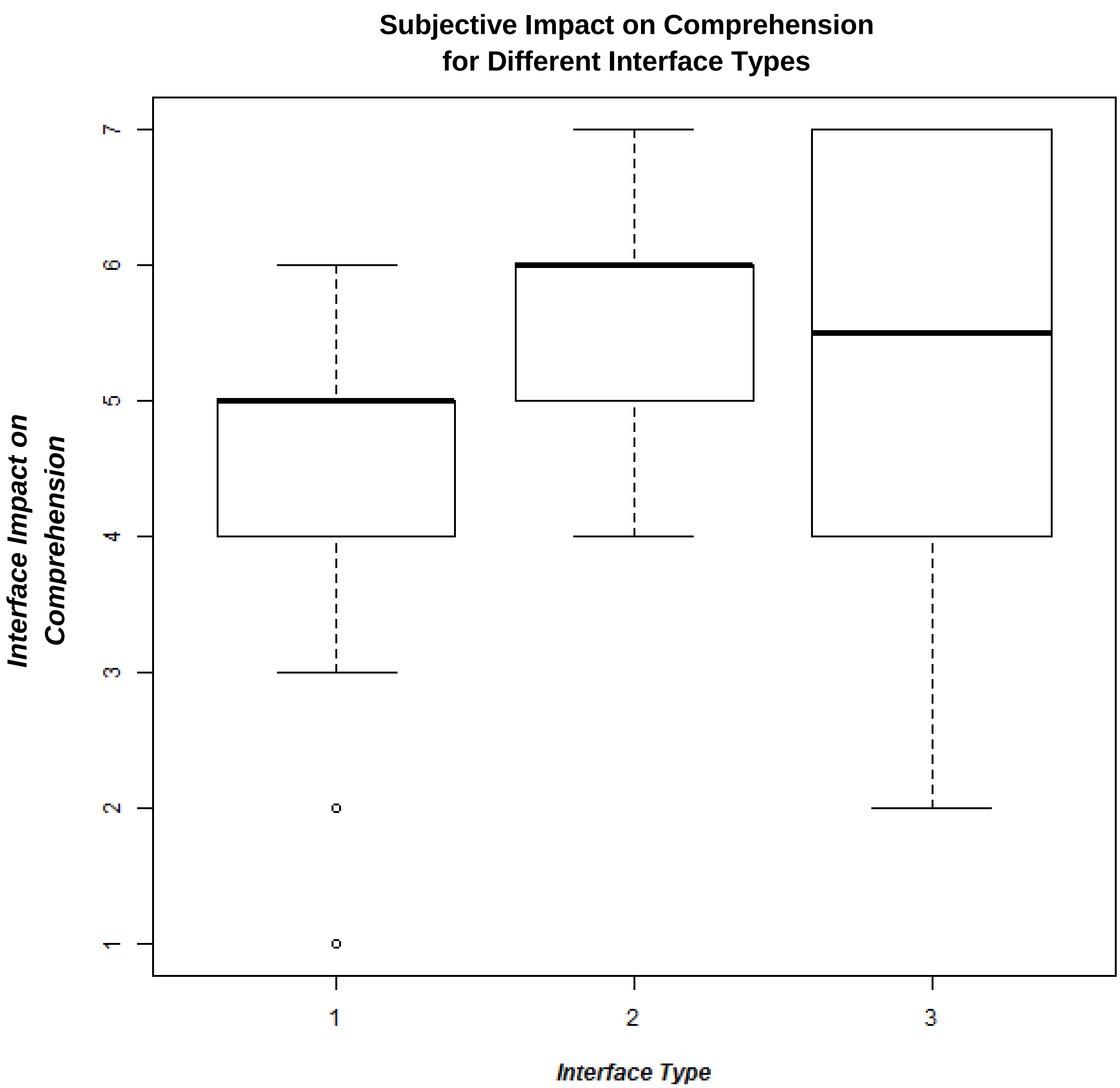
Comfort vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	4.278	1.565	5.000
2	4.889	1.605	5.000
3	4.111	1.530	4.000







*C.2.5.5 Help in Understanding**

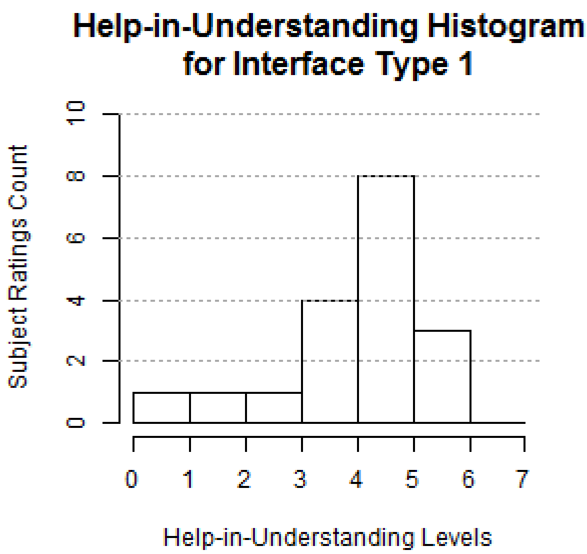


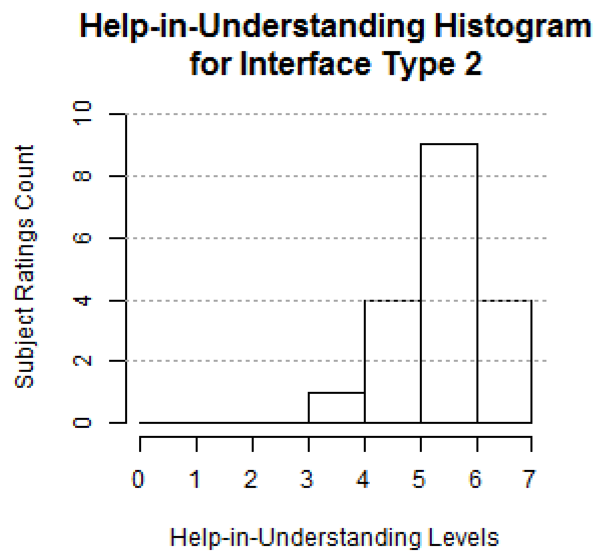
ANOVA: Help-in-Understanding Levels for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	18.93	9.463	4.867	0.012
Residuals	51	99.17	1.944		

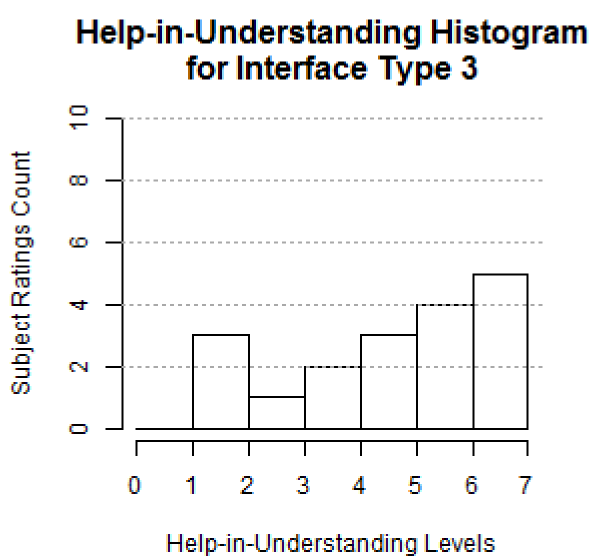
Help-in-Understanding vs. Interface Used - Friedman Test	
X^2	10.982
p	0.004
DoF	2.000

Help-in-Understanding vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	3.500	50.000	38.000
Z	-3.358	-1.053	1.359
p	< 0.001	0.299	0.188
R	-0.560	-0.176	0.227

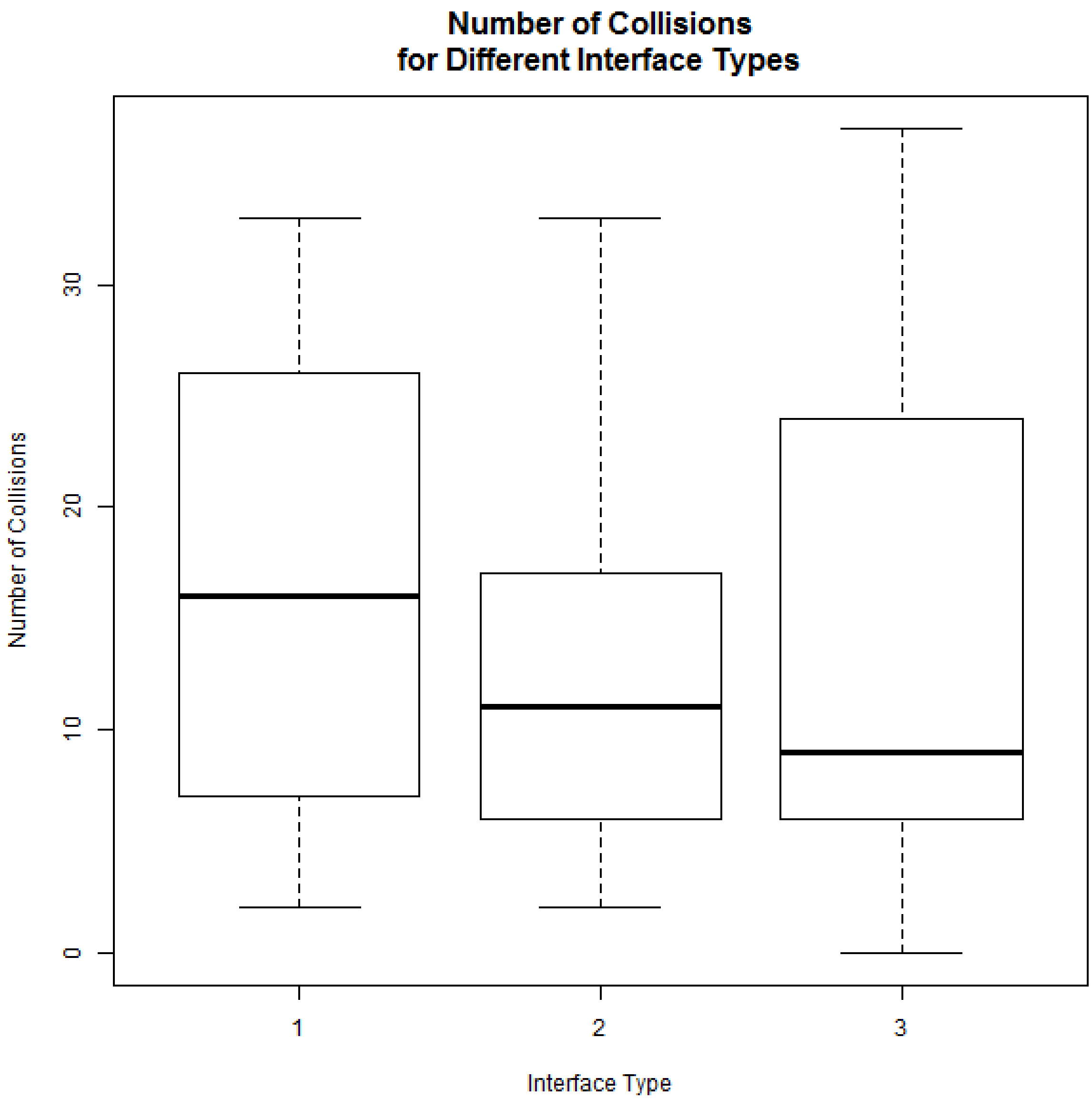
Help-in-Understanding vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	4.444	1.338	5.000
2	5.889	0.832	6.000
3	5.056	1.830	5.500





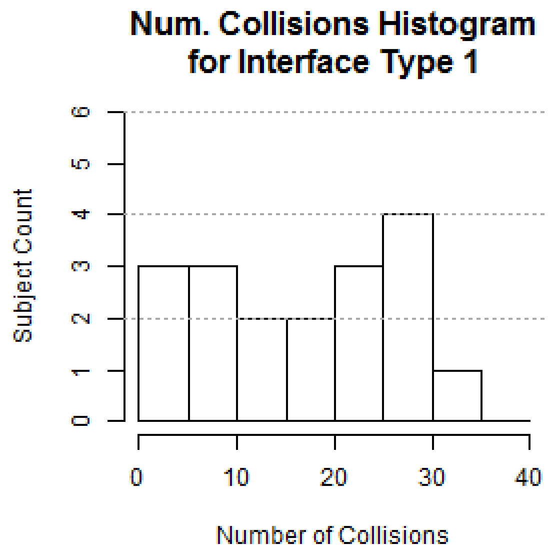


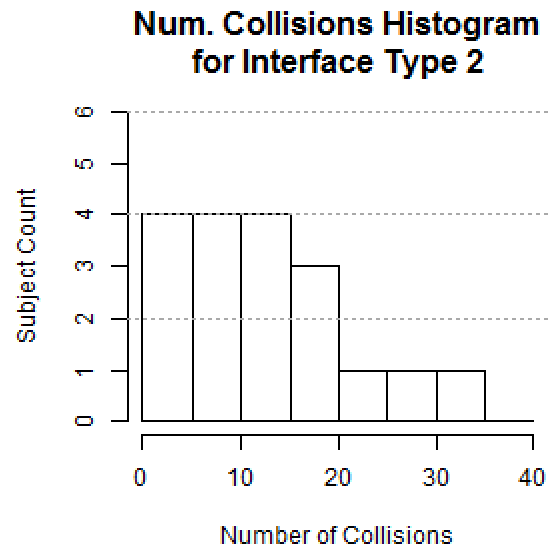
C.2.6 Number of Collisions

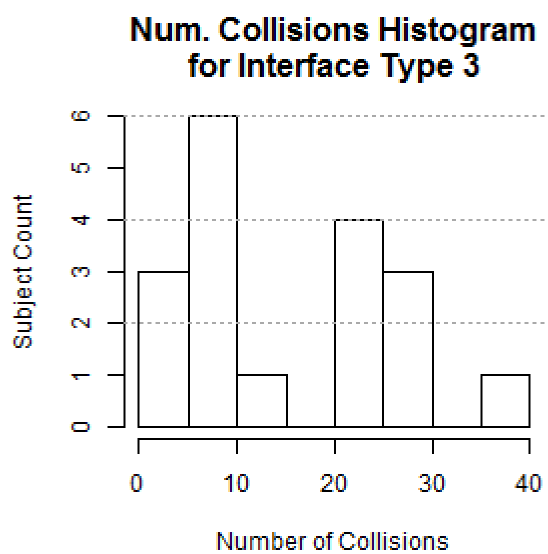


ANOVA: Number of Collisions for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	165	82.72	0.81	0.451
Residuals	51	5210	102.16		

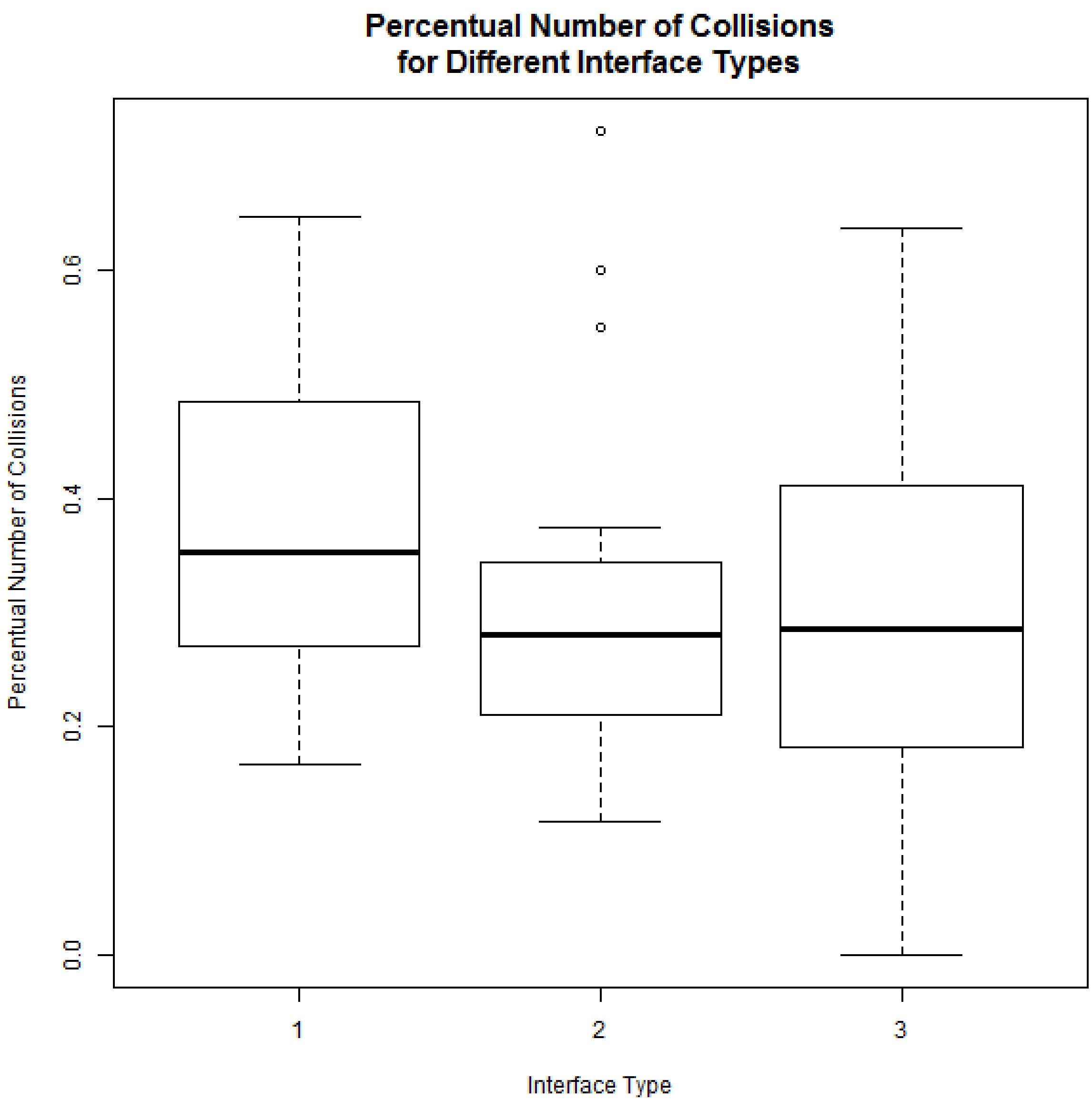
Number of Collisions vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	17.056	9.932	16.000
2	12.778	8.586	11.000
3	14.667	11.581	9.000


Num. Collisions Histogram
for Interface Type 1
Subject Count
0
1
2
3
4
5
6
0
10
20
30
40
Number of Collisions

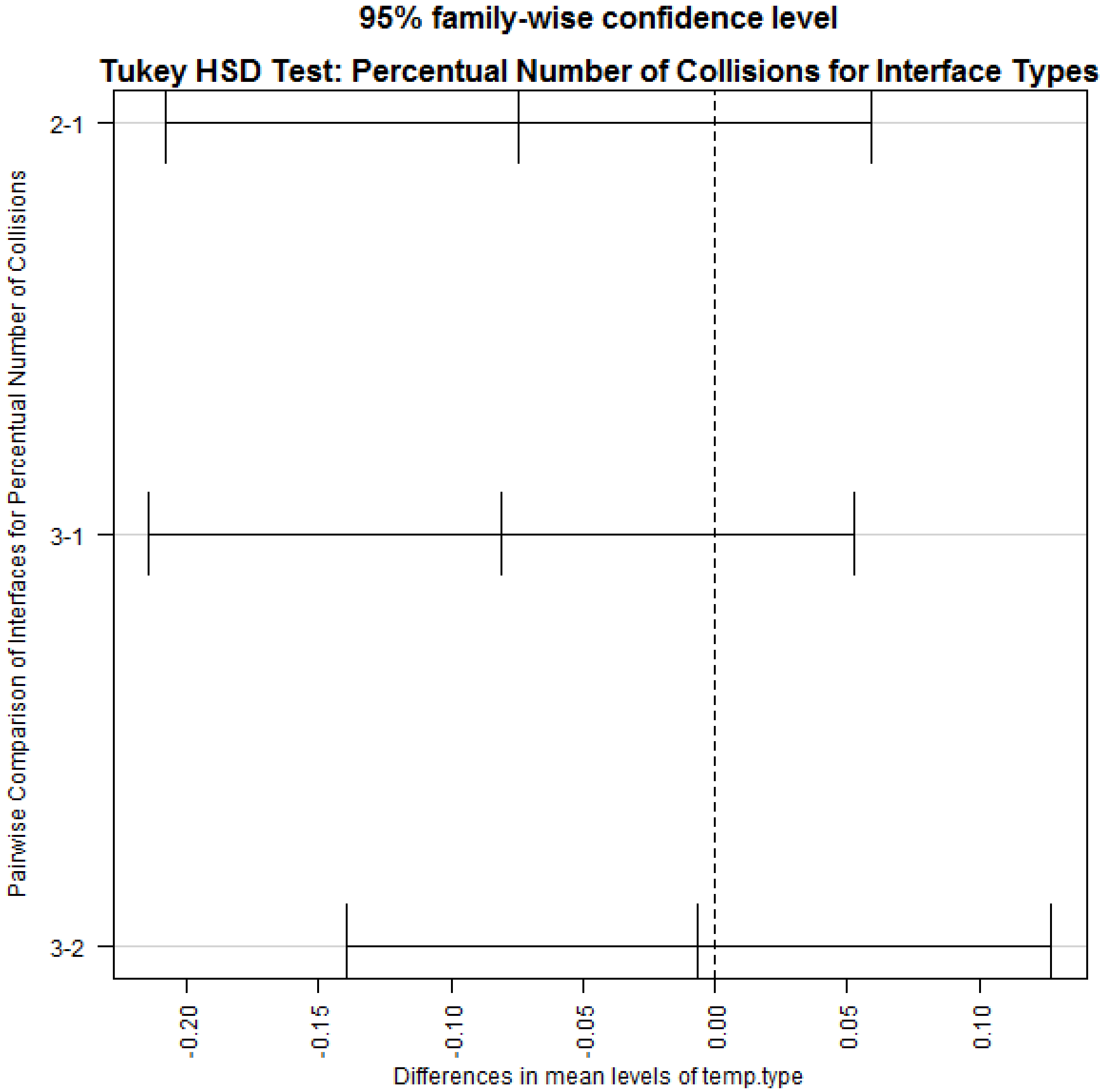

Num. Collisions Histogram
for Interface Type 2
Subject Count
0
1
2
3
4
5
6
0
10
20
30
40
Number of Collisions


Num. Collisions Histogram
for Interface Type 3
Subject Count
0
1
2
3
4
5
6
0
10
20
30
40
Number of Collisions

C.2.6.1 Normalized Number of Collisions



ANOVA: Normalized Number of Collisions for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.072	0.036	1.321	0.276
Residuals	51	1.401	0.027		



ANOVA: Normalized Number of Collisions for Groups With Interface Types 1 and 3					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.059	0.059	2.112	0.155
Residuals	34	0.943	0.028		

ANOVA: Normalized Number of Collisions for Groups With Interface Types 1 and 2					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.050	0.050	2.047	0.162
Residuals	34	0.828	0.024		

ANOVA: Normalized Number of Collisions for Groups With Interface Types 2 and 3					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.000	0.000	0.012	0.915
Residuals	34	1.030	0.030		

Normalized Number of Collisions vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.385	0.148	0.353
2	0.311	0.164	0.280
3	0304	0.184	0.285

*C.2.6.2 Interface Order Effect on Number of Collisions**

C.2.6.2.1 Interface 1

ANOVA: Interface 1 Number of Collisions in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	198.1	99.06	1.005	0.389
Residuals	15	1478.8	98.59		

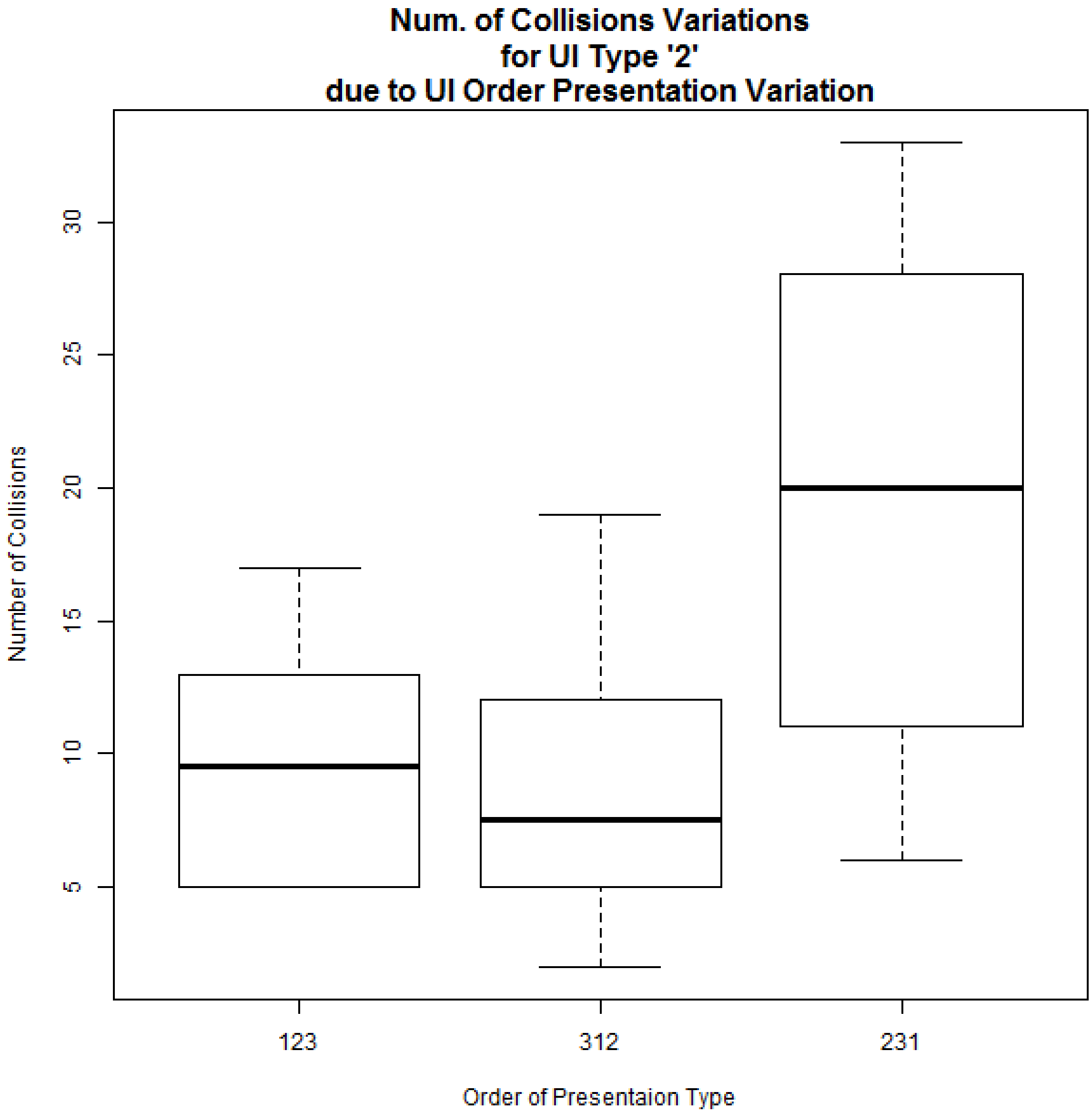
Interface 1 Number of Collisions vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	15.500	8.689	15.000
312 (3rd)	14.000	12.133	11.000
231 (1st)	21.667	8.548	25.500

ANOVA: Interface 1 Normalized Number of Collisions in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.025	0.012	0.535	0.596
Residuals	15	0.346	0.023		

Interface 3 Normalized Number of Collisions vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.434	0.190	0.480
312 (3rd)	0.377	0.177	0.362
231 (1st)	0.344	0.043	0.349

C.2.6.2.2 Interface 2

ANOVA: Interface 2 Number of Collisions in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	430.1	215.06	3.92	0.043
Residuals	15	823.0	54.87		



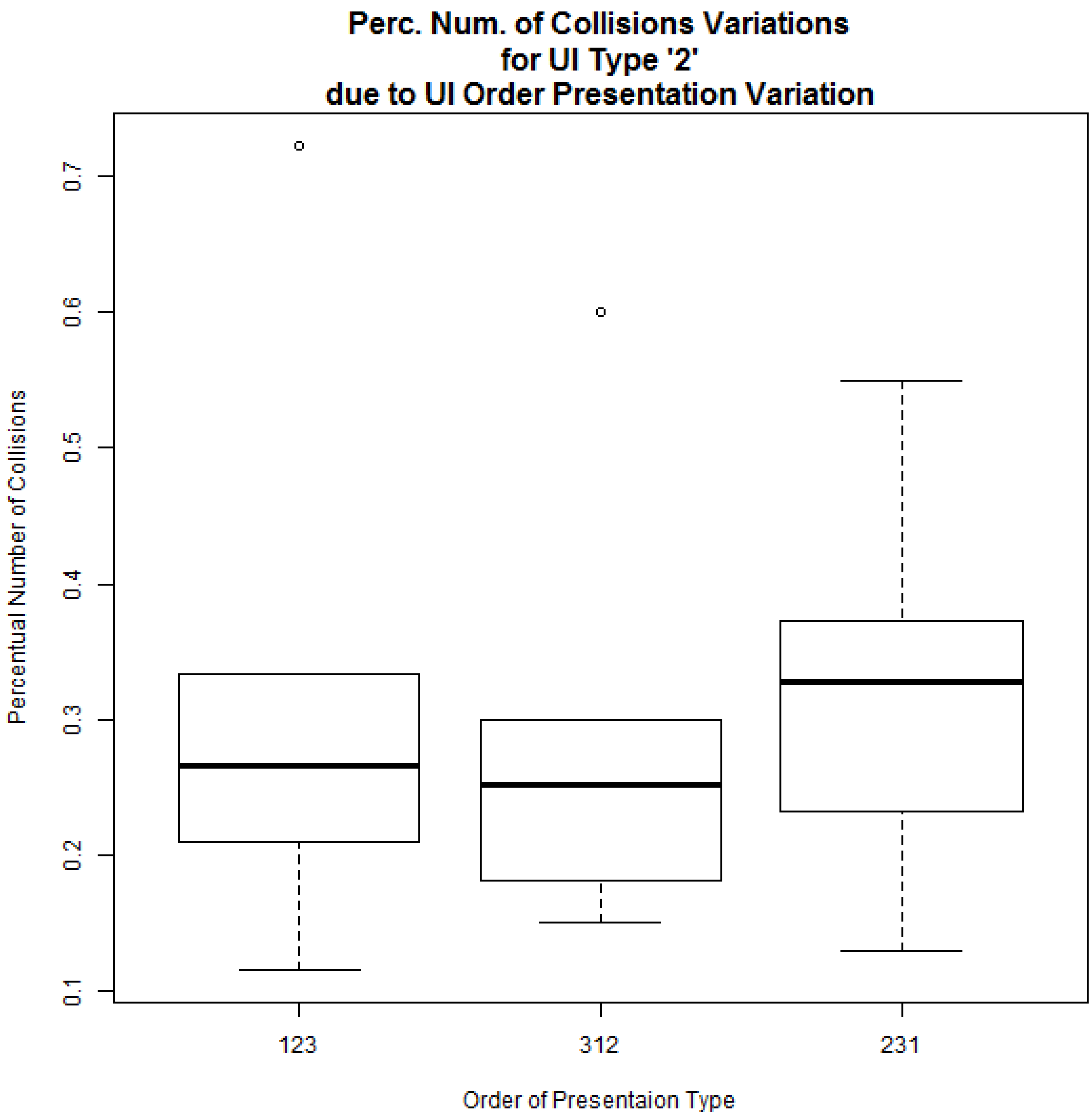
ANOVA: Interface 2 Number of Collisions for Interface Orders 123(2nd) and 312 (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	3.0	3.0	0.101	0.757
Residuals	10	295.7	29.57		

ANOVA: Interface 2 Number of Collisions for Interface Orders 123 (2^{nd}) and 231 (1^{st})					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	290.1	290.08	4.531	0.059
Residuals	10	640.2	64.02		

ANOVA: Interface 2 Number of Collisions for Interface Orders 312 (3^{rd}) and 231 (1^{st})					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	352.1	352.1	4.958	0.05
Residuals	10	710.2	71.0		

Interface 2 Number of Collisions vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2^{nd})	9.833	4.750	9.500
312 (3^{rd})	8.833	6.047	7.500
231 (1^{st})	19.667	10.270	20.000

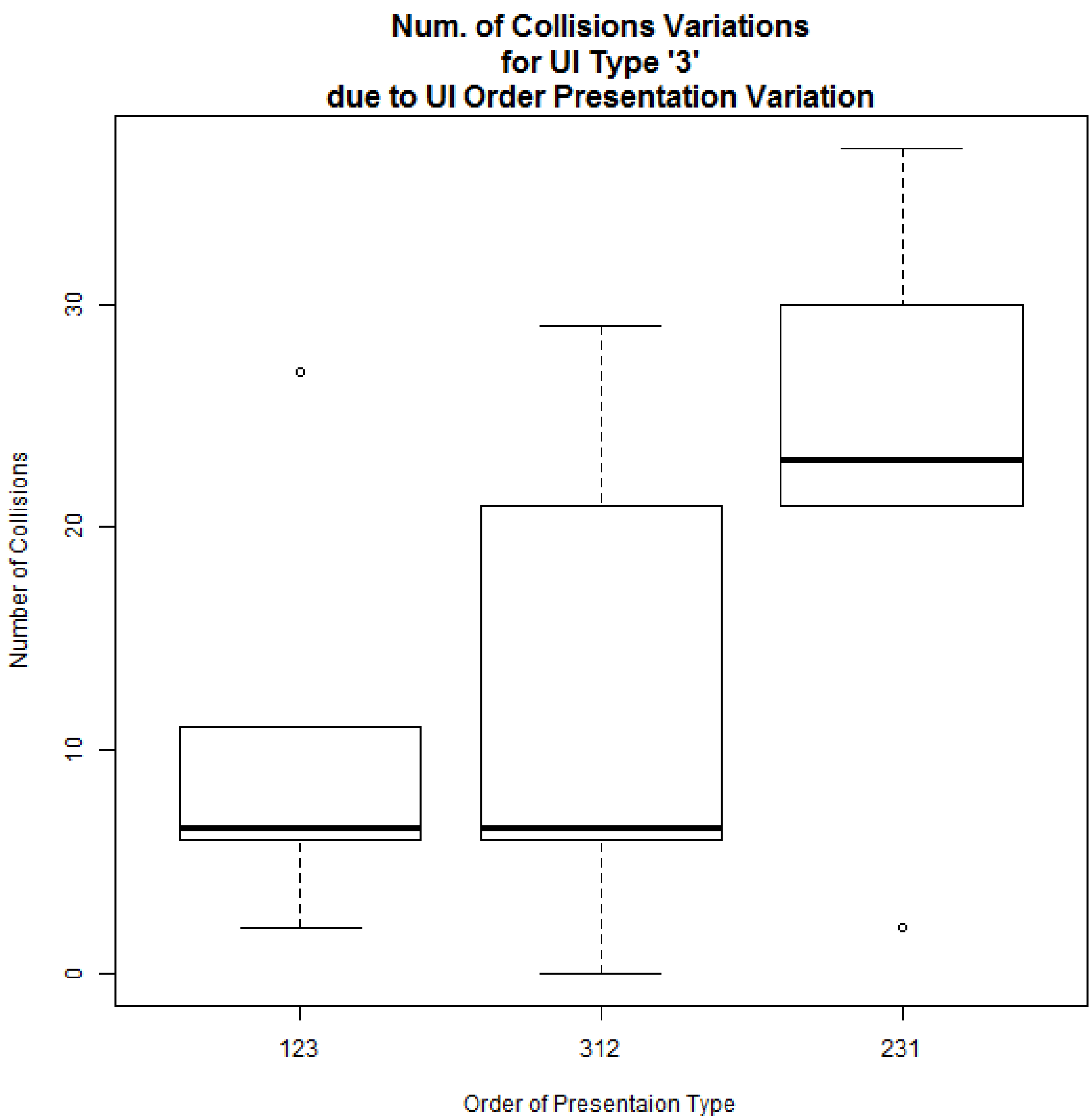
ANOVA: Interface 2 Normalized Number of Collisions in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.004	0.002	0.068	0.934
Residuals	15	0.453	0.030		



Interface 2 Normalized Number of Collisions vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.319	0.211	0.265
312 (3rd)	0.289	0.161	0.251
231 (1st)	0.323	0.141	0.327

C.2.6.2.3 Interface 3

ANOVA: Interface 3 Number of Collisions in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	584.3	292.2	2.585	0.109
Residuals	15	1695.7	113.0		



ANOVA: Interface 3 Number of Collisions for Interface Orders 123(3rd) and 312 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	8.3	8.33	0.083	0.779
Residuals	10	1004.3	100.43		

ANOVA: Interface 3 Number of Collisions for Interface Orders 123 (3rd) and 231 (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	494.1	494.1	4.549	0.059
Residuals	10	1086.2	108.6		

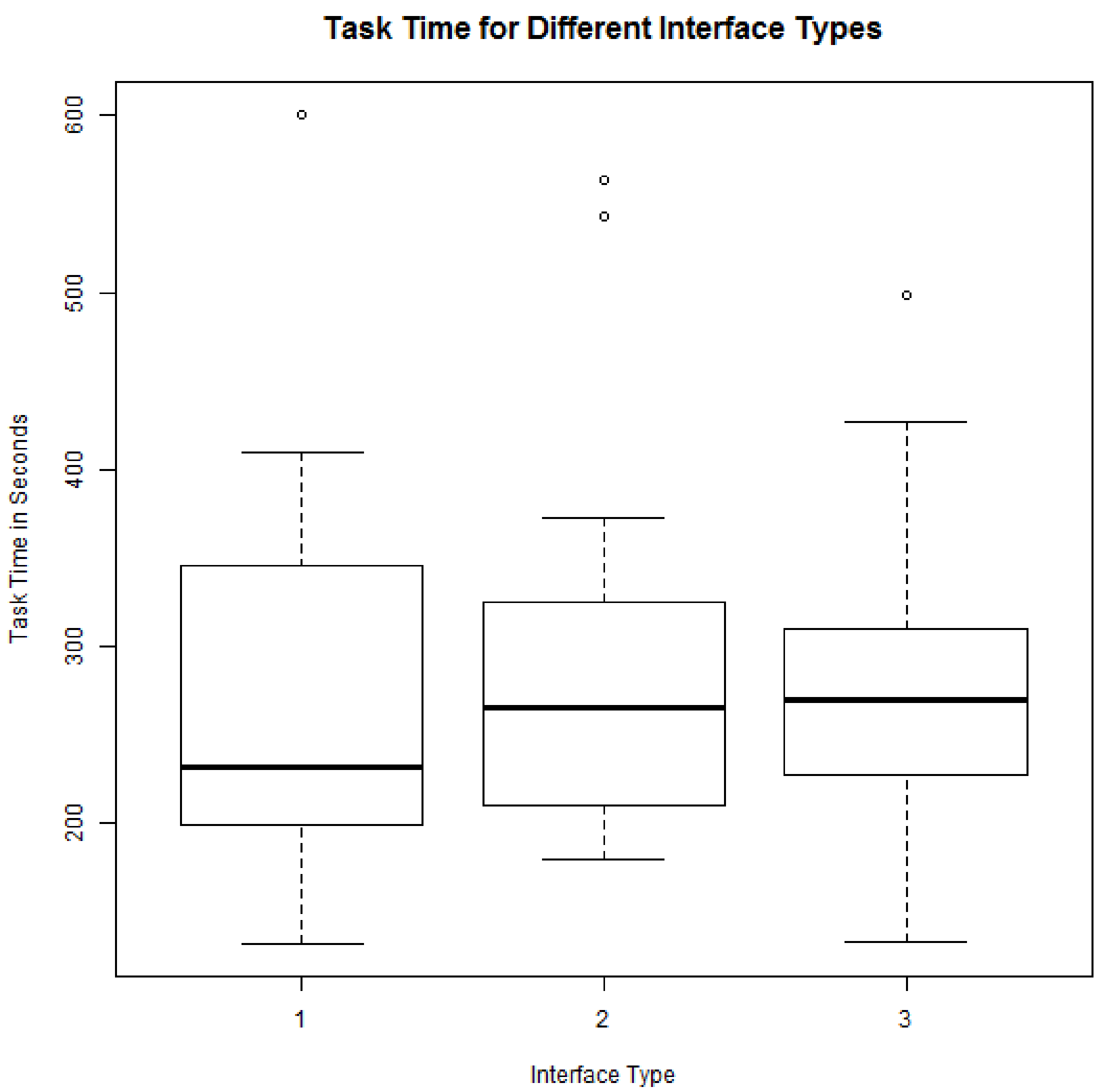
ANOVA: Interface 3 Number of Collisions for Interface Orders 312 (1st) and 231 (2nd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	374.1	374.1	2.876	0.121
Residuals	10	1300.8	130.1		

Interface 3 Number of Collisions vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	9.833	8.886	6.500
312 (3rd)	11.500	11.040	6.500
231 (1st)	22.667	11.758	23.000

ANOVA: Interface 3 Normalized Number of Collisions in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.029	0.014	0.403	0.675
Residuals	15	0.543	0.036		

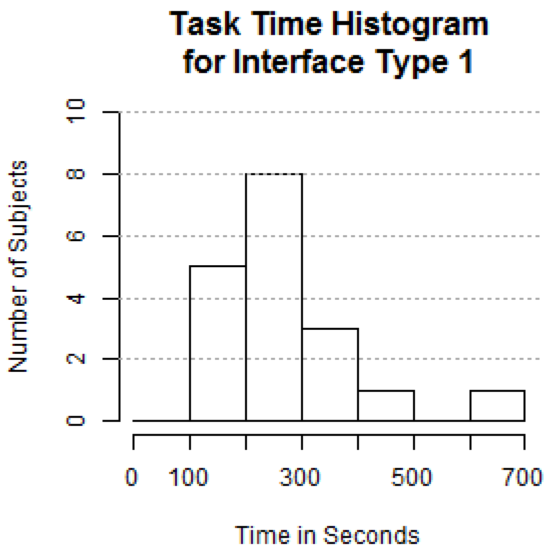
Interface 3 Normalized Number of Collisions vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.247	0.123	0.220
312 (3rd)	0.333	0.270	0.304
231 (1st)	0.332	0.143	0.339

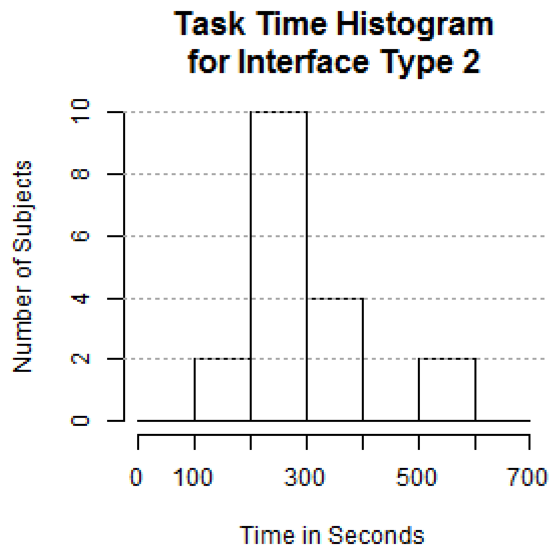
C.2.7 Task Time

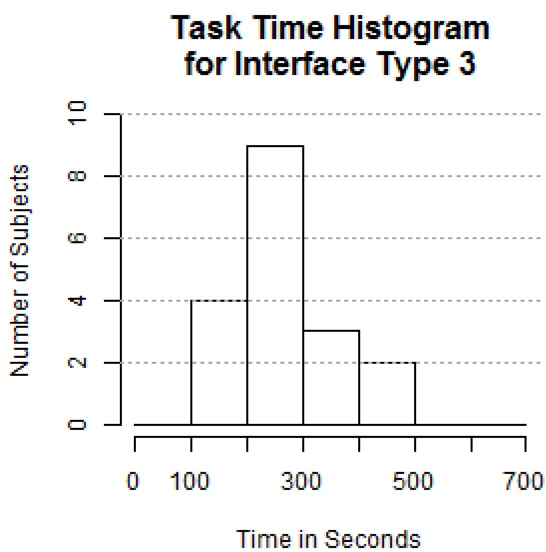


ANOVA: Task Time for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	3801	1900	0.172	0.843
Residuals	51	563693	11053		

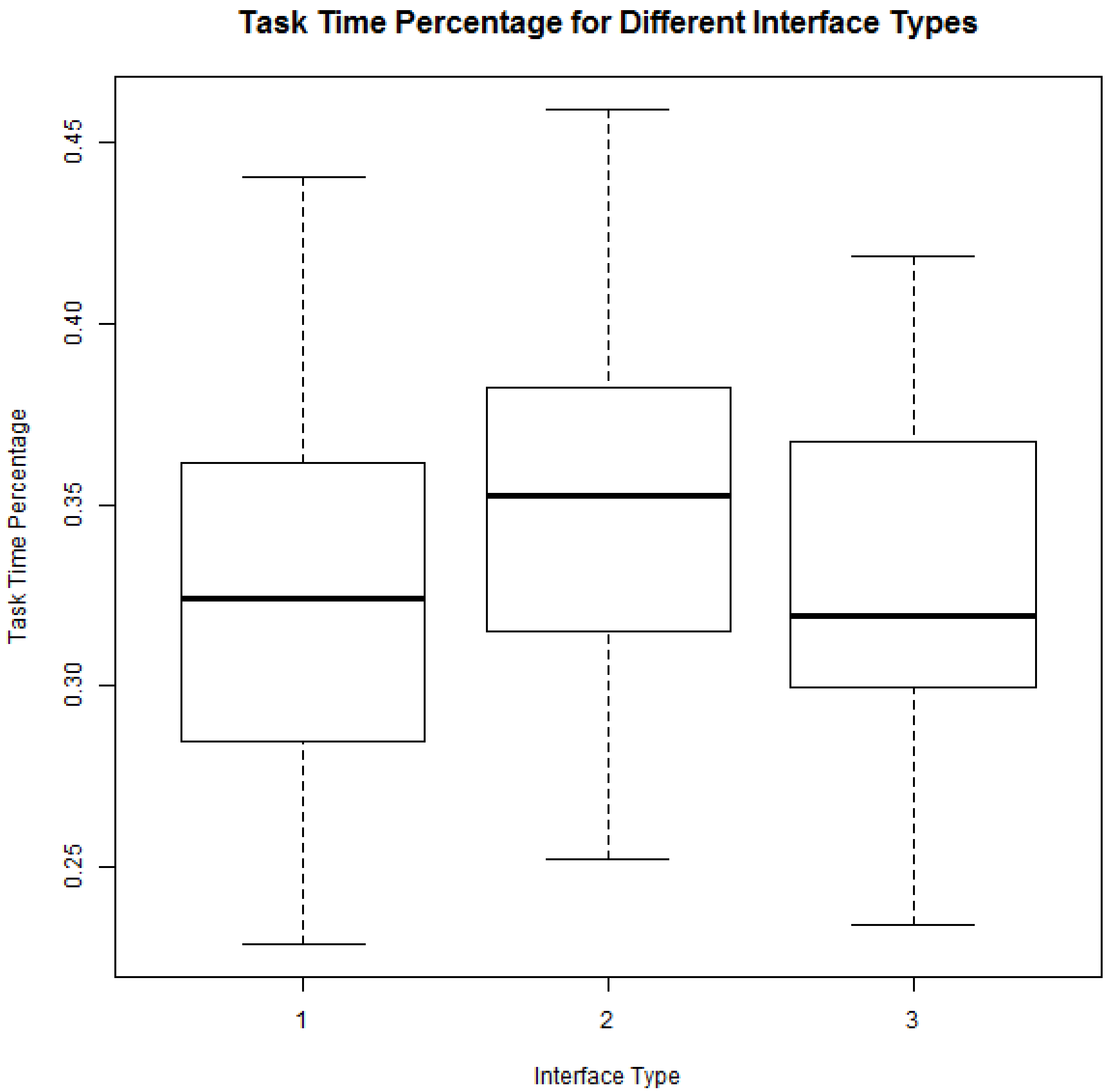
Task Time vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	274.648	111.822	231.878
2	290.749	109.238	264.715
3	271.639	93.388	269.195


Task Time Histogram
for Interface Type 1
Number of Subjects
0
2
4
6
8
10
0
100
300
500
700
Time in Seconds


Task Time Histogram
for Interface Type 2
Number of Subjects
0
2
4
6
8
10
0
100
300
500
700
Time in Seconds

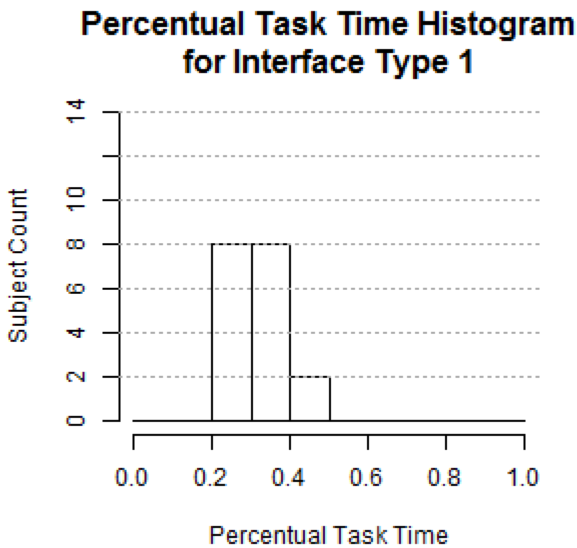

Task Time Histogram
for Interface Type 3
Number of Subjects
0
2
4
6
8
10
0
100
300
500
700
Time in Seconds

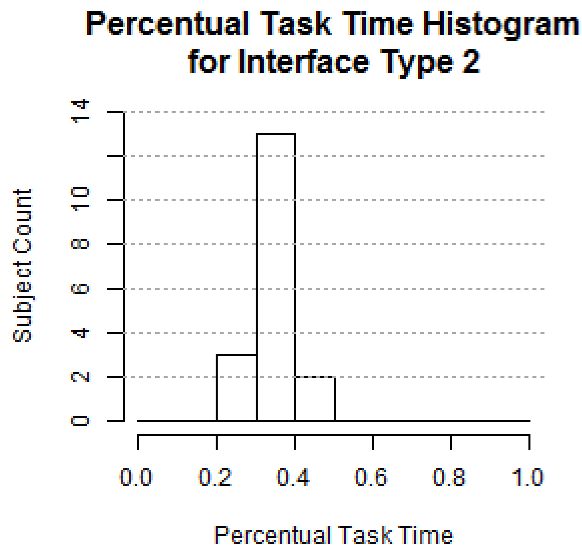
C.2.7.1 Normalized Task Time

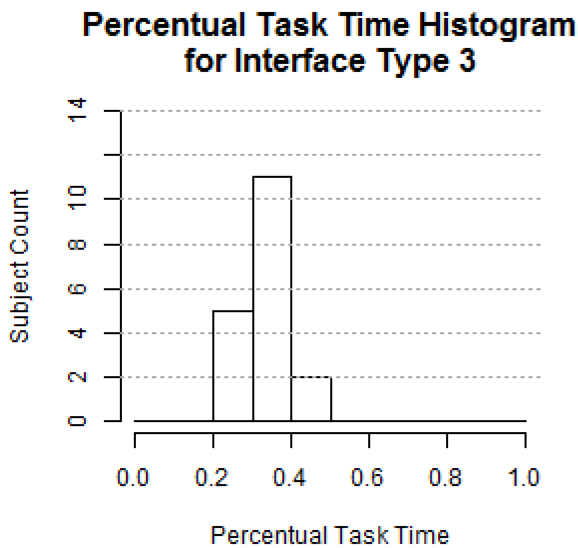


ANOVA: Normalized Task Time for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.006	0.003	1.104	0.339
Residuals	51	0.144	0.003		

Normalized Task Time vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.326	0.056	0.324
2	0.349	0.052	0.352
3	0.325	0.051	0.320


Percentual Task Time Histogram
for Interface Type 1
Subject Count
0
2
4
6
8
10
14
0.0
0.2
0.4
0.6
0.8
1.0
Percentual Task Time


Percentual Task Time Histogram
for Interface Type 2
Subject Count
0
2
4
6
8
10
14
0.0
0.2
0.4
0.6
0.8
1.0
Percentual Task Time


Percentual Task Time Histogram
for Interface Type 3
Subject Count
0
2
4
6
8
10
14
0.0
0.2
0.4
0.6
0.8
1.0
Percentual Task Time

*C.2.7.2 Interface Order Effect on Task Time**

C.2.7.2.1 Interface 1

ANOVA: Interface 1 Task Time in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	17692	8846	0.681	0.521
Residuals	15	194878	12992		

Interface 1 Task Time vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	236.845	92.704	228.118
312 (3rd)	273.487	82.245	252.868
231 (1st)	313.613	153.679	281.290

ANOVA: Interface 1 Normalized Task Time in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.007	0.003	1.151	0.343
Residuals	15	0.046	0.003		

Interface 3 Normalized Task Time vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.300	0.073	0.286
312 (3rd)	0.331	0.048	0.333
231 (1st)	0.347	0.039	0.356

C.2.7.2.2 Interface 2

ANOVA: Interface 2 Task Time in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	3369	1685	0.127	0.882
Residuals	15	199490	13299		

Interface 2 Task Time vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	284.242	42.707	284.395
312 (3rd)	309.782	132.900	273.638
231 (1st)	278.222	142.869	227.500

ANOVA: Interface 2 Normalized Task Time in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.012	0.006	2.781	0.093
Residuals	15	0.034	0.002		

ANOVA: Interface 2 Normalized Task Time for Interface Orders 123(2nd) and 312 (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.000	0.000	0.166	0.692
Residuals	22	0.020	0.002		

ANOVA: Interface 2 Normalized Task Time for Interface Orders 123 (2nd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.011	0.011	3.983	0.074
Residuals	22	0.028	0.003		

ANOVA: Interface 2 Normalized Task Time for Interface Orders 312 (3rd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.007	0.007	3.734	0.082
Residuals	22	0.020	0.002		

Interface 2 Normalized Task Time vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.372	0.052	0.364
312 (3rd)	0.361	0.035	0.357
231 (1st)	0.312	0.053	0.311

C.2.7.2.3 Interface 3

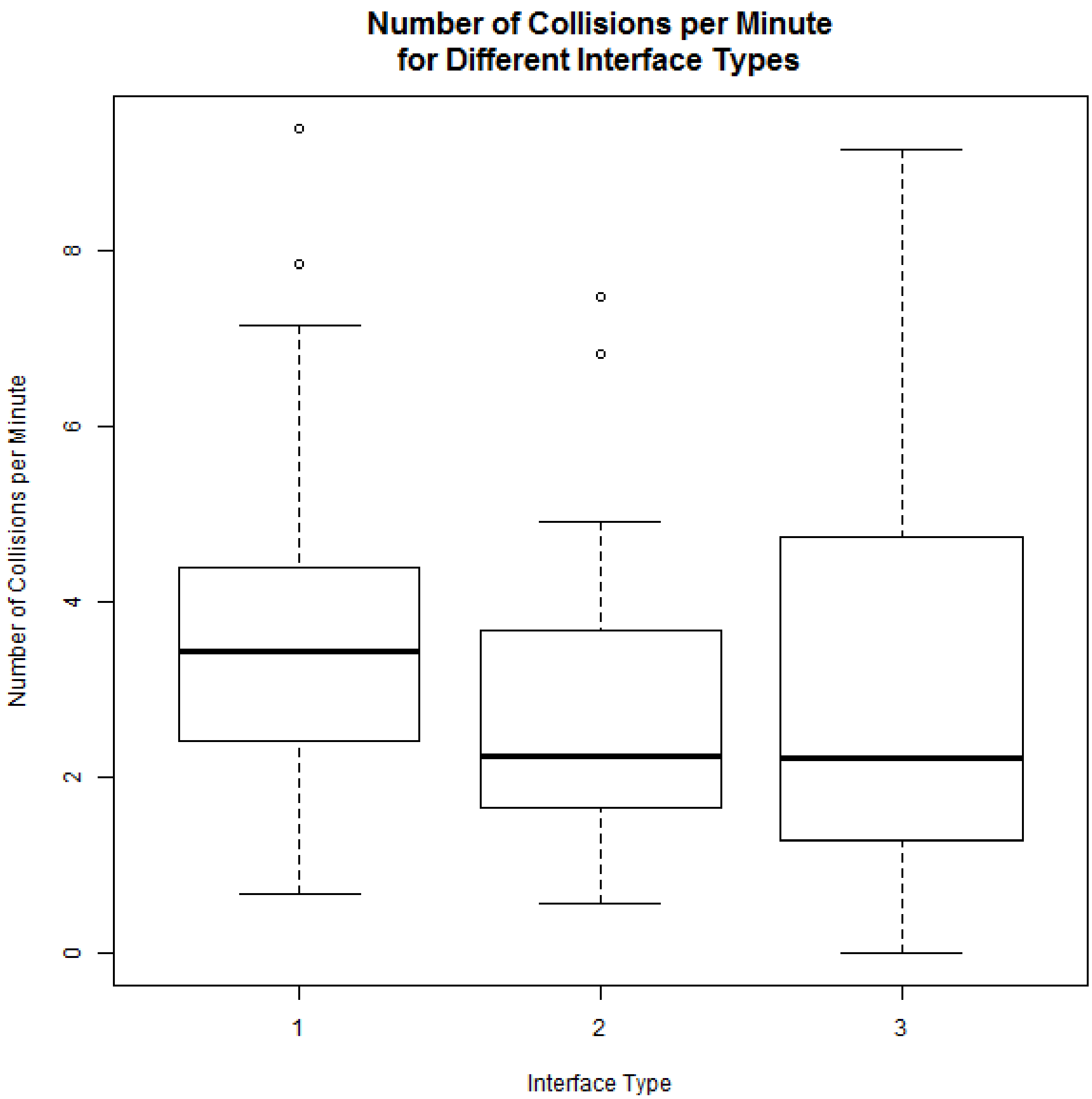
ANOVA: Interface 3 Task Time in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	8153	4076	0.436	0.654
Residuals	15	140110	9341		

Interface 3 Task Time vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	251.353	47.183	249.199
312 (3rd)	262.526	109.037	267.977
231 (1st)	301.037	117.926	286.623

ANOVA: Interface 3 Normalized Task Time in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.003	0.002	0.625	0.549
Residuals	15	0.041	0.003		

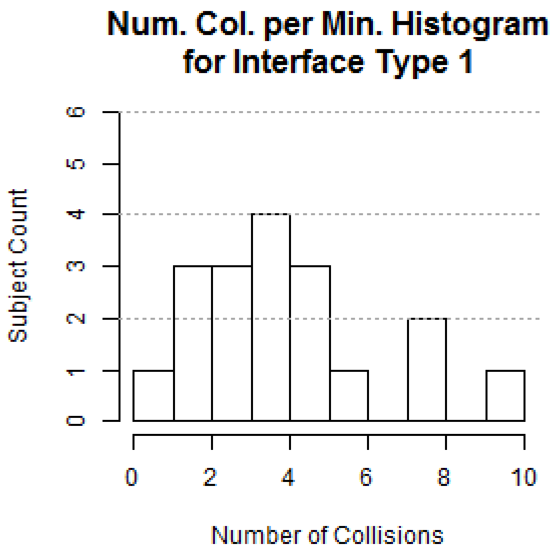
Interface 3 Normalized Task Time vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.328	0.048	0.337
312 (3rd)	0.307	0.060	0.310
231 (1st)	0.341	0.048	0.332

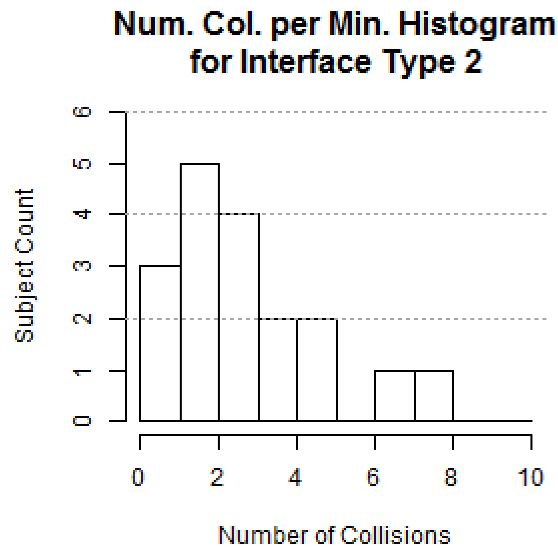
C.2.8 Number of Collisions per Minute

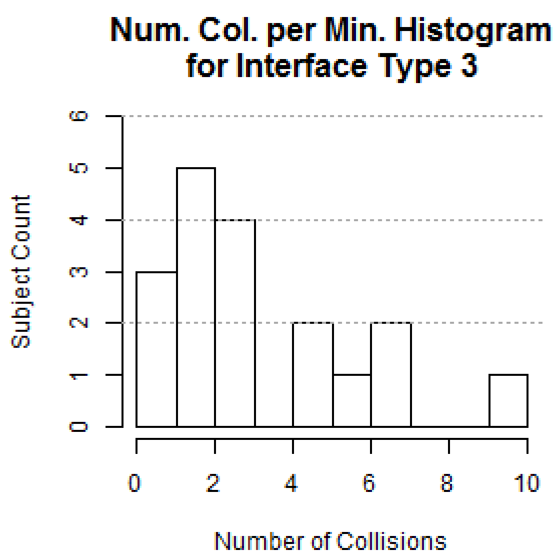


ANOVA: Number of Collisions per Minute for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	9.42	4.710	0.887	0.418
Residuals	51	270.88	5.311		

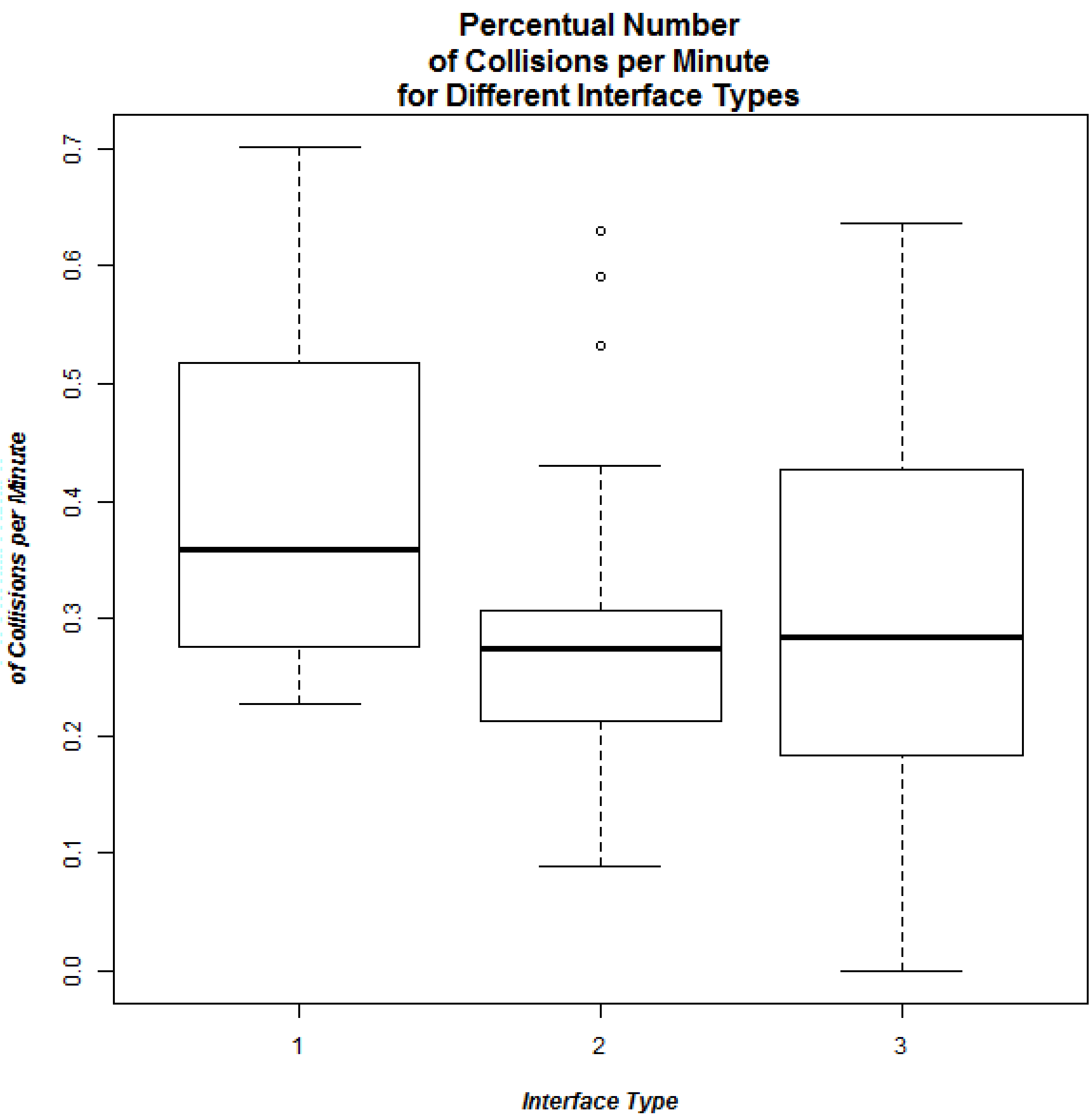
Number of Collisions per Minute vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	3.819	2.394	3.441
2	2.844	2.015	2.242
3	3.063	2.479	2.221


Num. Col. per Min. Histogram
for Interface Type 1
Subject Count
0
1
2
3
4
5
6
0
2
4
6
8
10
Number of Collisions

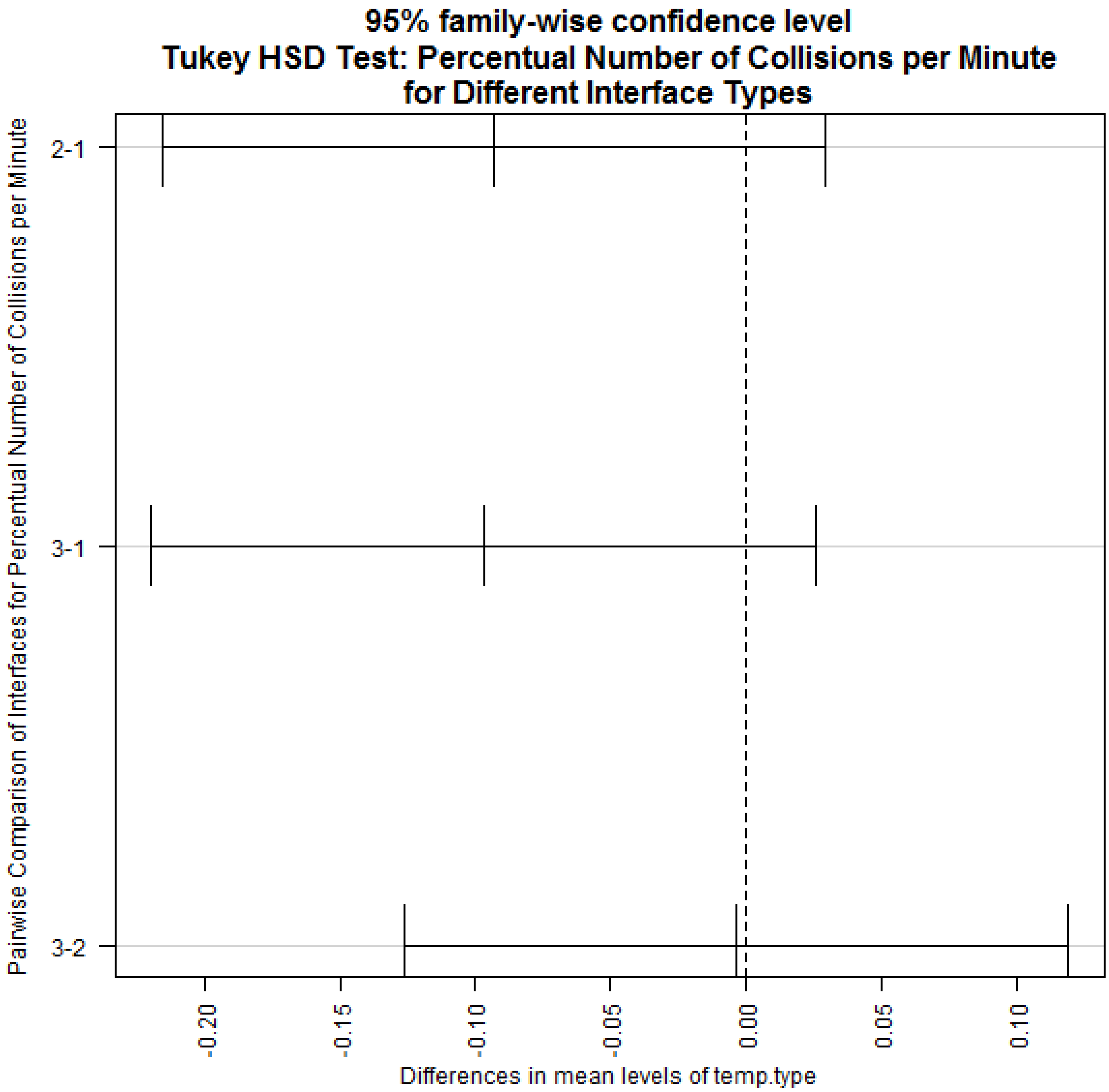

Num. Col. per Min. Histogram
for Interface Type 2
Subject Count
0
1
2
3
4
5
6
0
2
4
6
8
10
Number of Collisions


Num. Col. per Min. Histogram
for Interface Type 3
Subject Count
0
1
2
3
4
5
6
0
2
4
6
8
10
Number of Collisions

C.2.8.1 Normalized Number of Collisions per Minute+



ANOVA: Normalized Number of Collisions per Minute for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.109	0.054	2.362	0.104
Residuals	51	1.178	0.023		



ANOVA: Normalized Number of Collisions per Minute for Groups With Interfaces 1 and 2

Source of Variation	*Df*	*SS*	*MS*	*F*	*P-value*
Interface Type	1	0.079	0.079	3.697	0.063
Residuals	34	0.723	0.021		

ANOVA: Normalized Number of Collisions per Minute for Groups With Interfaces 1 and 3

Source of Variation	*Df*	*SS*	*MS*	*F*	*P-value*
Interface Type	1	0.085	0.085	3.649	0.065
Residuals	34	0.791	0.023		

ANOVA: Normalized Number of Collisions per Minute for Groups With Interfaces 2 and 3					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.000	0.000	0.005	0.945
Residuals	34	0.841	0.025		

Normalized Number of Collisions per Minute vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.397	0.141	0.358
2	0.303	0.151	0.274
3	0.300	0.163	0.284

*C.2.8.2 Interface Order Effect on Number of Collisions per Minute**

C.2.8.2.1 Interface 1

ANOVA: Interface 1 Number of Collisions per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	14.43	2.216	0.357	0.705
Residuals	15	0.841	0.025		

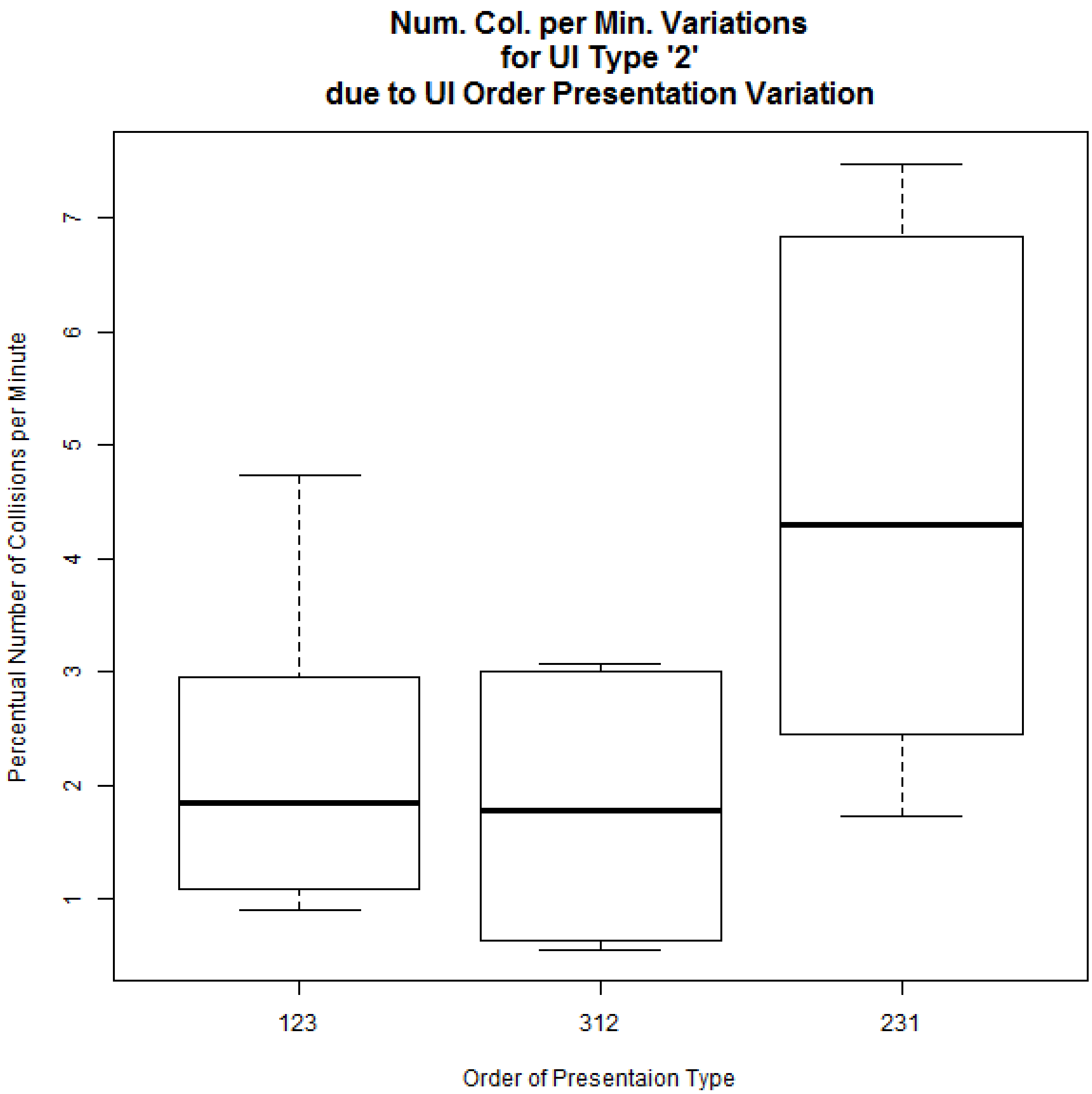
Interface 1 Number of Collisions per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	3.836	1.959	3.749
312 (3rd)	3.203	3.290	3.203
231 (1st)	4.418	3.928	

ANOVA: Interface 1 Normalized Number of Collisions per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.055	0.027	1.467	0.262
Residuals	15	0.281	0.019		

Interface 3 Normalized Number of Collisions per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.470	0.167	0.511
312 (3rd)	0.384	0.164	0.337
231 (1st)	0.337	0.038	0.338

C.2.8.2.2 Interface 2

ANOVA: Interface 2 Number of Collisions per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	25.68	12.842	4.448	0.030
Residuals	15	43.31	2.887		

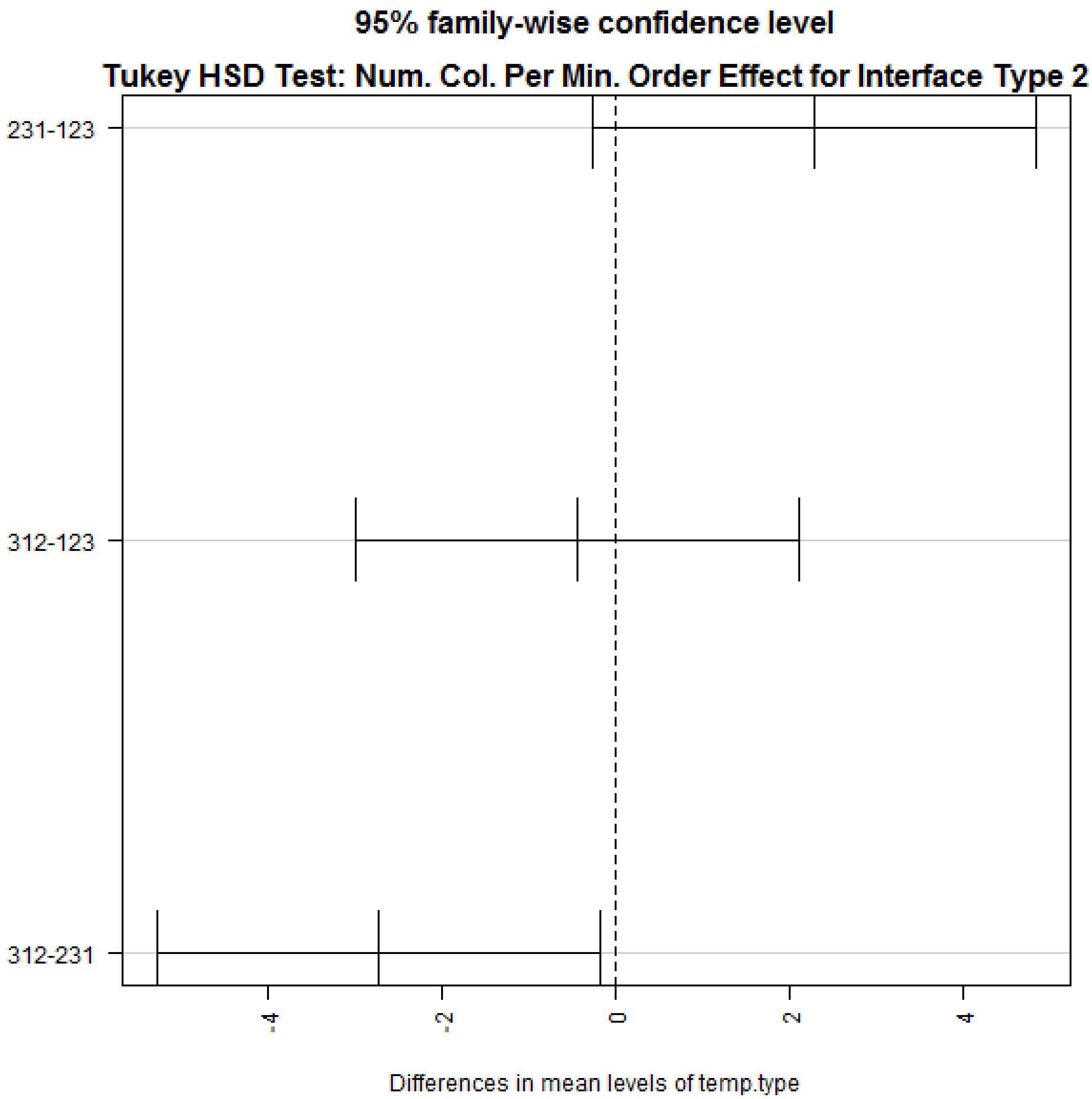


ANOVA: Interface 2 Number of Collisions per Minute for Interface Orders 123(2nd) and 312 (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.555	0.555	0.342	0.571
Residuals	10	16.194	1.619		

ANOVA: Interface 2 Number of Collisions per Minute for Interface Orders 123 (2nd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	15.75	15.75	4.218	0.067
Residuals	10	37.35	3.735		

ANOVA: Interface 2 Number of Collisions per Minute for Interface Orders 312 (3rd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	22.22	22.22	6.717	0.027
Residuals	10	33.08	3.308		

Interface 2 Number of Collisions per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	2.224	1.430	0.837
312 (3rd)	1.794	1.092	1.767
231 (1st)	4.515	2.329	4.302



ANOVA: Interface 2 Normalized Number of Collisions per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.014	0.007	0.284	0.727
Residuals	15	0.373	0.025		

Interface 2 Normalized Number of Collisions per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.284	0.167	0.254
312 (3rd)	0.283	0.179	0.232
231 (1st)	0.343	0.121	0.306

C.2.8.2.3 Interface 3

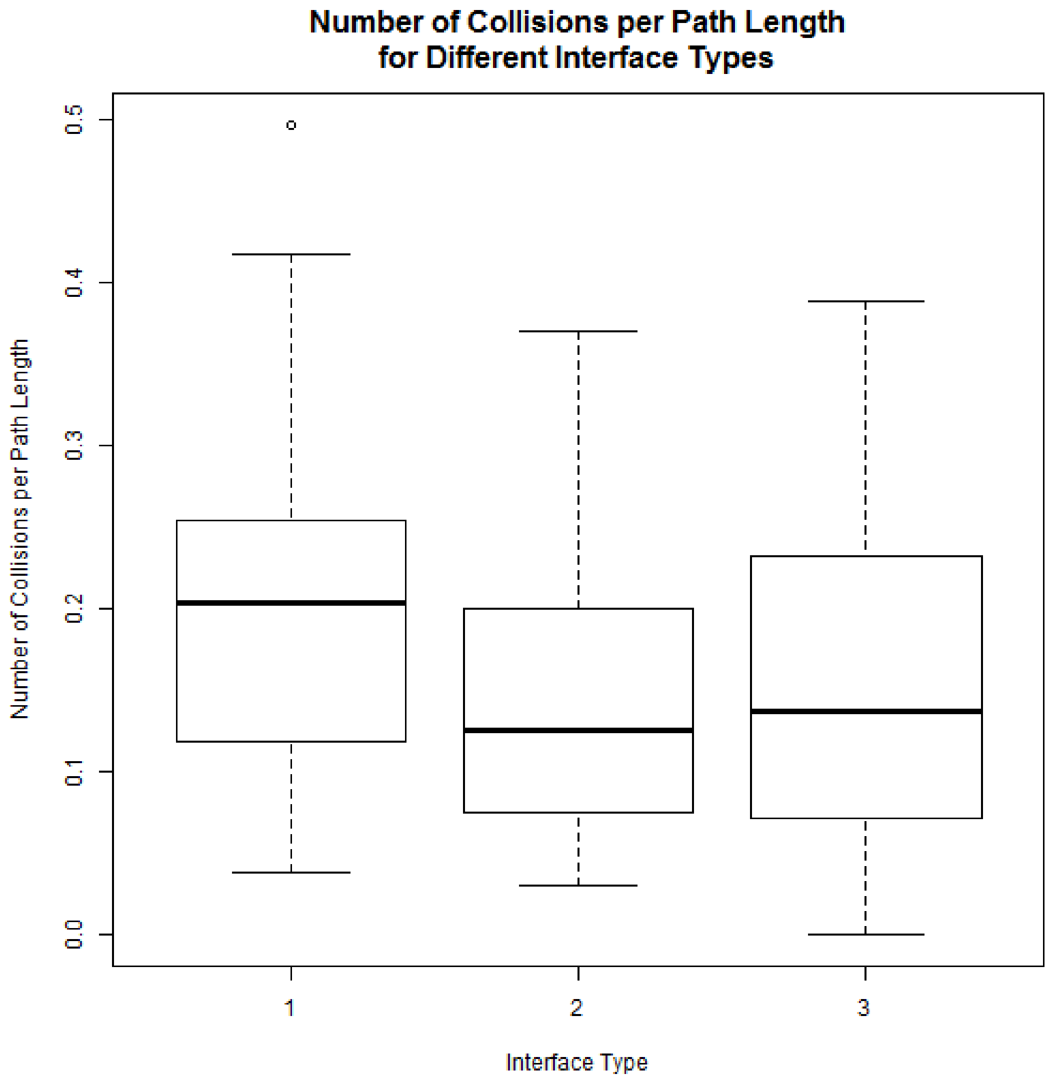
ANOVA: Interface 3 Number of Collisions per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	20.89	10.44	1.875	0.188
Residuals	15	83.54	5.57		

Interface 3 Number of Collisions per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	2.342	2.236	1.620
312 (3rd)	2.261	1.826	1.977
231 (1st)	4.586	2.894	4.439

ANOVA: Interface 3 Normalized Number of Collisions per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.027	0.013	0.476	0.630
Residuals	15	0.427	0.028		

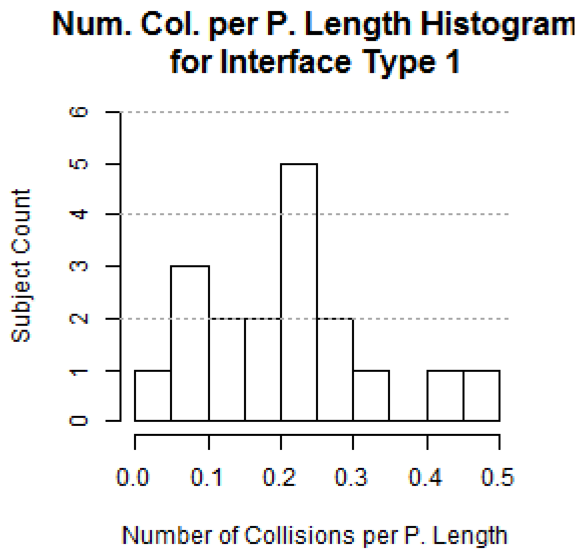
Interface 3 Normalized Number of Collisions per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.245	0.101	0.229
312 (3rd)	0.333	0.251	0.323
231 (1st)	0.320	0.110	0.344

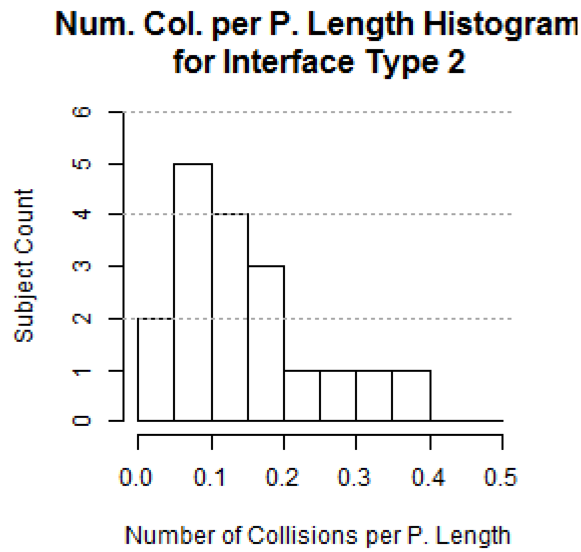
C.2.9 Number of Collisions per Path Length

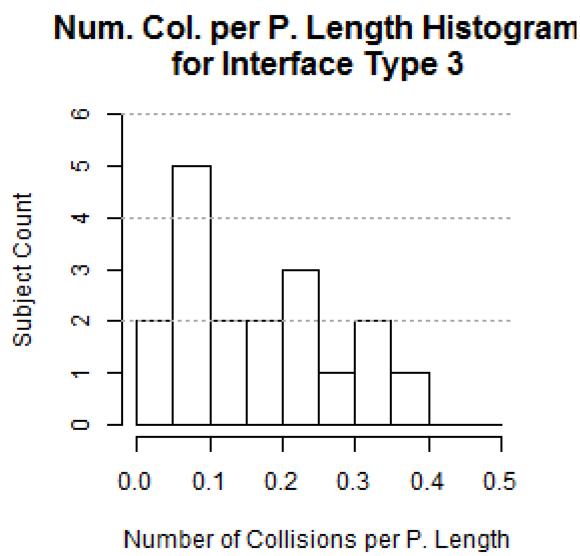


ANOVA: Number of Collisions per Path Length for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.031	0.016	1.26	0.292
Residuals	51	0.637	0.012		

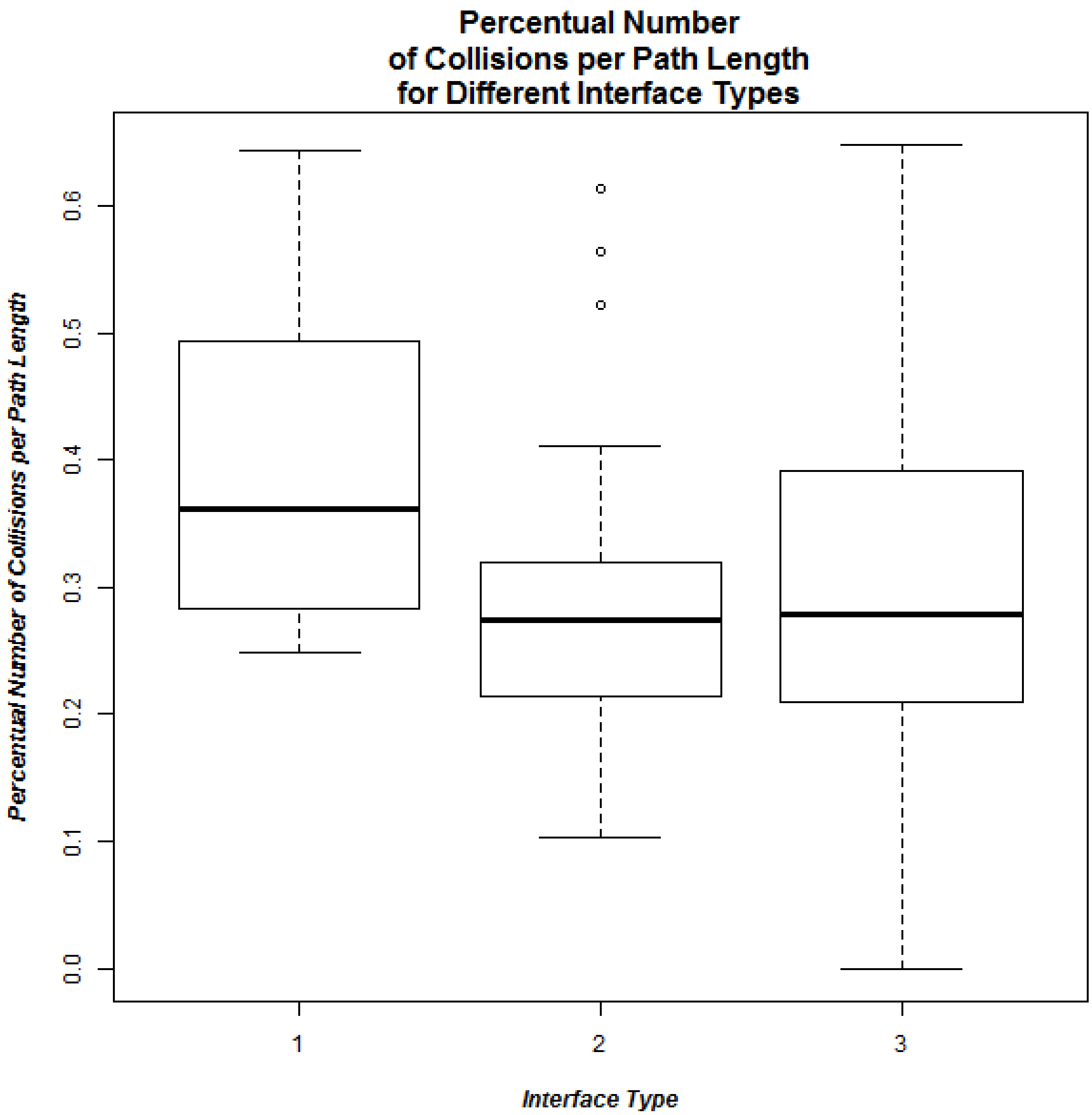
Number of Collisions per Path Length vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.206	0.123	0.203
2	0.150	0.096	0.125
3	0.164	0.114	0.137


Num. Col. per P. Length Histogram
for Interface Type 1
Subject Count
Number of Collisions per P. Length

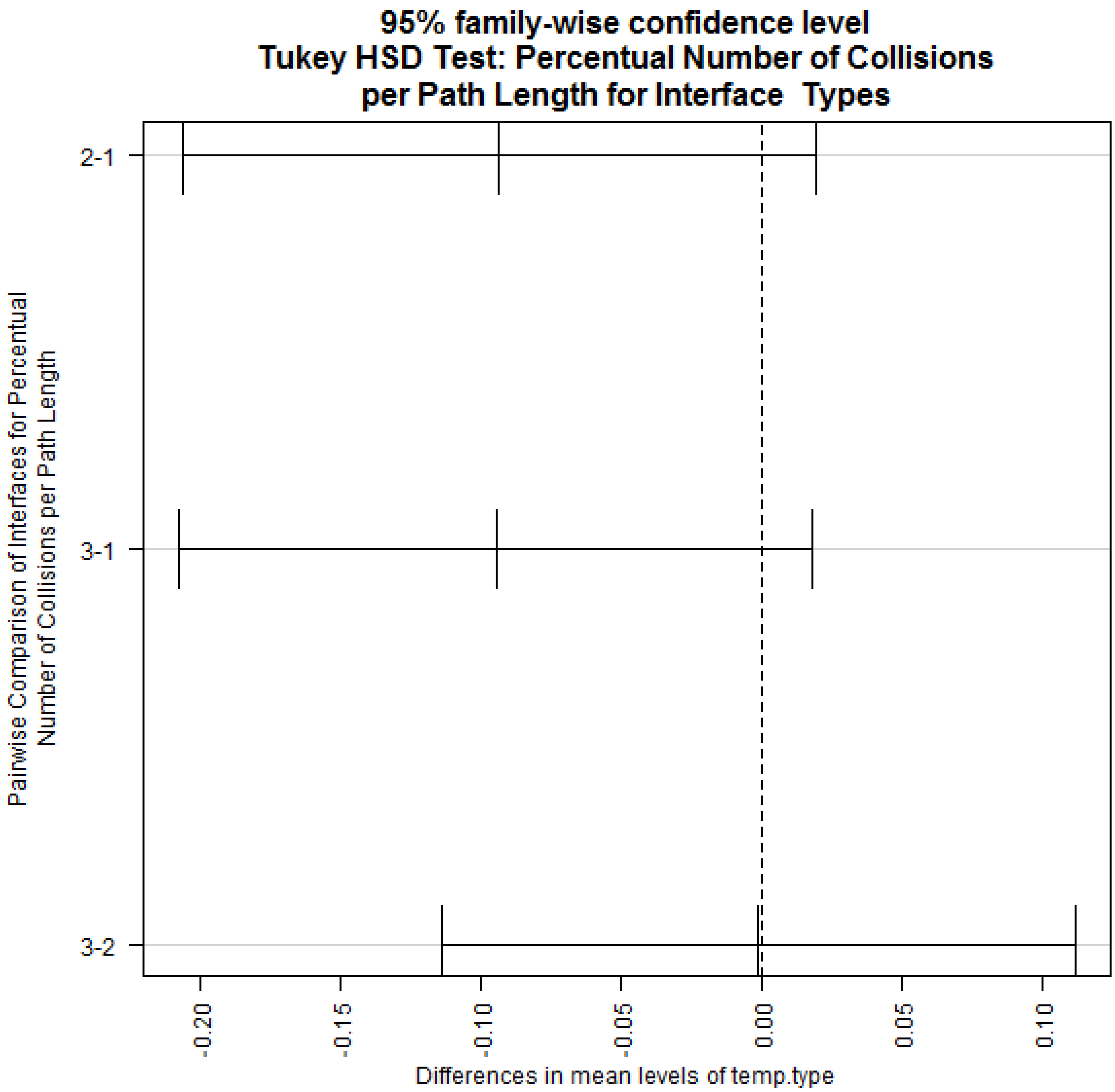

Num. Col. per P. Length Histogram
for Interface Type 2
Subject Count
Number of Collisions per P. Length


Num. Col. per P. Length Histogram
for Interface Type 3
Subject Count
Number of Collisions per P. Length

*C.2.9.1 Normalized Number of Collisions per Path Length**



ANOVA: Normalized Number of Collisions per Path Length for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.106	0.053	2.697	0.077
Residuals	51	1.000	0.019		



ANOVA: Normalized Number of Collisions per Path Length for Groups With Interfaces 1 and 2

Source of Variation	*Df*	*SS*	*MS*	*F*	*P-value*
Interface Type	1	0.078	0.078	4.325	0.045
Residuals	34	0.616	0.018		

ANOVA: Normalized Number of Collisions per Path Length for Groups With Interfaces 1 and 3

Source of Variation	*Df*	*SS*	*MS*	*F*	*P-value*
Interface Type	1	0.080	0.080	4.157	0.049
Residuals	34	0.656	0.019		

ANOVA: Normalized Number of Collisions per Path Length for Groups With Interfaces 2 and 3					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.000	0.000	0.001	0.982
Residuals	34	0.727	0.021		

Normalized Number of Collisions per Path Length vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.396	0.127	0.361
2	0.303	0.142	0.274
3	0.301	0.150	0.278

*C.2.9.2 Interface Order Effect on Number of Collisions per Path Length**

C.2.9.2.1 Interface 1

ANOVA: Interface 1 Number of Collisions per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.006	0.003	0.19	0.829
Residuals	15	0.252	0.017		

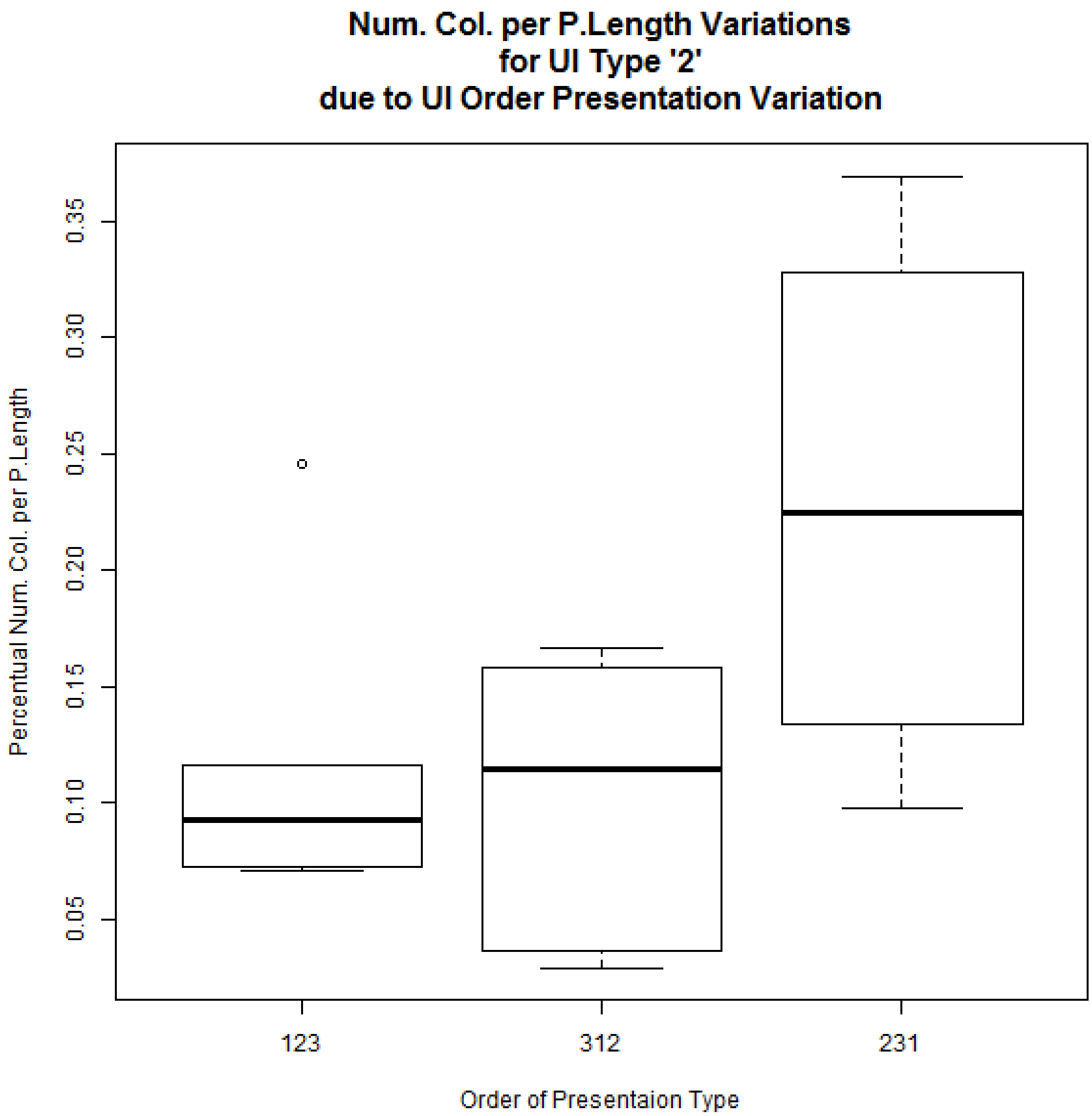
Interface 1 Number of Collisions per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.204	0.119	0.195
312 (3rd)	0.184	0.171	0.146
231 (1st)	0.230	0.084	0.234

ANOVA: Interface 1 Normalized Number of Collisions per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.046	0.023	1.534	0.248
Residuals	15	0.226	0.015		

Interface 1 Normalized Number of Collisions per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.459	0.154	0.496
312 (3rd)	0.393	0.140	0.378
231 (1st)	0.335	0.046	0.326

C.2.9.2.2 Interface 2

ANOVA: Interface 2 Number of Collisions per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.059	0.029	4.494	0.030
Residuals	15	0.098	0.006		

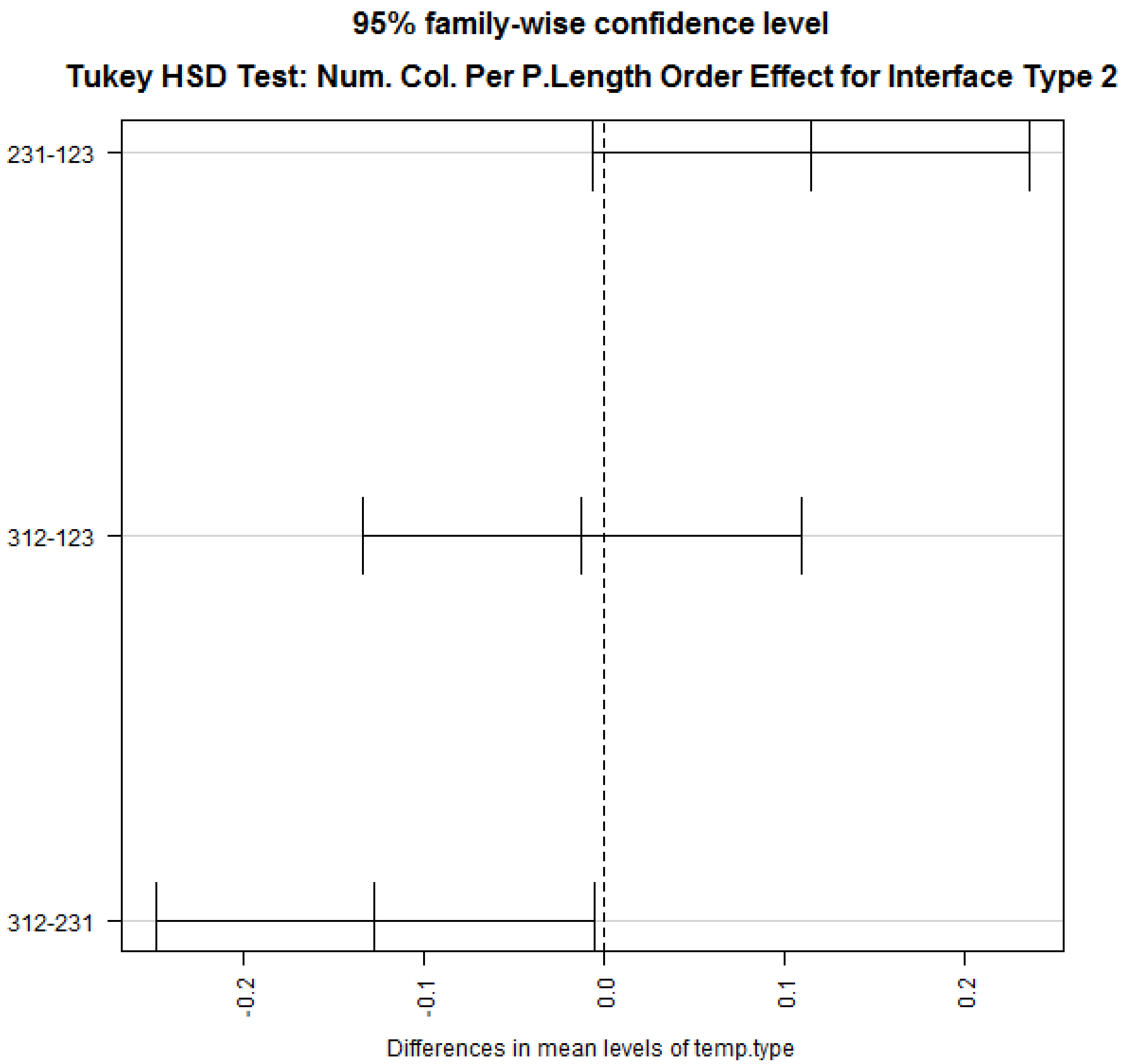


ANOVA: Interface 2 Number of Collisions per Path Length for Interface Orders 123(2nd) and 312 (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.000	0.000	0.107	0.751
Residuals	10	0.041	0.004		

ANOVA: Interface 2 Number of Collisions per Path Length for Interface Orders 123 (2nd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.039	0.039	4.948	0.050
Residuals	10	0.079	0.008		

ANOVA: Interface 2 Number of Collisions per Path Length for Interface Orders 312 (3rd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.048	0.048	6.387	0.03
Residuals	10	0.075	0.007		

Interface 2 Number of Collisions per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.115	0.067	0.093
312 (3rd)	0.103	0.060	0.114
231 (1st)	0.230	0.107	0.225



ANOVA: Interface 2 Normalized Number of Collisions per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.009	0.005	0.209	0.813
Residuals	15	0.334	0.022		

Interface 2 Normalized Number of Collisions per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.288	0.150	0.259
312 (3rd)	0.285	0.176	0.231
231 (1st)	0.335	0.116	0.303

C.2.9.2.3 Interface 3

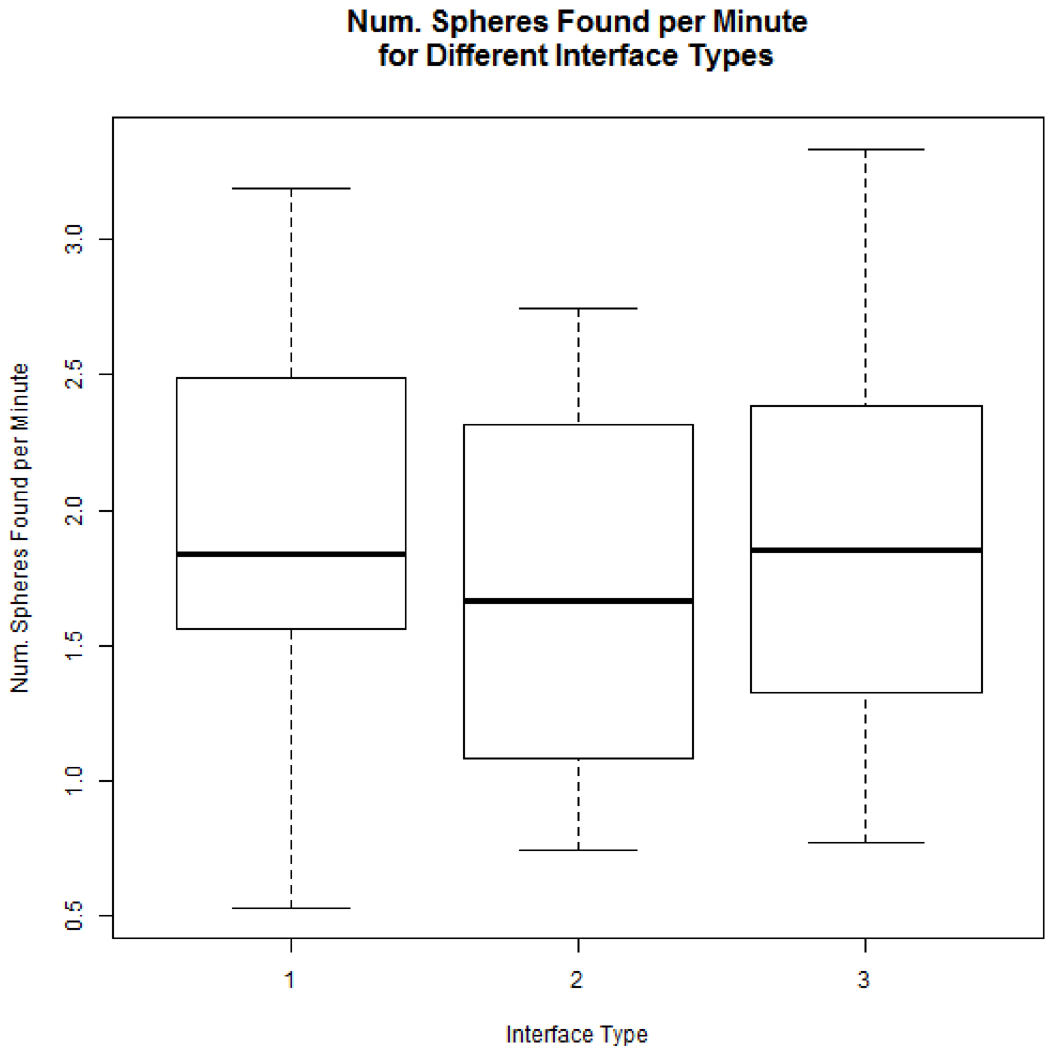
ANOVA: Interface 3 Number of Collisions per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.0.53	0.026	2.347	0.13
Residuals	15	0.169	0.011		

Interface 3 Number of Collisions per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.126	0.108	0.086
312 (3rd)	0.124	0.086	0.116
231 (1st)	0.240	0.121	0.239

ANOVA: Interface 3 Normalized Number of Collisions per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.021	0.011	0.446	0.649
Residuals	15	0.362	0.024		

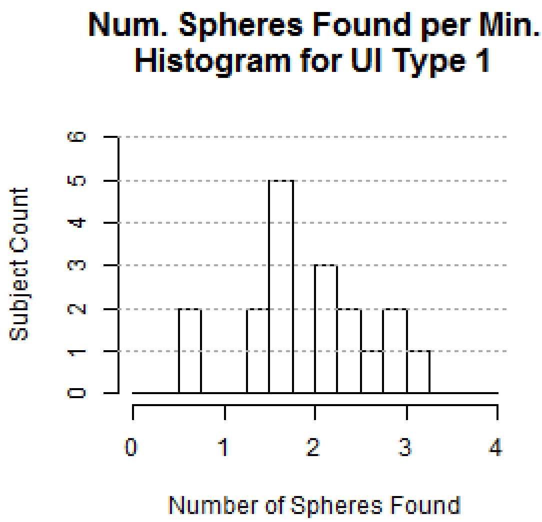
Interface 3 Normalized Number of Collisions per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.252	0.086	0.239
312 (3rd)	0.321	0.240	0.306
231 (1st)	0.330	0.085	0.360

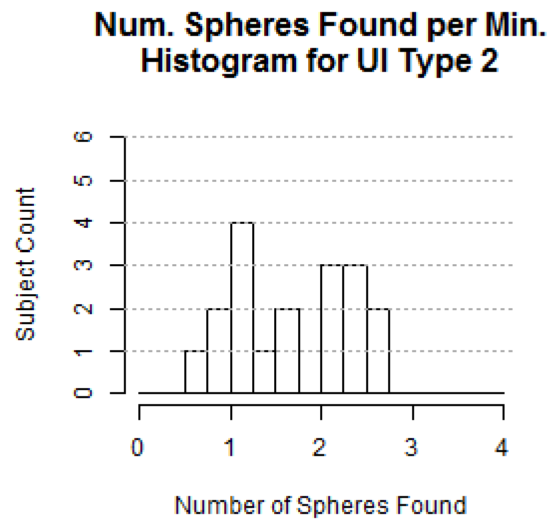
C.2.10 Number of Spheres Found per Minute

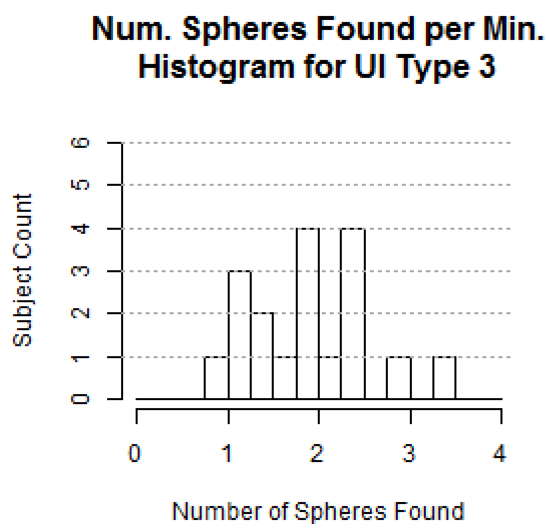


ANOVA: Number of Spheres Found per Minute for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.582	0.294	0.598	0.554
Residuals	51	24.837	0.487		

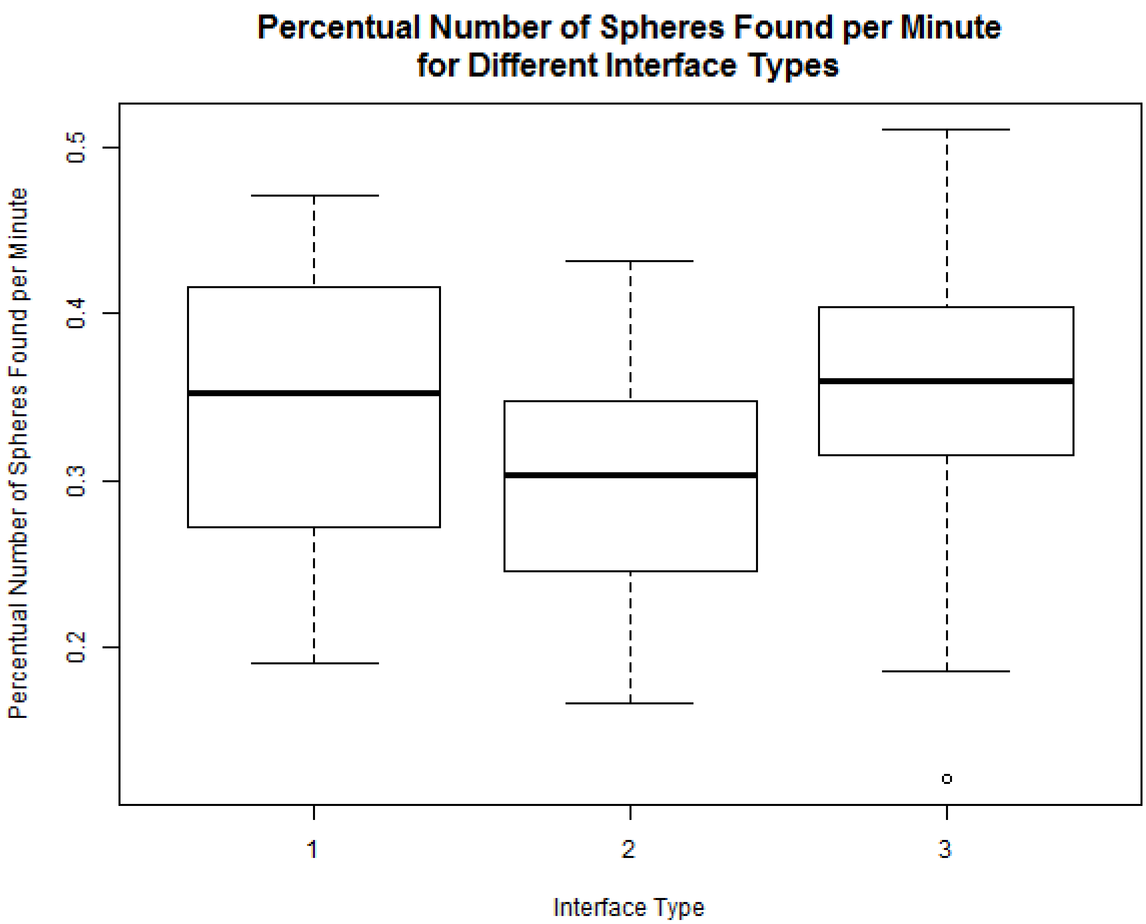
Number of Spheres Found per Minute vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	1.937	0.755	1.839
2	1.695	0.664	1.662
3	1.883	0.671	1.852


Num. Spheres Found per Min.
Histogram for UI Type 1
Subject Count
0 1 2 3 4 5 6
0 1 2 3 4
Number of Spheres Found


Num. Spheres Found per Min.
Histogram for UI Type 2
Subject Count
0 1 2 3 4 5 6
0 1 2 3 4
Number of Spheres Found


Num. Spheres Found per Min.
Histogram for UI Type 3
Subject Count
0 1 2 3 4 5 6
0 1 2 3 4
Number of Spheres Found

C.2.10.1 Normalized Number of Spheres Found per Minute



ANOVA: Normalized Number of Spheres Found per Minute for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.022	0.011	1.562	0.22
Residuals	51	0.367	0.007		

Normalized Number of Spheres Found per Minute vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.345	0.087	0.352
2	0.305	0.071	0.303
3	0.350	0.095	0.359

*C.2.10.2 Interface Order Effect on Number of Spheres Found per Minute**

C.2.10.2.1 Interface 1

ANOVA: Interface 1 Number of Spheres Found per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.356	0.178	0.286	0.755
Residuals	15	9.331	0.622		

Interface 1 Number Spheres Found per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	1.817	0.878	1.816
312 (3rd)	2.135	0.652	1.900
231 (1st)	1.860	0.819	1.989

ANOVA: Interface 1 Normalized Number of Spheres Found per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.020	0.010	1.404	0.276
Residuals	15	0.108	0.007		

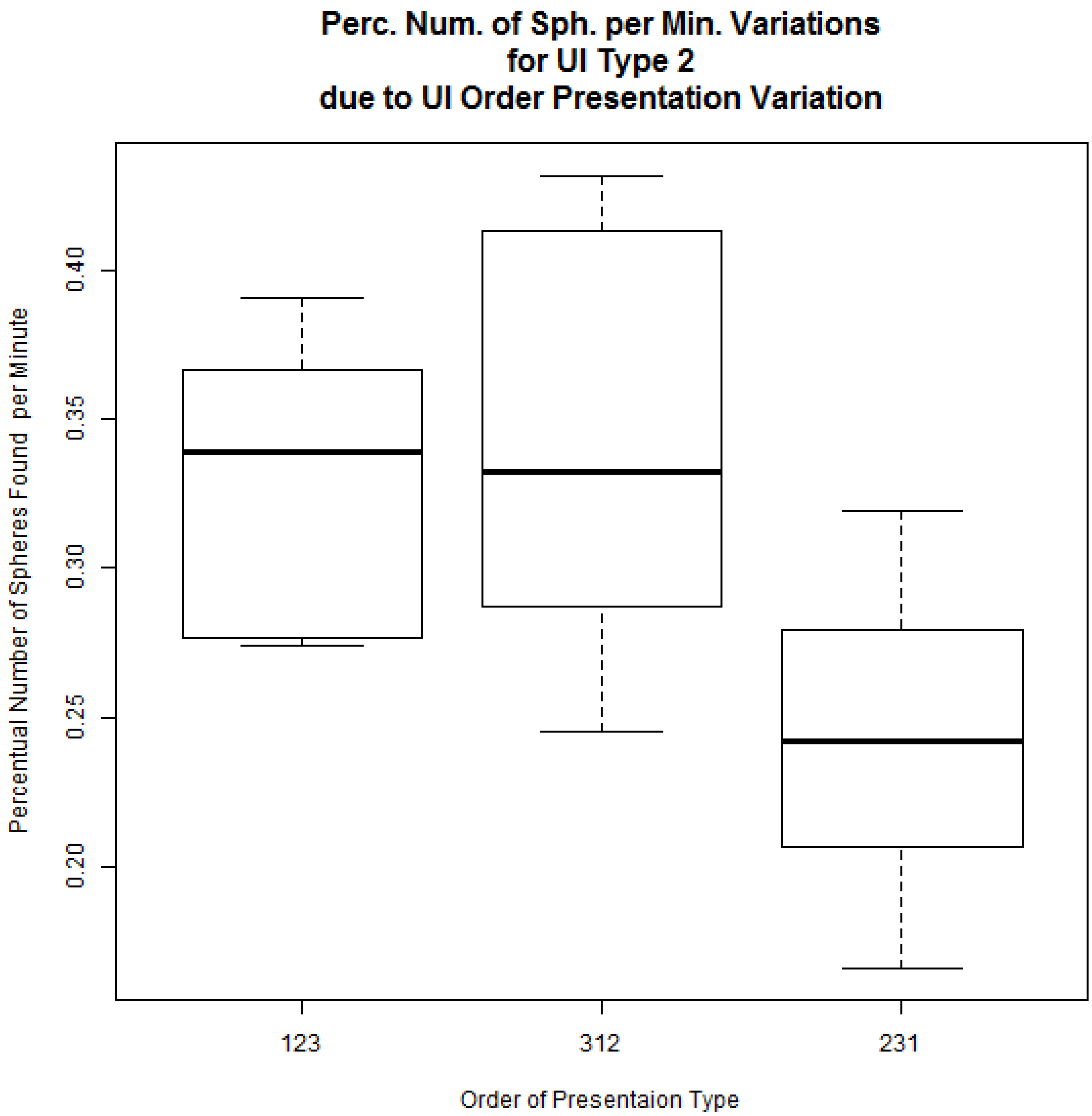
Interface 3 Normalized Number of Spheres Found per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.300	0.088	0.301
312 (3rd)	0.381	0.077	0.385
231 (1st)	0.353	0.089	0.365

C.2.10.2.2 Interface 2

ANOVA: Interface 2 Number of Spheres Found per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	1.806	0.903	2.382	0.126
Residuals	15	5.685	0.379		

Interface 2 Number of Spheres Found per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	1.892	0.567	1.894
312 (3rd)	1.945	0.676	2.164
231 (1st)	1.248	0.598	0.991

ANOVA: Interface 2 Normalized Number of Spheres Found per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.035	0.017	5.106	0.020
Residuals	15	0.051	0.003		

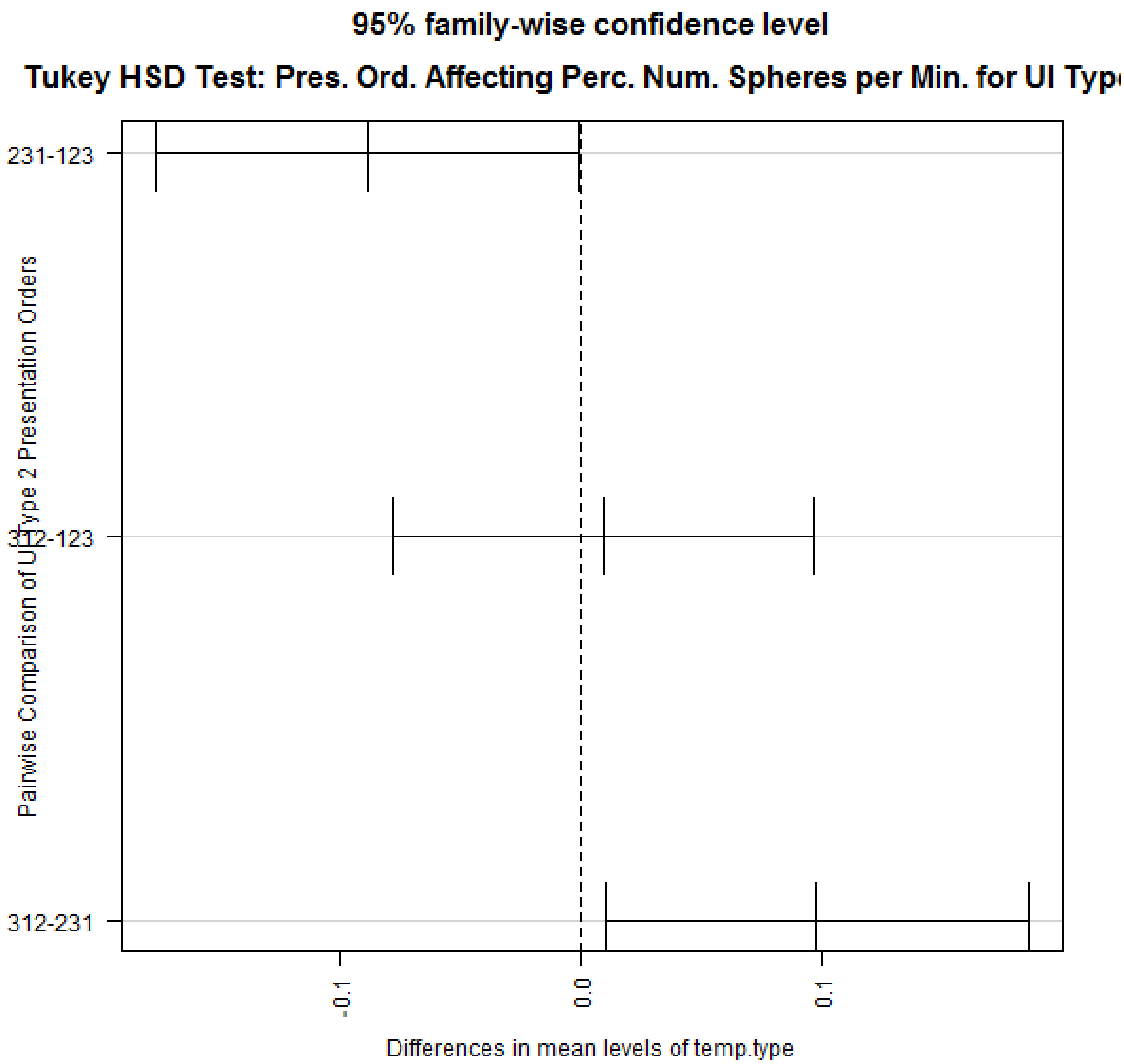


ANOVA: Interface 2 Normalized Number of Spheres Found per Minute for Interface Orders 123(2nd) and 312 (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.000	0.000	0.071	0.796
Residuals	10	0.037	0.004		

ANOVA: Interface 2 Normalized Number of Spheres Found per Minute for Interface Orders 123 (2nd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.023	0.023	9.157	0.013
Residuals	10	0.025	0.002		

ANOVA: Interface 2 Normalized Number of Spheres Found per Minute for Interface Orders 312 (3rd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.029	0.029	7.161	0.023
Residuals	10	0.040	0.004		

Interface 2 Normalized Number of Spheres Found per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.331	0.047	0.339
312 (3rd)	0.340	0.072	0.332
231 (1st)	0.242	0.053	0.242

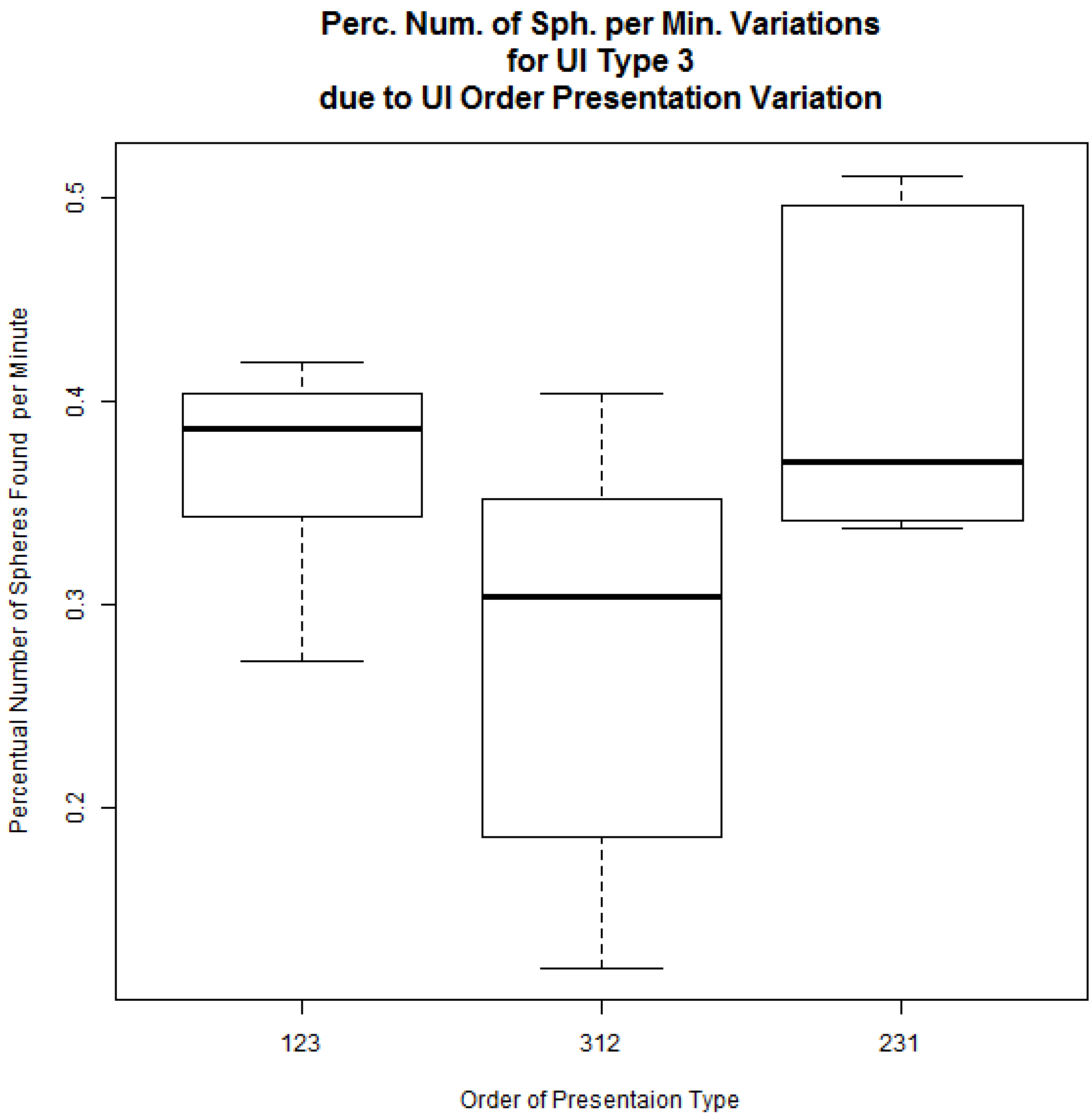


C.2.10.2.3 Interface 3

ANOVA: Interface 3 Number of Spheres Found per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	1.317	0.658	1.557	0.243
Residuals	15	6.342	0.423		

Interface 3 Number Spheres Found per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	2.154	0.827	2.116
312 (3rd)	1.514	0.587	1.493
231 (1st)	1.981	0.489	2.064

ANOVA: Interface 3 Normalized Number of Spheres Found per Minute in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.050	0.025	3.715	0.049
Residuals	15	0.102	0.007		

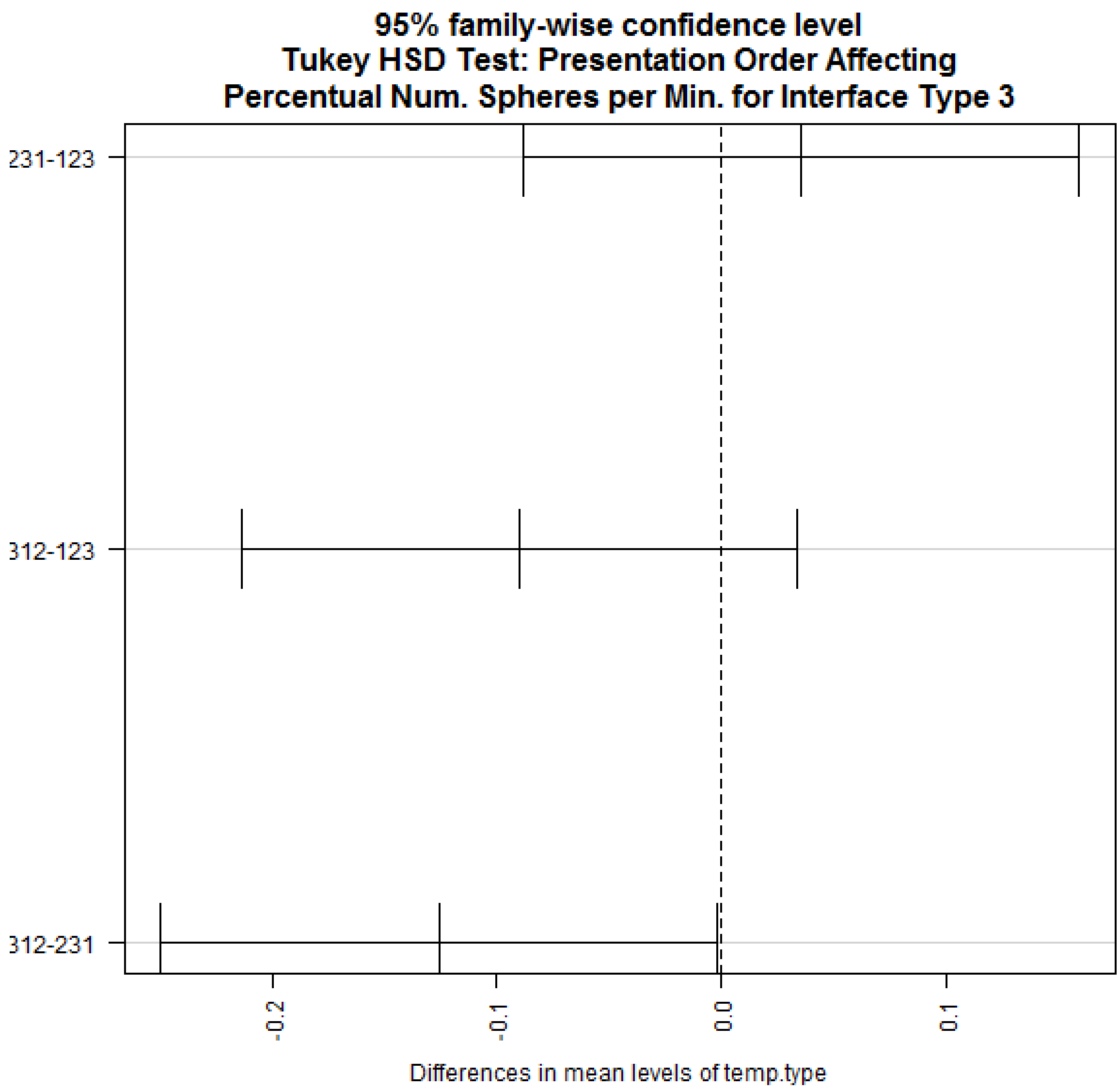


ANOVA: Interface 2 Normalized Number of Spheres Found per Minute for Interface Orders 123(2nd) and 312 (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.024	0.024	3.436	0.093
Residuals	22	0.071	0.007		

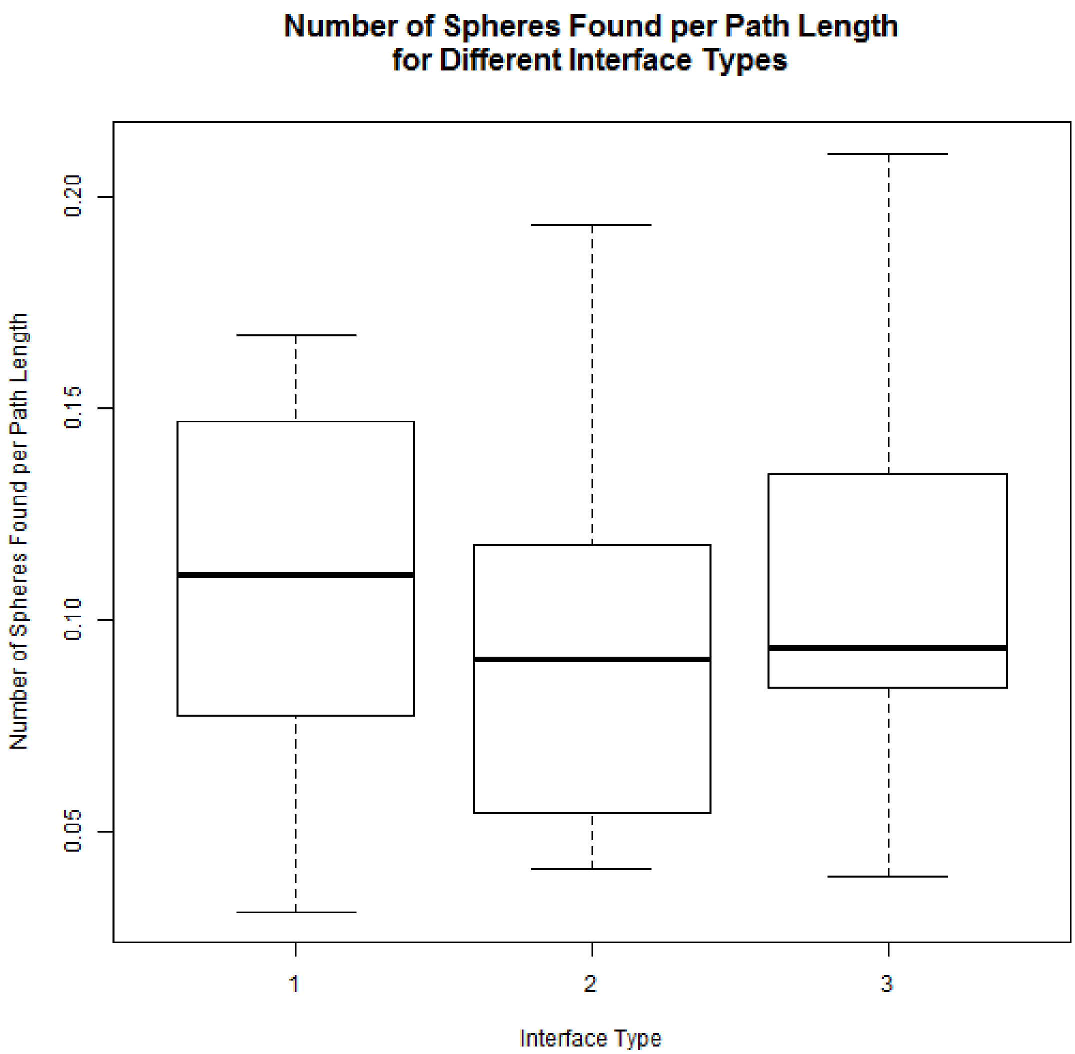
ANOVA: Interface 2 Normalized Number of Spheres Found per Minute for Interface Orders 123 (2nd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.004	0.004	0.826	0.385
Residuals	22	0.046	0.004		

ANOVA: Interface 2 Normalized Number of Spheres Found per Minute for Interface Orders 312 (3rd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.047	0.047	5.466	0.041
Residuals	22	0.087	0.009		

Interface 3 Normalized Number of Spheres Found per Minute vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.369	0.055	0.387
312 (3rd)	0.278	0.106	0.304
231 (1st)	0.404	0.078	0.370

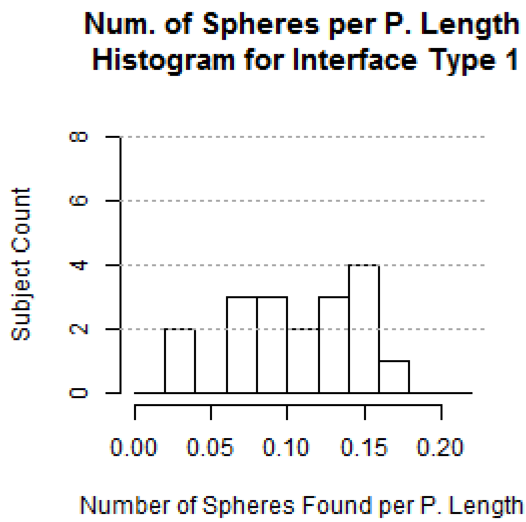


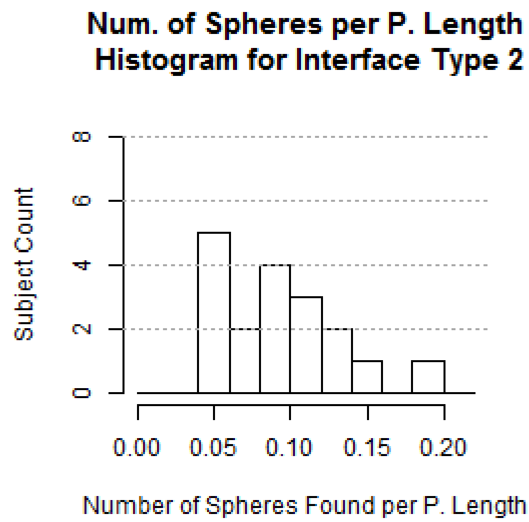
C.2.11 Number of Spheres per Path Length

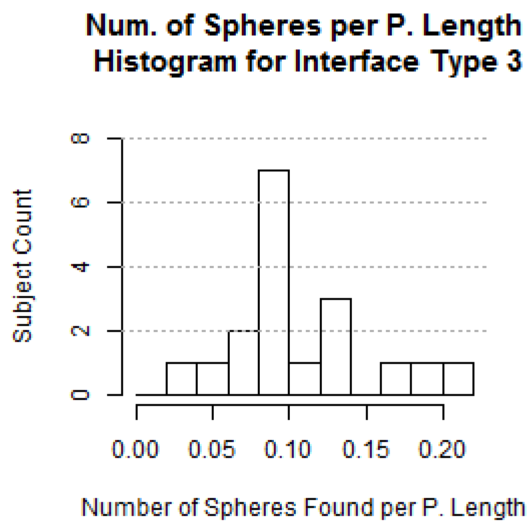


ANOVA: Number of Spheres per Path Length for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.002	0.001	0.648	0.527
Residuals	51	0.093	0.002		

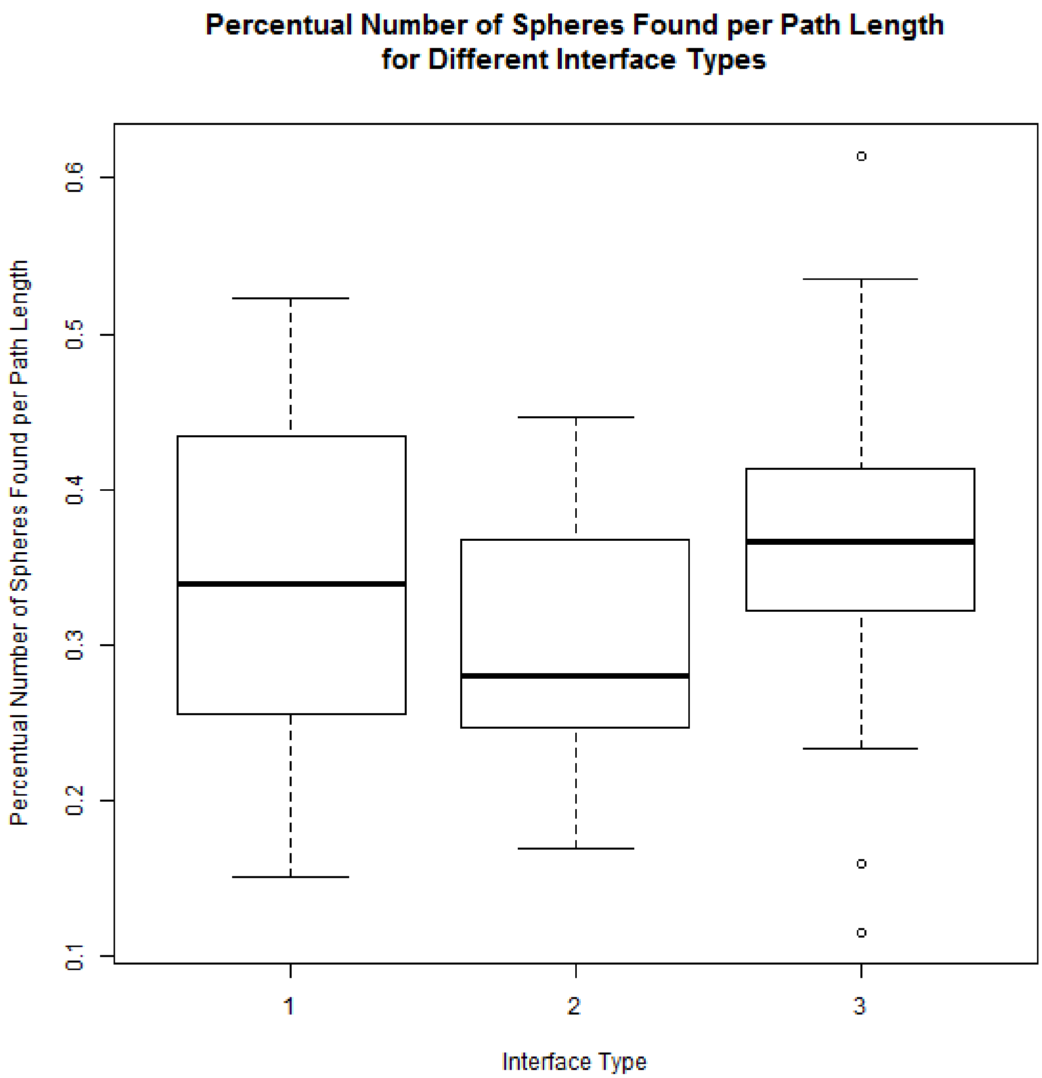
Number of Spheres per Path Length vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.106	0.042	0.110
2	0.094	0.040	0.090
3	0.109	0.046	0.093


Num. of Spheres per P. Length
Histogram for Interface Type 1
Subject Count
0
2
4
6
8
0.00
0.05
0.10
0.15
0.20
Number of Spheres Found per P. Length


Num. of Spheres per P. Length
Histogram for Interface Type 2
Subject Count
0
2
4
6
8
0.00
0.05
0.10
0.15
0.20
Number of Spheres Found per P. Length


Num. of Spheres per P. Length
Histogram for Interface Type 3
Subject Count
0
2
4
6
8
0.00
0.05
0.10
0.15
0.20
Number of Spheres Found per P. Length

C.2.11.1 Normalized Number of Spheres per Path Length



ANOVA: Normalized Number of Spheres per Path Length for Groups With Different Interface Types					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.033	0.016	1.519	0.229
Residuals	51	0.553	0.011		

Normalized Number of Spheres per Path Length vs. Interface Used Summary			
	Mean	***Std. Dev.***	***Median***
1	0.343	0.110	0.339
2	0.299	0.083	0.280
3	0.358	0.116	0.367

*C.2.11.2 Interface Order Effect on Number of Spheres Found per Path Length**

C.2.11.2.1 Interface 1

ANOVA: Interface 1 Number of Spheres Found per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	43.72	21.86	1.315	0.298
Residuals	15	249.27	16.62		

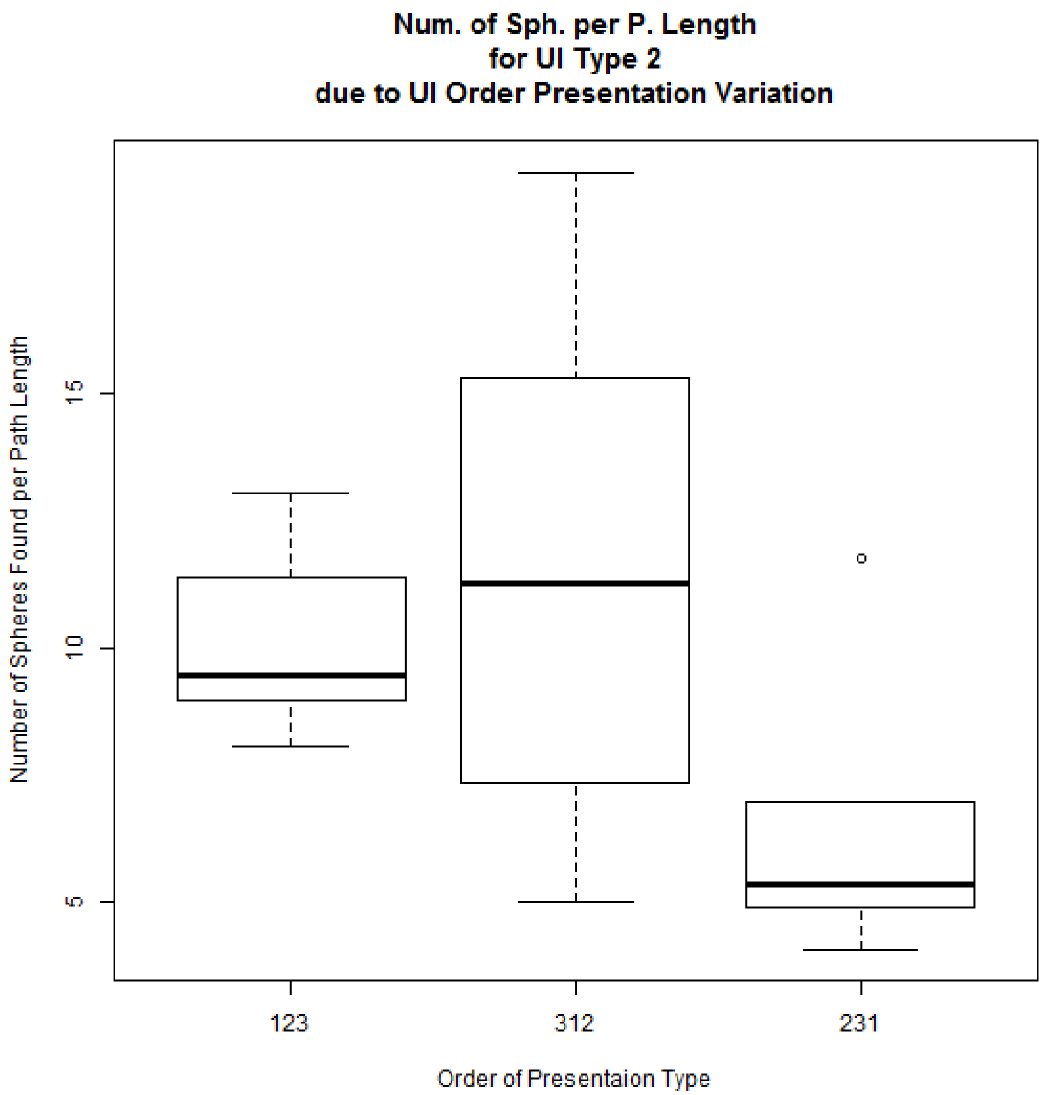
Interface 1 Number of Spheres Found per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	9.231	4.394	8.982
312 (3rd)	12.809	3.370	13.771
231 (1st)	9.868	4.379	10.501

ANOVA: Interface 1 Normalized Number of Spheres Found per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.034	0.017	1.485	0.258
Residuals	15	0.173	0.011		

Interface 3 Normalized Number of Spheres Found per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.287	0.099	0.290
312 (3rd)	0.394	0.102	0.429
231 (1st)	0.347	0.120	0.370

C.2.11.2.2 Interface 2

ANOVA: Interface 2 Number of Spheres Found per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	85.17	42.58	3.301	0.065
Residuals	15	193.51	12.90		

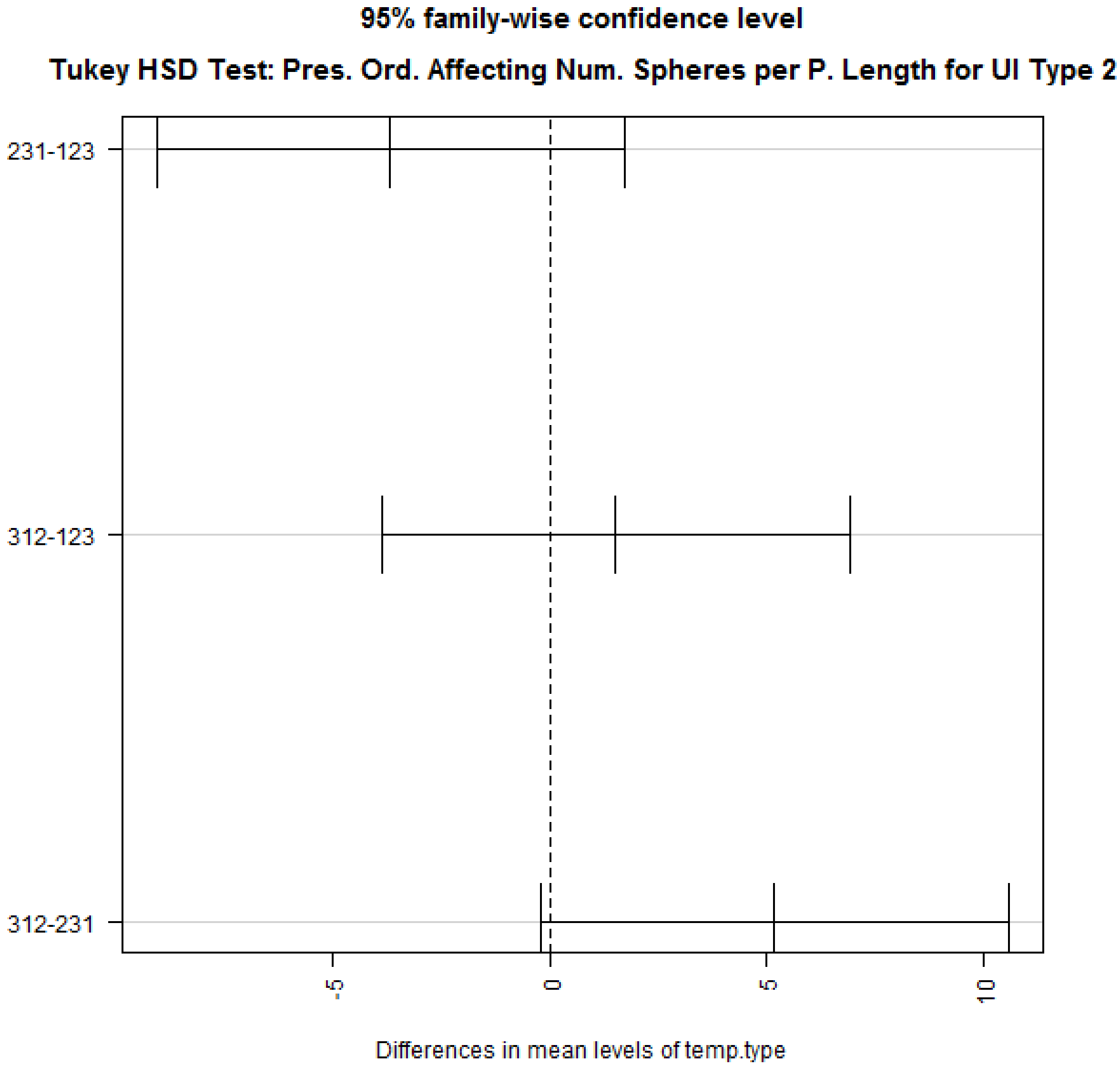


ANOVA: Interface 2 Number of Spheres Found per Path Length for Interface Orders 123(2nd) and 312 (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.000	0.000	0.452	0.517
Residuals	10	0.015	0.001		

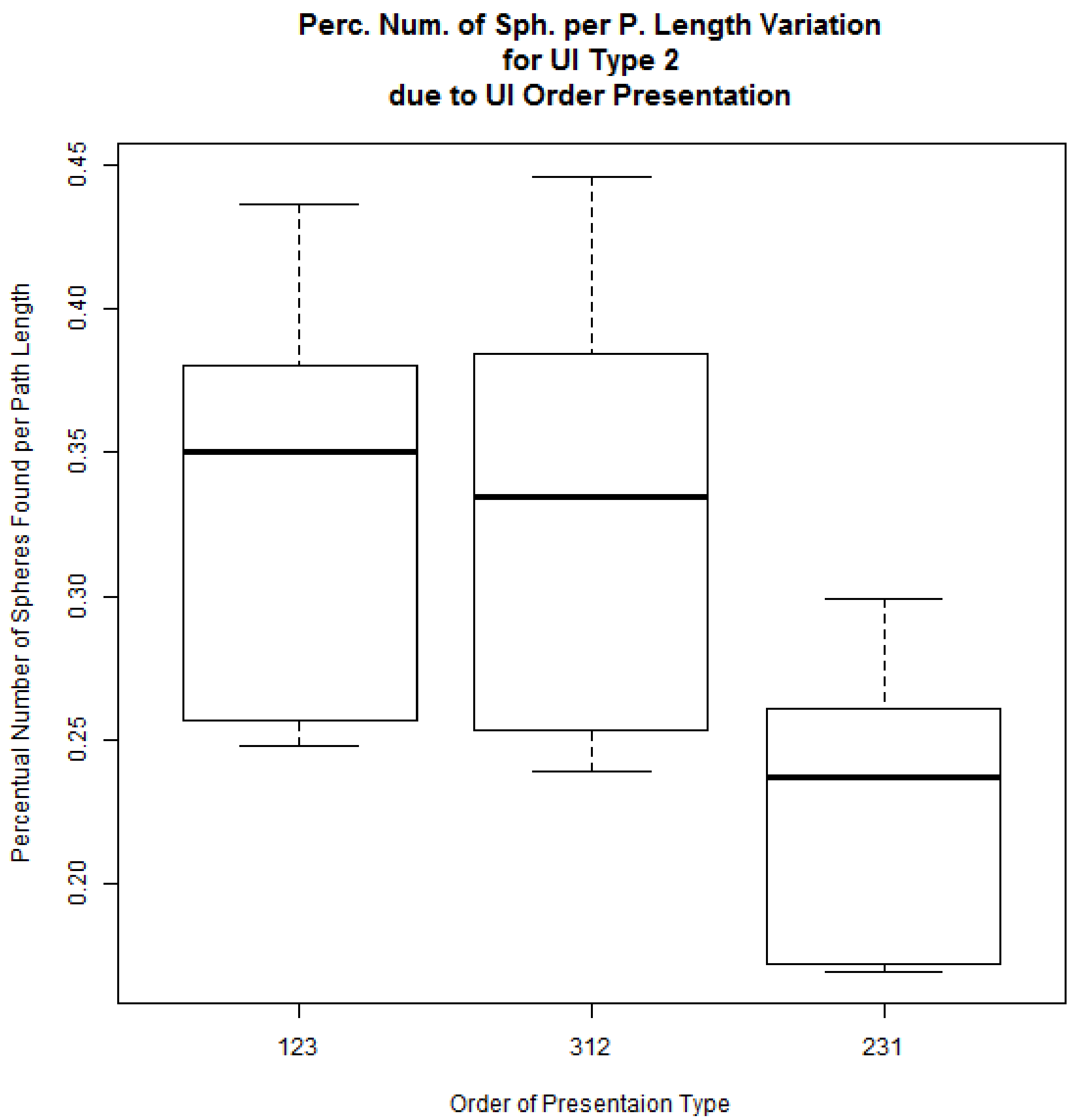
ANOVA: Interface 2 Number of Spheres Found per Path Length for Interface Orders 123 (2nd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.004	0.004	7.209	0.023
Residuals	10	0.005	0.000		

ANOVA: Interface 2 Number of Spheres Found per Path Length for Interface Orders 312 (3rd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.008	0.008	4.558	0.058
Residuals	10	0.018	0.002		

Interface 2 Number of Spheres Found per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	10.063	1.825	9.461
312 (3rd)	11.589	5.250	11.264
231 (1st)	6.406	2.794	5.364



ANOVA: Interface 2 Normalized Number of Spheres Found per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.044	0.022	4.673	0.026
Residuals	15	0.018	0.002		

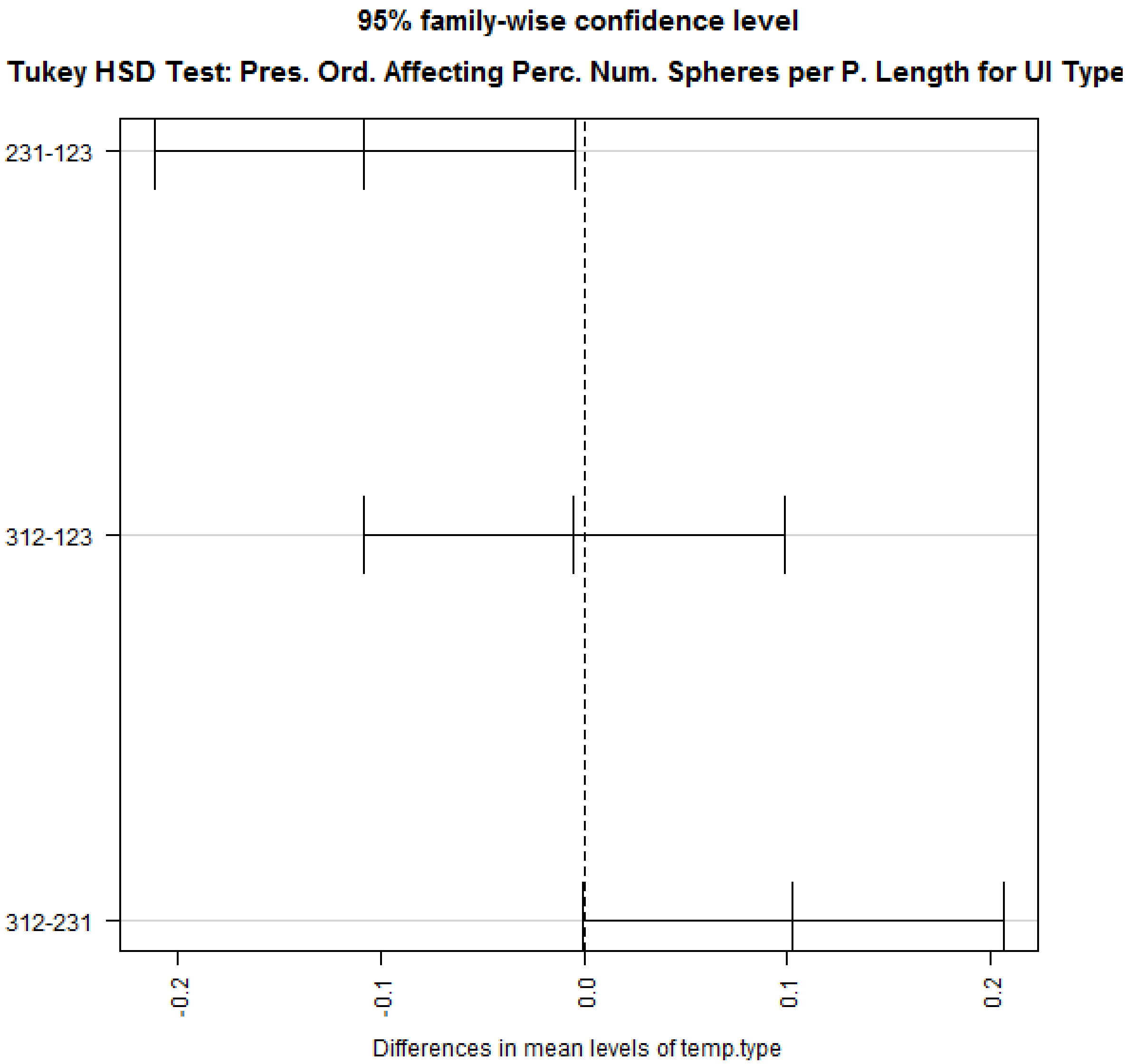


ANOVA: Interface 2 Normalized Number of Spheres Found per Path Length for Interface Orders 123(2nd) and 312 (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.000	0.000	0.012	0.914
Residuals	10	0.058	0.006		

ANOVA: Interface 2 Normalized Number of Spheres Found per Path Length for Interface Orders 123 (2nd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.035	0.035	8.668	0.015
Residuals	10	0.040	0.004		

ANOVA: Interface 2 Normalized Number of Spheres Found per Path Length for Interface Orders 312 (3rd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.032	0.032	7.188	0.023
Residuals	10	0.044	0.004		

Interface 2 Normalized Number of Spheres Found per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.337	0.074	0.350
312 (3rd)	0.332	0.079	0.335
231 (1st)	0.229	0.051	0.237

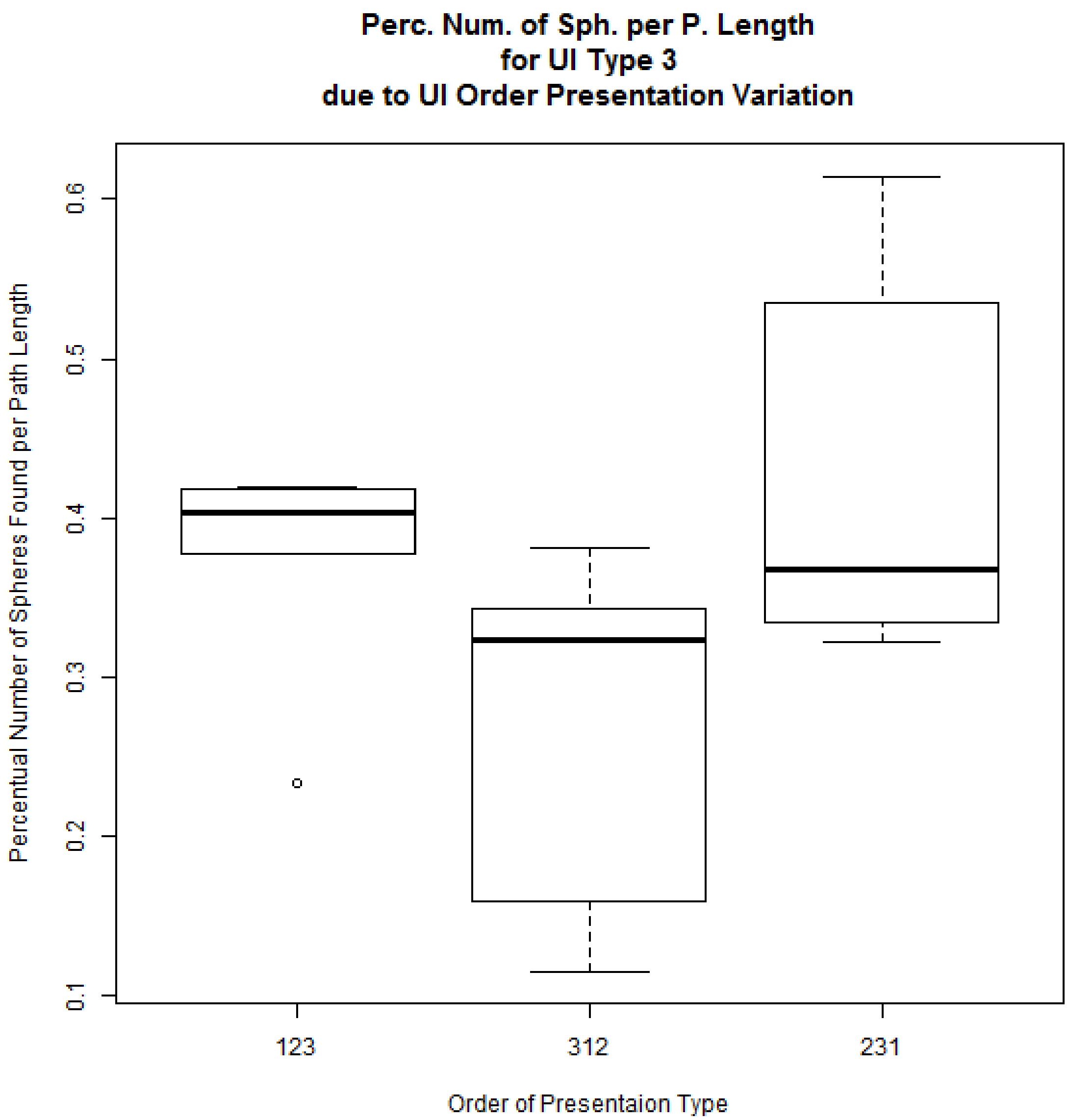


C.2.11.2.3 Interface 3

ANOVA: Interface 3 Number of Spheres Found per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	16.4	8.204	0.355	0.707
Residuals	15	346.2	23.080		

Interface 3 Number of Spheres Found per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	11.507	3.429	11.248
312 (3rd)	9.507	6.188	8.003
231 (1st)	11.557	4.380	9.360

ANOVA: Interface 3 Normalized Number of Spheres Found per Path Length in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.070	0.035	3.262	0.067
Residuals	15	0.160	0.011		

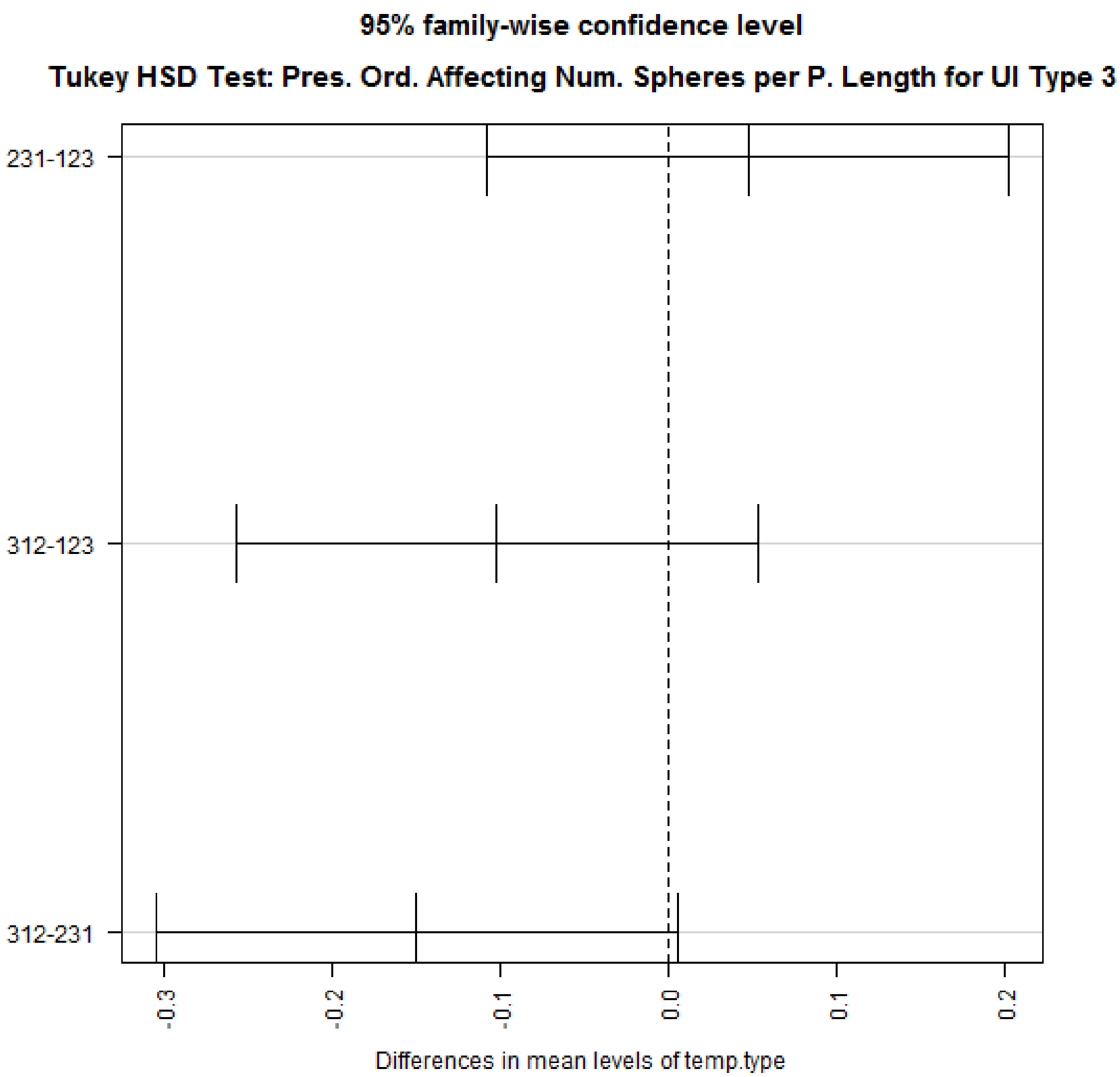


ANOVA: Interface 3 Normalized Number of Spheres Found per Path Length for Interface Orders 123(2nd) and 312 (3rd)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.031	0.031	3.601	0.087
Residuals	10	0.086	0.009		

ANOVA: Interface 3 Normalized Number of Spheres Found per Path Length for Interface Orders 123 (2nd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.007	0.007	0.678	0.429
Residuals	10	0.100	0.010		

ANOVA: Interface 3 Normalized Number of Spheres Found per Path Length for Interface Orders 312 (3rd) and 231 (1st)					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	1	0.067	0.067 0	4.964	0.05
Residuals	10	0.135	0.013		

Interface 3 Normalized Number of Spheres Found per Path Length vs. Interface Order Used Summary			
	Mean	***Std. Dev.***	***Median***
123 (2nd)	0.376	0.072	0.403
312 (3rd)	0.274	0.110	0.323
231 (1st)	0.423	0.122	0.367



C.2.12 Fairness Evaluation of Population Distribution Among Groups Exposed to Interfaces in Different Orders

C.2.12.1 Number of Spheres Found

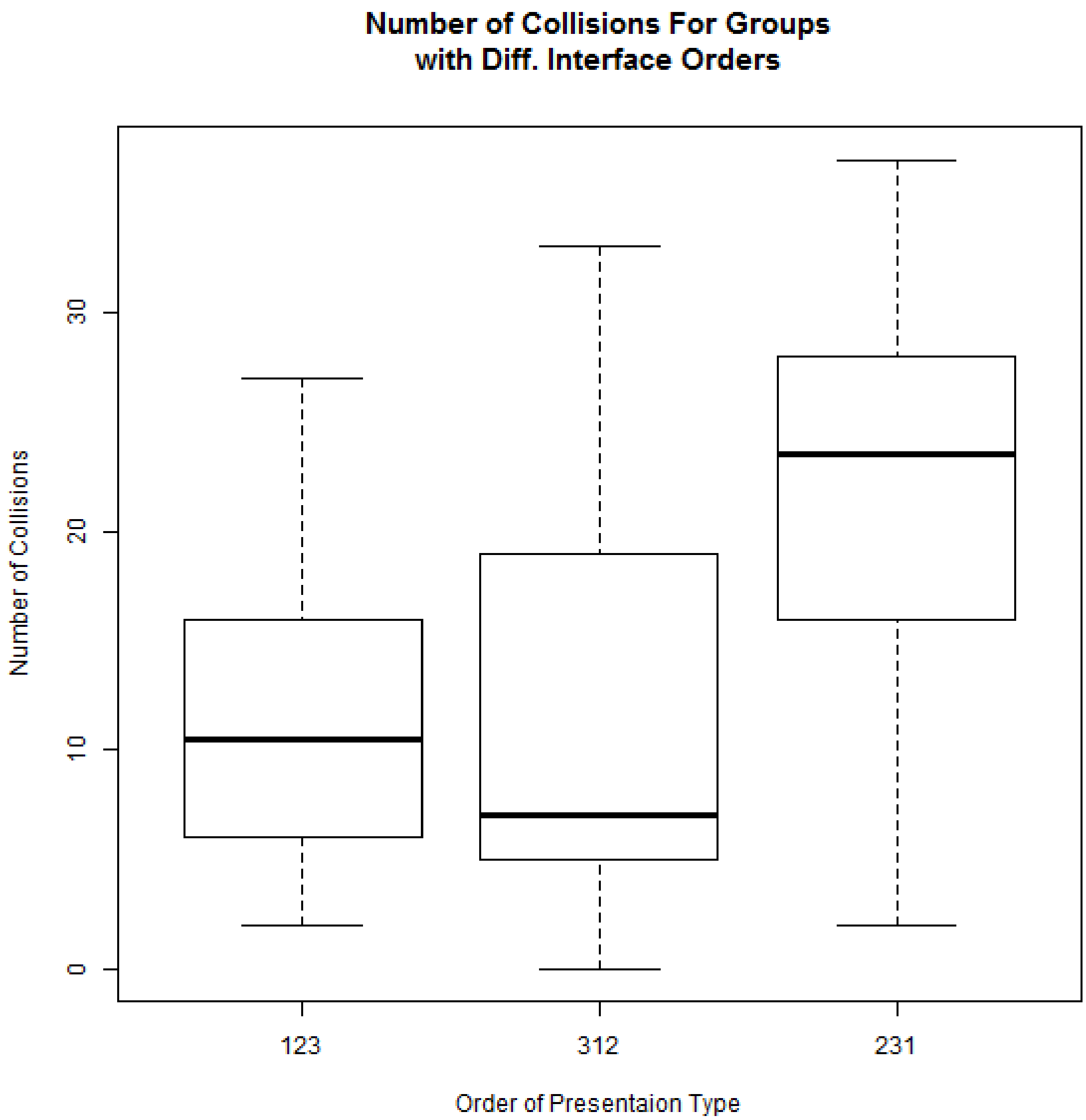
ANOVA: Number of Spheres Found for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.6	0.296	0.038	0.962
Residuals	51	394.2	7.729		

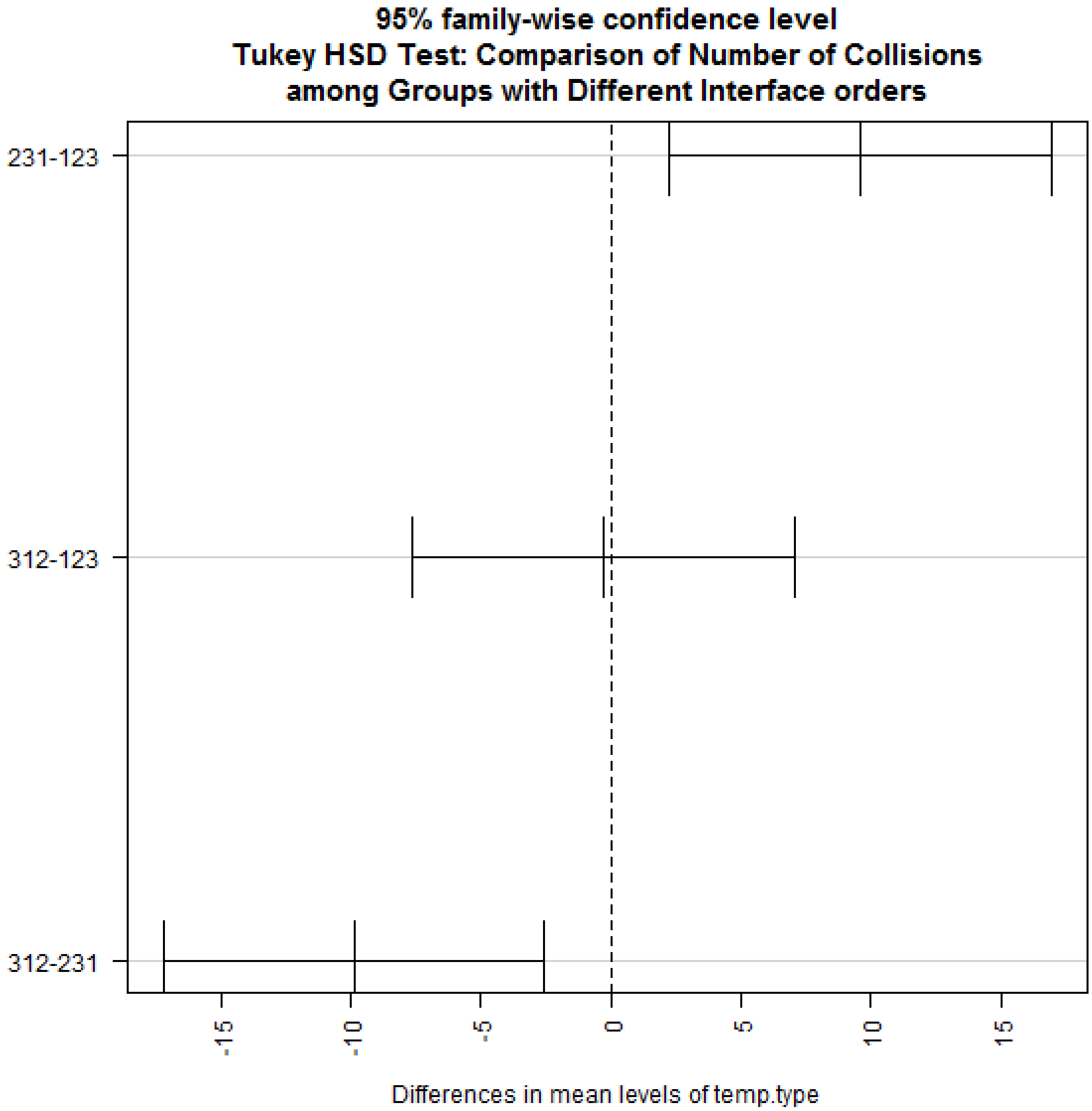
C.2.12.2 Quality of Sketchmaps

ANOVA: Quality of Sketchmaps for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.28	0.14	0.123	0.885
Residuals	51	58.14	1.14		

*C.2.12.3 Number of Collisions**

ANOVA: Number of Collisions for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	1141	570.7	6.874	0.002
Residuals	51	4234	83.0		


Number of Collisions For Groups
with Diff. Interface Orders
Number of Collisions
0
10
20
30
123
312
231
Order of Presentaion Type


95% family-wise confidence level
Tukey HSD Test: Comparison of Number of Collisions
among Groups with Different Interface orders
231-123
312-123
312-231
-15
-10
-5
0
5
10
15
Differences in mean levels of temp.type

C.2.12.4 Task Time

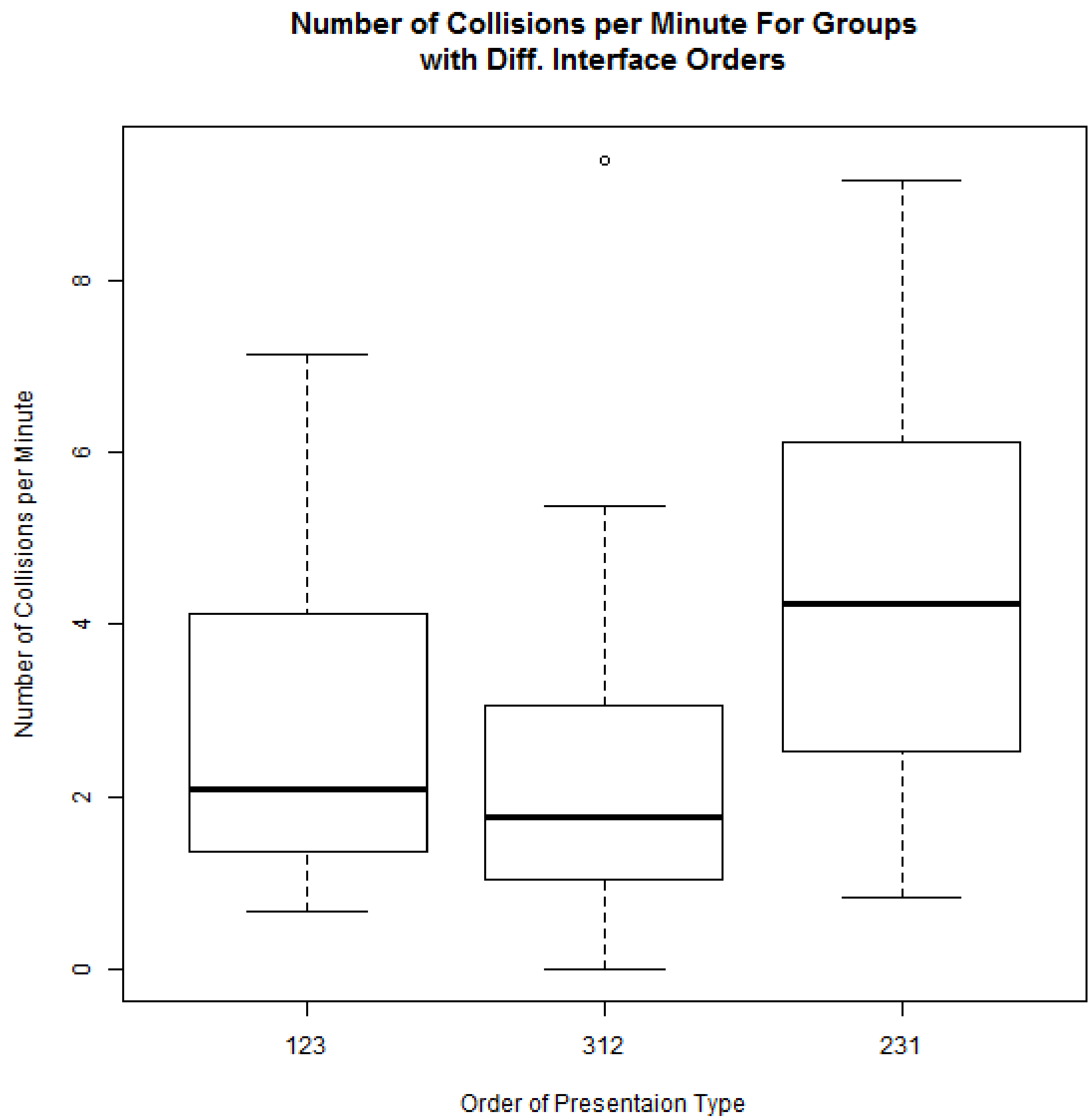
ANOVA: Task Time for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	14734	7367	0.68	0.511
Residuals	51	552760	10838		

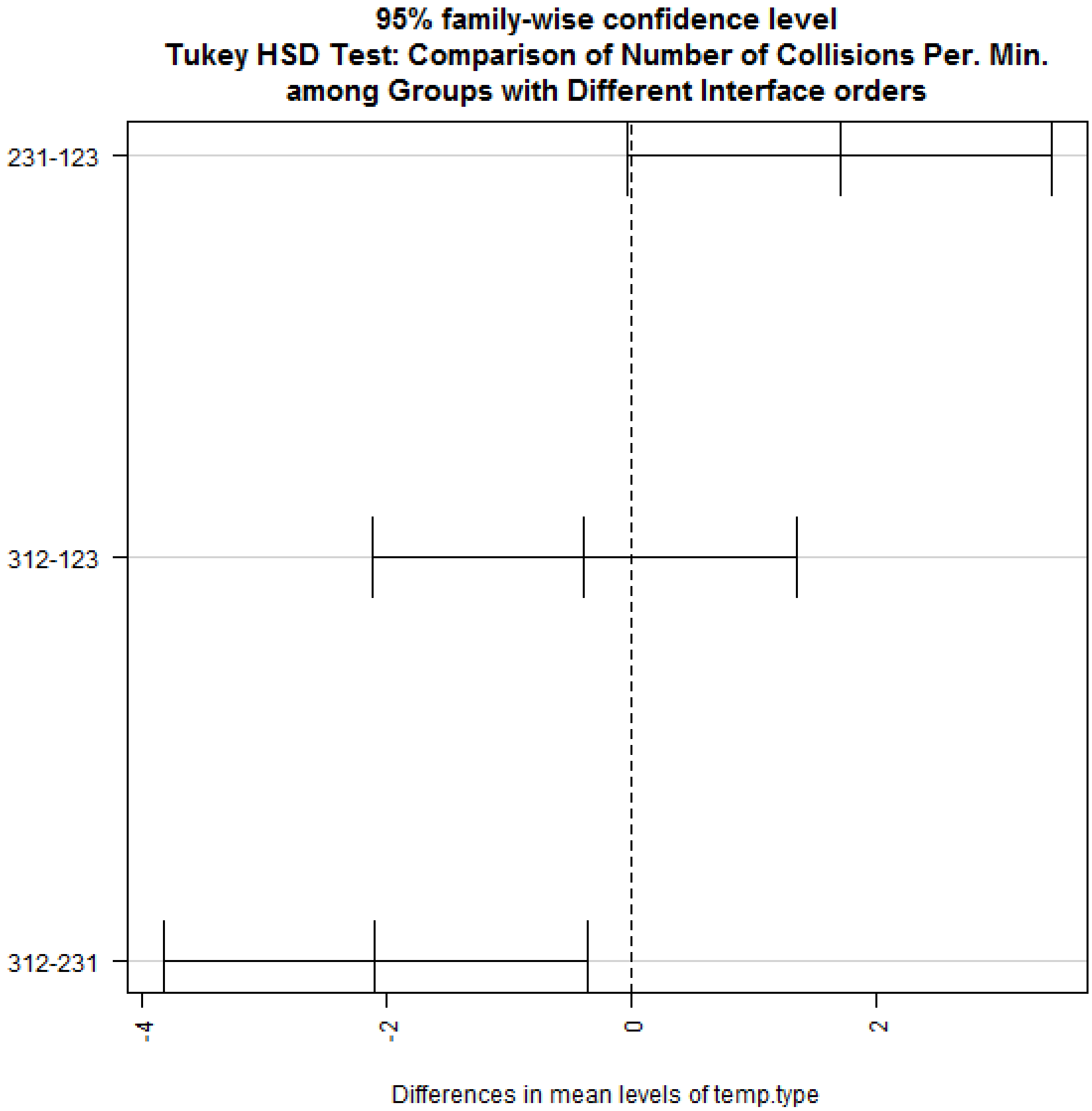
C.2.12.5 Number of Spheres Found per Minute

ANOVA: Number of Spheres Found per Minute for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	1.082	0.541	1.047	0.359
Residuals	51	26.349	0.517		

C.2.12.6 Number of Collisions per Minute*

ANOVA: Number of Collisions per Minute for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	44.46	22.231	4.808	0.012
Residuals	51	235.84	4.624		


Number of Collisions per Minute For Groups
with Diff. Interface Orders
Number of Collisions per Minute
0
2
4
6
8
123
312
231
Order of Presentaion Type

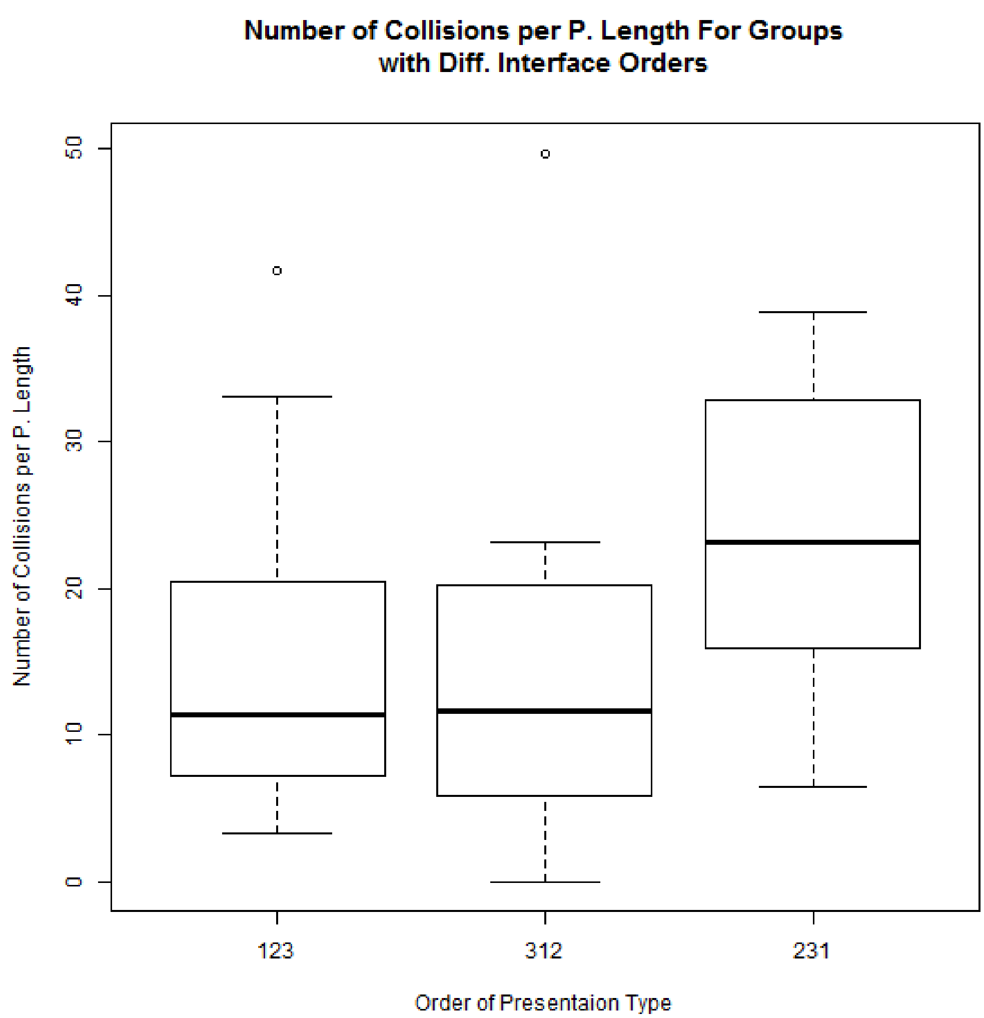

95% family-wise confidence level
Tukey HSD Test: Comparison of Number of Collisions Per. Min.
among Groups with Different Interface orders
231-123
312-123
312-231
-4
-2
0
2
Differences in mean levels of temp.type

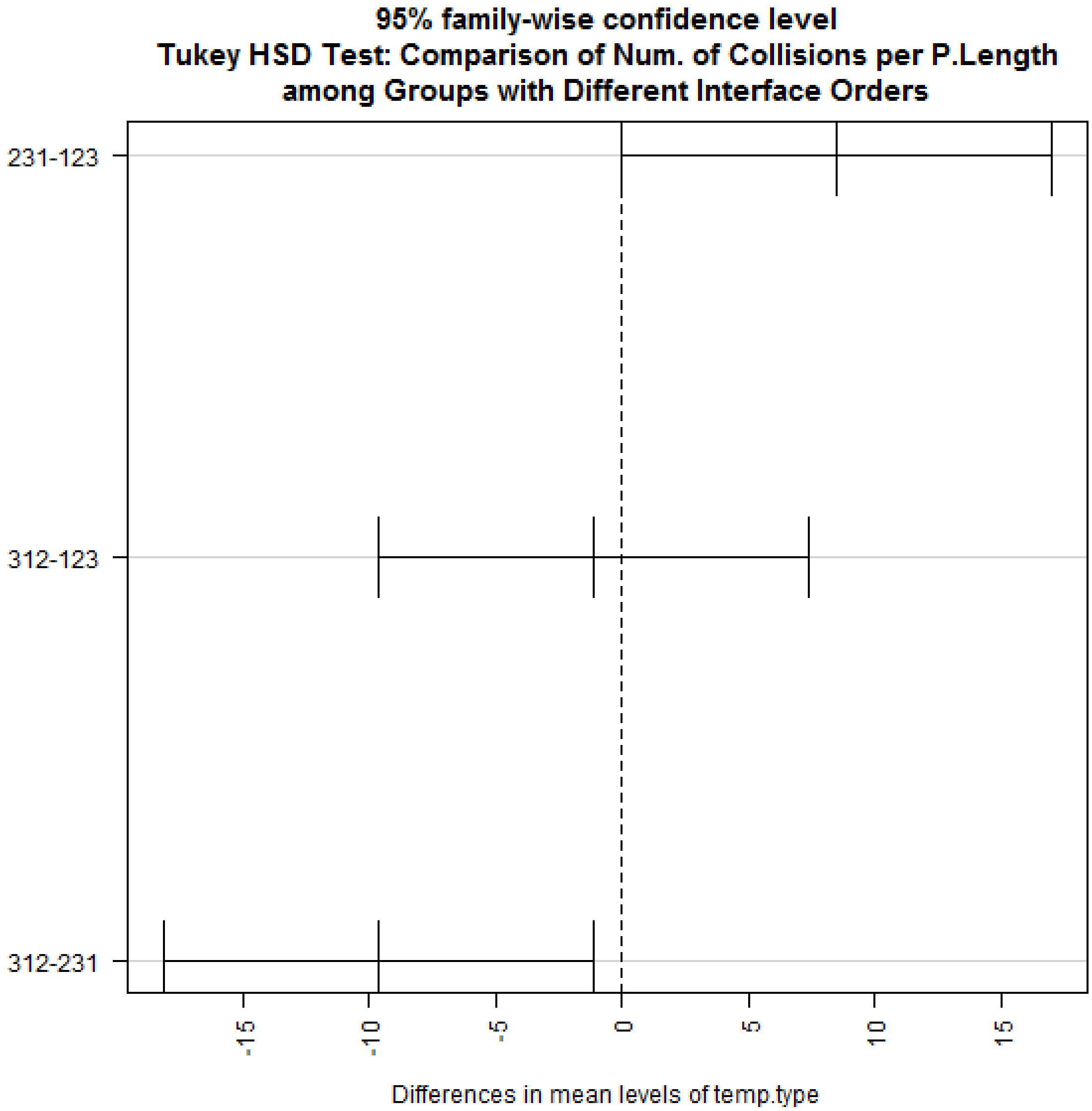
C.2.12.7 Number of Spheres Found per Path Length

ANOVA: AAA Levels for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	36.9	18.46	1.022	0.367
Residuals	51	921.1	18.06		

C.2.12.8 Number of Collisions per Path Length

ANOVA: AAA Levels for Groups With Different Interface Orders					
Source of Variation	***Df***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	995	497.7	4.462	0.016
Residuals	51	5689	111.6		

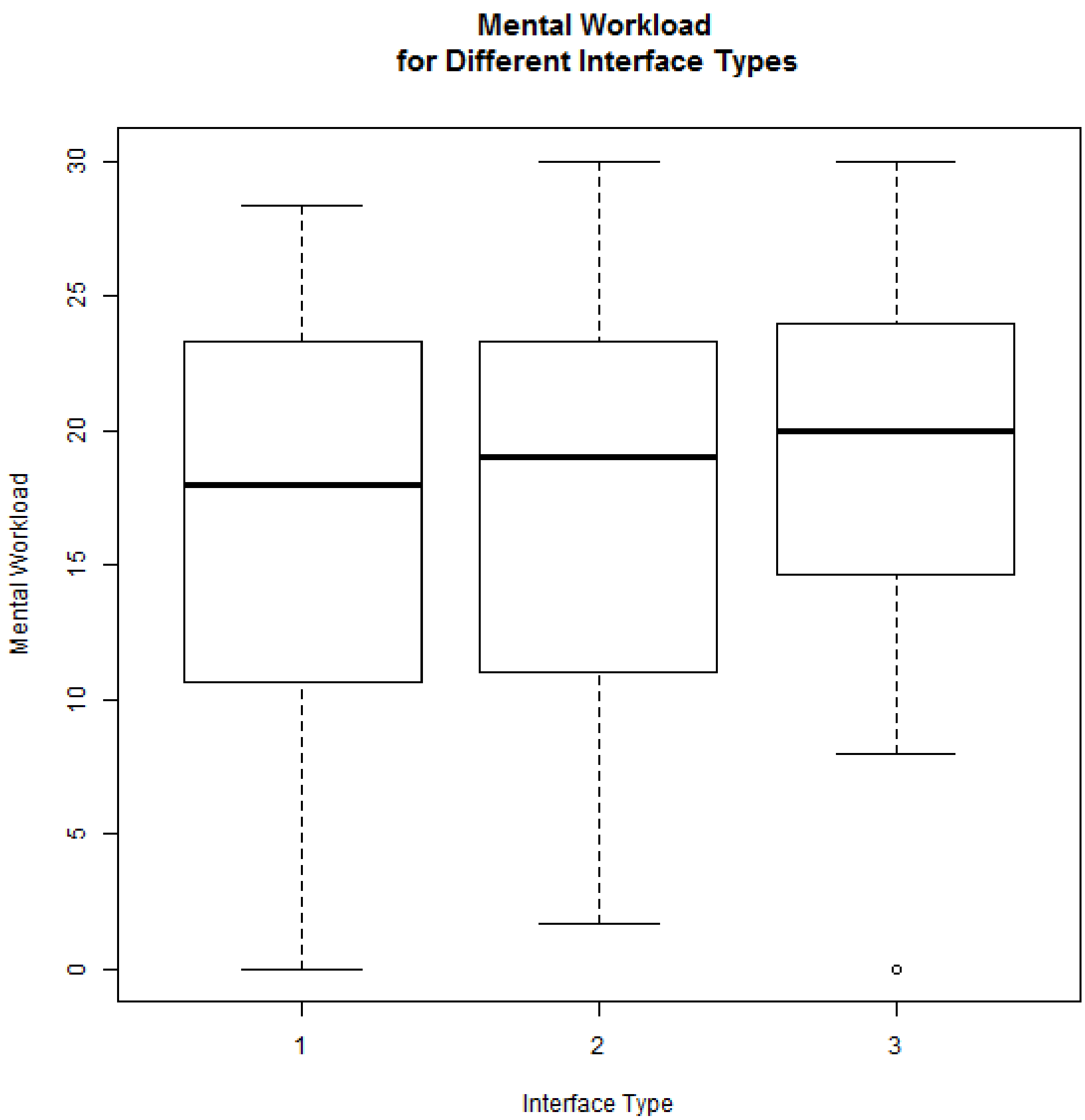



95% family-wise confidence level
Tukey HSD Test: Comparison of Num. of Collisions per P.Length
among Groups with Different Interface Orders
231-123
312-123
312-231
-15
-10
-5
0
5
10
15
Differences in mean levels of temp.type

C.2.13 NASA-TLX Results

C.2.13.1 Mental Workload Evaluation

C.2.13.1.1 Weighted Scores

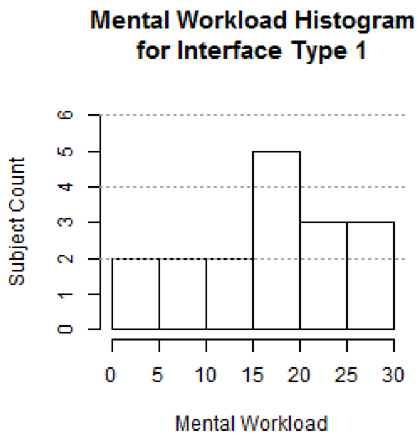


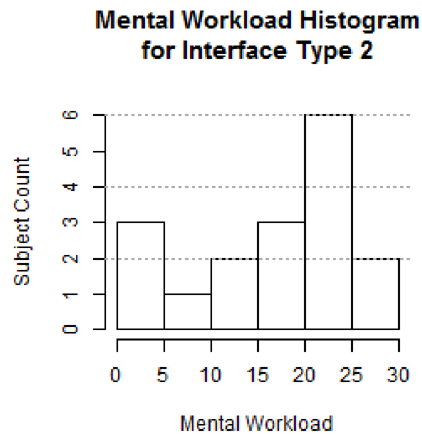
ANOVA: Mental Workload Weighted Scores for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	30	15.06	0.216	0.807
Residuals	48	3351	69.82		

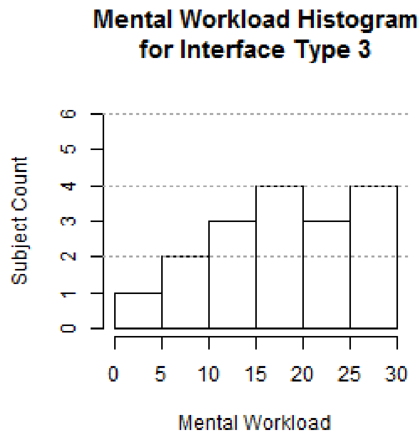
Mental Workload Weighted Scores vs. Interface Used - Friedman Test	
X^2	3.446
p	0.179
DoF	2.000

Mental Workload Weighted Scores vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	55.500	43.000	51.000
Z	-0.734	-1.326	-0.852
p	0.480	0.198	0.410
R	-0.122	-0.221	-0.142

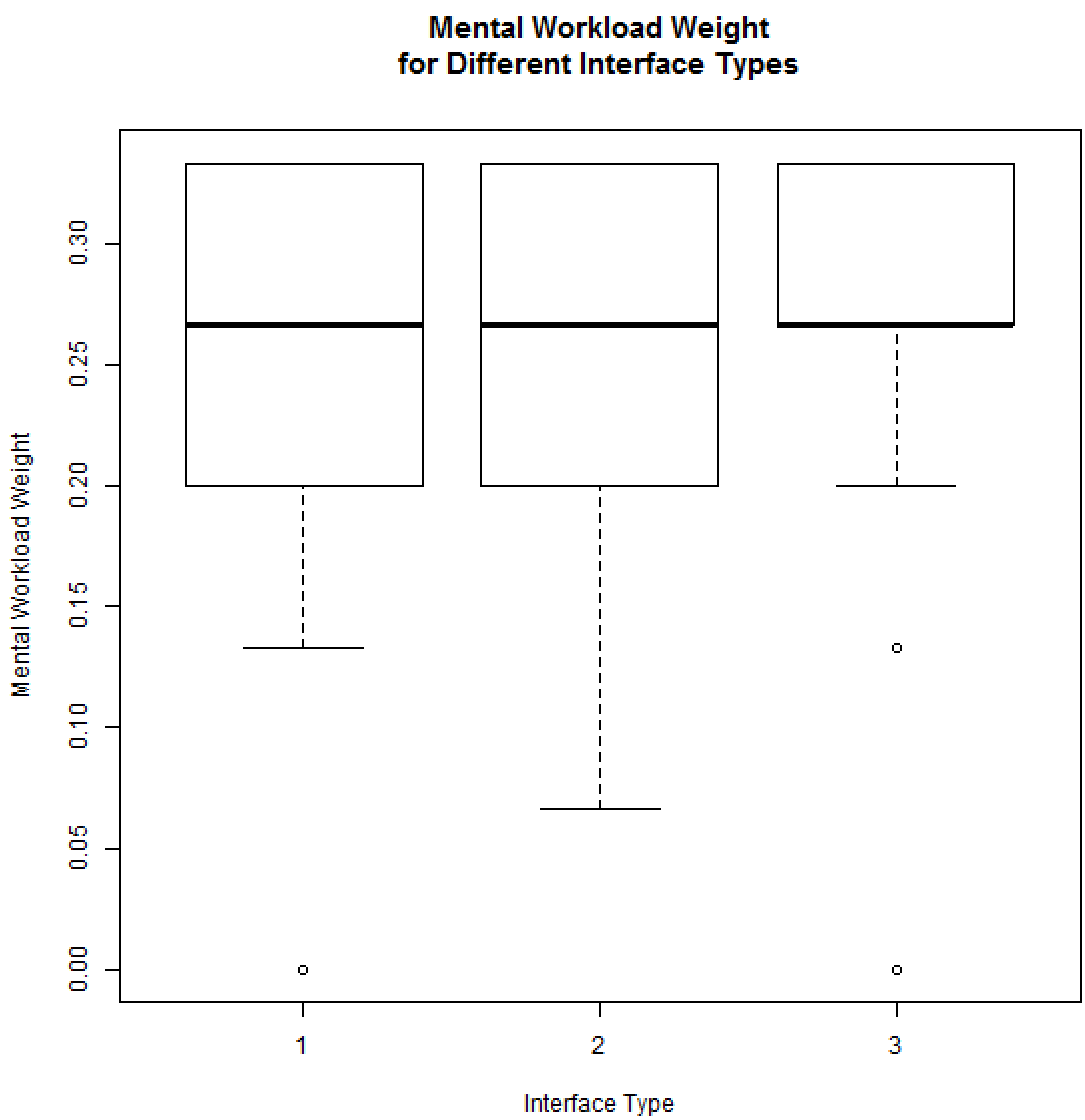
Mental Workload Weighted Scores vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	16.529	8.330	18.000
2	16.902	8.622	19.000
3	18.314	8.107	20.000







C.2.13.1.2 Weight

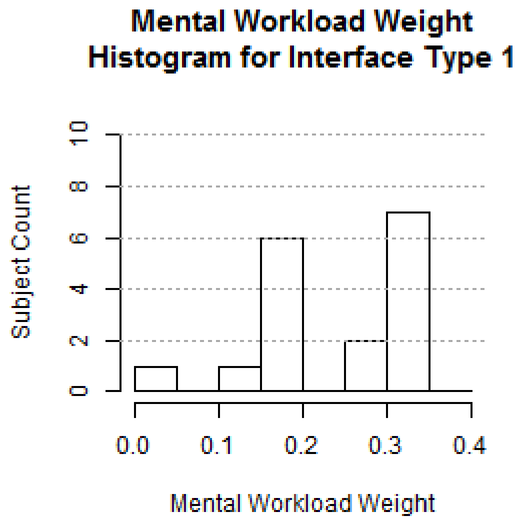


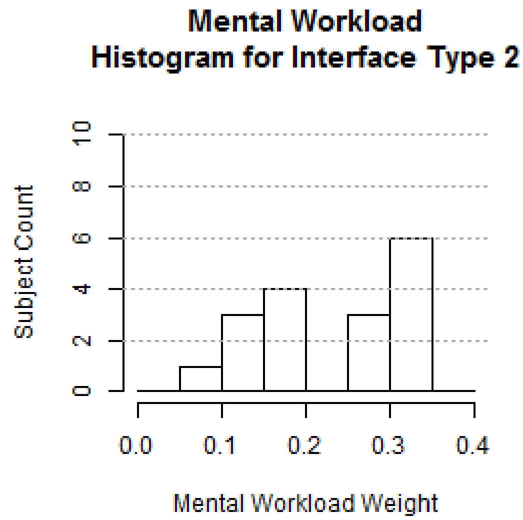
ANOVA: Mental Workload Weight for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.003	0.002	0.209	0.812
Residuals	48	0.380	0.008		

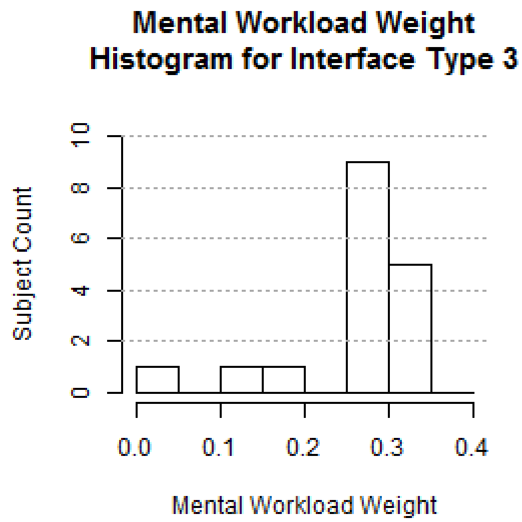
Mental Workload Weight vs. Interface Used - Friedman Test	
X^2	0.578
p	0.749
DoF	2.000

Mental Workload Weight vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	30.500	22.500	12.500
Z	0.604	-1.038	-1.086
p	0.559	0.300	0.297
R	0.101	-0.173	-0.181

Mental Workload Weight vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.247	0.094	0.267
2	0.239	0.088	0.267
3	0.259	0.085	0.267

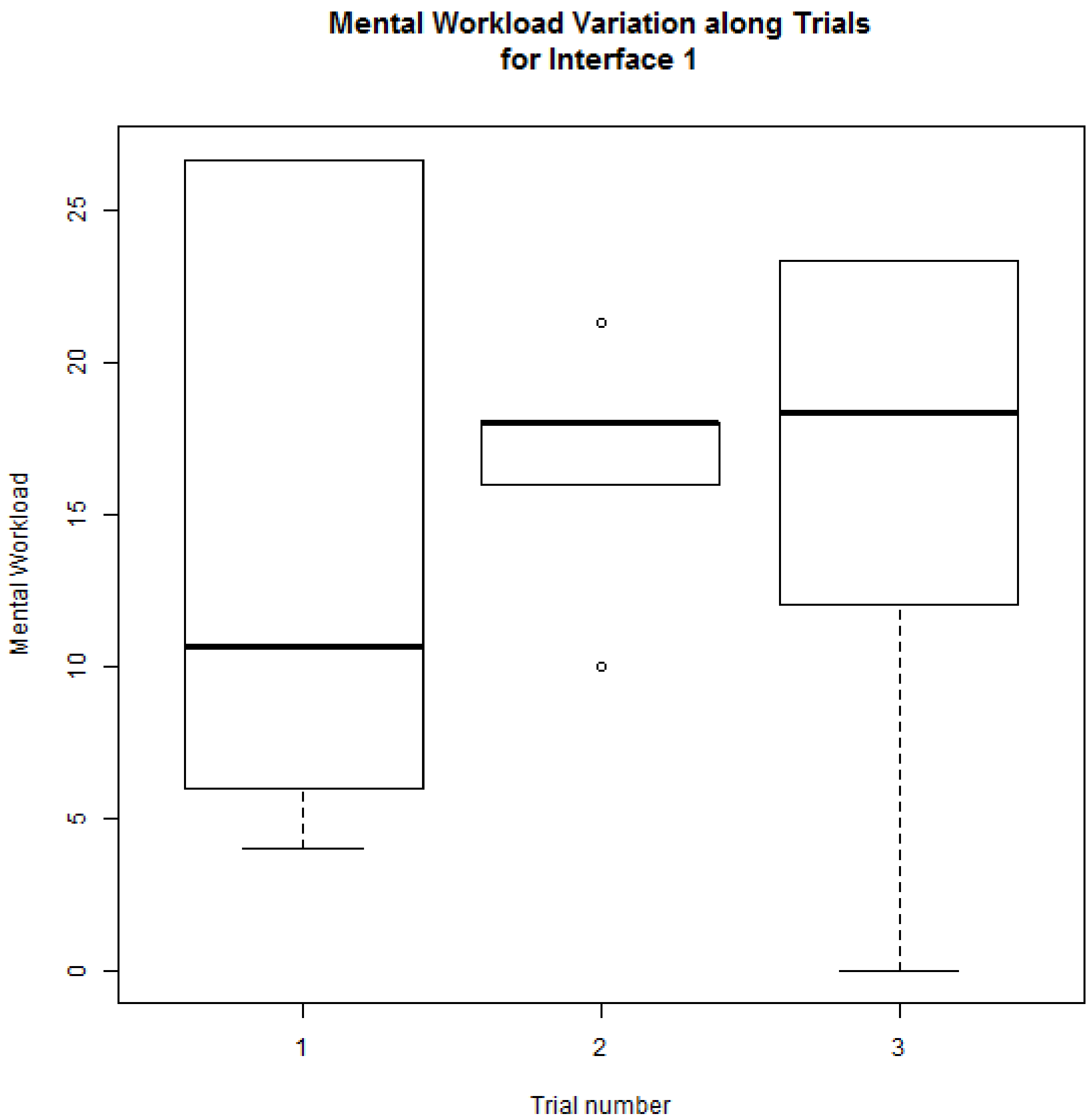






C.2.13.1.3 Interface Order Effect on Mental Workload Score

Interface 1

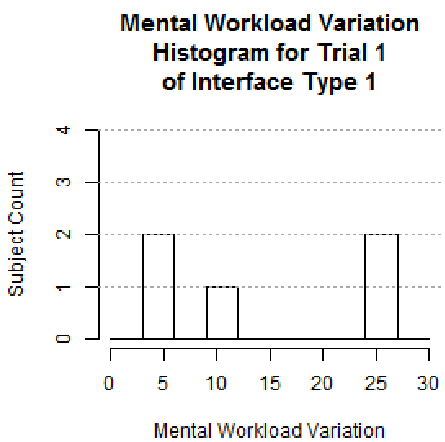


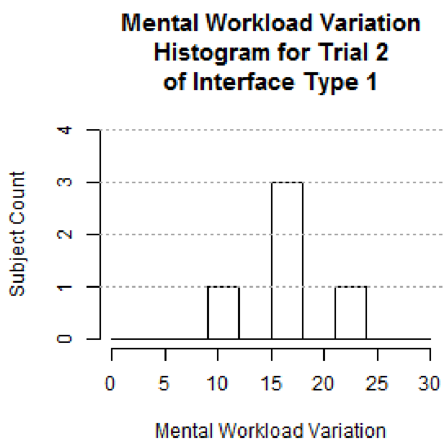
ANOVA: Interface 1 Mental Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	9.1	4.54	0.058	0.944
Residuals	12	946.2	78.85		

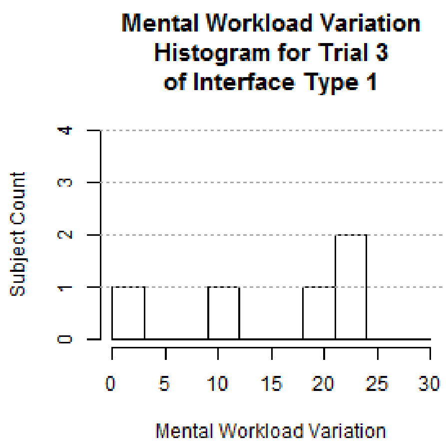
Interface 1 Mental Workload Score vs. Interface Order - Friedman Test	
X^2	0.400
p	0.819
DoF	2.000

Interface 1 Mental Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	6.000	7.000	8.000
Z	-0.405	-0.135	0.135
p	0.812	1.000	1.000
R	-0.067	-0.022	0.022

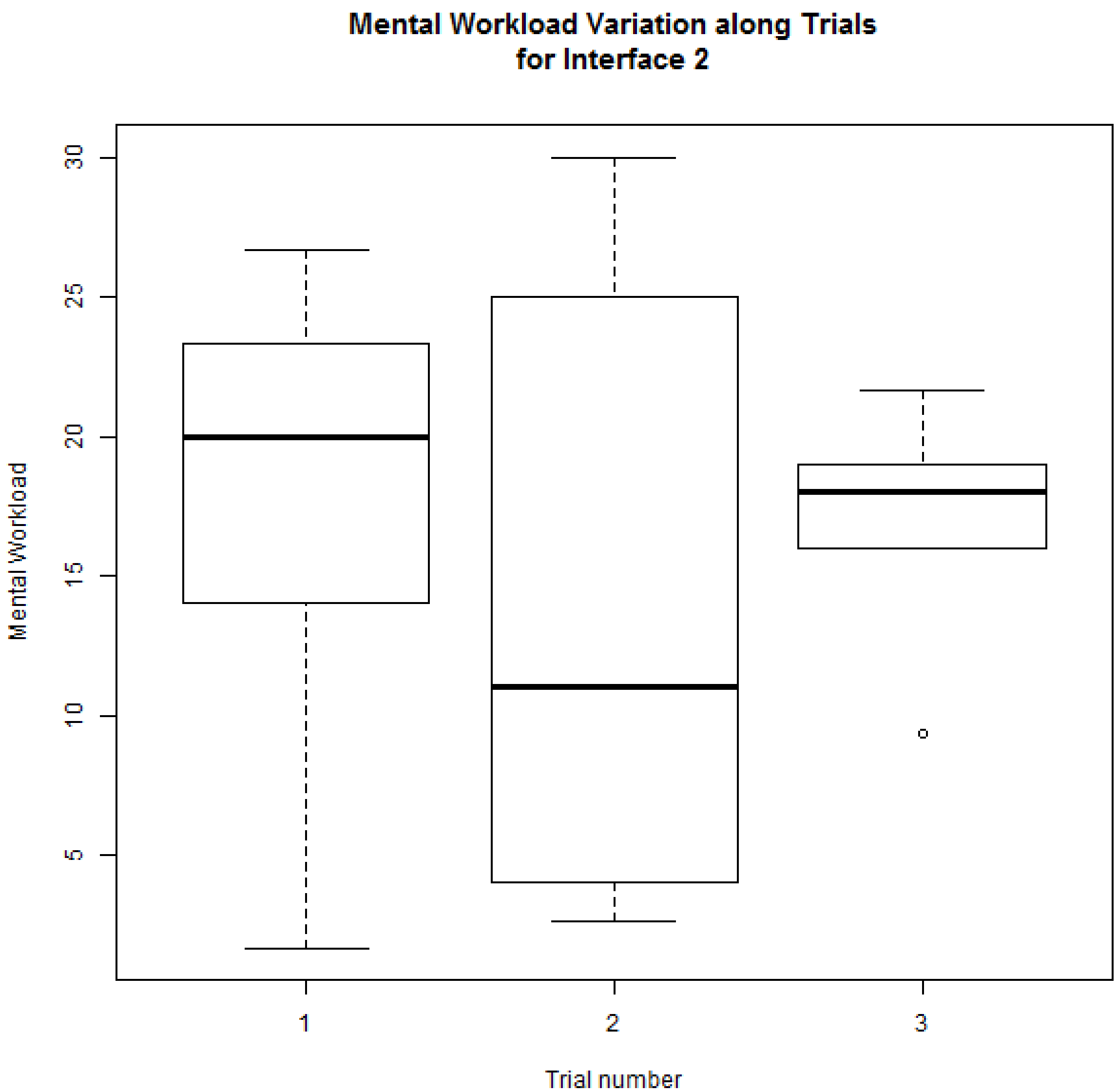
Interface 1 Mental Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	14.800	11.100	10.667
2	16.667	4.190	18.000
3	15.400	9.788	18.333







Interface 2

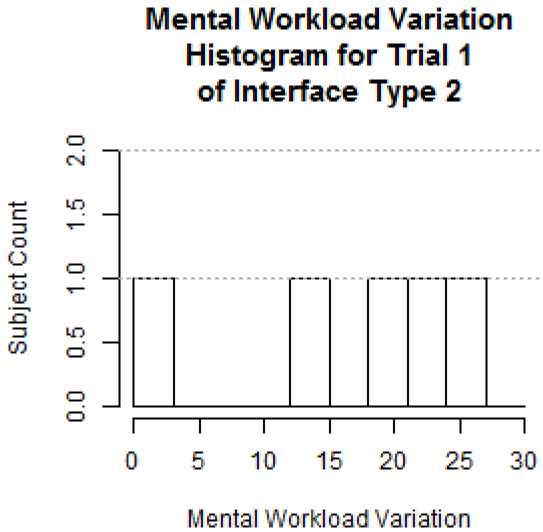


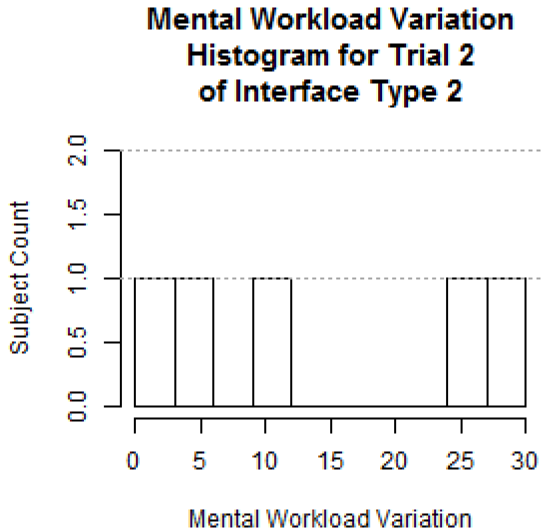
ANOVA: Interface 2 Mental Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	20	10.01	0.111	0.896
Residuals	12	1086	90.50		

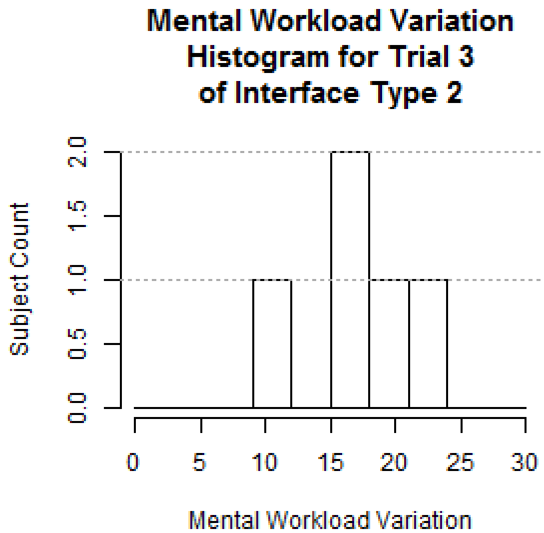
Interface 2 Mental Workload Score vs. Interface Order - Friedman Test	
X^2	1.200
p	0.549
DoF	2.000

Interface 2 Mental Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	10.000	9.000	6.000
Z	0.674	0.405	-0.405
p	0.625	0.812	0.812
R	0.112	0.067	-0.067

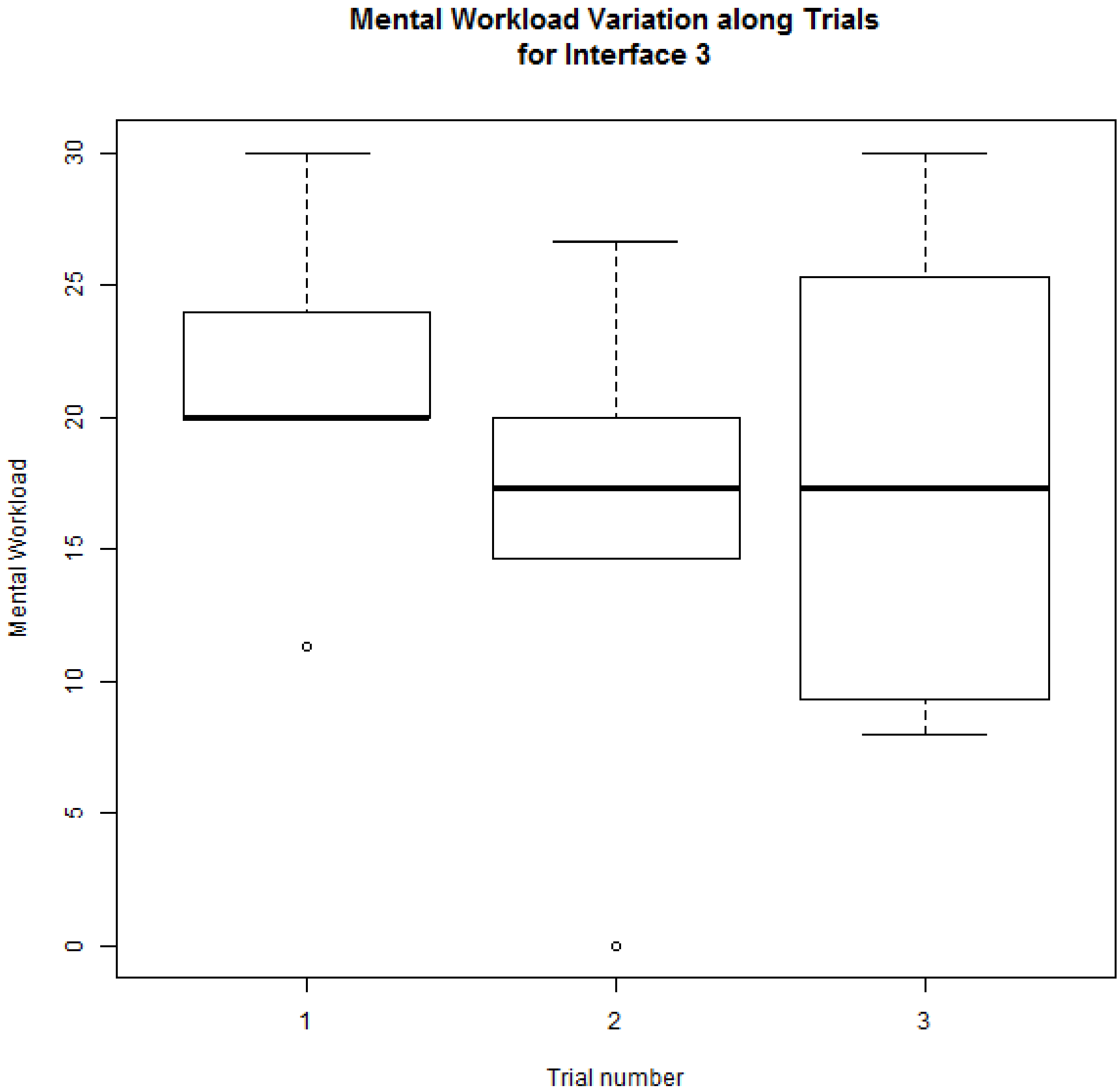
Interface 2 Mental Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	17.133	9.831	20.000
2	14.533	12.380	11.000
3	16.800	4.646	18.000







Interface 3

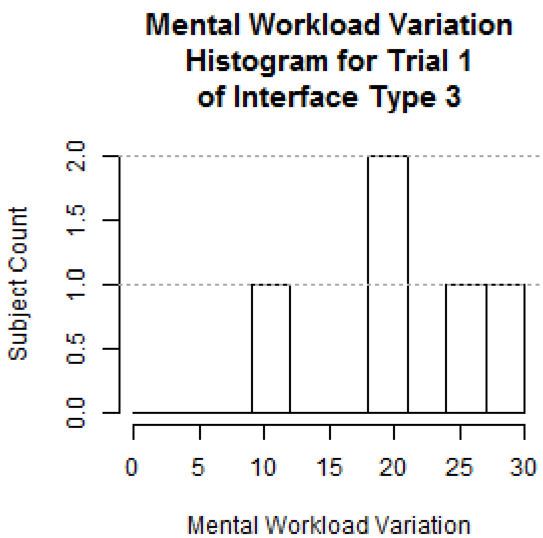


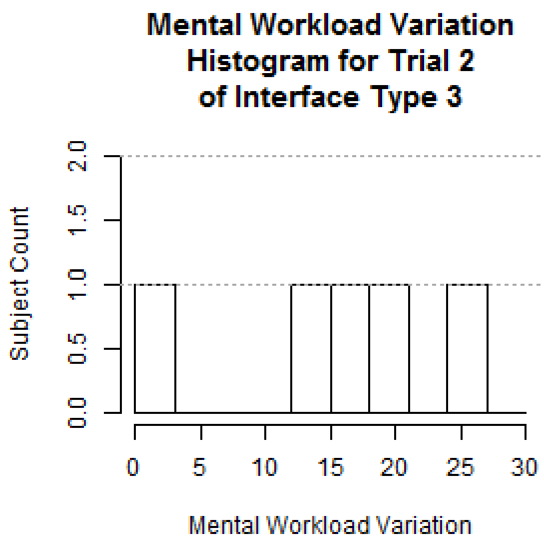
ANOVA: Interface 3 Mental Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	71.6	35.82	0.454	0.646
Residuals	12	947.7	79.98		

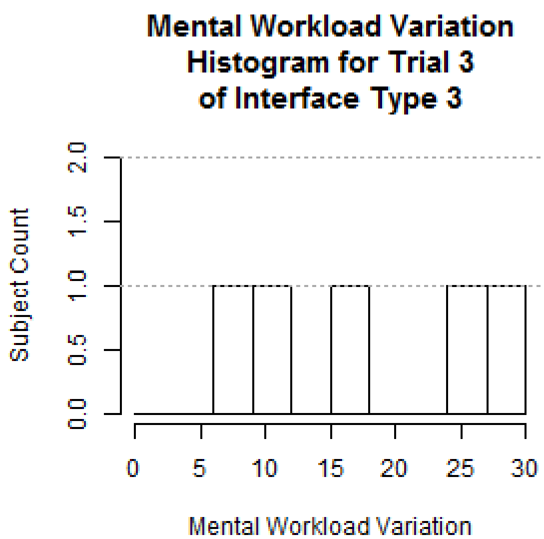
Interface 3 Mental Workload Score vs. Interface Order - Friedman Test	
X^2	0.737
p	0.692
DoF	2.000

Interface 3 Mental Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	7.000	11.000	7.000
Z	0.544	0.944	-0.135
p	0.750	0.438	1.000
R	0.091	0.157	-0.022

Interface 3 Mental Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	21.067	6.808	20.000
2	15.733	9.861	17.333
3	18.000	9.661	17.333

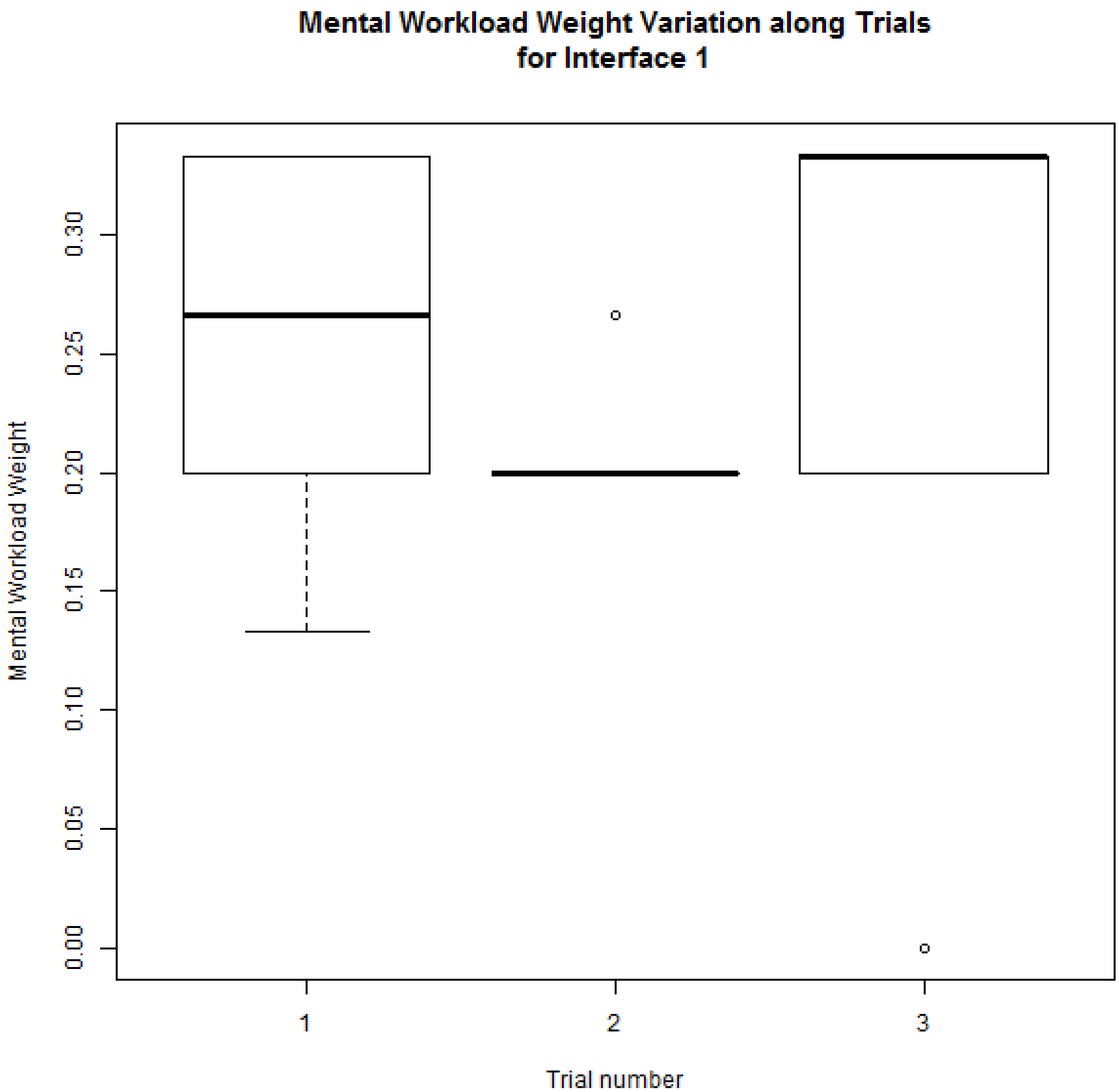






C.2.13.1.4 Interface Order Effect on Mental Workload Weight

Interface 1

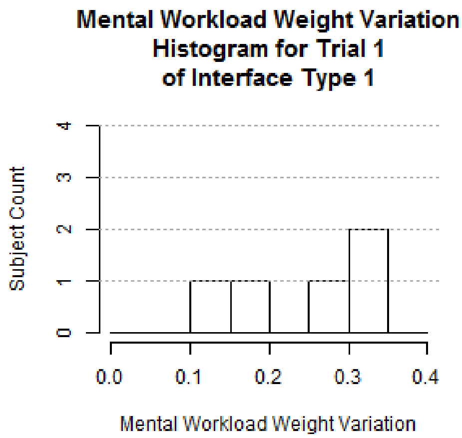


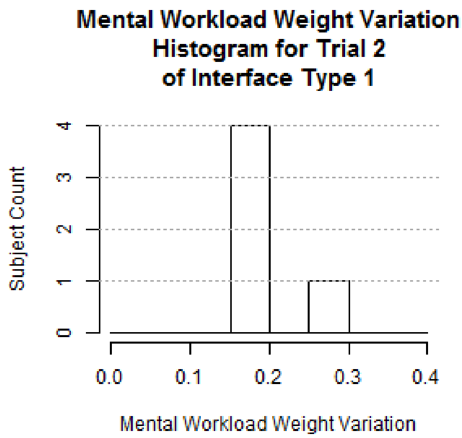
ANOVA: Interface 1 Mental Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.004	0.002	0.209	0.814
Residuals	12	0.119	0.010		

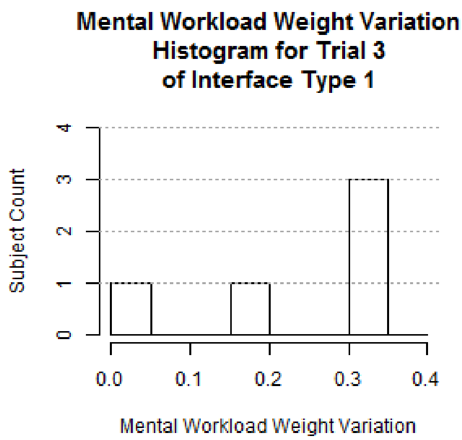
Interface 1 Mental Workload Weight vs. Interface Order - Friedman Test	
X^2	1.412
p	0.494
DoF	2.000

Interface 1 Mental Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	7.000	5.000	4.000
Z	0.816	0.000	-0.555
p	0.500	1.000	0.625
R	0.136	0.000	-0.092

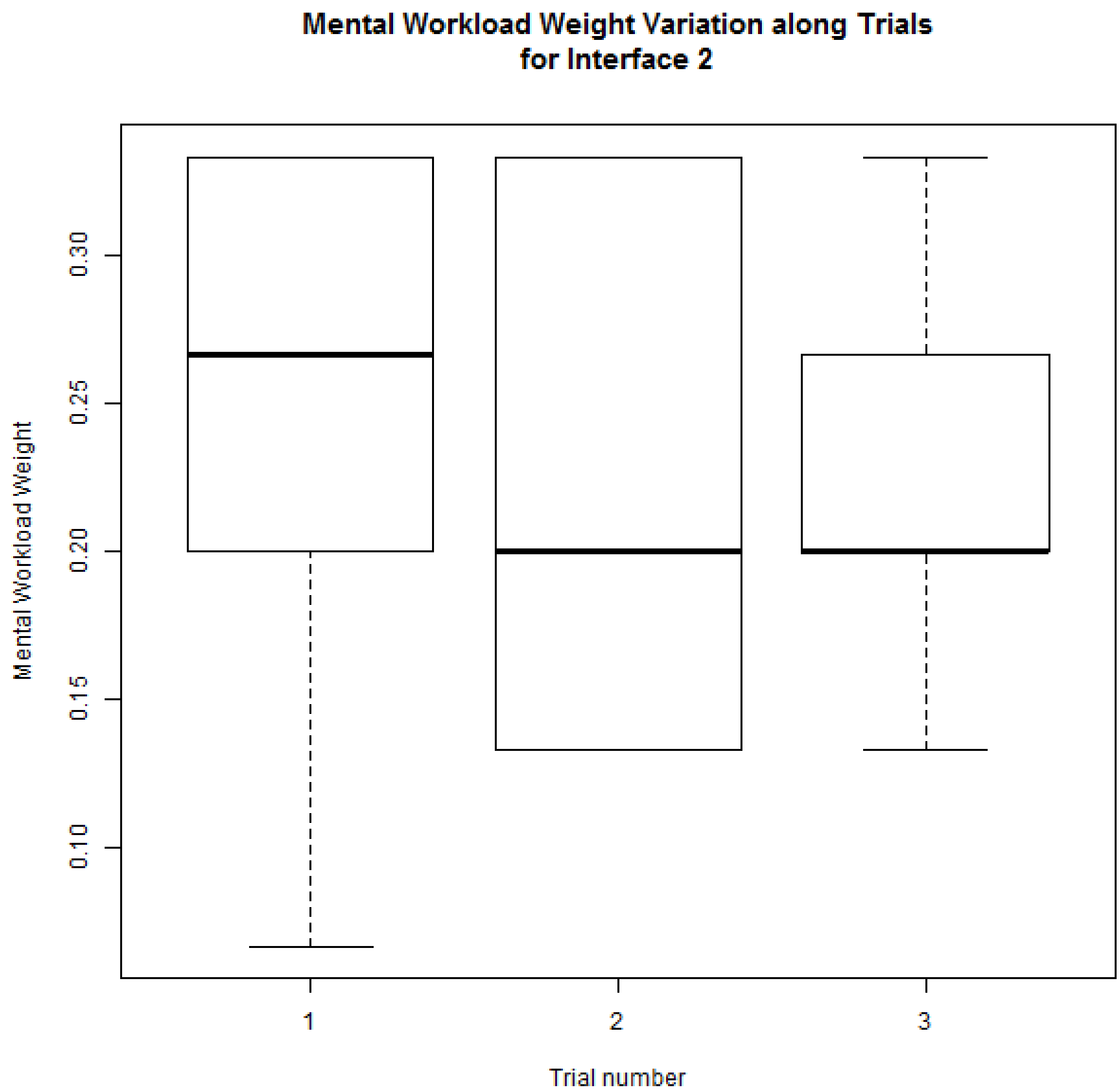
Interface 1 Mental Workload Weight Variation vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.253	0.087	0.267
2	0.213	0.030	0.200
3	0.240	0.146	0.333







Interface 2

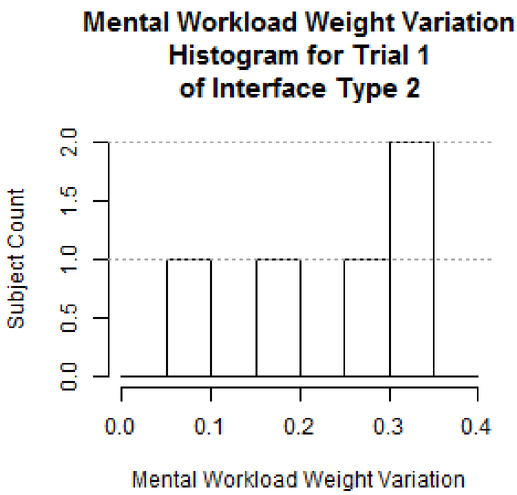


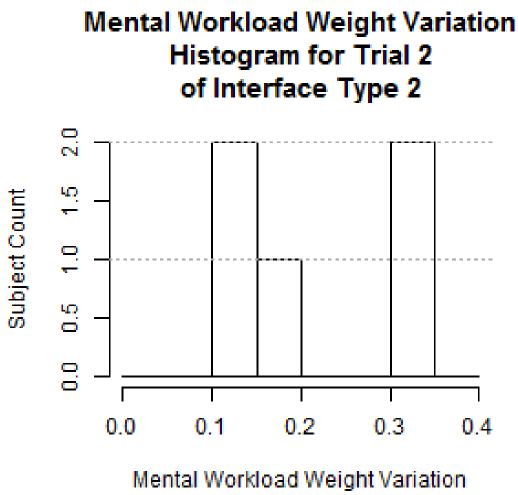
ANOVA: Interface 2 Mental Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.000	0.000	0.031	0.969
Residuals	12	0.114	0.009		

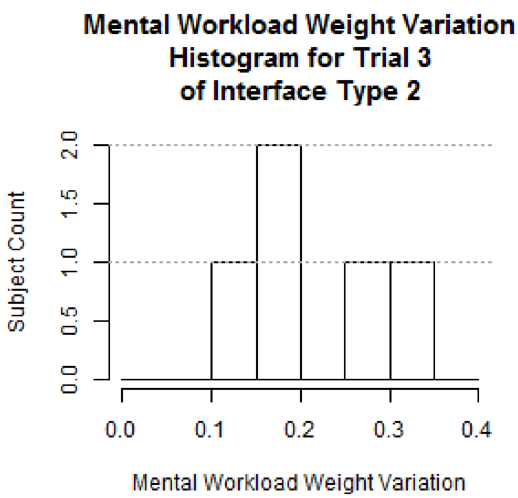
Interface 2 Mental Workload Weight vs. Interface Order - Friedman Test	
X^2	1.412
p	0.494
DoF	2.000

Interface 2 Mental Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	6.000	6.000	4.000
Z	0.544	0.544	-0.277
p	0.750	0.750	1.000
R	0.091	0.091	-0.046

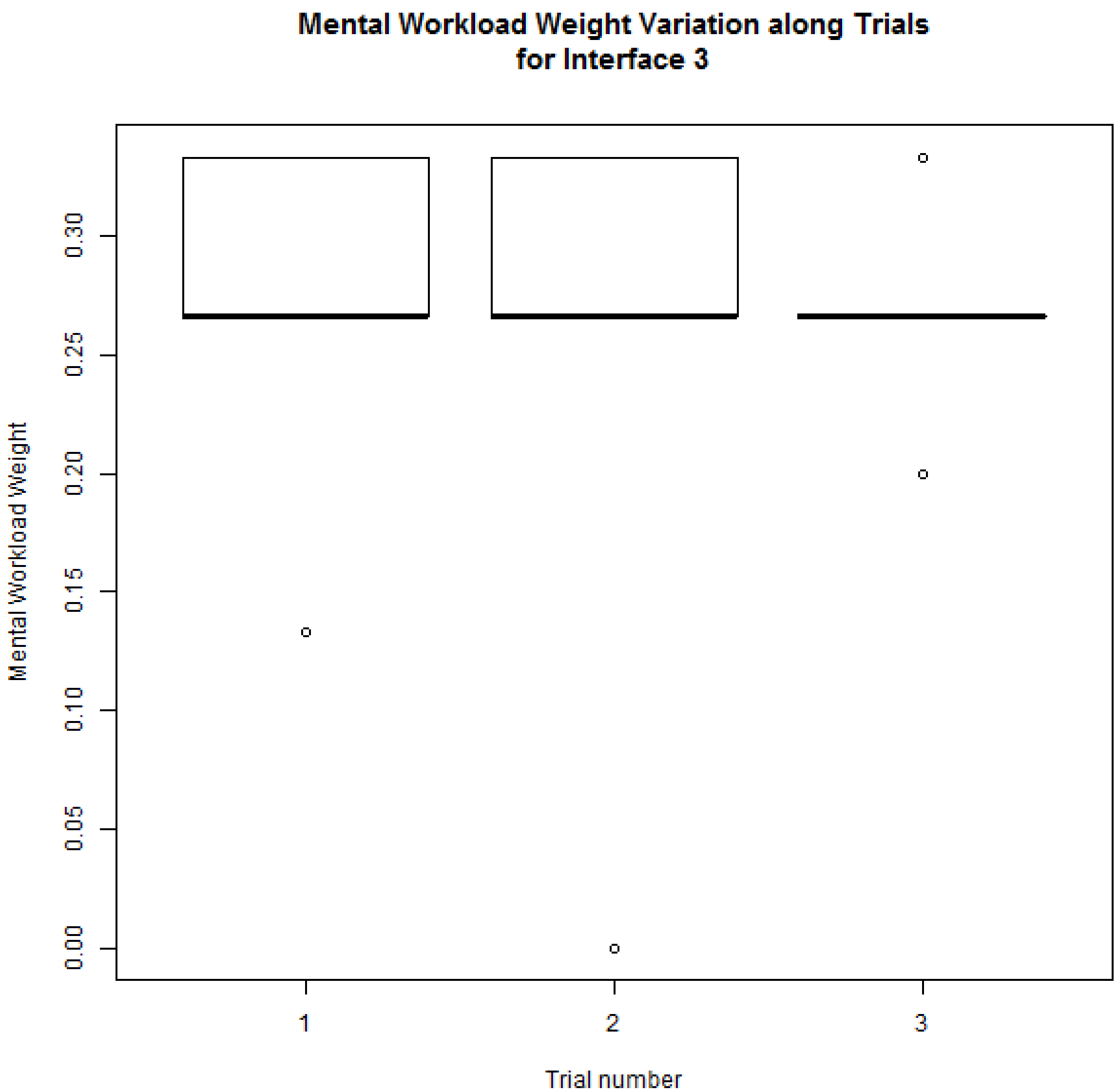
Interface 2 Mental Workload Weight vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.240	0.112	0.267
2	0.227	0.101	0.200
3	0.227	0.076	0.200







Interface 3

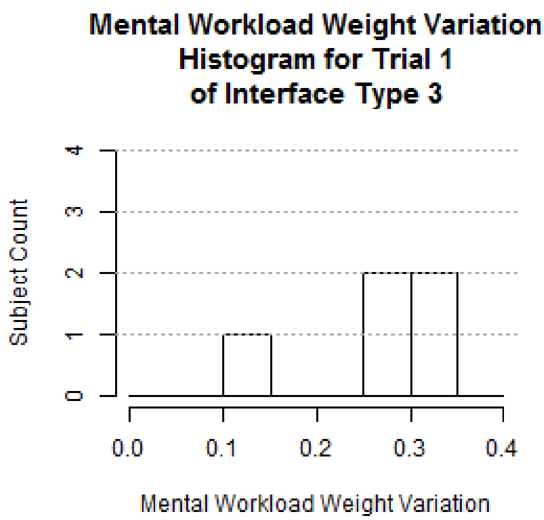


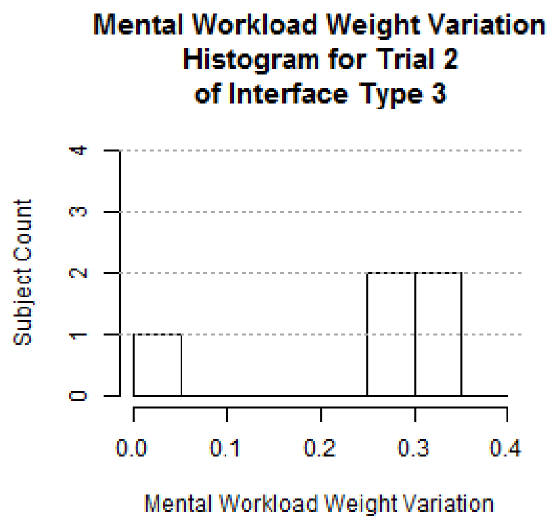
ANOVA: Interface 3 Mental Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.002	0.001	0.127	0.882
Residuals	12	0.112	0.009		

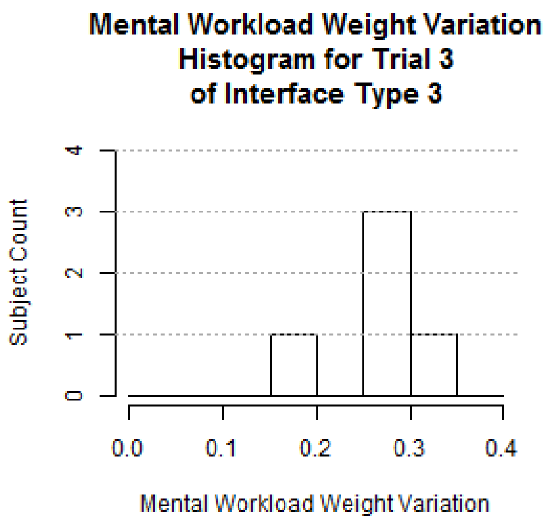
Interface 3 Mental Workload Weight vs. Interface Order - Friedman Test	
X^2	0.429
p	0.807
DoF	2.000

Interface 3 Mental Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	3.000	4.000	3.000
Z	-0.283	-0.277	0.283
p	1.000	1.000	1.000
R	-0.047	-0.046	0.047

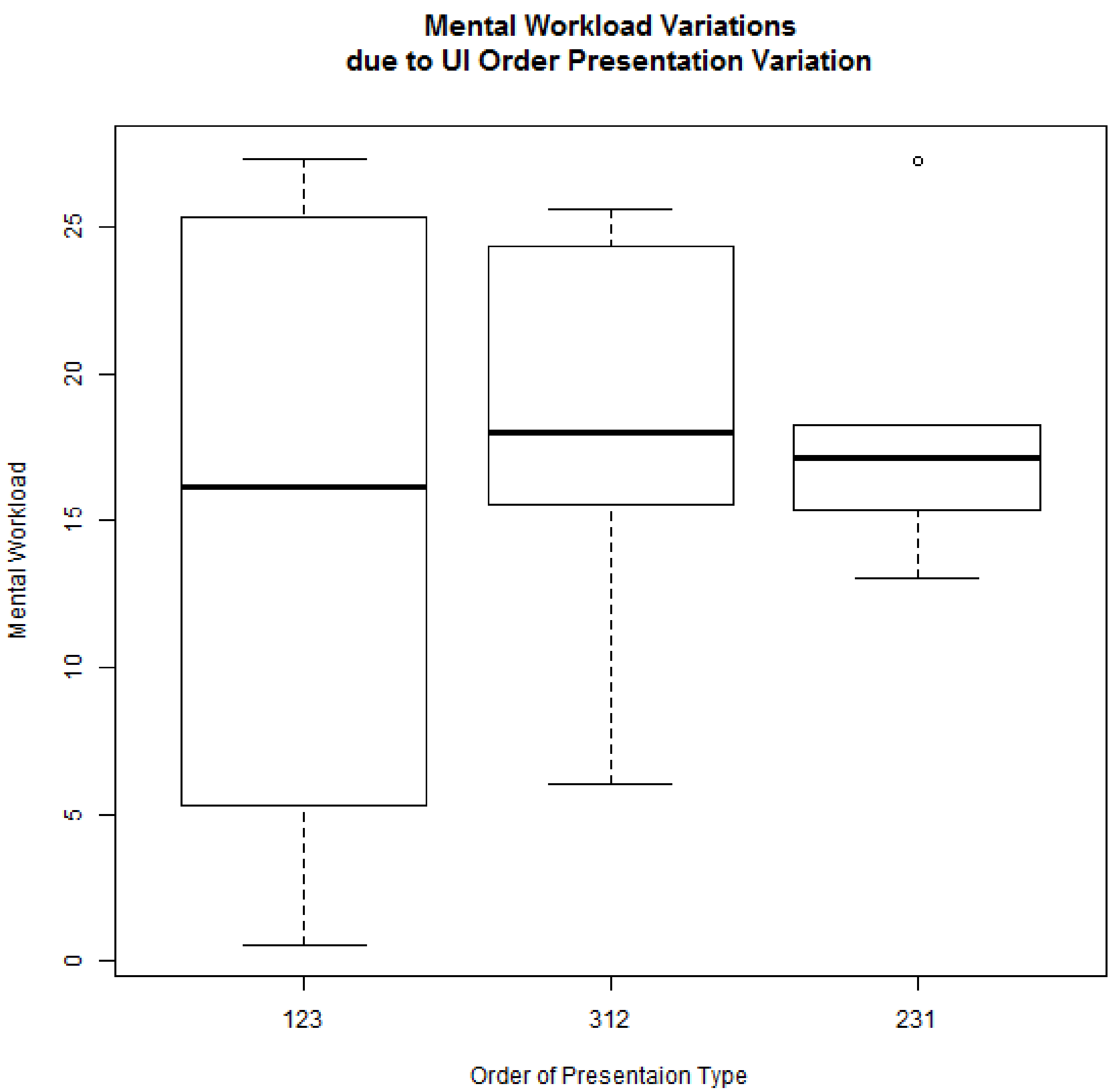
Interface 3 Mental Workload Weight vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.267	0.082	0.267
2	0.240	0.138	0.267
3	0.267	0.047	0.267







C.2.13.1.5 Mental Workload for Groups with Different Interface orders

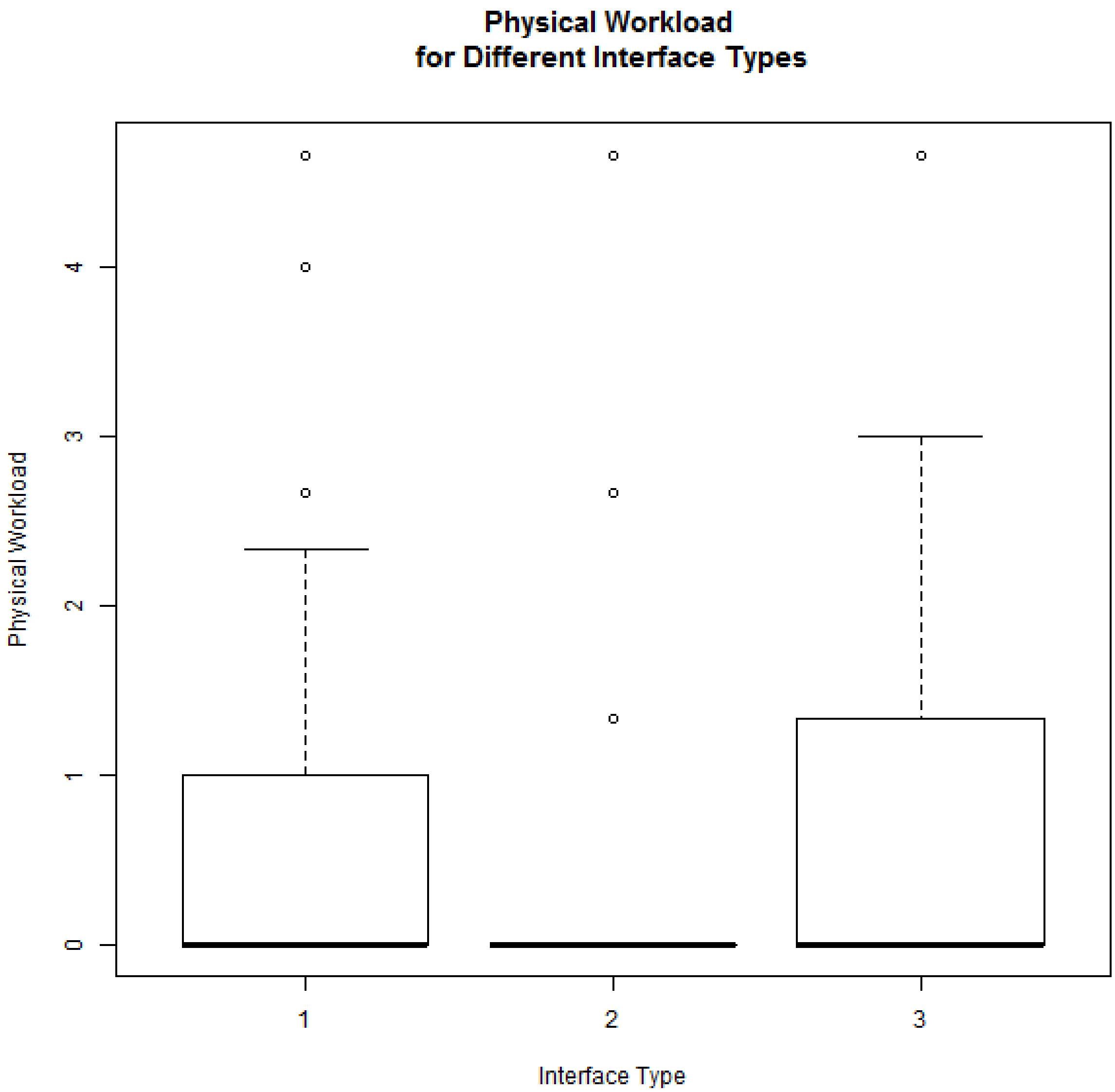


ANOVA: Overall Mental Workload for Subjects with Different Interface Orders					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	32.2	16.12	0.209	0.815
Residuals	12	927.1	77.26		

Overall Mental Workload vs. Subjects with Different Interface Orders Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	14.933	11.855	16.111
2	17.889	7.860	18.000
3	18.178	5.428	17.111

C.2.13.2 Physical Workload Evaluation

C.2.13.2.1 Weighted Scores

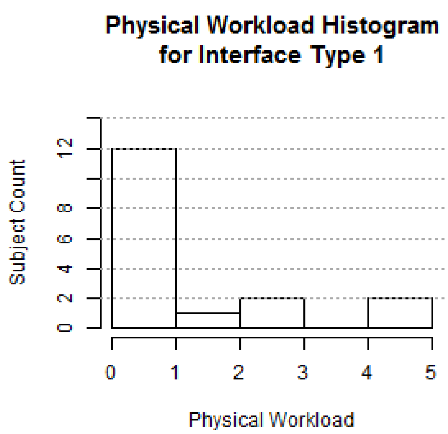


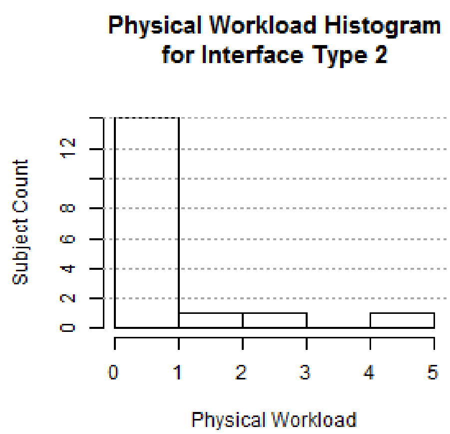
ANOVA: Physical Workload Weighted Scores for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	1.27	0.636	0.319	0.729
Residuals	48	95.84	1.997		

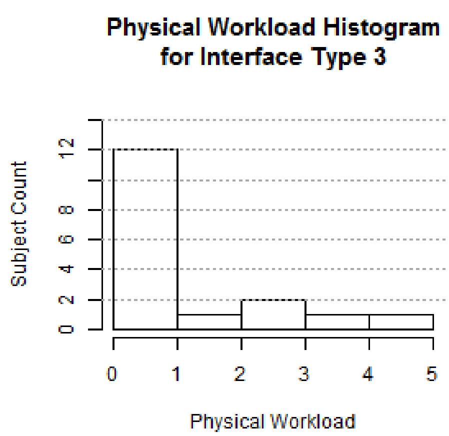
Physical Workload Weighted Scores vs. Interface Used - Friedman Test	
X^2	0.400
p	0.819
DoF	2.000

Physical Workload Weighted Scores vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	11.000	7.500	3.000
Z	0.564	-0.356	-0.623
p	0.500	0.938	0.438
R	0.094	-0.059	-0.104

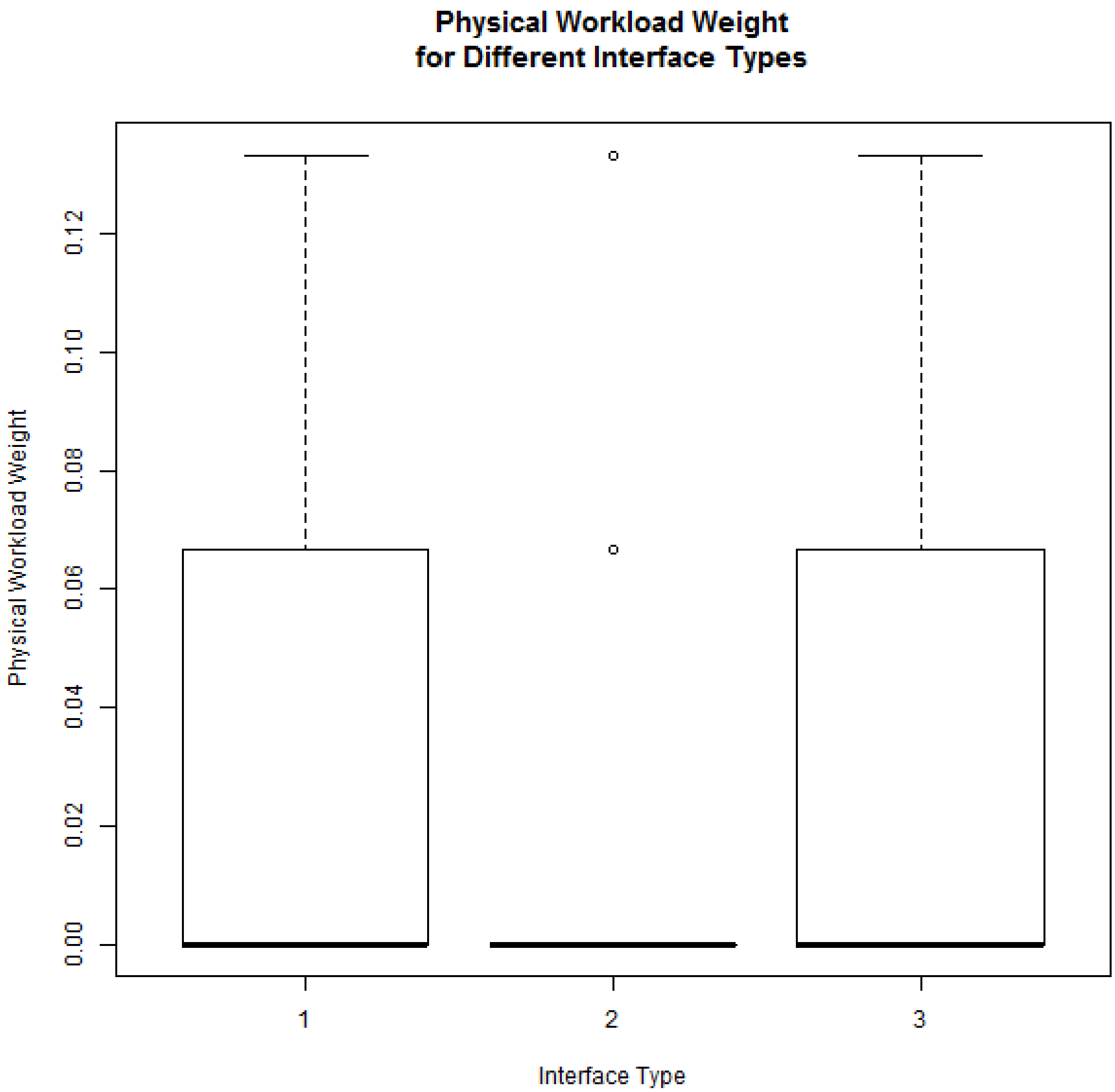
Physical Workload Weighted Scores vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.863	1.555	0.000
2	0.510	1.281	0.000
3	0.824	1.390	0.000







C.2.13.2.2 Weight

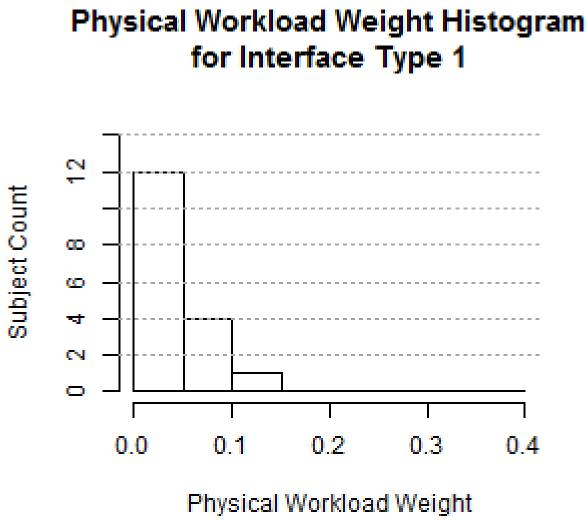


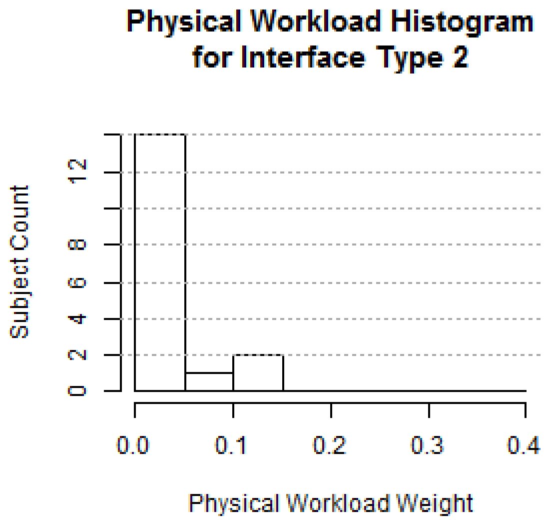
ANOVA: Physical Workload Weight for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.000	0.000	0.145	0.866
Residuals	48	0.087	0.002		

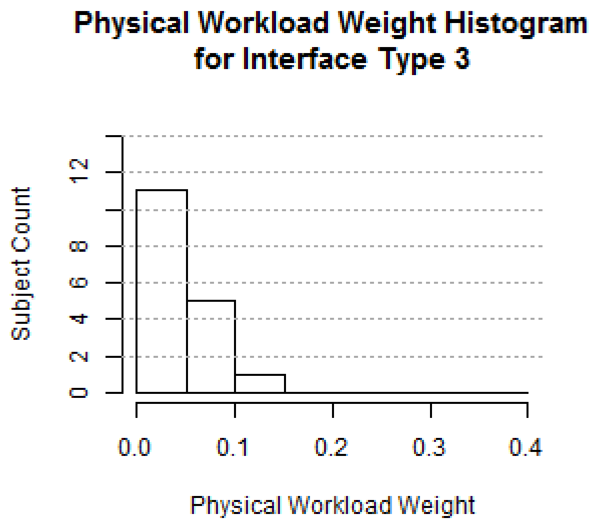
Physical Workload Weight vs. Interface Used - Friedman Test	
X^2	1.200
p	0.549
DoF	2.000

Physical Workload Weight vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	10.500	0.000	1.000
Z	0.535	-1.000	-1.095
p	0.625	1.000	0.250
R	0.089	-0.167	-0.183

Physical Workload Weight vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.024	0.040	0.000
2	0.020	0.046	0.000
3	0.027	0.041	0.000

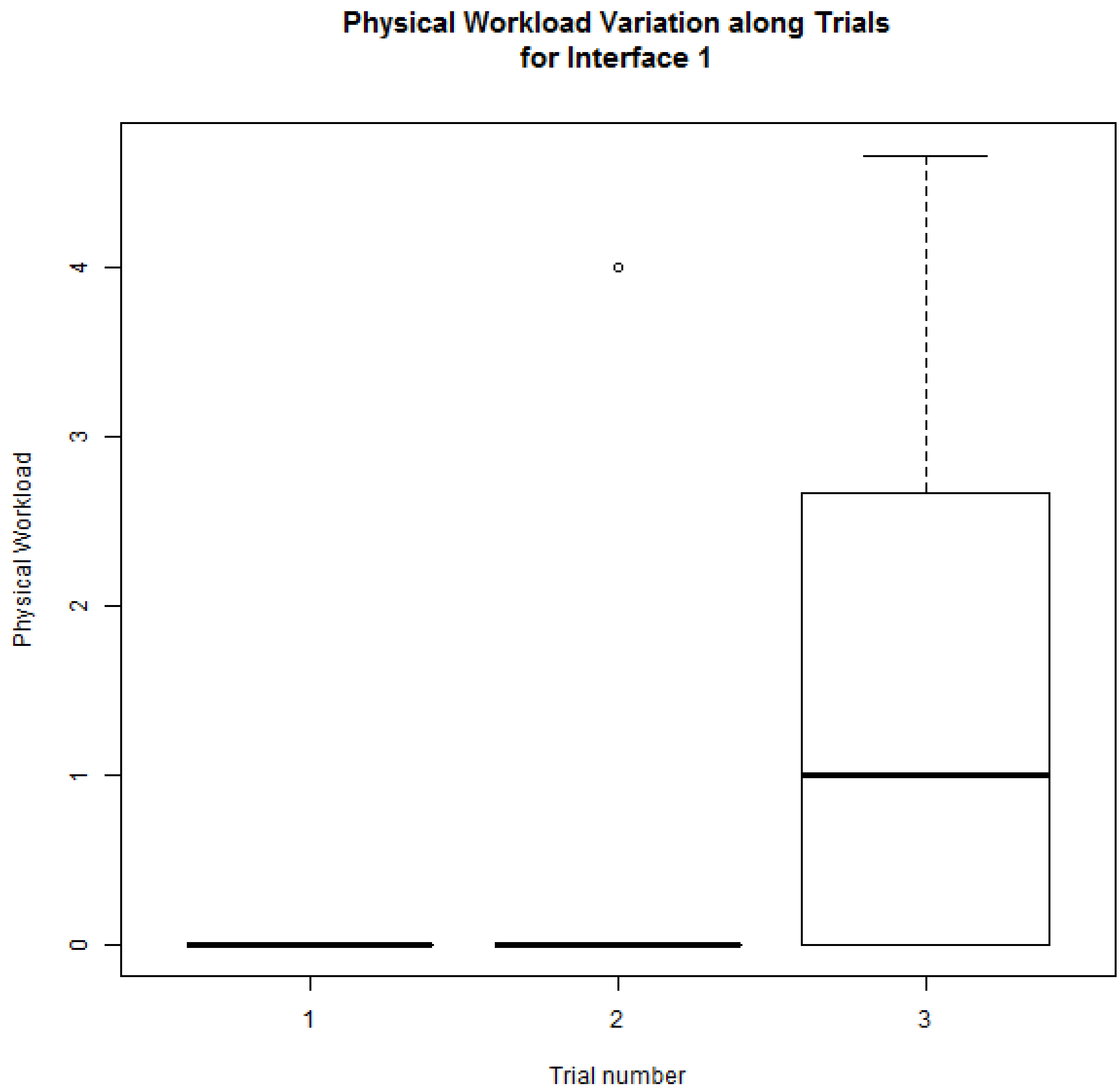






C.2.13.2.3 Interface Order Effect on Physical Workload Score

Interface 1

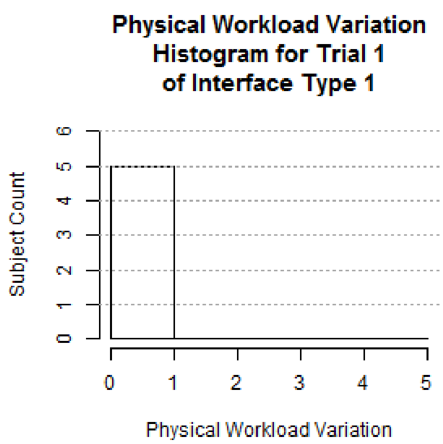


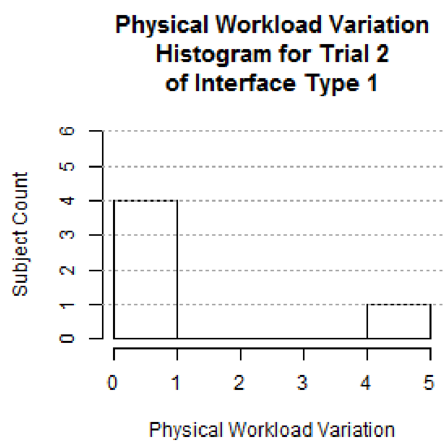
ANOVA: Interface 1 Physical Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	6.948	3.474	1.448	0.273
Residuals	12	28.800	2.400		

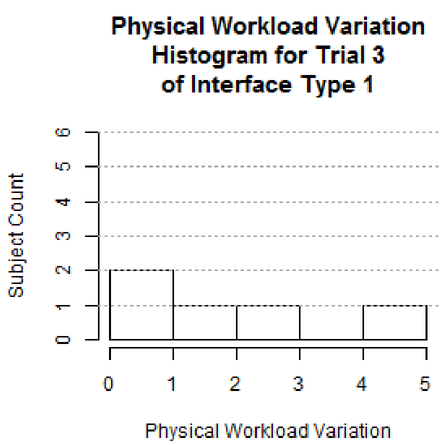
Interface 1 Physical Workload Score vs. Interface Order - Friedman Test	
X^2	3.200
p	0.202
DoF	2.000

Interface 1 Physical Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	0.000	0.000	2.000
Z	-1.000	-1.697	-0.566
p	1.000	0.250	0.750
R	-0.167	-0.283	-0.094

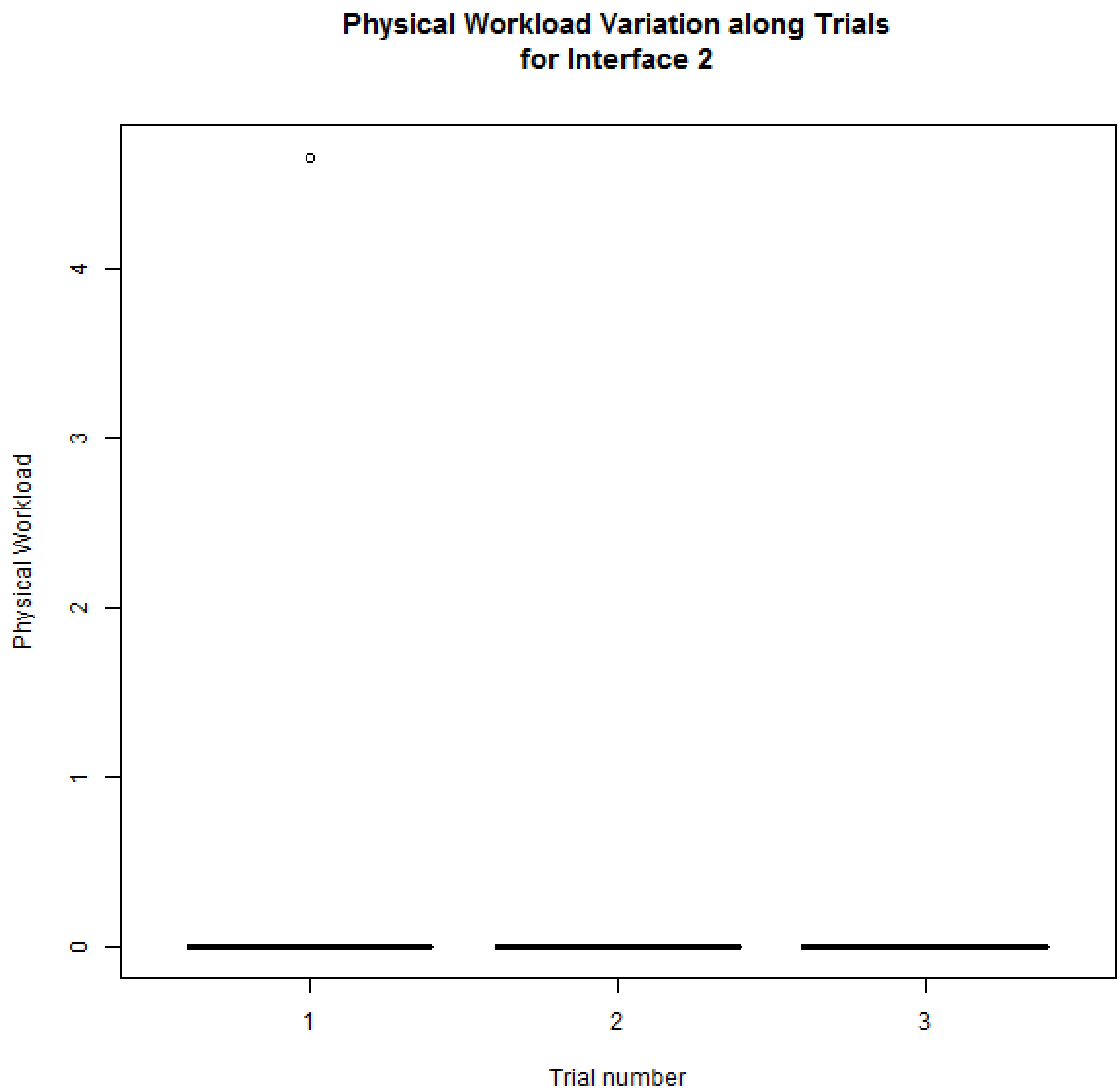
Interface 1 Physical Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.000	0.000	0.000
2	0.800	1.789	0.000
3	1.667	2.000	1.000







Interface 2

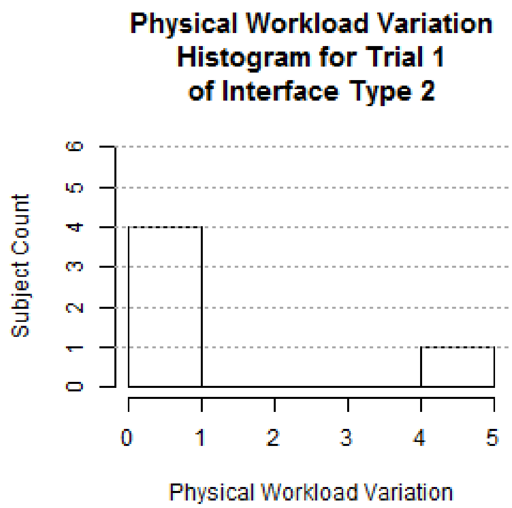


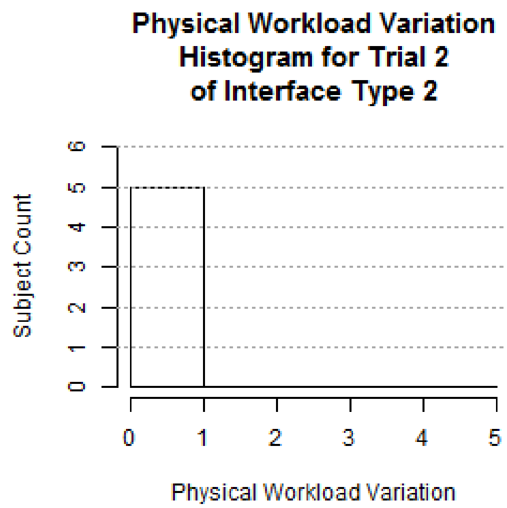
ANOVA: Interface 2 Physical Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	2.904	1.452	1	0.397
Residuals	12	17.422	1.452		

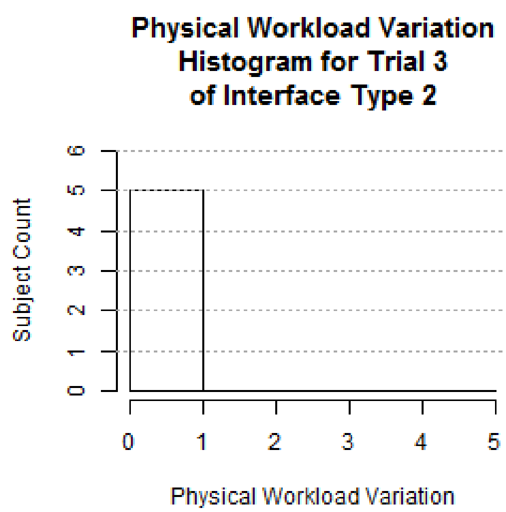
Interface 2 Physical Workload Score vs. Interface Order - Friedman Test	
X^2	2.000
p	0.368
DoF	2.000

Interface 2 Physical Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	1.000	1.000	-
Z	1.000	1.000	-
p	1.000	1.000	-
R	0.167	0.167	-

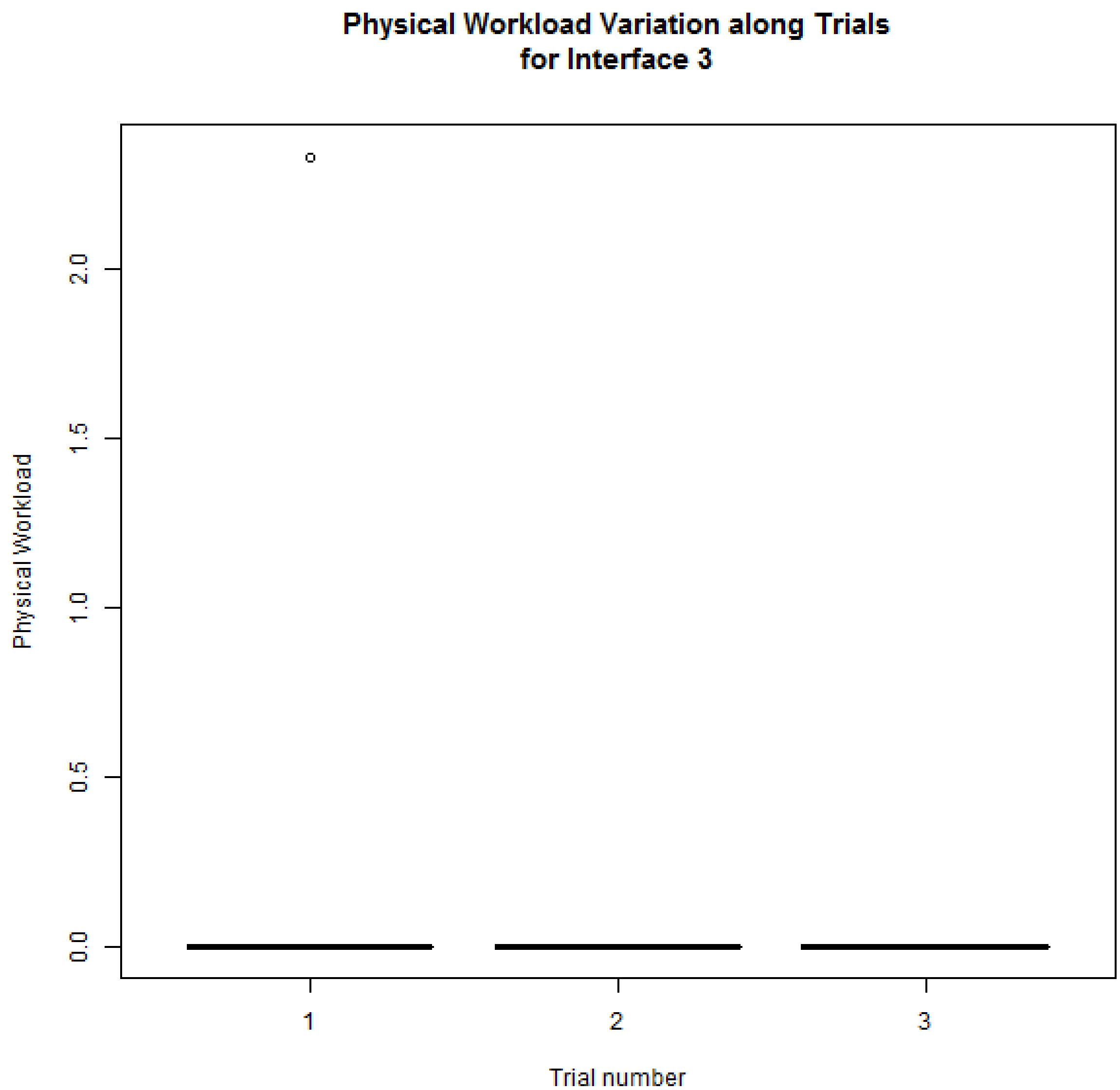
Interface 2 Physical Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.933	2.087	0.000
2	0.000	0.000	0.000
3	0.000	0.000	0.000







Interface 3

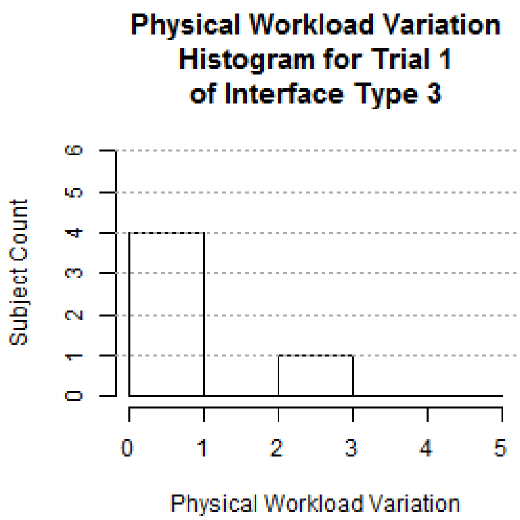


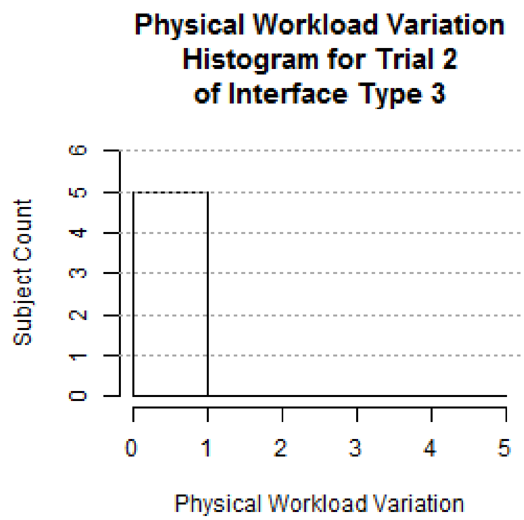
ANOVA: Interface 3 Physical Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.726	0.363	1	0.397
Residuals	12	4.356	0.363		

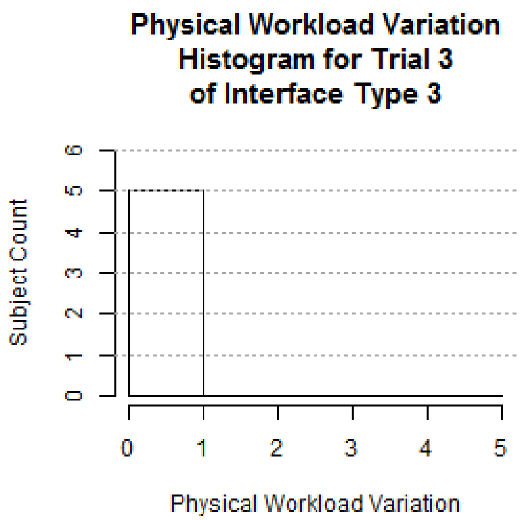
Interface 3 Physical Workload Score vs. Interface Order - Friedman Test	
X^2	2.000
p	0.368
DoF	2.000

Interface 3 Physical Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	1.000	1.000	-
Z	1.000	1.000	-
p	1.000	1.000	-
R	0.167	0.167	-

Interface 3 Physical Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.467	1.043	0.000
2	0.000	0.000	0.000
3	0.000	0.000	0.000

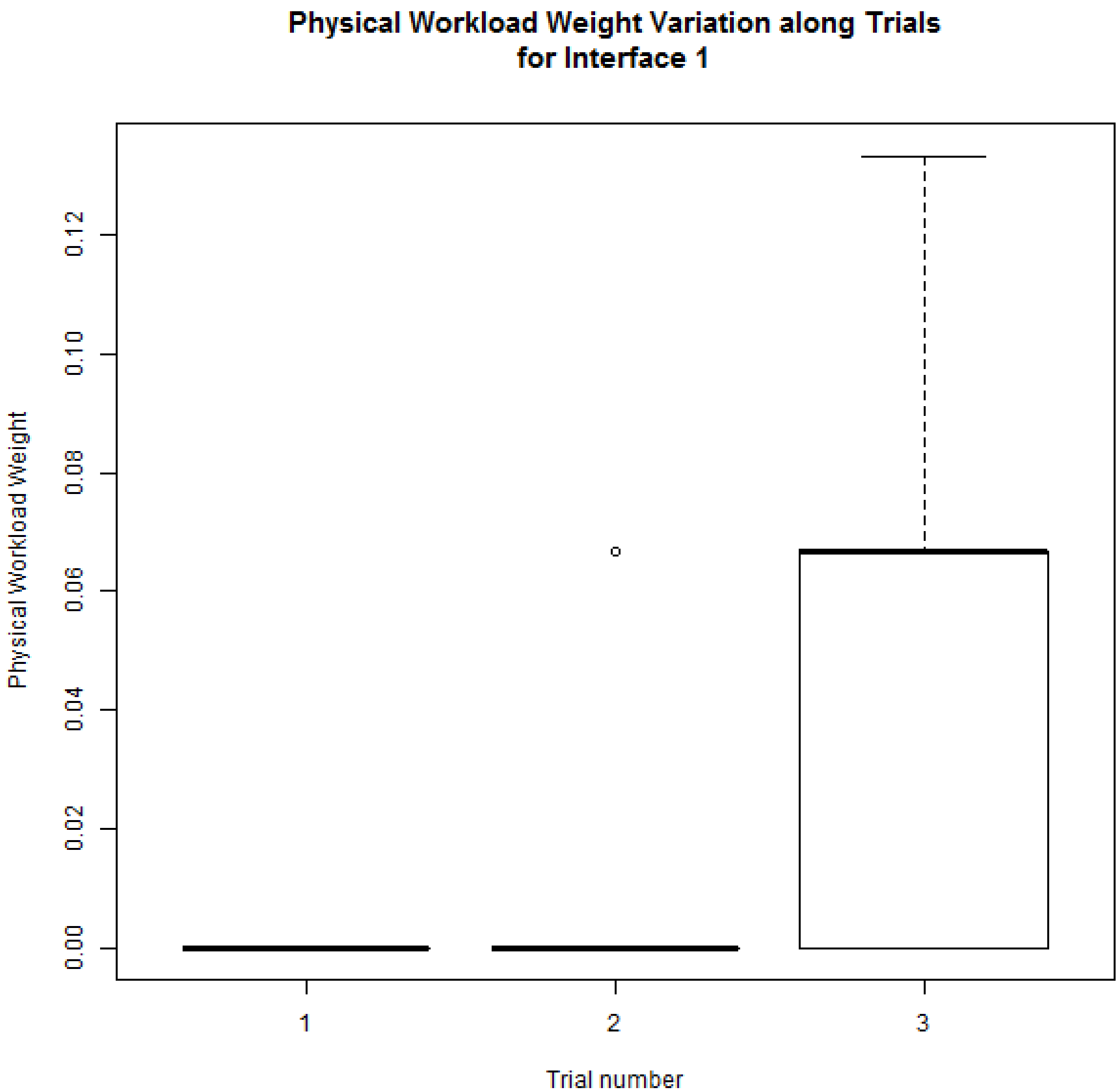






C.2.13.2.4 Interface Order Effect on Physical Workload Weight+

Interface 1

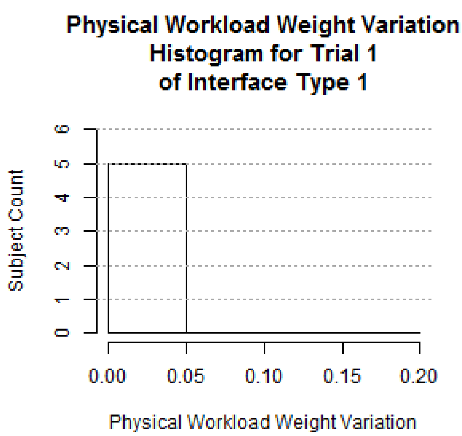


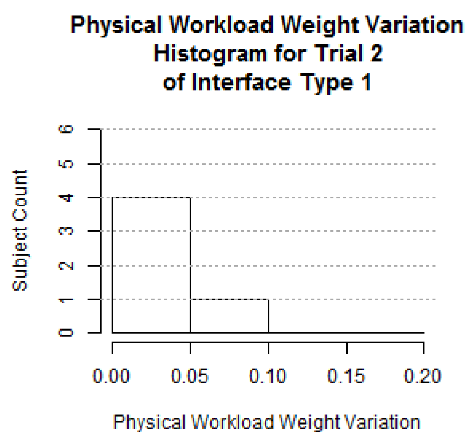
ANOVA: Interface 1 Physical Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.008	0.004	2.889	0.095
Residuals	12	0.016	0.001		

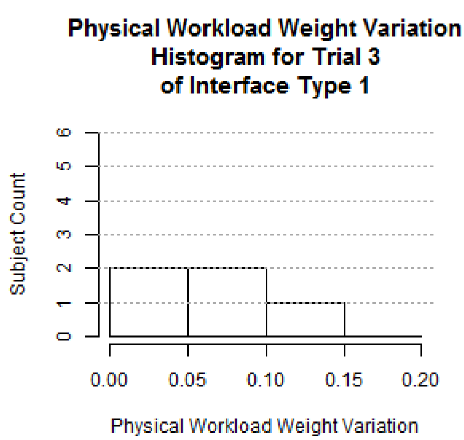
Interface 1 Physical Workload Weight vs. Interface Order - Friedman Test	
X^2	4.667
p	0.097
DoF	2.000

Interface 1 Physical Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	0.000	0.000	0.000
Z	-1.000	-1.706	-1.406
p	1.000	0.250	0.500
R	-0.167	-0.284	-0.234

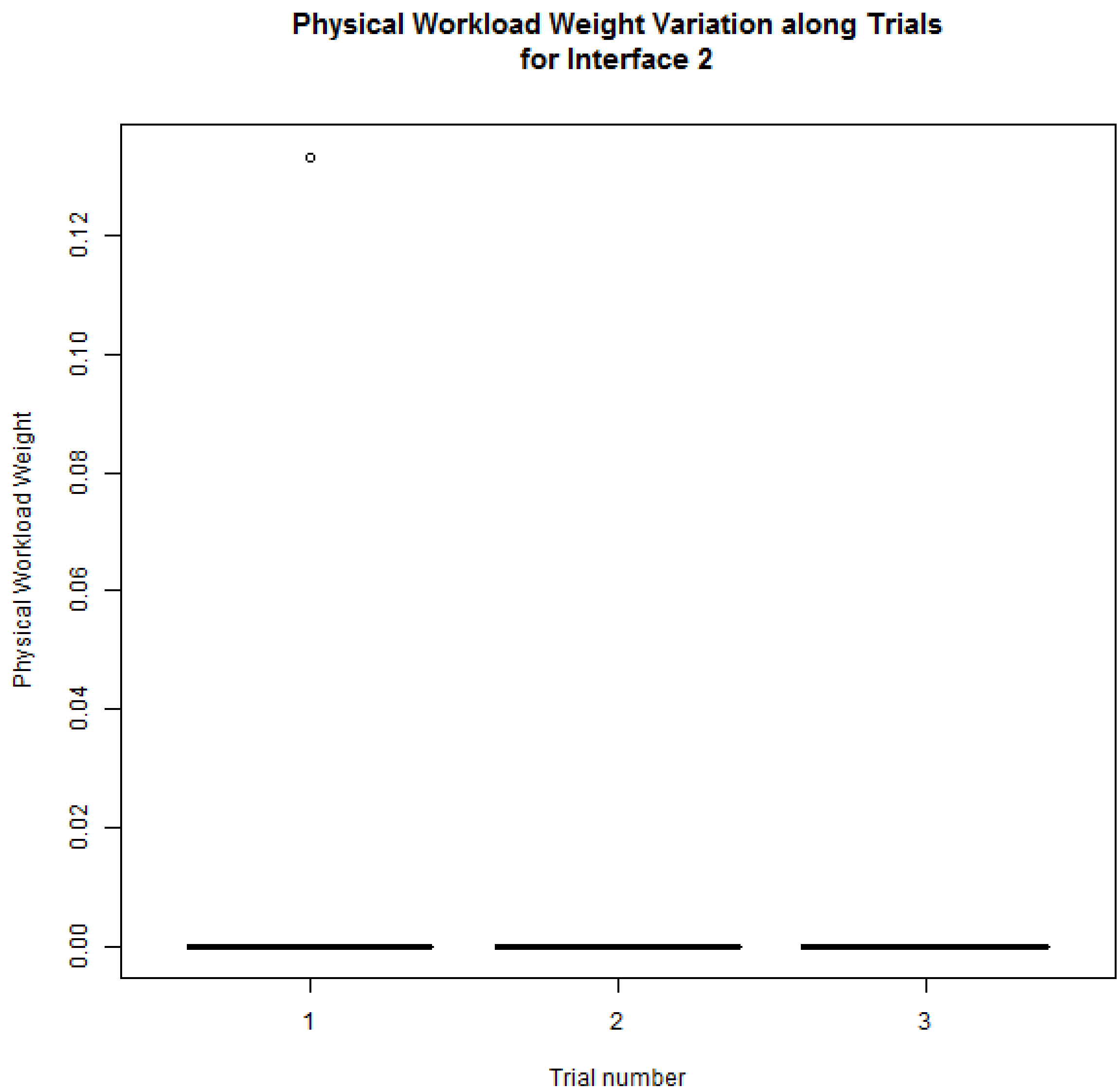
Interface 1 Physical Workload Weight Variation vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.000	0.000	0.000
2	0.013	0.030	0.000
3	0.053	0.056	0.067







Interface 2

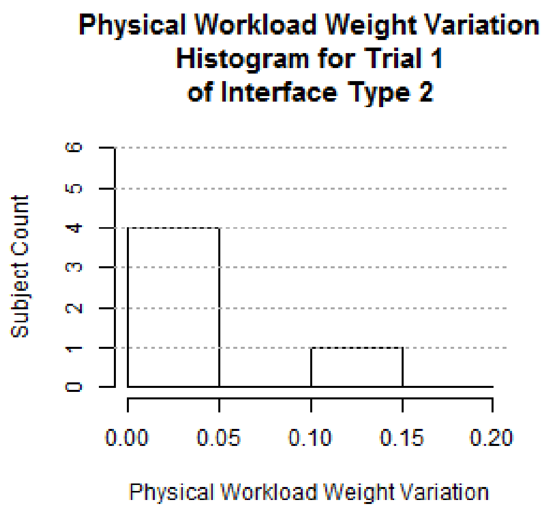


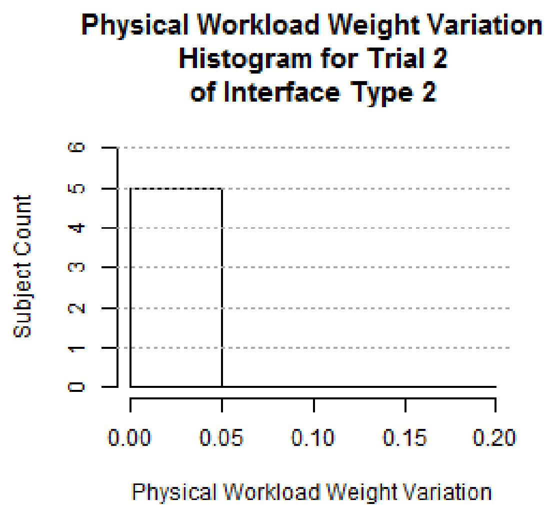
ANOVA: Interface 2 Physical Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.002	0.001	1	0.397
Residuals	12	0.014	0.001		

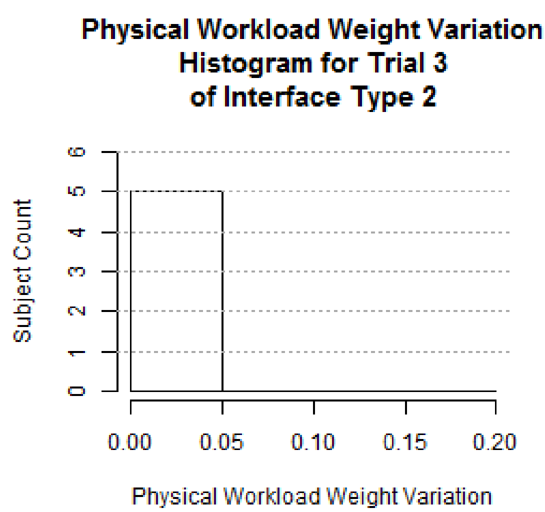
Interface 2 Physical Workload Weight vs. Interface Order - Friedman Test	
X^2	2.000
p	0.368
DoF	2.000

Interface 2 Physical Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	1.000	1.000	-
Z	1.000	1.000	-
p	1.000	1.000	-
R	0.167	0.167	-

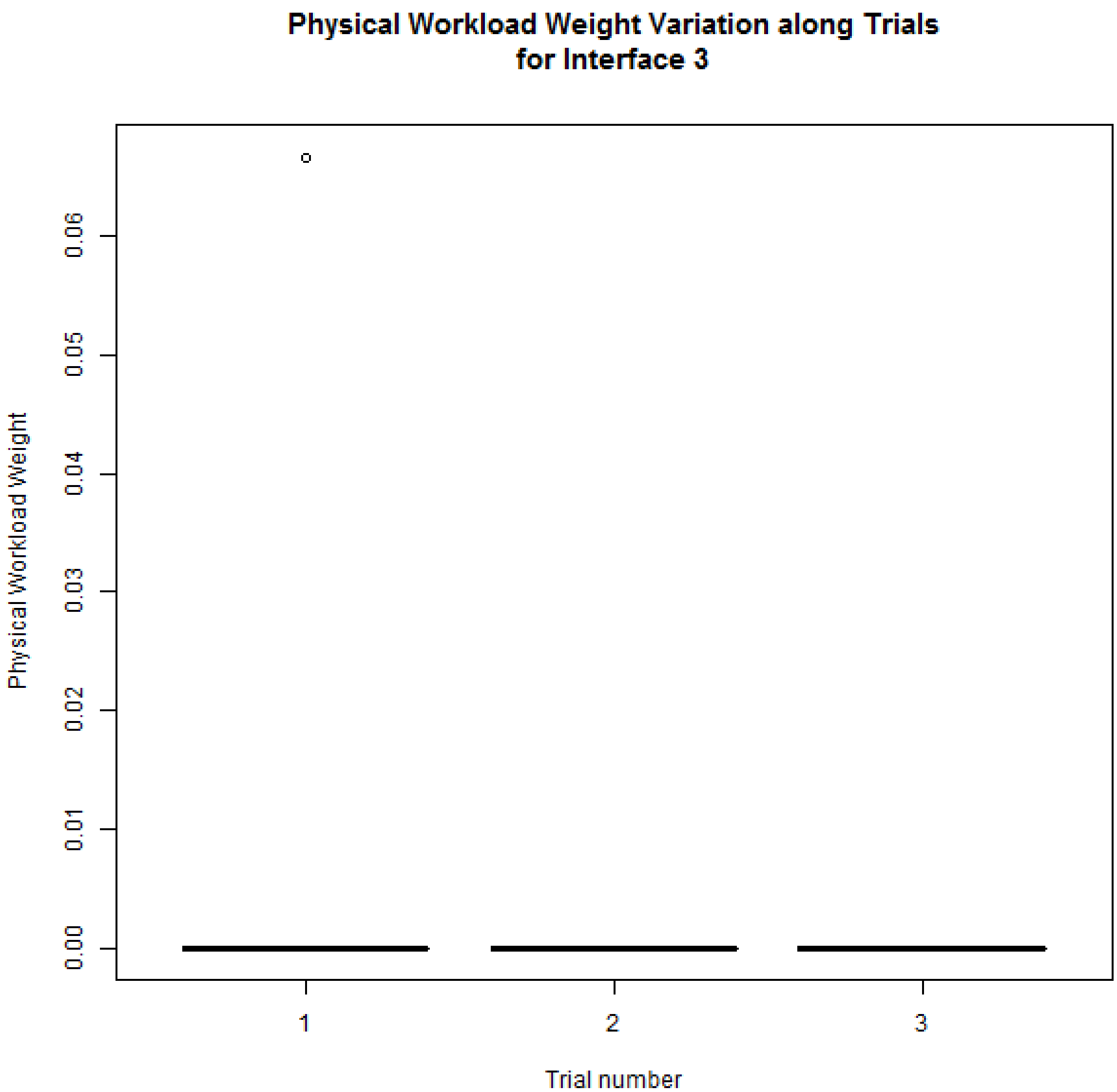
Interface 2 Physical Workload Weight vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.027	0.060	0.000
2	0.000	0.000	0.000
3	0.000	0.000	0.000







Interface 3

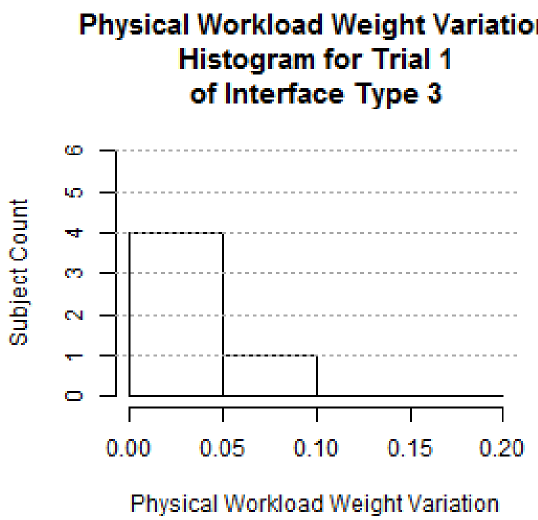


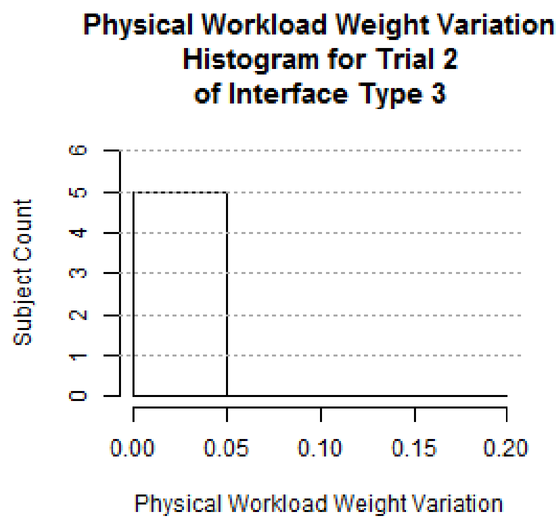
ANOVA: Interface 3 Physical Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2				
Residuals	12				

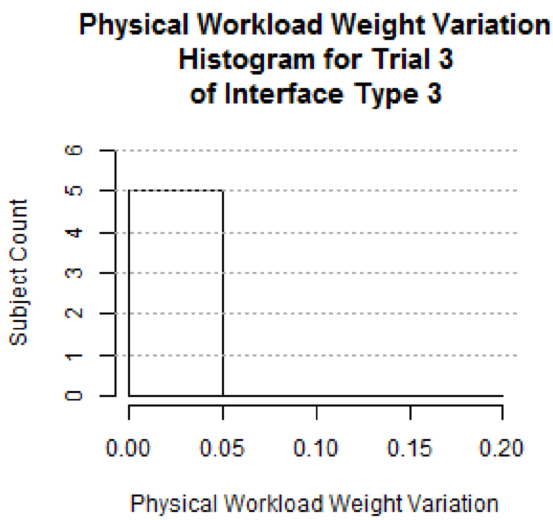
Interface 3 Physical Workload Weight vs. Interface Order - Friedman Test	
X^2	2.000
p	0.368
DoF	2.000

Interface 3 Physical Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	1.000	1.000	-
Z	1.000	1.000	-
p	1.000	1.000	-
R	0.167	0.167	-

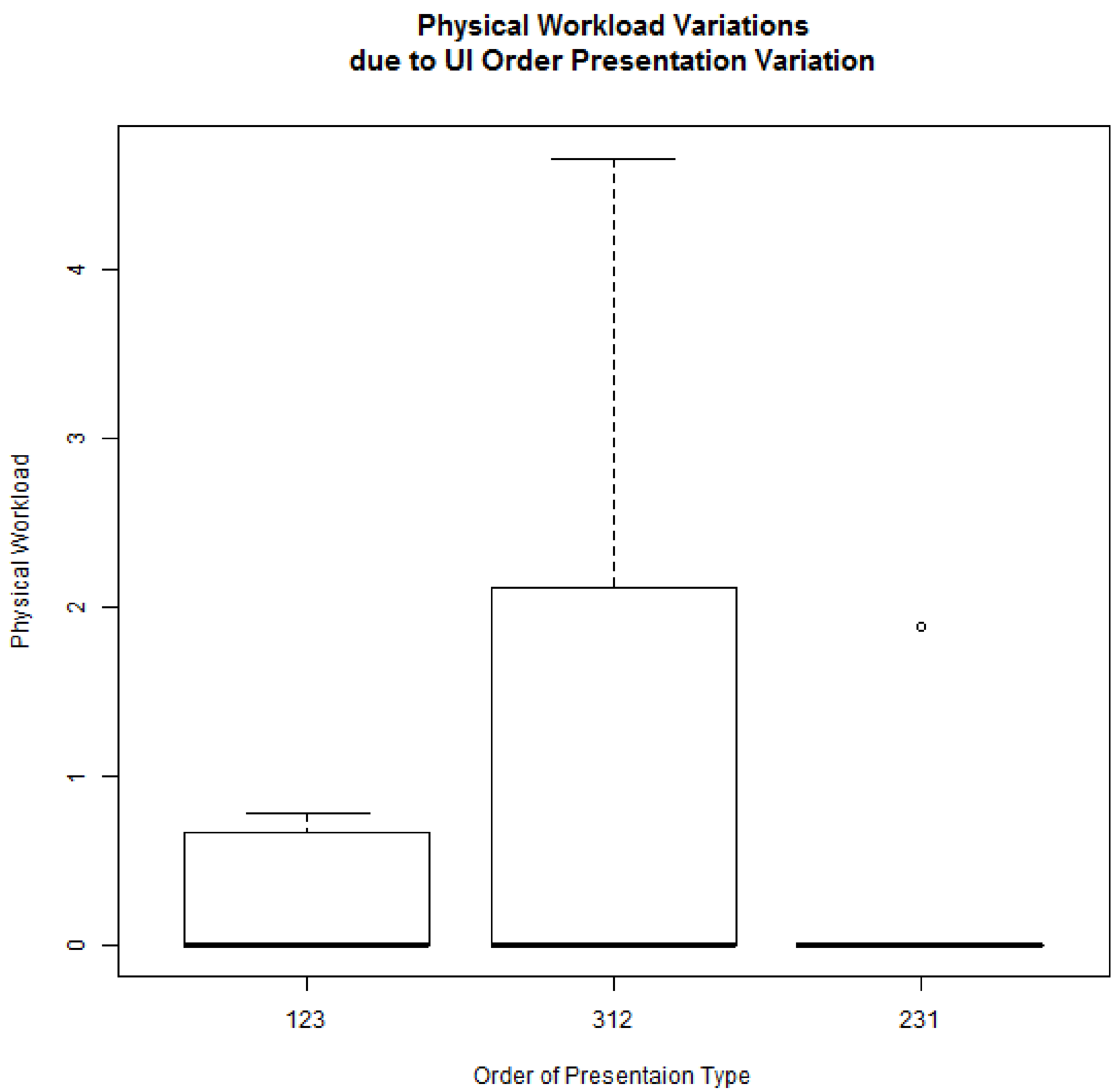
Interface 3 Physical Workload Weight vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.013	0.030	0.000
2	0.000	0.000	0.000
3	0.000	0.000	0.000







C.2.13.2.5 Physical Workload for Groups with Different Interface orders

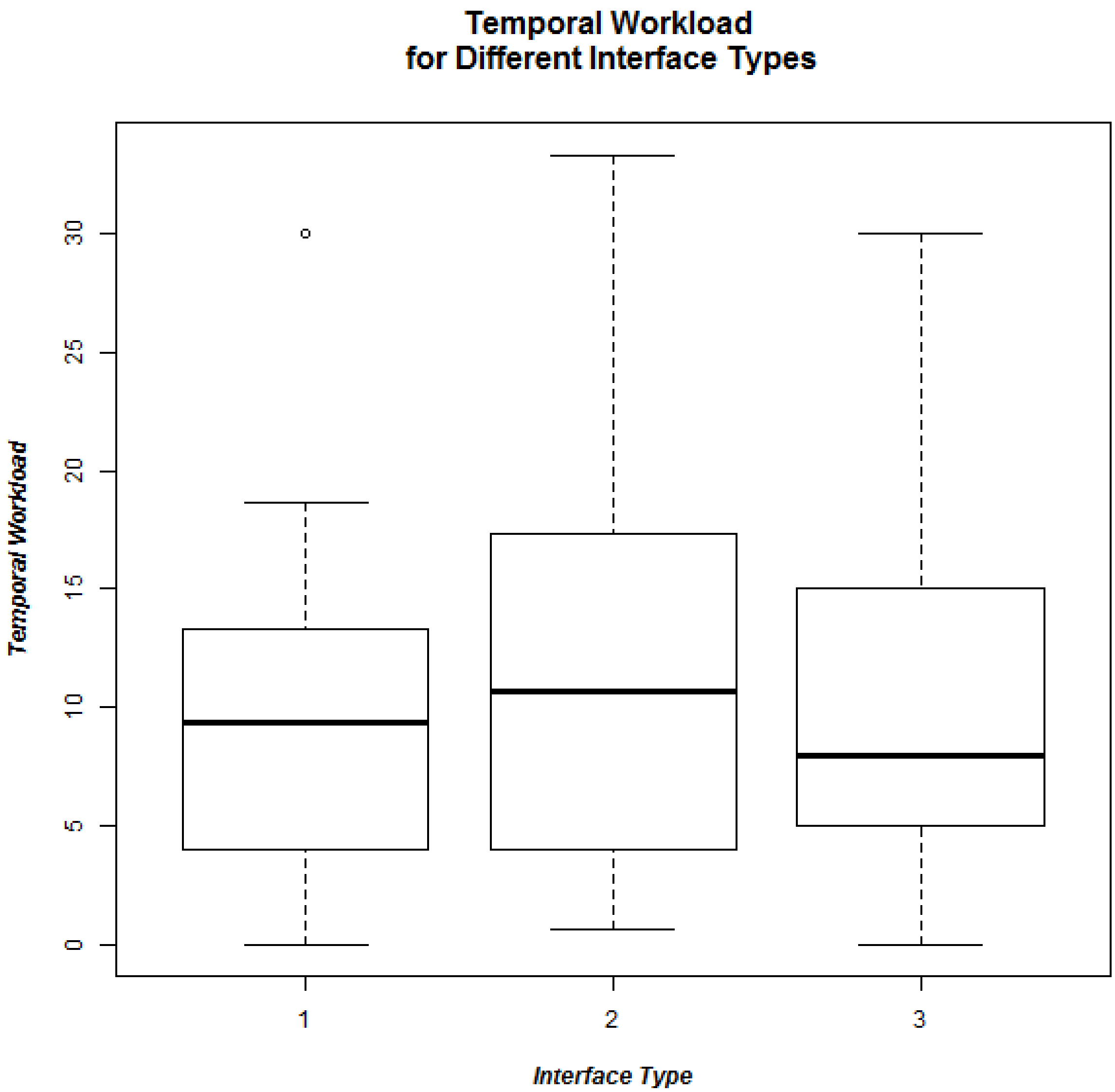


ANOVA: Overall Physical Workload for Subjects with Different Interface Orders					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	3.503	1.751	1.024	0.389
Residuals	12	20.533	1.711		

Overall Physical Workload vs. Subjects with Different Interface Orders Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.289	0.397	0.000
2	1.355	20.64	0.000
3	0.378	0.845	0.000

C.2.13.3 Temporal Workload Evaluation

C.2.13.3.1 Weighted Scores+

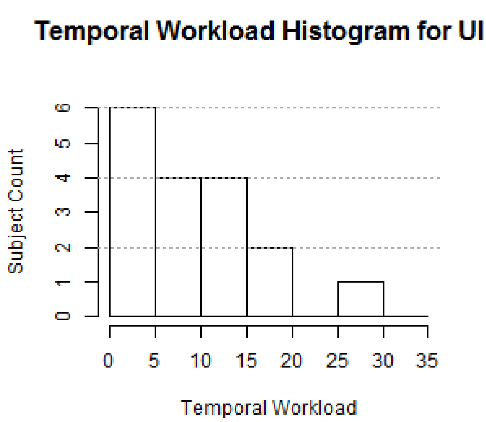


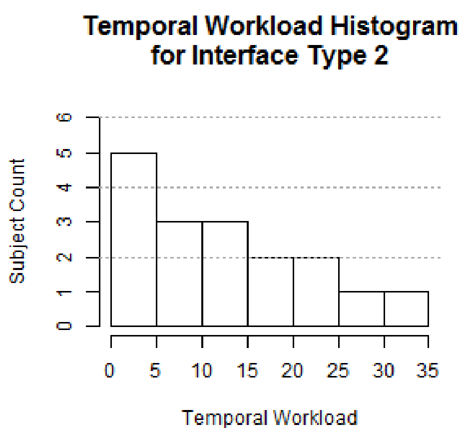
ANOVA: Temporal Workload Weighted Scores for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	78	39.11	0.53	0.592
Residuals	48	3545	73.86		

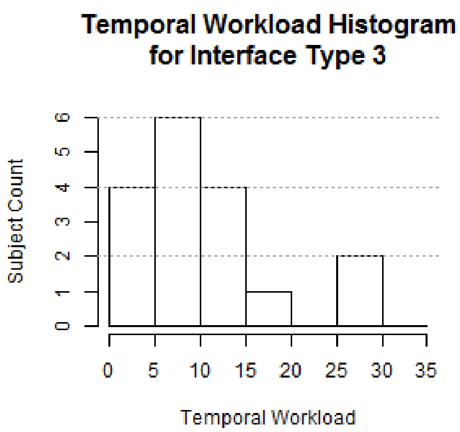
Temporal Workload Weighted Scores vs. Interface Used - Friedman Test	
X^2	2.065
p	0.356
DoF	2.000

Temporal Workload Weighted Scores vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	37.000	41.000	65.000
Z	-1.870	-1.043	1.217
p	0.064	0.317	0.240
R	-0.312	-0.174	0.203

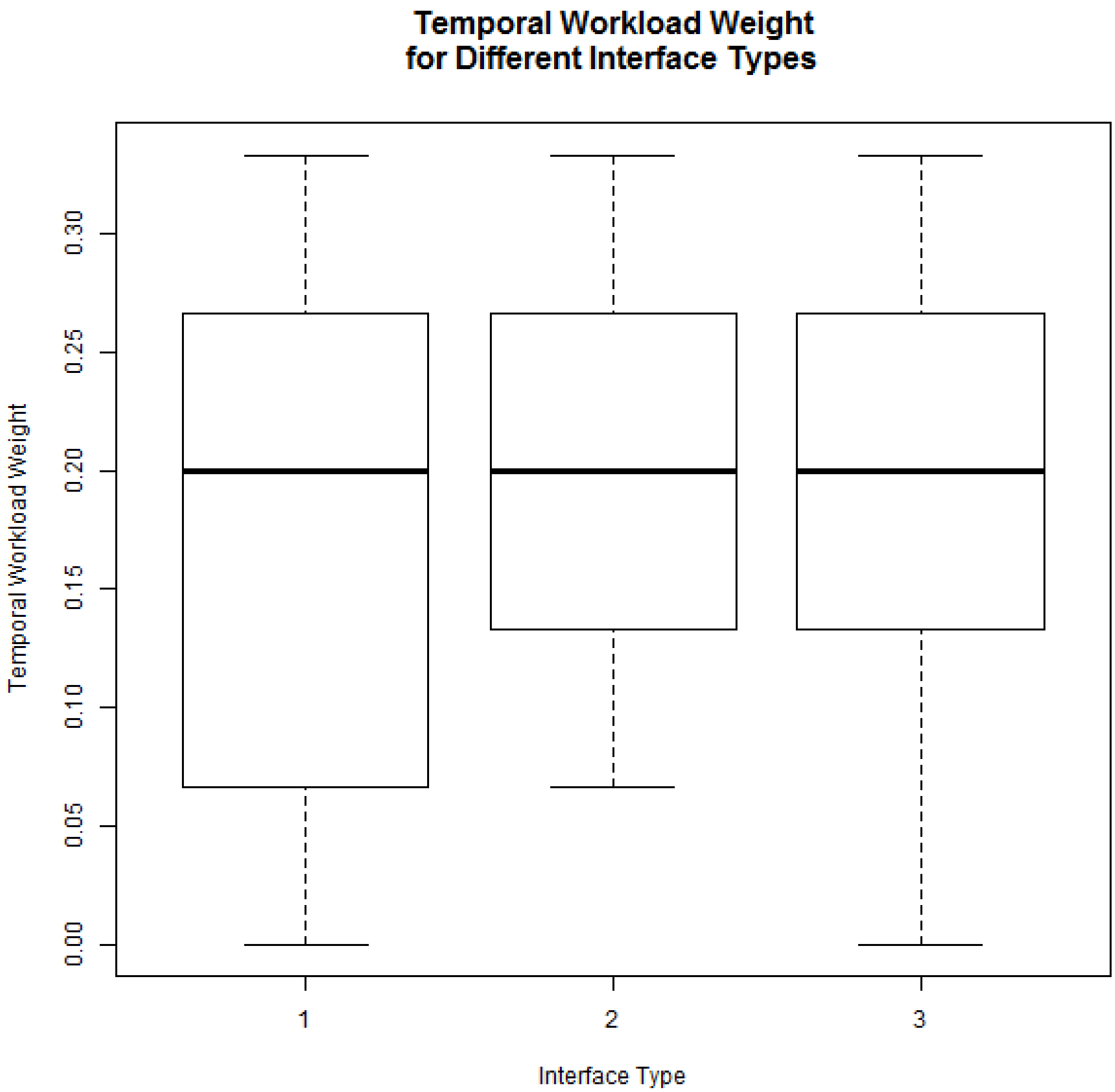
Temporal Workload Weighted Scores vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	9.569	7.815	9.333
2	12.549	9.475	10.667
3	10.569	8.410	8.000







C.2.13.3.2 Weight

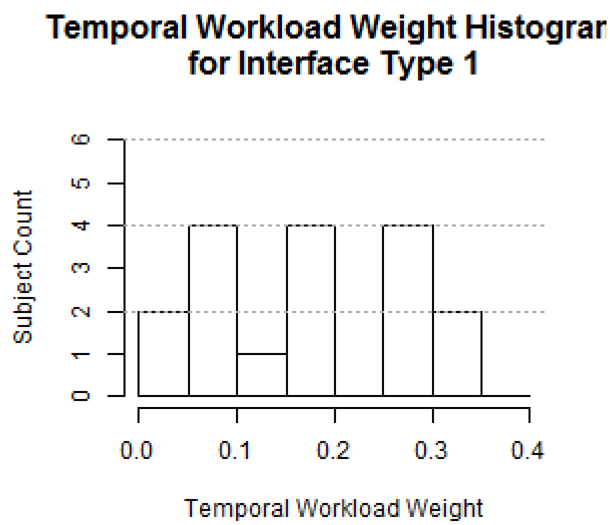


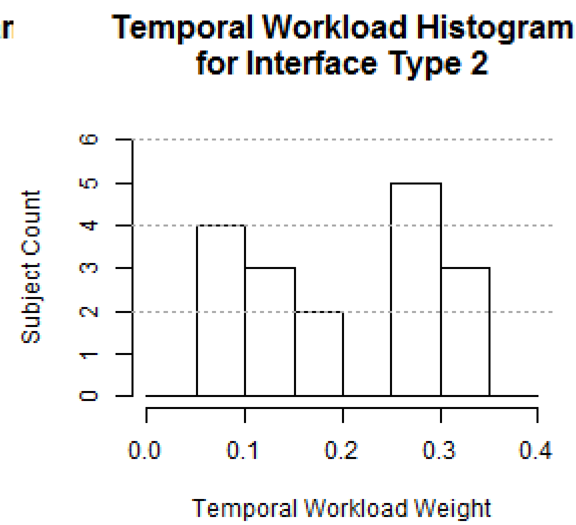
ANOVA: Temporal Workload Weight for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.006	0.003	0.308	0.737
Residuals	48	0.503	0.010		

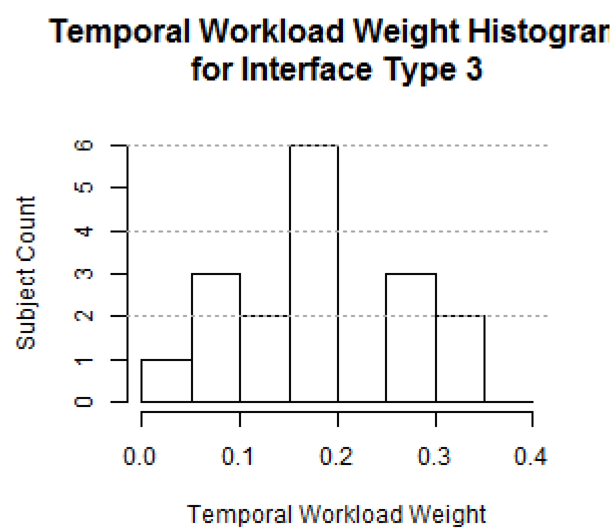
Temporal Workload Weight vs. Interface Used - Friedman Test	
X^2	2.714
p	0.257
DoF	2.000

Temporal Workload Weight vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	16.000	25.500	25.500
Z	-1.258	-0.802	1.318
p	0.223	0.442	0.234
R	-0.210	-0.134	0.220

Temporal Workload Weight vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.173	0.111	0.200
2	0.200	0.100	0.200
3	0.184	0.096	0.200

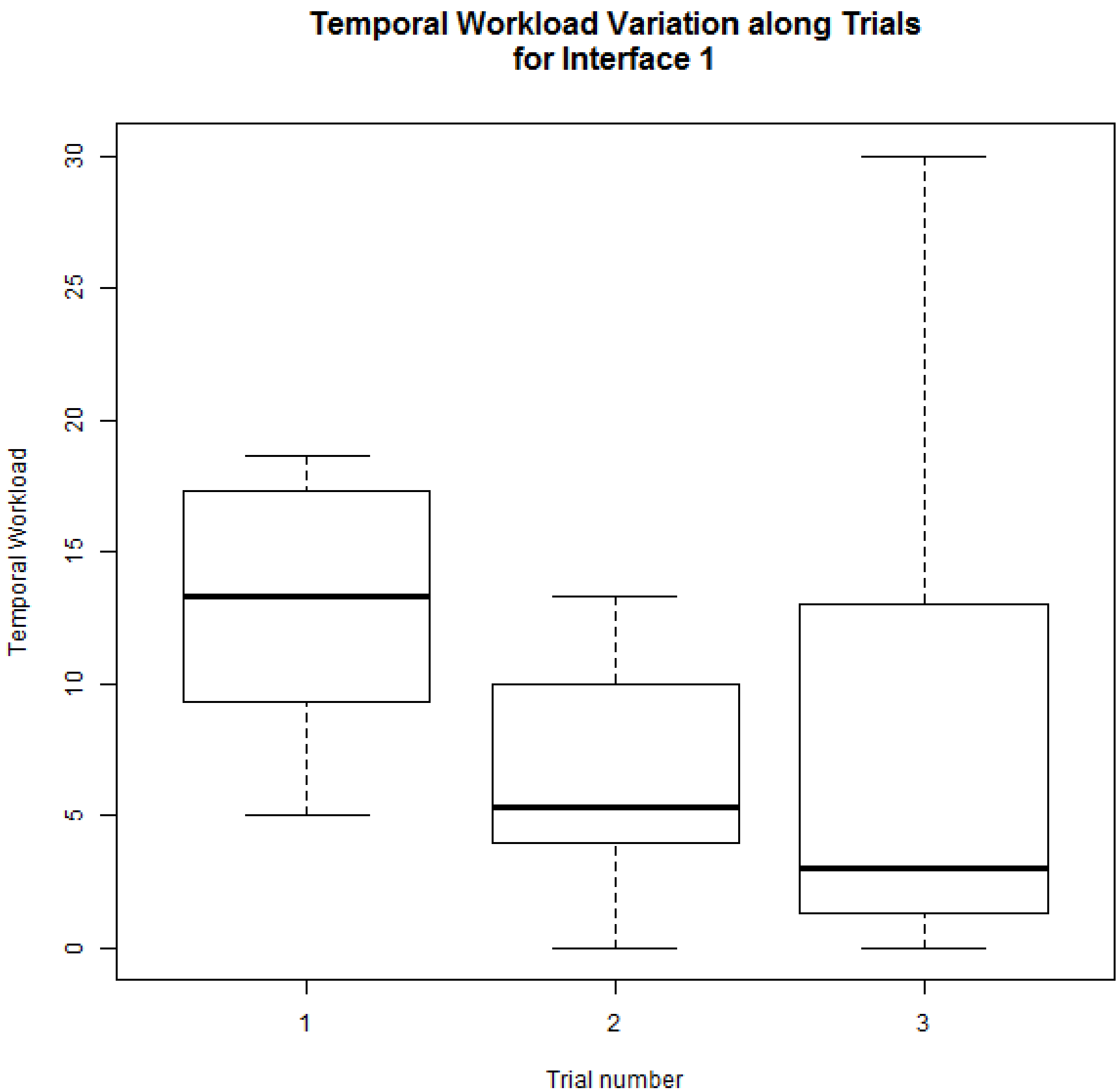






C.2.13.3.3 Interface Order Effect on Temporal Workload Score

Interface 1

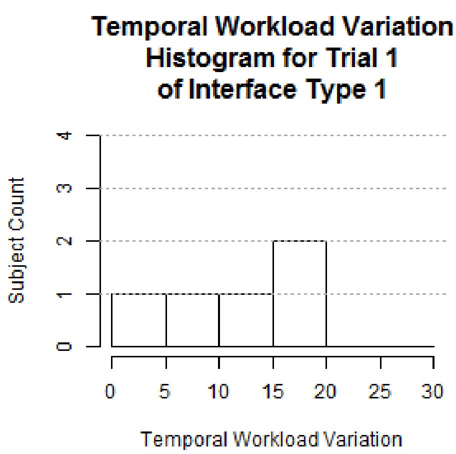


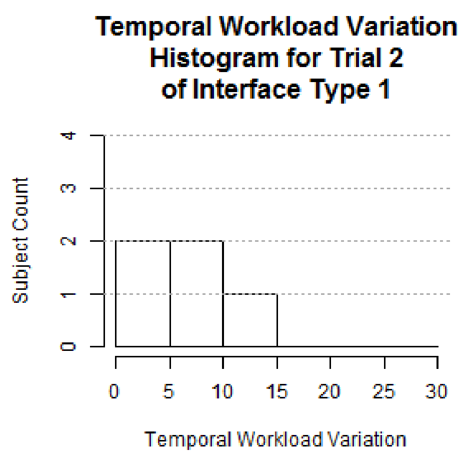
ANOVA: Interface 1 Temporal Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	96.2	48.10	0.664	0.532
Residuals	12	868.6	72.38		

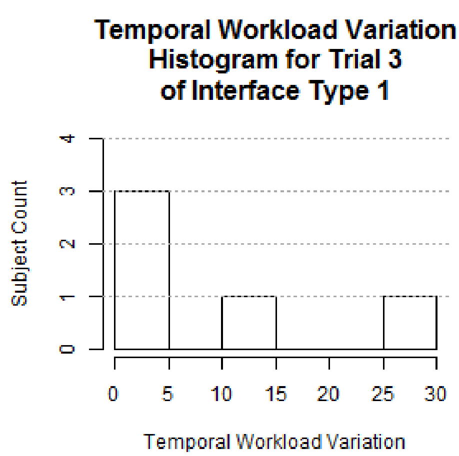
Interface 1 Temporal Workload Score vs. Interface Order - Friedman Test	
X^2	0.400
p	0.819
DoF	2.000

Interface 1 Temporal Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	12.000	10.000	8.000
Z	1.214	0.674	0.135
p	0.312	0.625	1.000
R	0.202	0.112	0.022

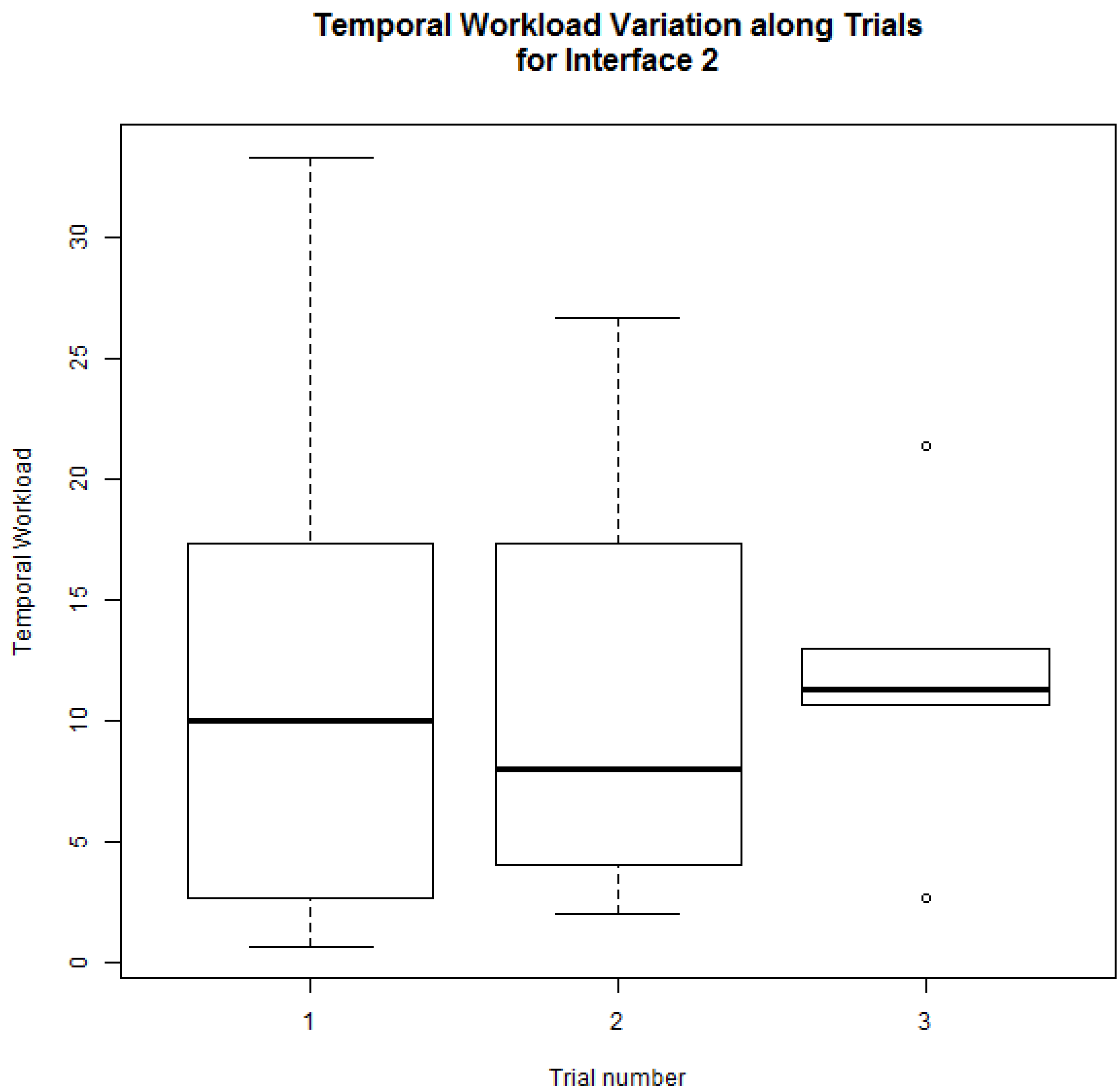
Interface 1 Temporal Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	12.733	5.659	13.333
2	6.533	5.215	5.333
3	9.467	12.567	3.000







Interface 2

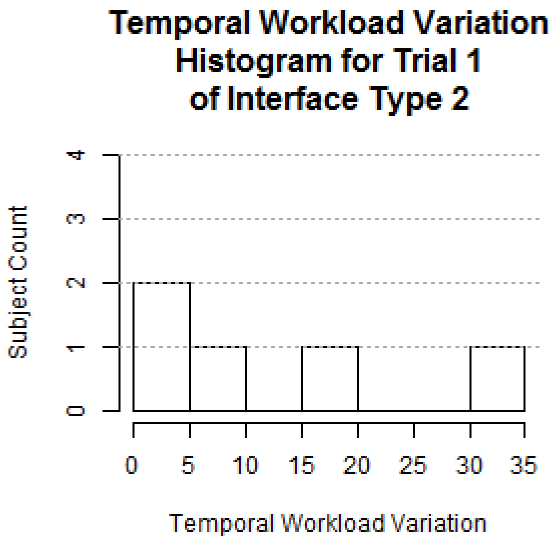


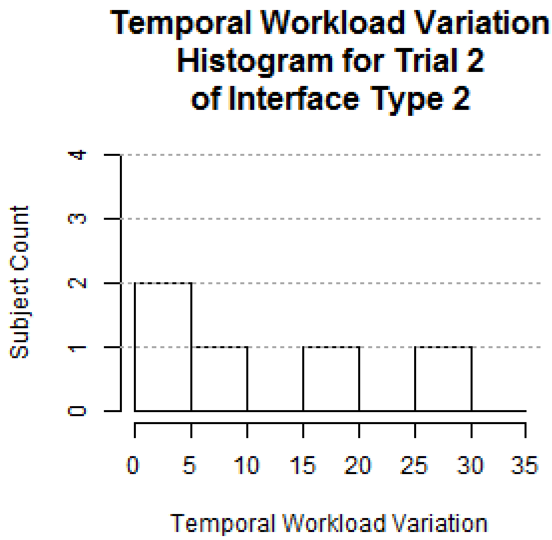
ANOVA: Interface 2 Temporal Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	4.1	2.07	0.019	0.981
Residuals	12	1299.9	108.33		

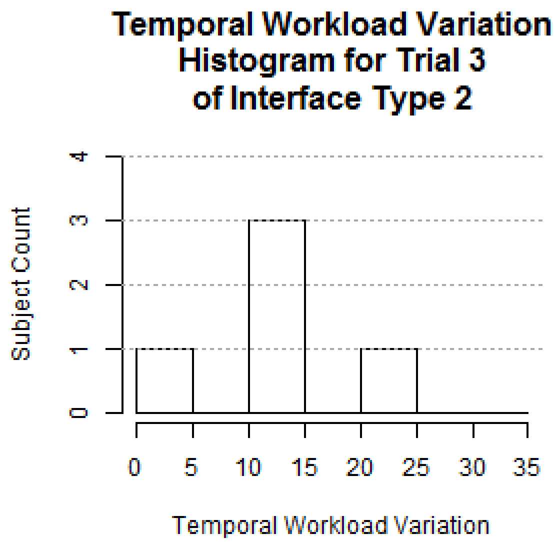
Interface 2 Temporal Workload Score vs. Interface Order - Friedman Test	
X^2	0.400
p	0.819
DoF	2.000

Interface 2 Temporal Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	7.000	7.000	7.000
Z	-0.135	-0.135	-0.135
p	1.000	1.000	1.000
R	-0.022	-0.022	-0.022

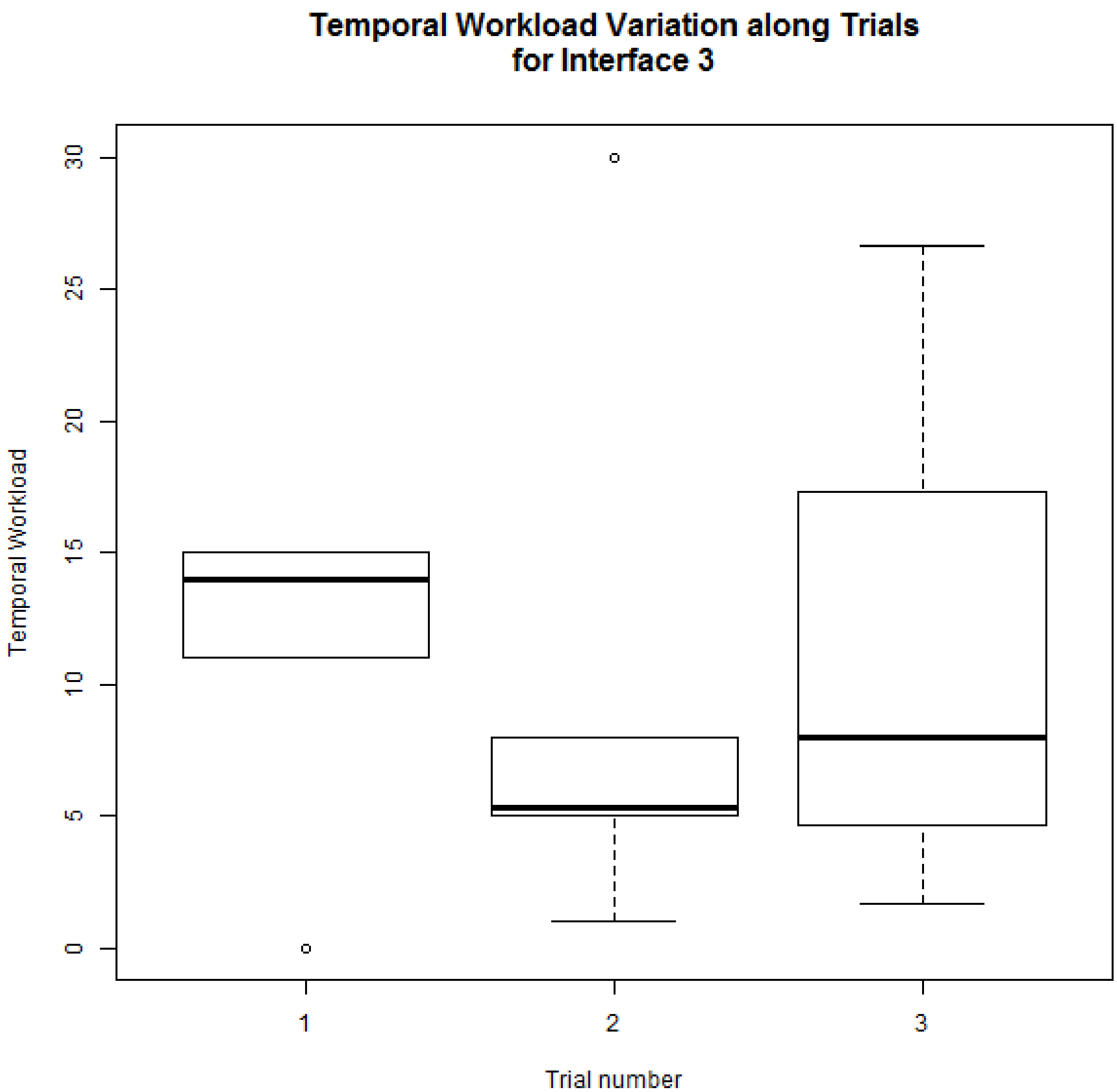
Interface 2 Temporal Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	12.800	13.228	10.000
2	11.600	10.281	8.000
3	11.800	6.657	11.333







Interface 3

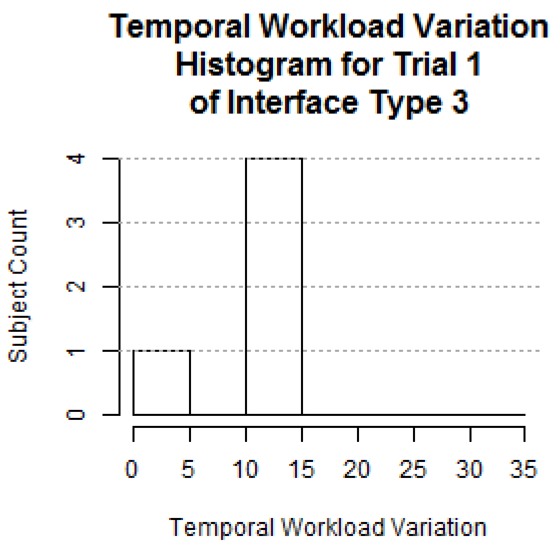


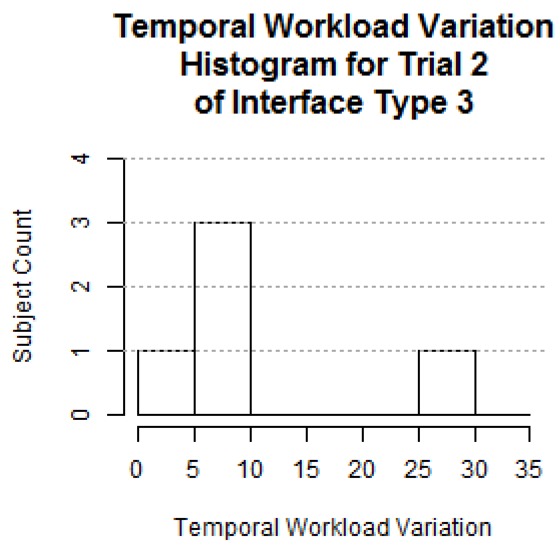
ANOVA: Interface 3 Temporal Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	8.3	4.14	0.045	0.957
Residuals	12	1113.2	92.77		

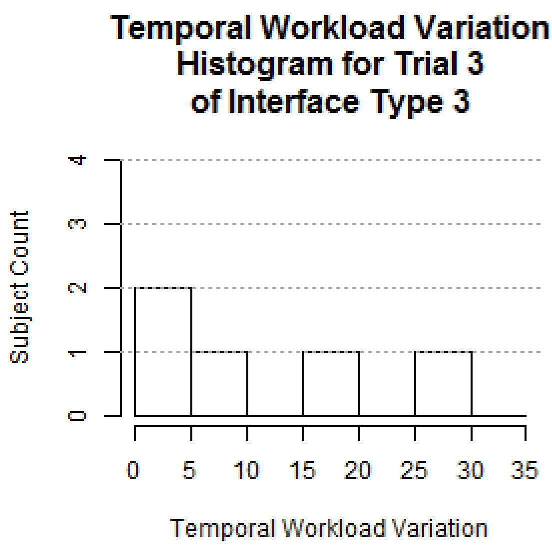
Interface 3 Temporal Workload Score vs. Interface Order - Friedman Test	
X^2	1.200
p	0.549
DoF	2.000

Interface 3 Temporal Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	10.000	7.000	7.000
Z	0.674	-0.135	-0.135
p	0.625	1.000	1.000
R	0.112	-0.022	-0.022

Interface 3 Temporal Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	11.000	6.364	14.000
2	9.867	11.529	5.333
3	11.667	10.242	8.000

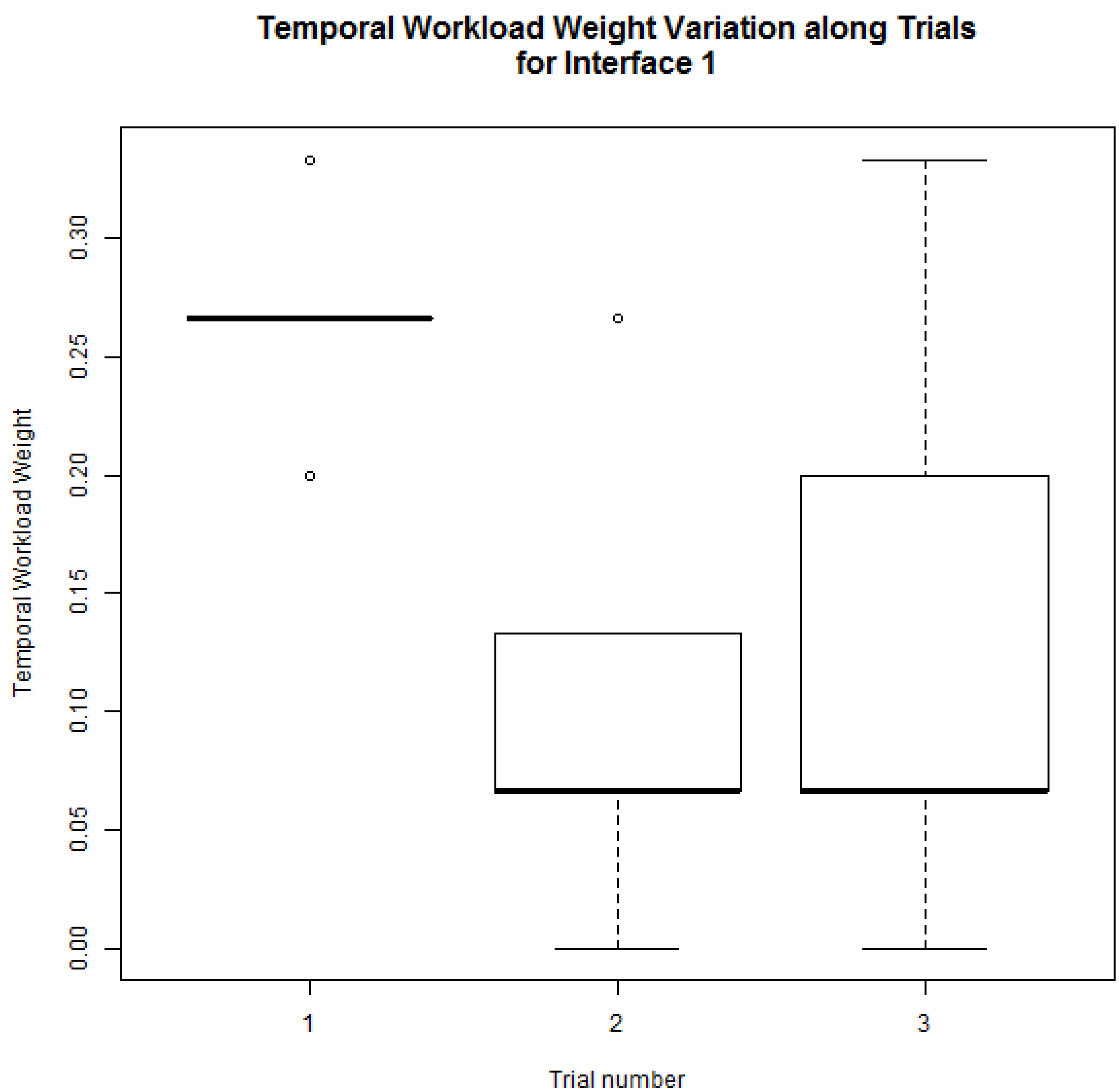






C.2.13.3.4 Interface Order Effect on Temporal Workload Weight+

Interface 1

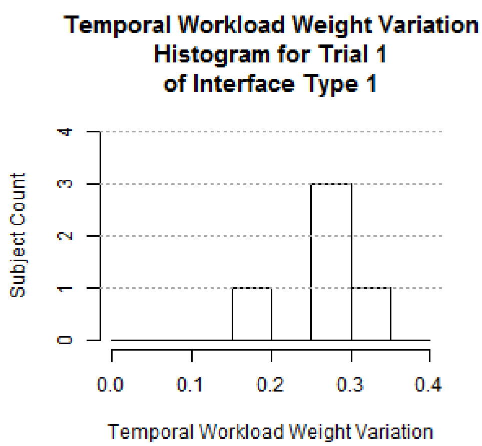


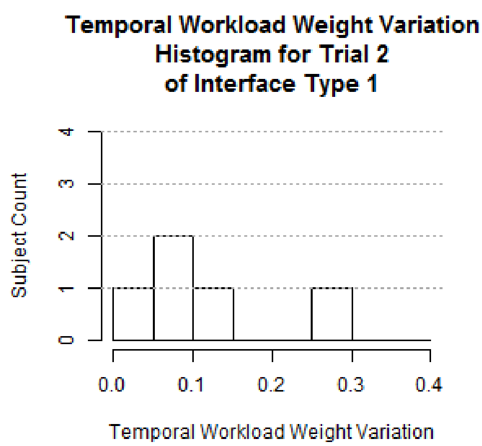
ANOVA: Interface 1 Temporal Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.073	0.037	3.647	0.058
Residuals	12	0.121	0.010		

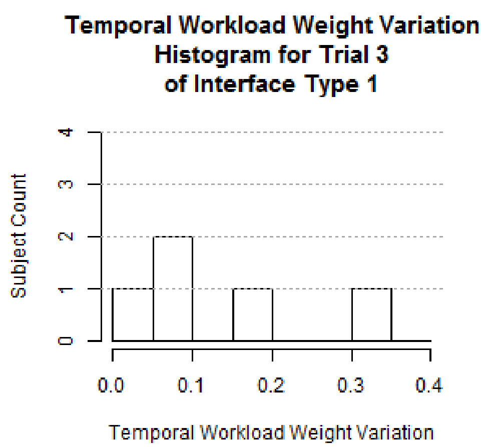
Interface 1 Temporal Workload Weight vs. Interface Order - Friedman Test	
X^2	4.333
p	0.115
DoF	2.000

Interface 1 Temporal Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	15.000	9.000	4.000
Z	2.023	1.361	-0.272
p	0.062	0.250	0.875
R	0.337	0.227	-0.045

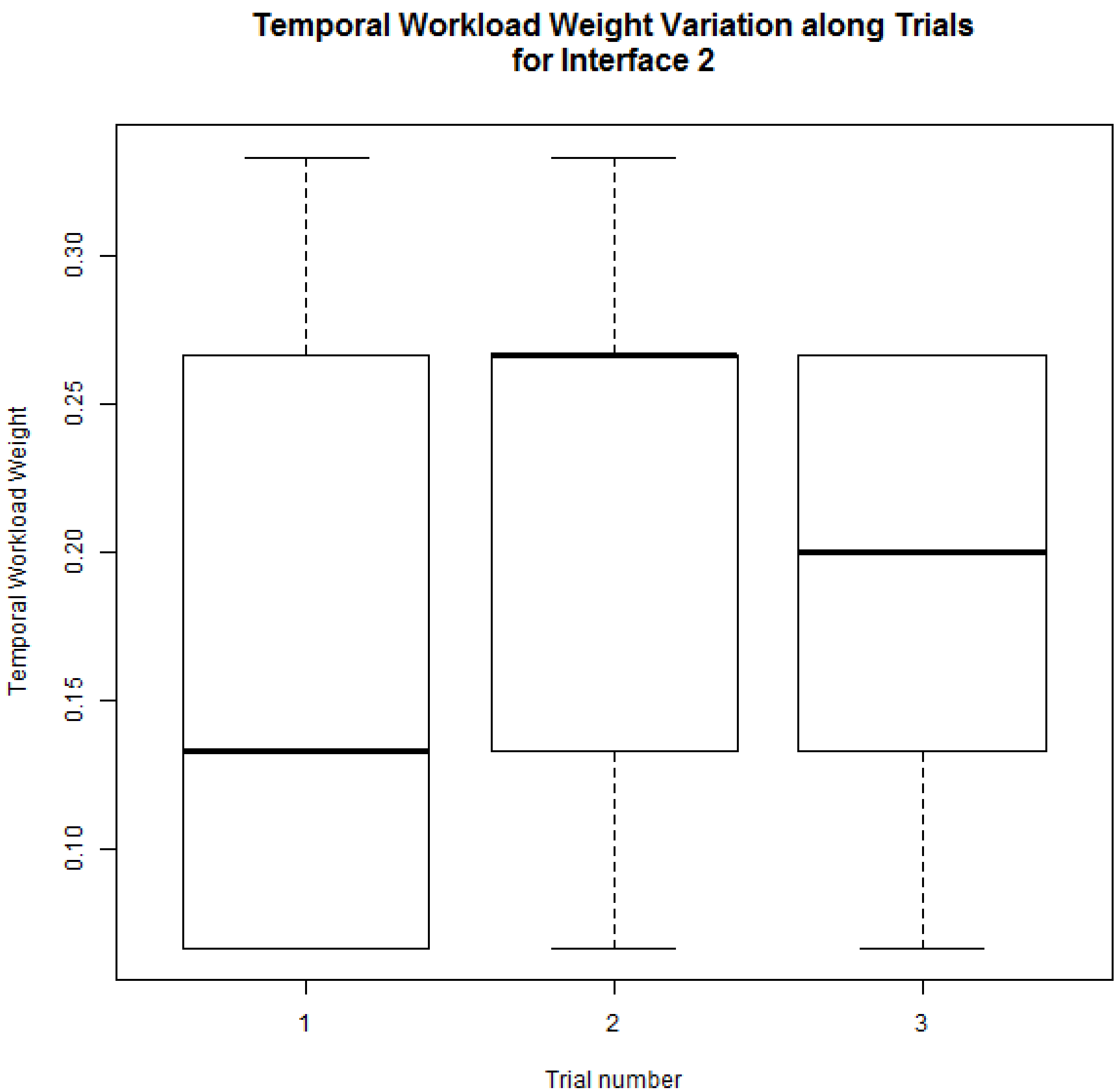
Interface 1 Temporal Workload Weight Variation vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.267	0.047	0.267
2	0.107	0.101	0.067
3	0.133	0.133	0.067







Interface 2

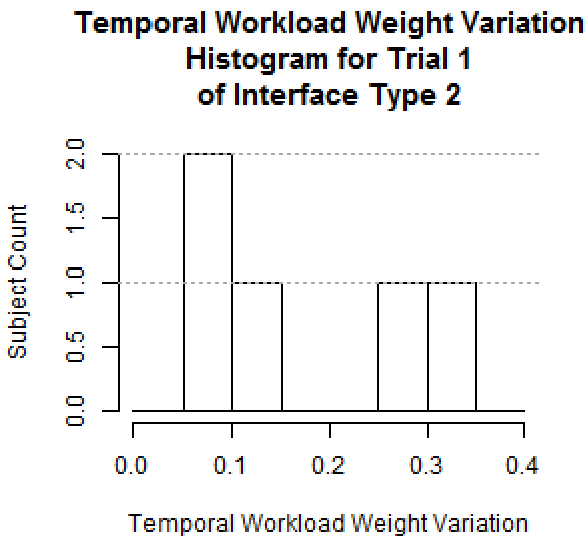


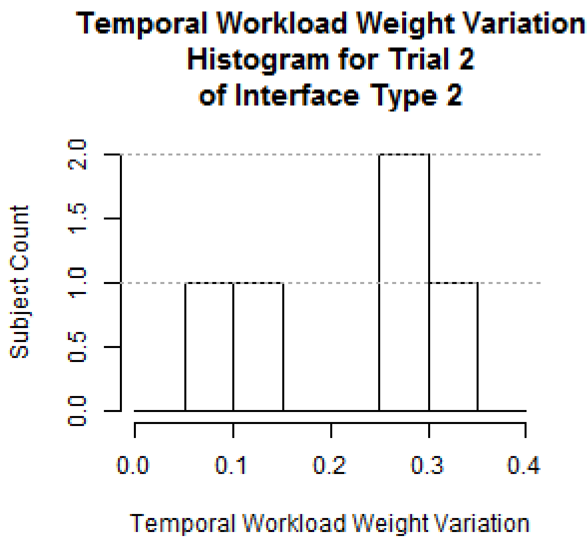
ANOVA: Interface 2 Temporal Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.004	0.002	0.182	0.836
Residuals	12	0.137	0.011		

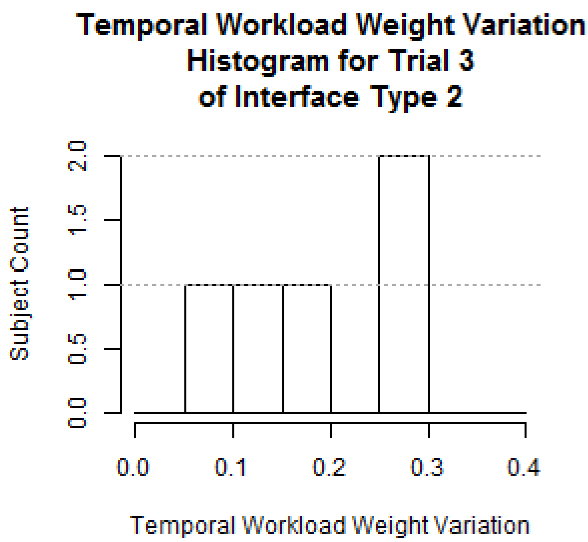
Interface 2 Temporal Workload Weight vs. Interface Order - Friedman Test	
X^2	0.500
p	0.779
DoF	2.000

Interface 2 Temporal Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	6.000	3.000	4.000
Z	-0.406	-0.283	0.566
p	0.750	1.000	0.750
R	-0.068	-0.047	0.094

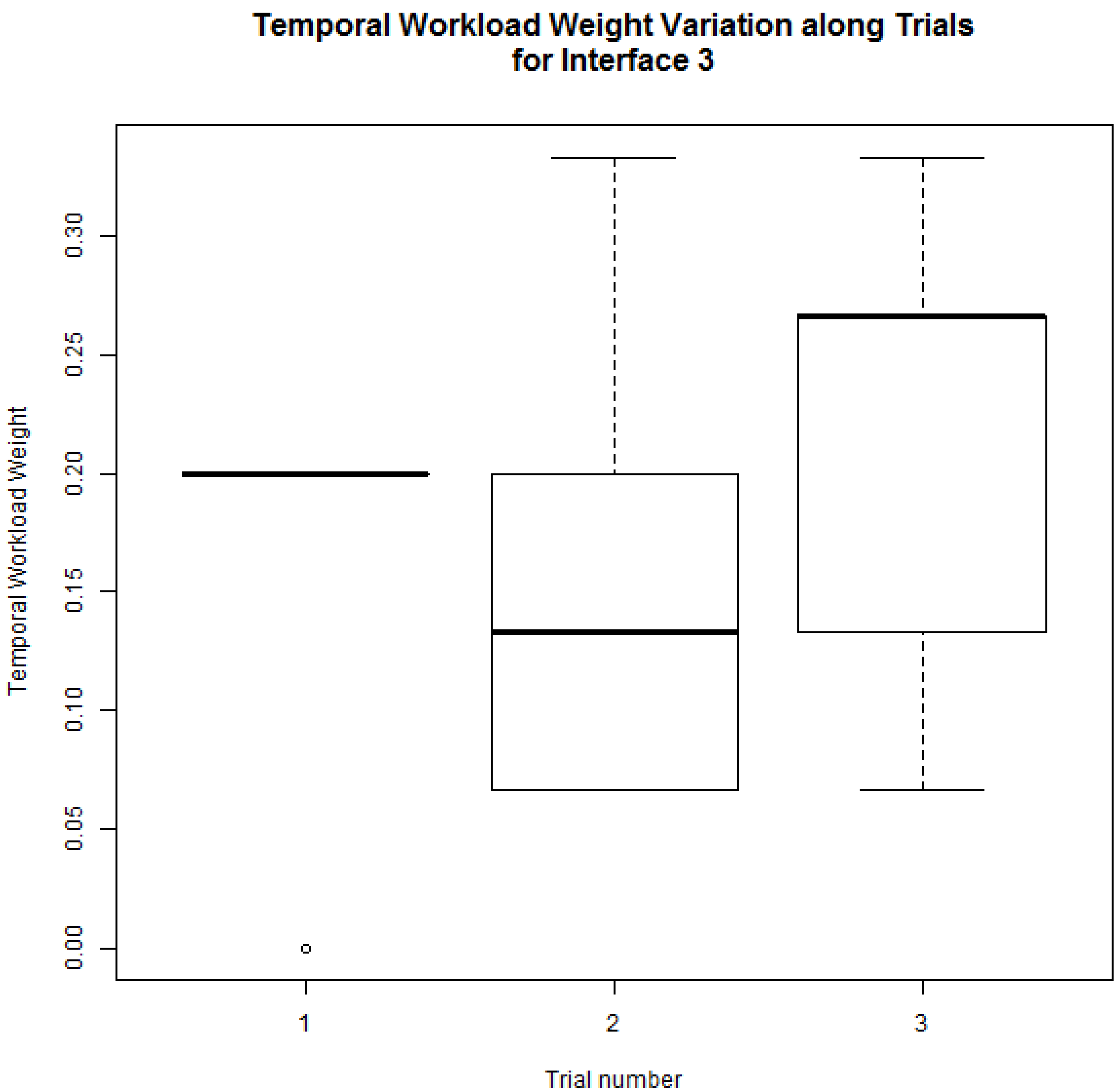
Interface 2 Temporal Workload Weight vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.173	0.121	0.133
2	0.213	0.110	0.267
3	0.187	0.087	0.200







Interface 3

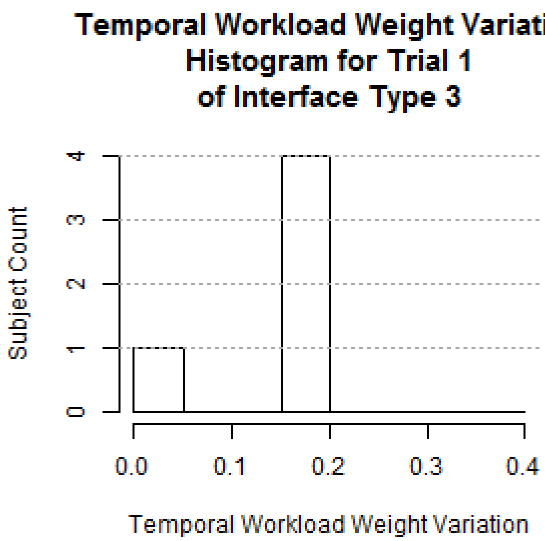


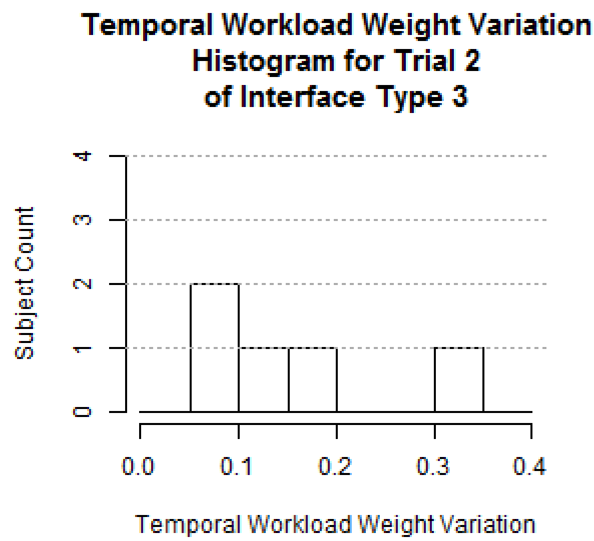
ANOVA: Interface 3 Temporal Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.009	0.005	0.438	0.655
Residuals	12	0.129	0.011		

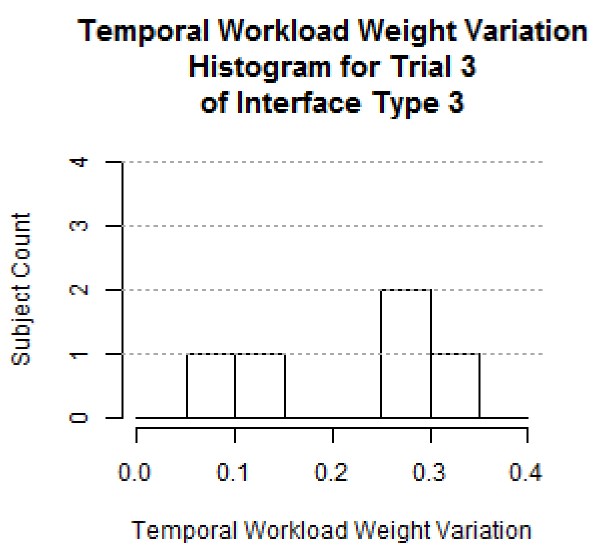
Interface 3 Temporal Workload Weight vs. Interface Order - Friedman Test	
X^2	1.368
p	0.504
DoF	2.000

Interface 3 Temporal Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	6.000	4.000	5.500
Z	0.547	-0.948	-0.542
p	0.625	0.438	0.688
R	0.091	-0.158	-0.090

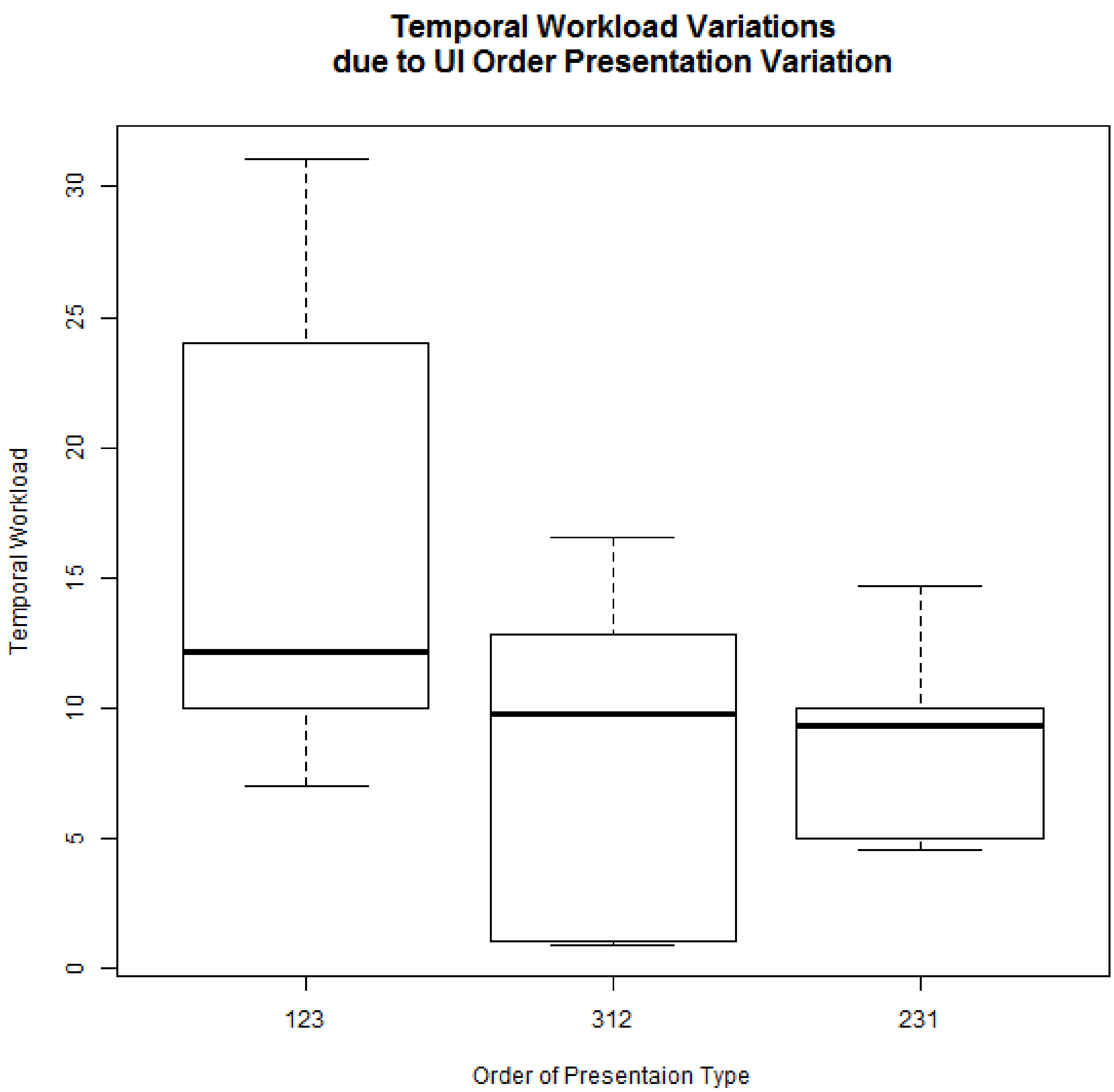
Interface 3 Temporal Workload Weight vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.160	0.089	0.200
2	0.160	0.112	0.133
3	0.213	0.110	0.267







C.2.13.3.5 Temporal Workload for Groups with Different Interface orders

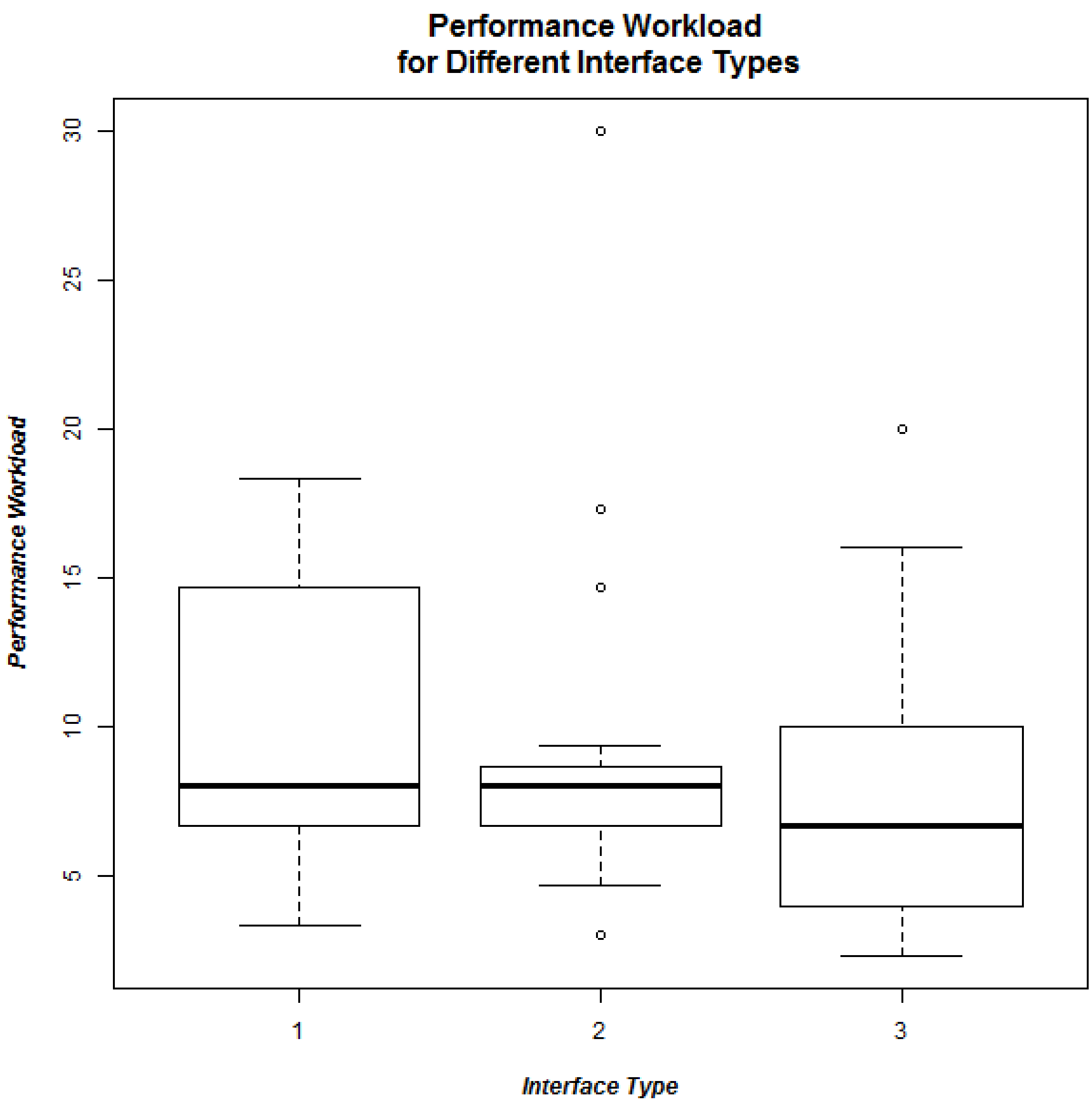


ANOVA: Overall Temporal Workload for Subjects with Different Interface Orders					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	235.2	117.62	2.051	0.171
Residuals	12	688.0	57.33		

Overall Temporal Workload vs. Subjects with Different Interface Orders Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	16.844	10.258	12.111
2	8.200	7.045	9.778
3	8.711	4.140	9.333

C.2.13.4 Performance Workload Evaluation

C.2.13.4.1 Weighted Scores+

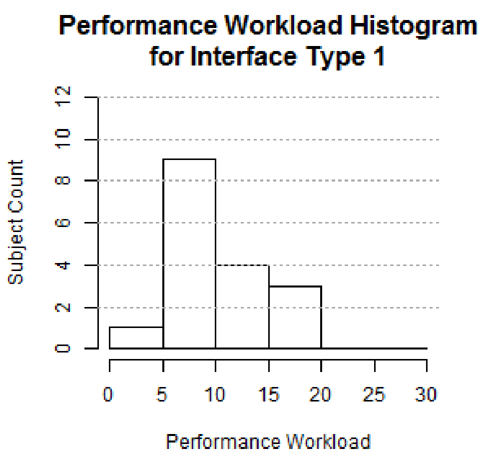


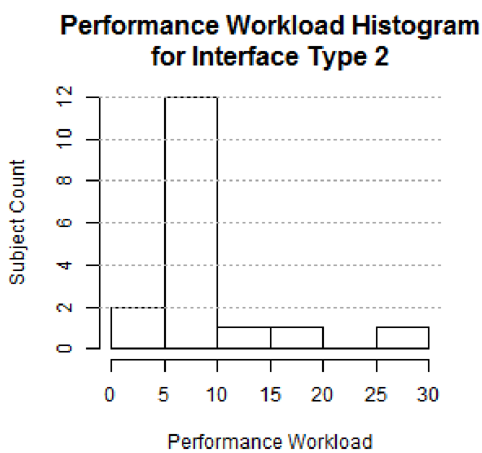
ANOVA: Performance Workload Weighted Scores for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	59.5	29.73	0.992	0.378
Residuals	48	1439.3	29.98		

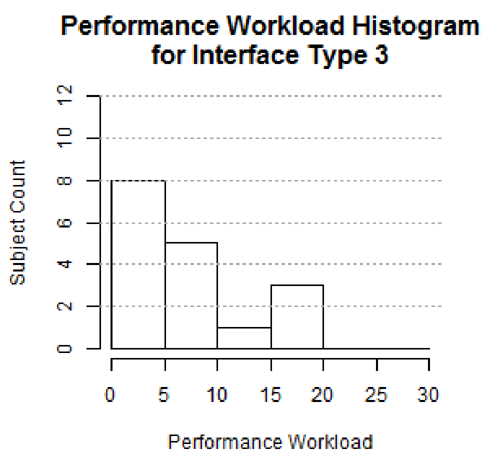
Performance Workload Weighted Scores vs. Interface Used - Friedman Test	
X^2	2.394
p	0.302
DoF	2.000

Performance Workload Weighted Scores vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	85.000	103.000	93.000
Z	0.900	1.799	0.781
p	0.391	0.075	0.451
R	0.150	0.300	0.130

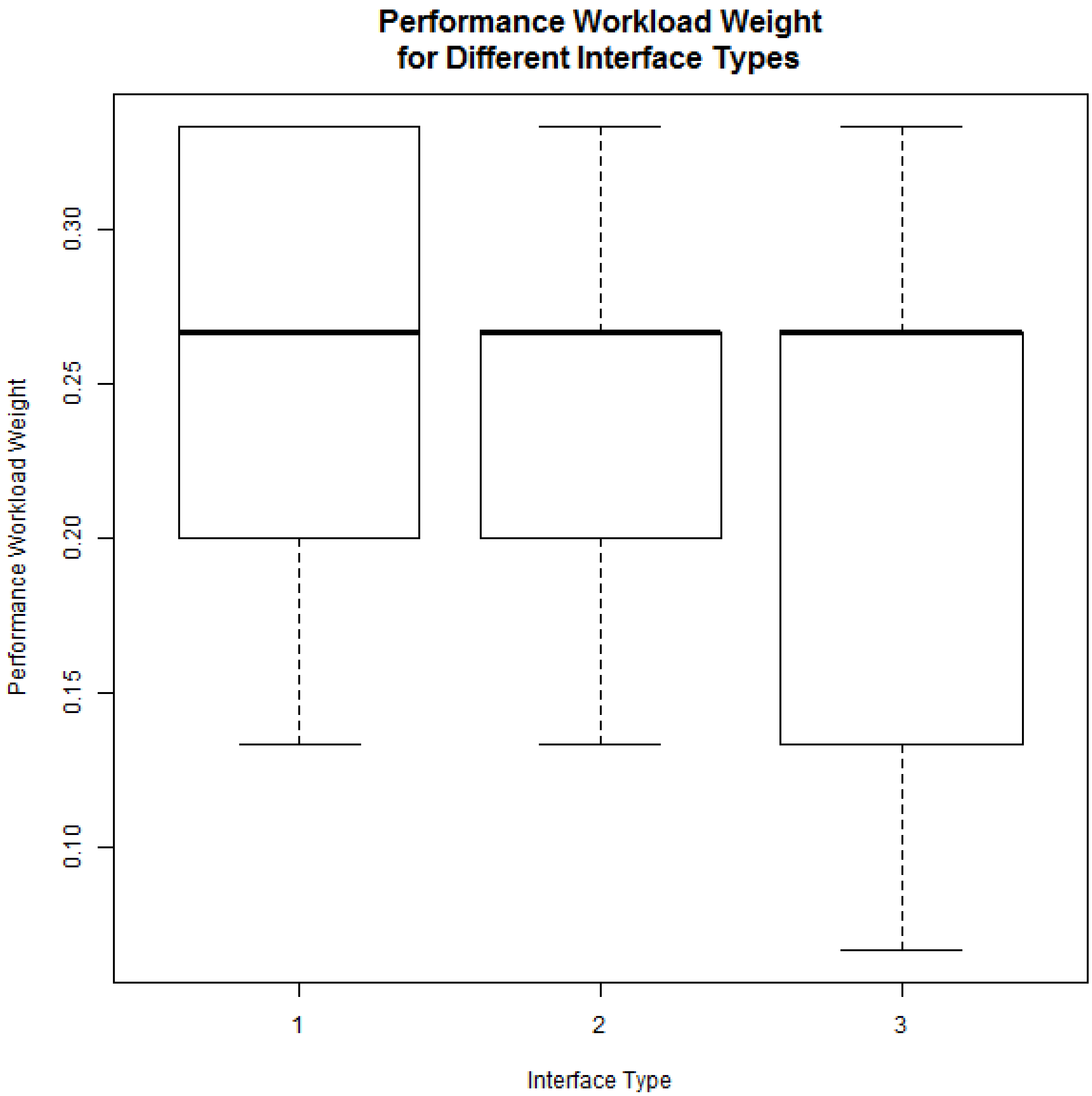
Performance Workload Weighted Scores vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	10.353	4.682	8.000
2	9.431	6.293	8.000
3	7.745	5.331	6.667







C.2.13.4.2 Weight

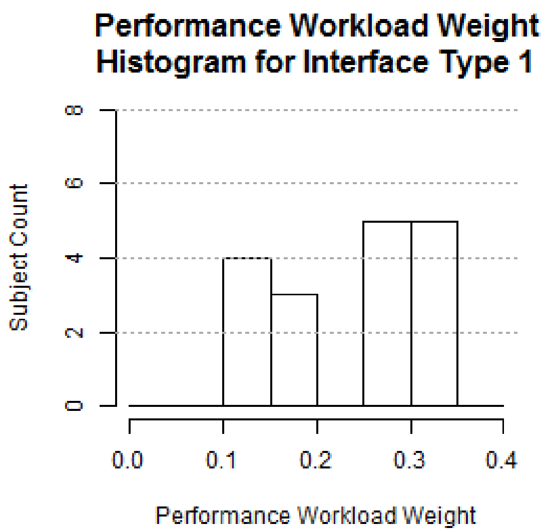


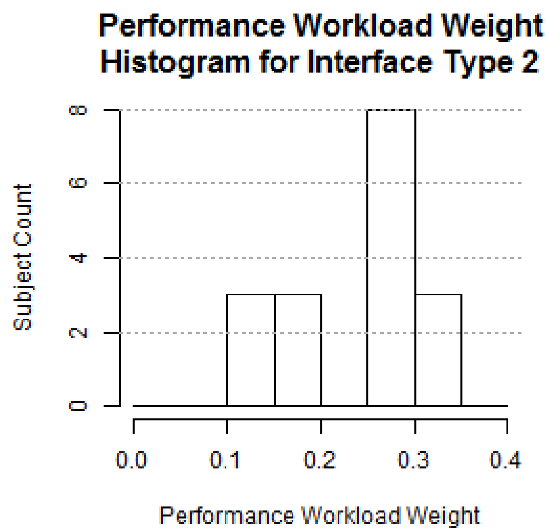
ANOVA: Performance Workload Weight for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.004	0.002	0.338	0.715
Residuals	48	0.309	0.006		

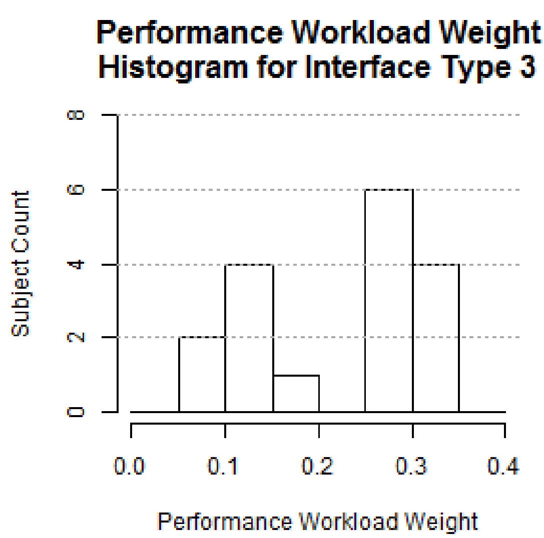
Performance Workload Weight vs. Interface Used - Friedman Test	
X^2	1.292
p	0.524
DoF	2.000

Performance Workload Weight vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	48.500	30.000	44.000
Z	-0.191	1.384	0.681
p	0.873	0.176	0.516
R	-0.032	0.231	0.113

Performance Workload Weight vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.243	0.078	0.267
2	0.243	0.066	0.267
3	0.224	0.094	0267

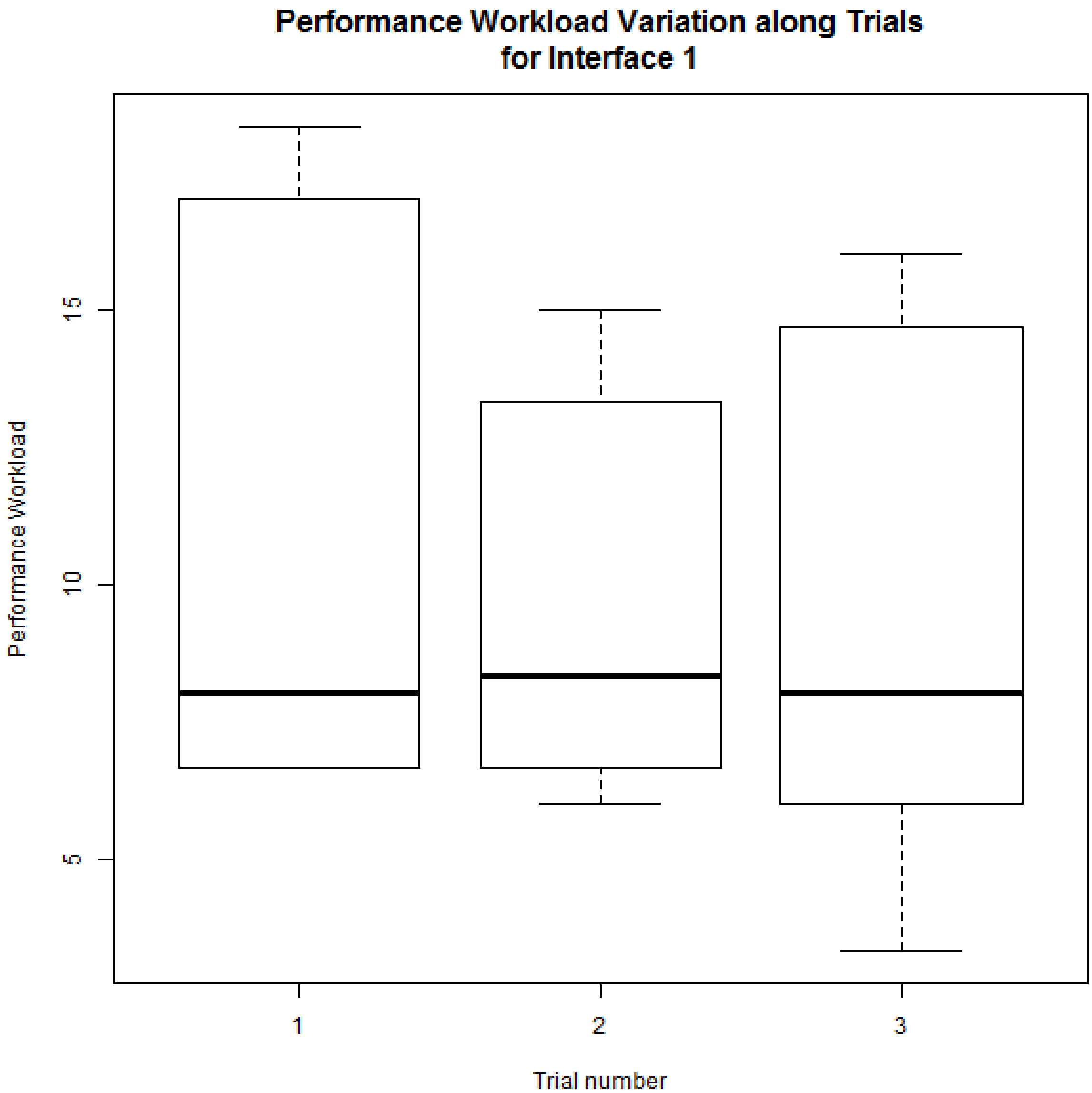






C.2.13.4.3 Interface Order Effect on Performance Workload Score

Interface 1

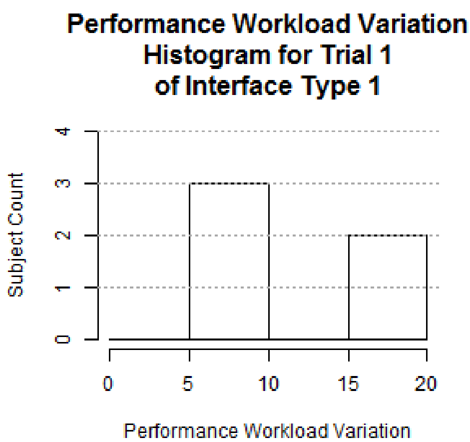


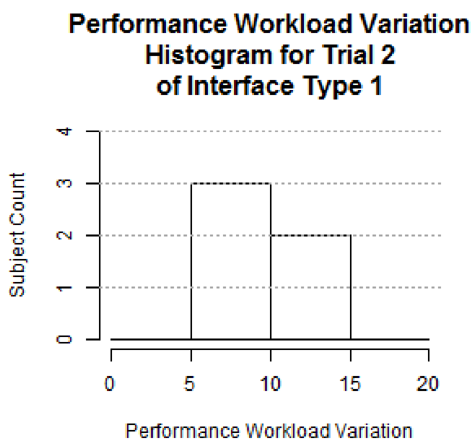
ANOVA: Interface 1 Performance Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	8.7	4.356	0.162	0.852
Residuals	12	323.1	26.926		

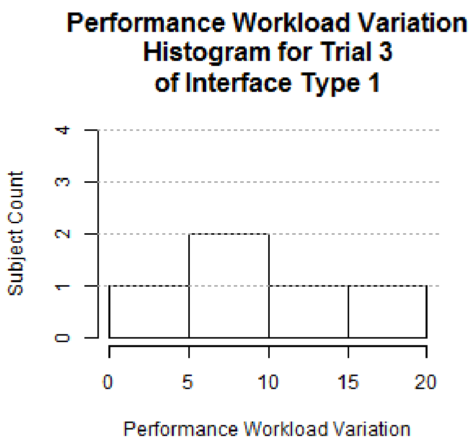
Interface 1 Performance Workload Score vs. Interface Order - Friedman Test	
X^2	0.400
p	0.819
DoF	2.000

Interface 1 Performance Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	9.000	9.000	8.000
Z	0.405	0.405	0.135
p	0.812	0.812	1.000
R	0.067	0.067	0.022

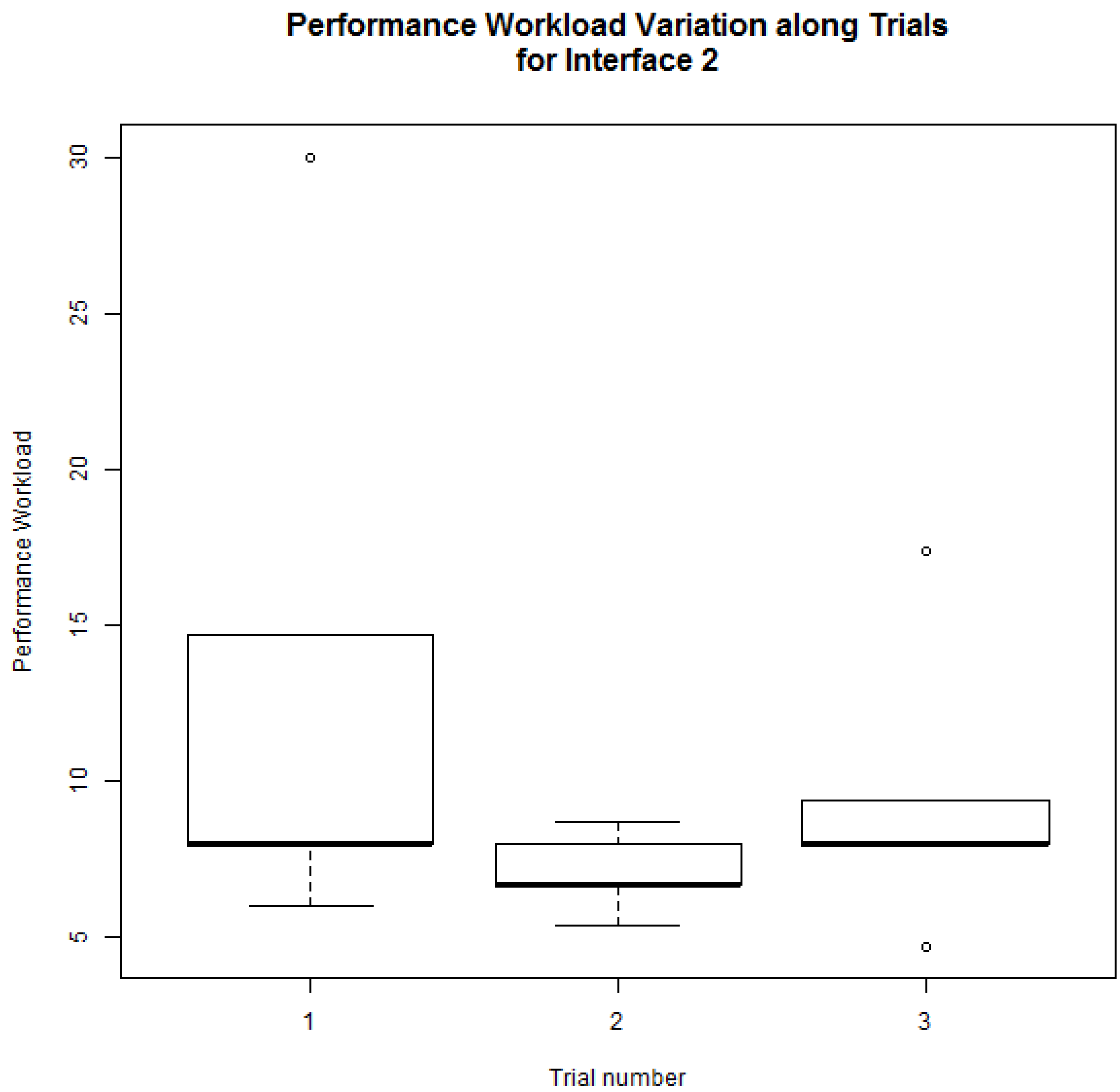
Interface 1 Performance Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	11.333	5.826	8.000
2	9.867	4.059	8.333
3	9.600	5.510	8.000







Interface 2

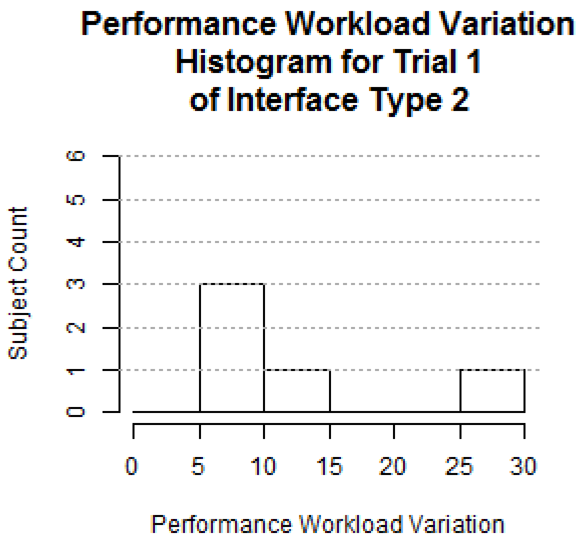


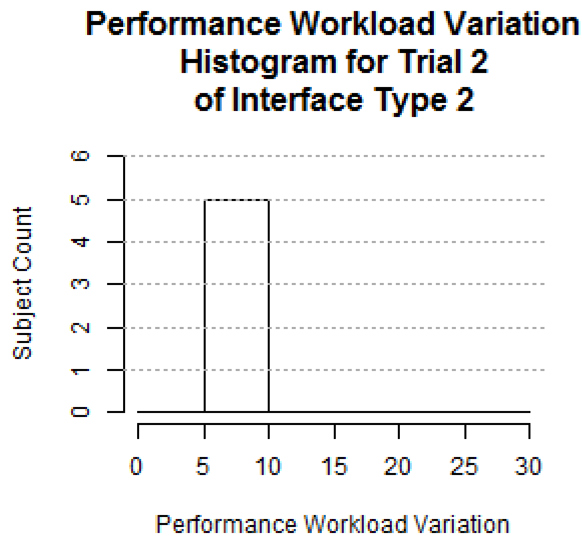
ANOVA: Interface 2 Performance Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	100.0	49.99	1.234	0.326
Residuals	12	486.2	40.52		

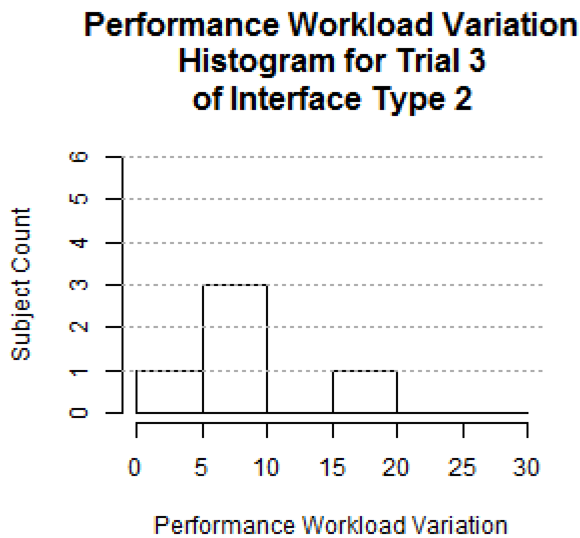
Interface 2 Performance Workload Score vs. Interface Order - Friedman Test	
X^2	2.842
p	0.241
DoF	2.000

Interface 2 Performance Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	12.000	6.000	1.000
Z	1.214	0.272	-1.761
p	0.312	0.875	0.125
R	0.202	0.045	-0.293

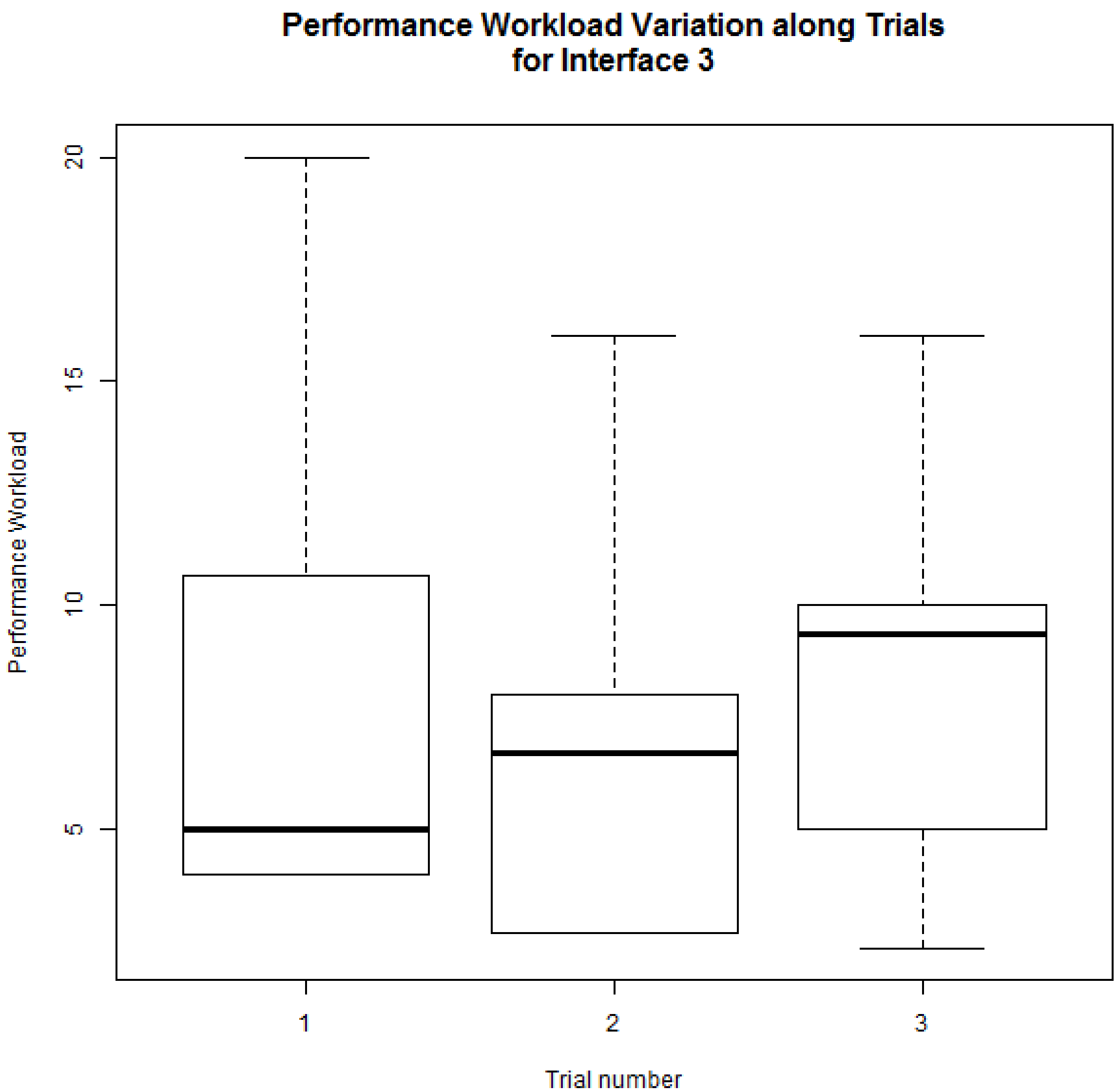
Interface 2 Performance Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	13.333	9.877	8.000
2	7.067	1.300	6.667
3	9.467	4.723	8.000







Interface 3

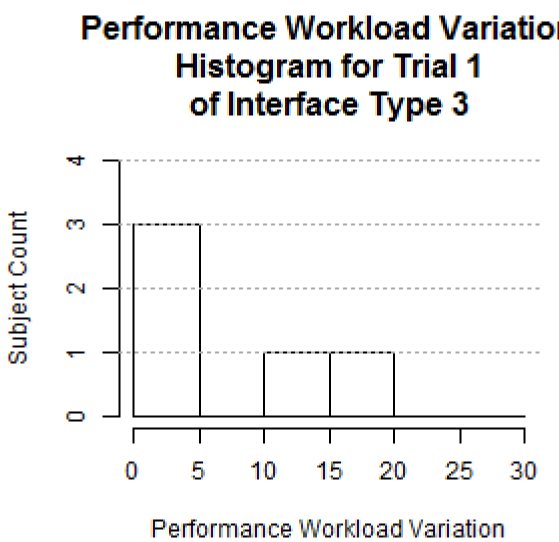


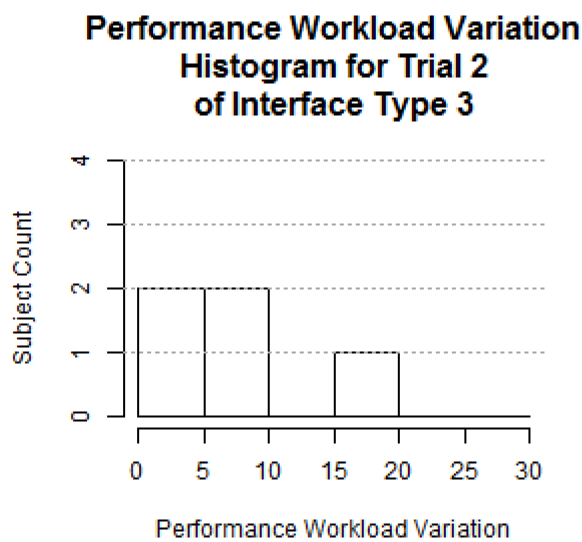
ANOVA: Interface 3 Performance Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	6.9	3.47	0.1	0.906
Residuals	12	418.4	34.86		

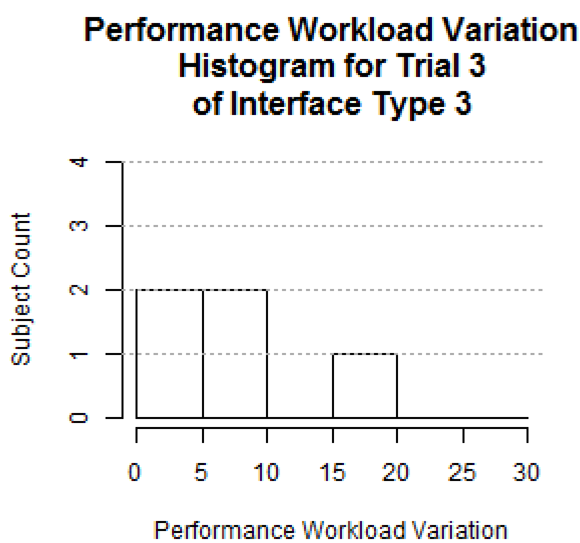
Interface 3 Performance Workload Score vs. Interface Order - Friedman Test	
X^2	1.200
p	0.549
DoF	2.000

Interface 3 Performance Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	9.000	5.000	6.000
Z	0.405	-0.674	-0.405
p	0.812	0.625	0.812
R	0.067	-0.112	-0.067

Interface 3 Performance Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	8.733	6.882	5.000
2	7.200	5.465	6.667
3	8.533	5.231	9.333

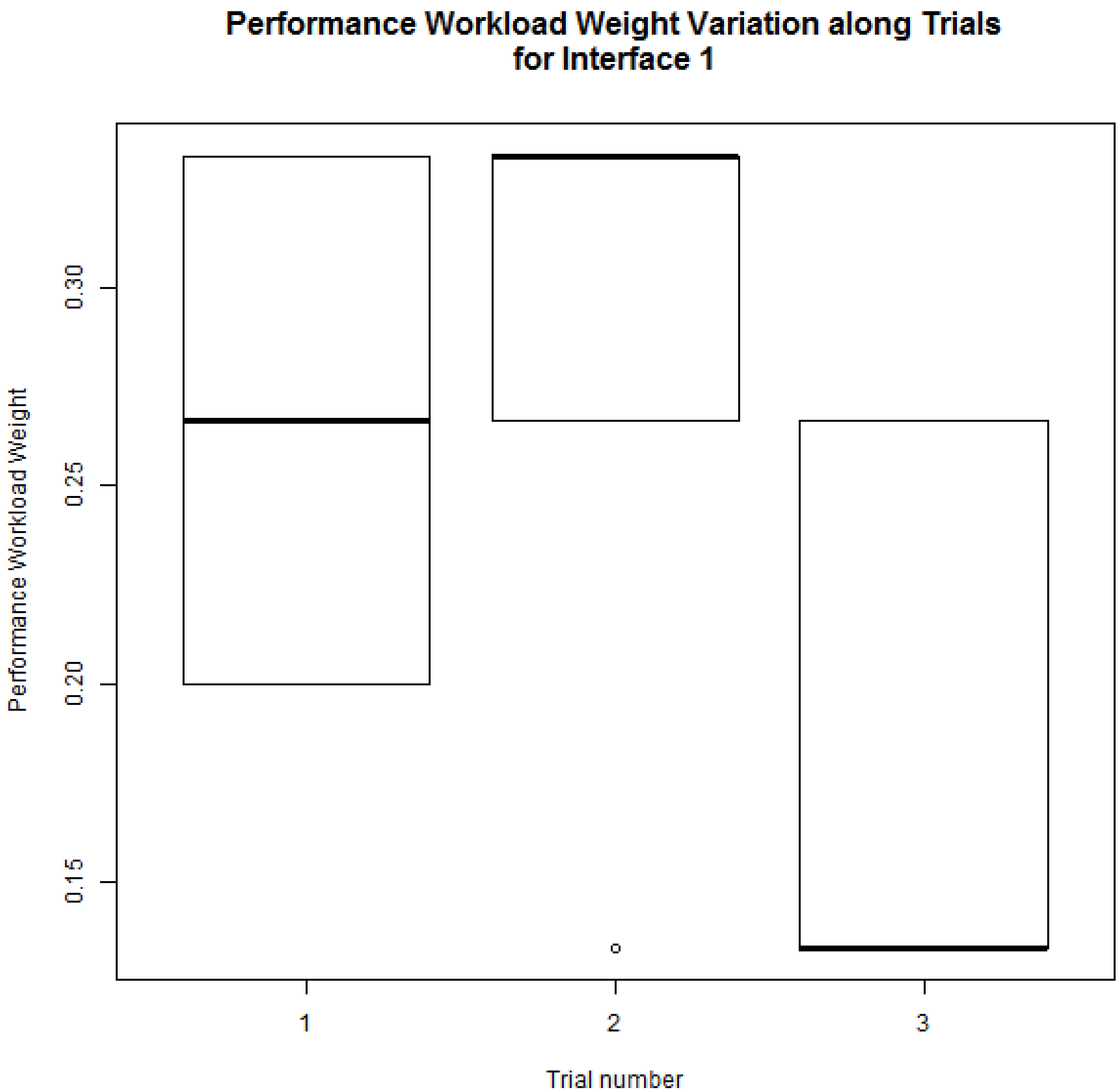






C.2.13.4.4 Interface Order Effect on Performance Workload Weight

Interface 1

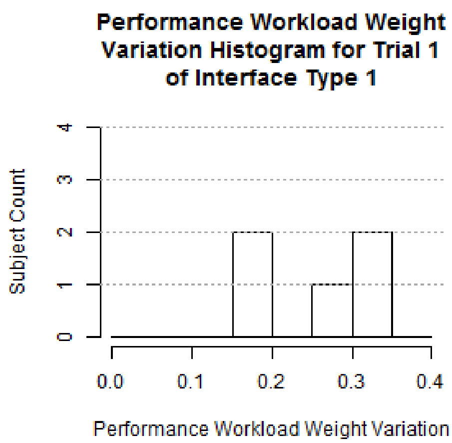


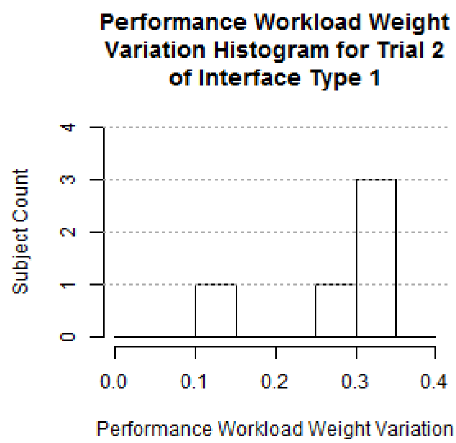
ANOVA: Interface 1 Performance Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.025	0.013	2.205	0.153
Residuals	12	0.069	0.006		

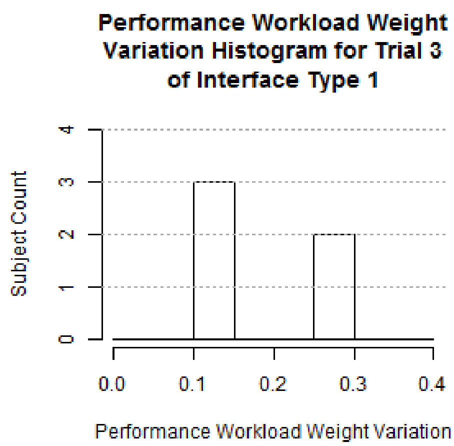
Interface 1 Performance Workload Weight vs. Interface Order - Friedman Test	
X^2	3.176
p	0.204
DoF	2.000

Interface 1 Performance Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	4.500	13.000	6.000
Z	-0.137	1.483	1.706
p	1.000	0.188	0.250
R	-0.023	0.247	0.284

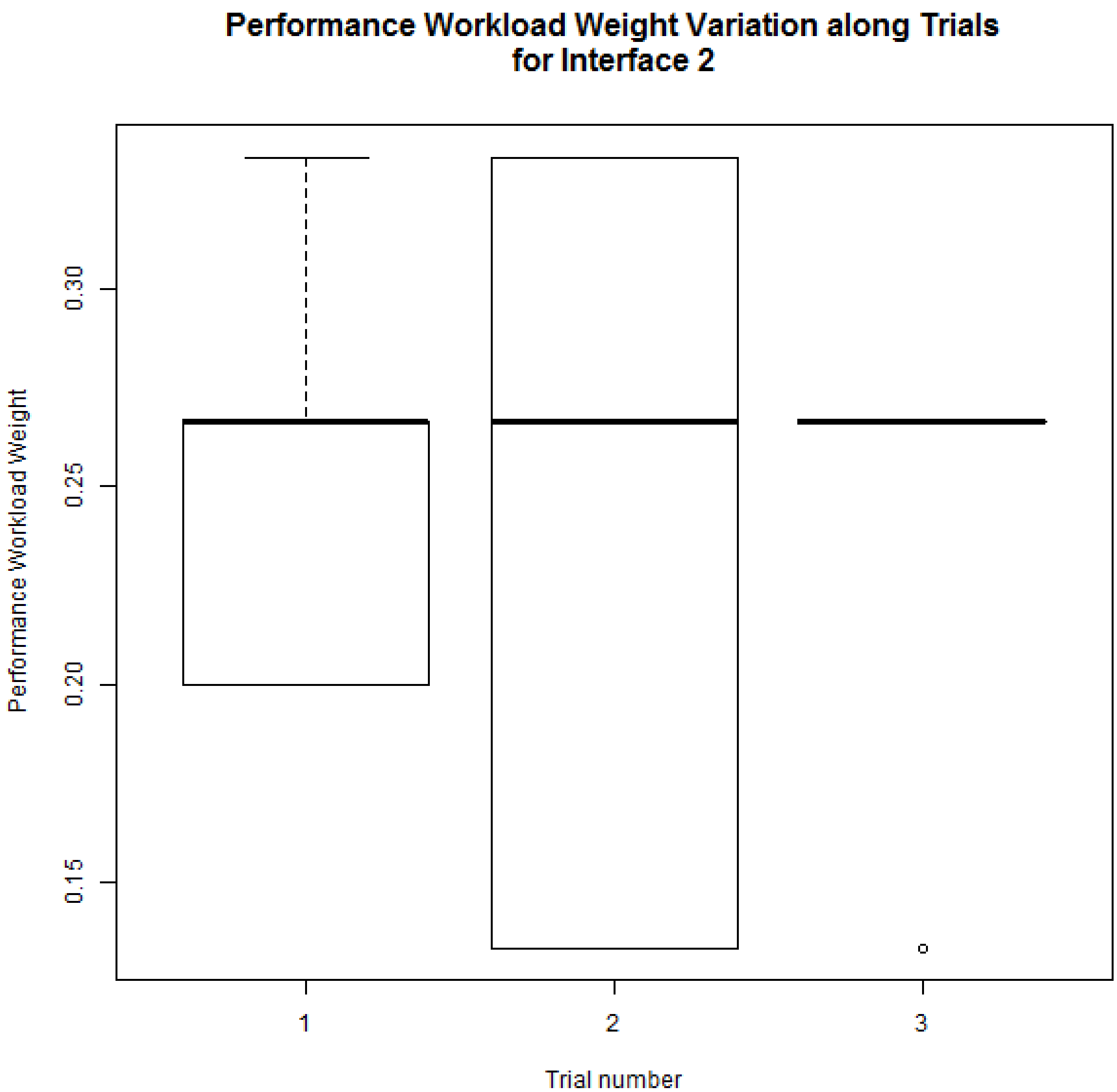
Interface 1 Performance Workload Weight Variation vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.267	0.067	0.267
2	0.280	0.087	0.333
3	0.187	0.073	0.133







Interface 2

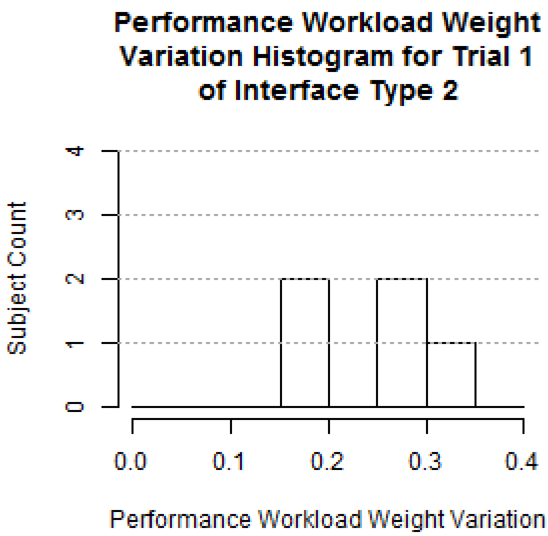


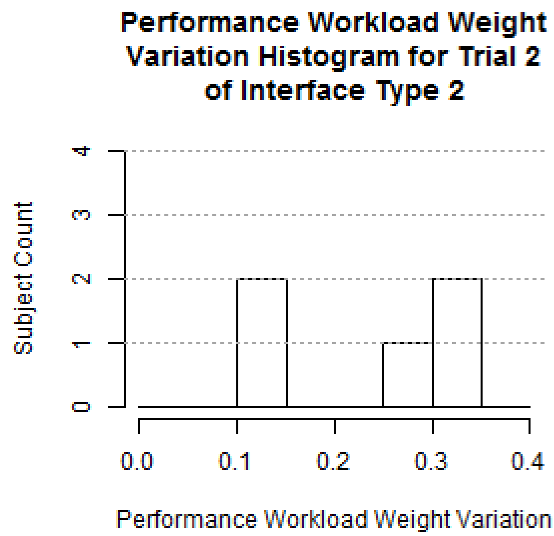
ANOVA: Interface 2 Performance Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.000	0.000	0.053	0.949
Residuals	12	0.067	0.006		

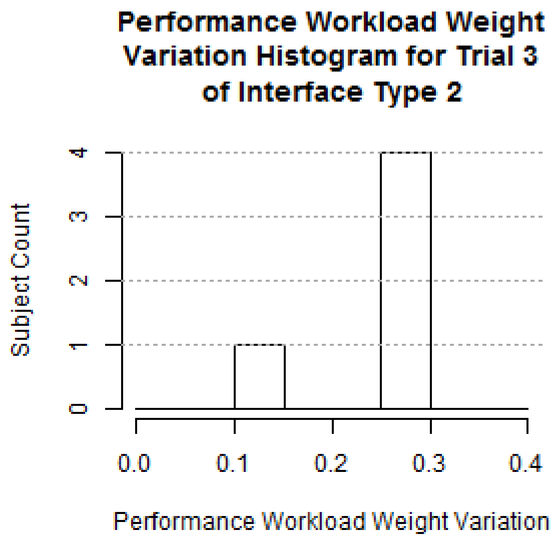
Interface 2 Performance Workload Weight vs. Interface Order - Friedman Test	
X^2	0.118
p	0.943
DoF	2.000

Interface 2 Performance Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	9.500	5.000	3.000
Z	0.542	0.000	0.284
p	0.688	1.000	1.000
R	0.090	0.000	0.047

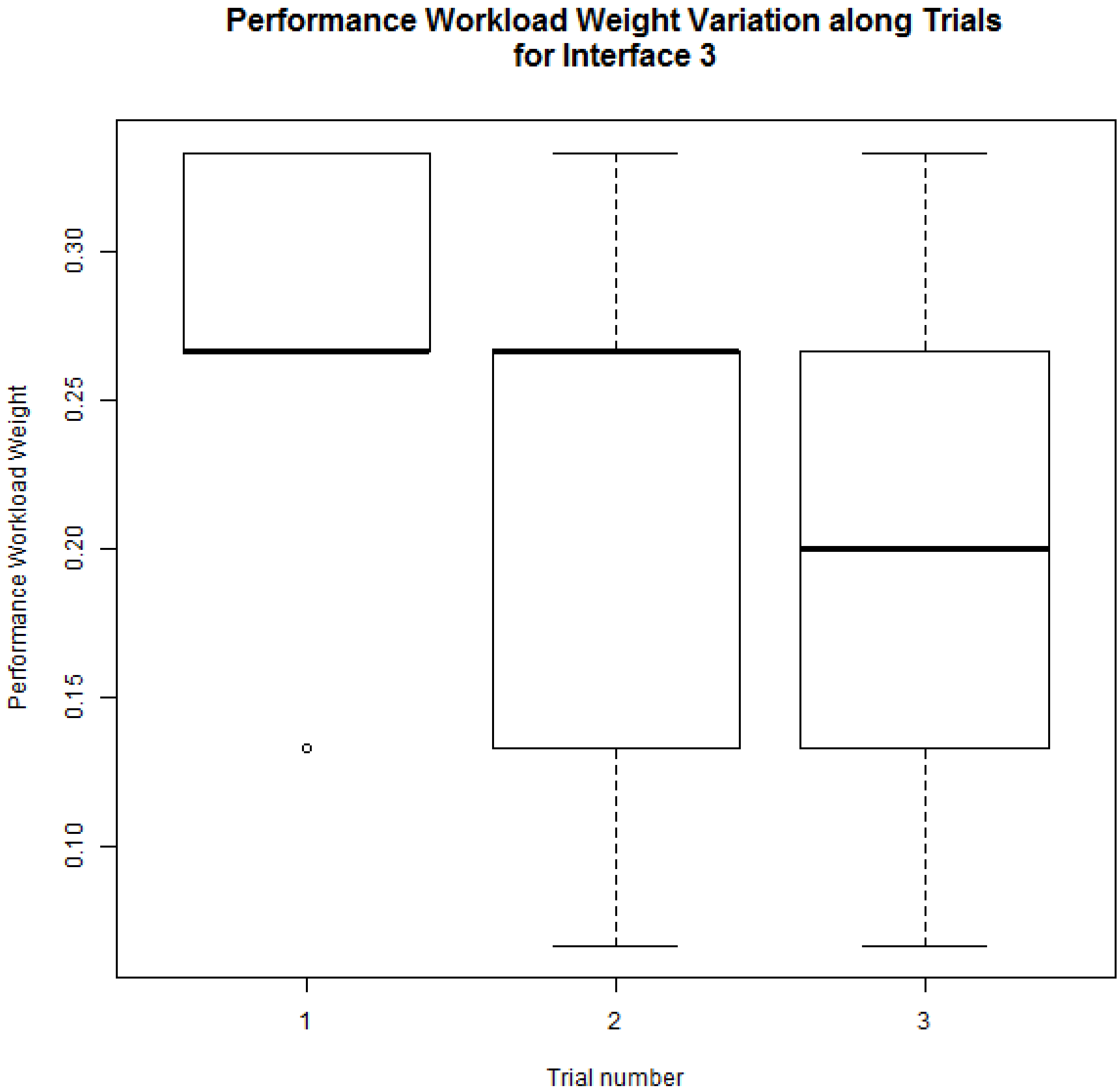
Interface 2 Performance Workload Weight vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.253	0.056	0.267
2	0.240	0.101	0.267
3	0.240	0.060	0.267







Interface 3

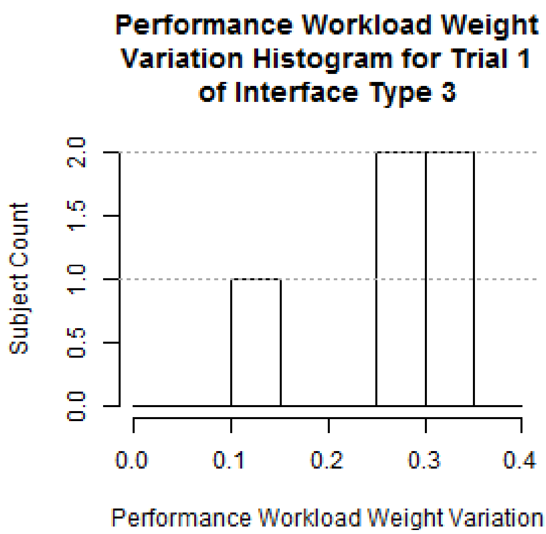


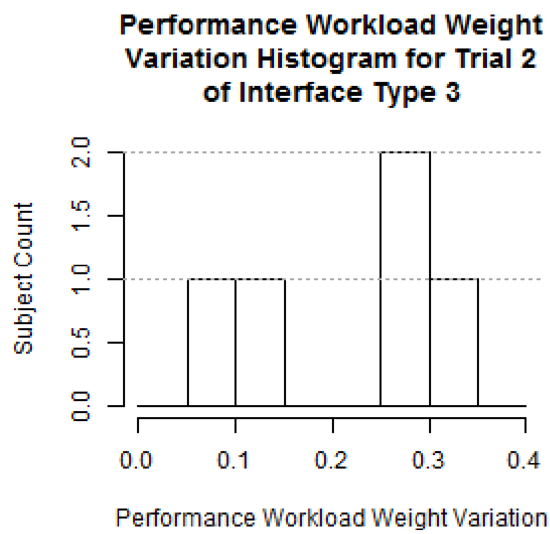
ANOVA: Interface 3 Performance Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2				
Residuals	12				

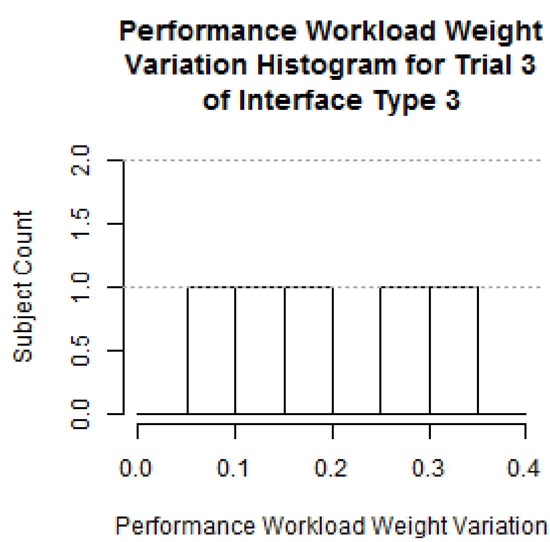
Interface 3 Performance Workload Weight vs. Interface Order - Friedman Test	
X^2	26.00
p	0.273
DoF	2.000

Interface 3 Performance Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	3.000	3.000	3.500
Z	1.406	1.406	0.426
p	0.500	0.500	1.000
R	0.234	0.234	0.071

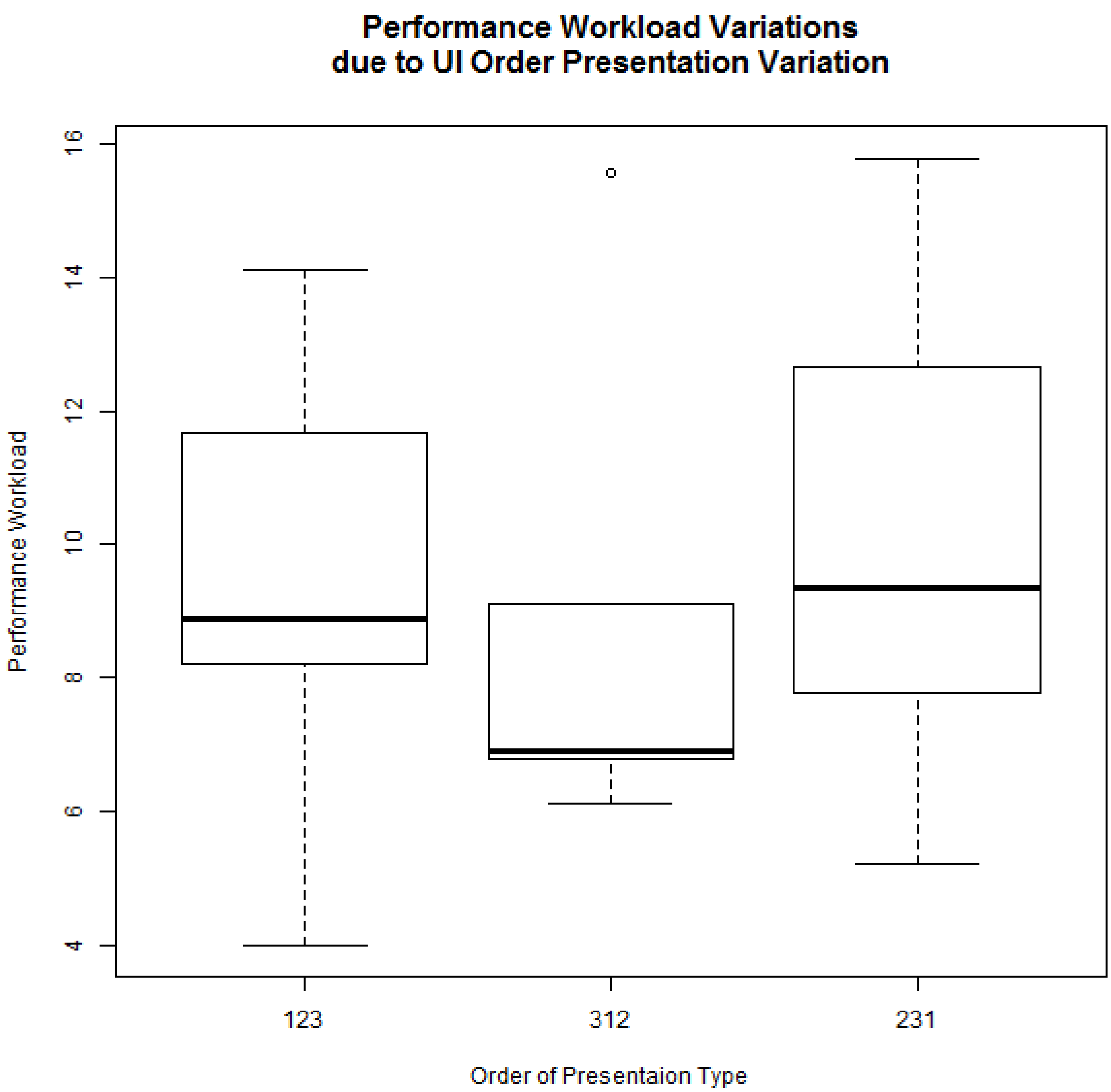
Interface 3 Performance Workload Weight vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.267	0.082	0.267
2	0.213	0.110	0.267
3	0.200	0.105	0.200







C.2.13.4.5 Performance Workload for Groups with Different Interface orders

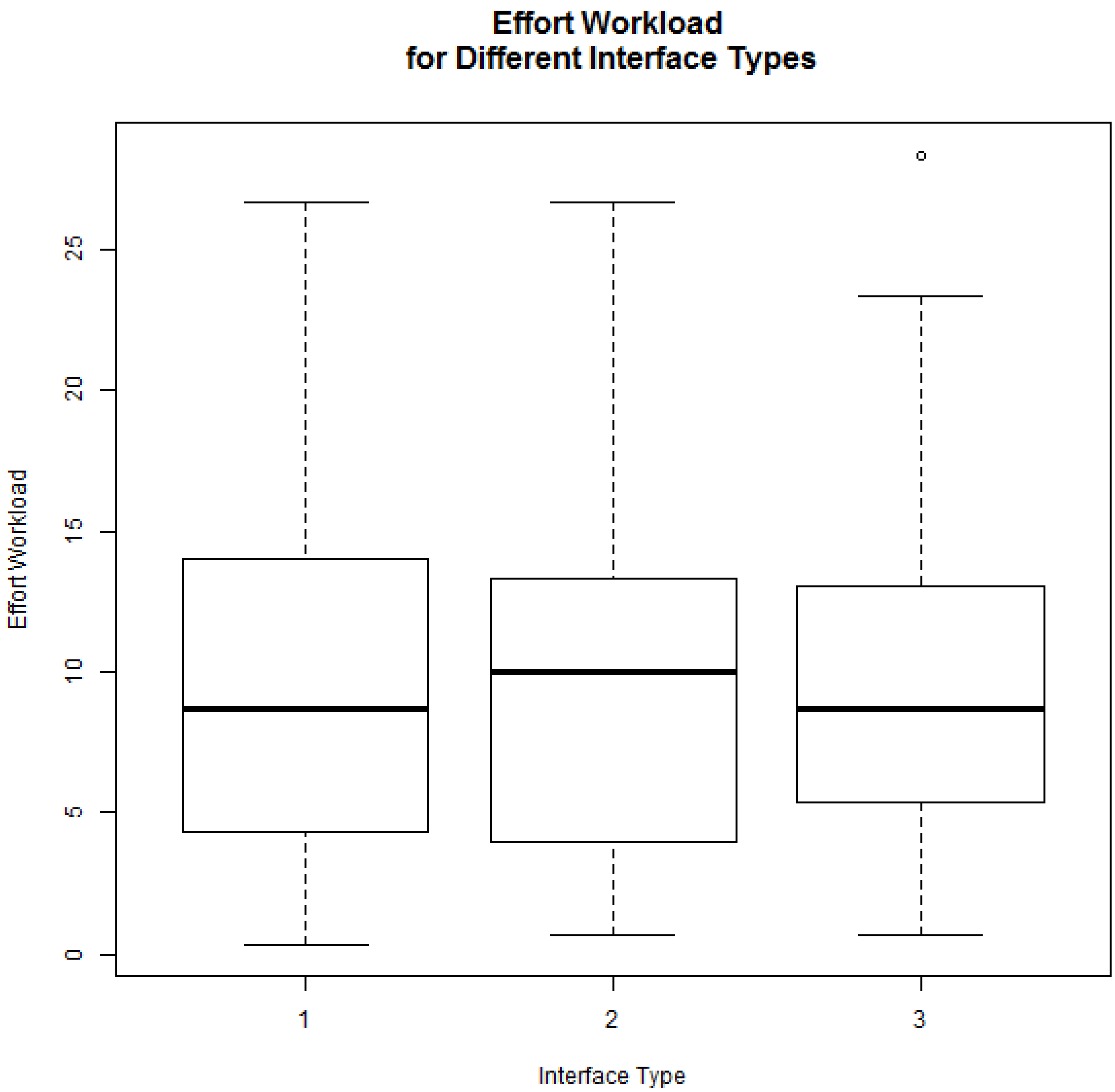


ANOVA: Overall Performance Workload for Subjects with Different Interface Orders					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	4.08	2.04	0.131	0.879
Residuals	12	187.39	15.62		

Overall Performance Workload vs. Subjects with Different Interface Orders Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	9.378	3.812	8.889
2	8.889	3.894	6.889
3	10.155	4.141	9.333

C.2.13.5 Effort Workload Evaluation

C.2.13.5.1 Weighted Scores

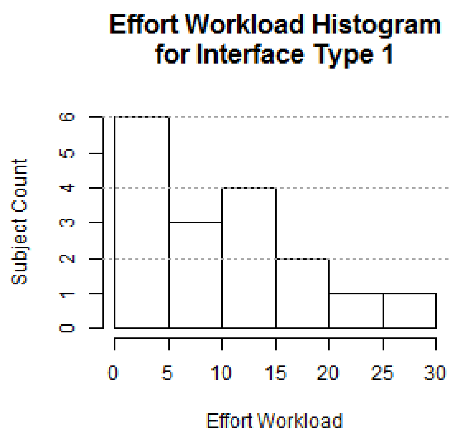


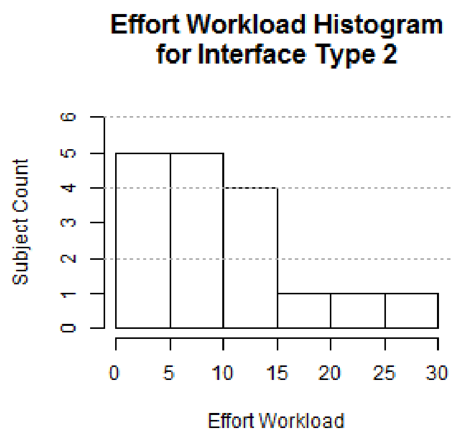
ANOVA: Effort Workload Weighted Scores for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	12	5.98	0.096	0.909
Residuals	48	2991	62.32		

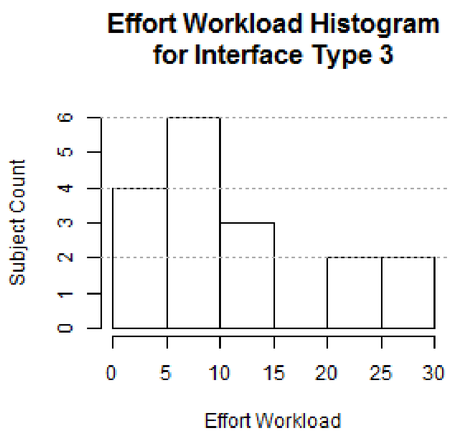
Effort Workload Weighted Scores vs. Interface Used - Friedman Test	
X^2	1.238
p	0.538
DoF	2.000

Effort Workload Weighted Scores vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	60.000	56.000	48.000
Z	-0.047	-0.663	-0.711
p	0.972	0.532	0.494
R	-0.008	-0.110	-0.119

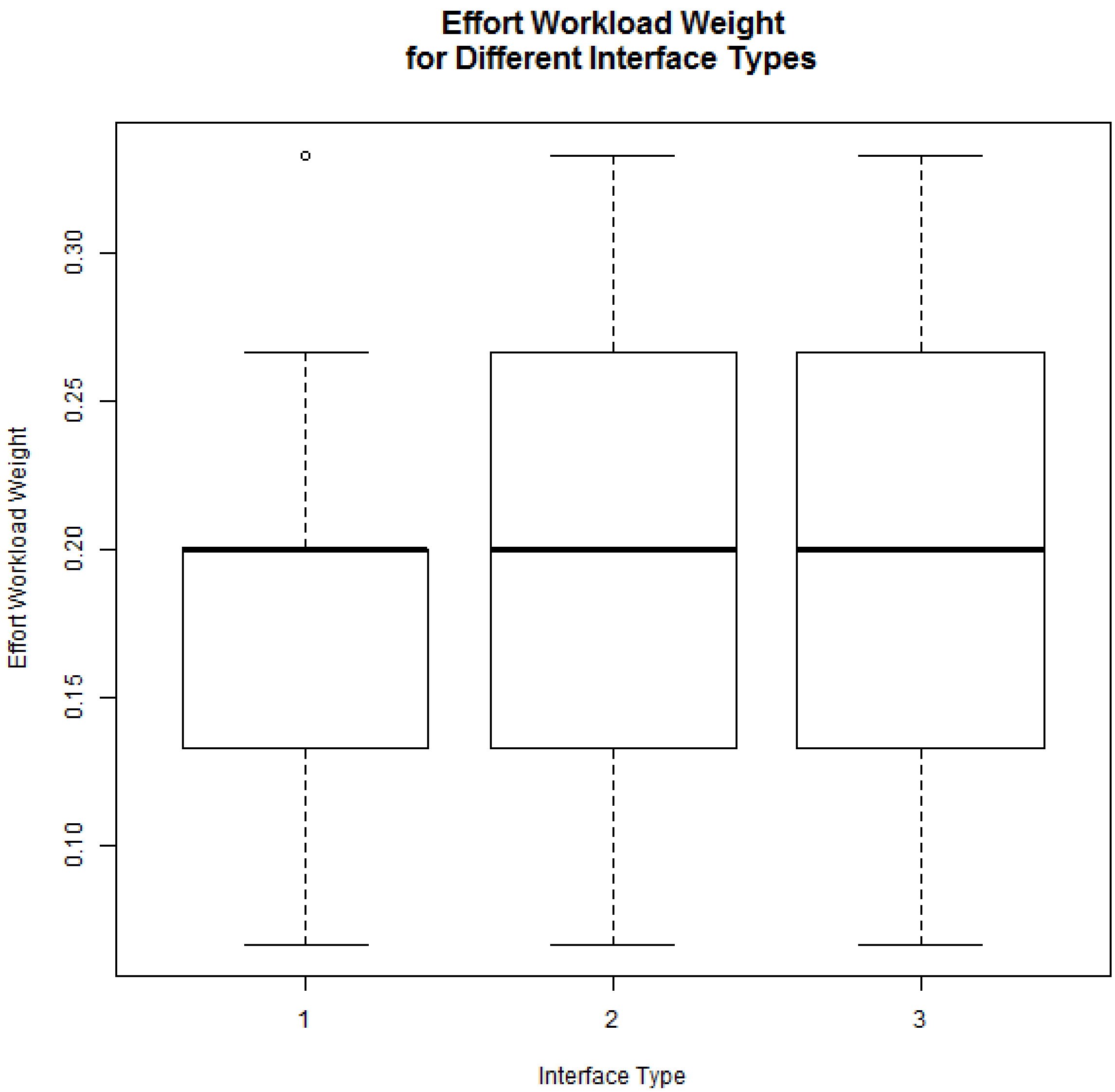
Effort Workload Weighted Scores vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	10.196	7.409	8.667
2	10.412	7.447	10.000
3	11.314	8.752	8.667







C.2.13.5.2 Weight

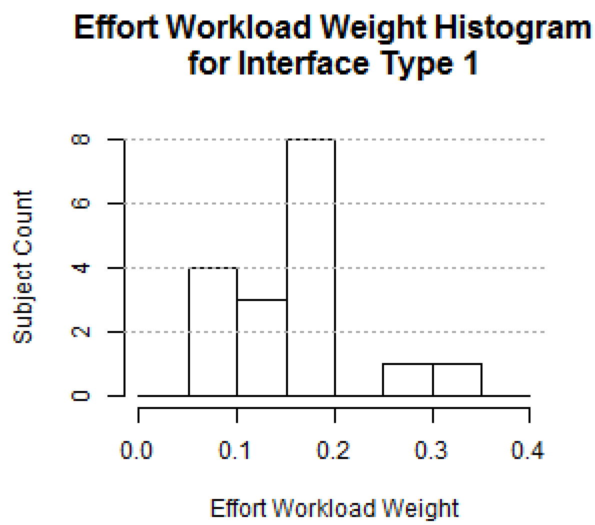


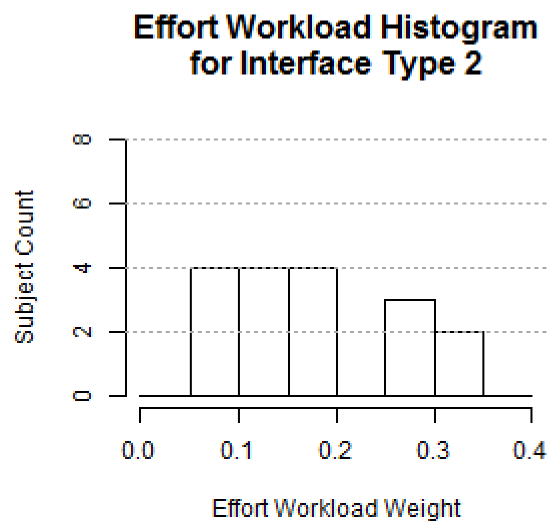
ANOVA: Effort Workload Weight for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2				
Residuals	48				

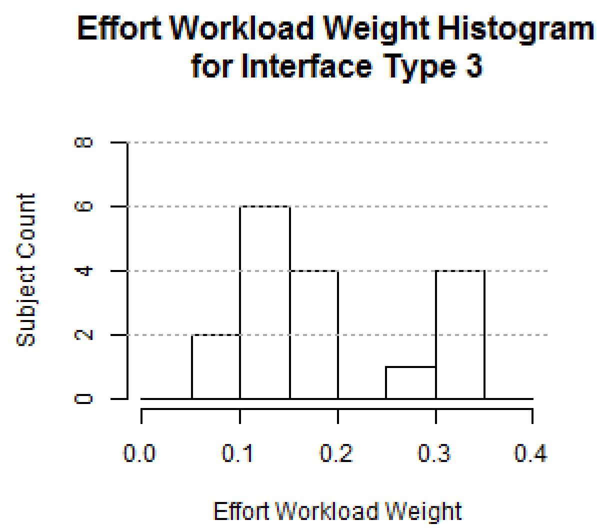
Effort Workload Weight vs. Interface Used - Friedman Test	
X^2	2.205
p	0.332
DoF	2.000

Effort Workload Weight vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	13.500	20.500	19.000
Z	-0.698	-1.036	-0.780
p	0.547	0.320	0.465
R	-0.116	-0.173	-0.130

Effort Workload Weight vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.169	0.075	0.200
2	0.180	0.091	0.200
3	0.196	0.093	0.200

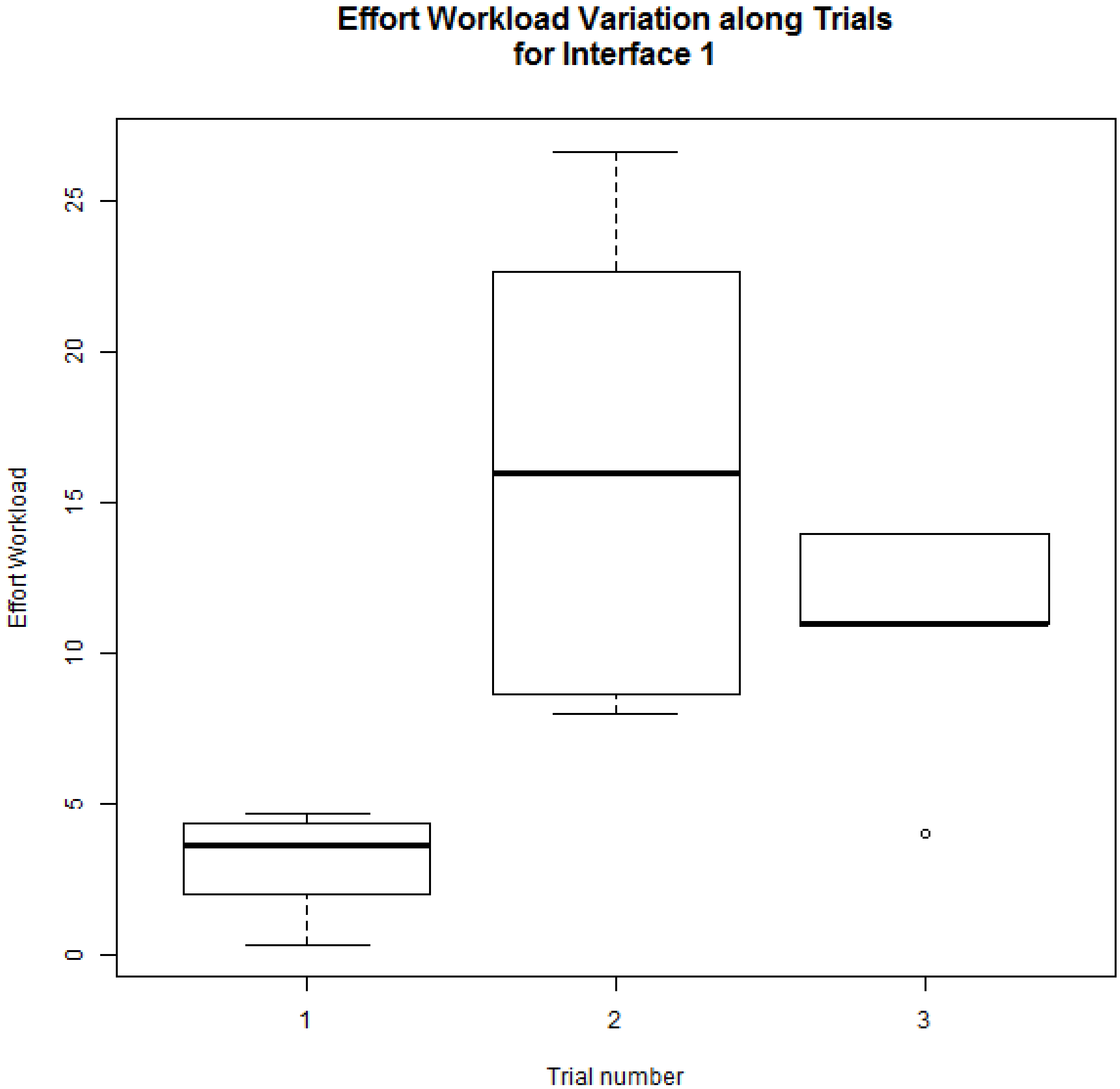




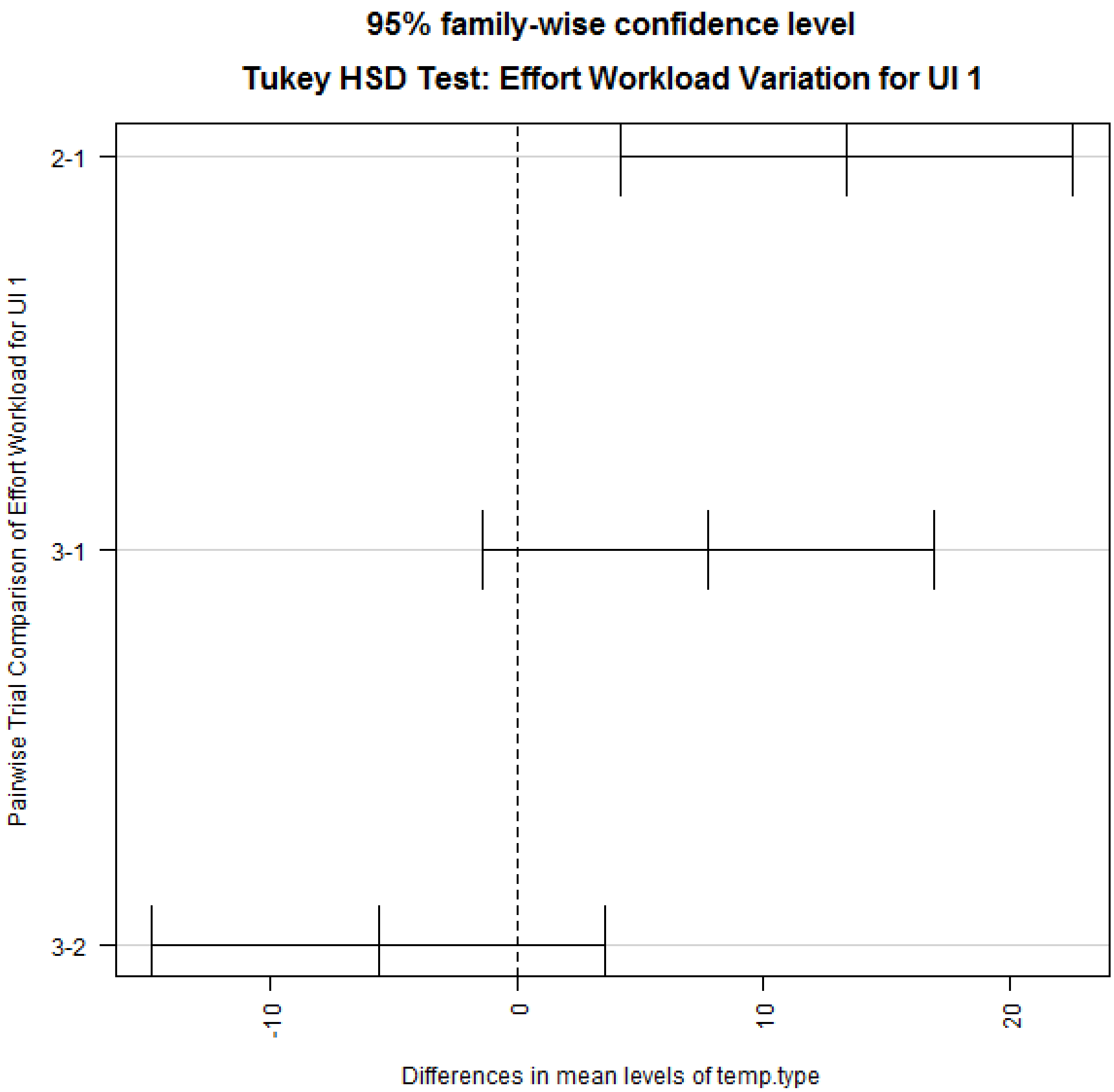


C.2.13.5.3 Interface Order Effect on Effort Workload Score*

Interface 1



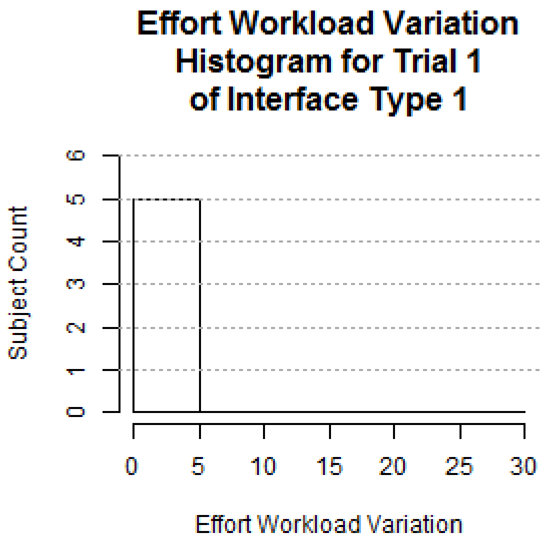
ANOVA: Interface 1 Effort Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	452.9	226.47	7.653	0.007
Residuals	12	355.1	29.59		

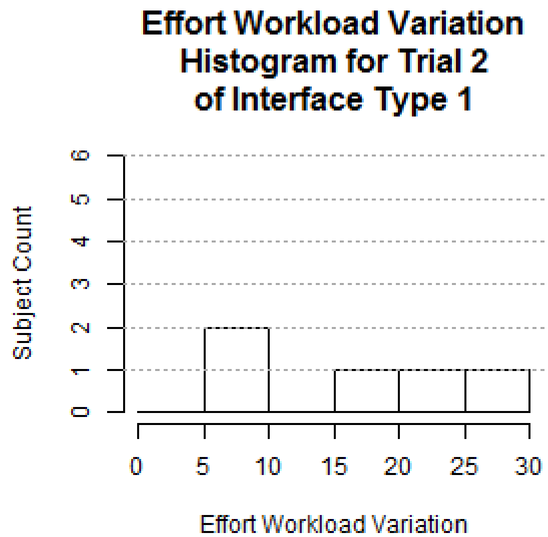


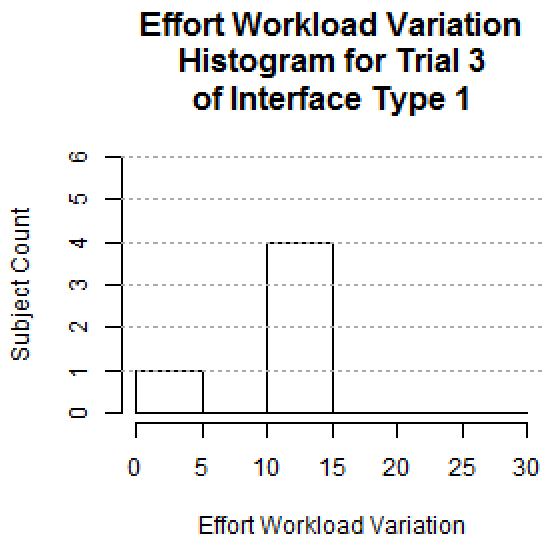
Interface 1 Effort Workload Score vs. Interface Order - Friedman Test	
X^2	6.400
p	0.041
DoF	2.000

Interface 1 Effort Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	0.000	1.000	12.000
Z	-2.023	-1.753	1.214
p	0.062	0.125	0.312
R	-0.337	-0.292	0.202

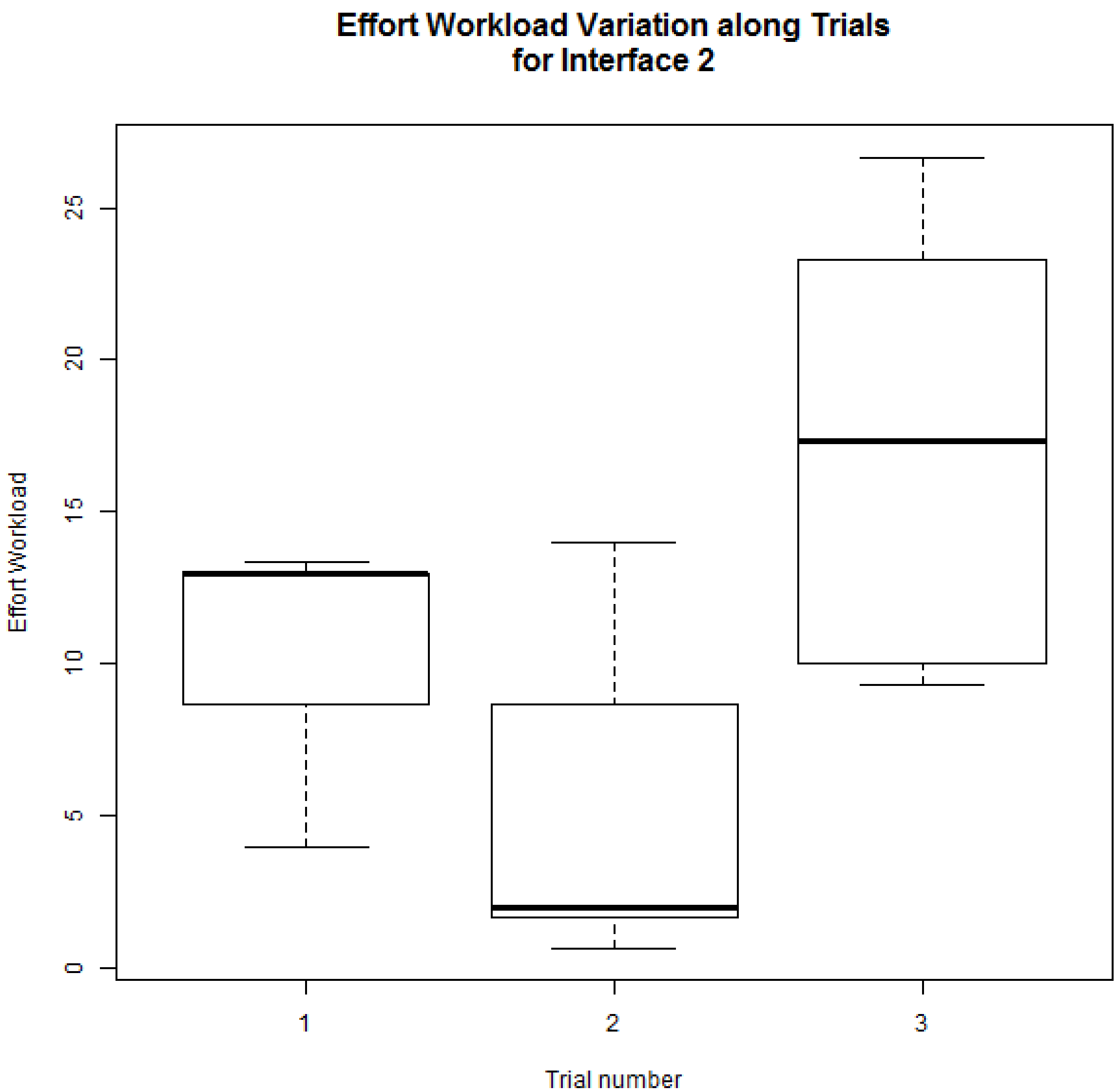
Interface 1 Effort Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	3.000	1.810	3.667
2	16.400	8.295	16.000
3	10.800	4.087	11.000



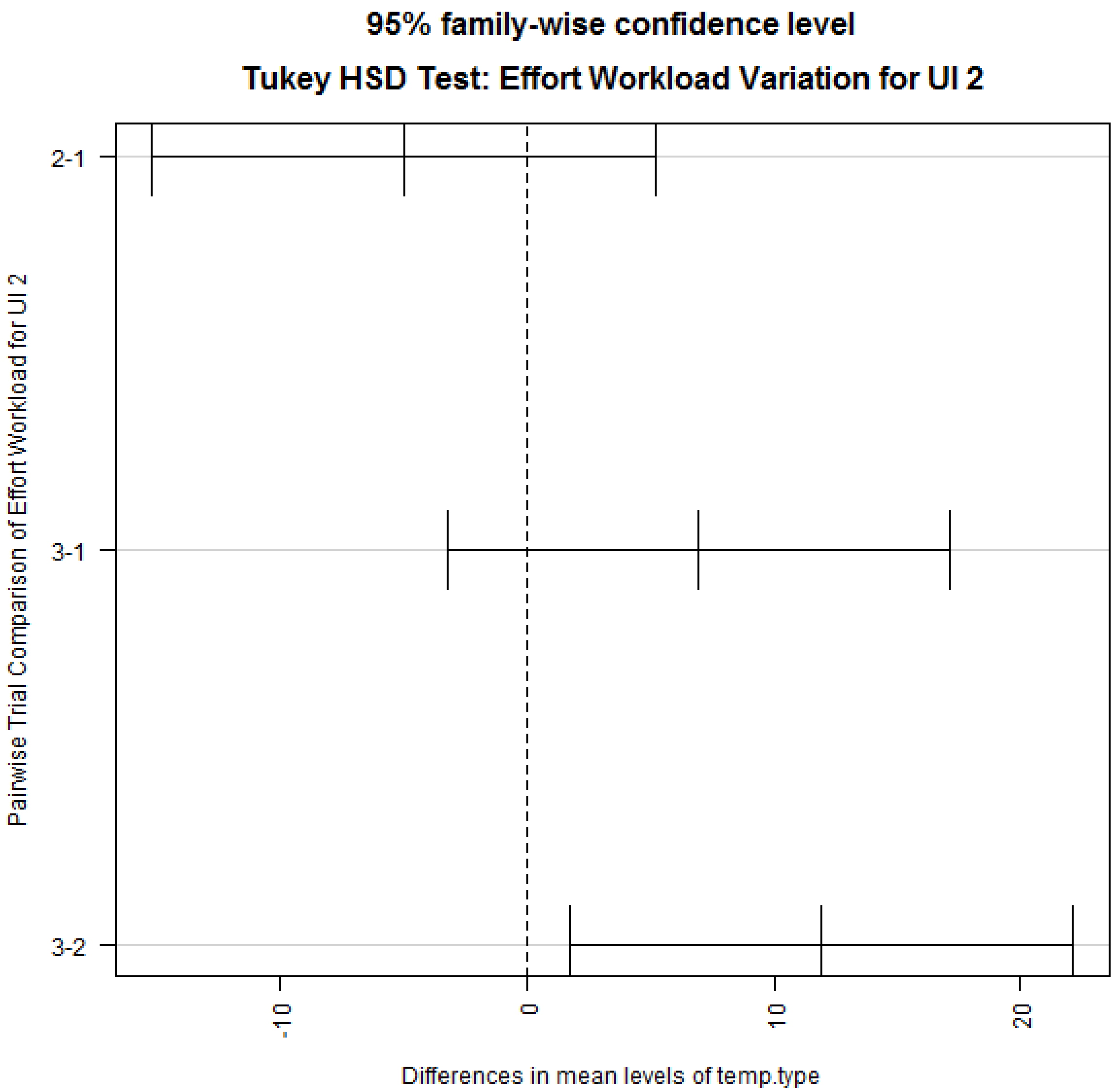




Interface 2



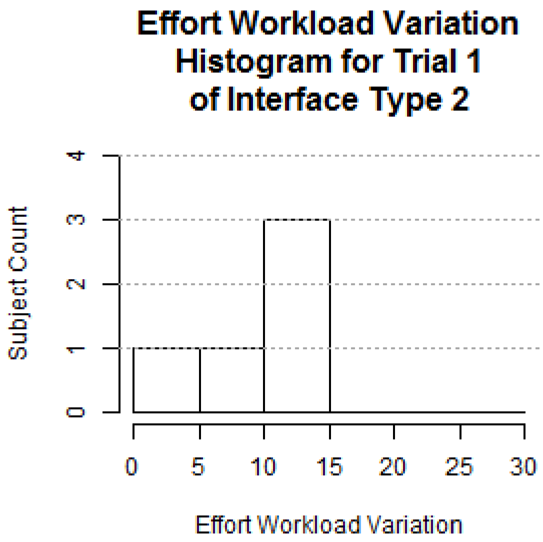
ANOVA: Interface 2 Effort Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	359.1	179.56	4.903	0.028
Residuals	12	439.5	36.63		

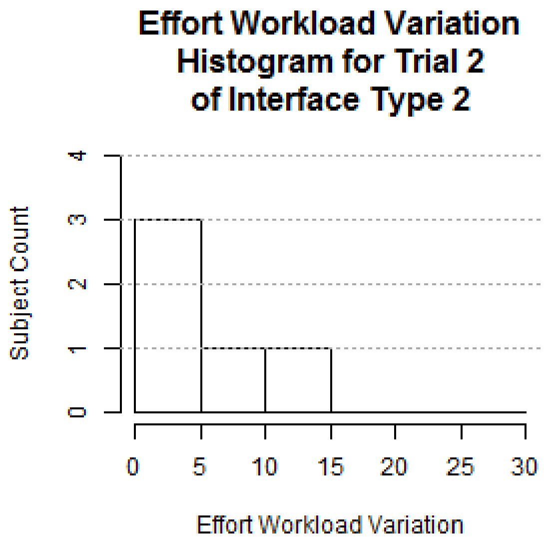


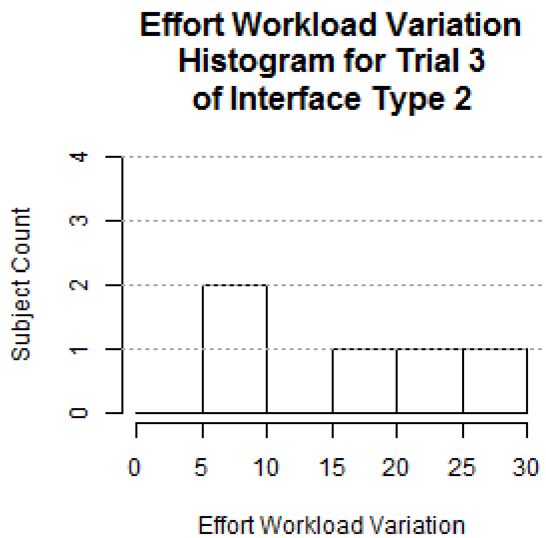
Interface 2 Effort Workload Score vs. Interface Order - Friedman Test	
X^2	3.263
p	0.196
DoF	2.000

Interface 2 Effort Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	9.000	1.000	1.000
Z	1.361	-1.753	-1.753
p	0.250	0.125	0.125
R	0.227	-0.292	-0.292

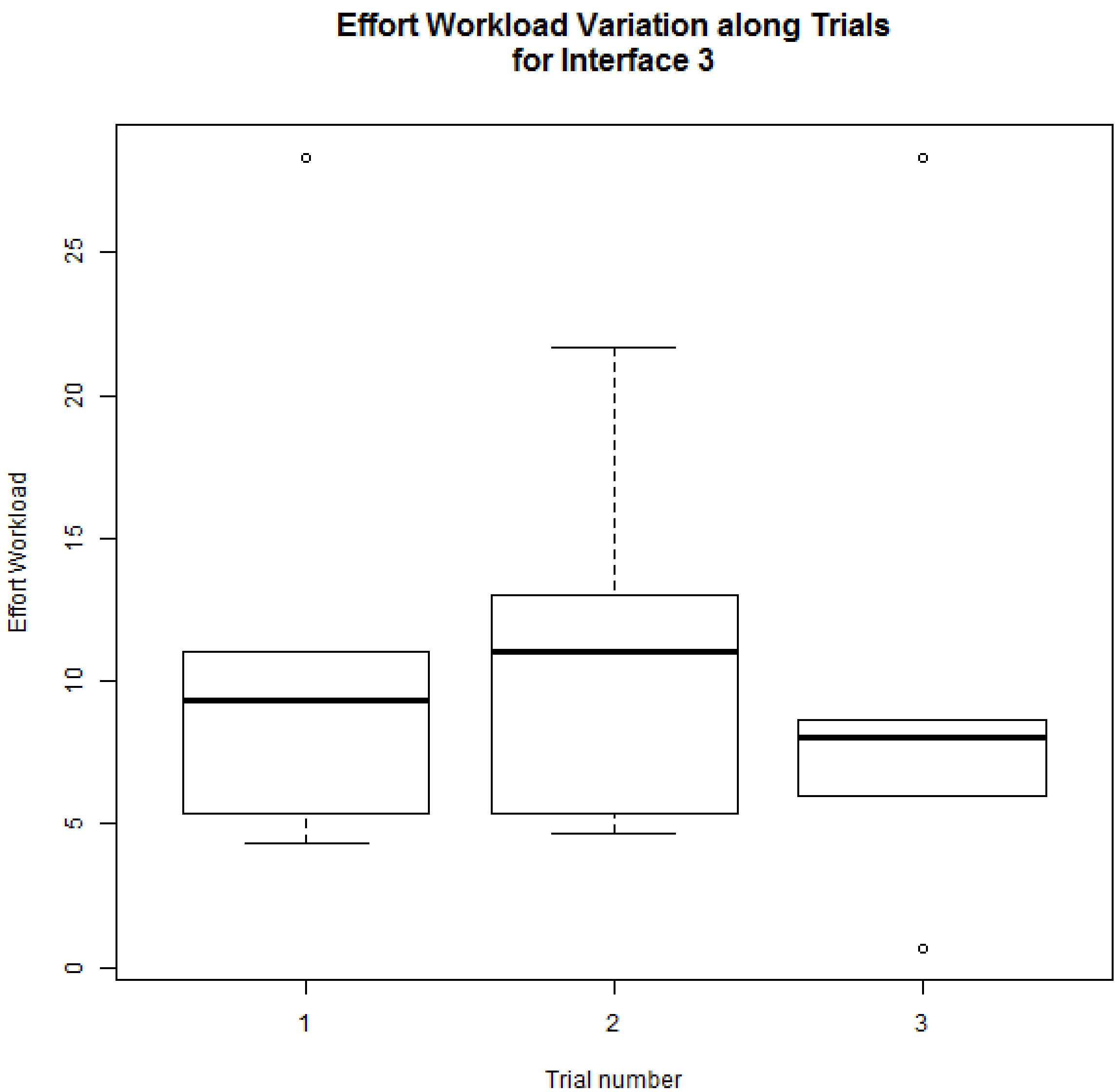
Interface 2 Effort Workload Score vs. Interface Order Summary			
Interface #	*Mean*	*Std. Dev.*	*Median*
1	10.400	4.065	13.000
2	5.400	5.756	2.000
3	17.333	7.760	17.333







Interface 3

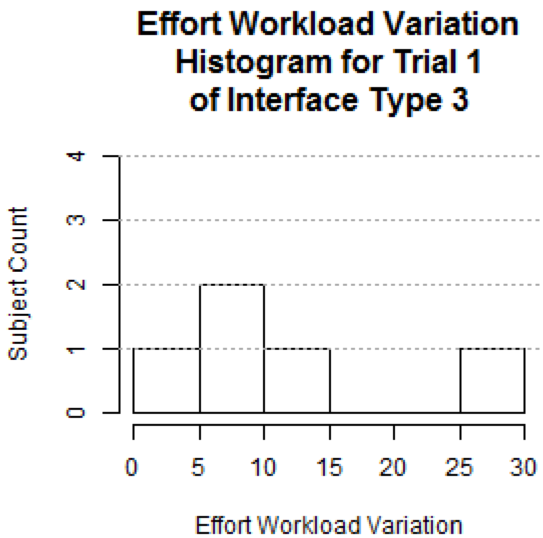


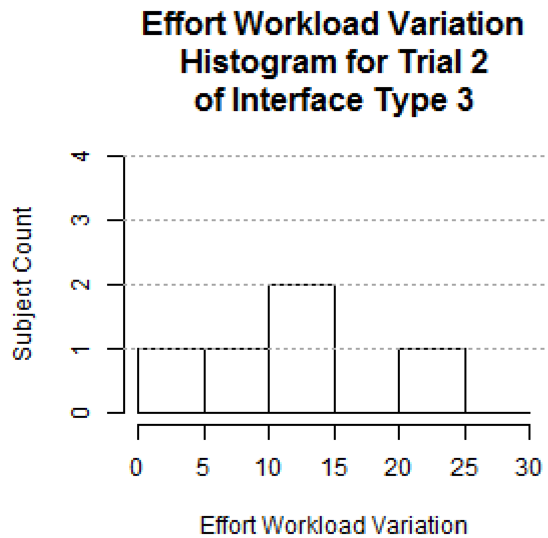
ANOVA: Interface 3 Effort Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	4.5	2.25	0.027	0.974
Residuals	12	1011.9	84.33		

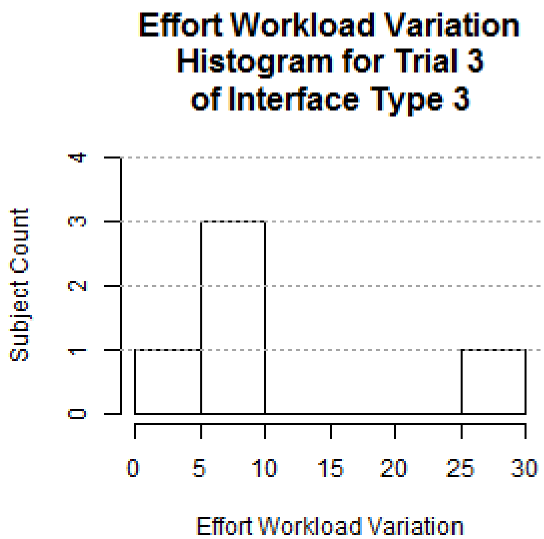
Interface 3 Effort Workload Score vs. Interface Order - Friedman Test	
X^2	0.000
p	1.000
DoF	2.000

Interface 3 Effort Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	6.000	6.000	9.000
Z	-0.405	-0.405	0.405
p	0.812	0.812	0.812
R	-0.067	-0.067	0.067

Interface 3 Effort Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	11.667	9.715	9.333
2	11.133	6.890	11.000
3	10.333	10.541	8.000

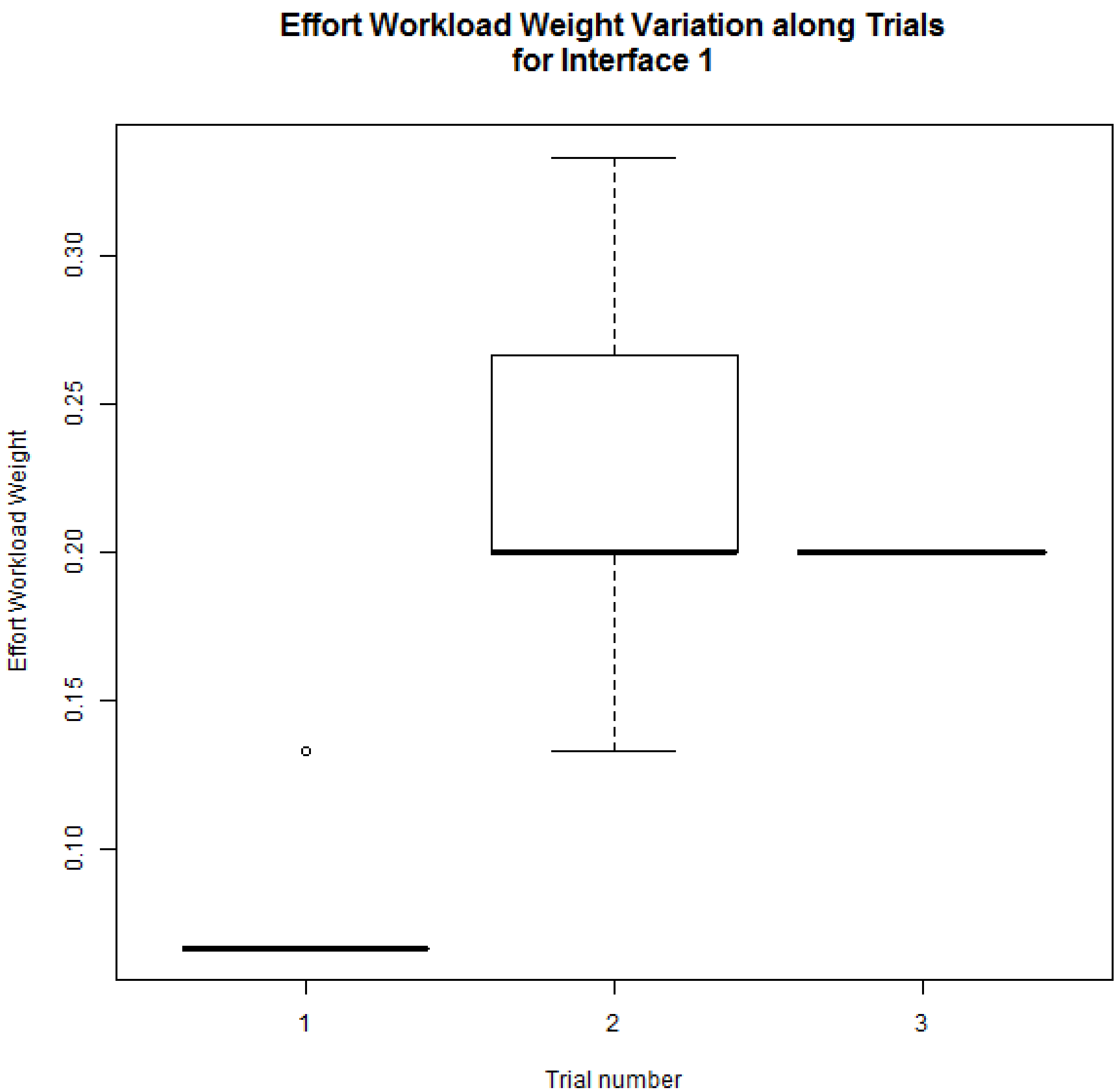




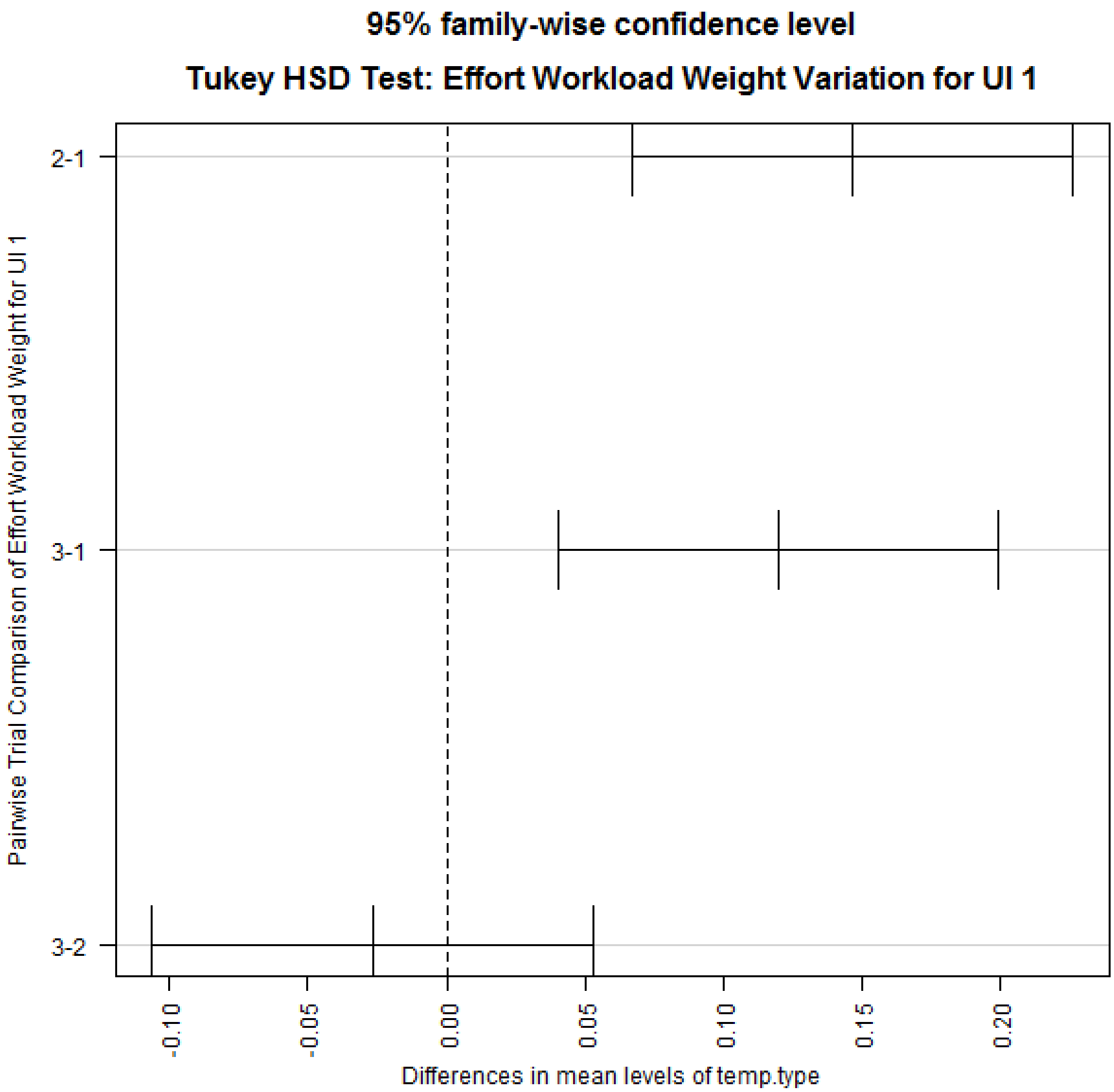


C.2.13.5.4 Interface Order Effect on Effort Workload Weight*

Interface 1



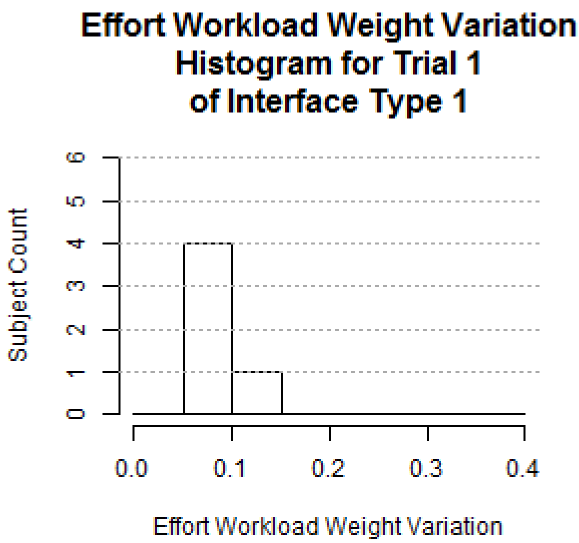
ANOVA: Interface 1 Effort Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.061	0.305	13.73	0.001
Residuals	12	0.027	0.002		

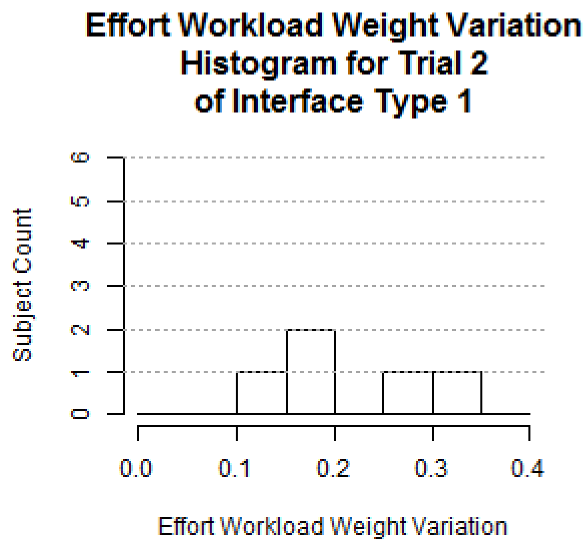


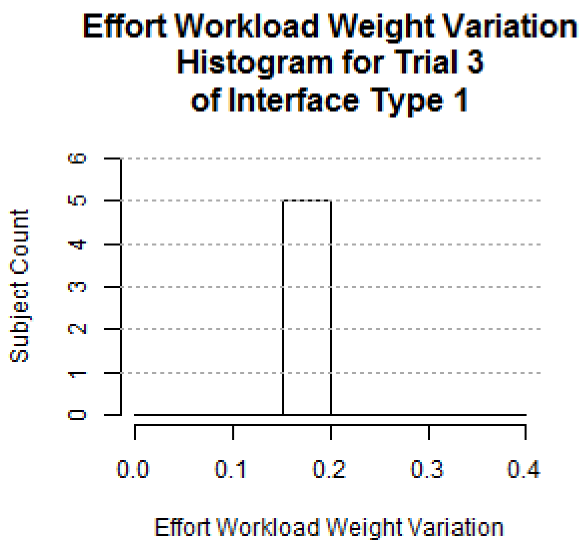
Interface 1 Effort Workload Weight vs. Interface Order - Friedman Test	
X^2	8.444
p	0.015
DoF	2.000

Interface 1 Effort Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	0.000	0.000	4.000
Z	-2.023	-2.121	0.566
p	0.062	0.062	0.750
R	-0.337	-0.354	0.094

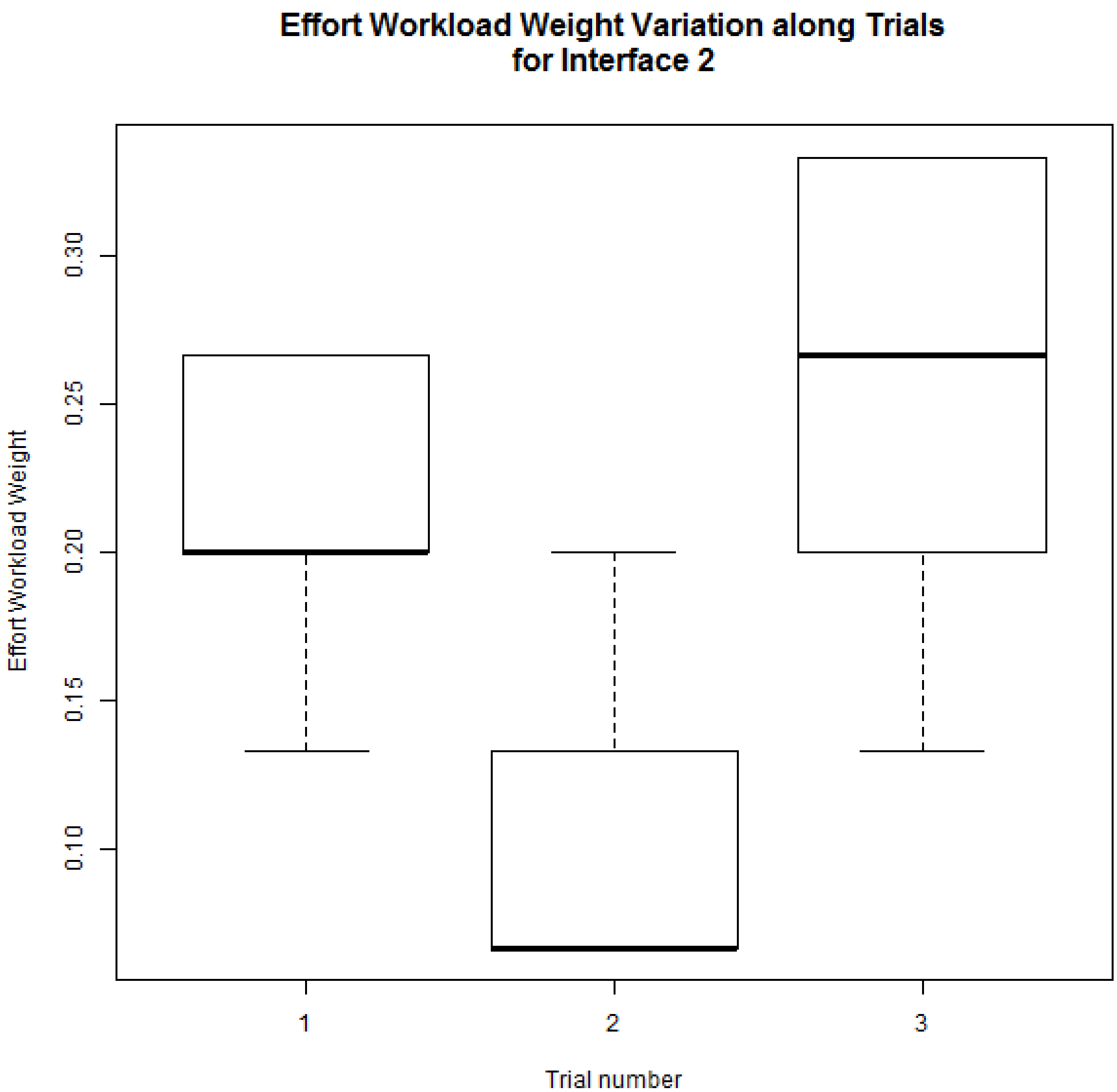
Interface 1 Effort Workload Weight Variation vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.080	0.030	0.067
2	0.227	0.076	0.200
3	0.200	0.000	0.200



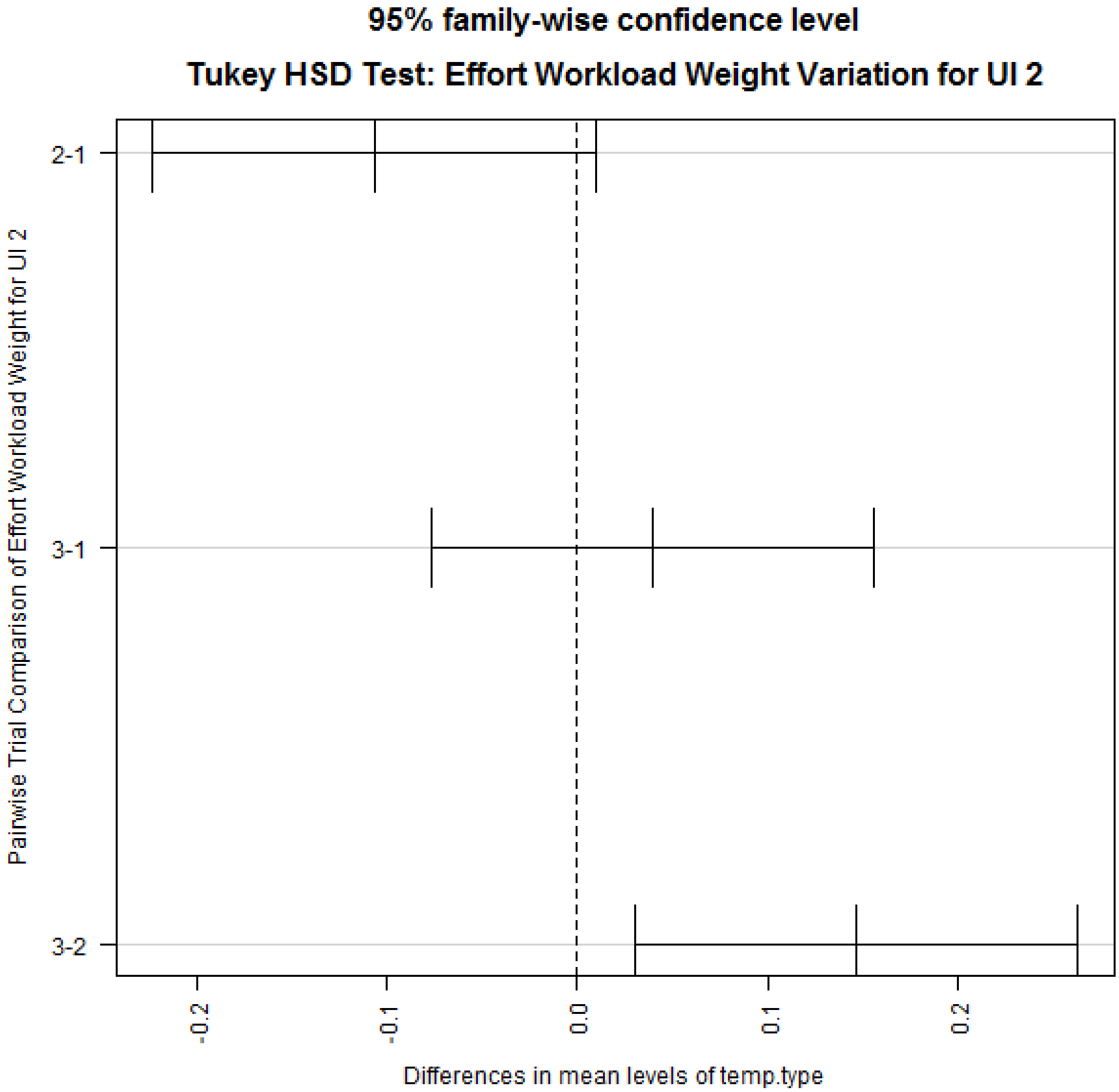




Interface 2



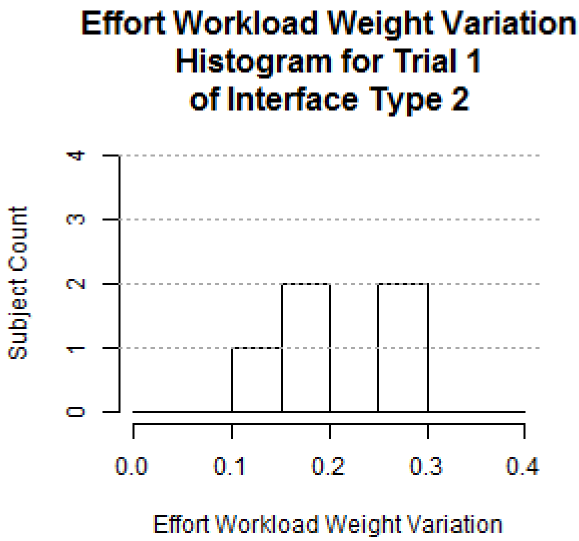
ANOVA: Interface 2 Effort Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.057	0.029	6.062	0.015
Residuals	12	0.057	0.005		

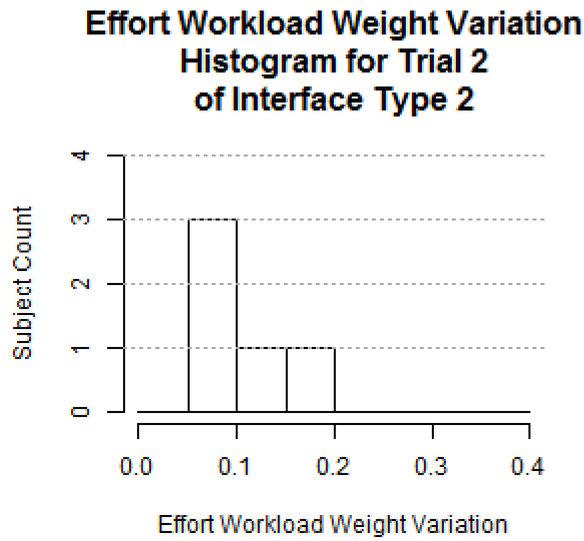


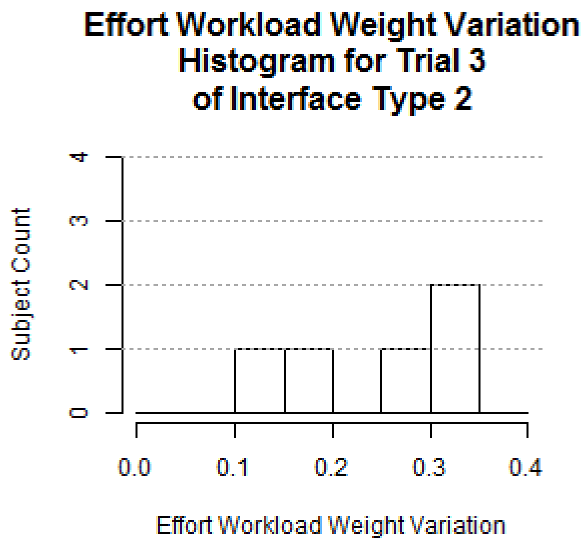
Interface 2 Effort Workload Weight vs. Interface Order - Friedman Test	
X^2	5.444
p	0.066
DoF	2.000

Interface 2 Effort Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	10.000	5.500	0.000
Z	1.914	-0.544	-1.914
p	0.125	0.688	0.125
R	0.319	-0.091	-0.319

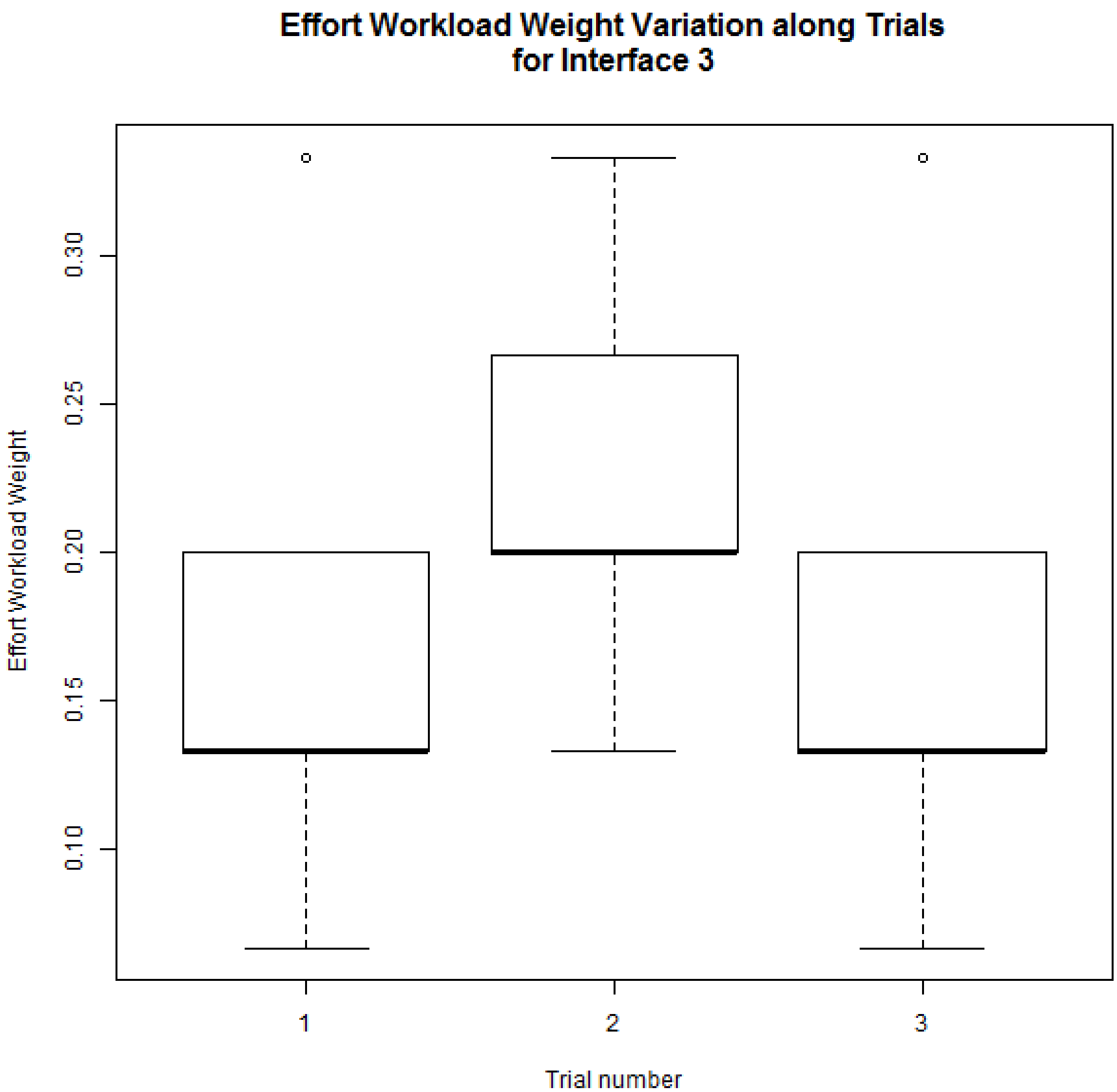
Interface 2 Effort Workload Weight vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.213	0.056	0.200
2	0.107	0.060	0.067
3	0.253	0.087	0.267







Interface 3

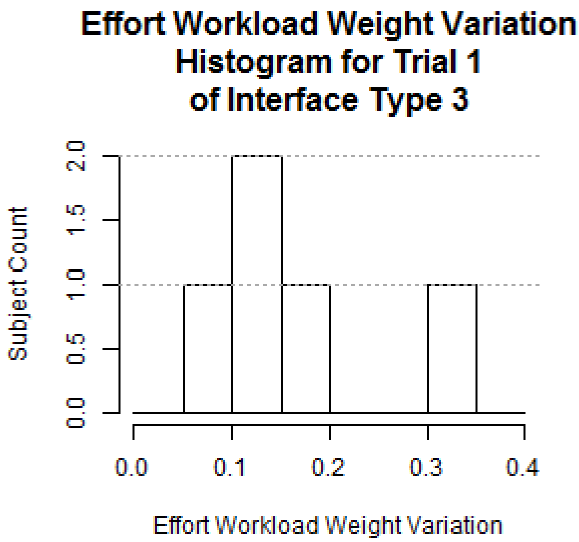


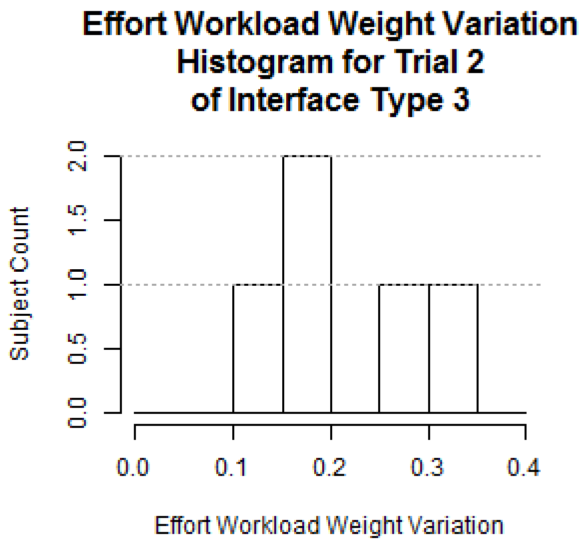
ANOVA: Interface 3 Effort Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.009	0.005	0.542	0.595
Residuals	12	0.105	0.009		

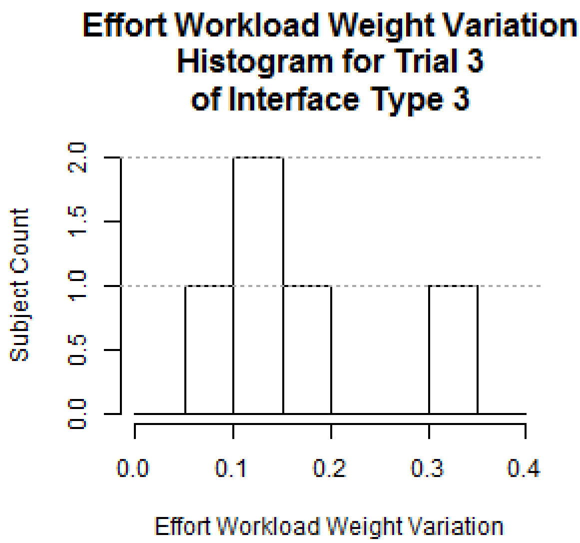
Interface 3 Effort Workload Weight vs. Interface Order - Friedman Test	
X^2	3.000
p	0.223
DoF	2.000

Interface 3 Effort Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	0.000	4.000	5.000
Z	-1.697	-0.544	0.849
p	0.250	0.750	0.500
R	-0.283	-0.091	0.141

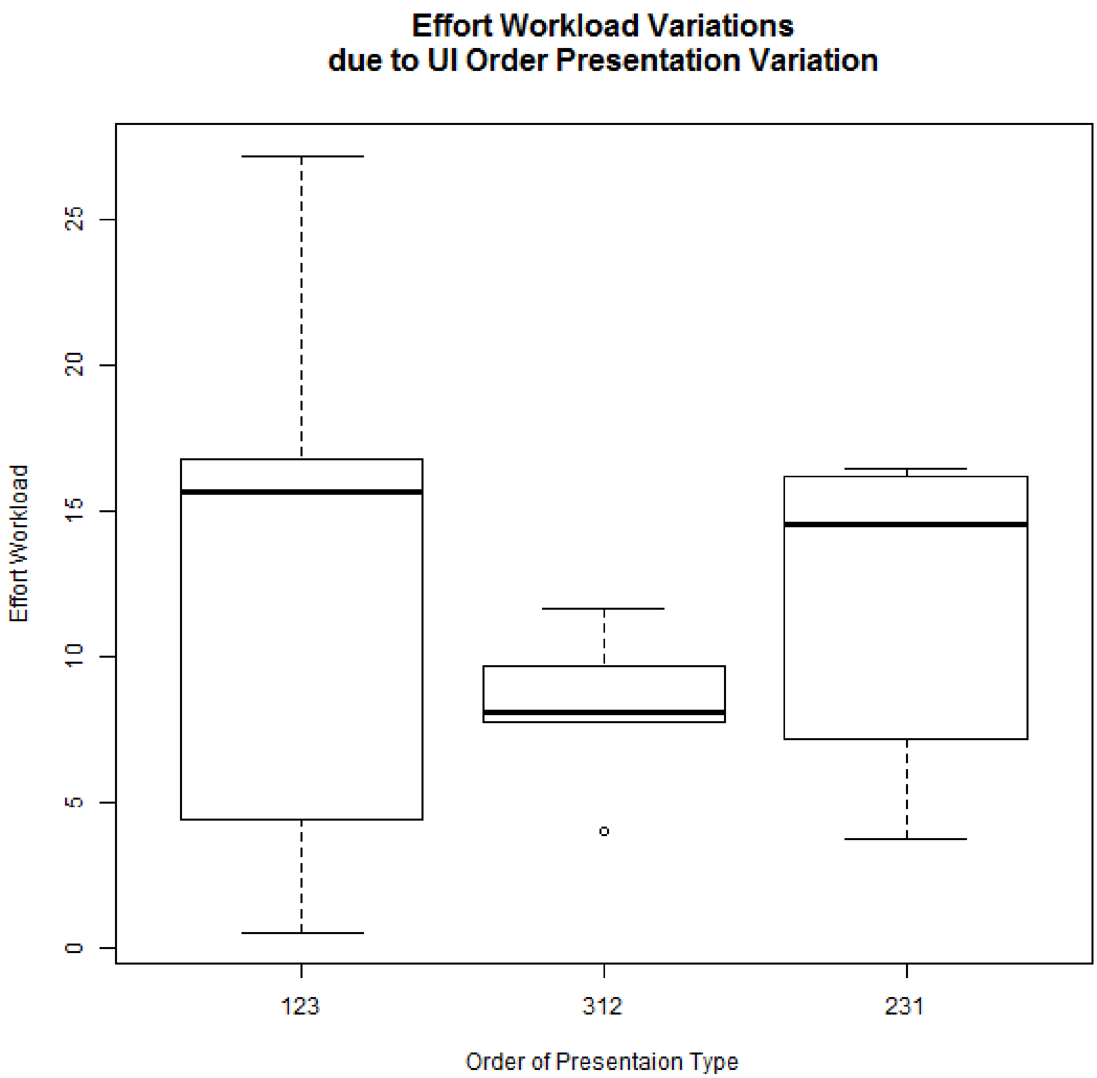
Interface 3 Effort Workload Weight vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.173	0.101	0.133
2	0.227	0.101	0.200
3	0.173	0.101	0.133







C.2.13.5.5 Effort Workload for Groups with Different Interface orders

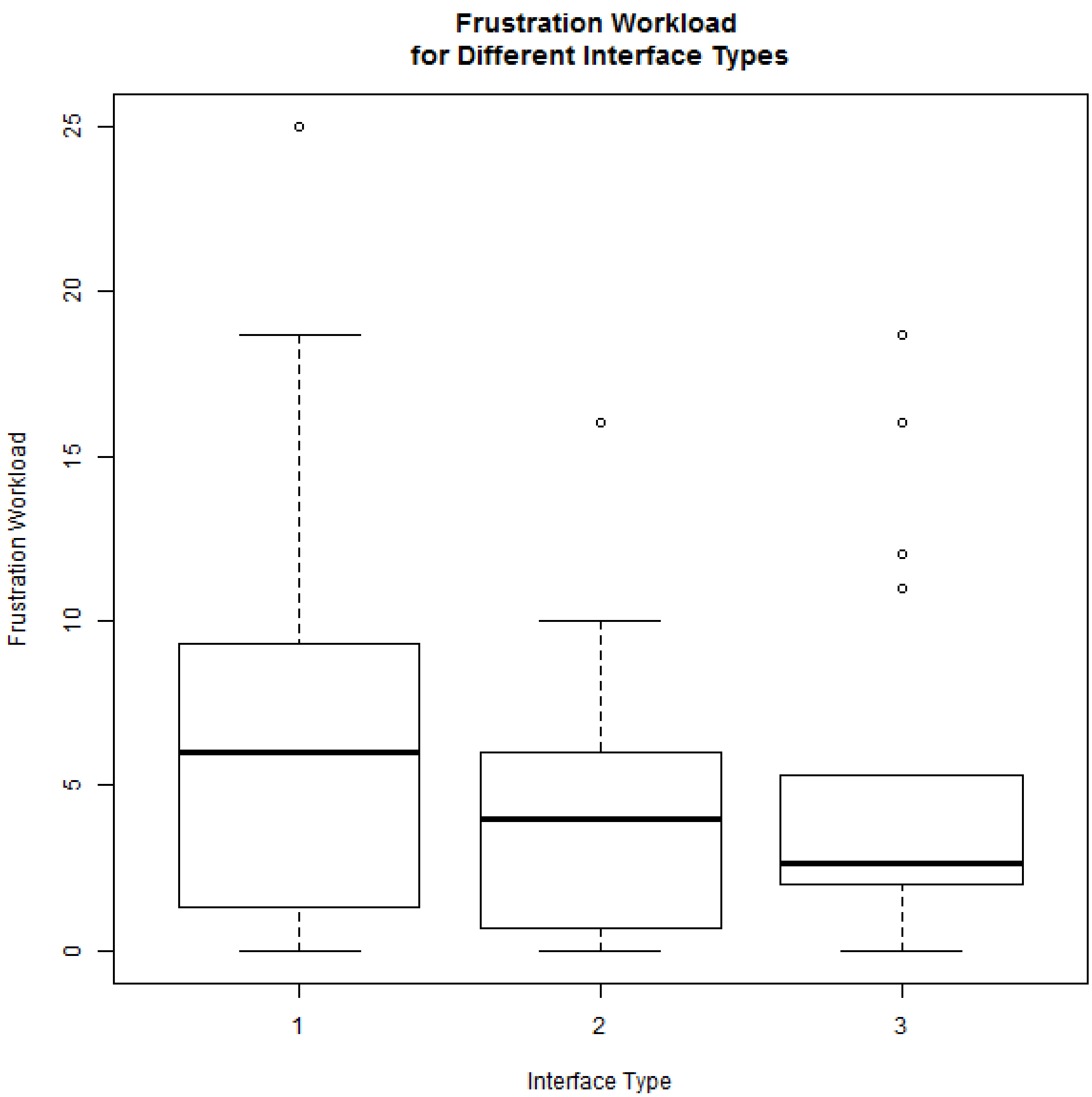


ANOVA: Overall Effort Workload for Subjects with Different Interface Orders					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	58.7	29.34	0.57	0.58
Residuals	12	617.6	51.47		

Overall Effort Workload vs. Subjects with Different Interface Orders Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	12.933	10.626	15.667
2	8.244	1.828	8.111
3	1.644	5.786	14.555

C.2.13.6 Frustration Workload Evaluation

C.2.13.6.1 Weighted Scores

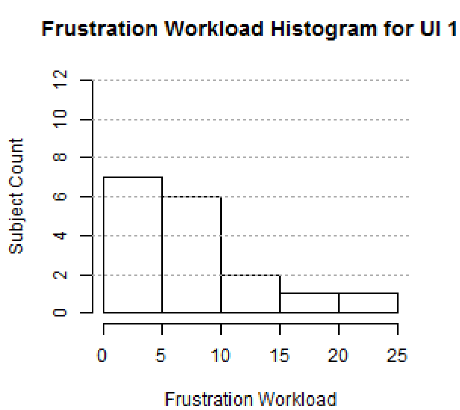


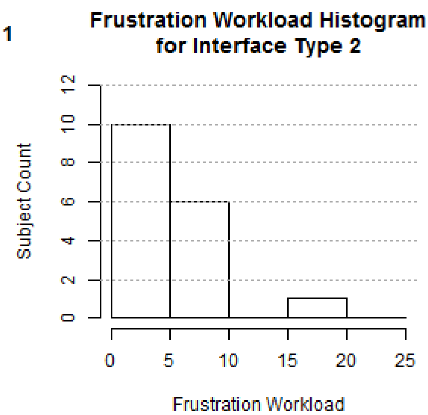
ANOVA: Frustration Workload Weighted Scores for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	64.4	32.18	0.955	0.392
Residuals	48	1618.2	33.71		

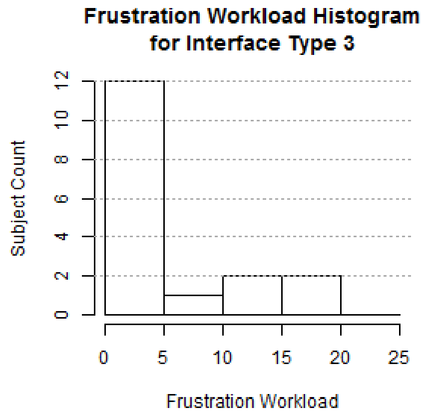
Frustration Workload Weighted Scores vs. Interface Used - Friedman Test	
X^2	2.821
p	0.244
DoF	2.000

Frustration Workload Weighted Scores vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	72.000	73.000	44.000
Z	1.212	1.402	0.024
p	0.242	0.173	1.000
R	0.202	0.234	0.004

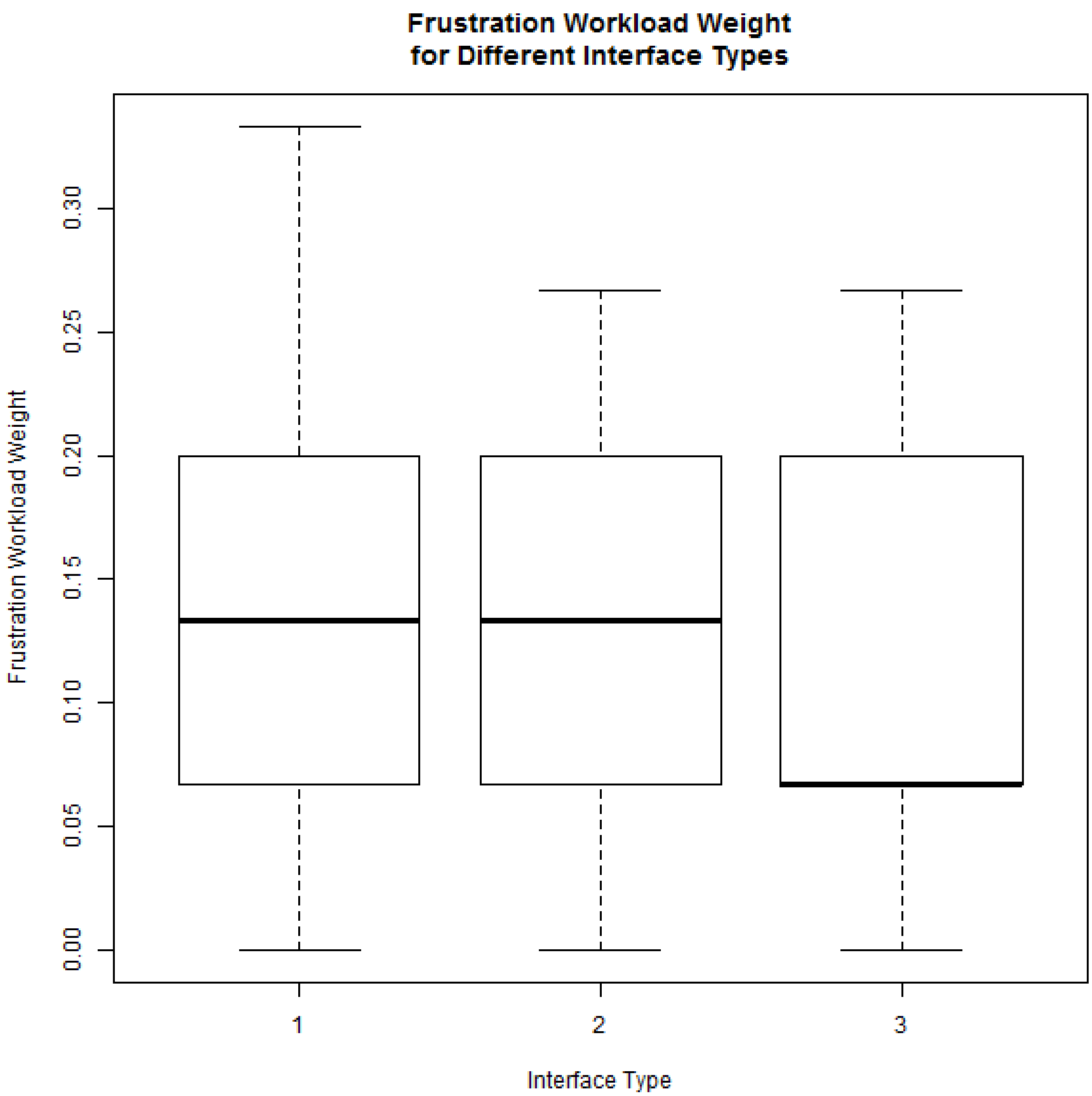
Frustration Workload Weighted Scores vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	7.078	7.002	6.000
2	4.412	4.374	4.000
3	5.157	5.743	2.667







C.2.13.6.2 Weight

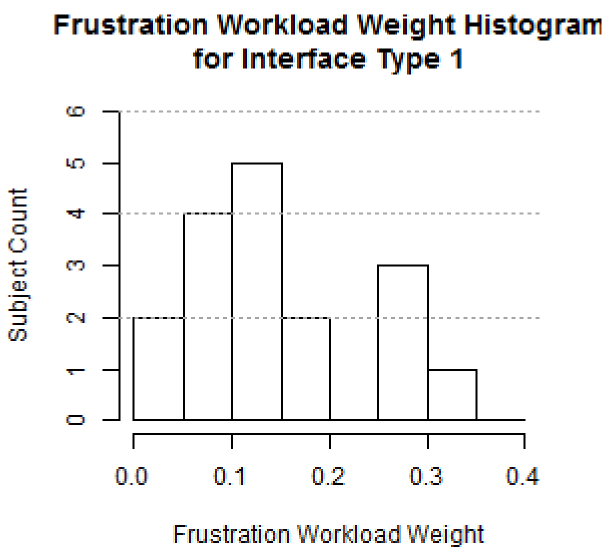


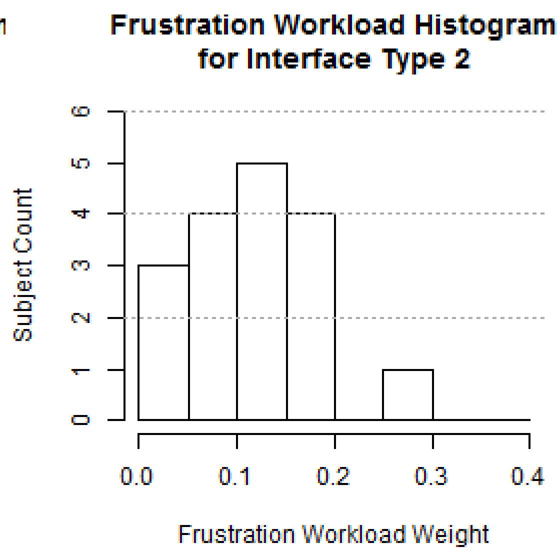
ANOVA: Frustration Workload Weight for Groups With Different Interface Types					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.012	0.006	0.775	0.467
Residuals	48	0.362	0.007		

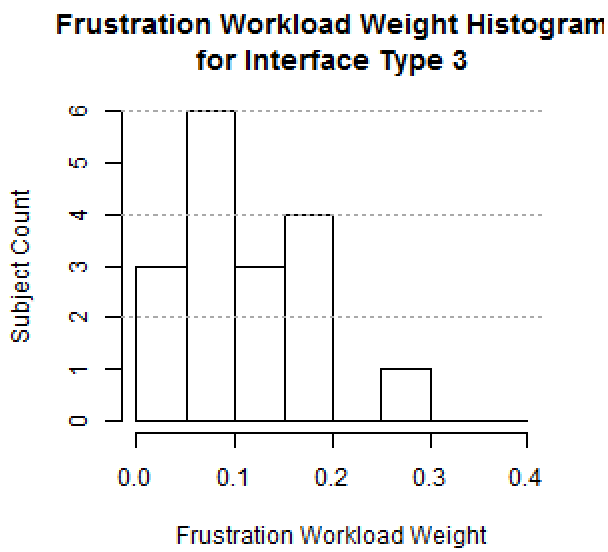
Frustration Workload Weight vs. Interface Used - Friedman Test	
X^2	2.667
p	0.264
DoF	2.000

Frustration Workload Weight vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	50.000	53.000	30.000
Z	0.770	1.397	0.469
p	0.462	0.173	0.678
R	0.128	0.233	0.078

Frustration Workload Weight vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.145	0.098	0.133
2	0.118	0.080	0.133
3	0.110	0.081	0.067

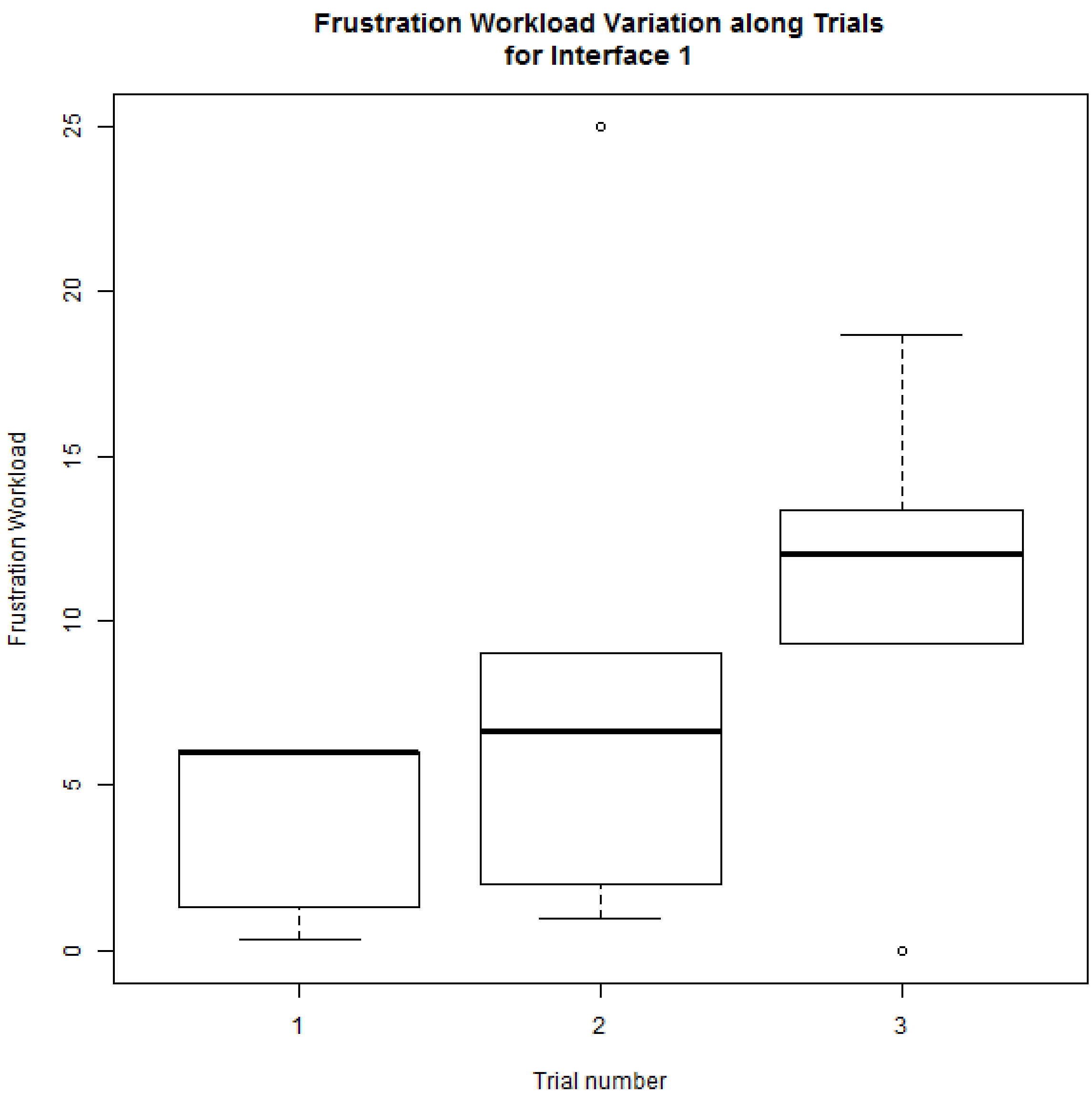






C.2.13.6.3 Interface Order Effect on Frustration Workload Score*

Interface 1

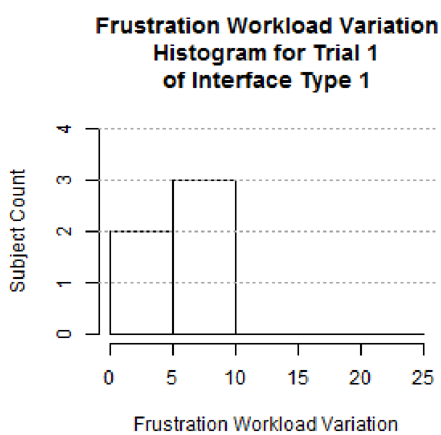


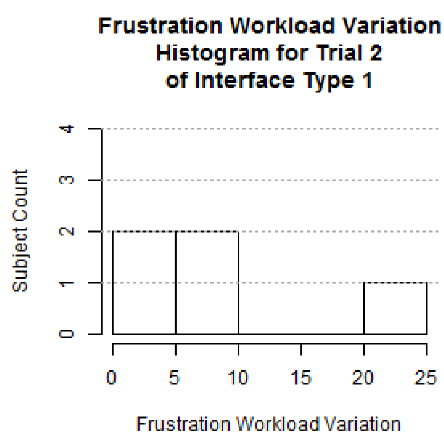
ANOVA: Interface 1 Frustration Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	120.2	60.10	1.212	0.332
Residuals	12	595.1	49.59		

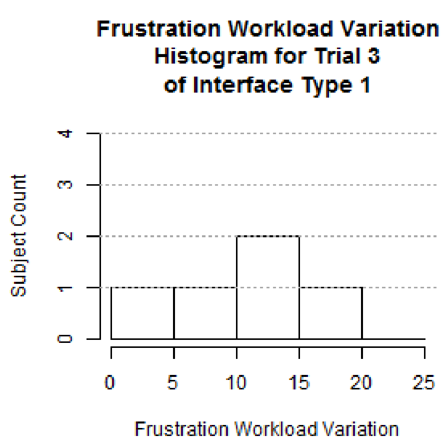
Interface 1 Frustration Workload Score vs. Interface Order - Friedman Test	
X^2	2.800
p	0.247
DoF	2.000

Interface 1 Frustration Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	4.000	2.000	7.000
Z	-0.944	-1.483	-0.135
p	0.438	0.188	1.000
R	-0.157	0-0.247	-0.022

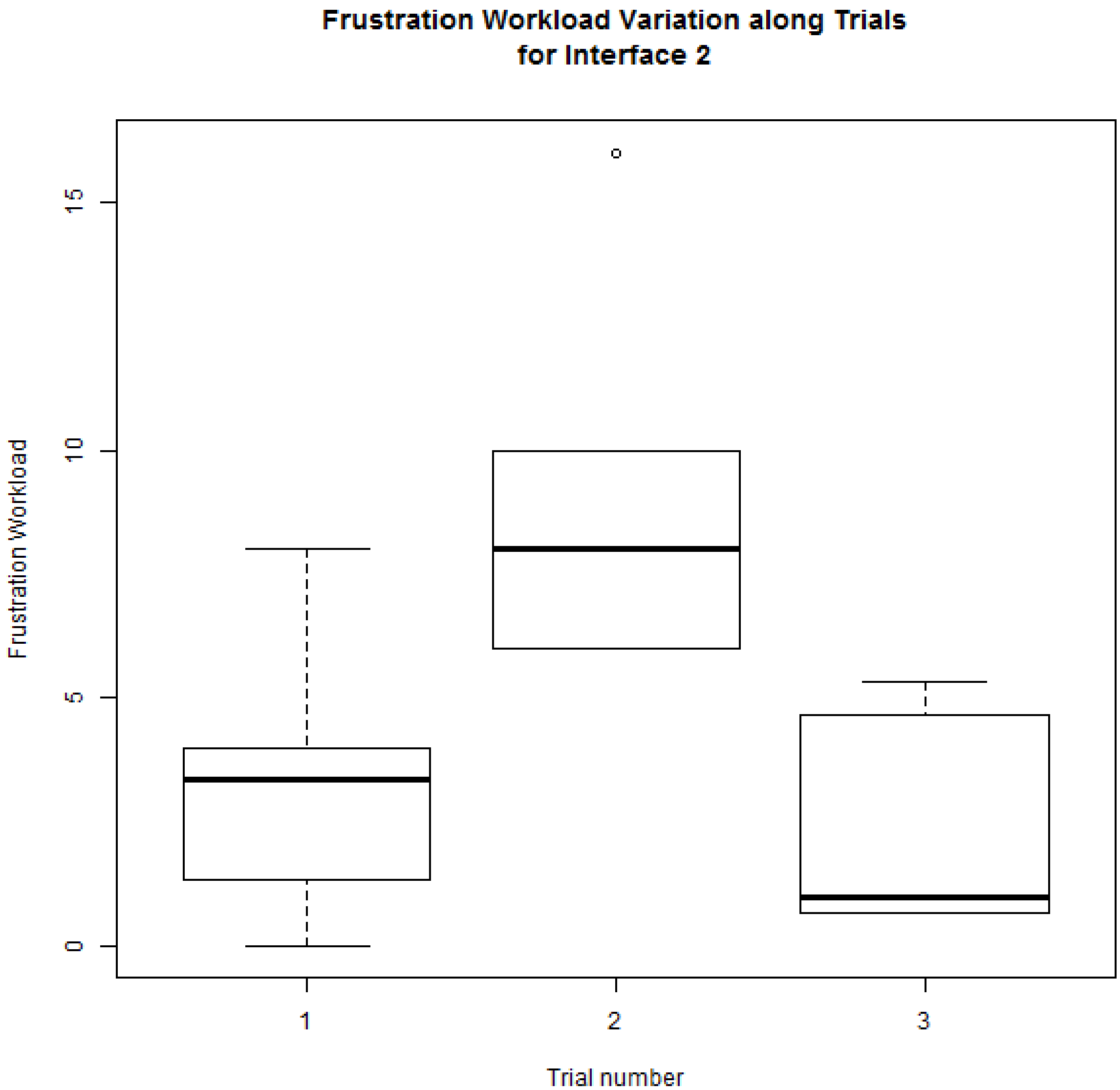
Interface 1 Frustration Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	3.933	2.852	6.000
2	8.733	9.671	6.667
3	10.667	6.864	12.000



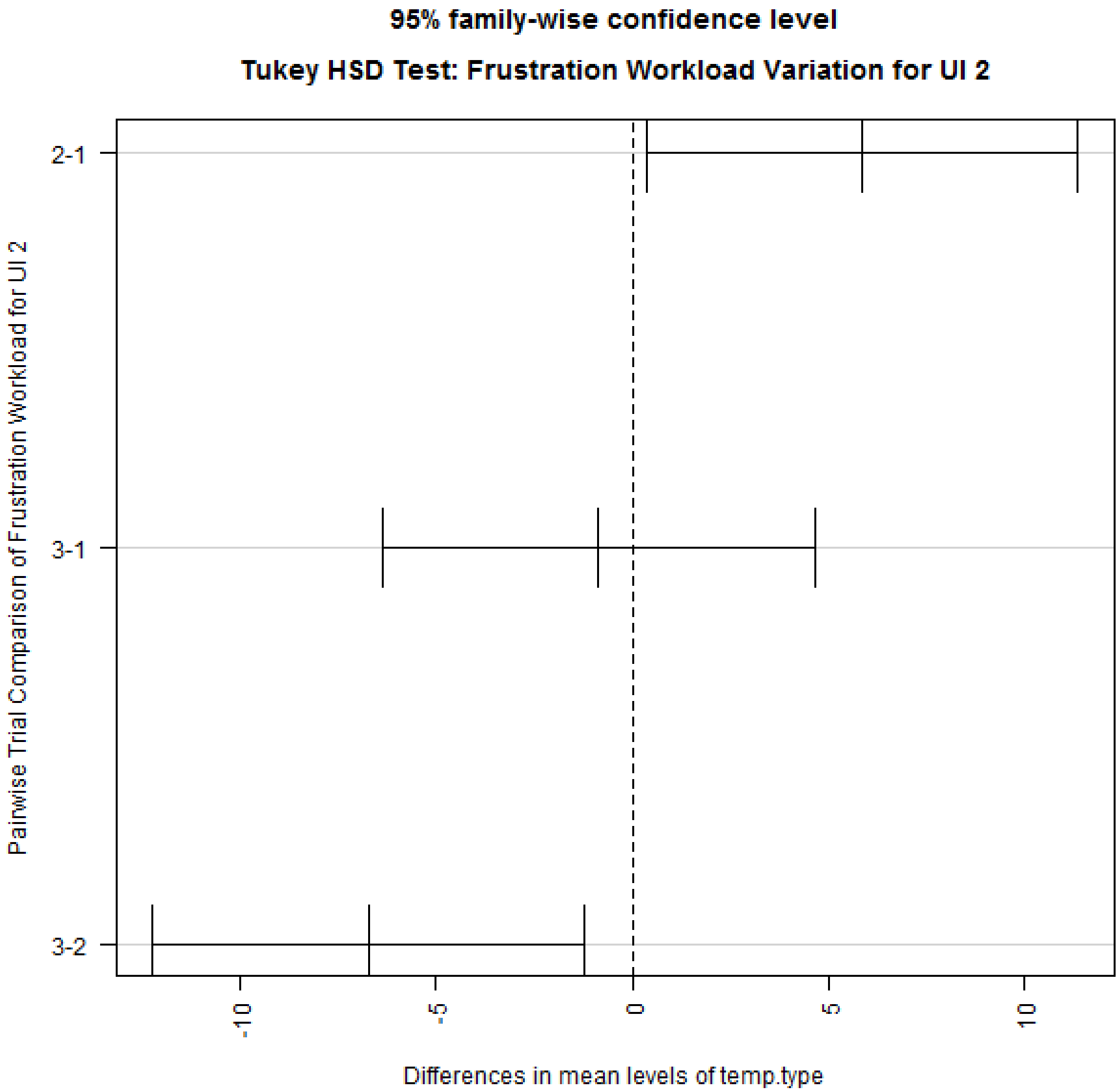




Interface 2



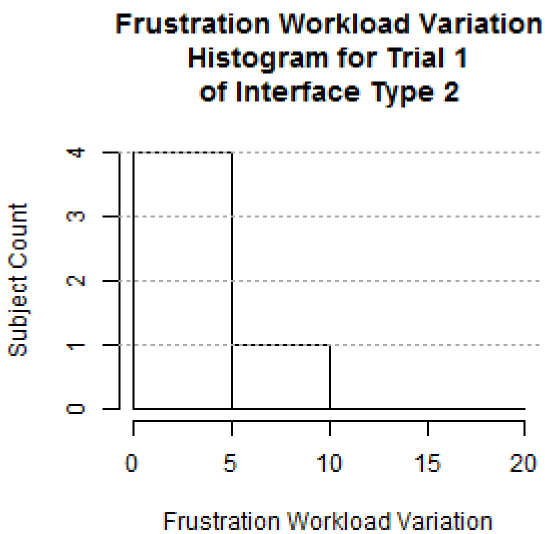
ANOVA: Interface 2 Frustration Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	134.2	67.09	6.298	0.013
Residuals	12	127.8	10.65		

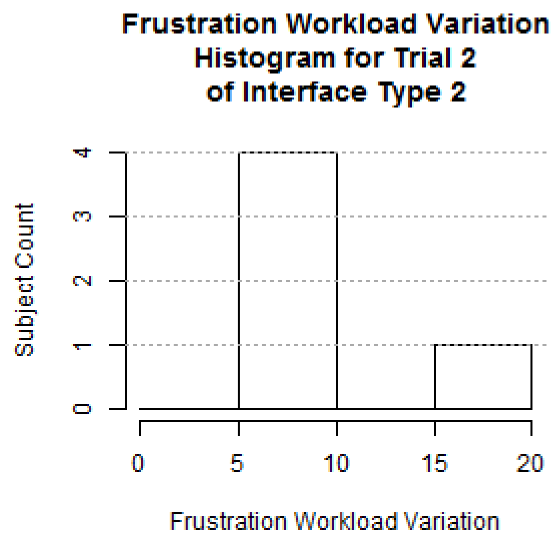


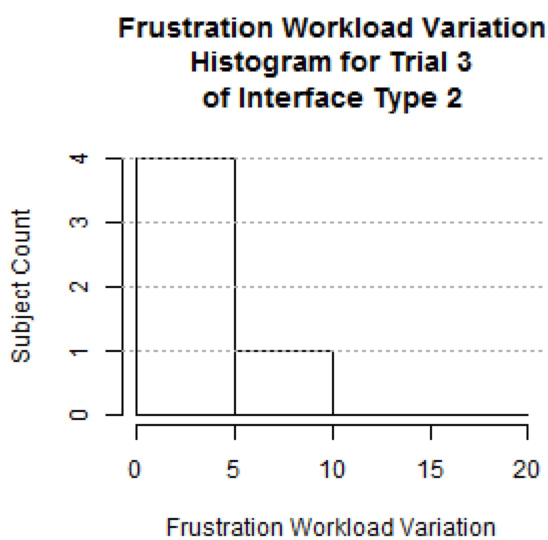
Interface 2 Frustration Workload Score vs. Interface Order - Friedman Test	
X^2	4.800
p	0.091
DoF	2.000

Interface 2 Frustration Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	1.000	9.000	15.000
Z	-1.753	0.405	2.023
p	0.125	0.812	0.062
R	-0.292	0.067	0.337

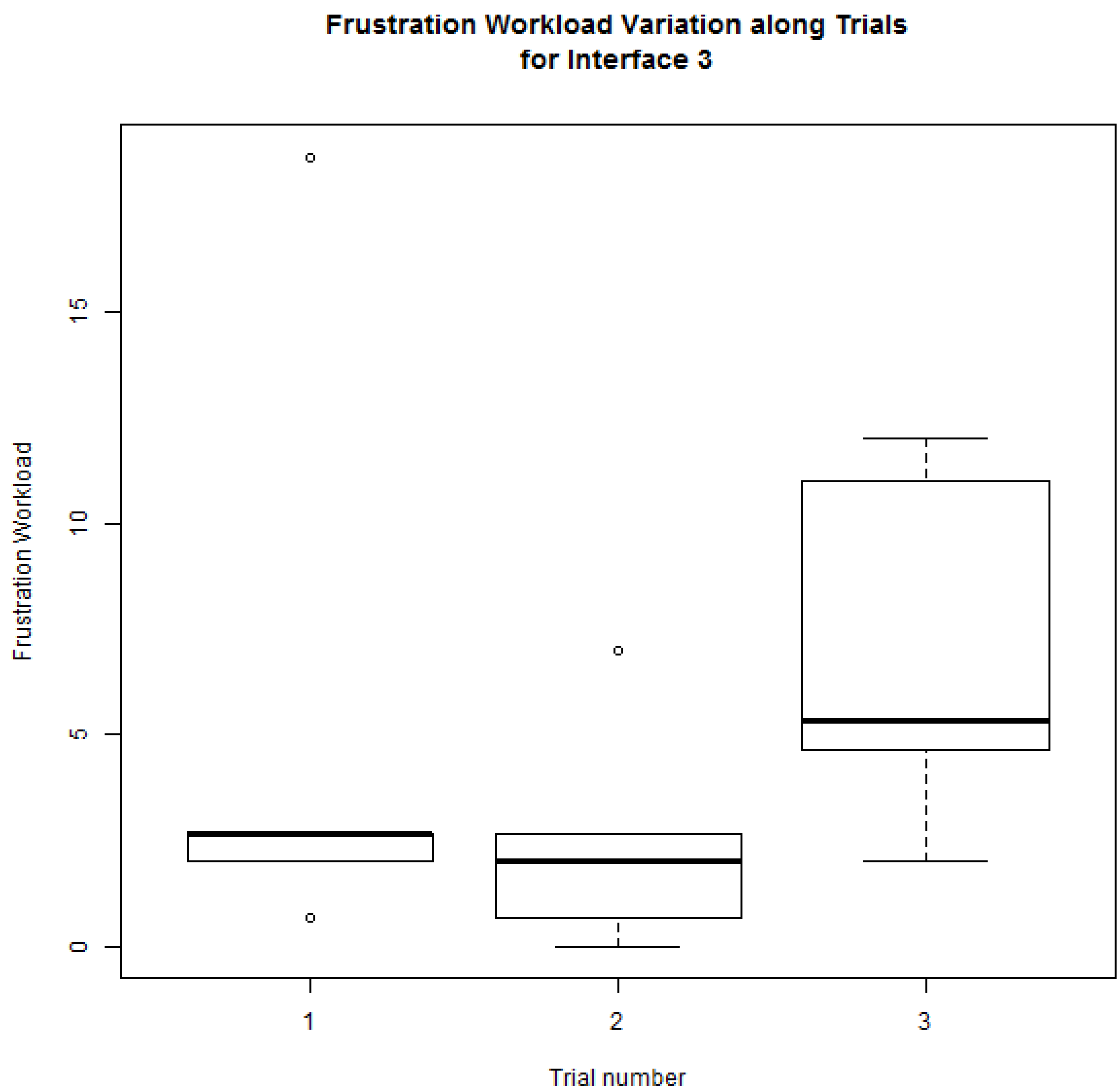
Interface 2 Frustration Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	3.333	3.055	3.333
2	9.200	4.147	8.000
3	2.467	2.329	1.000







Interface 3

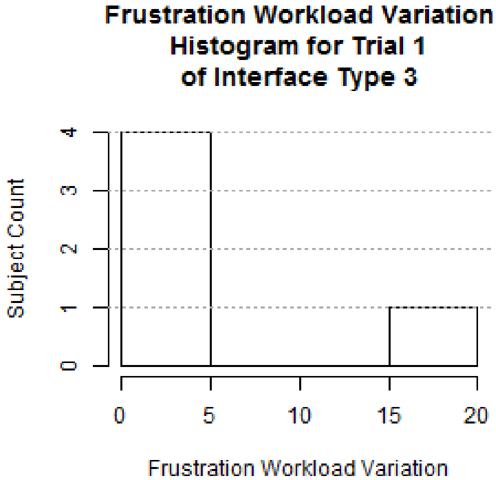


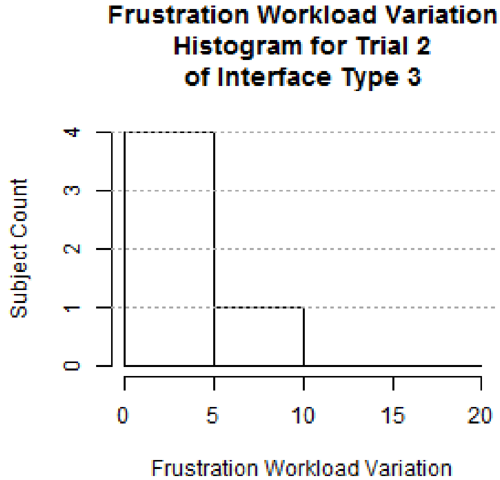
ANOVA: Interface 3 Frustration Workload Score in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	52.6	26.29	0.958	0.411
Residuals	12	329.2	27.44		

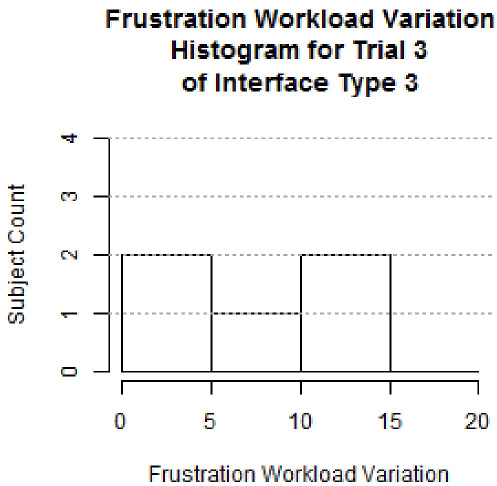
Interface 3 Frustration Workload Score vs. Interface Order - Friedman Test	
X^2	2.211
p	0.331
DoF	2.000

Interface 3 Frustration Workload Score vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	12.000	3.000	1.000
Z	1.214	-0.816	-0.753
p	0.312	0.500	0.125
R	0.202	-0.136	-0.292

Interface 3 Frustration Workload Score vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	5.333	7.498	2.667
2	2.467	2.745	2.000
3	7.000	4.308	5.333

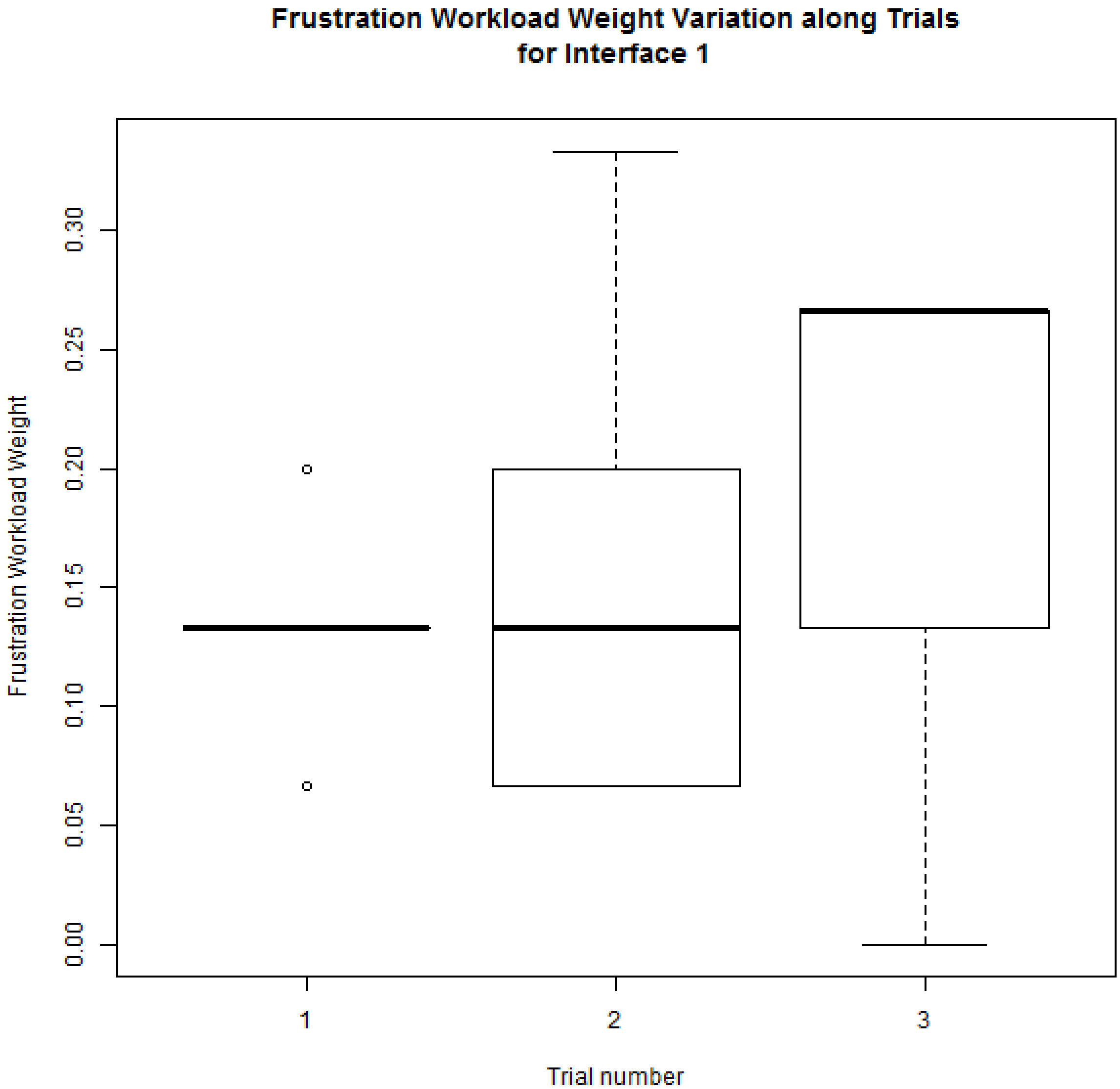






C.2.13.6.4 Interface Order Effect on Frustration Workload Weight*

Interface 1

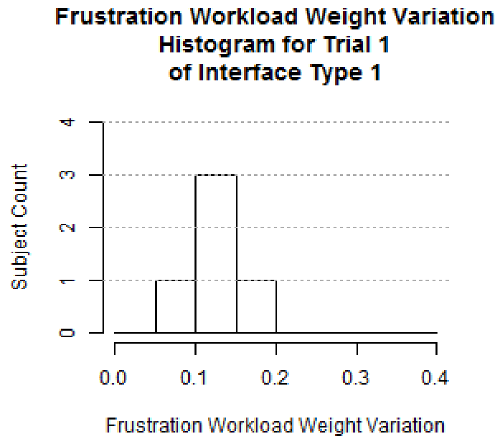


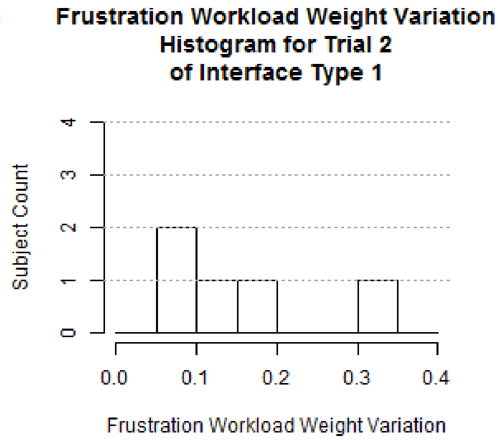
ANOVA: Interface 1 Frustration Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.007	0.003	0.369	0.699
Residuals	12	0.115	0.010		

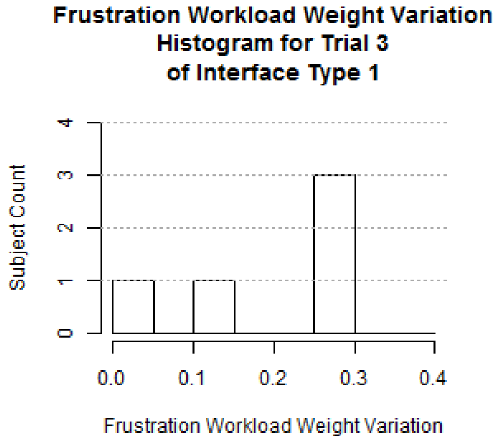
Interface 1 Frustration Workload Weight vs. Interface Order - Friedman Test	
X^2	0.316
p	0.854
DoF	2.000

Interface 1 Frustration Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	4.000	3.000	5.000
Z	-0.272	-1.219	-0.674
p	0.875	0.250	0.625
R	-0.045	-0.203	-0.112

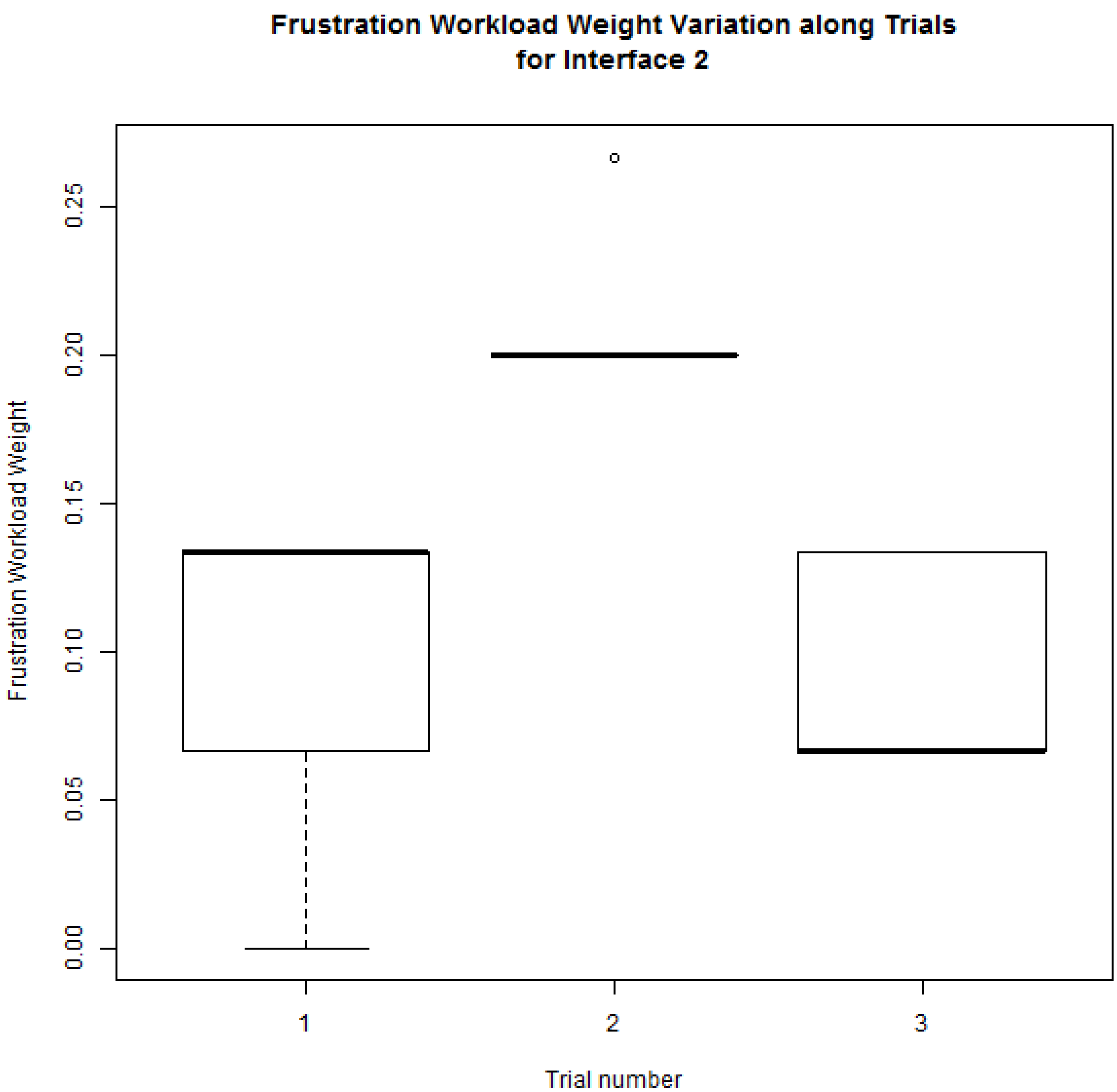
Interface 1 Frustration Workload Weight Variation vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.133	0.047	0.133
2	0.160	0.112	0.133
3	0.187	0.119	0.267



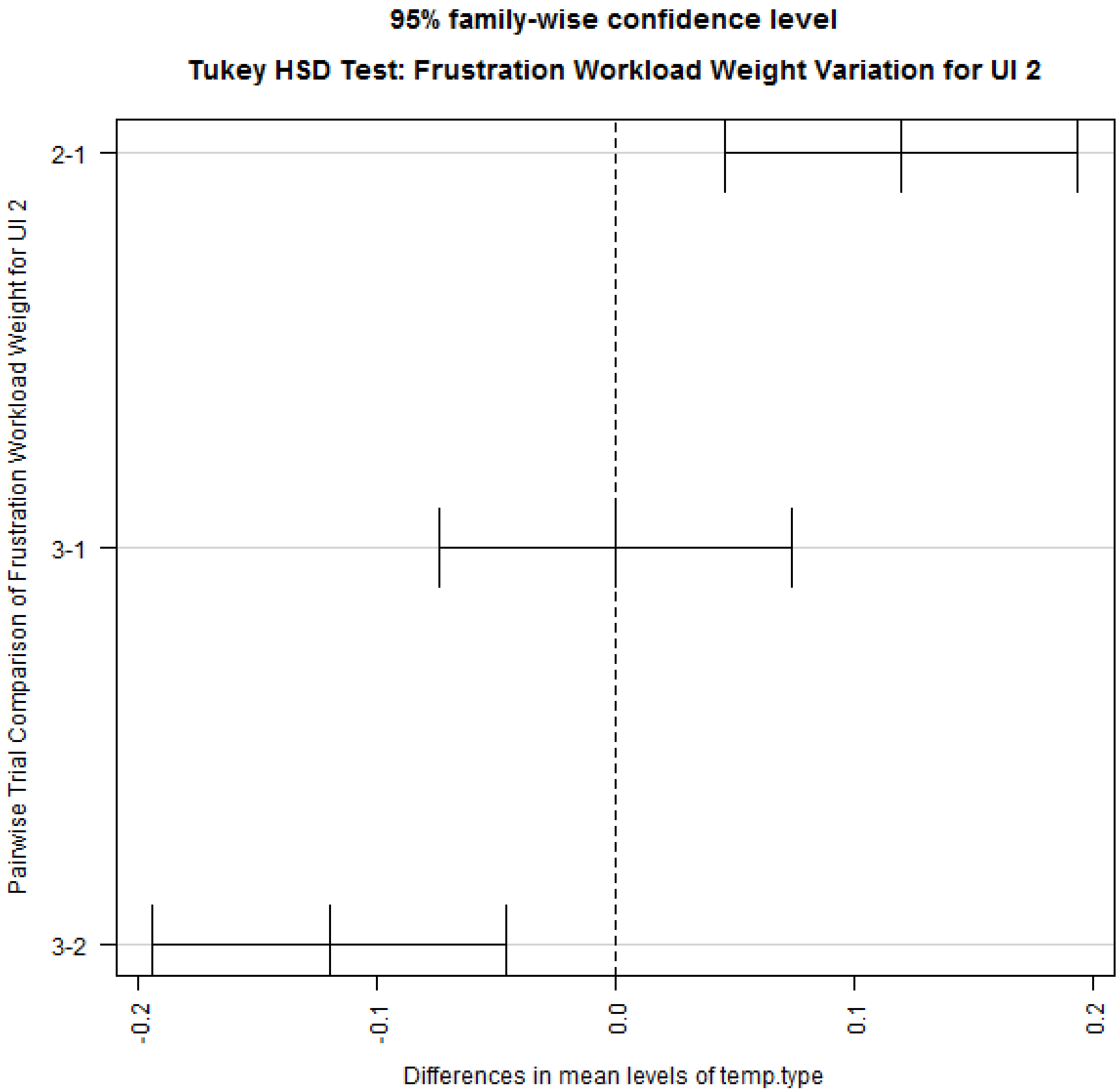




Interface 2



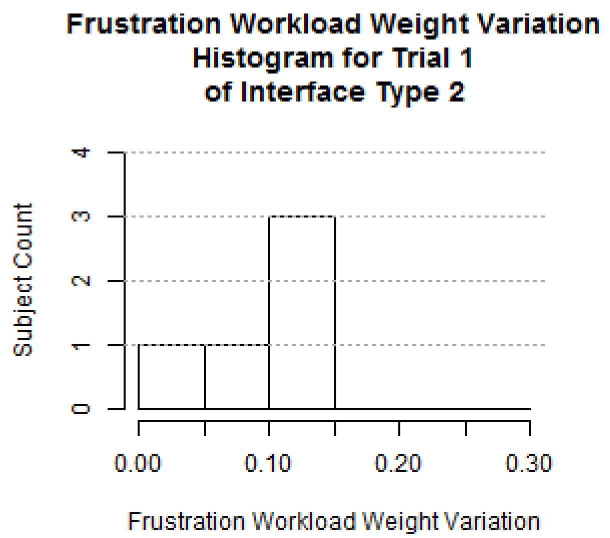
ANOVA: Interface 2 Frustration Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.048	0.024	12.46	0.001
Residuals	12	0.023	0.002		

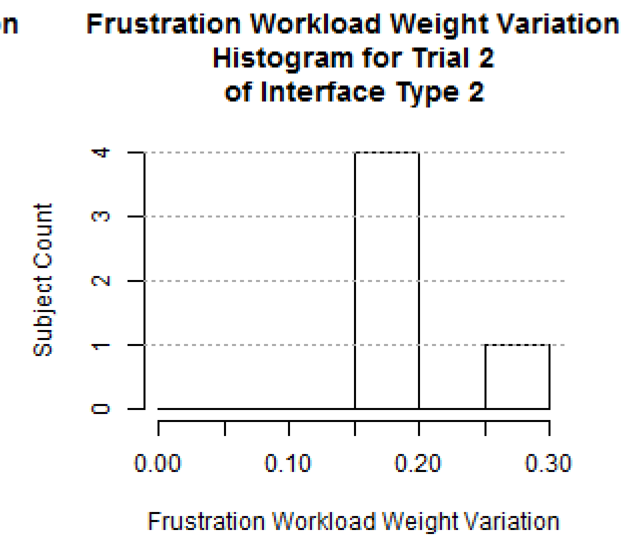


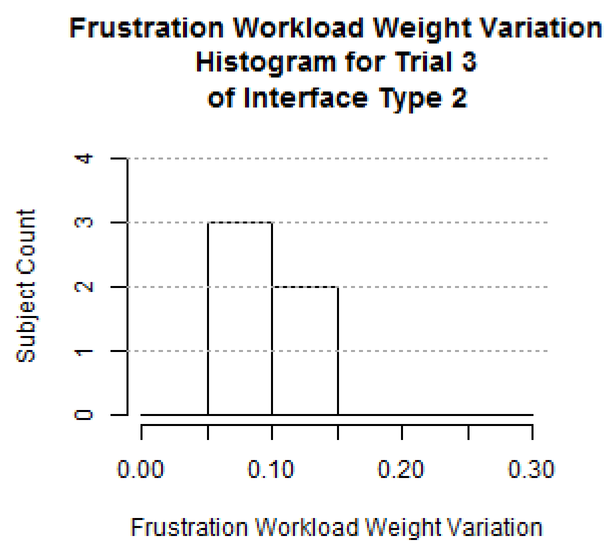
Interface 2 Frustration Workload Weight vs. Interface Order - Friedman Test	
X^2	8.824
p	0.012
DoF	2.000

Interface 2 Frustration Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	0.000	1.000	15.000
Z	-2.032	-0.156	2.060
p	0.062	1.000	0.062
R	-0.339	-0.026	0.343

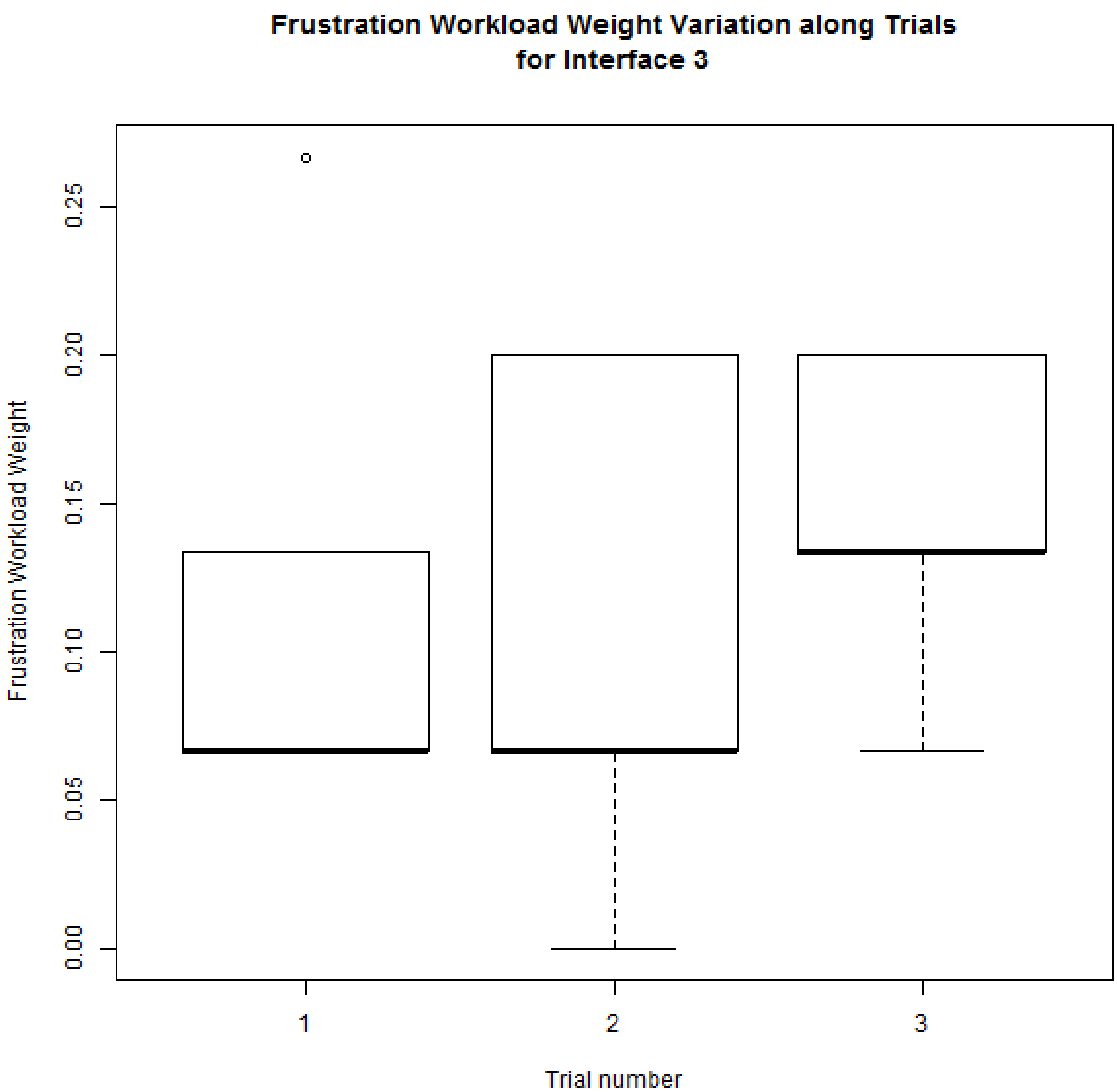
Interface 2 Frustration Workload Weight vs. Interface Order Summary			
Interface #	*Mean*	*Std. Dev.*	*Median*
1	0.093	0.060	0.133
2	0.213	0.030	0.200
3	0.093	0.037	0.067







Interface 3

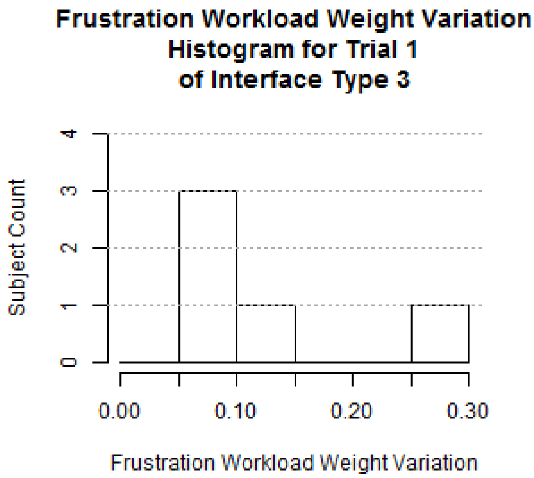


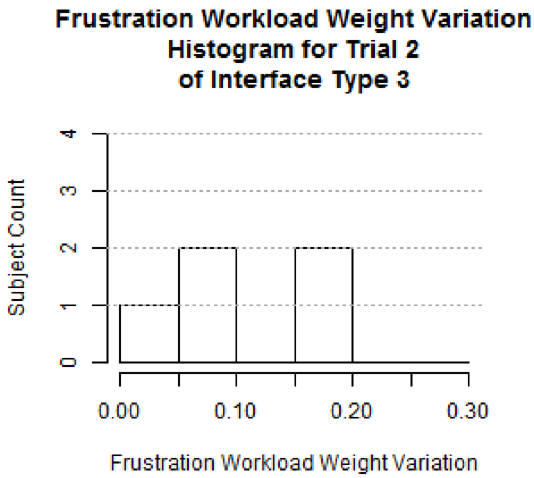
ANOVA: Interface 3 Frustration Workload Weight in Different Interface Order					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.004	0.002	0.333	0.723
Residuals	12	0.075	0.006		

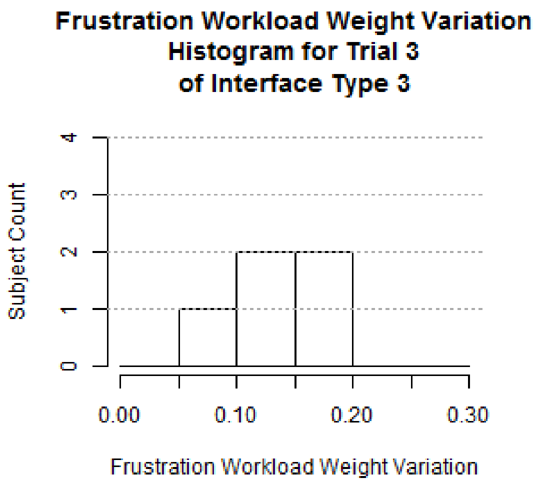
Interface 3 Frustration Workload Weight vs. Interface Order - Friedman Test	
X^2	1.000
p	0.607
DoF	2.000

Interface 3 Frustration Workload Weight vs. Interface Order – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	3.000	3.000	2.000
Z	0.283	-0.820	-0.566
p	1.000	0.500	0.750
R	0.047	-0.137	-0.094

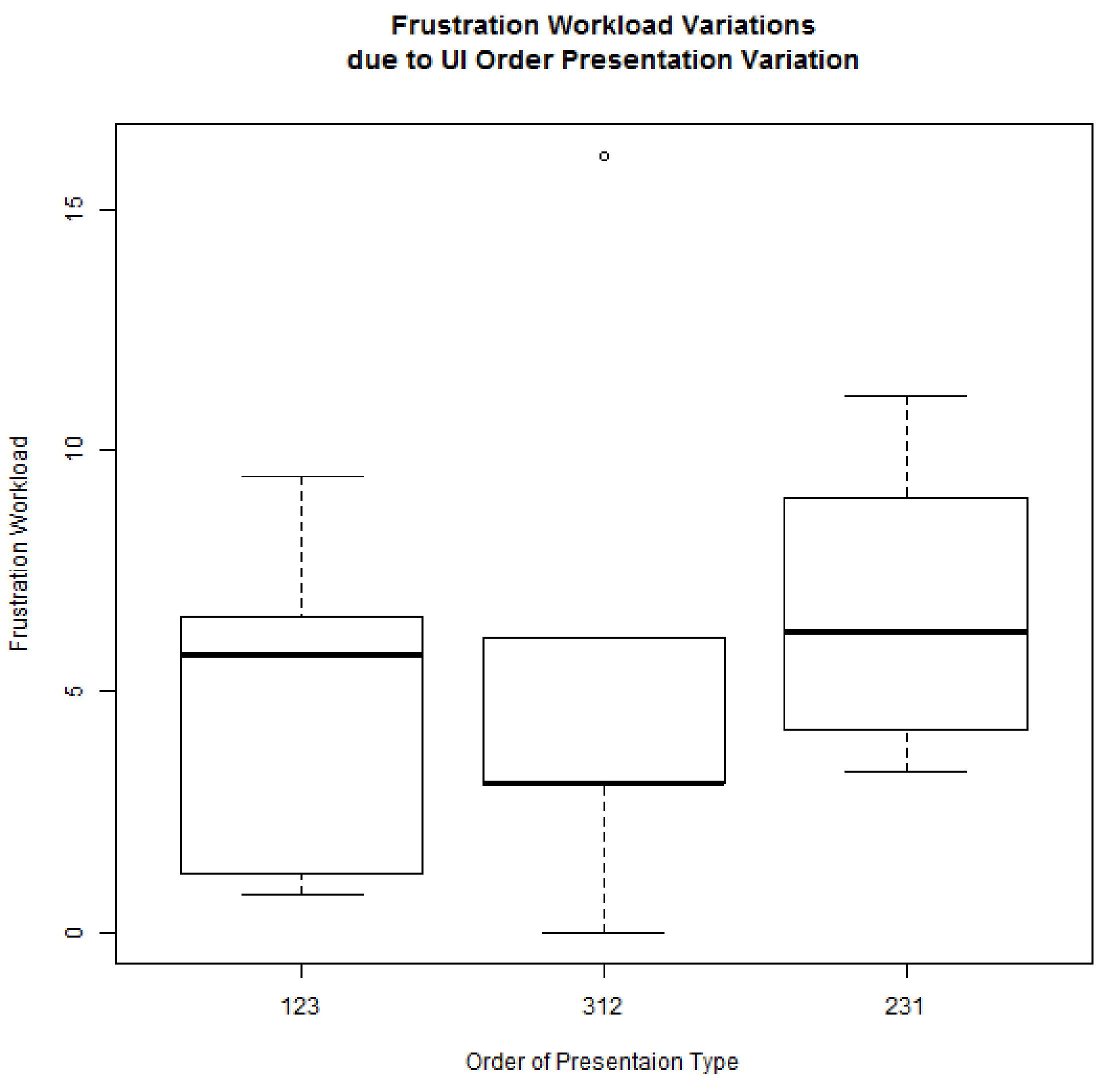
Interface 3 Frustration Workload Weight vs. Interface Order Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.120	0.087	0.067
2	0.107	0.089	0.067
3	0.147	0.056	0.133







C.2.13.6.5 Frustration Workload for Groups with Different Interface orders

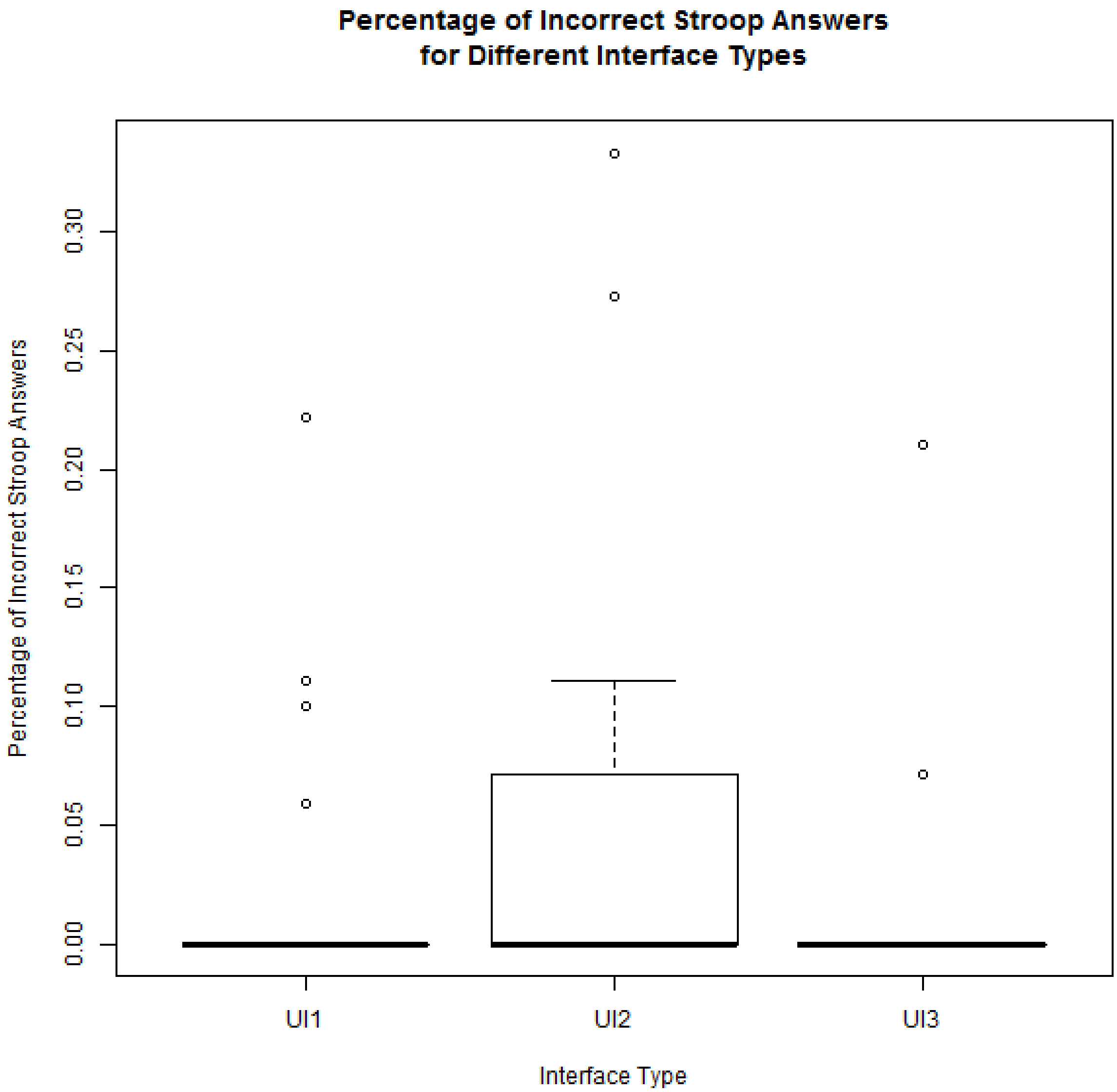


ANOVA: Overall Frustration Workload for Subjects with Different Interface Orders					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	10.24	5.122	0.244	0.787
Residuals	12	251.45	20.954		

Overall Frustration Workload vs. Subjects with Different Interface Orders Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	4.755	3.694	5.778
2	5.689	6.214	3.111
3	6.778	3.256	6.222

C.2.14 Stroop Task

C.2.14.1 Percentage of Incorrect Responses

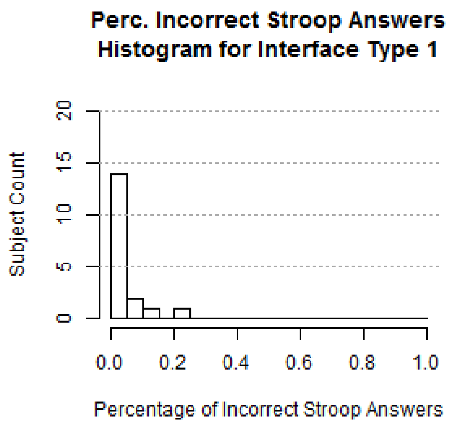


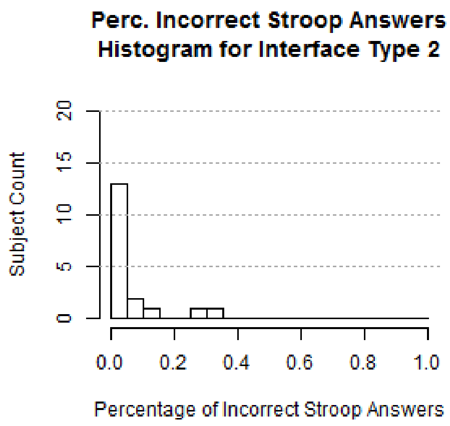
ANOVA: Percentage of Incorrect Responses with Different Interfaces					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.111	0.005	1.05	0.357
Residuals	51	0.272	0.005		

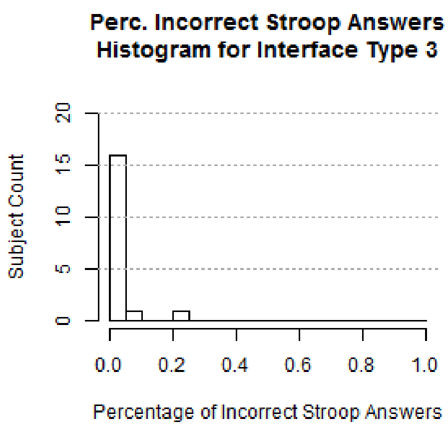
Percentage of Incorrect Responses vs. Interface Used - Friedman Test	
X^2	2.600
p	0.273
DoF	2.000

Percentage of Incorrect Responses vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	16.500	11.000	17.000
Z	-0.492	1.281	1.597
p	0.617	0.312	0.156
R	-0.082	0.213	0.266

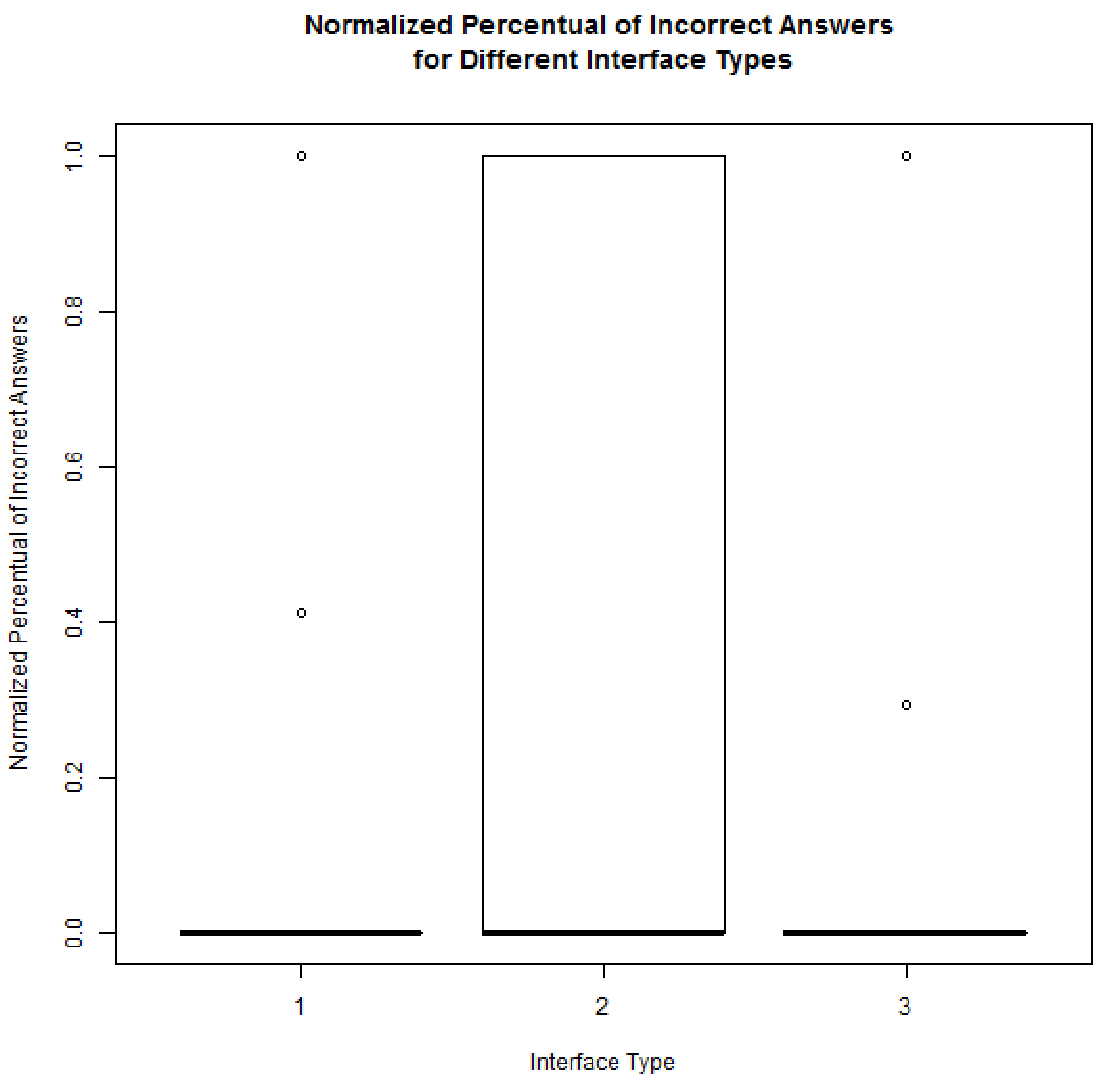
Percentage of Incorrect Responses vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.027	0.060	0.000
2	0.050	0.098	0.000
3	0.016	0.051	0.000







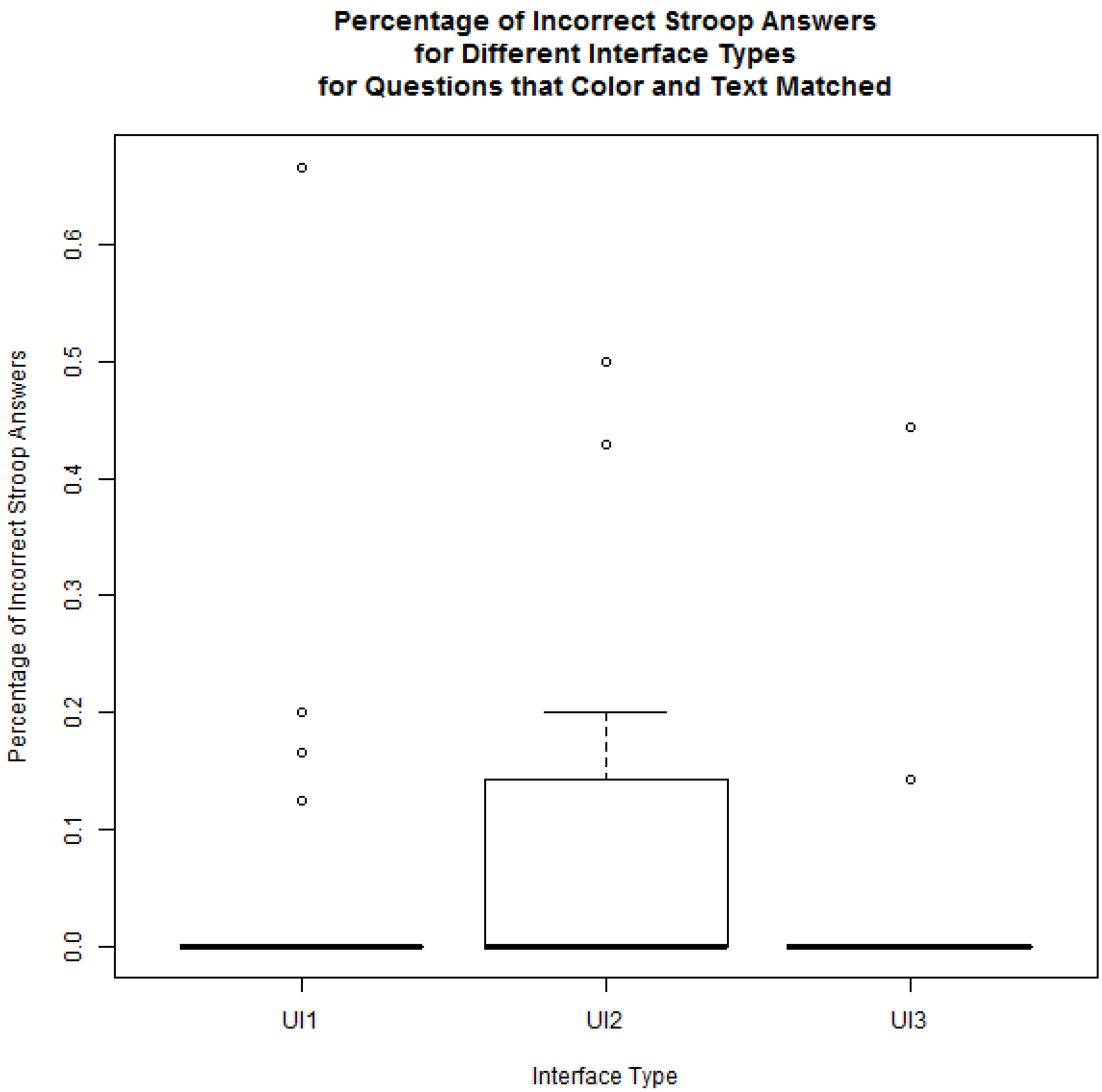
C.2.14.1.1 Normalized Percentage of Incorrect Responses



ANOVA: Percentage of Incorrect Responses with Different Interfaces					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.445	0.222	1.61	0.21
Residuals	51	7.046	0.138		

Percentage of Incorrect Responses vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.190	0.385	0.000
2	0.294	0.456	0.000
3	0.072	0.242	0.000

C.2.14.1.2 Percentage of Incorrect Responses Where Question Color Matched

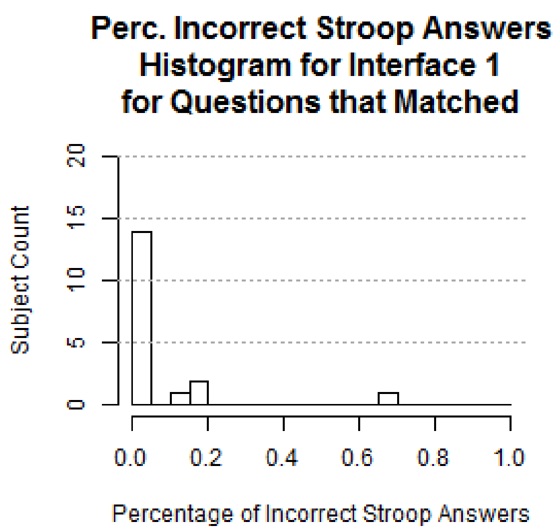


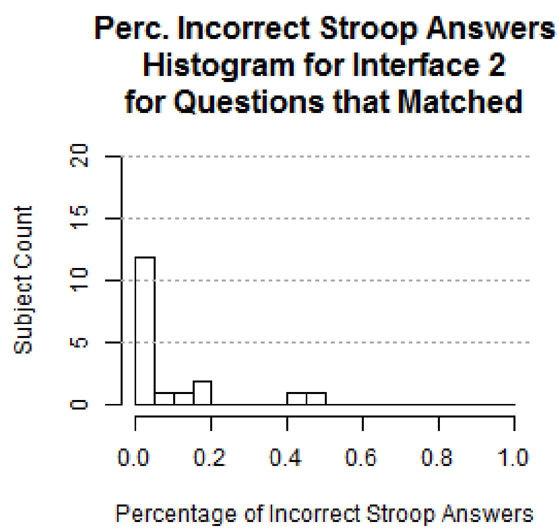
ANOVA: Percentage of Incorrect Responses (Color Match) with Different Interfaces					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.024	0.012	0.59	0.558
Residuals	51	1.052	0.020		

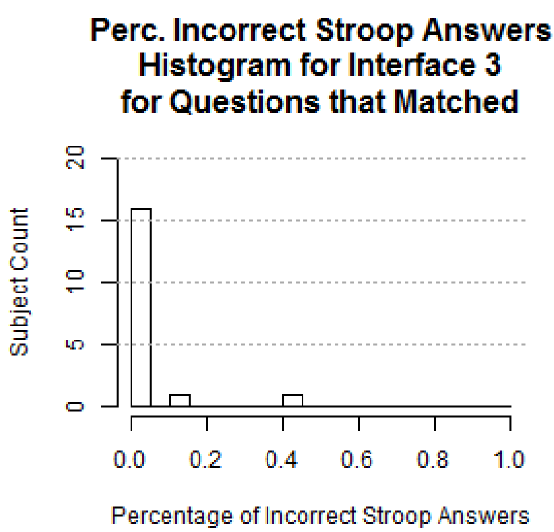
Percentage of Incorrect Responses (Color Match) vs. Interface Used - Friedman Test	
X^2	2.600
p	0.273
DoF	2.000

Percentage of Incorrect Responses (Color Match) vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	18.500	11.000	16.000
Z	-0.398	1.281	1.545
p	0.703	0.312	0.188
R	-0.066	0.213	0.257

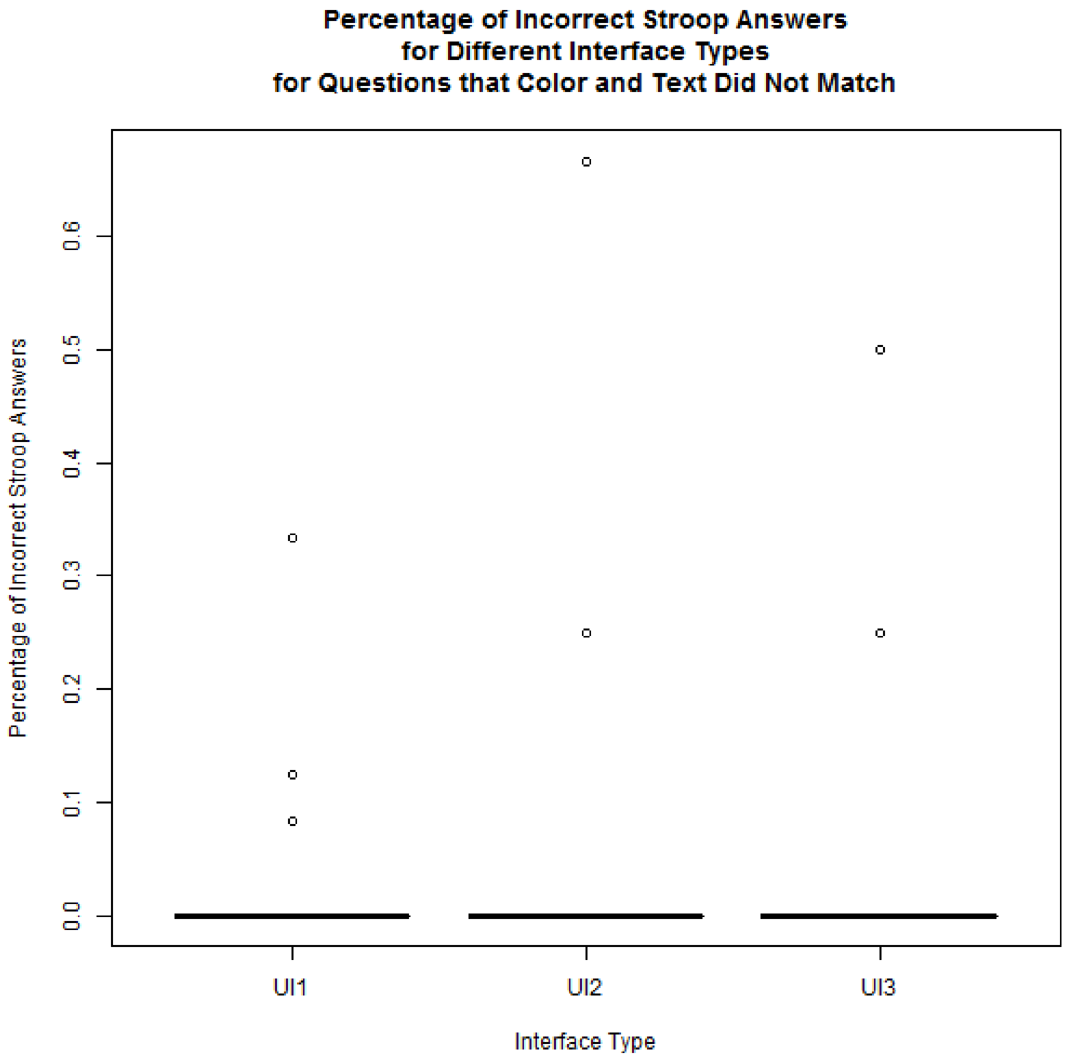
Percentage of Incorrect Responses (Color Match) vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.064	0.163	0.000
2	0.084	0.153	0.000
3	0.033	0.108	0.000







C.2.14.1.3 Percentage of Incorrect Responses Where Question Color Did Not Match

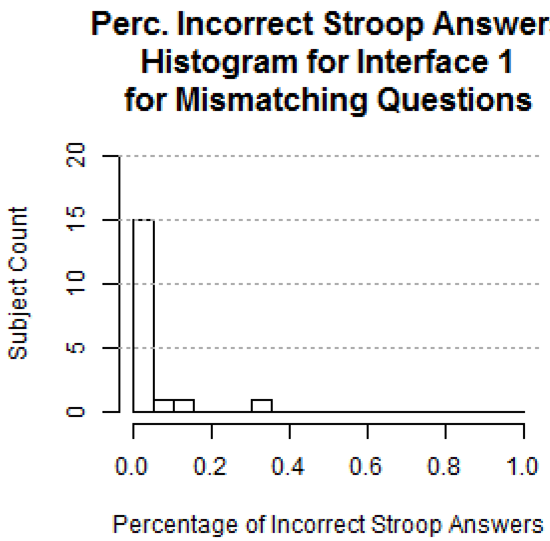


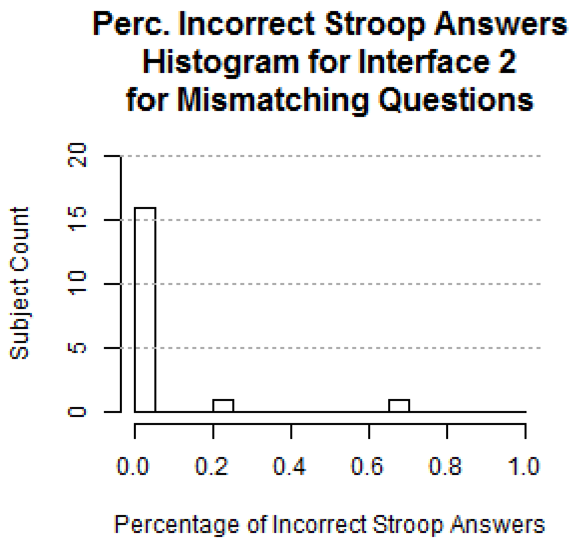
ANOVA: Percentage of Incorrect Responses (Color Mismatch) with Different Interfaces					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.004	0.002	0.116	0.89
Residuals	51	0.859	0.017		

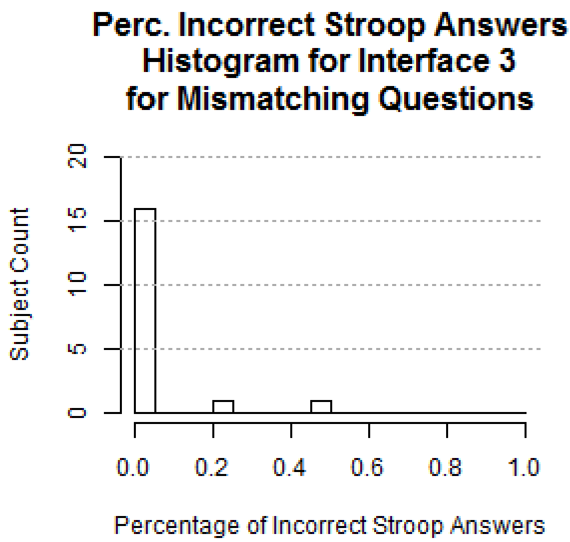
Percentage of Incorrect Responses (Color Mismatch) vs. Interface Used - Friedman Test	
X^2	0.286
p	0.867
DoF	2.000

Percentage of Incorrect Responses (Color Mismatch) vs. Interface Used – Wilcoxon Test			
	1 – 2	***1 – 3***	***2 – 3***
W	7.000	7.000	5.500
Z	0.334	0.334	0.030
p	0.938	0.938	1.000
R	0.056	0.056	0.005

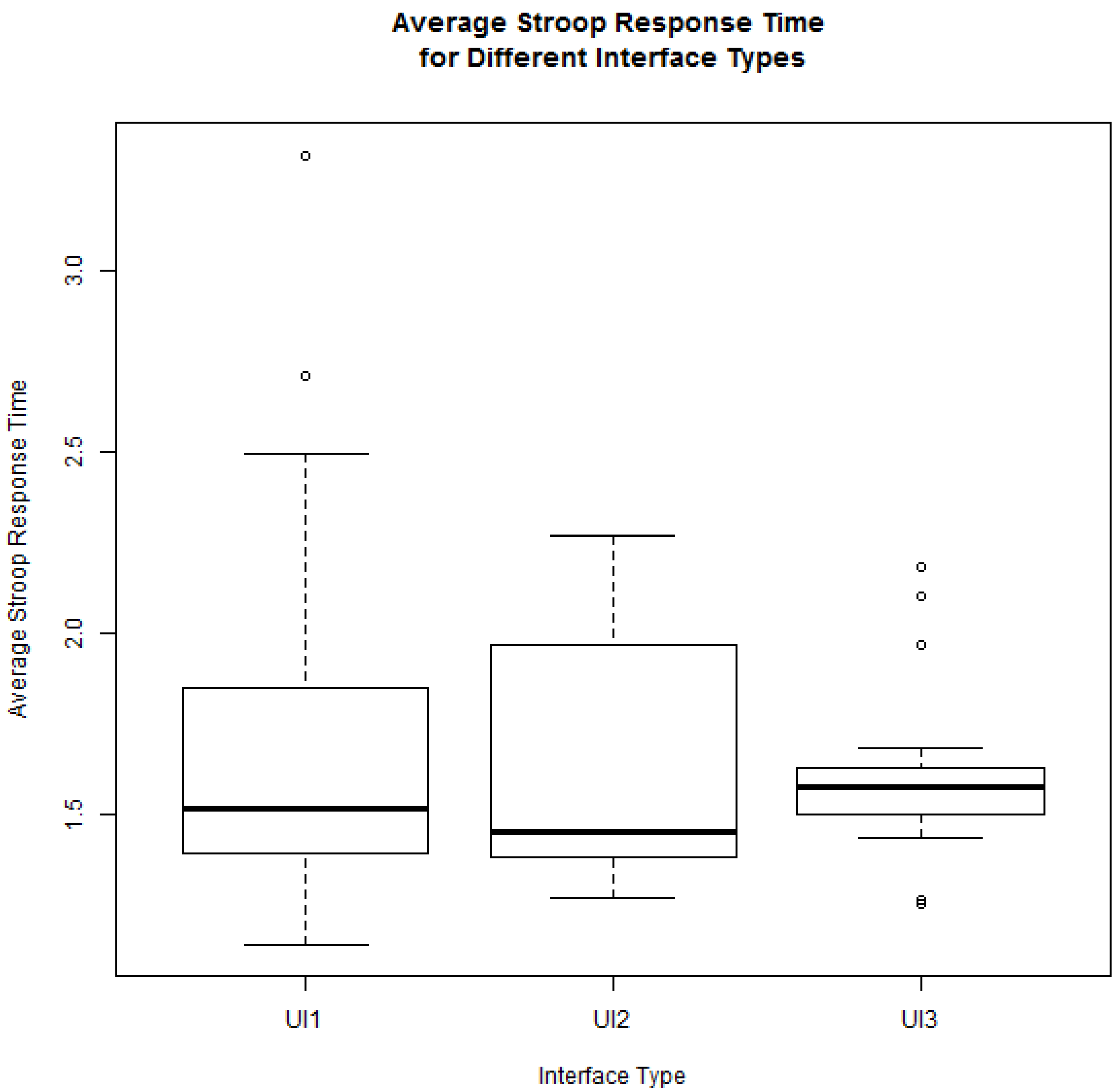
Percentage of Incorrect Responses (Color Mismatch) vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.030	0.083	0.000
2	0.051	0.165	0.000
3	0.042	0.129	0.000





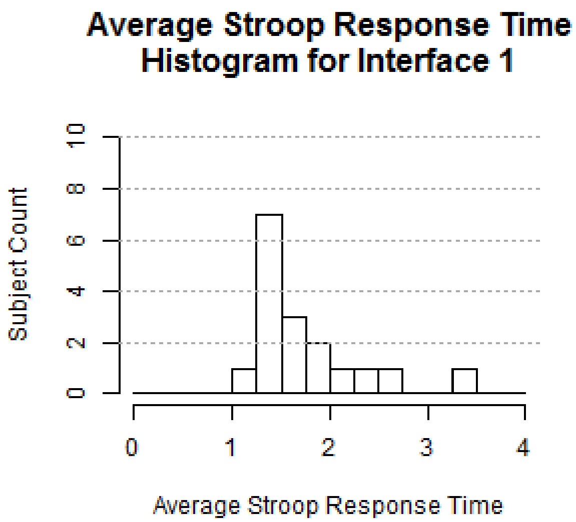


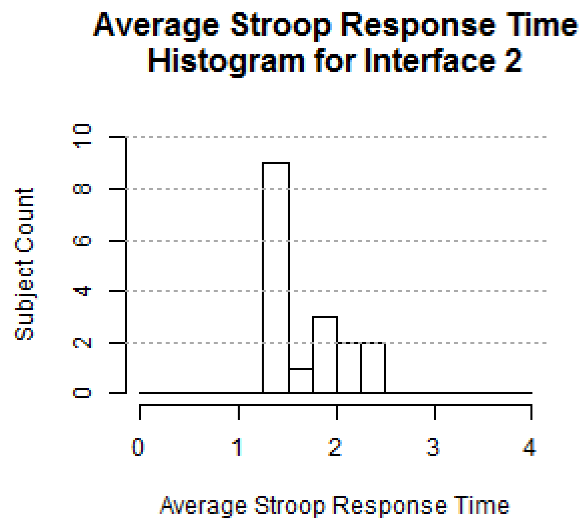
C.2.14.2 Response Time

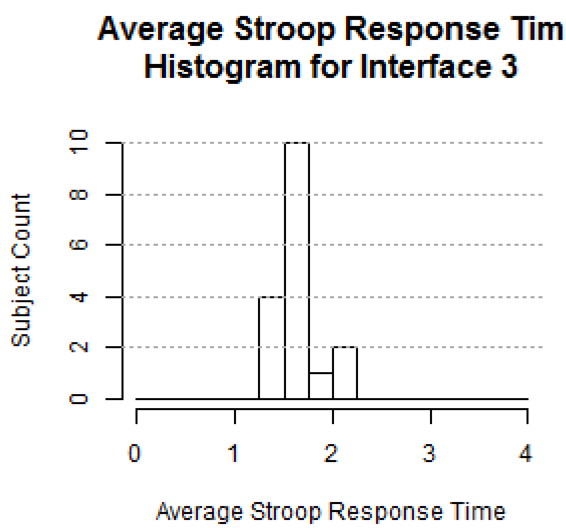


ANOVA: Response Time with Different Interfaces					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.152	0.075	0.42	0.659
Residuals	48	8.675	0.181		

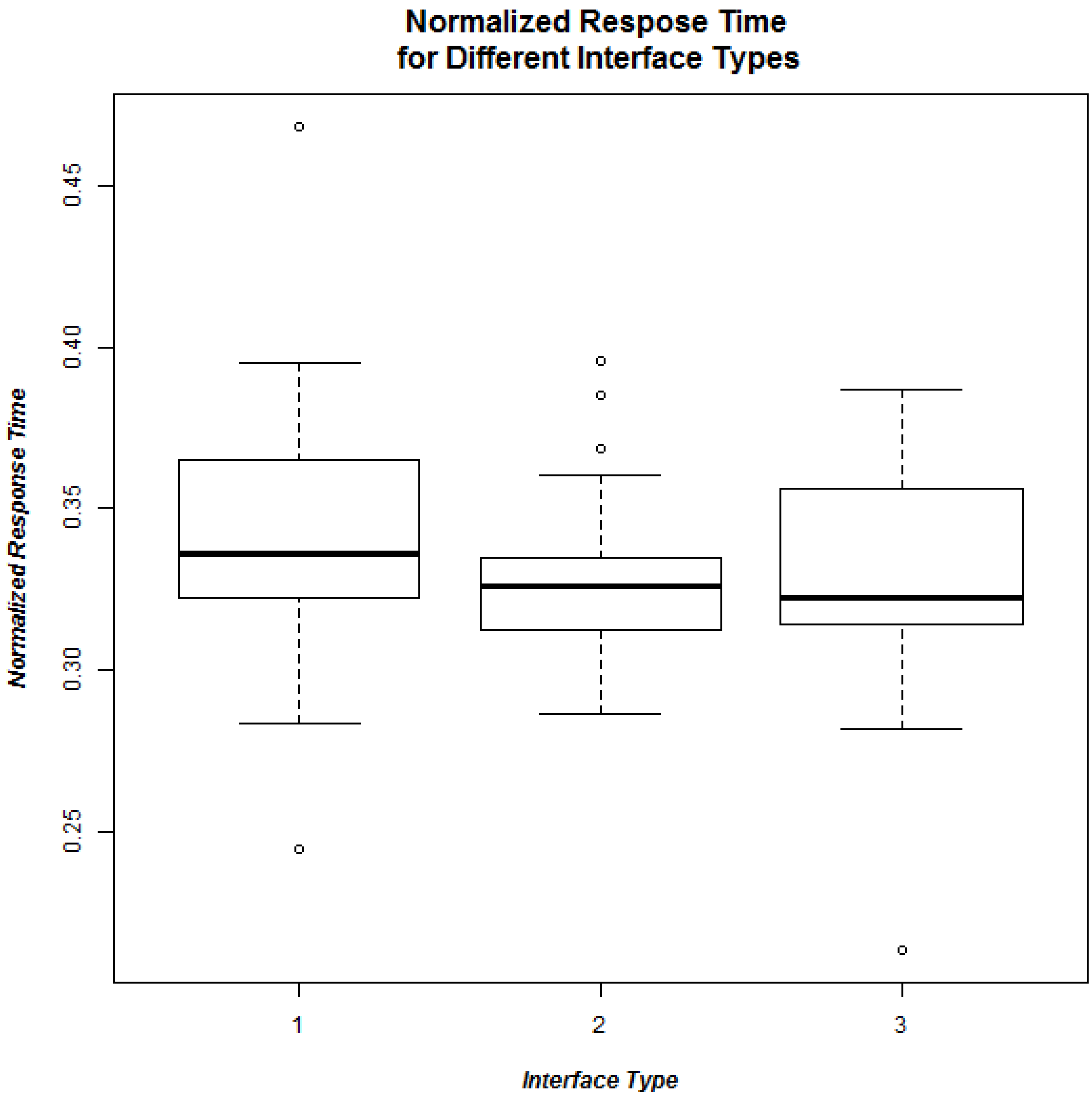
Response Time vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	1.750	0.588	1.518
2	1.663	0.364	1.453
3	1.618	0.253	1.575


Average Stroop Response Time
Histogram for Interface 1
Subject Count
0
2
4
6
8
10
0
1
2
3
4
Average Stroop Response Time


Average Stroop Response Time
Histogram for Interface 2
Subject Count
0
2
4
6
8
10
0
1
2
3
4
Average Stroop Response Time


Average Stroop Response Tim
Histogram for Interface 3
Subject Count
0
2
4
6
8
10
0
1
2
3
4
Average Stroop Response Time

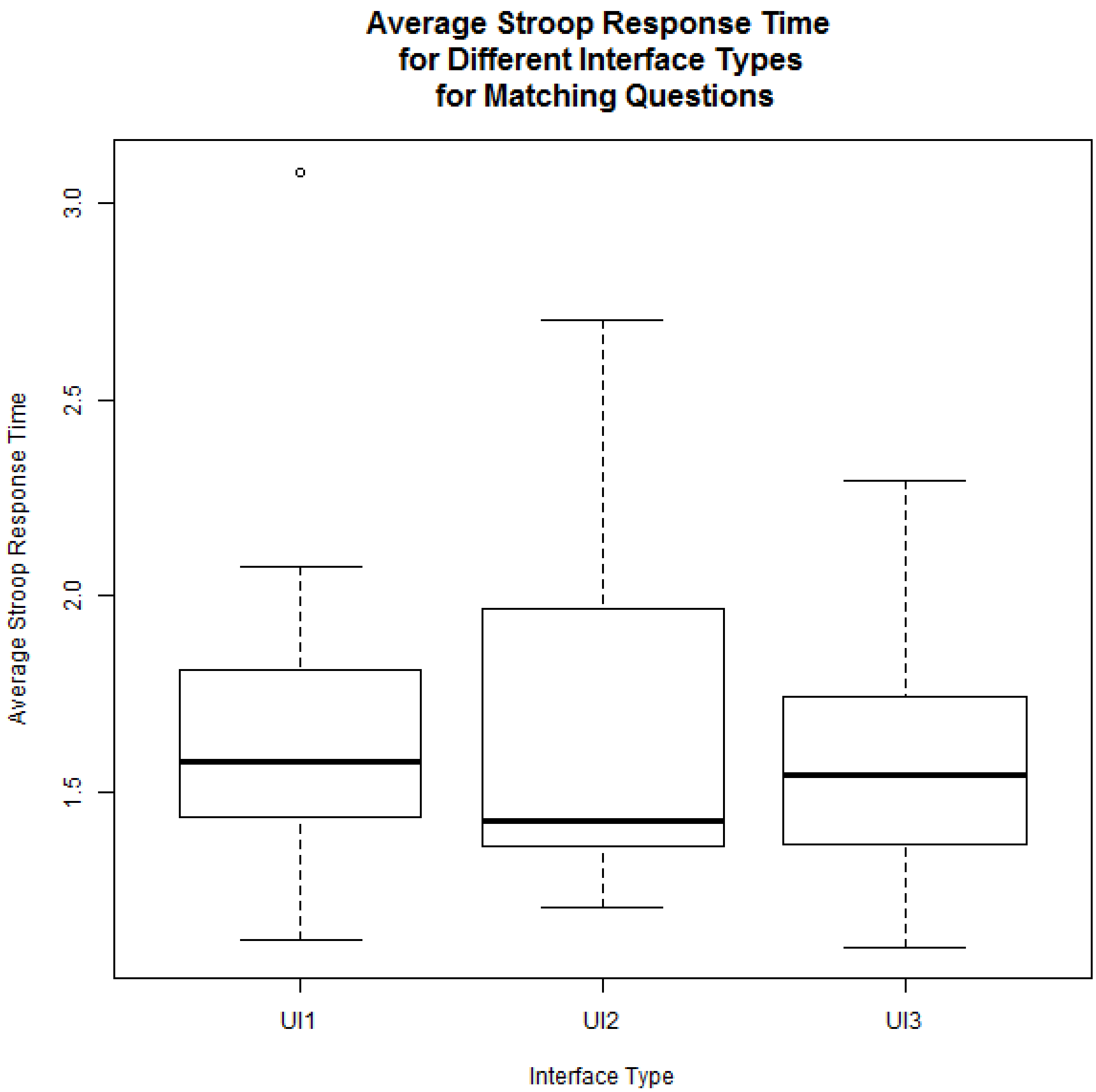
C.2.14.2.1 Normalized Response Time



ANOVA: AAA with Different Interfaces					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.002	0.001	0.659	0.522
Residuals	48	0.080	0.002		

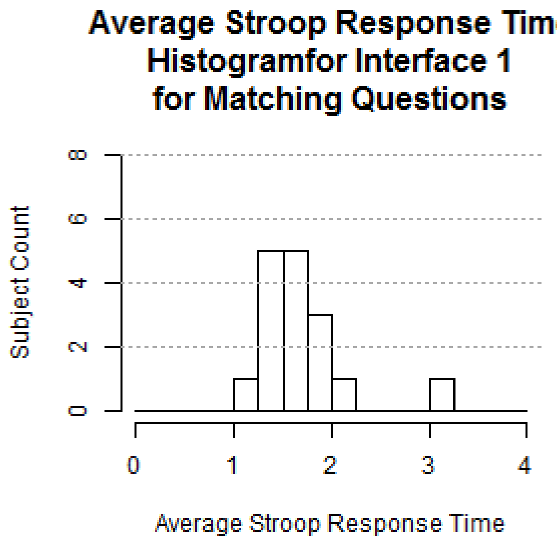
AAA vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.342	0.049	0.336
2	0.331	0.031	0.326
3	0.327	0.041	0.322

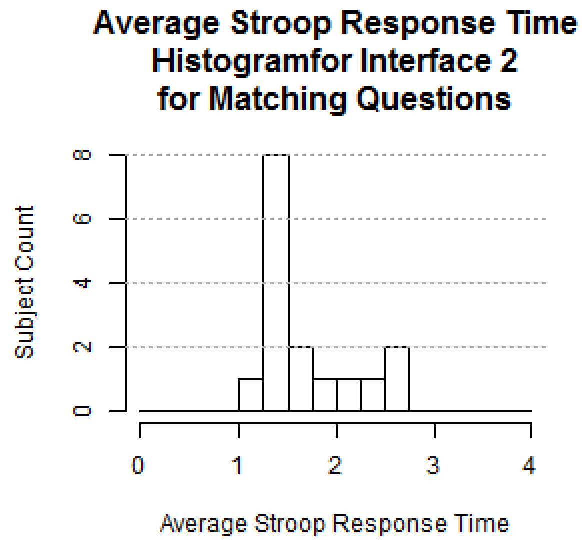
C.2.14.2.2 Response Time Where Question Color Matched

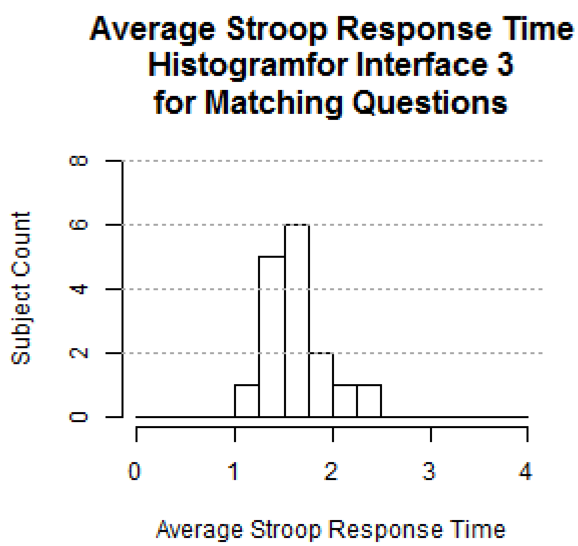


ANOVA: Response Time (Color Match) with Different Interfaces					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.082	0.041	0.237	0.79
Residuals	45	7.764	0.172		

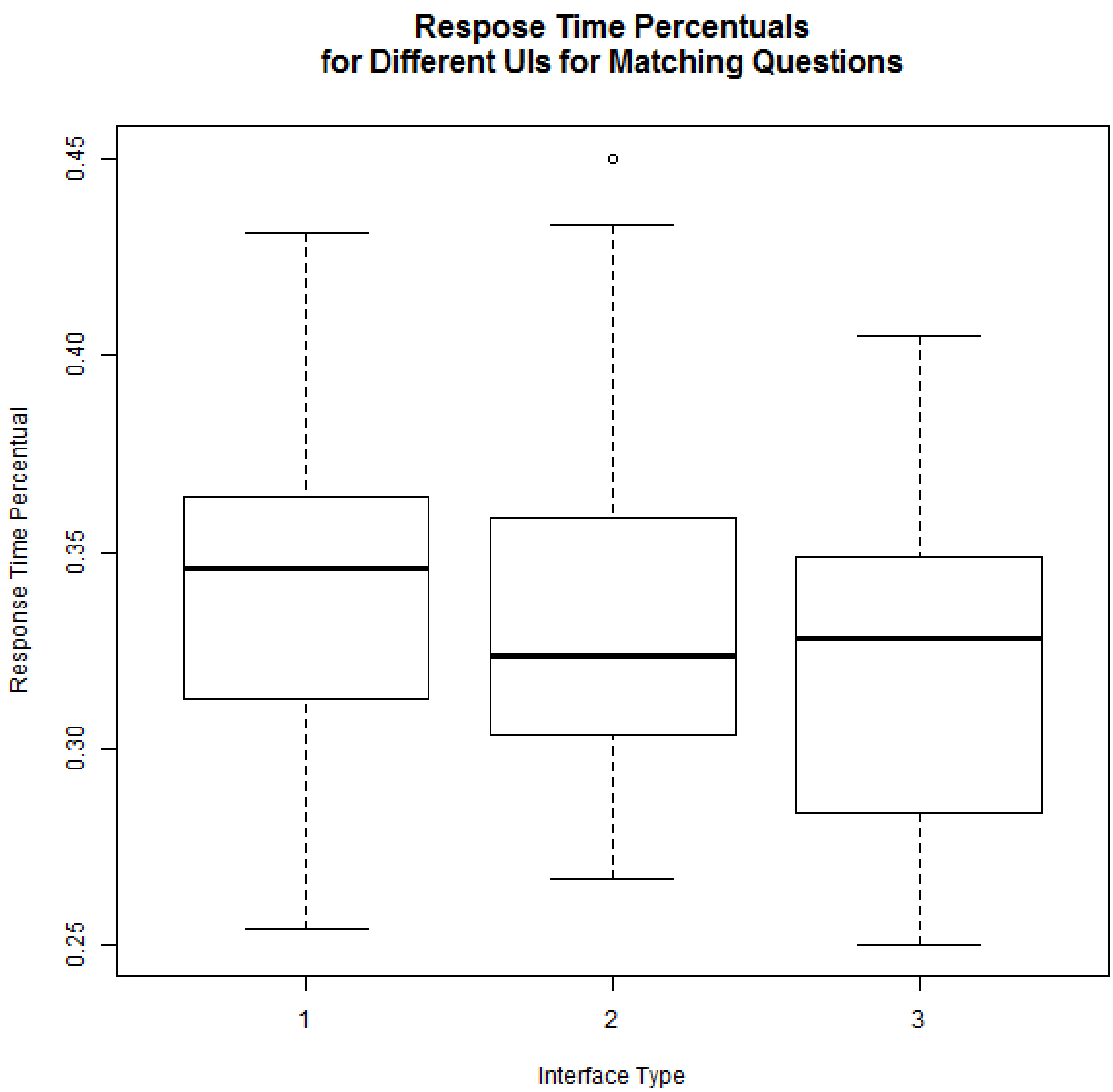
Response Time (Color Match)vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.683	0.439	1.578
2	1.679	0.474	1.428
3	1.593	0.316	1.545







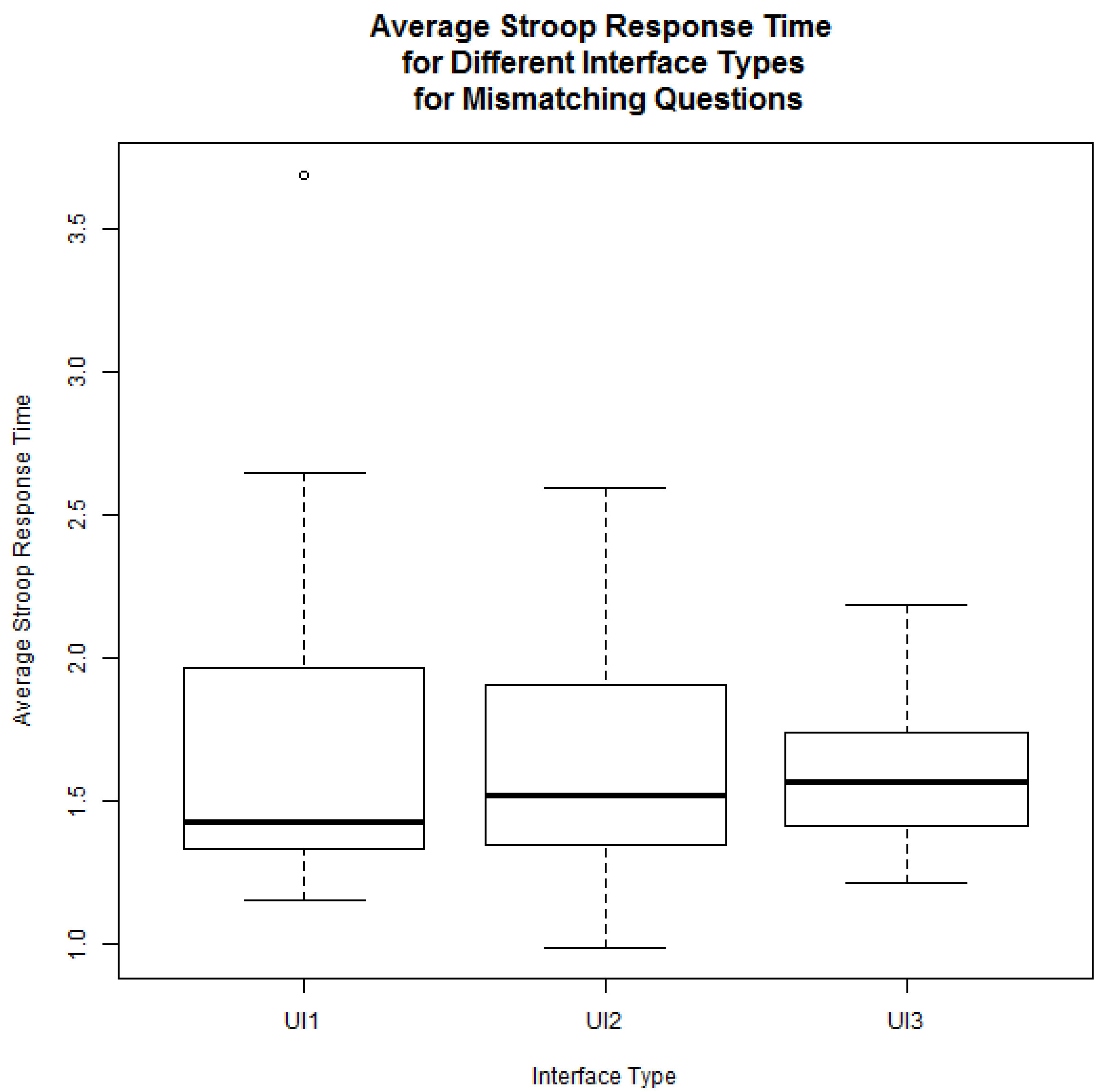
C.2.14.2.3 Normalized Response Time Where Question Color Matched



ANOVA: Normalized Response Time (Color Match) with Different Interfaces					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.002	0.001	0.532	0.591
Residuals	45	0.099	0.002		

Normalized Response Time (Color Match) vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.340	0.049	0.346
2	0.336	0.049	0.324
3	0.324	0.042	0.328

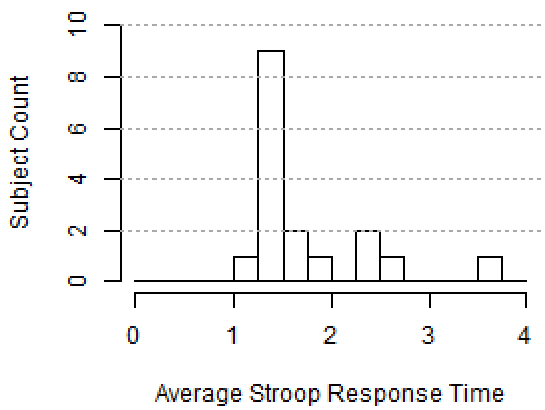
C.2.14.2.4 Response Time Where Question Color Did Not Match



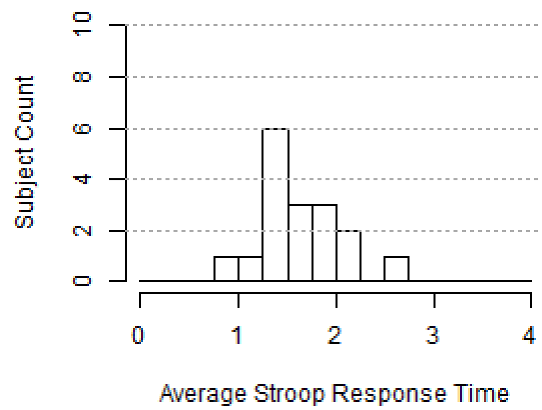
ANOVA: Response Time (Color Mismatch) with Different Interfaces					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.193	0.096	0.409	0.667
Residuals	48	11.328	0.236		

Response Time (Color Mismatch) vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	1.741	0.680	1.428
2	1.610	0.402	1.517
3	1.611	0.290	1.567

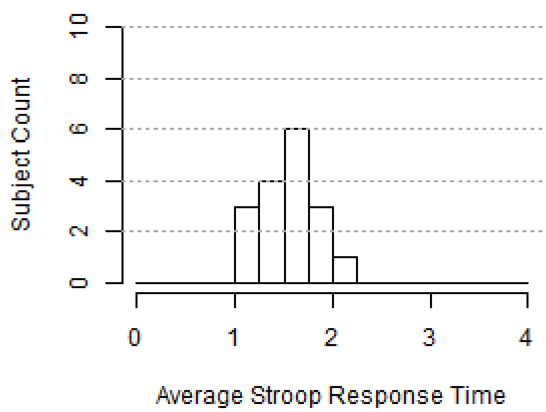
Average Stroop Response Time Histogram for Interface 1 for Mismatching Questions



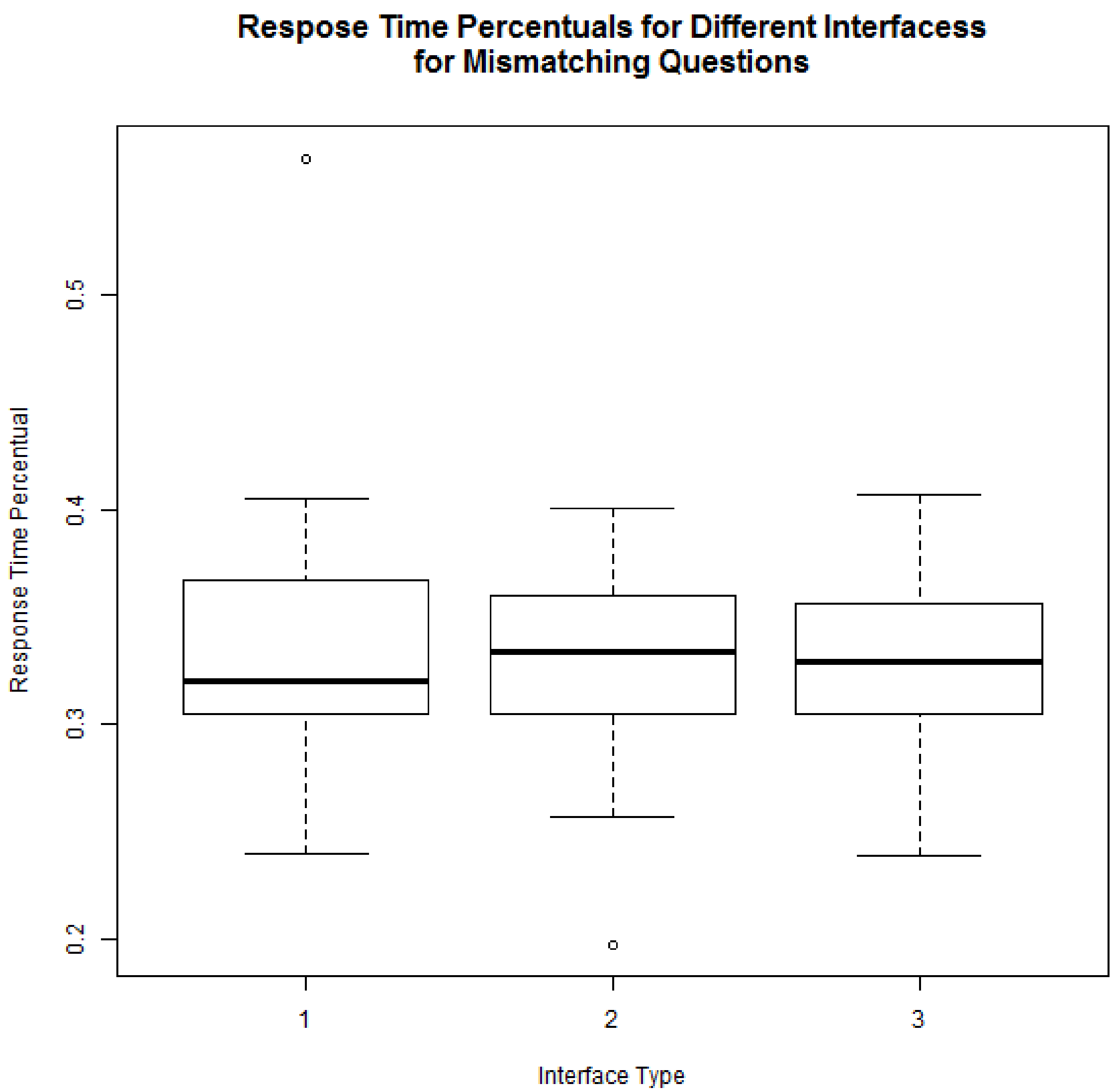
Average Stroop Response Time Histogram for Interface 2 for Mismatching Questions



Average Stroop Response Time Histogram for Interface 3 for Mismatching Questions



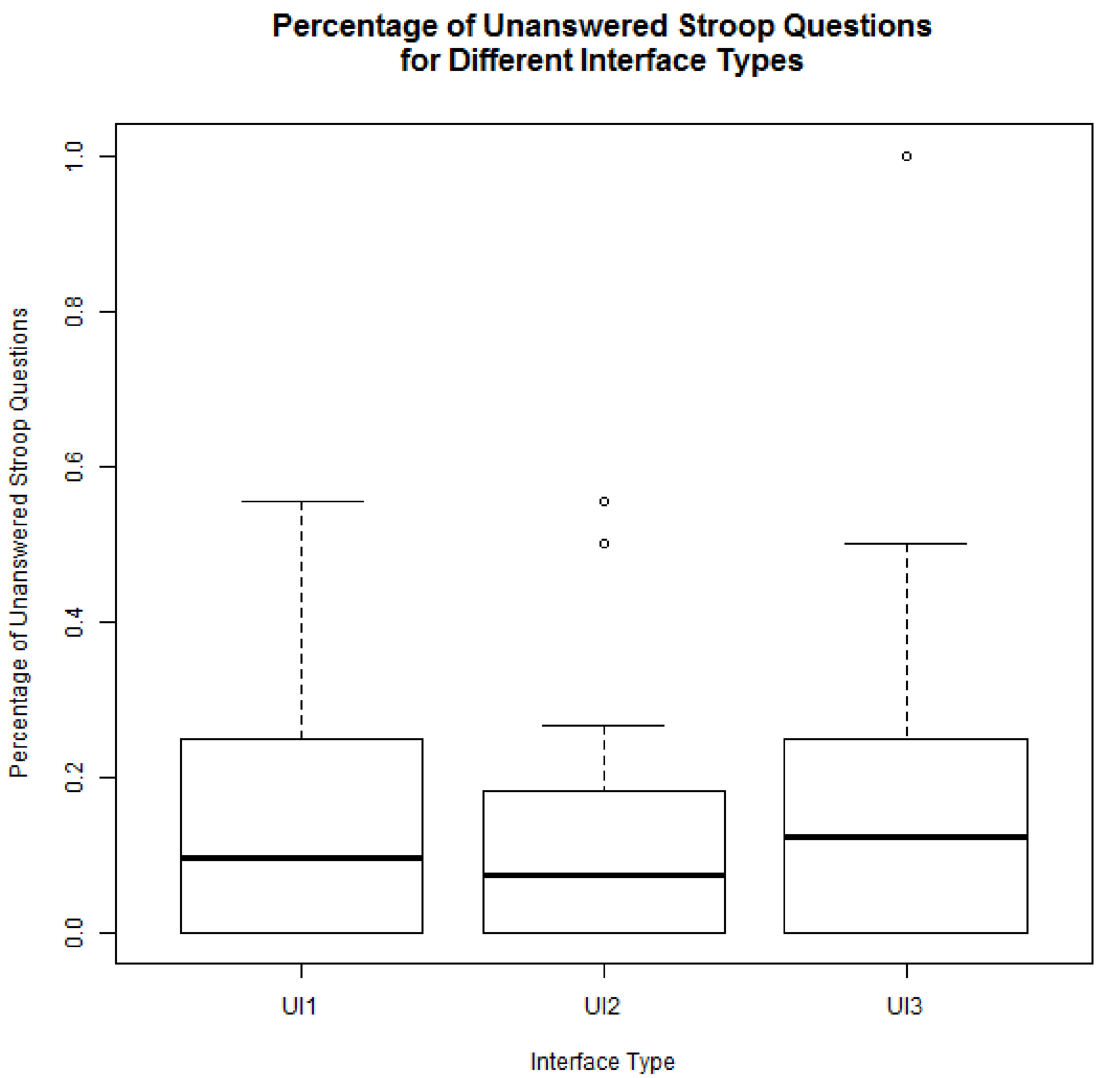
C.2.14.2.5 Normalized Response Time Where Question Color Did Not Match



ANOVA: Normalized Response Time (Color Mismatch) with Different Interfaces					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.003	0.001	0.447	0.642
Residuals	48	0.162	0.003		

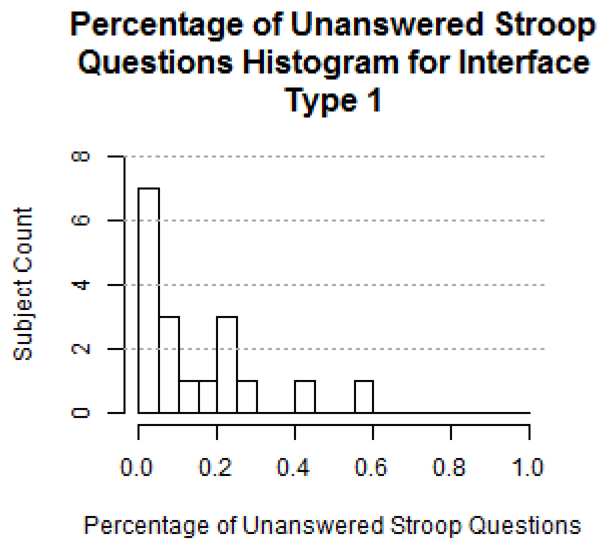
Normalized Response Time (Color Mismatch) vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.344	0.071	0.320
2	0.327	0.055	0.333
3	0.329	0.046	0.330

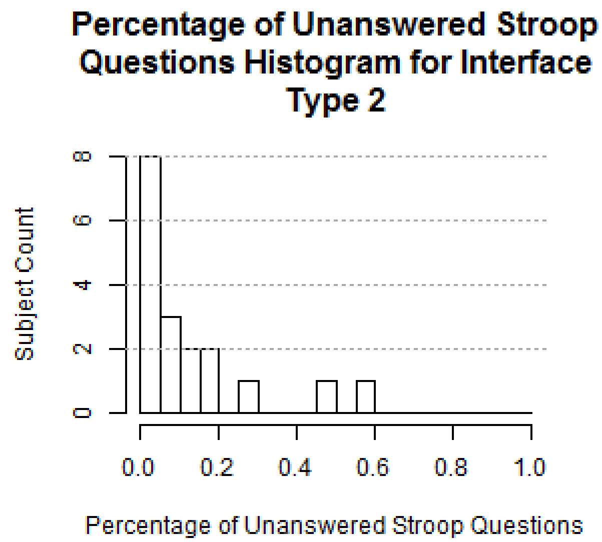
C.2.14.3 Percentage of Unanswered Questions

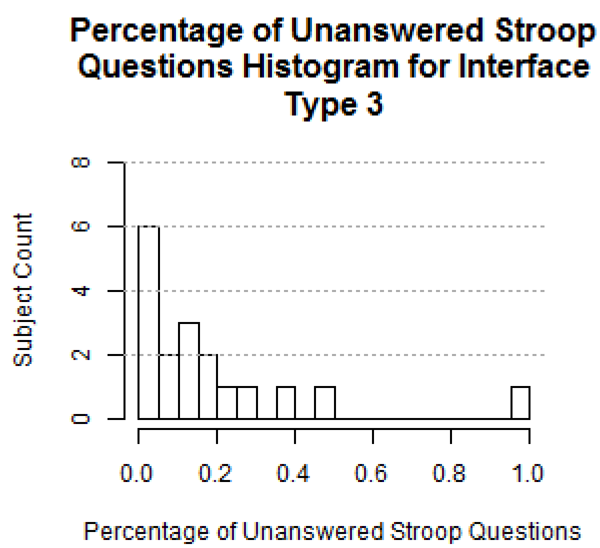


ANOVA: Percentage of Unanswered Questions with Different Interfaces					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.036	0.018	0.459	0.635
Residuals	51	2.007	0.039		

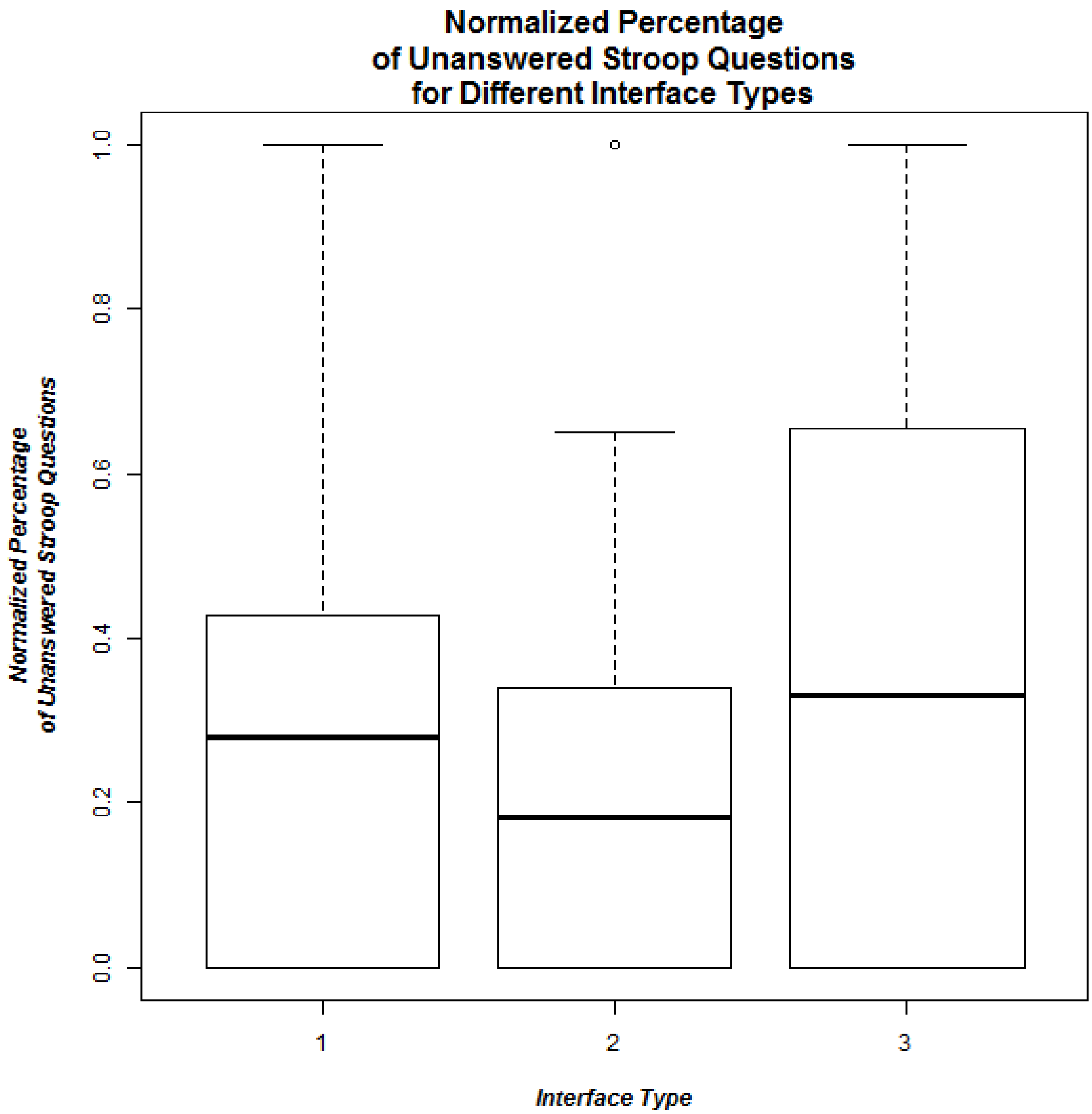
Percentage of Unanswered Questions vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.142	0.164	0.095
2	0.122	0.169	0.074
3	0.184	0.250	0.124


Percentage of Unanswered Stroop Questions Histogram for Interface Type 1
Subject Count
Percentage of Unanswered Stroop Questions


Percentage of Unanswered Stroop Questions Histogram for Interface Type 2
Subject Count
Percentage of Unanswered Stroop Questions


Percentage of Unanswered Stroop Questions Histogram for Interface Type 3
Subject Count
Percentage of Unanswered Stroop Questions

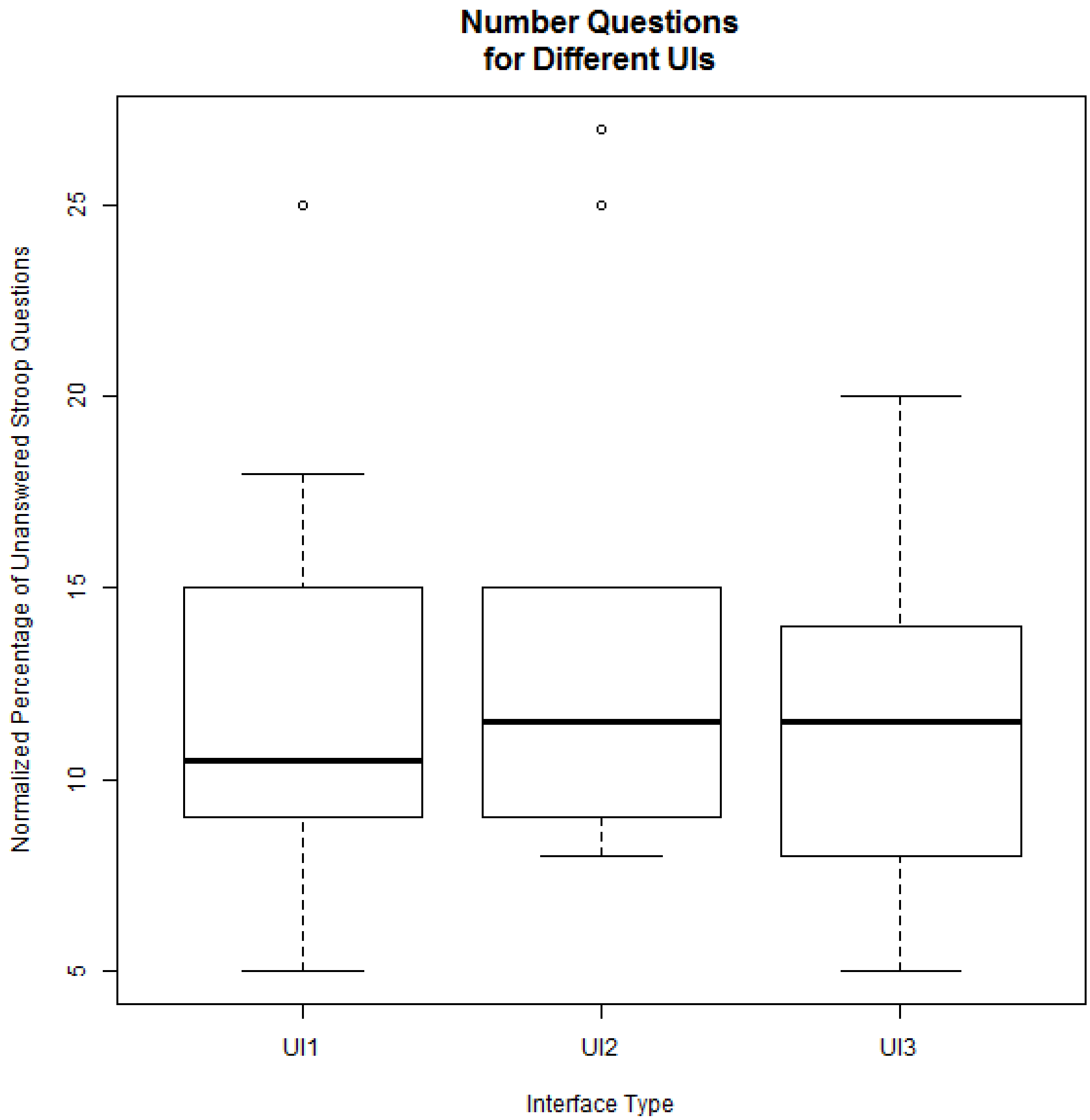
C.2.14.3.1Normalized Percentage of Unanswered Questions



ANOVA: Normalized Percentage of Unanswered Questions with Different Interfaces					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.256	0.128	1.261	0.292
Residuals	51	5.183	0.102		

Normalized Percentage of Unanswered Questions vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.286	0.304	0.280
2	0.217	0.281	0.183
3	0.385	0.366	0.330

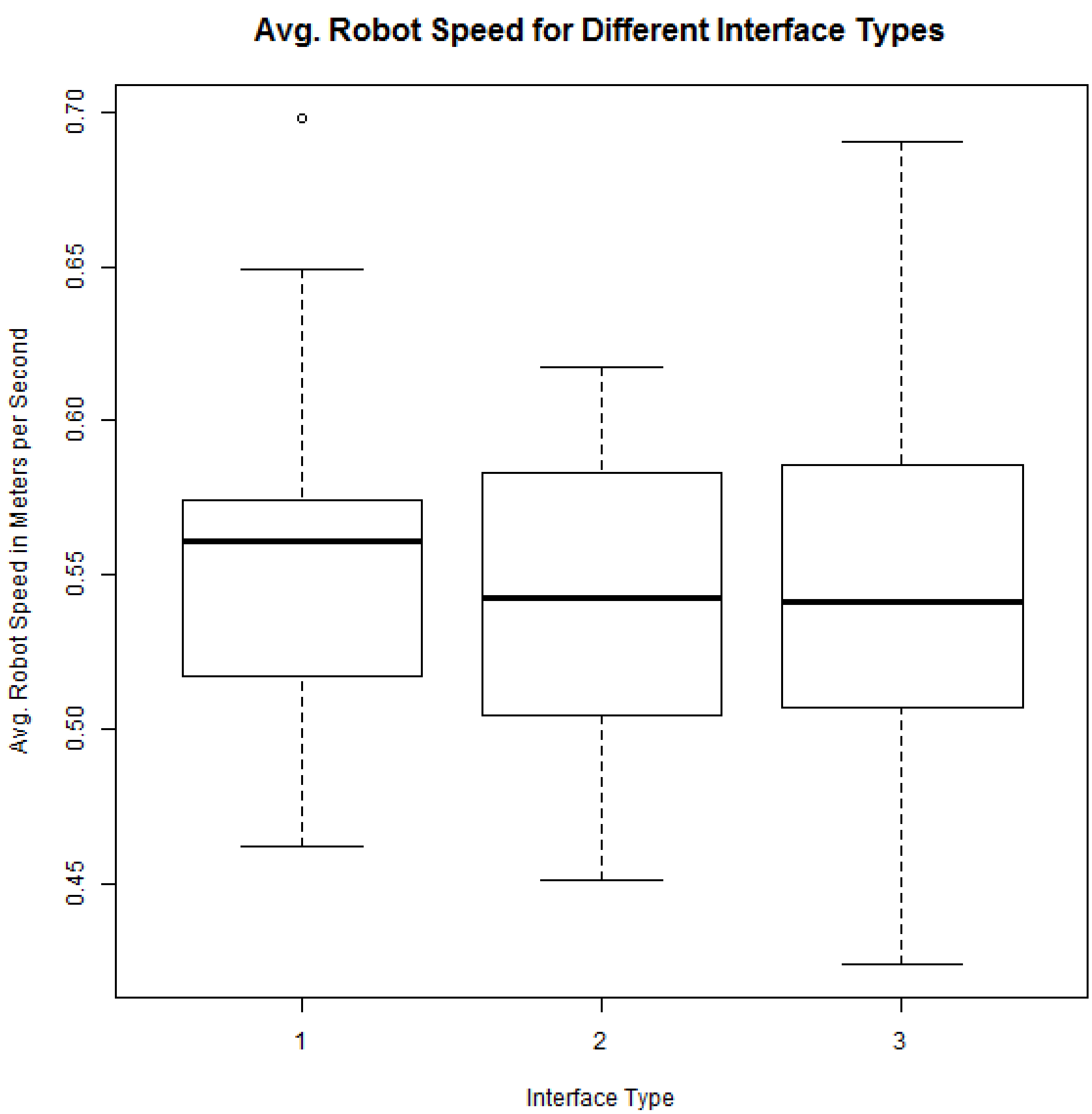
C.2.14.4 Questions Distribution Fairness Among Interface Types



ANOVA: AAA with Different Interfaces					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	16.3	8.167	0.355	0.703
Residuals	51	1174.5	23.029		

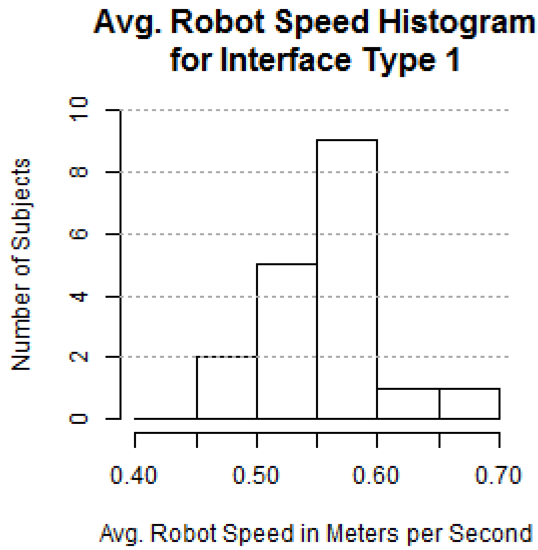
AAA vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	12.617	4.829	10.500
2	13.000	5.280	11.500
3	11.667	4.229	11.500

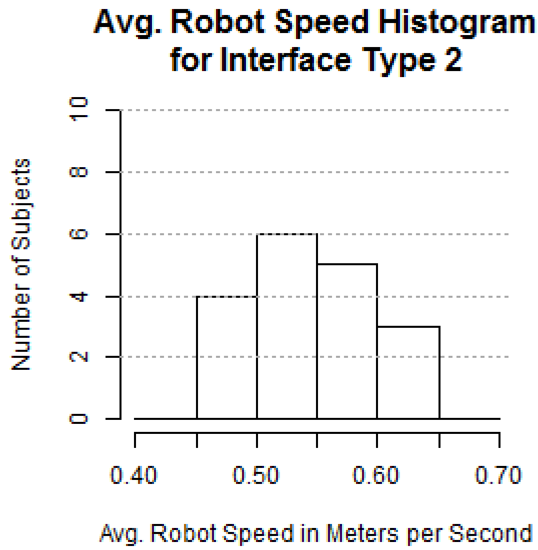
C.2.15 Average Speed

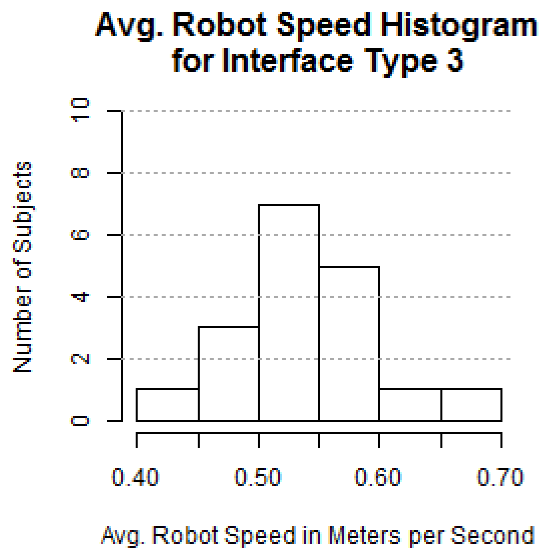


ANOVA: Average Speed with Different Interfaces					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.002	0.001	0.29	0.749
Residuals	51	0.164	0.003		

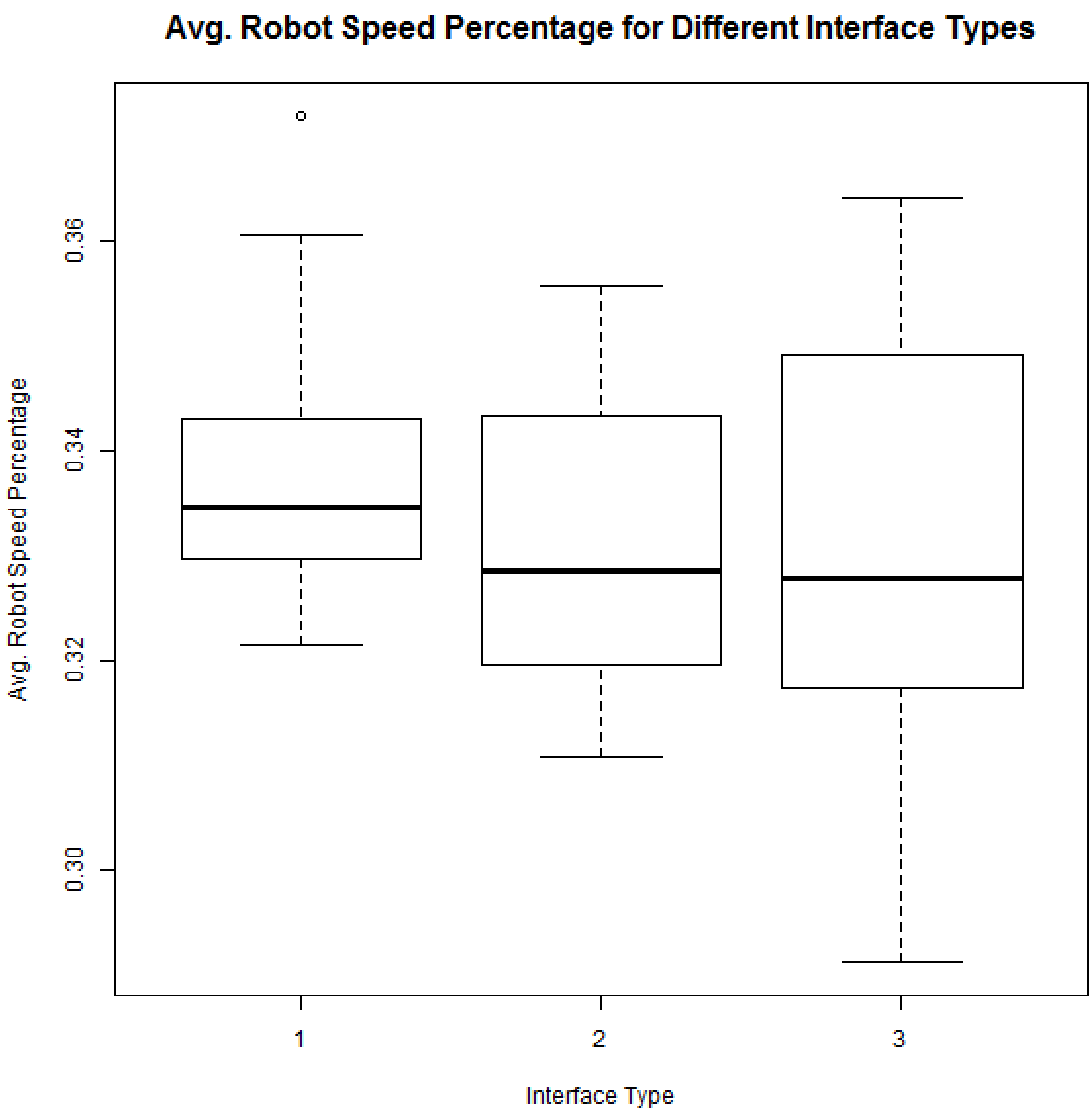
Average Speed vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.556	0.056	0.561
2	0.544	0.049	0.543
3	0.543	0.064	0.542


Avg. Robot Speed Histogram
for Interface Type 1
Number of Subjects
0
2
4
6
8
10
0.40
0.50
0.60
0.70
Avg. Robot Speed in Meters per Second


Avg. Robot Speed Histogram
for Interface Type 2
Number of Subjects
0
2
4
6
8
10
0.40
0.50
0.60
0.70
Avg. Robot Speed in Meters per Second

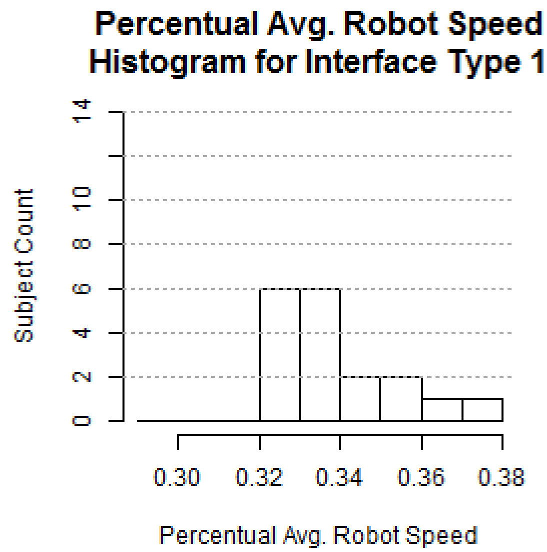

Avg. Robot Speed Histogram
for Interface Type 3
Number of Subjects
0
2
4
6
8
10
0.40
0.50
0.60
0.70
Avg. Robot Speed in Meters per Second

C.2.15.1 Normalized Average Speed

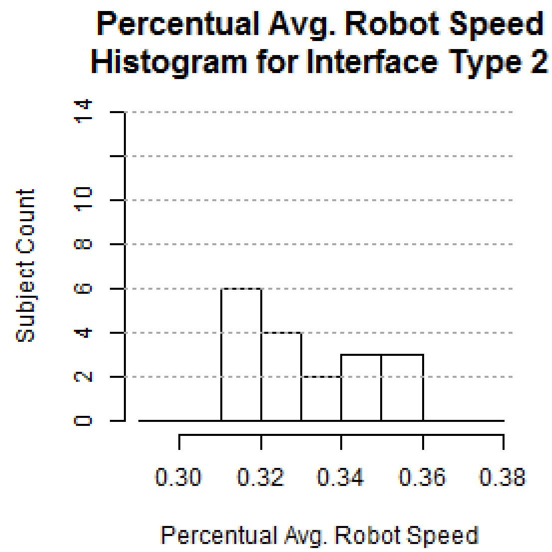


ANOVA: Average Speed with Different Interfaces					
Source of Variation	***DoF***	***SS***	***MS***	***F***	***P-value***
Interface Type	2	0.001	0.000	1.391	0.258
Residuals	51	0.013	0.000		

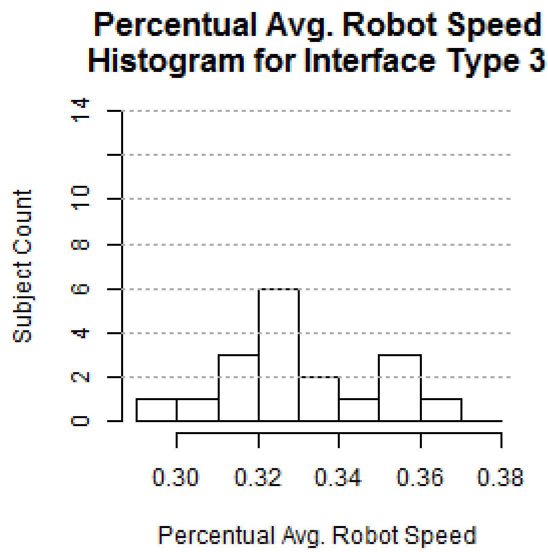
Average Speed vs. Interface Used Summary			
Interface #	***Mean***	***Std. Dev.***	***Median***
1	0.338	0.014	0.335
2	0.331	0.015	0.329
3	0.330	0.019	0.328



Percentual Avg. Robot Speed
Histogram for Interface Type 1
Subject Count
0
2
4
6
8
10
14
0.30
0.32
0.34
0.36
0.38
Percentual Avg. Robot Speed



Percentual Avg. Robot Speed
Histogram for Interface Type 2
Subject Count
0
2
4
6
8
10
14
0.30
0.32
0.34
0.36
0.38
Percentual Avg. Robot Speed



Percentual Avg. Robot Speed
Histogram for Interface Type 3
Subject Count
0
2
4
6
8
10
14
0.30
0.32
0.34
0.36
0.38
Percentual Avg. Robot Speed

Appendix D: Study 4 Material

This appendix contains all the forms used and data analysis done for user study #4. Source code, videos and images can be found on-line (de Barros & Lindeman, 2014).

D.1 Forms

The forms used in study #4 are contained in this section. The text listed is presented as it was originally was given to subjects, with the exception of the removal of watermarks and institutional logotypes.

D.1.1 Instructions Sheet

This experiment aims at evaluating the effect of smell, audio, and vibro-tactile interfaces on robot teleoperation.

Task: You will be asked to safely navigate a robot located in a remote room filled with debris in search for red spheres. Once the search is completed, you will have to safely exit the environment with the robot. This is a simulation of a collapsed building search-and-rescue operation, so you have to perform the search as fast and effectively as possible. This will increase the chances that survivors are saved and reduce the chances that the robot gets stuck if further collapses occur in the building structure.

The room will emulate an office room affected by an earthquake. The room will have objects spread around in a chaotic manner, so as to reproduce a catastrophic situation. Among the objects there will be colored spheres of different sizes. You will have to locate them by navigating a robot through the debris around the entire area. **Please try to memorize the**

location of the spheres so that you can report them later by sketching a map of the room, its objects and the spheres' location.

The world will be seen by using the robot camera present in the robot interface. The camera will display the remote room. Other information obtained from the robot and the room (robot speed, CO_2 levels, robot collisions and distance to nearby objects) will also be visually displayed to you through the monitor. The interface of the program contains a virtual representation (avatar) of the robot and a virtual representation of the robot camera that displays images in a panel. The camera panel rotates around the robot avatar to indicate the robot camera pointing direction relative to the robot forward direction. The top of the robot may light up in the direction the robot is about to collide. The brighter the robot top illuminates in yellow, the closer the robot is to an object in that direction. If it becomes red, a collision is happening in that direction. A speedometer displaying the current robot speed may also be visually displayed on its back. There is also a vertical bar indicating the CO_2 levels in the nearby area. High CO_2 levels may be an indication that someone is alive and breathing nearby. In other words, the robot must be getting close to a catastrophe survivor (a red sphere).

Information may also be displayed through devices other than the computer monitor in front of you. For example, you are wearing a belt with eight pager motors (tactors). They may provide you with feedback on imminent collision situations with the robot. When the tactors are active, the closer the robot is to colliding, the more intensely they will vibrate in the approximate direction of the imminent collision. If a collision occurs, they will vibrate at maximum intensity in the direction of the collision.

You may also receive sound feedback through the headset you are wearing. If so, sounds indicating robot speed and collisions with objects will be displayed. The direction with which the collision sound is heard is the direction you are colliding with the robot. White noise will also be presented through the headset to reduce the effect of external noise on the experiment. It is important to notice that if you are trying to move the robot and it does not move, it is because the robot is colliding with objects in the remote environment.

There is also a fan in a white box in front of you. If the CO_2 levels rise above the red level on the visual bar on screen, the fan may blow the smell of rosemary into the air to indicate that. The more intense the smell, the higher the CO_2 level is where the robot currently is. Even if the display of smell is not enabled for you as random participant, the fan will still always be blowing wind on your face.

The effect of introducing displays to senses other than the vision in the robot interface is what we are measuring in this experiment. **Because the selection of the displays for each subject is random, information may be presented to you through some, but not all of the above described displays.** The experiment observer will notify you of the subset of displays you are going to be exposed to.

A timer will be displayed on screen. It will count the amount of time spent during the task. The task will be over once you exit the house through the exit door, identified by an emergency exit symbol. You should park the robot on top of an X sign on the ground.

While performing the task, you will also be performing a text-color matching task. You will be presented with text in the middle of the screen with one of the following words: “red”, “green”, “blue”. If the color of the text font matches the string description, you have to press the button with the green triangle. If they do not match, you will have to press the button with a red circle to indicate that. Hence, you should respond as soon as you notice the text on screen and as fast as you can. Once you press either of these two buttons, the text will disappear. The text also disappears after a while if no button is pressed. Therefore, you need to respond to these questions as soon as you see them.

Please sit comfortably during the experiment, but pay attention to the search task. After reading this, you will be presented with the controls for the robot and given time to get accustomed to the controls in a training area. If you have questions about how to proceed in the experiment, please, ask during the training session.

After that, feel free to ask the instructor to start the experiment whenever you are ready. Further information about the project can be given by the experiment instructor after you have finished the experiment. **Please do not ask the instructor questions about the room or task while performing the main task. Only interactions about technical problems with the robot or its software will be allowed during that time.**

D.1.2 Consent Form

Primary Investigator: Robert W. Lindeman

Contact Information:

WPI / Department of Computer Science

100 Institute Road

Worcester, MA 01609

Tel: 508-831-6712

E-Mail: gogo@wpi.edu

Title of Research Study:

Evaluation of Multi-sensory Feedback for Teleoperated Robots

Sponsor: None.

Introduction

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you make a fully informed decision regarding your participation.

Purpose of the study**:**

This study is designed to assess the effect of using smell, vibro-tactile and audio interfaces in robot teleoperation.

Procedures to be followed:

You will be asked to remotely navigate a robot through a room filled with debris using a gamepad with two thumb-joysticks and monitor. The task is a search task in a simulated collapsed building. Your control of the robot movement will make it move forward and backward by moving a thumbstick to the front and to the back respectively. Moving the thumbstick to the left or to the right will make the robot turn left or right respectively. Releasing the thumbstick at its central static position will bring the robot to a stop. In addition, another thumbstick will give you control over the robot's pan-and-tilt camera. Moving this thumbstick to the left or right will turn the camera to the left or right respectively. Moving it forward or backward will turn the camera down or upward respectively. Releasing this second thumbstick at its central static position will bring the robot camera to a stop. You can also reset the camera to its center by pressing a button in the gamepad. The camera vertical movement may not always match the camera real orientation. You will also be able to take pictures of the environment using the robot camera, details on that will be explained by the experiment observer.

You will also be wearing a belt with eight vibration units (called *tactors*) distributed in cardinal directions that may provide you with feedback on imminent collisions in specific directions. If a tactor is active, the higher the intensity of its vibration is, the closer the robot is to colliding along the tactor's pointing direction. Similarly, the top of the virtual robot may light up in yellow if collision is imminent in the direction the robot top illuminates. If collision actually occurs, the top of the robot will illuminate in red in the direction of the collision. A speedometer presenting current robot speed may also be present.

Furthermore, you may hear sounds through the headset you are wearing. These sounds represent collisions between the robot and the surrounding environment as well as indicate how fast the robot wheels are moving. Last, a vertical bar will be presented on screen indicating the current CO_2 level in the area of the room the robot is in. Besides this visual bar, a fragrance of rosemary may be cast into the air around you with varying intensity that matches the varying amount of CO_2 present in the air surrounding the remote robot.

Before the experiment, you will be asked to fill-in a health-related form reporting your current physical and mental well-being.

You will have to perform a search task with a feedback interface comprised of all or part of these types of displays/feedbacks. The task will be preceded by an interface familiarization period in a special room. After the familiarization period, the real search task will be performed. You will have to search for red circles of about 7 inches in diameter ("victims") that are always going to be located at ground level. You will be asked to perform this search *as fast and effectively as you can*. You will also be asked to memorize victims' locations and report them later on. You will have to move in a closed space through an entrance and exit the environment through an exit door. A timer will count the time you have spent on each search task. During the task, you may see people in the environment. Please, disregard them as they are simply sharing the office space, but not participating in the experiment.

While performing the task, you will also be performing a text-color matching task. You will be presented with text in the middle of the screen with one of the following words: “red”, “green”, “blue”. If the color of the text font matches the string description, you have to press the button with the green triangle. If they do not match, you will have to press the button with a red circle to indicate that. Hence, you should respond as soon as you notice the text on screen and as fast as you can. Once you press either of these two buttons, the text will disappear. The text also disappears after a while if no button is pressed, so you should respond to the text as soon you see it.

Following the search task you will be asked to draw a map identifying the number and location of each of the red circles relative to other objects in the environment. You will be able to use the pictures you took to help you with that.

After drawing the map, you will be asked once again to fill-in a health-related form reporting your current physical and mental well-being. You will also take a short spatial test.

Finally, after that, you will be given the opportunity to provide any additional comments on the interface, the experiment and the application.

A questionnaire has already collected information about your experience with videogame, computer, robot and remote-controlled vehicles. This is going to be used for demographics of our population of subjects. During the experiment a video will record both you and the computer screen in front of you for the sole purpose of analyzing behavioral changes due to interface use. These videos will be kept confidential and only statistical results derived from them will be directly presented as research results.

Risks to study participants:

The risks to you in participating in this study are minimal. There is, however, a small chance that you will feel nauseated or dizzy during the experiment due to any of the displays used. If this happens, please, ask the experimenter for assistance and the experiment will be interrupted.

Benefits to research participants and others**:**

You will be provided with refreshments (snacks and beverages). If you are attending class that requires you to attend a user study through the SONA system, you will also get the necessary credit(s).

Record keeping and confidentiality:

Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. No data identifying you by name will be collected, and any publication or presentation of the data will not identify you.

You will be given a copy of this consent form for your records; it contains the contact information for the investigator. The investigator's copy will be stored in a locked file cabinet, and retained for a period of 3 years.

Compensation or treatment in the event of injury:

This study will put you at minimal risk. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact me using the information at the top of this page. In addition, you may contact the IRB Chair (Professor Kent Rissmiller, Tel: 508-831-5019, E-Mail: kjr@wpi.edu) and the University Compliance Officer (Michael J. Curley, Tel. 508-831-5519, E-Mail: mjcurley@wpi.edu).

Your participation in this research is voluntary.

Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

_____________________________ Date: ____________________

Study Participant Signature

____

Study Participant Name (Please print)

______________________________________ Date: ____________________

Signature of Person who explained this study

D.1.3 Demographics Collection Form

1. How old are you?
2. Are you claustrophobic?

○ Yes ○ No

3. Are you color blind?

○ Yes ○ No

Comment: If yes, please explain it here.

4. Do you have any hearing problems?

○ Yes ○ No

Comment: If yes, please explain it here.

5. Are you allergic to Rosemary or any smell?

○ Yes ○ No

Comment: If yes, please explain it here.

6. Do you have any olfactory problems or problem distinguishing smells?

○ Yes ○ No

Comment: If yes, please explain it here.

7. How many hours per week do you use computers?

Please click on your answer.

- 1-10 hours
- 11-20 hours
- 21-40 hours
- More than 40 hours

8. How often do you use or work with robots: daily, weekly, seldom or never?

Please click on your answer.

- Daily
- Weekly
- Seldom
- Never

9. How often do you use remote-controlled ground/aerial/aquatic vehicles?

Please click on your answer.

- Daily
- Weekly
- Seldom
- Never

10. How often do you play video-games?

Please click on your answer.

- Daily
- Weekly
- Seldom
- Never

11. How often do you use gamepads or joysticks?

Please click on your answer.

- Daily
- Weekly
- Seldom
- Never

Don't worry about the field below. The experimenter will fill it in when it receives the form from you.
Subject#:

D.1.4 Post-Treatment Questionnaire

Subject #:

Please answer the questions in the empty space following them.

1. How many red circles did you find?
2. Using the pictures taken as a reference and using sketch paper and the pen/pencil and eraser in front of you, please, draw a map of the office room, and locate the red circles with respect to the rooms and debris.
3. How difficult was it to perform the task compared to actually performing it yourself? Please answer on the following 1 to 7 scale.

Please click on your answer.

- ○ 1 (very difficult)
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7 (very easy)

4. Please rate *your sense of being there* in the remote room on the following 1 to 7 scale.

In the remote room I had a sense of "being there" ...

Please click on your answer.

- 1 (not at all)
- 2
- 3
- 4
- 5
- 6
- 7 (very much)

5. To what extent were there times during the experience when the remote room became the "reality" for you, and you almost forgot about the place you are located in? Please answer on the following 1 to 7 scale.

There were times during the experience when the remote room became more real or present for me compared to the place I am located in...

Please click on your answer

- 1 (at no time)
- 2
- 3
- 4
- 5
- 6
- 7 (almost all the time)

6. When you think back about your experience, do you think of the remote room more as *something that you saw*, or more as *somewhere that you visited*? Please answer on the following 1 to 7 scale.

The remote room seems to me to be more like…

Please tick against your answer.

- ○ 1 (something I saw)
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7 (somewhere I visited)

7. When navigating in the remote room did you feel more like *driving* through the room or *walking* in the room? Please answer on the following 1 to 7 scale.

Moving around the remote room seems to me to be more like…

Please click on your answer.

- ○ 1 (driving)
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7 (walking)

8. How easy was it for you to learn how to use the interface? **Make the selection only for the part of the interface that you have experienced.**

Learning how the interface worked was…

	Type of output interface			
Difficulty	Visual	Aural	Vibration	Smell
Very Difficult	◉ 1	◉ 1	○ 1	○ 1
	○ 2	○ 2	○ 2	○ 2
	○ 3	○ 3	○ 3	○ 3
	○ 4	○ 4	○ 4	○ 4
	○ 5	○ 5	○ 5	○ 5
	○ 6	○ 6	○ 6	○ 6
Very easy	○ 7	○ 7	○ 7	○ 7

9. How confusing was the interface?

Make the selection only for the part of the interface that you have experienced.

Understanding the information the interface was presenting was…

Type of output interface

Understanding	Visual	Sound	Vibration	Smell
Confusing	○ 1	○ 1	○ 1	○ 1
	○ 2	○ 2	○ 2	○ 2
	○ 3	○ 3	○ 3	○ 3
	○ 4	○ 4	○ 4	○ 4
	○ 5	○ 5	○ 5	○ 5
	○ 6	○ 6	○ 6	○ 6
Straight-forward	○ 7	○ 7	○ 7	○ 7

10. How distracting was the feedback provided by the interface?

Make the selection only for the part of the interface that you have experienced.

The feedback provided by the interface…

Type of output interface

Feedback	Visual	Sound	Vibration	Smell
Caused distraction	○ 1	○ 1	○ 1	○ 1
	○ 2	○ 2	○ 2	○ 2
	○ 3	○ 3	○ 3	○ 3
	○ 4	○ 4	○ 4	○ 4
	○ 5	○ 5	○ 5	○ 5
	○ 6	○ 6	○ 6	○ 6
Did not distract me	○ 7	○ 7	○ 7	○ 7

11. How comfortable was using the interface?

Make the selection only for the part of the interface that you have experienced.

Using the interface was...

Type of output interface

Use	Visual	Sound	Vibration	Smell
Very uncomfortable	○ 1	○ 1	○ 1	○ 1
	○ 2	○ 2	○ 2	○ 2
	○ 3	○ 3	○ 3	○ 3
	○ 4	○ 4	○ 4	○ 4
	○ 5	○ 5	○ 5	○ 5
	○ 6	○ 6	○ 6	○ 6
Very comfortable	○ 7	○ 7	○ 7	○ 7

12. How much did the interface help you understand the environment?

Make the selection only for the part of the interface that you have experienced.

Using the interface impacted my understanding of the environment in a…

Type of output interface

Impact	Visual	Sound	Vibration	Smell
Negative way	○ 1	○ 1	○ 1	○ 1
	○ 2	○ 2	○ 2	○ 2
	○ 3	○ 3	○ 3	○ 3
	○ 4	○ 4	○ 4	○ 4
	○ 5	○ 5	○ 5	○ 5
	○ 6	○ 6	○ 6	○ 6
Positive way	○ 7	○ 7	○ 7	○ 7

13. Please provide any comments about the robot interface.

14. Do you have any comments about the experiment in general?

15. If you wish to know about the final results of this experiment, please, provide us with your e-mail address:

D.1.5 Health Form

Subject #:

Please, report below how you are currently feeling.

SSQ Symptom	***Intensity***		
	None	*Slight*	*Moderate*
General discomfort	○	○	○
Fatigue	○	○	○
Headache	○	○	○
Eyestrain	○	○	○
Difficulty focusing	○	○	○
Increased salivation	○	○	○
Sweating	○	○	○
Nausea	○	○	○
Difficulty concentrating	○	○	○
Fullness of head	○	○	○
Blurred vision	○	○	○
Dizzy (eyes open)	○	○	○
Dizzy (eyes closed)	○	○	○
Vertigo	○	○	○
Stomach awareness	○	○	○
Burping	○	○	○

1.1.1 Spatial Aptitude Test

The same test as in study #2 was used for study #3. Please, see appendix B.1.6 for details.

1.1.2 Instructor Script

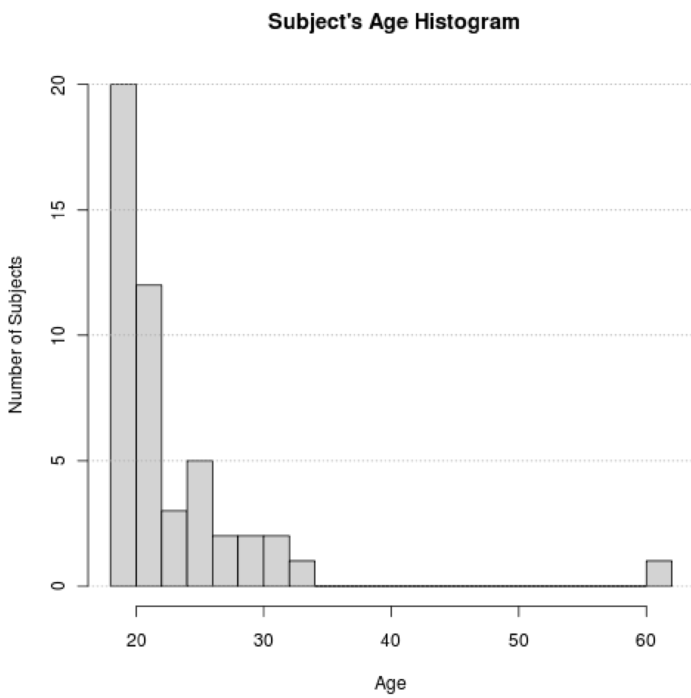
A script similar to the one in study#2 was used with small alterations.

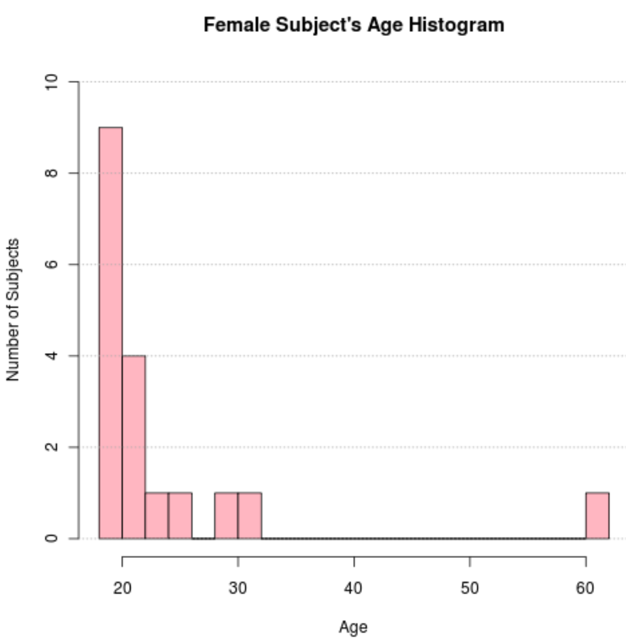
D.2 Data Analysis

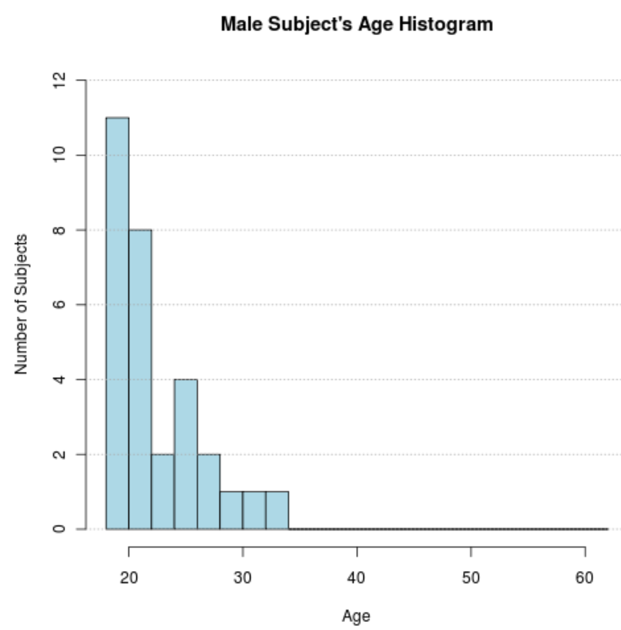
The section contains all the data collected for study #3 as well as the statistical analysis performed on it. In the section, subsections whose title is marked with an asterisk (*) contain statistically significant differences (SSD) in the data analysis. If the title of a subsection is marked with a plus sign (+) after it, it means trends are present in its data analysis.

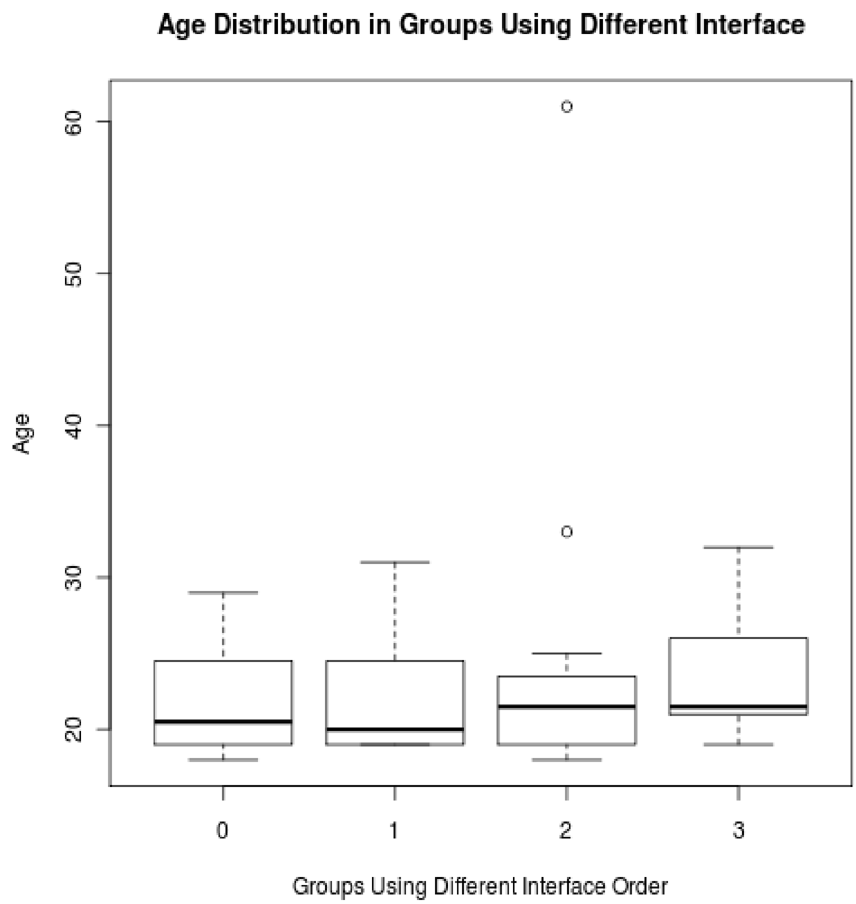
D.2.1 Population

D.2.1.1 Age







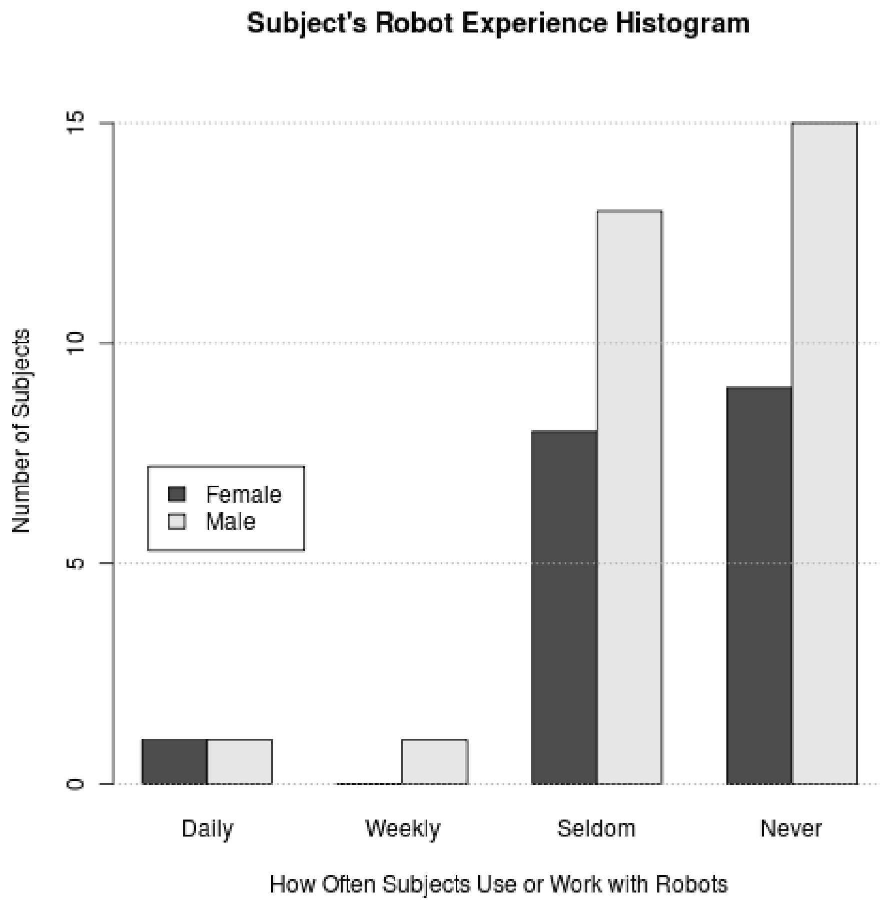


One-way ANOVA: Interface vs. Age (interfaceVSAgeAOV)					
	Df	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	78.060	26.021	0.544	0.655
Residuals	44	2104.750	47.835		

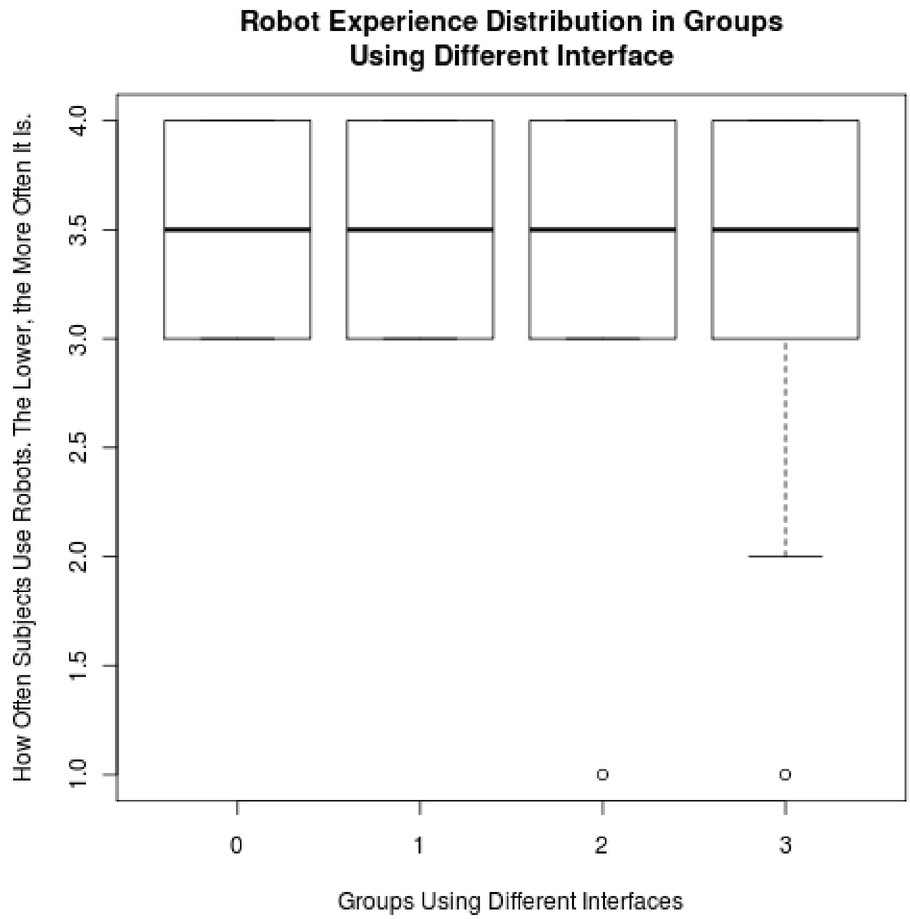
Age vs.Interface Used Friedman test:	
X^2	0.462
p	0.927
DoF	3

Subject Count	UI1	UI2	UI3	UI4
1	19	19	19	21
2	19	20	22	21
3	20	20	22	19
4	20	31	19	26
5	21	19	20	22
6	21	19	21	20
7	29	27	22	23
8	19	19	33	21
9	18	21	18	21
10	28	19	18	29
11	26	23	61	32
12	23	26	25	26

D.2.1.2 Robot Experience



Subject Count	UI1	UI2	UI3	UI4
1	4	4	4	4
2	4	4	4	3
3	4	4	3	1
4	3	4	4	4
5	3	4	4	3
6	3	4	3	3
7	3	3	1	4
8	3	3	3	2
9	4	3	3	4
10	3	3	4	4
11	4	3	4	4
12	4	3	3	3

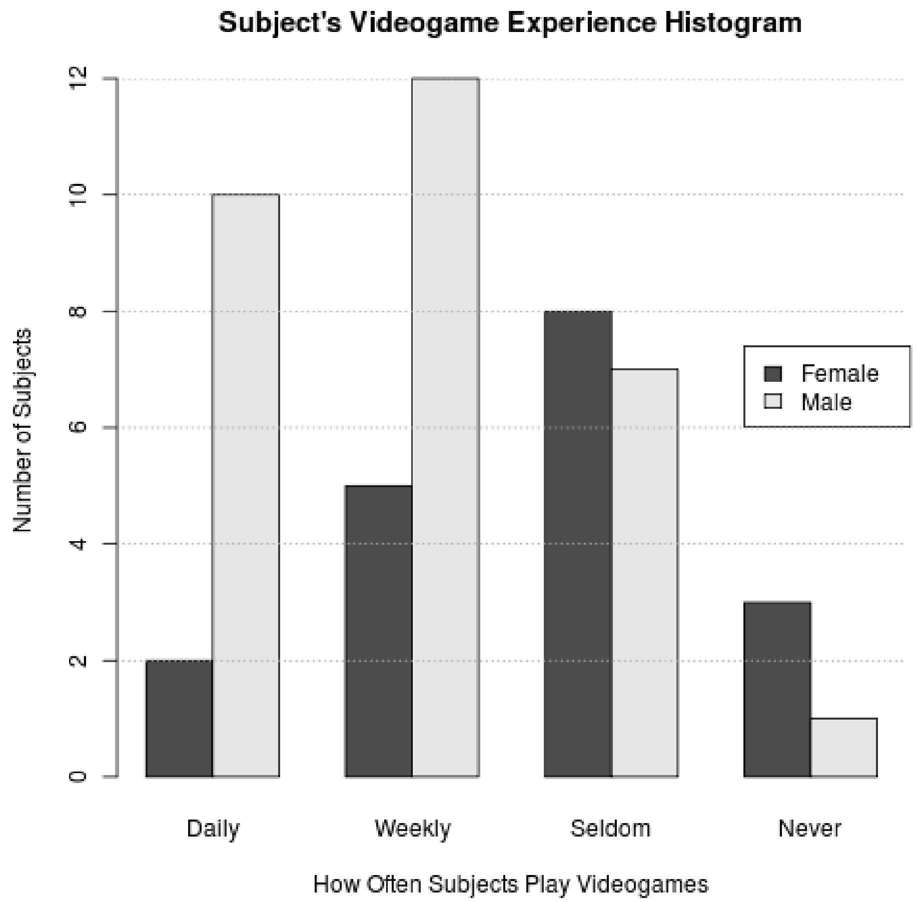


One-way ANOVA: Robot Experience vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.563	0.188	0.331	0.803
Residuals	44	24.917	0.566		

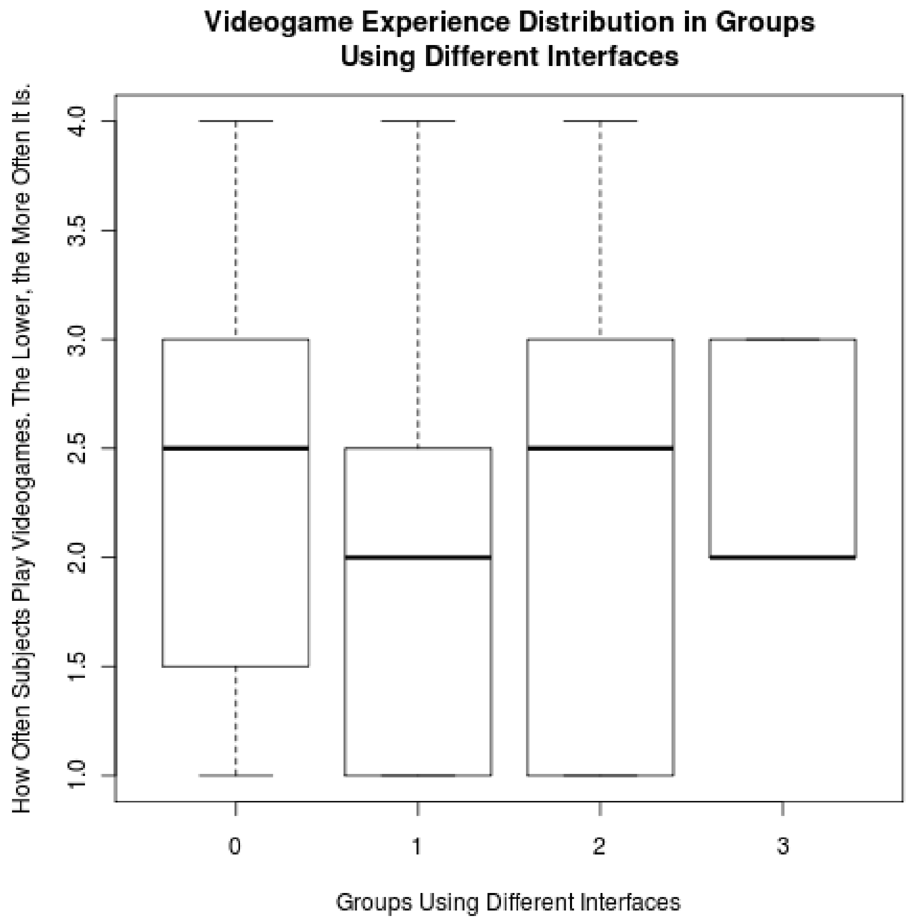
Robot Experience vs. Interface Used Friedman test:	
X^2	0.462
p	0.927
DoF	3

Robot Experience vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	3.500	0.520	3.500
2	3.500	0.520	3.500
3	3.330	0.890	3.500
4	3.250	0.970	3.500

D.2.1.3 Videogame Experience



Subject Count	UI1	UI2	UI3	UI4
1	4	4	1	2
2	2	2	2	2
3	2	1	3	2
4	1	2	1	3
5	1	3	4	3
6	3	1	3	2
7	3	2	3	2
8	2	1	1	2
9	4	3	1	2
10	3	1	3	3
11	3	2	3	3
12	1	1	2	2

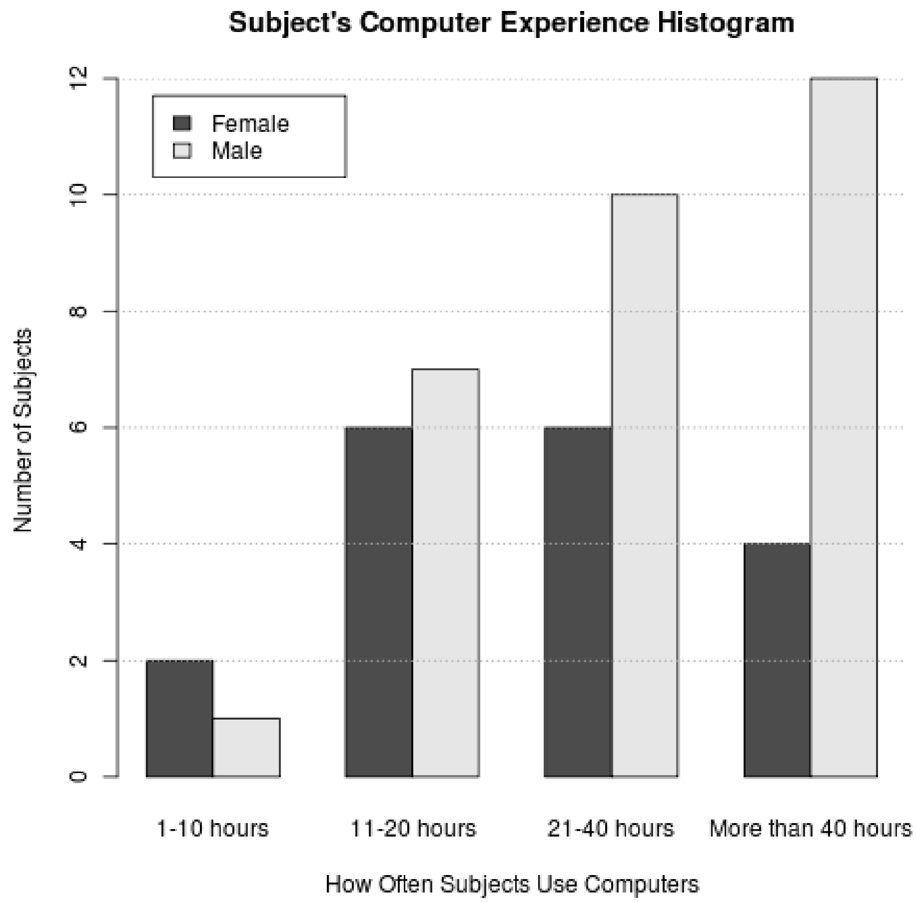


One-way ANOVA: Videogame Experience vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	1.729	0.576	0.655	0.584
Residuals	44	38.750	0.881		

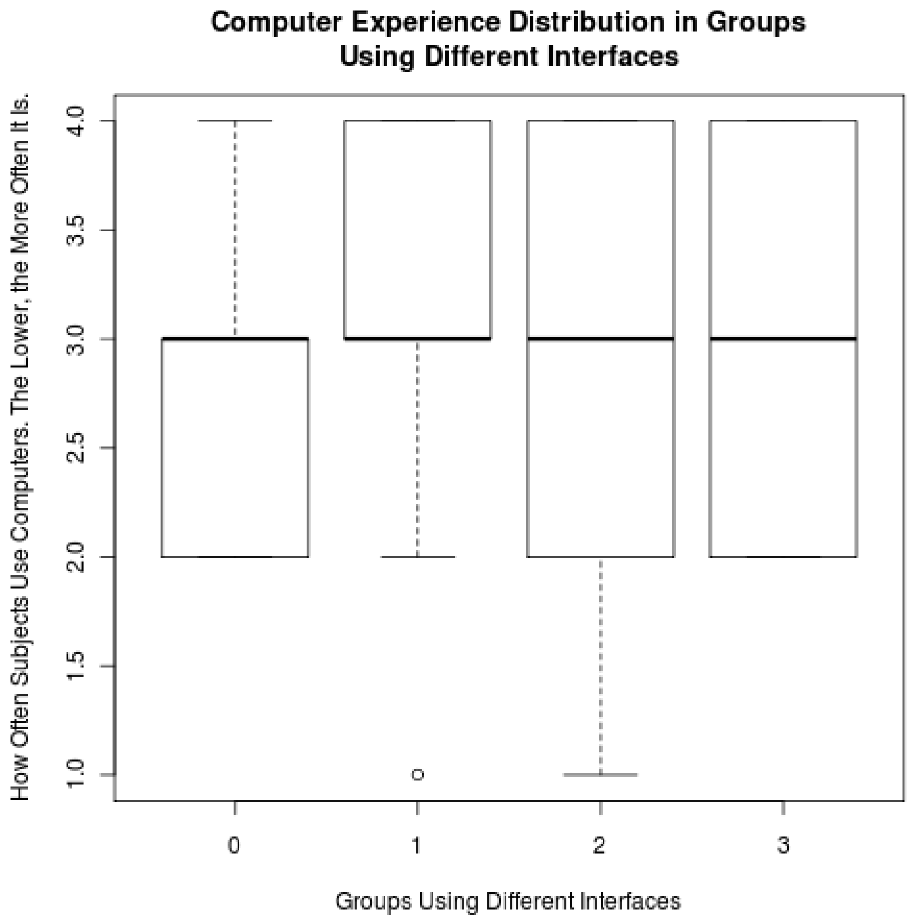
Videogame Experience vs. Interface Used Friedman test:	
X^2	4.352
p	0.226
DoF	3

Videogame Experience vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	2.420	1.080	2.500
2	1.920	1.000	2.000
3	2.250	1.060	2.500
4	2.330	0.490	2.000

D.2.1.4 Computer Experience



Subject Count	UI1	UI2	UI3	UI4
1	2	3	4	2
2	3	3	2	3
3	4	3	1	4
4	3	4	4	4
5	4	3	3	4
6	3	3	3	2
7	2	4	2	2
8	3	4	4	4
9	2	2	2	3
10	3	1	3	2
11	2	4	1	2
12	3	4	4	4

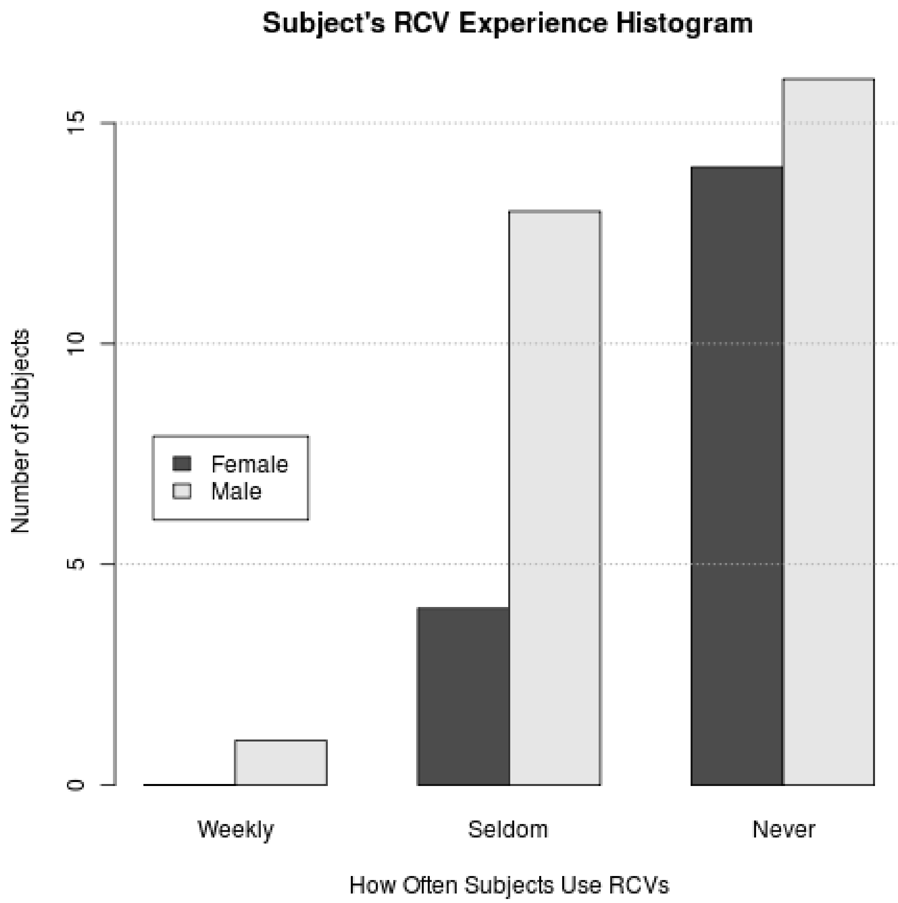


One-way ANOVA: Computer Experience vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	1.229	0.410	0.455	0.715
Residuals	44	39.583	0.900		

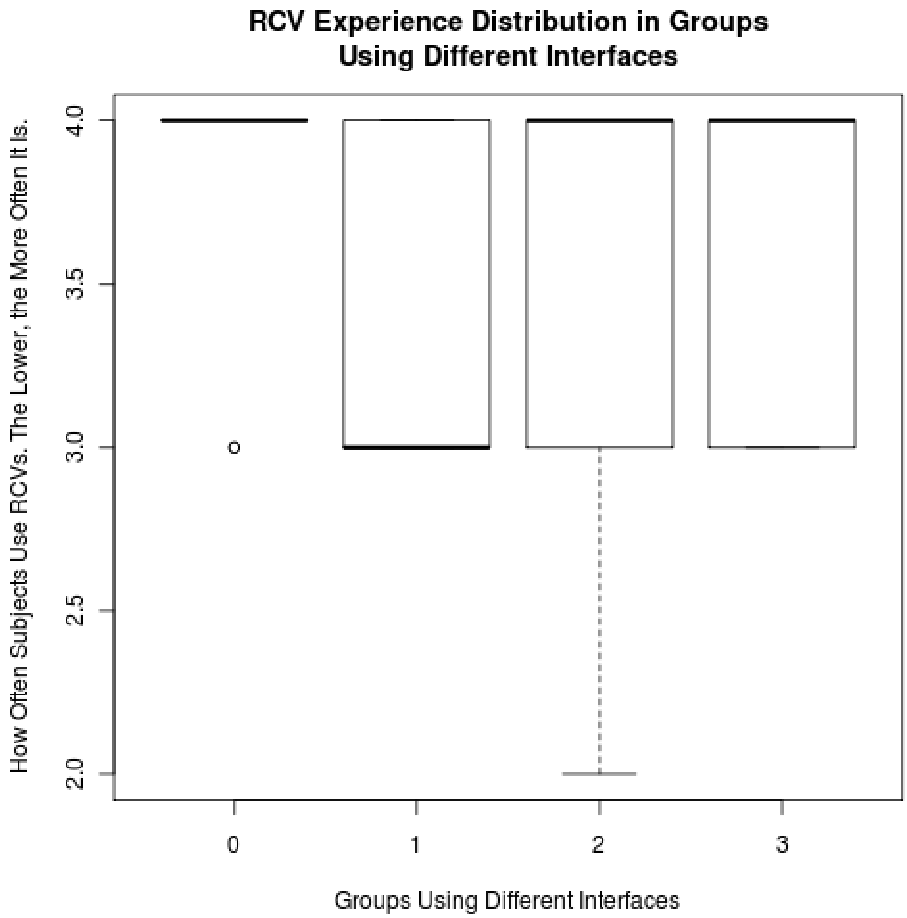
Computer Experience vs. Interface Used Friedman test:	
X^2	1.430
p	0.698
DoF	3

Computer Experience vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	2.830	0.720	3.000
2	3.170	0.940	3.000
3	2.750	1.140	3.000
4	3.000	0.950	3.000

D.2.1.5 Remote-Controlled Vehicle Experience



Subject Count	UI1	UI2	UI3	UI4
1	4	4	4	4
2	4	3	4	3
3	4	4	4	3
4	4	4	4	3
5	4	4	4	4
6	3	4	3	4
7	4	3	2	4
8	4	3	3	3
9	4	3	4	4
10	3	3	4	4
11	4	3	4	4
12	4	3	3	3

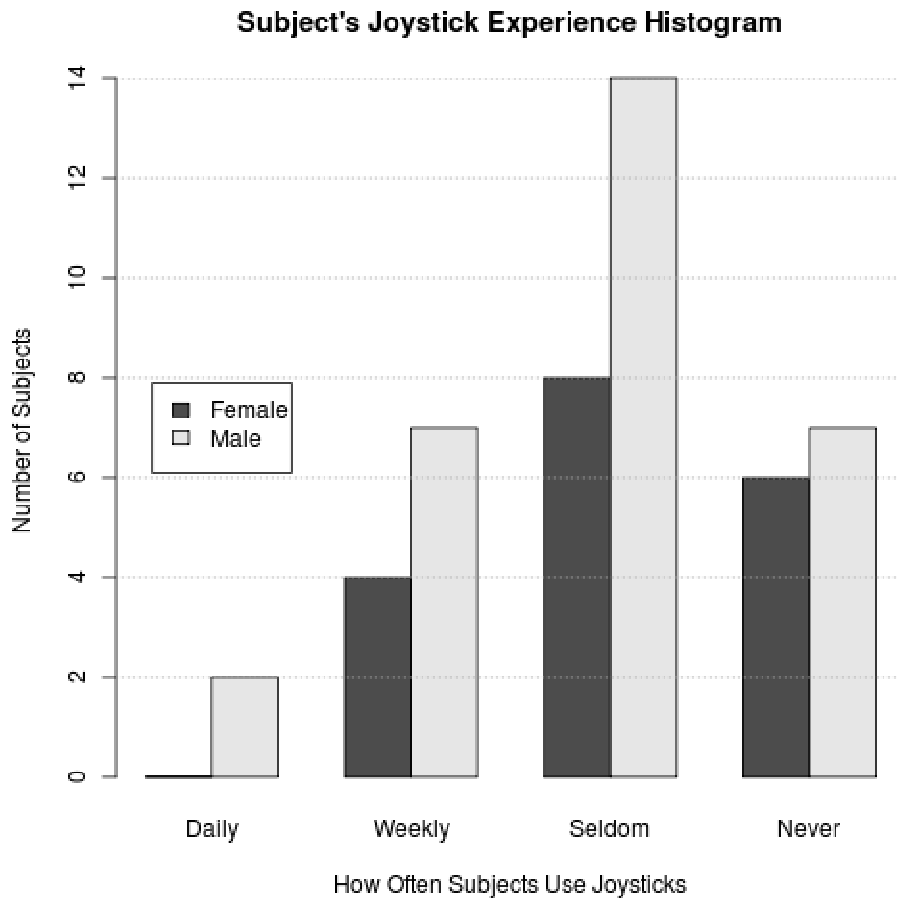


One-way ANOVA: Remote-Controlled Vehicle Experience vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	1.063	0.354	1.255	0.301
Residuals	44	12.417	0.282		

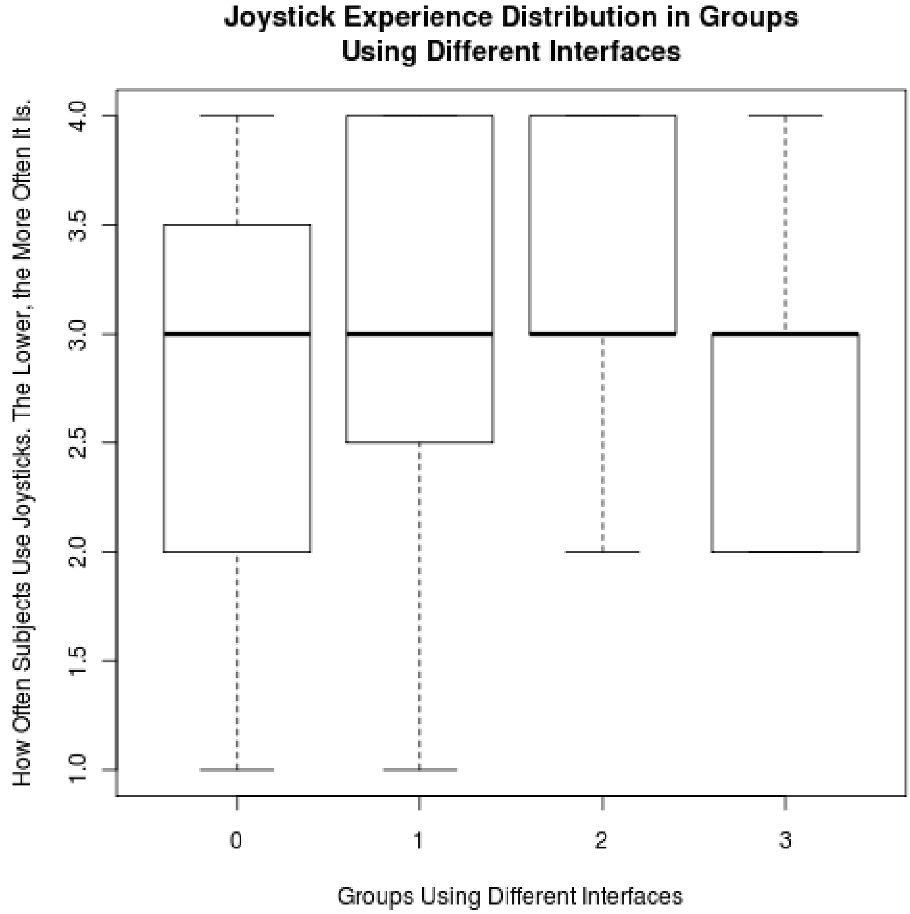
Remote-Controlled Vehicle Experience vs. Interface Used Friedman test:	
X^2	4.043
p	0.257
DoF	3

Remote-Controlled Vehicle Experience vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	3.830	0.390	4.000
2	3.420	0.510	3.000
3	3.580	0.670	4.000
4	3.580	0.510	4.000

D.2.1.6 Joystick Experience



Subject Count	UI1	UI2	UI3	UI4
1	4	4	3	4
2	2	4	4	3
3	3	1	3	2
4	2	3	2	3
5	2	4	4	3
6	3	4	4	4
7	4	2	4	2
8	3	3	3	2
9	4	3	3	2
10	3	3	3	3
11	3	2	3	3
12	1	3	3	2

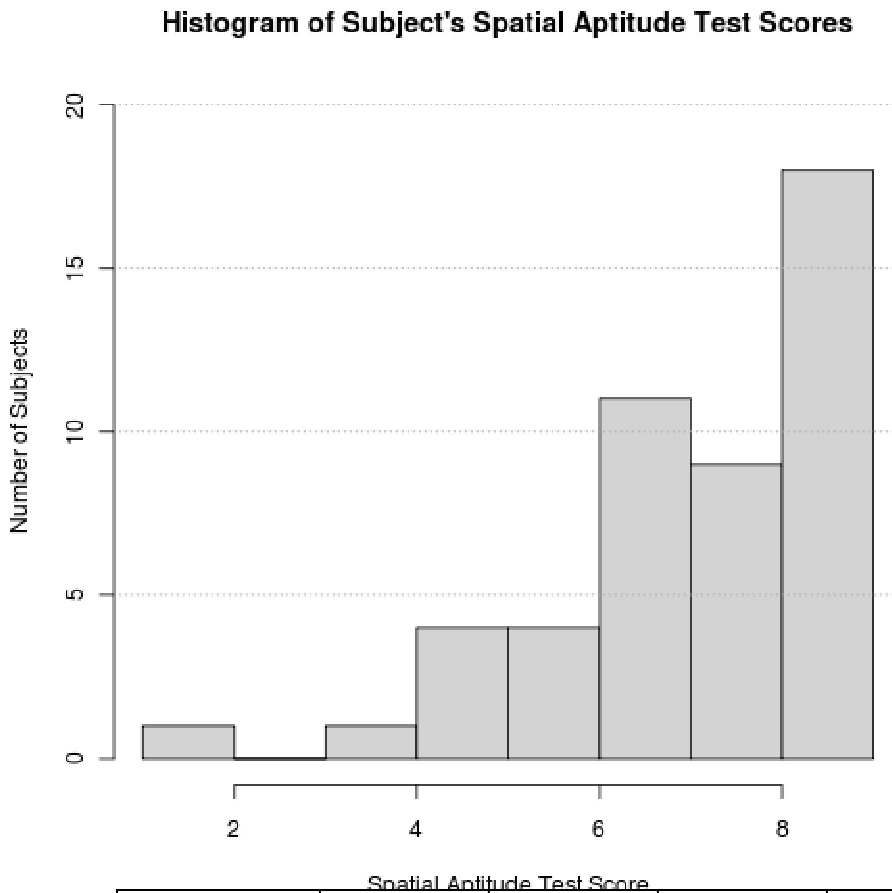


One-way ANOVA: Joystick Experience vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	1.750	0.583	0.851	0.474
Residuals	44	30.167	0.686		

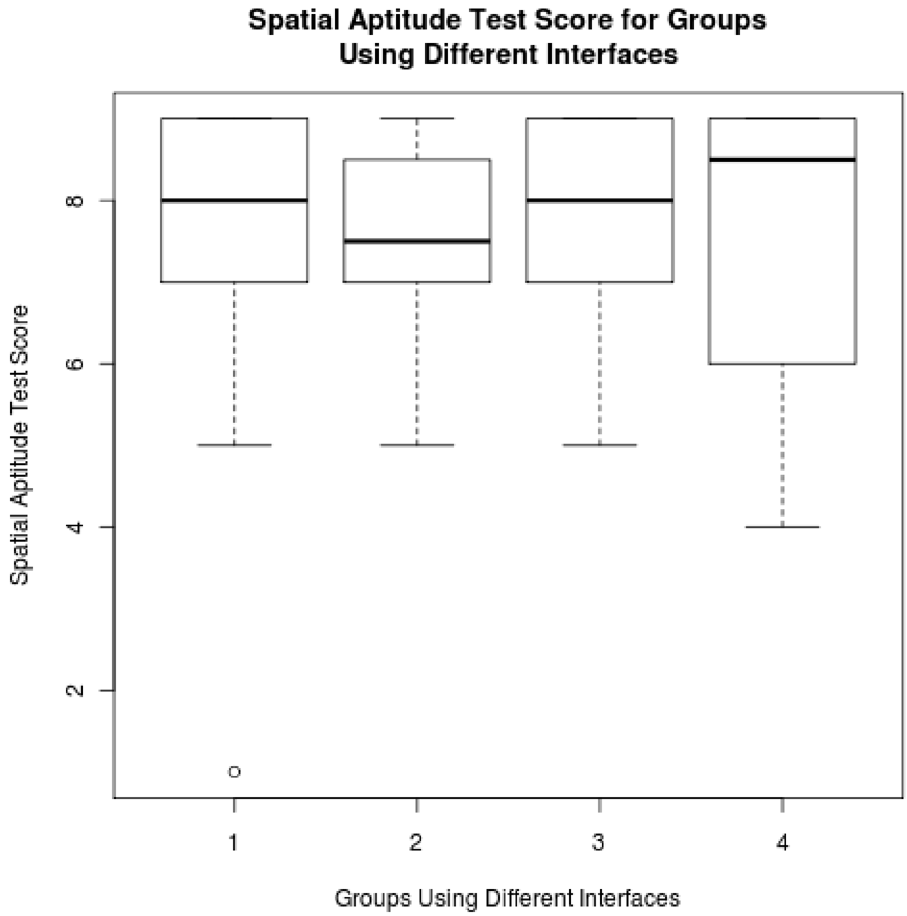
Joystick Experience vs. Interface Used Friedman test:	
X^2	2.435
p	0.487
DoF	3

Joystick Experience vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	2.830	0.940	3.000
2	3.000	0.950	3.000
3	3.250	0.620	3.000
4	2.750	0.750	3.000

D.2.1.7 Spatial Aptitude



Subject Count	UI1	UI2	UI3	UI4
1	7	6	7	6
2	9	5	9	9
3	8	9	9	6
4	8	7	9	5
5	9	8	6	9
6	9	7	8	9
7	7	8	8	9
8	7	7	9	8
9	9	7	7	9
10	5	9	7	4
11	1	8	5	9
12	9	9	8	7

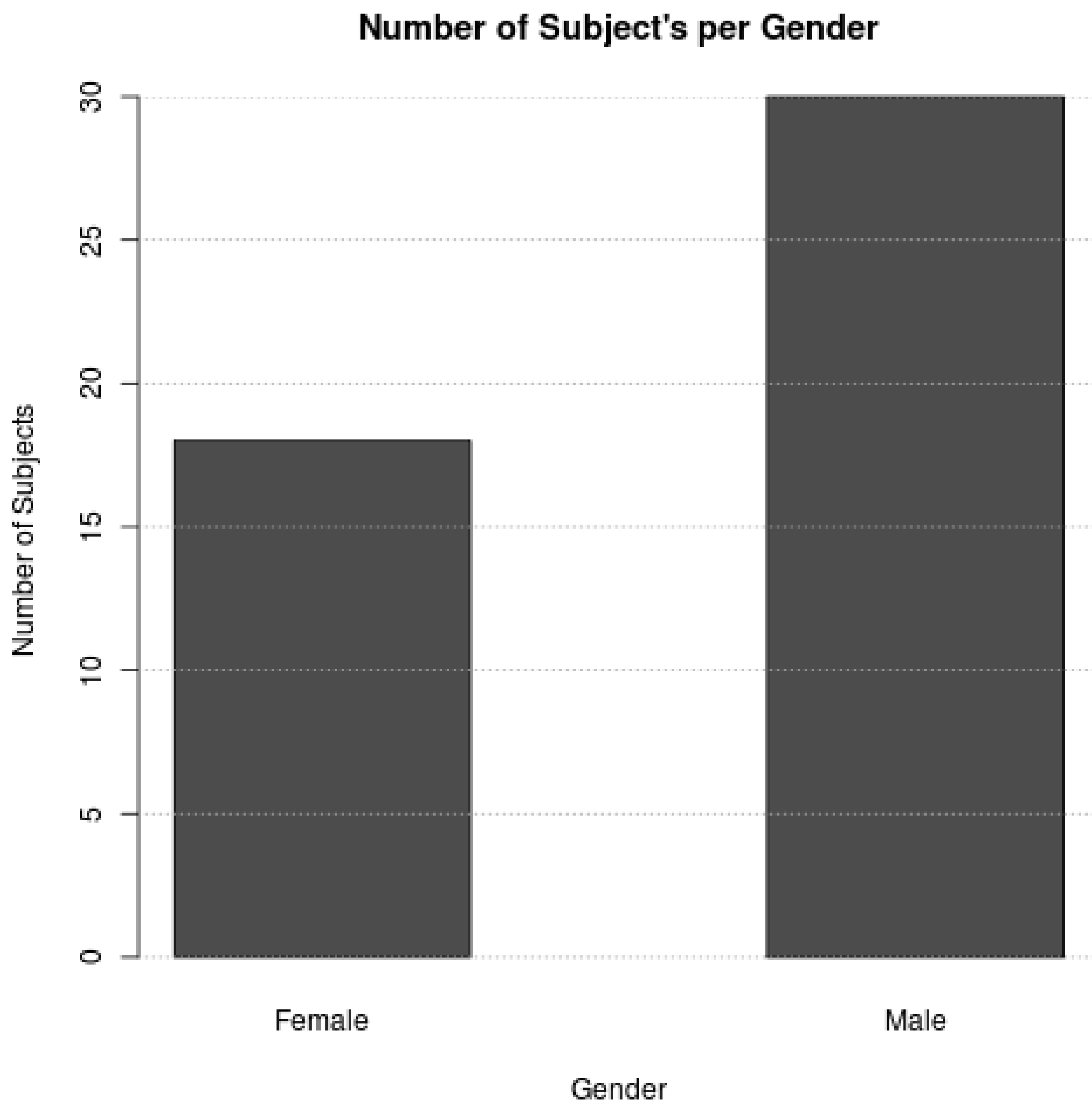


One-way ANOVA: Spatial Aptitude vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.667	0.222	0.073	0.974
Residuals	44	133.333	3.030		

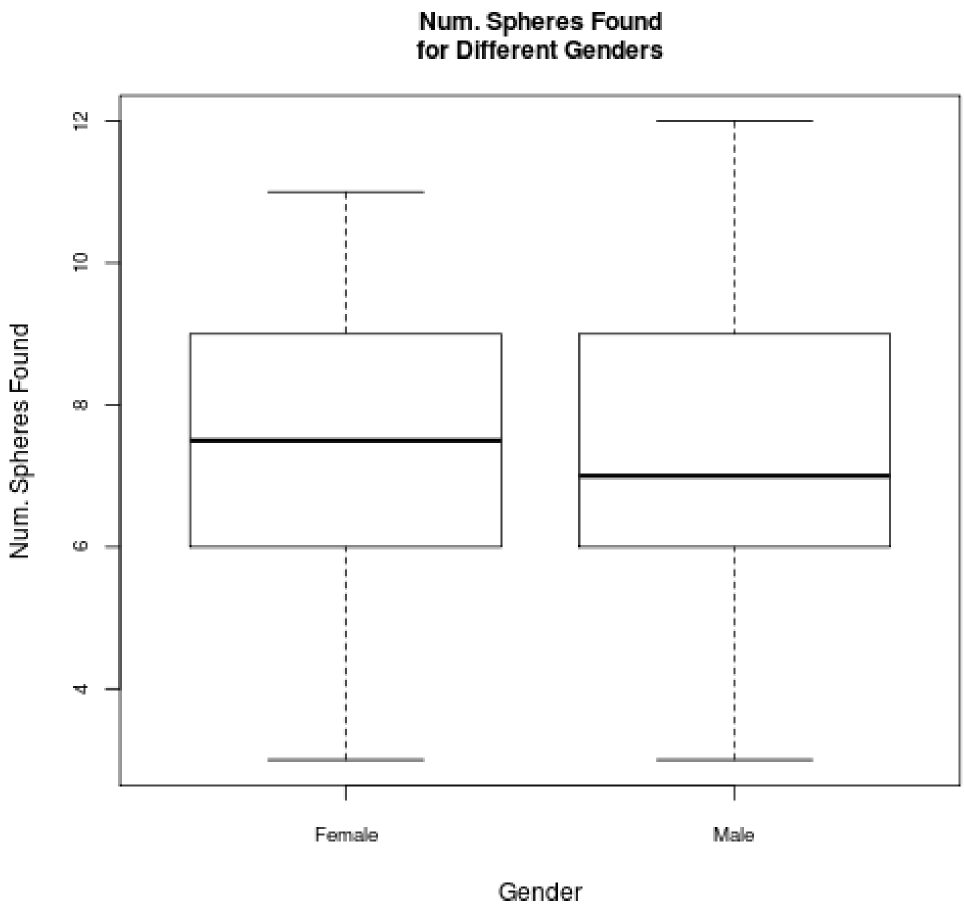
Spatial Aptitude vs. Interface Used Friedman test:	
X^2	0.792
p	0.851
DoF	3

Spatial Aptitude vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	7.420	1.440	7.500
2	7.750	1.600	8.500
3	8.080	1.240	8.500
4	6.750	2.220	7.000

D.2.1.8 Gender Distribution



D.2.1.8.1 Gender vs. Number of Spheres Found

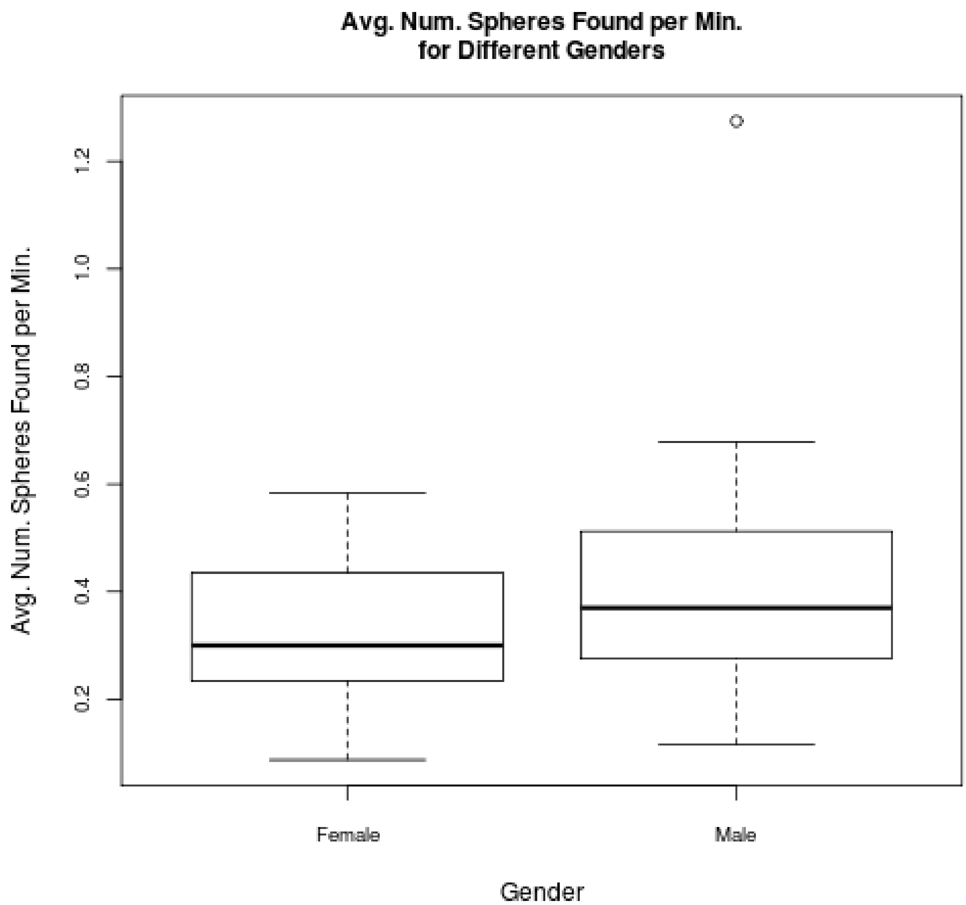


One-way ANOVA: Gender vs. Num. Spheres Found					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	0.672	0.672	0.131	0.719
Residuals	46	236.578	5.143		

Gender vs. Num. Spheres Found Kruskal-Wallis test:	
X^2	0.026
DoF	1
p	0.872

Gender vs. Num. Spheres Found Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
Female	7.222	2.340	7.500
Male	7.467	2.224	7.000

D.2.1.8.2 Gender vs. Number of Spheres Found per Minute

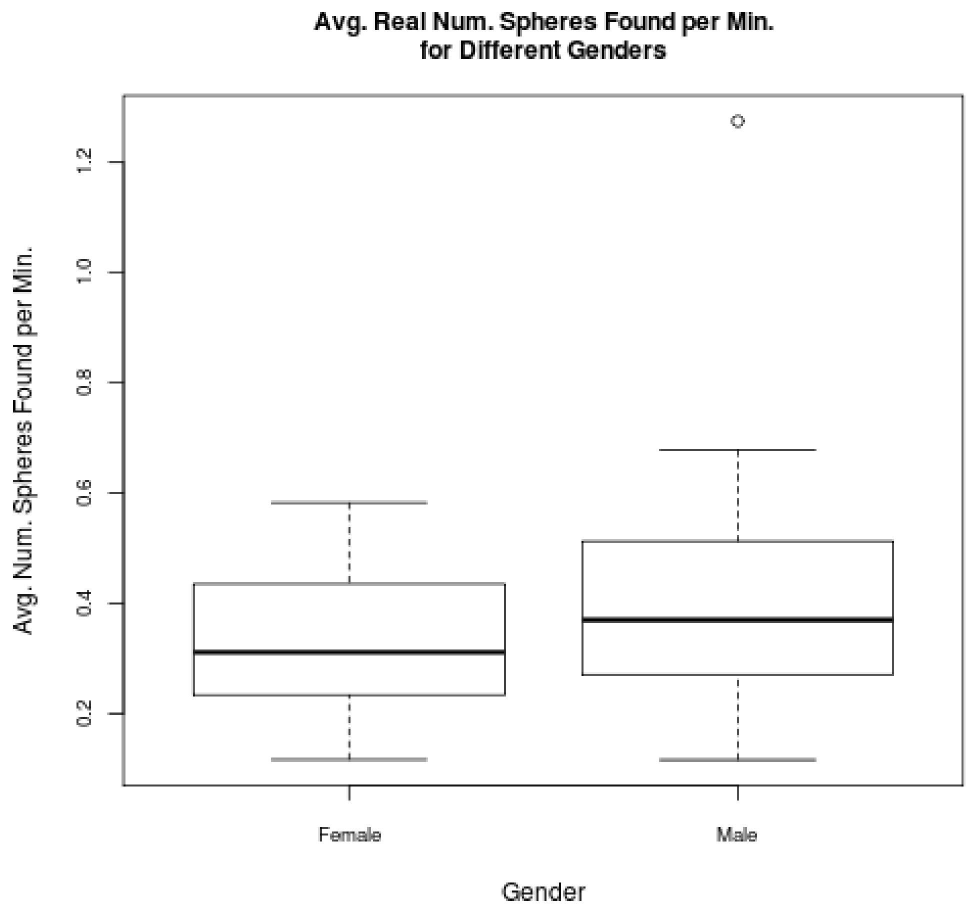


One-way ANOVA: Gender vs. Num. Spheres Found per Minute					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	0.095	0.095	2.520	0.119
Residuals	46	1.742	0.038		

Gender vs. Num. Spheres Found per Minute – Kruskal-Wallis test:	
X^2	1.916
DoF	1
p	0.166

Gender vs. Num. Spheres Found per Minute Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
Female	0.316	0.133	0.292
Male	0.408	0.223	0.370

D.2.1.8.3 Gender vs. Real Number of Spheres Found per Minute

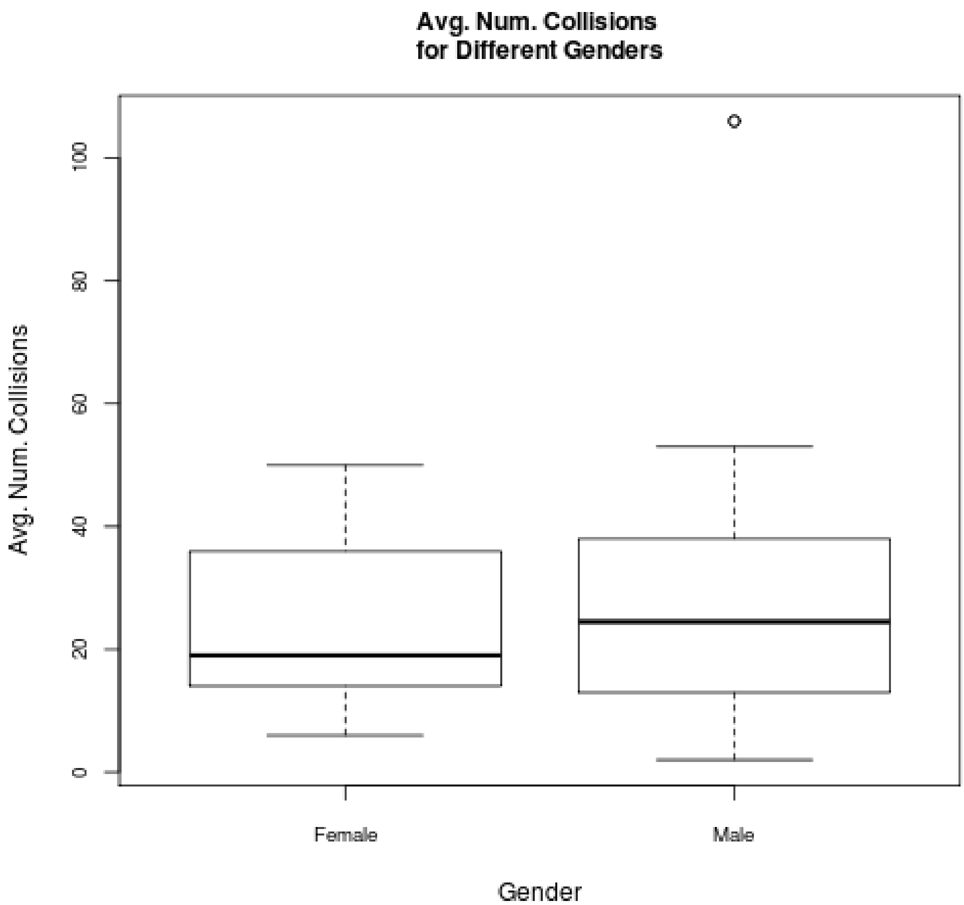


One-way ANOVA: Gender vs. Real Num. Spheres Found per Minute					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	0.101	0.101	2.721	0.106
Residuals	46	1.701	0.037		

Gender vs. Real Num. Spheres Found per Minute – Kruskal-Wallis test:	
X^2	2.351
DoF	1
p	0.125

Gender vs. Real Num. Spheres Found per Minute Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
Female	0.314	0.127	0.297
Male	0.409	0.222	0.370

D.2.1.8.4 Gender vs. Number of Collisions

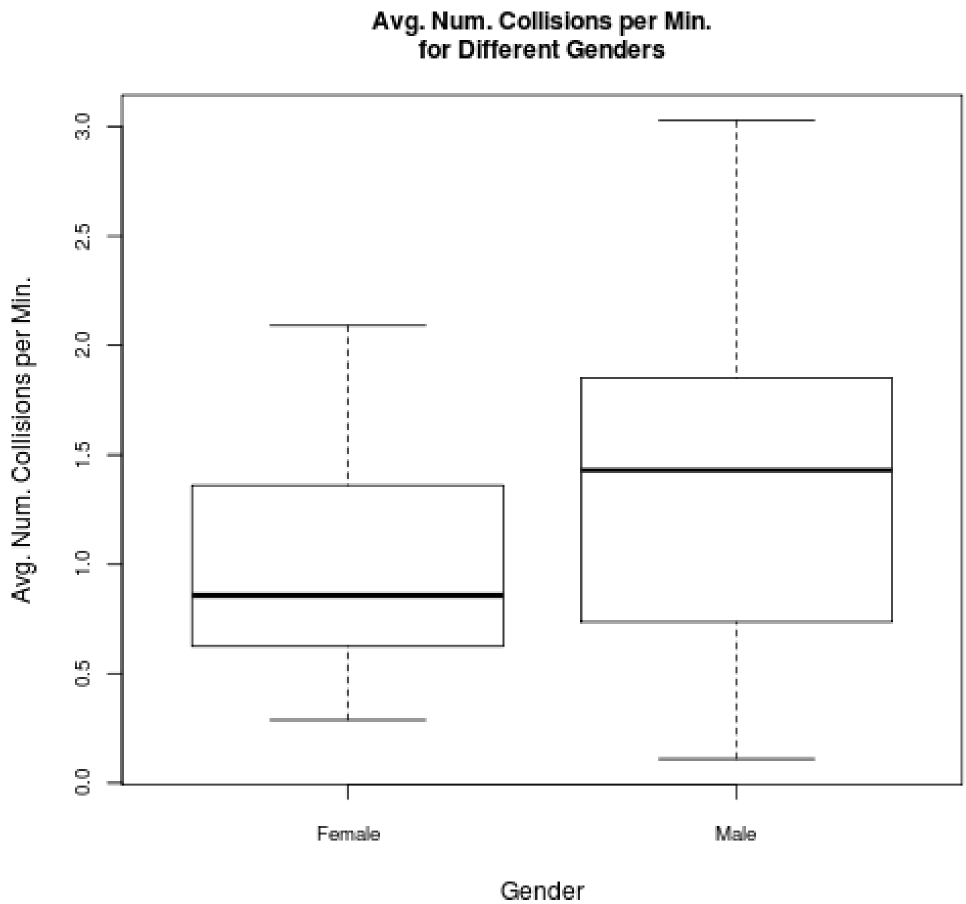


One-way ANOVA: Gender vs. Num. Collisions					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	510.100	510.050	1.130	0.293
Residuals	46	20759.200	451.290		

Gender vs. Num. Collisions Kruskal-Wallis test:	
X^2	0.673
DoF	1
p	0.412

Gender vs. Num. Collisions Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
Female	23.167	14.076	19.000
Male	29.900	24.488	24.500

D.2.1.8.5 Gender vs. Number of Collisions per Minute

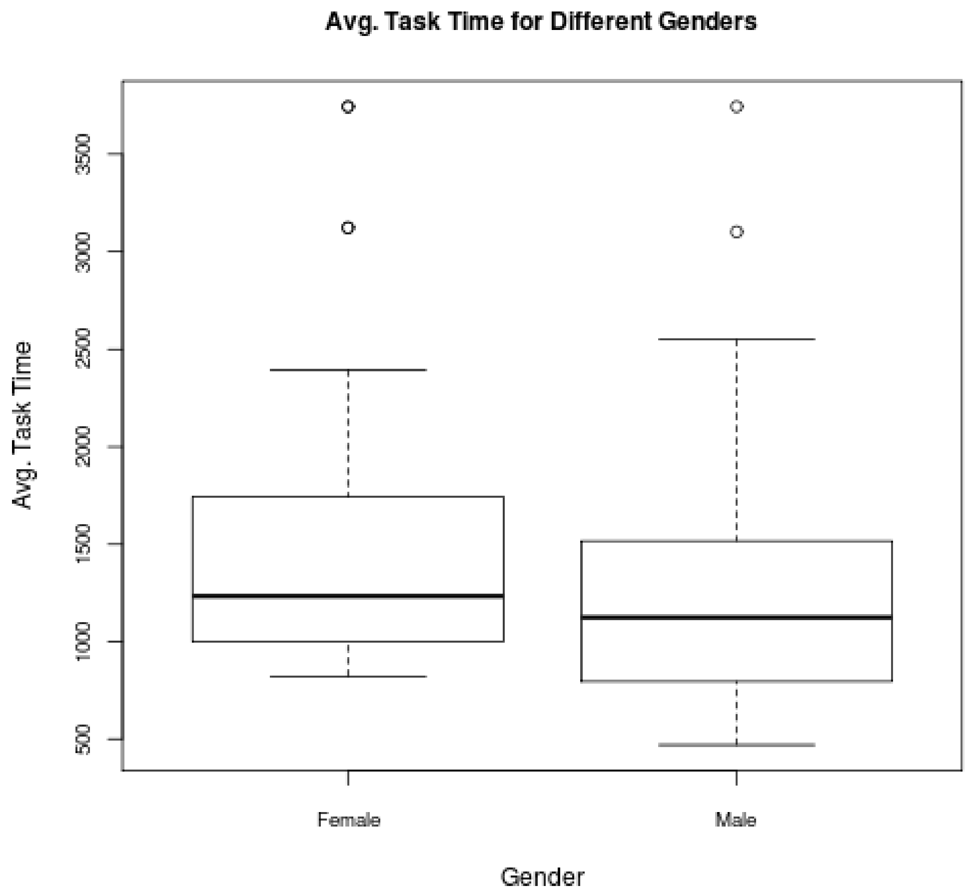


One-way ANOVA: Gender vs. Num. Collisions per Minute					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	2.188	2.188	4.477	0.040
Residuals	46	22.486	0.489		

Gender vs. Num. Collisions per Minute – Kruskal-Wallis test:	
X^2	3.673
DoF	1
p	0.055

Gender vs. Num. Collisions per Minute Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
Female	0.952	0.502	0.857
Male	1.393	0.792	1.430

D.2.1.8.6 Gender vs. Task Time

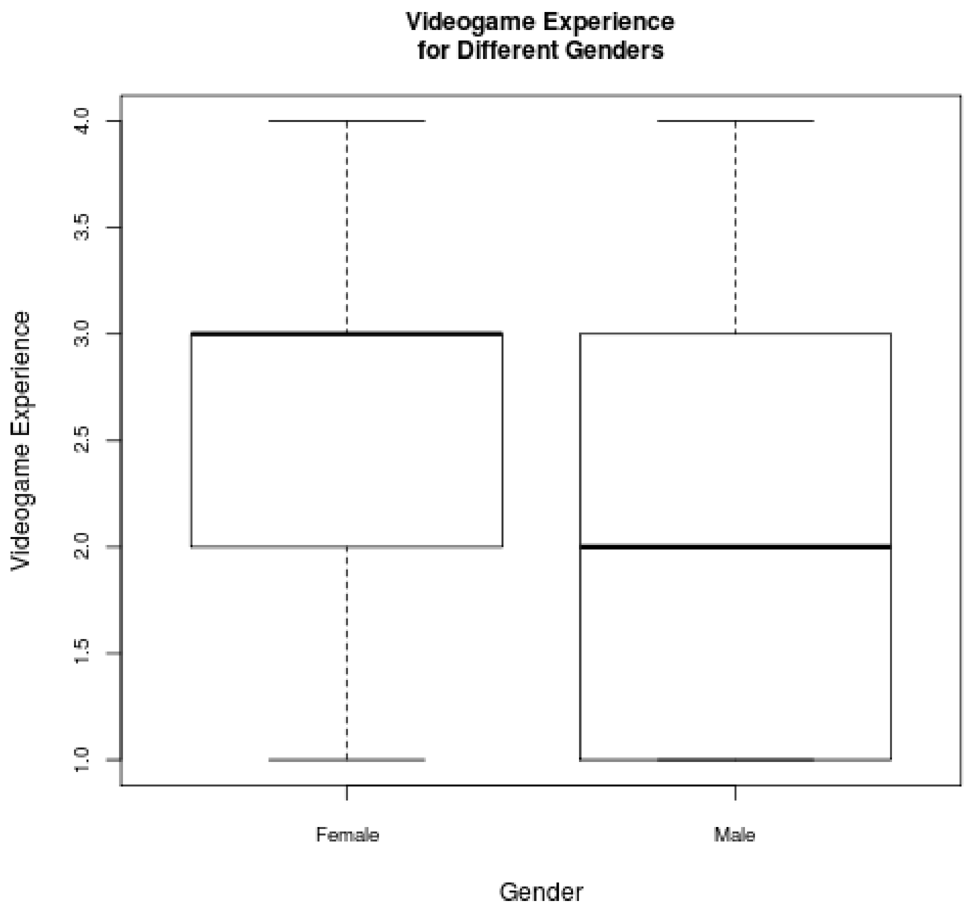


One-way ANOVA: Gender vs.Task Time					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	690833.000	690833.000	1.193	0.280
Residuals	46	26632809.000	578974.000		

Gender vs.Task Time Kruskal-Wallis test:	
X^2	1.975
DoF	1
p	0.160

Gender vs.Task Time Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
Female	1574.807	813.672	1279.935
Male	1327.002	728.195	1124.155

D.2.1.8.7 Gender vs. Videogame Experience

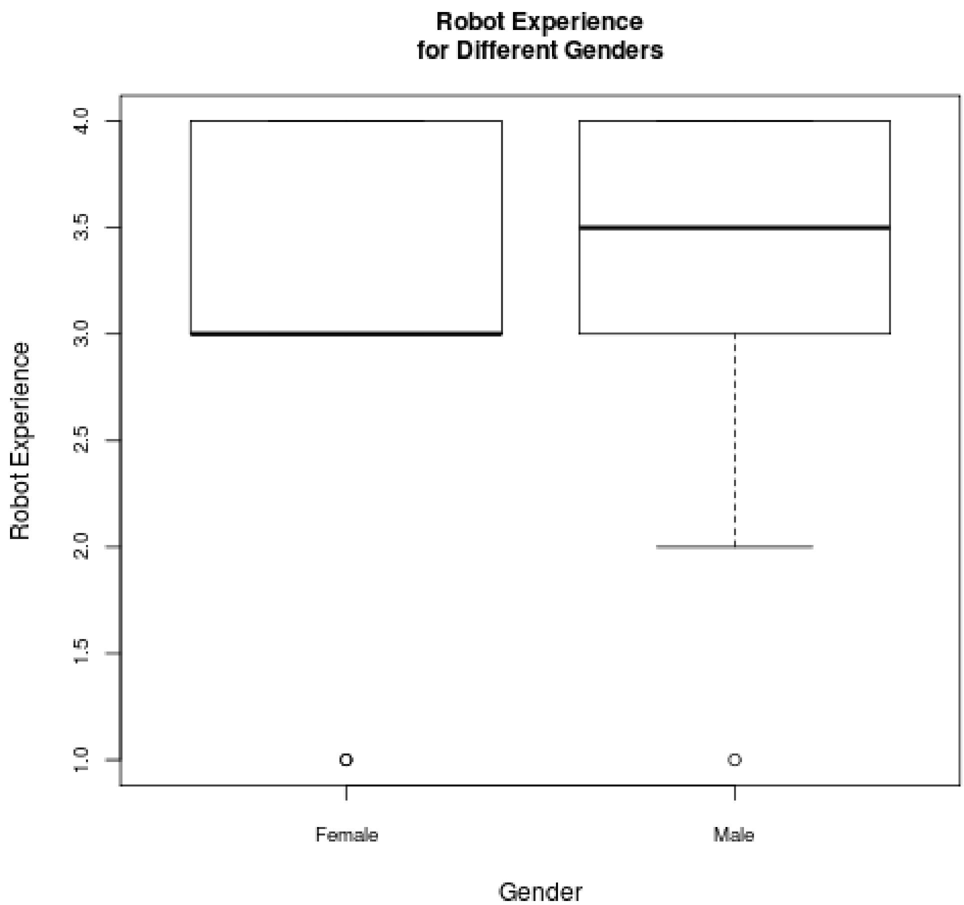


One-way ANOVA: Gender vs. Videogame Experience					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	5.512	5.513	7.252	0.010
Residuals	46	34.967	0.760		

Gender vs. Videogame Experience Kruskal-Wallis test:	
X^2	6.313
DoF	1
p	0.012

Gender vs. Videogame Experience Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
Female	2.667	0.907	3.000
Male	1.967	0.850	2.000

D.2.1.8.8 Gender vs. Robot Experience

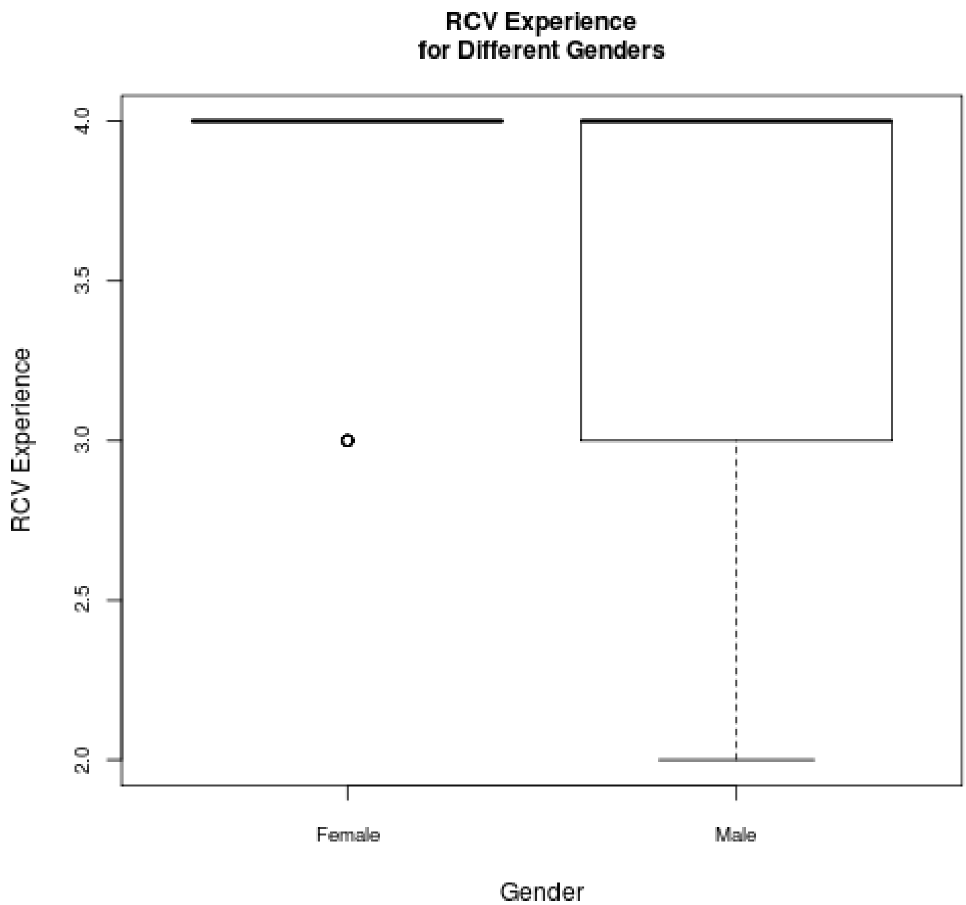


One-way ANOVA: Gender vs. Robot Experience					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	0.001	0.001	0.003	0.960
Residuals	46	25.478	0.554		

Gender vs. Robot Experience Kruskal-Wallis test:	
X^2	0.001
DoF	1
p	0.981

Gender vs. Robot Experience Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
Female	3.389	0.778	3.500
Male	3.400	0.724	3.500

D.2.1.8.9 Gender vs. RCV Experience

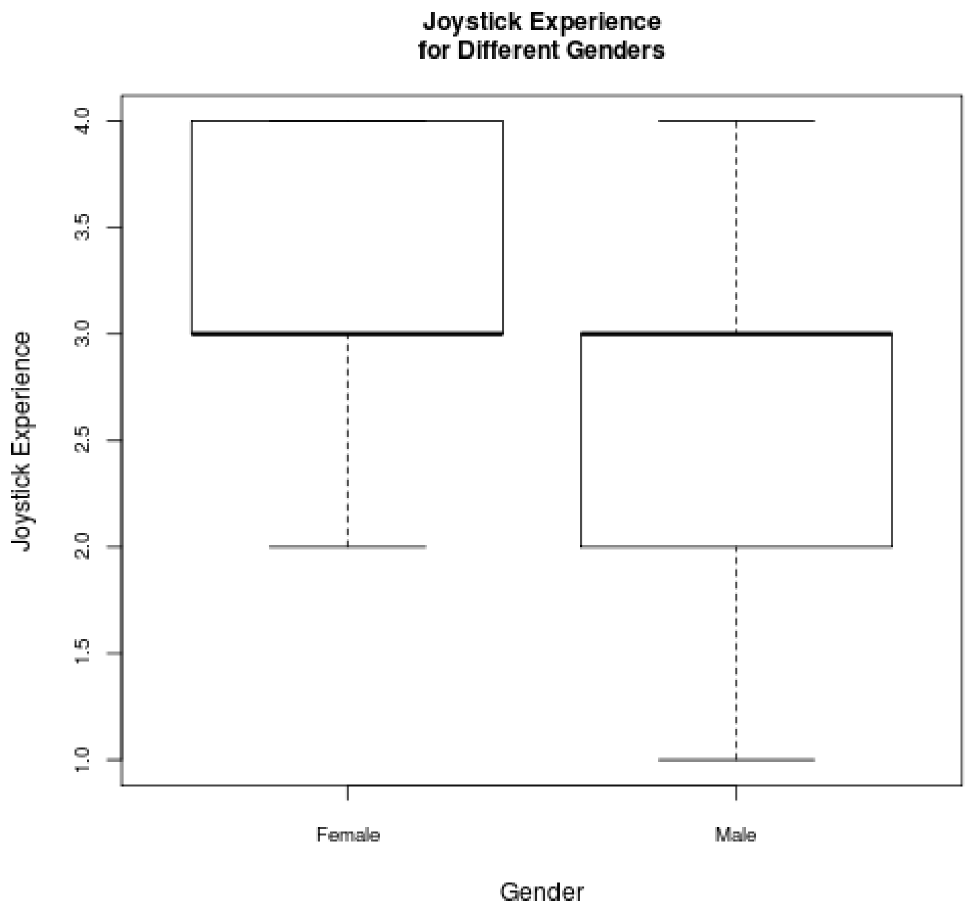


One-way ANOVA: Gender vs. RCV Experience					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	0.868	0.868	3.166	0.082
Residuals	46	12.611	0.274		

Gender vs. RCV Experience Kruskal-Wallis test:	
X^2	2.946
DoF	1
p	0.086

Gender vs. RCV Experience Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
Female	3.778	0.428	4.000
Male	3.500	0.572	4.000

D.2.1.8.10 Gender vs. Joystick Experience

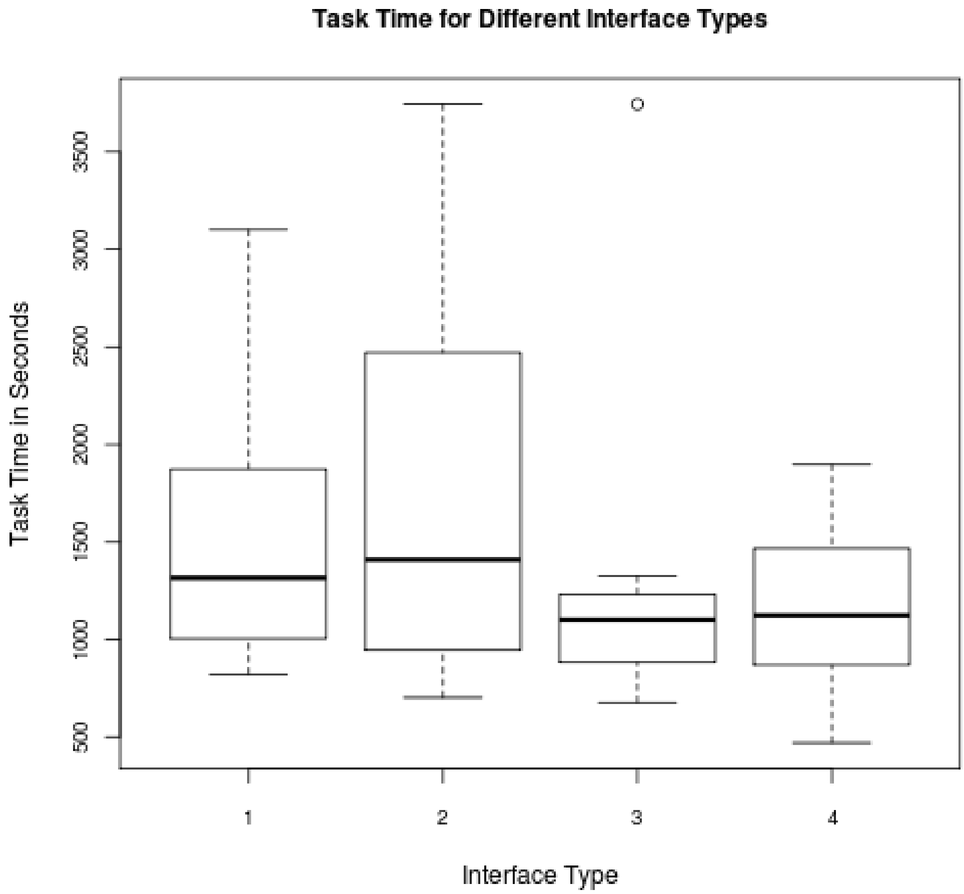


One-way ANOVA: Gender vs. Joystick Experience					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	0.672	0.672	0.990	0.325
Residuals	46	31.244	0.679		

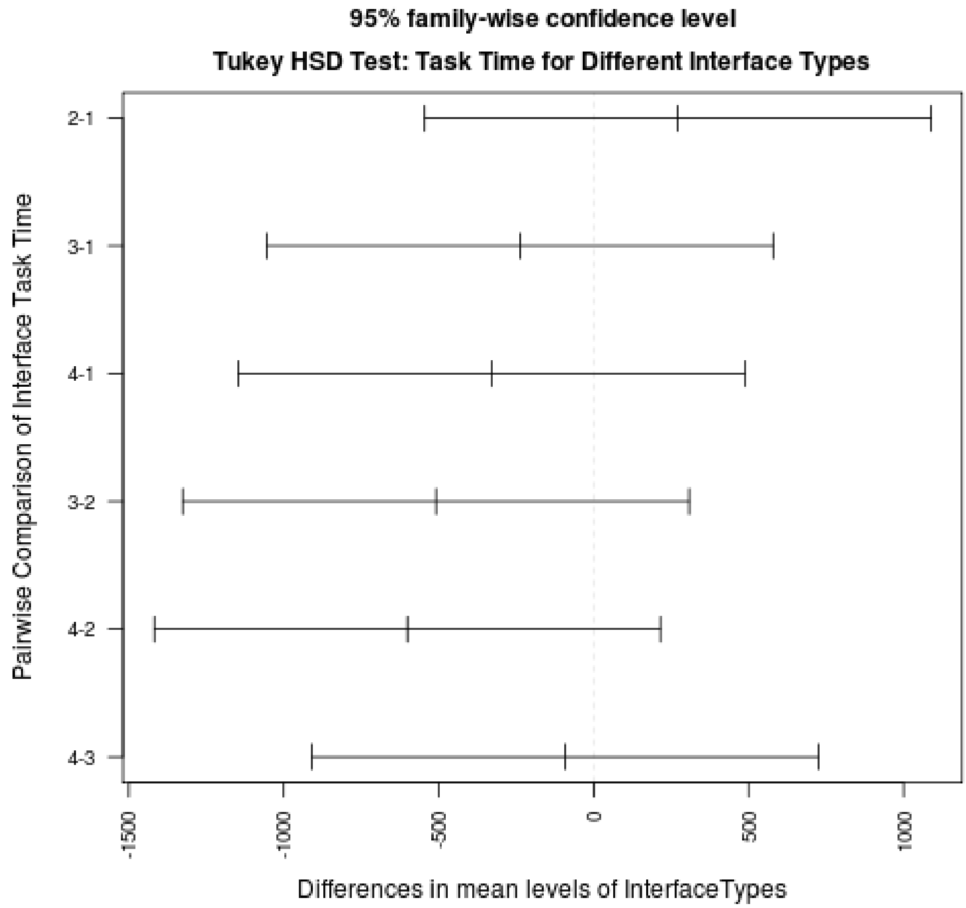
Gender vs. Joystick Experience Kruskal-Wallis test:	
X^2	0.791
DoF	1
p	0.374

Gender vs. Joystick Experience Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
Female	3.111	0.758	3.000
Male	2.867	0.860	3.000

D.2.2 Task Time

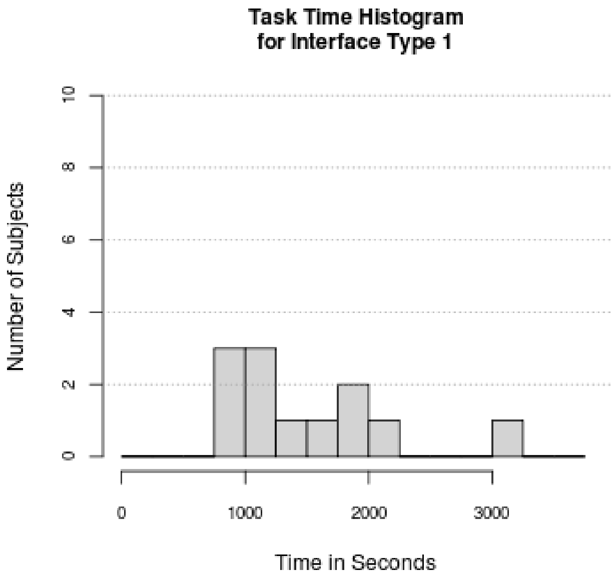


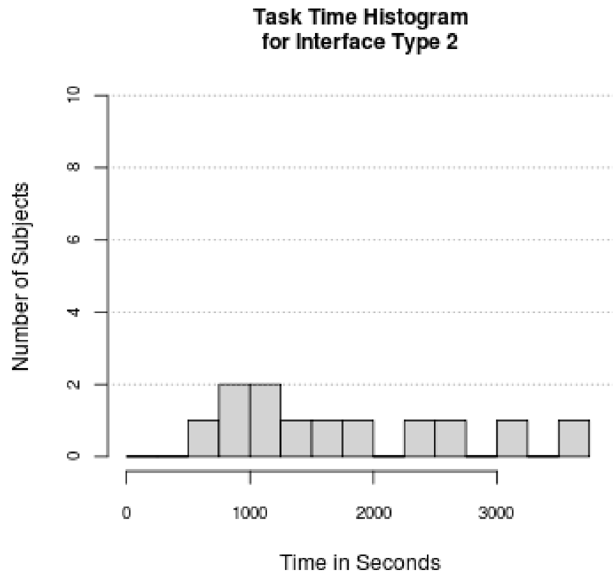
Subject Count	UI1	UI2	UI3	UI4
1	1233.490	845.965	1177.040	942.132
2	1976.320	1303.900	1287.438	750.730
3	1538.730	796.216	1326.380	1144.010
4	1147.070	1517.120	1111.700	1236.310
5	823.681	3123.383	1136.610	1348.213
6	861.760	3744.000	3743.550	1103.050
7	1771.650	702.556	793.839	1585.824
8	1398.817	2548.880	677.534	951.932
9	959.112	1935.194	1089.320	796.898
10	3102.170	1228.837	758.676	1898.620
11	2060.721	2393.780	1001.240	1743.176
12	1050.409	1045.440	972.455	470.730

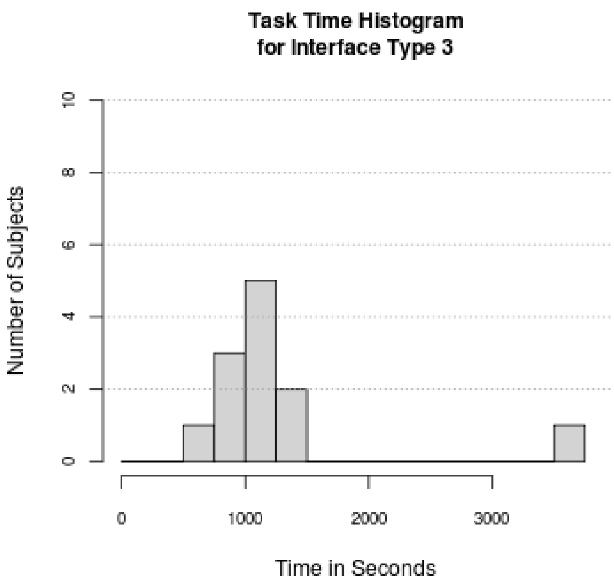


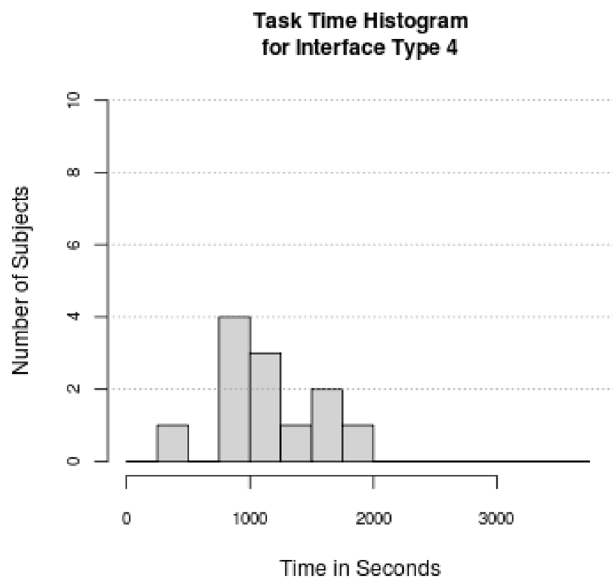
One-way ANOVA: Task Time vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	2603140.000	867713.000	1.544	0.216
Residuals	44	24720502.000	561830.000		

Task Time vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	1493.661	657.013	1316.153
2	1765.439	990.486	1410.510
3	1256.315	809.253	1100.510
4	1164.302	423.910	1123.530

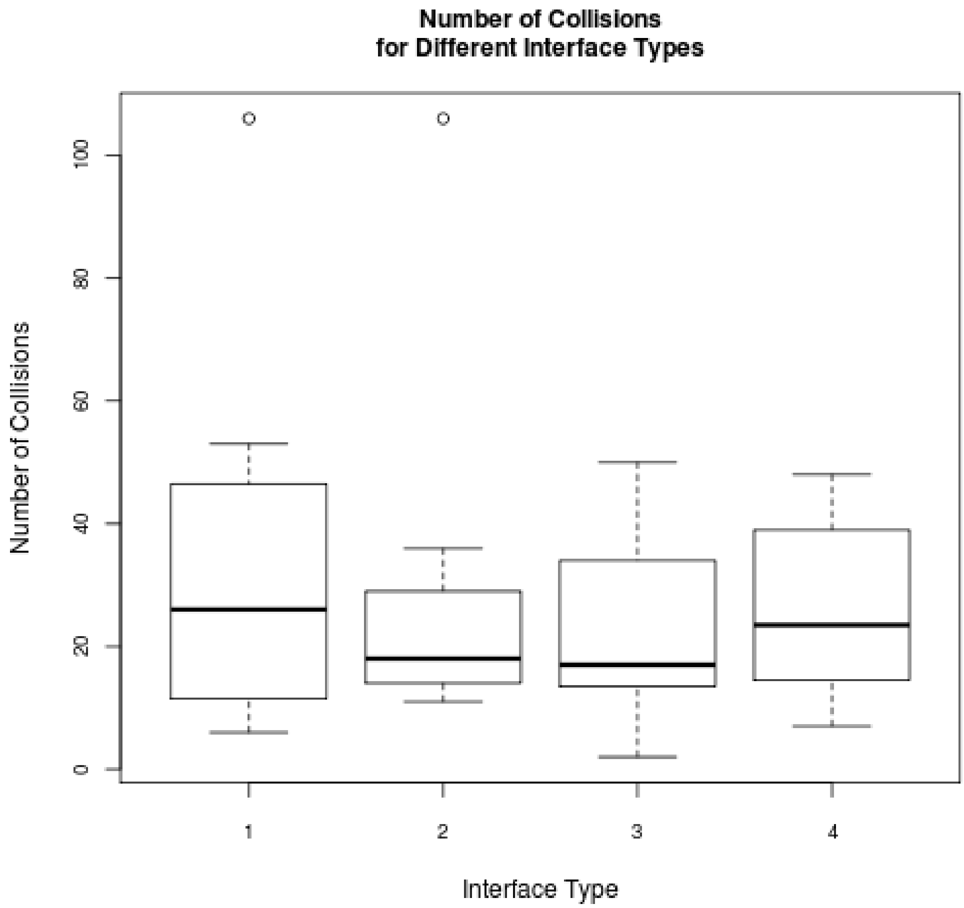

Task Time Histogram
for Interface Type 1
Number of Subjects
Time in Seconds


Task Time Histogram
for Interface Type 2
Number of Subjects
Time in Seconds

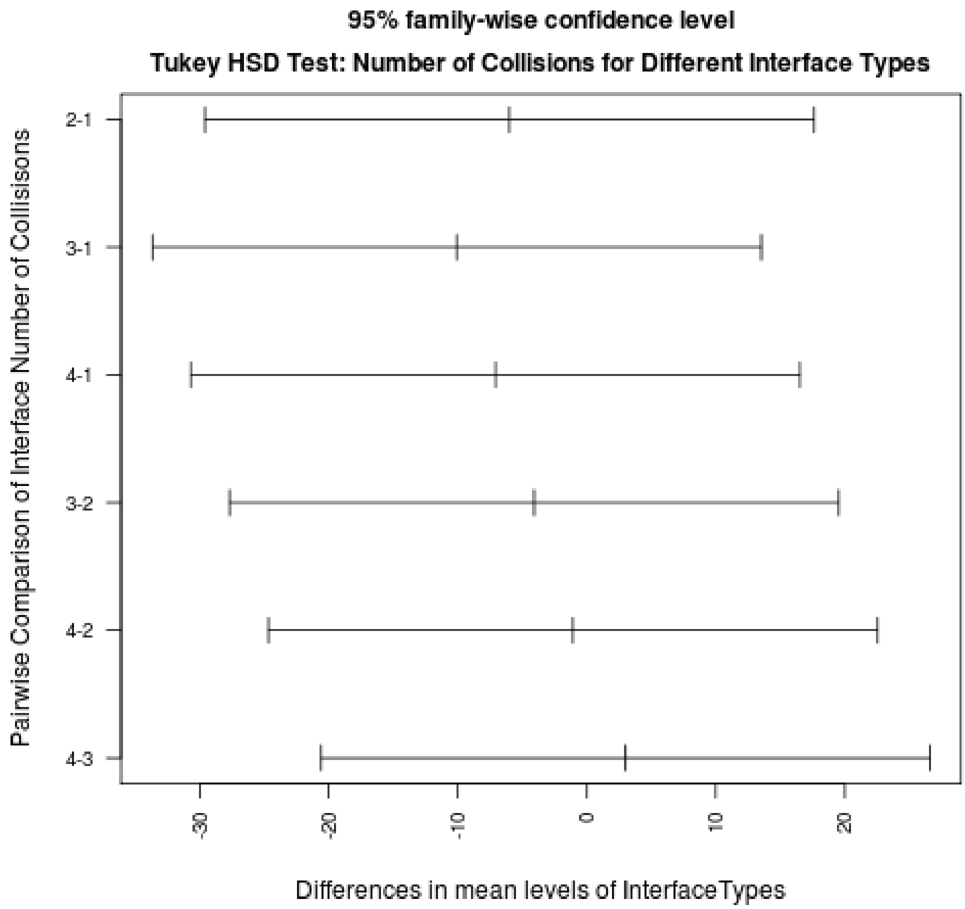

Task Time Histogram
for Interface Type 3
Number of Subjects
Time in Seconds


Task Time Histogram
for Interface Type 4
Number of Subjects
Time in Seconds

D.2.3 Number of Collisions



Subject Count	UI1	UI2	UI3	UI4
1	43	17	17	42
2	30	16	38	28
3	37	23	16	22
4	6	12	13	36
5	22	15	42	10
6	9	106	50	25
7	19	11	10	45
8	9	26	17	48
9	14	19	2	18
10	106	32	28	11
11	50	36	14	21
12	53	13	30	7

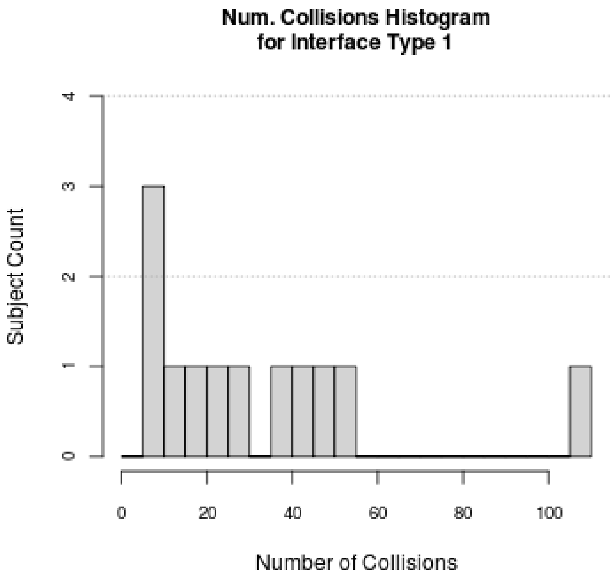


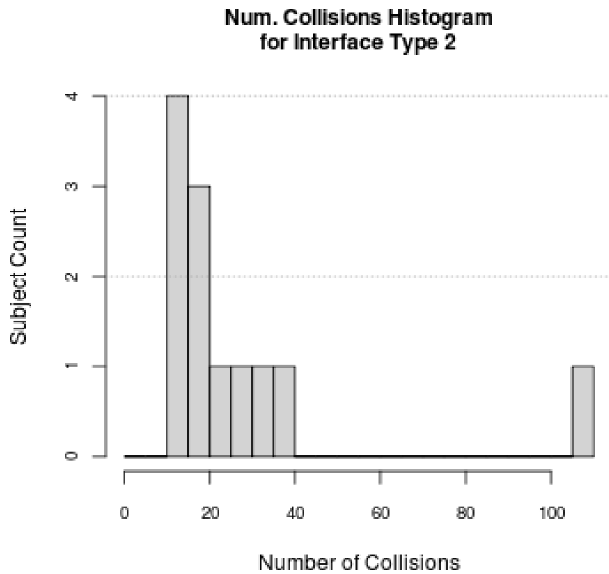
One-way ANOVA: Num. of Collisions vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	644.100	214.690	0.458	0.713
Residuals	44	20625.200	468.750		

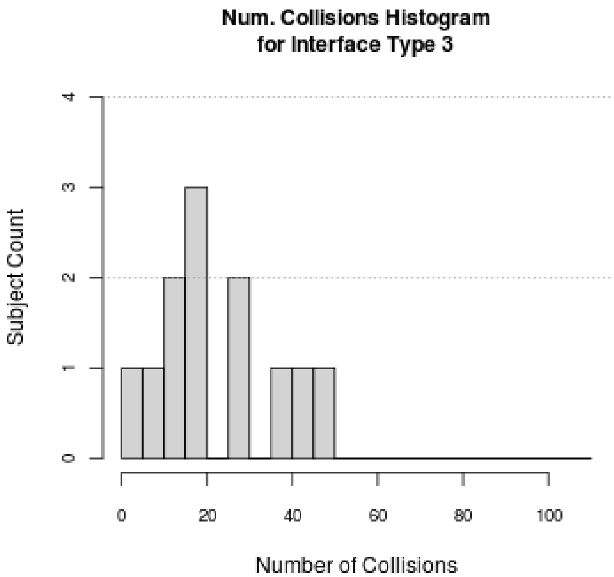
Num. of Collisions vs. Interface Used Friedman test:	
X^2	1.487
p	0.685
DoF	3

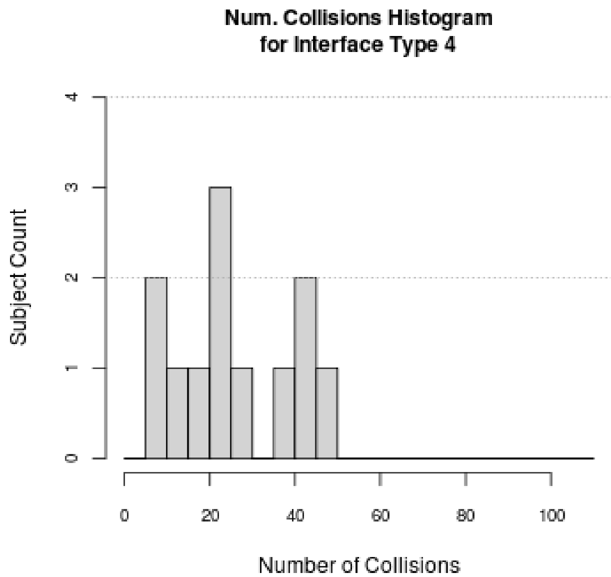
Num. of Collisions vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	55.000	55.000	43.000	39.500	35.000	34.000
Z	1.257	1.256	0.314	0.629	-0.314	-0.393
p	0.232	0.226	0.791	0.561	0.776	0.720
R	0.128	0.128	0.032	0.064	-0.032	-0.040

Num. of Collisions vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	33.167	28.126	26.000
2	27.167	26.059	18.000
3	23.083	14.463	17.000
4	26.083	13.990	23.500

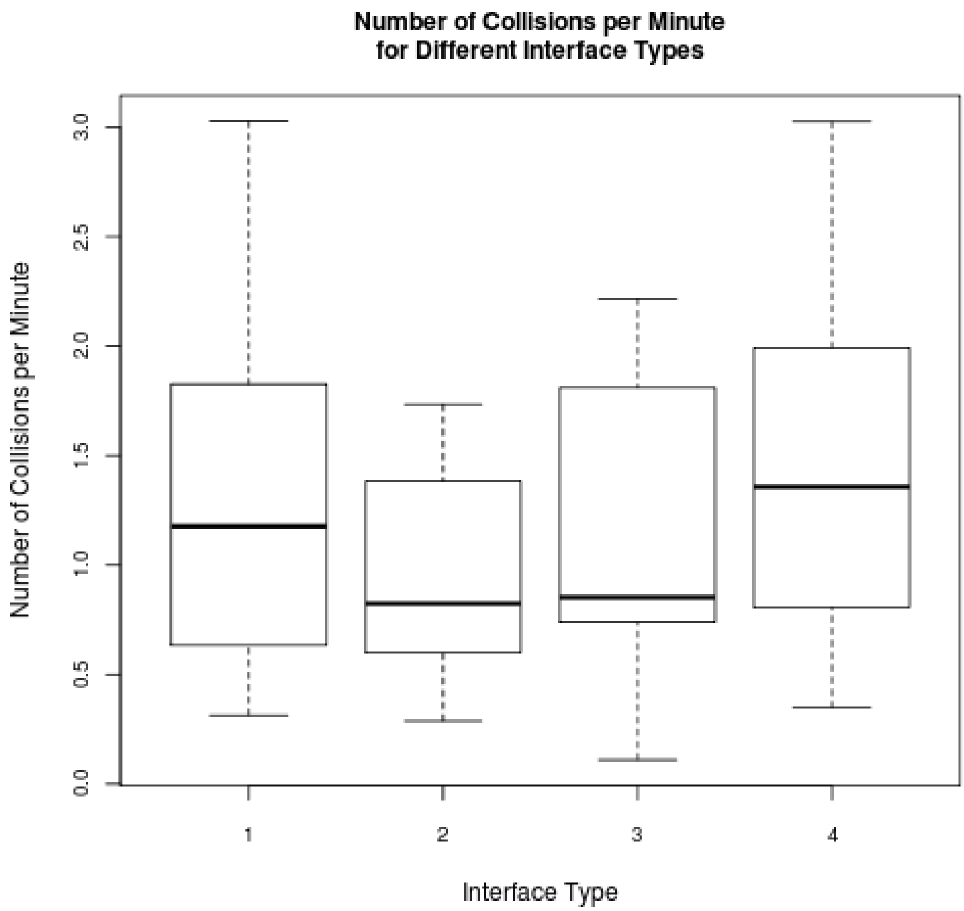




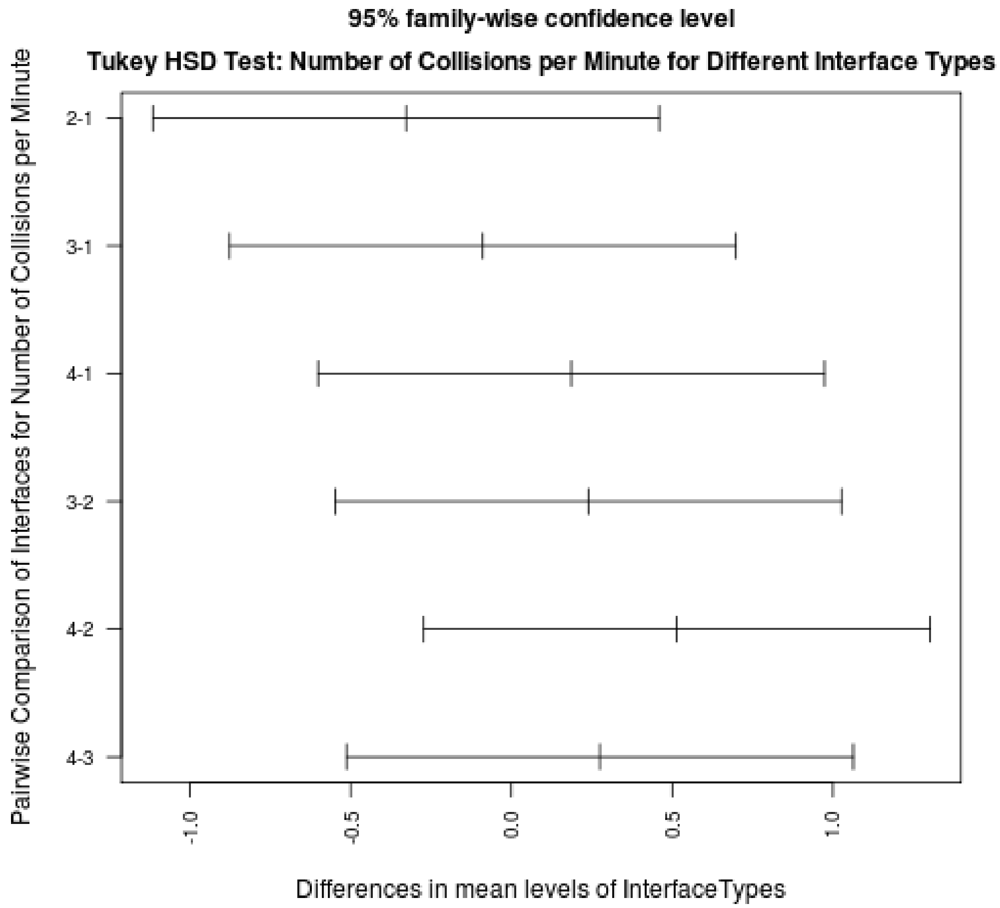




D.2.3.1 Number of Collisions per Minute



Subject Count	UI1	UI2	UI3	UI4
1	2.092	1.206	0.867	2.675
2	0.911	0.736	1.771	2.238
3	1.443	1.733	0.724	1.154
4	0.314	0.475	0.702	1.747
5	1.603	0.288	2.217	0.445
6	0.627	1.699	0.801	1.360
7	0.643	0.939	0.756	1.703
8	0.386	0.612	1.505	3.025
9	0.876	0.589	0.110	1.355
10	2.050	1.562	2.214	0.348
11	1.456	0.902	0.839	0.723
12	3.027	0.746	1.851	0.892

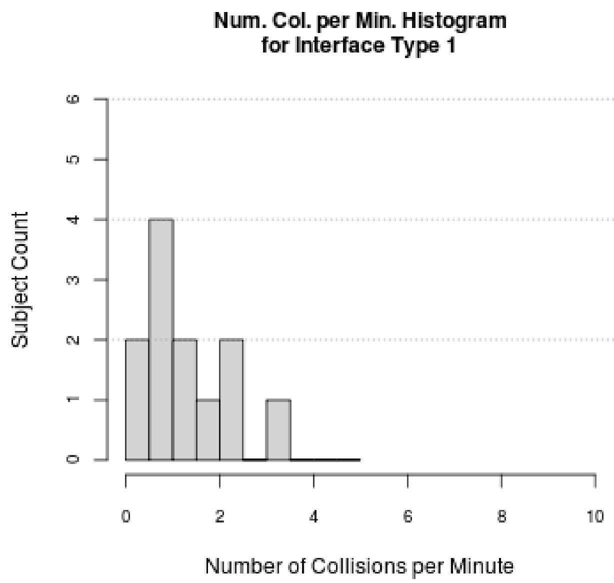


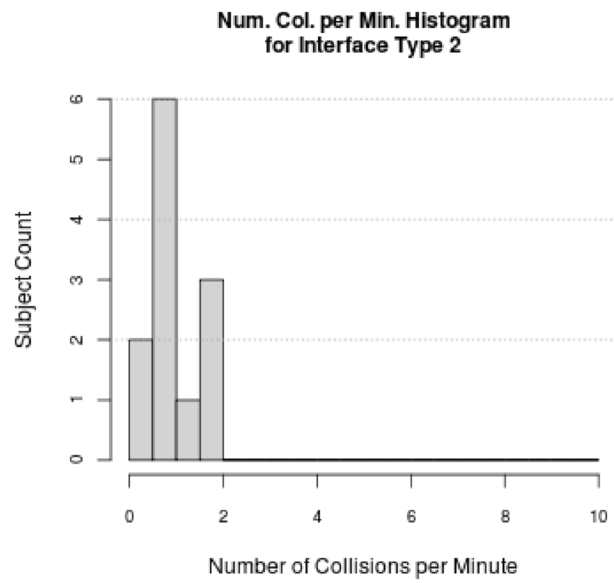
One-way ANOVA: Num. of Collisions per Minute vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	1.646	0.548	1.048	0.381
Residuals	44	23.029	0.523		

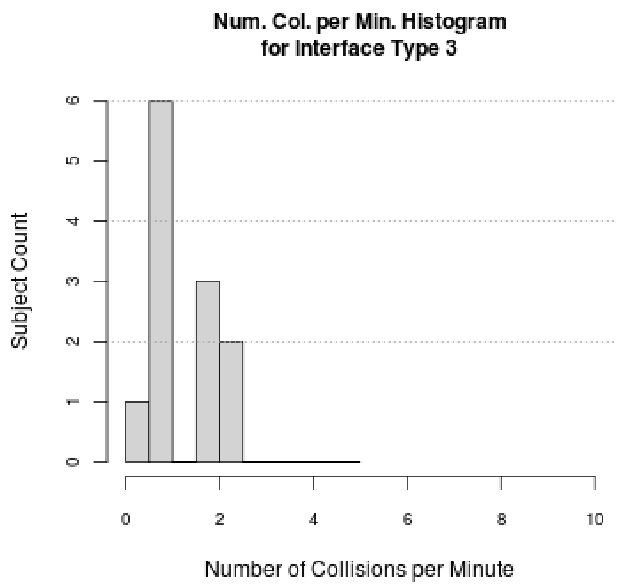
Num. of Collisions per Minute vs. Interface Used Friedman test:	
X^2	1.800
p	0.615
DoF	3

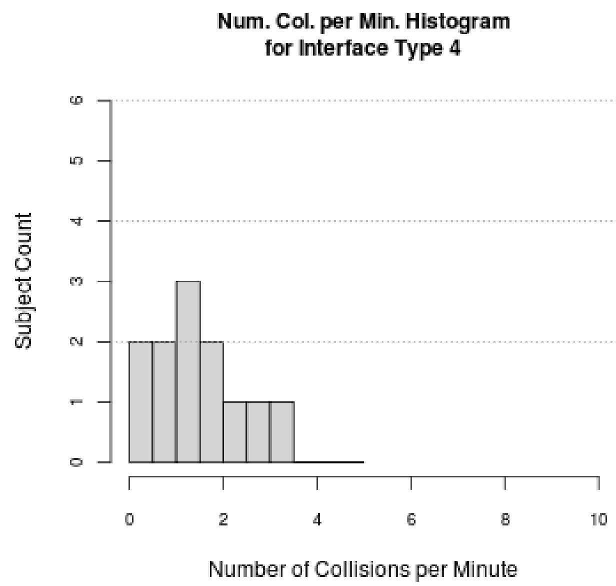
Num. of Collisions per Minute vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	53.000	44.000	33.000	29.000	20.000	29.000
Z	1.098	0.392	-0.471	-0.784	-1.490	-0.784
p	0.301	0.733	0.677	0.470	0.151	0.470
R	0.112	0.040	-0.048	-0.080	-0.152	-0.080

Num. of Collisions per Minute vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	1.286	0.816	1.177
2	0.957	0.487	0.824
3	1.196	0.685	0.853
4	1.472	0.848	1.358



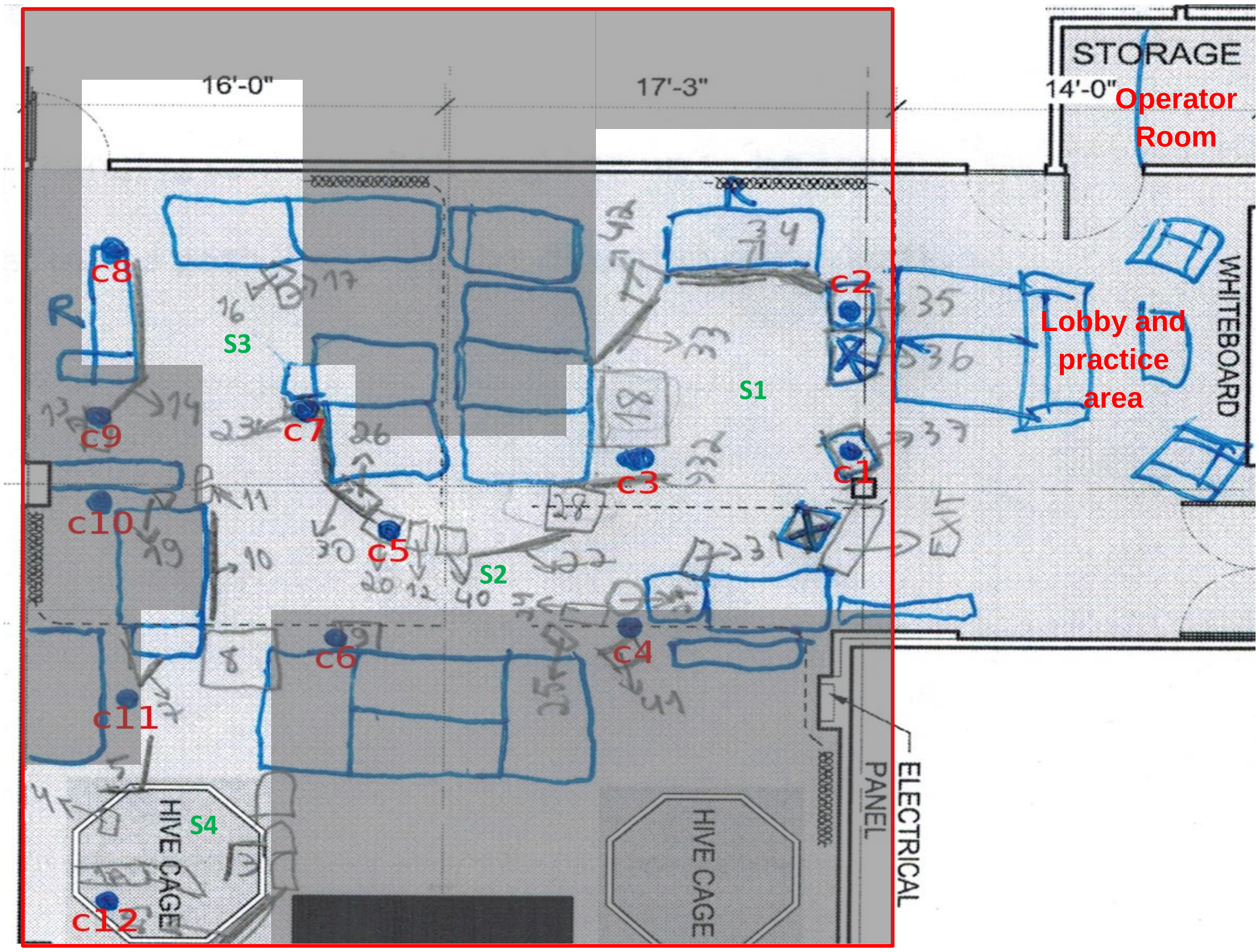






D.2.4 Number of Circles Found

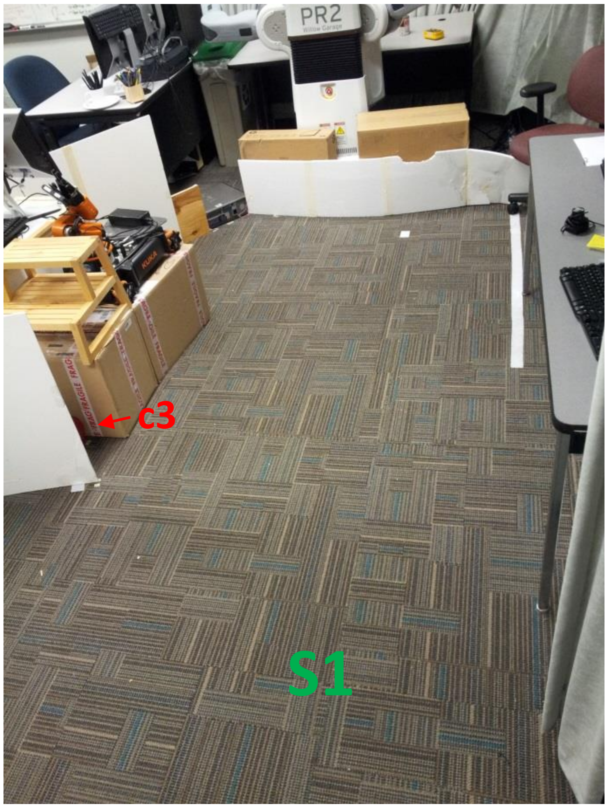
D.2.4.1 Circles Location, Numbering and Study Environment

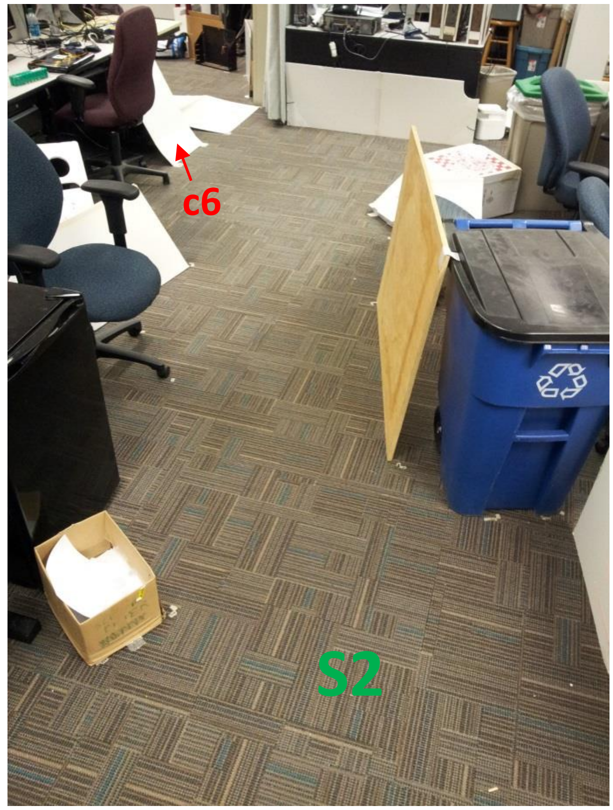


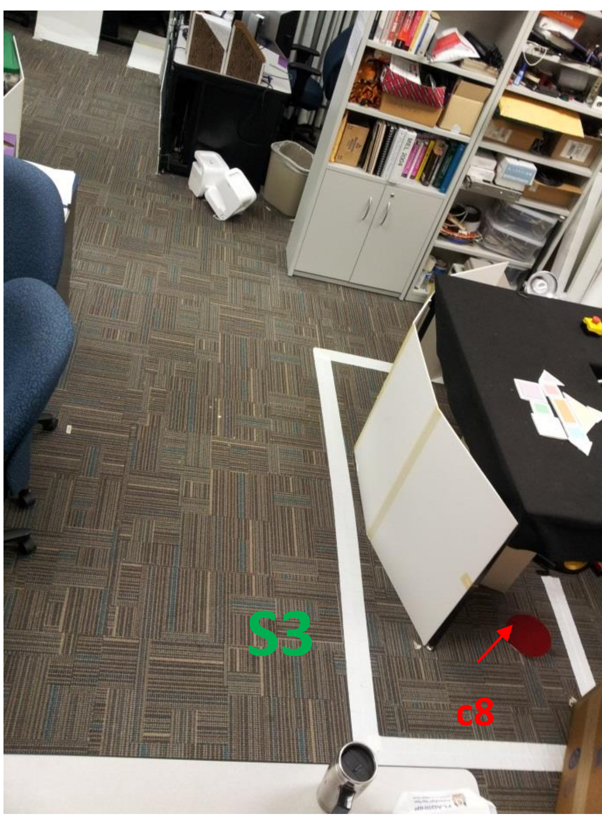
Legend:

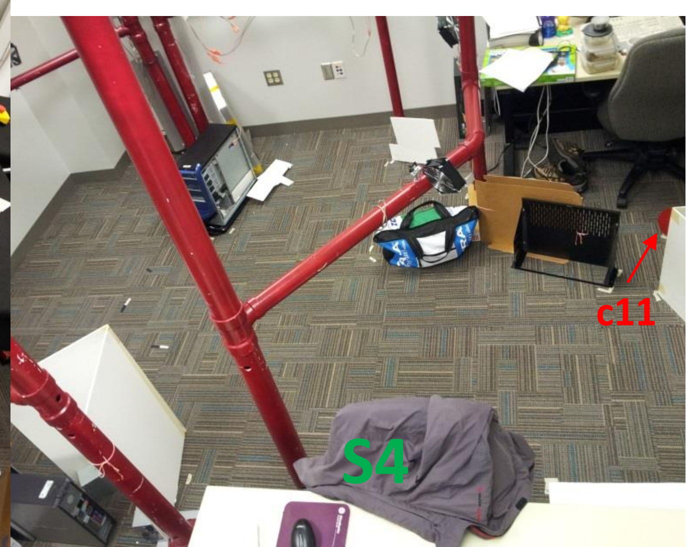
- **Blue dots:** Circles to be searched for;
- **c1…c12:** Identification number for the circle close to this label;
- **S1…S4:** different section of the lab accessible by the robot, and illustrated by the pictures below;
- **Black lines:** Lab walls;
- **Blue lines:** Lab objects (tables, chairs, etc.);
- **Gray lines:** Debris added to the lab;
- **Grayed out areas:** Areas visible through the robot camera but inaccessible to the robot;
- **Red Square Line:** lab area used for the experiment.

D.2.4.1.1 Sub-sections of Study Environment

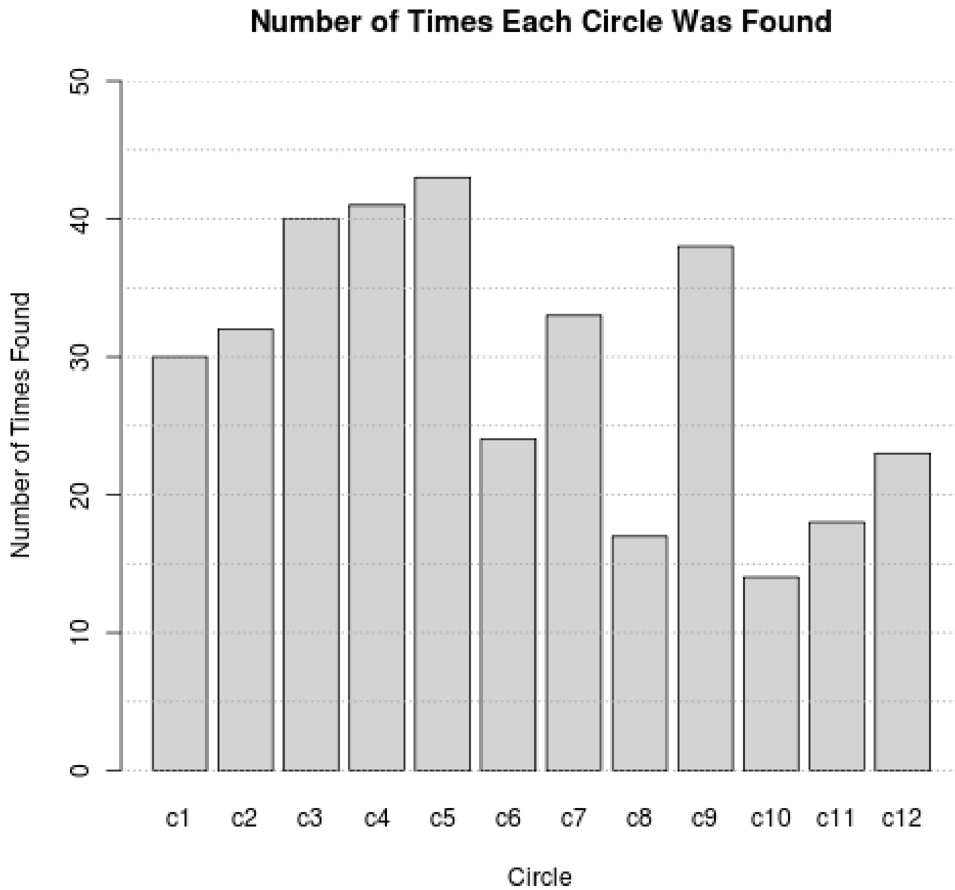




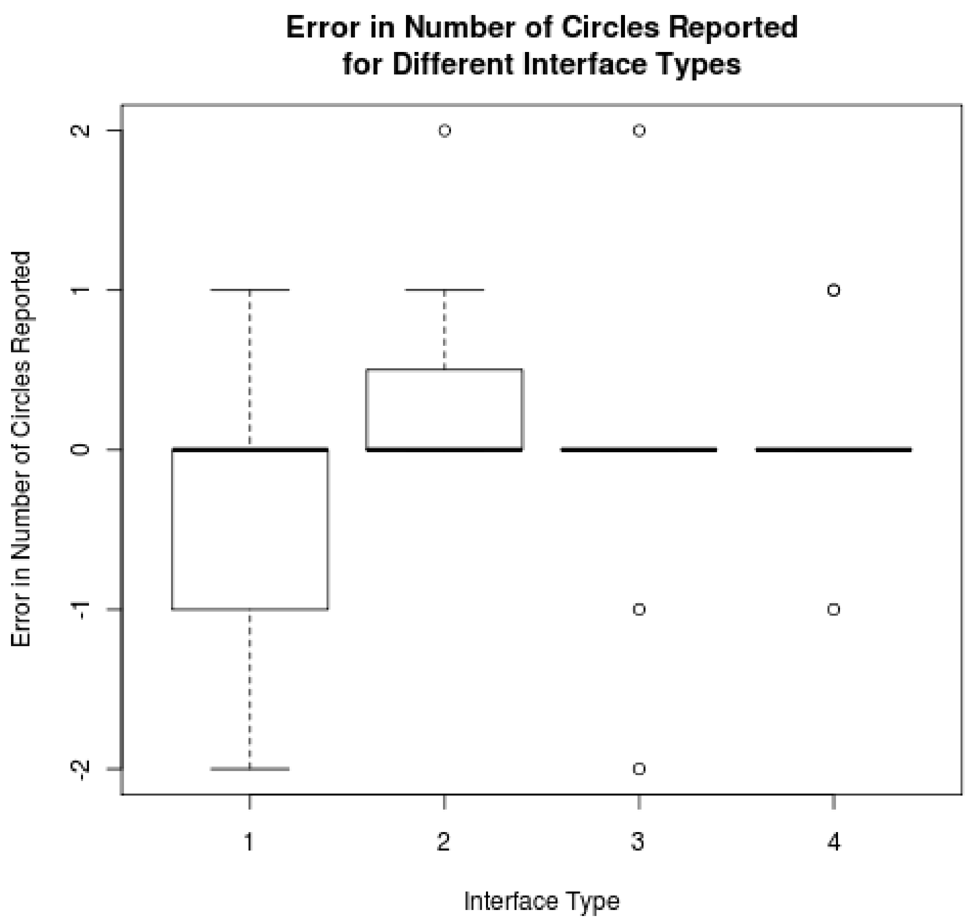




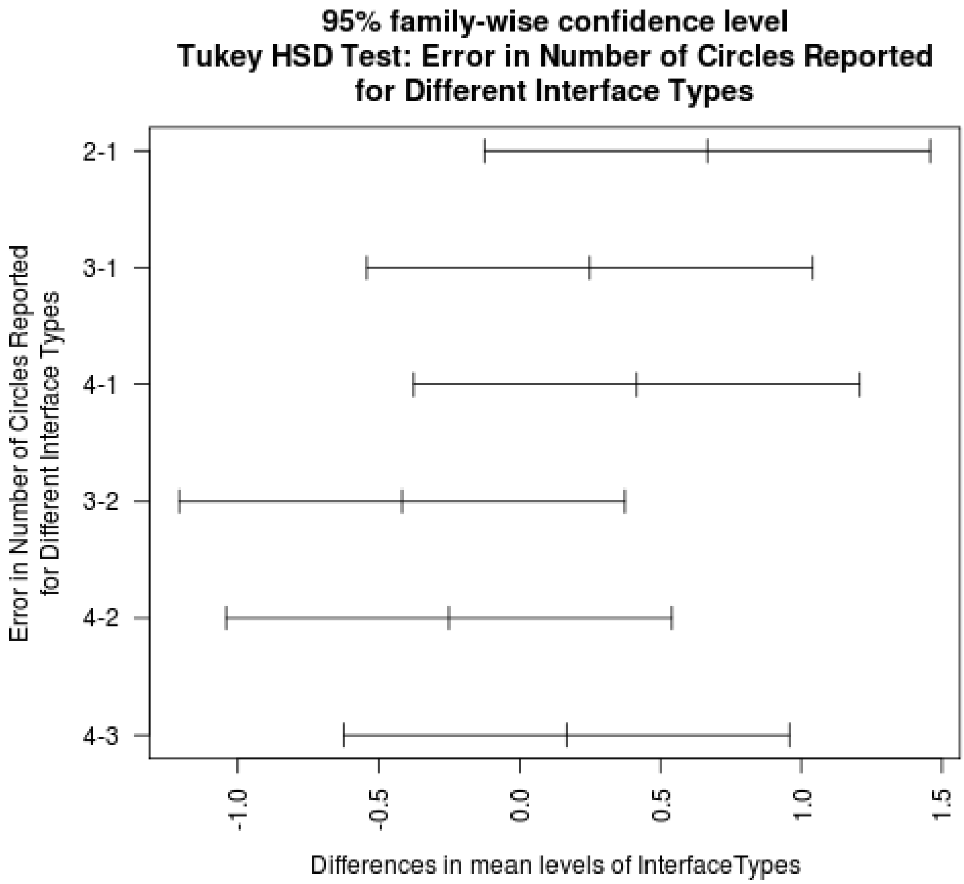
D.2.4.2 Number of Times Each Circle Was Found



D.2.4.3 Error on Reporting Number of Circles



Subject Count	UI1	UI2	UI3	UI4
1	0	1	2	0
2	-2	0	-2	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	-1
6	0	0	0	0
7	0	0	0	0
8	-1	1	0	1
9	1	0	0	1
10	0	0	-1	0
11	-1	2	0	0
12	-1	0	0	0



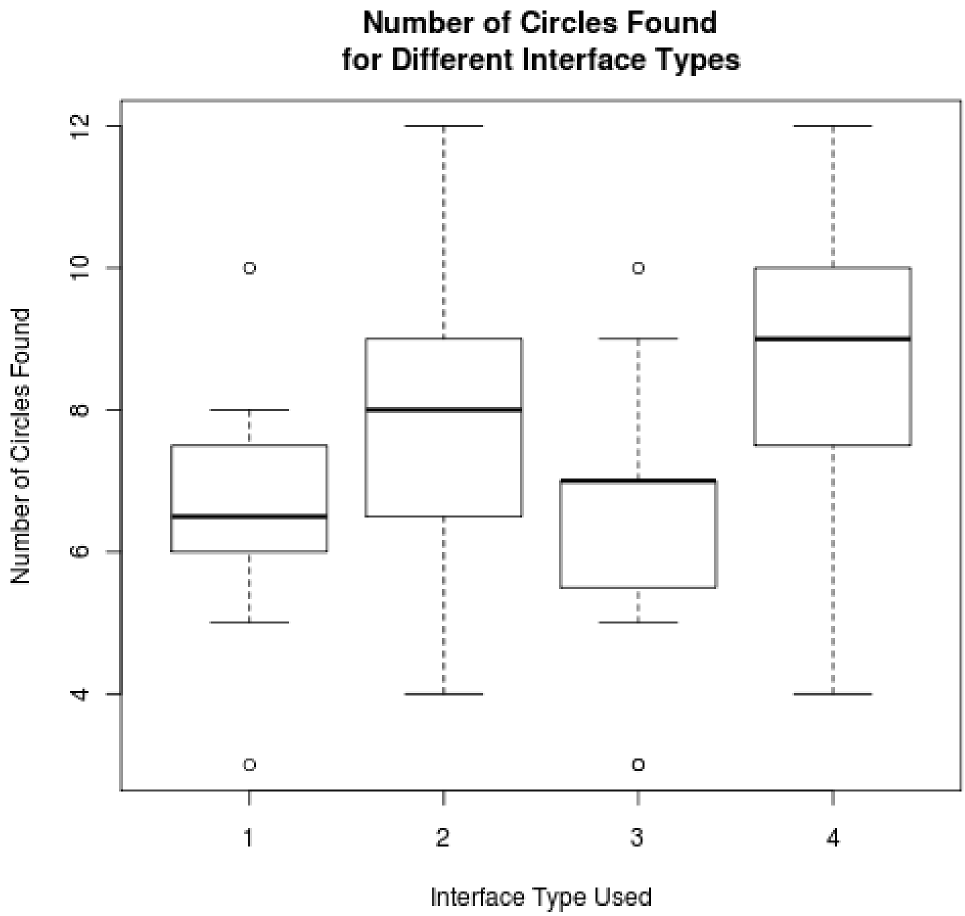
One-way ANOVA: Error in Number of Circles Reported vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	2.833	0.944	1.794	0.162
Residuals	44	23.167	0.527		

Error in Number of Circles Reported vs. Interface Used Friedman test:	
X^2	4.426
p	0.219
DoF	3

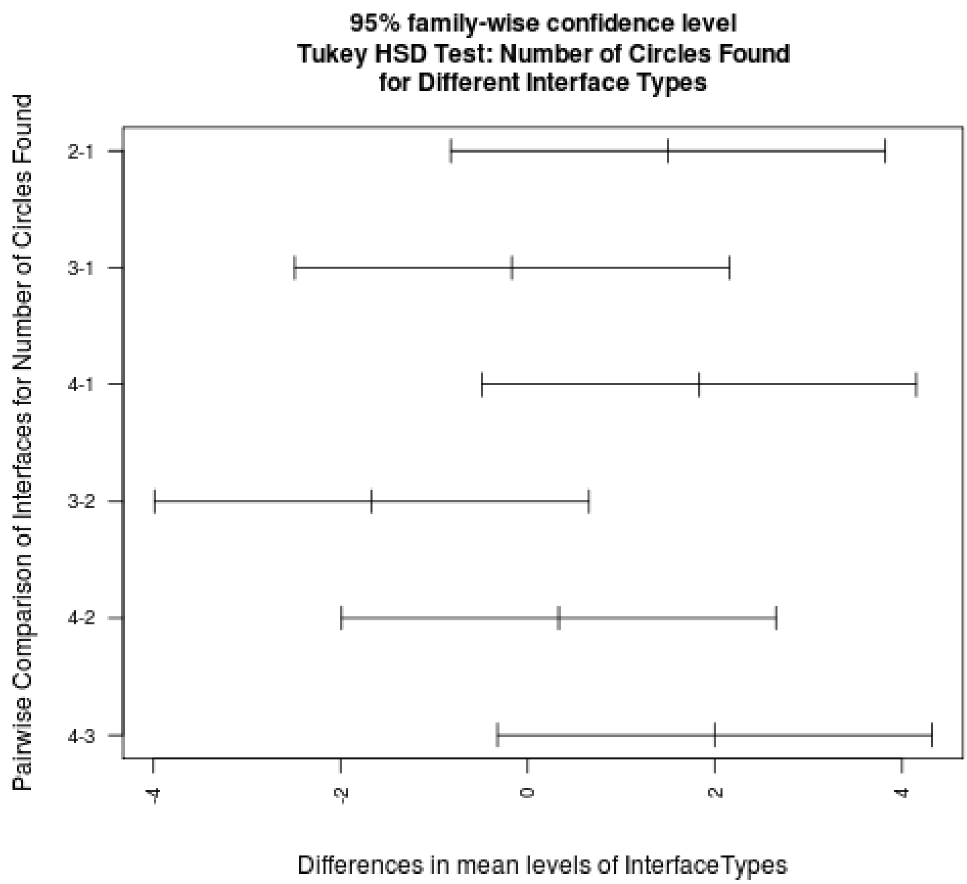
Error in Number of Circles Reported vs. Interface Used Wicoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	2.000	6.000	2.000	13.000	8.000	8.000
Z	-1.738	-0.896	-1.420	1.420	1.044	-0.723
p	0.125	0.531	0.250	0.250	0.500	0.656
R	-0.177	-0.091	-0.145	0.145	0.107	-0.074

Error in Number of Circles Reported vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	-0.333	0.778	0.000
2	0.333	0.651	0.000
3	-0.083	0.900	0.000
4	0.083	0.515	0.000

D.2.4.4 Subjective Number of Circles Found



Subject Count	UI1	UI2	UI3	UI4
1	10	4	9	10
2	5	6	7	8
3	6	9	6	9
4	7	8	5	4
5	8	8	7	9
6	6	8	10	8
7	8	6	3	12
8	7	12	7	7
9	6	11	7	4
10	6	7	7	9
11	3	9	3	11
12	7	9	6	10

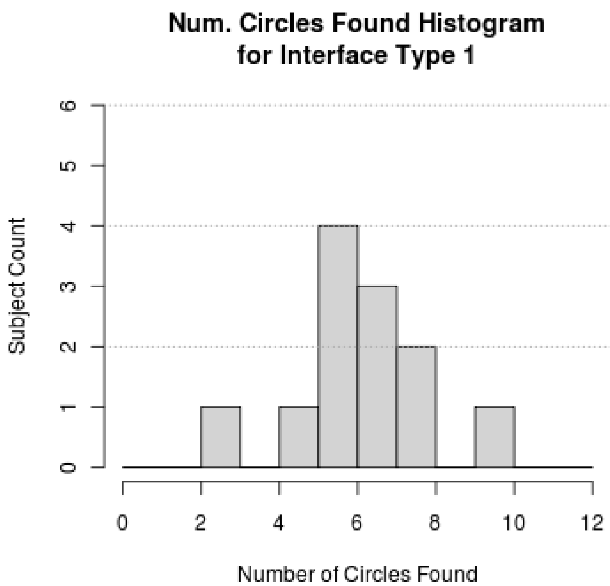


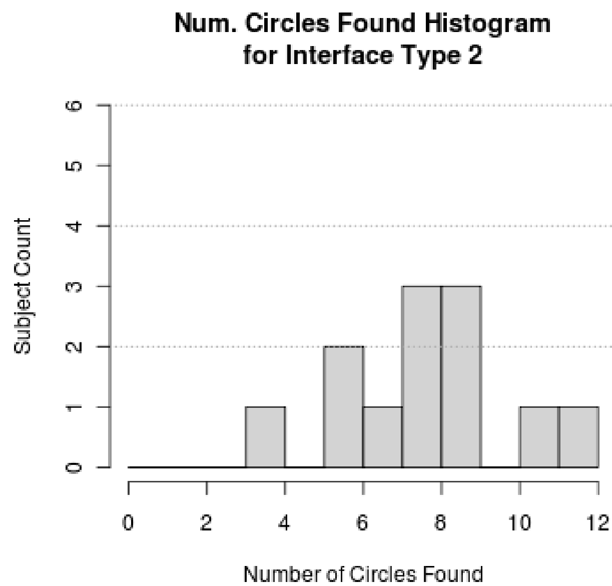
One-way ANOVA: Num. Circles Found vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	37.583	12.528	2.761	0.053
Residuals	44	199.667	4.538		

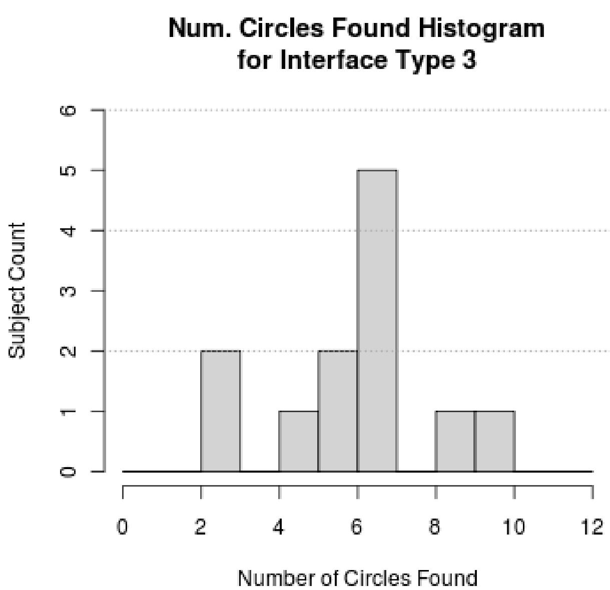
Num. Circles Found vs. Interface Used Friedman test:	
X^2	7.624
p	0.054
DoF	3

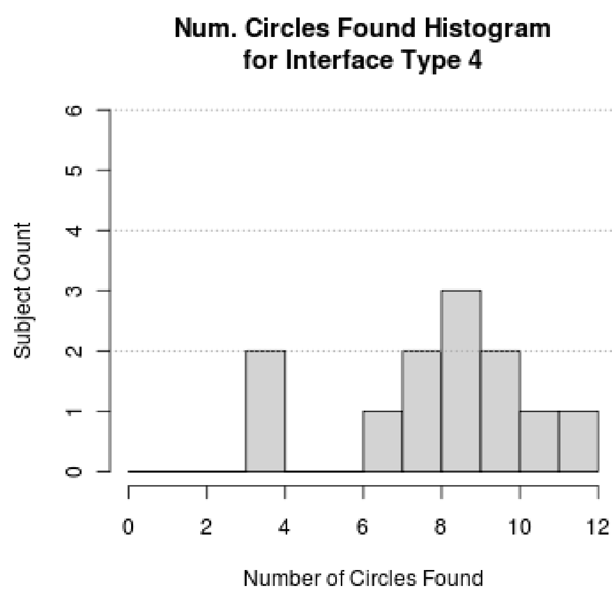
Num. Circles Found vs. Interface Used Wicoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	15.500	24.500	8.500	52.000	23.000	14.500
Z	-1.655	0.280	-1.985	1.696	-0.671	-1.654
p	0.104	0.805	0.059	0.100	0.531	0.106
R	-0.169	0.029	-0.203	0.173	-0.068	-0.169

Num. Circles Found vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	6.583	1.730	6.500
2	8.083	2.193	8.000
3	6.417	2.065	7.000
4	8.417	2.466	9.000

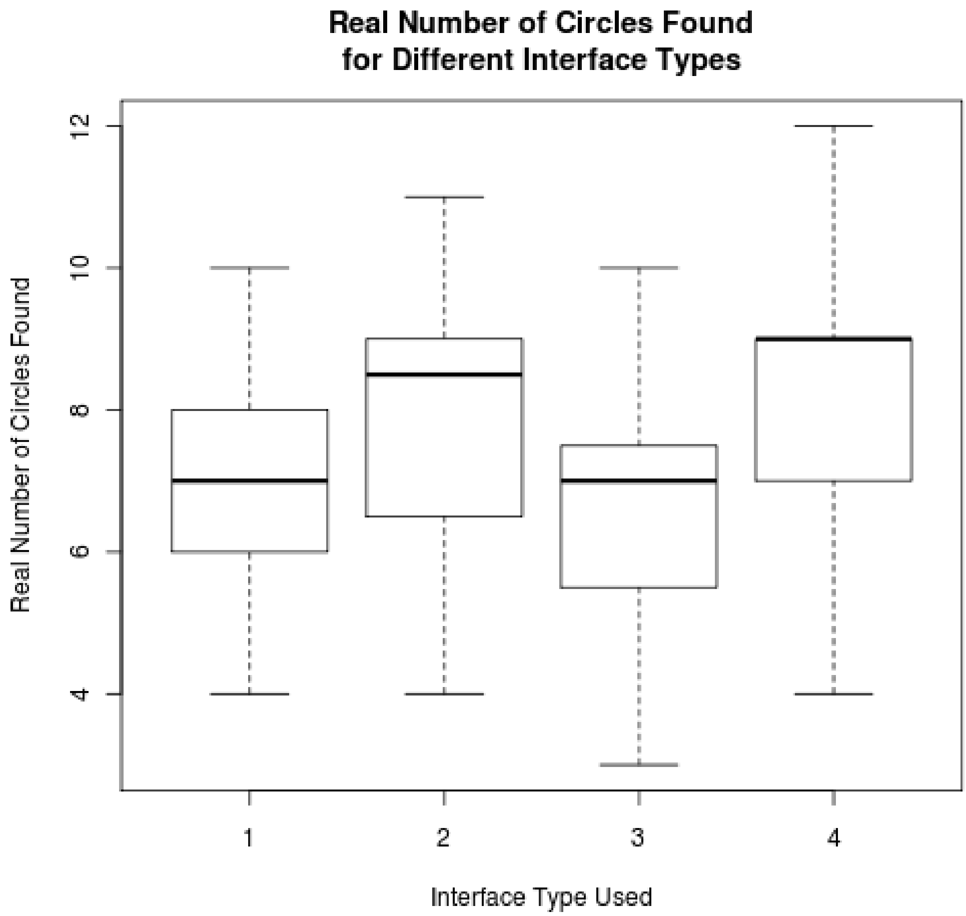




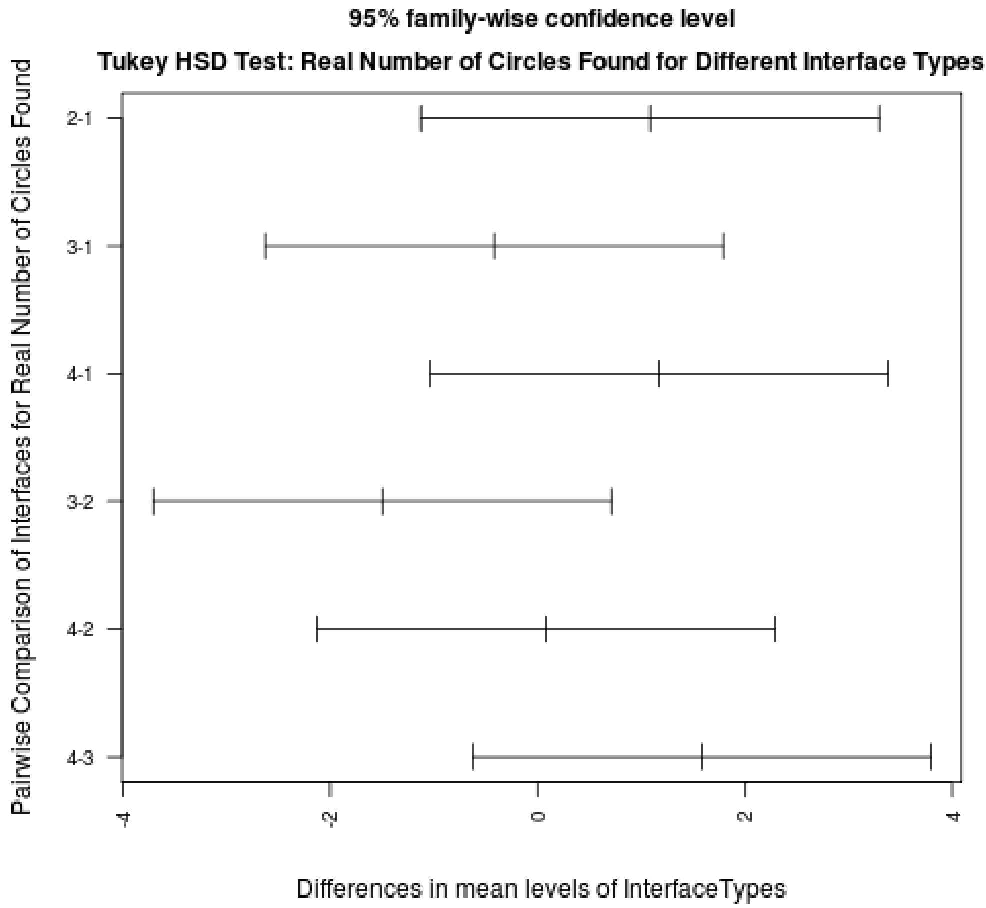




D.2.4.5 Real Number of Circles Found



Subject Count	UI1	UI2	UI3	UI4
1	10	4	7	9
2	7	6	9	8
3	6	9	6	9
4	7	8	5	4
5	8	9	7	9
6	6	8	10	8
7	8	6	3	12
8	8	11	7	6
9	5	10	7	4
10	6	7	8	9
11	4	9	3	9
12	8	9	6	10

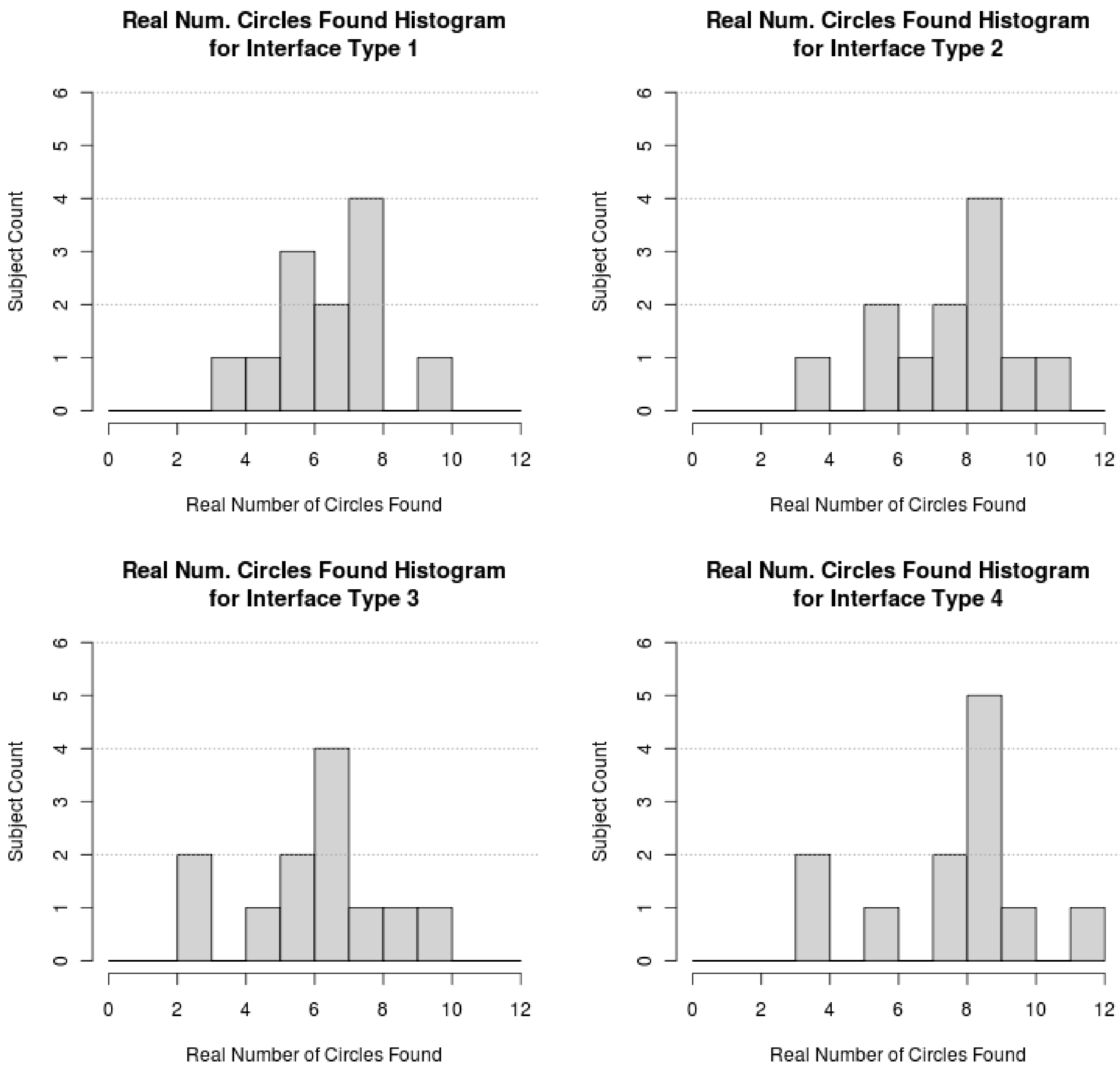


One-way ANOVA: Real Num. Circles Found vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	22.417	7.472	1.818	0.158
Residuals	44	180.833	4.110		

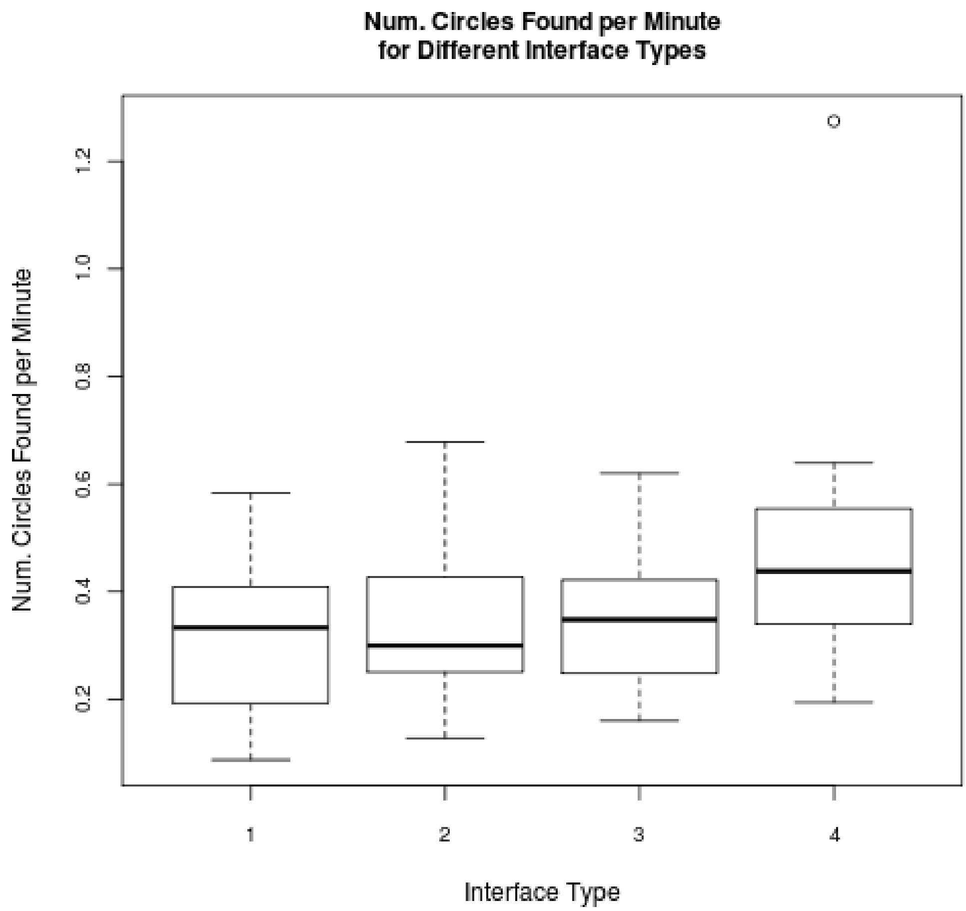
Real Num. Circles Found vs. Interface Used Friedman test:	
X^2	3.365
p	0.339
DoF	3

Real Num. Circles Found vs. Interface Used Wicoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	21.500	38.000	20.000	60.500	17.000	22.000
Z	-1.385	0.515	-1.501	1.725	-0.402	-1.341
p	0.179	0.655	0.152	0.100	0.727	0.201
R	-0.141	0.053	-0.153	0.176	-0.041	-0.137

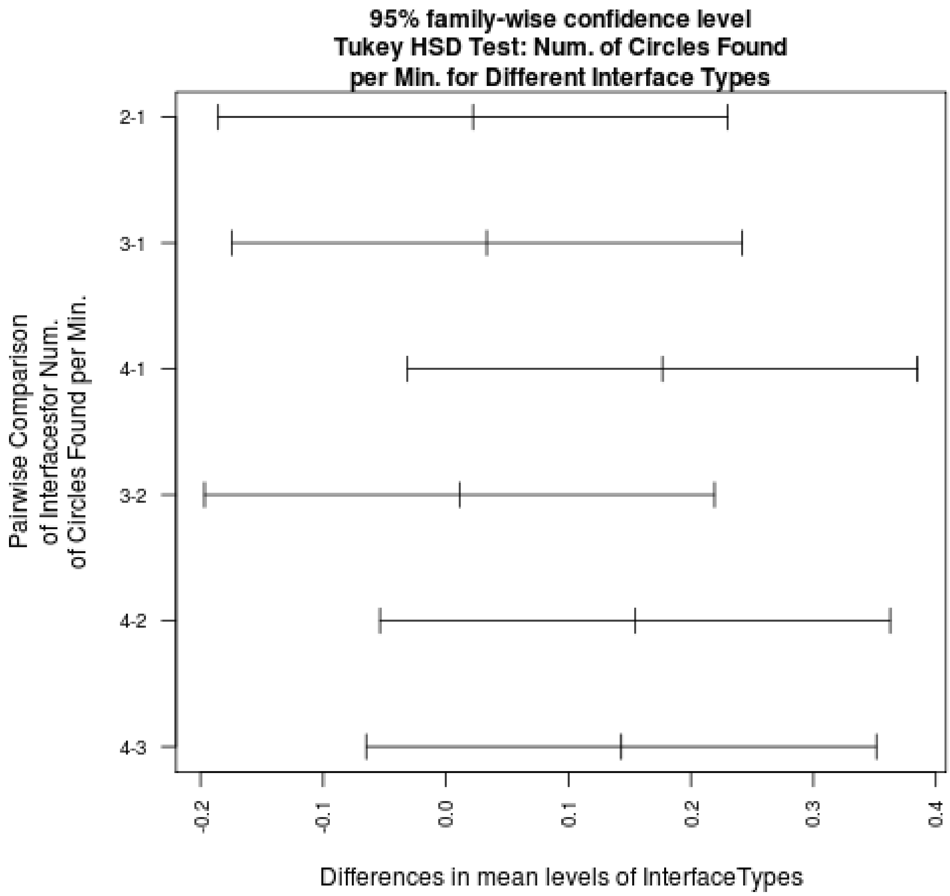
Real Num. Circles Found vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	6.917	1.621	7.000
2	8.000	1.954	8.500
3	6.500	2.111	7.000
4	8.083	2.353	9.000



D.2.4.6 Subjective Number of Circles Found per Minute



Subject Count	UI1	UI2	UI3	UI4
1	0.486	0.284	0.459	0.637
2	0.152	0.276	0.326	0.639
3	0.234	0.678	0.271	0.472
4	0.366	0.316	0.270	0.194
5	0.583	0.154	0.370	0.401
6	0.418	0.128	0.160	0.435
7	0.271	0.512	0.227	0.454
8	0.300	0.282	0.620	0.441
9	0.375	0.341	0.386	0.301
10	0.116	0.342	0.554	0.284
11	0.087	0.226	0.180	0.379
12	0.400	0.517	0.370	1.275

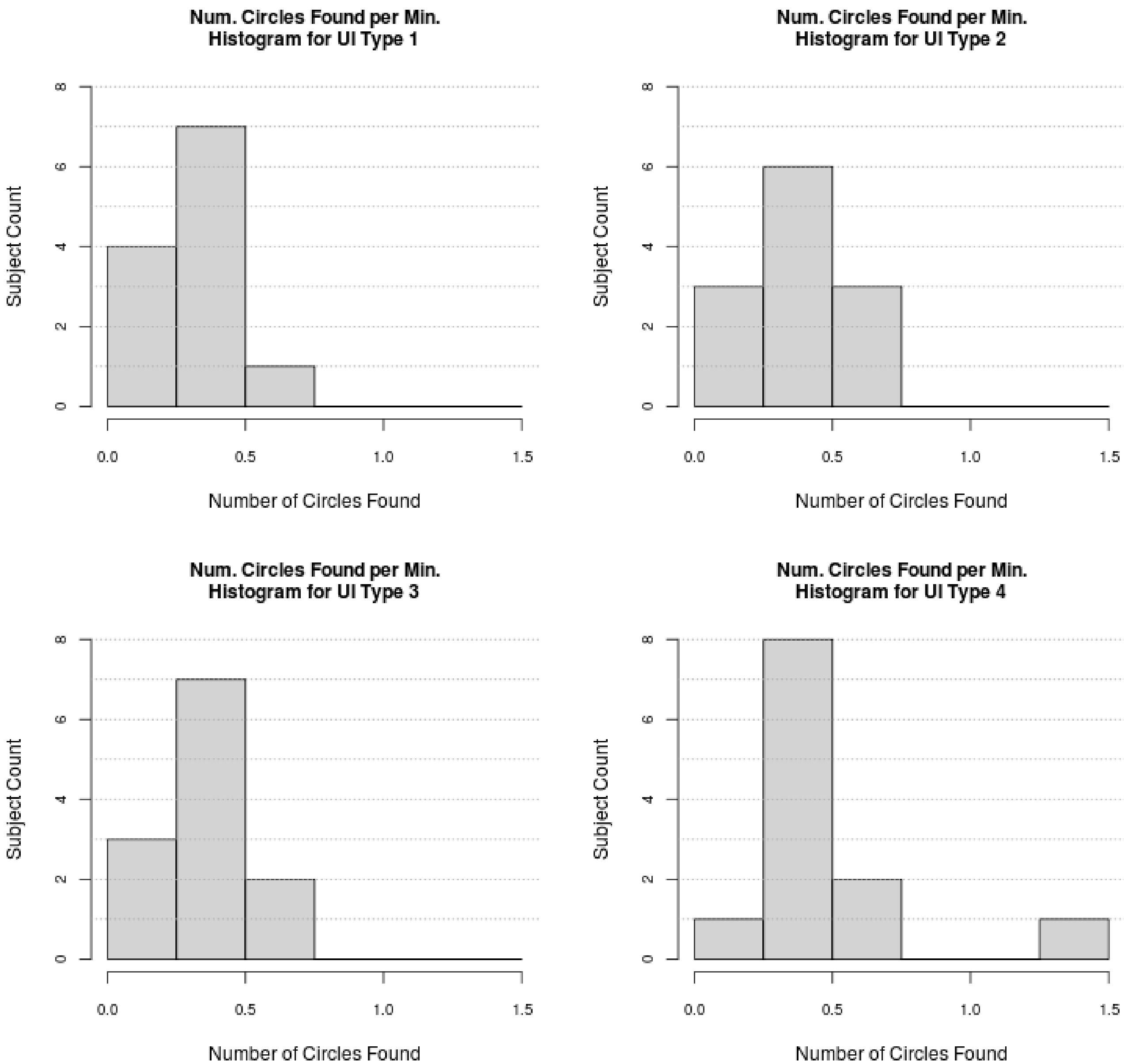


One-way ANOVA: Num. Circles Found Per Minute vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.233	0.078	2.126	0.111
Residuals	44	1.605	0.036		

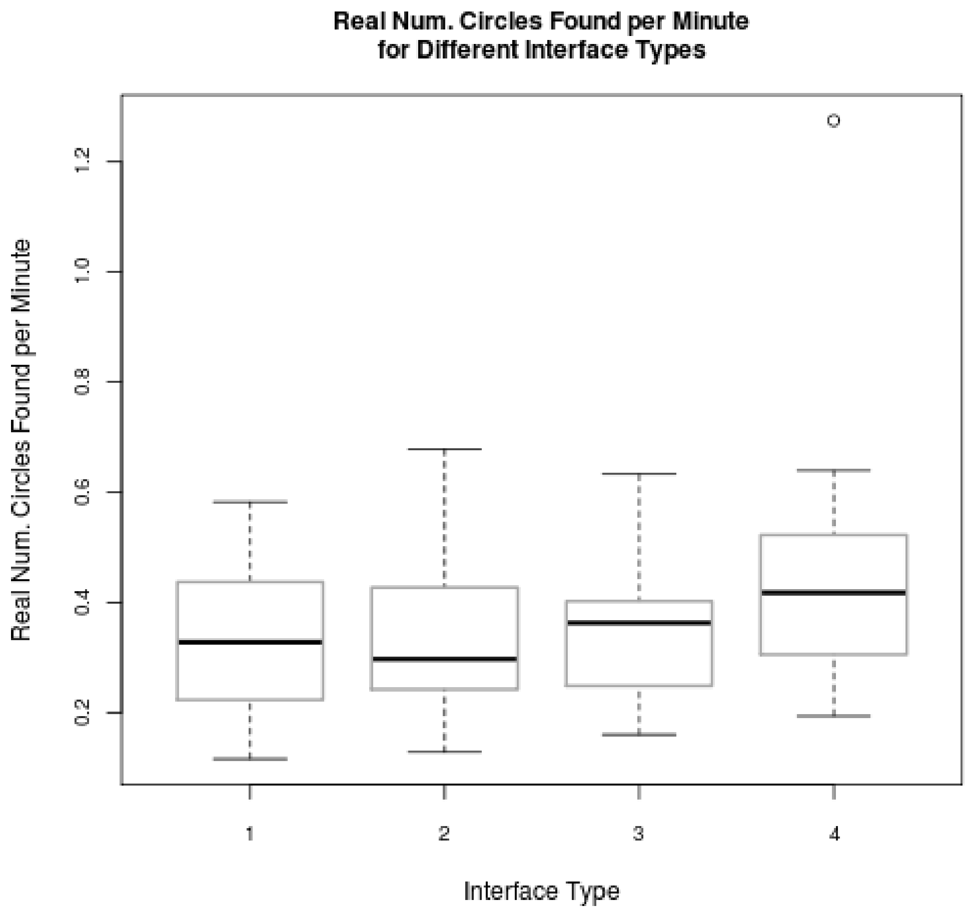
Num. Circles Found Per Minute vs. Interface Used Friedman test:	
X^2	2.500
p	0.475
DoF	3

Num. Circles Found Per Minute vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	34.000	36.000	15.000	35.000	17.000	19.000
Z	-0.392	-0.235	-1.883	-0.314	-1.726	-1.569
p	0.733	0.850	0.064	0.791	0.092	0.129
R	-0.040	-0.024	-0.192	-0.032	-0.176	-0.160

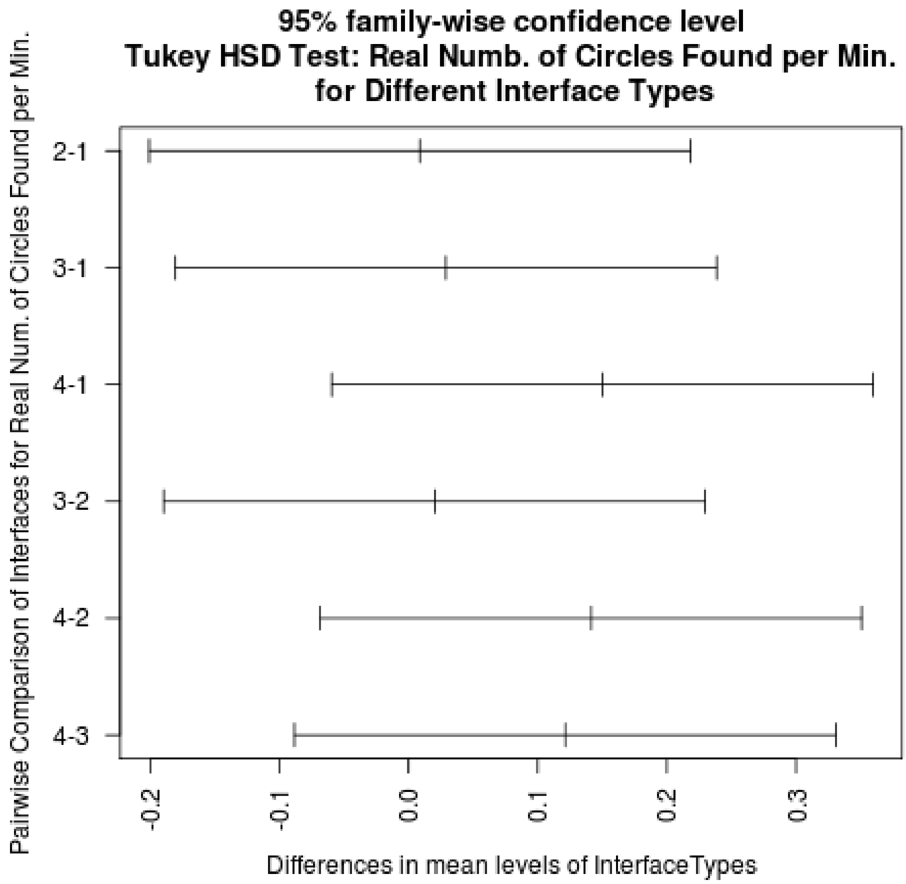
Num. Circles Found Per Minute vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.316	0.151	0.333
2	0.338	0.159	0.300
3	0.349	0.142	0.348
4	0.493	0.278	0.438



D.2.4.7 Real Number of Circles Found per Minute



Subject Count	UI1	UI2	UI3	UI4
1	0.486	0.284	0.357	0.573
2	0.213	0.276	0.419	0.639
3	0.234	0.678	0.271	0.472
4	0.366	0.316	0.270	0.194
5	0.583	0.173	0.370	0.401
6	0.418	0.128	0.160	0.435
7	0.271	0.512	0.227	0.454
8	0.343	0.259	0.620	0.378
9	0.313	0.310	0.386	0.301
10	0.116	0.342	0.633	0.284
11	0.116	0.226	0.180	0.310
12	0.457	0.517	0.370	1.275

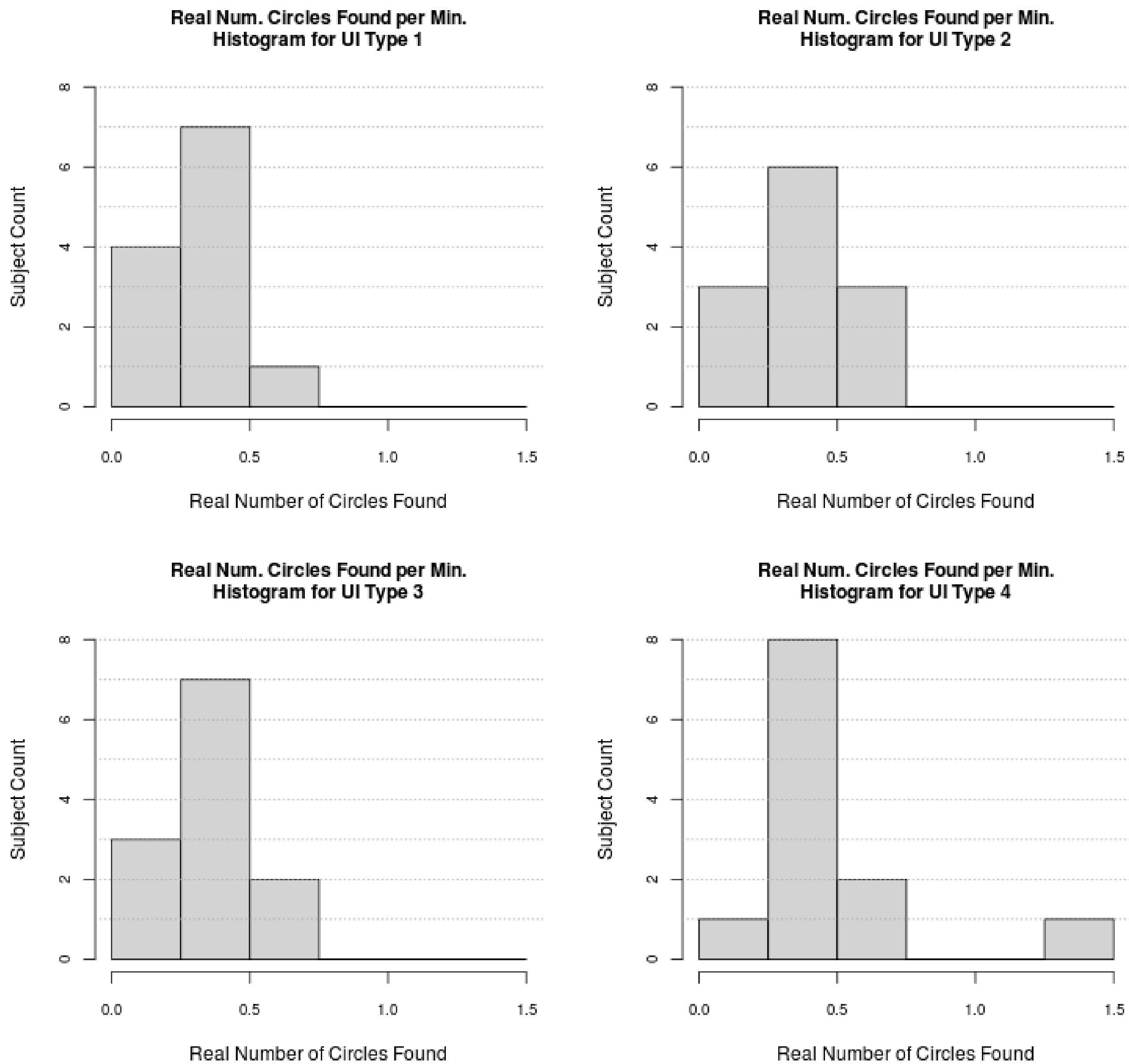


One-way ANOVA: Real Num. Circles Found Per Minute vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.175	0.058	1.583	0.207
Residuals	44	1.626	0.037		

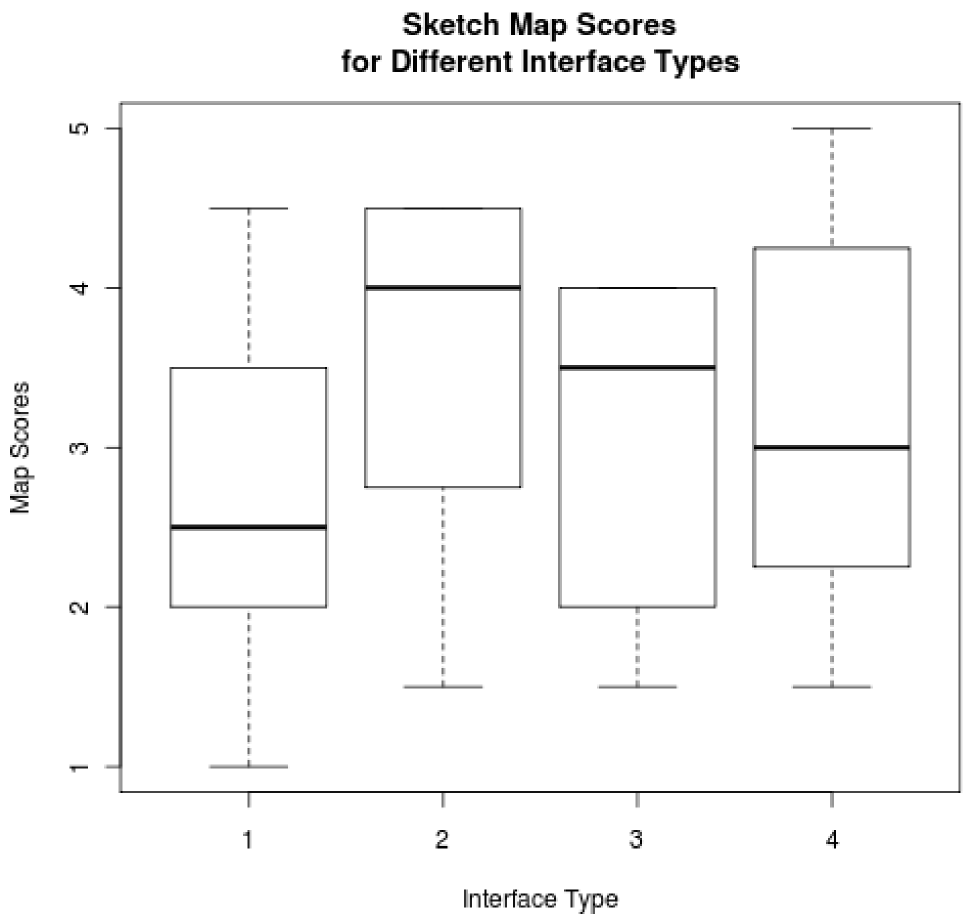
Real Num. Circles Found Per Minute vs. Interface Used Friedman test:	
X^2	2.500
p	0.475
DoF	3

Real Num. Circles Found Per Minute vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	36.000	39.000	14.000	33.000	19.000	25.000
Z	-0.235	0.000	-1.961	-0.471	-1.569	-1.098
p	0.850	1.000	0.052	0.677	0.129	0.301
R	-0.024	0.000	-0.200	-0.048	-0.160	-0.112

Real Num. Circles Found Per Minute vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.326	0.145	0.328
2	0.335	0.158	0.297
3	0.355	0.151	0.363
4	0.476	0.281	0.418

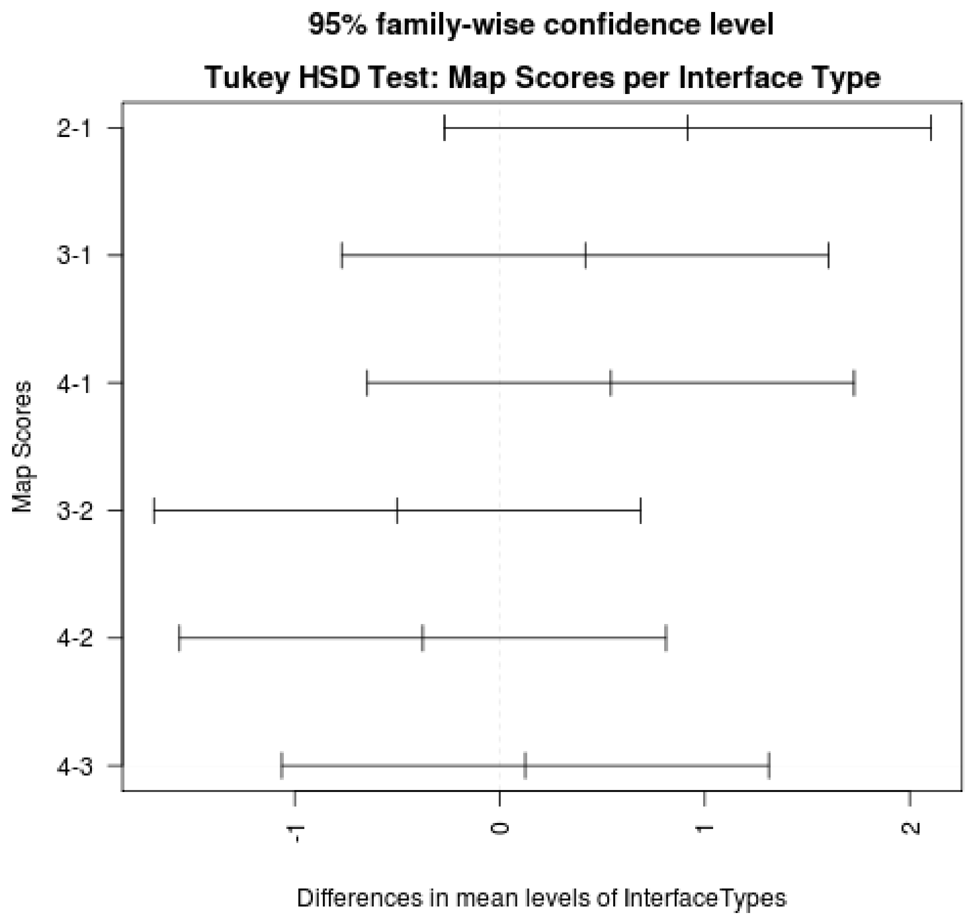


D.2.5 Quality of Sketchmaps



Subject Count	UI1	UI2	UI3	UI4
1	4.5	2.0	1.5	1.5
2	2.5	4.0	4.0	2.0
3	2.0	4.5	3.5	4.0
4	2.0	4.0	3.5	2.5
5	3.0	4.5	2.0	5.0
6	2.5	2.5	3.0	4.5
7	4.0	3.5	4.0	4.0
8	2.0	3.0	3.5	2.5
9	2.5	1.5	4.0	3.0
10	1.5	4.5	2.0	1.5
11	1.0	4.5	1.5	3.0
12	4.0	4.0	4.0	4.5

Correlation of Map scores between graders:
0.748

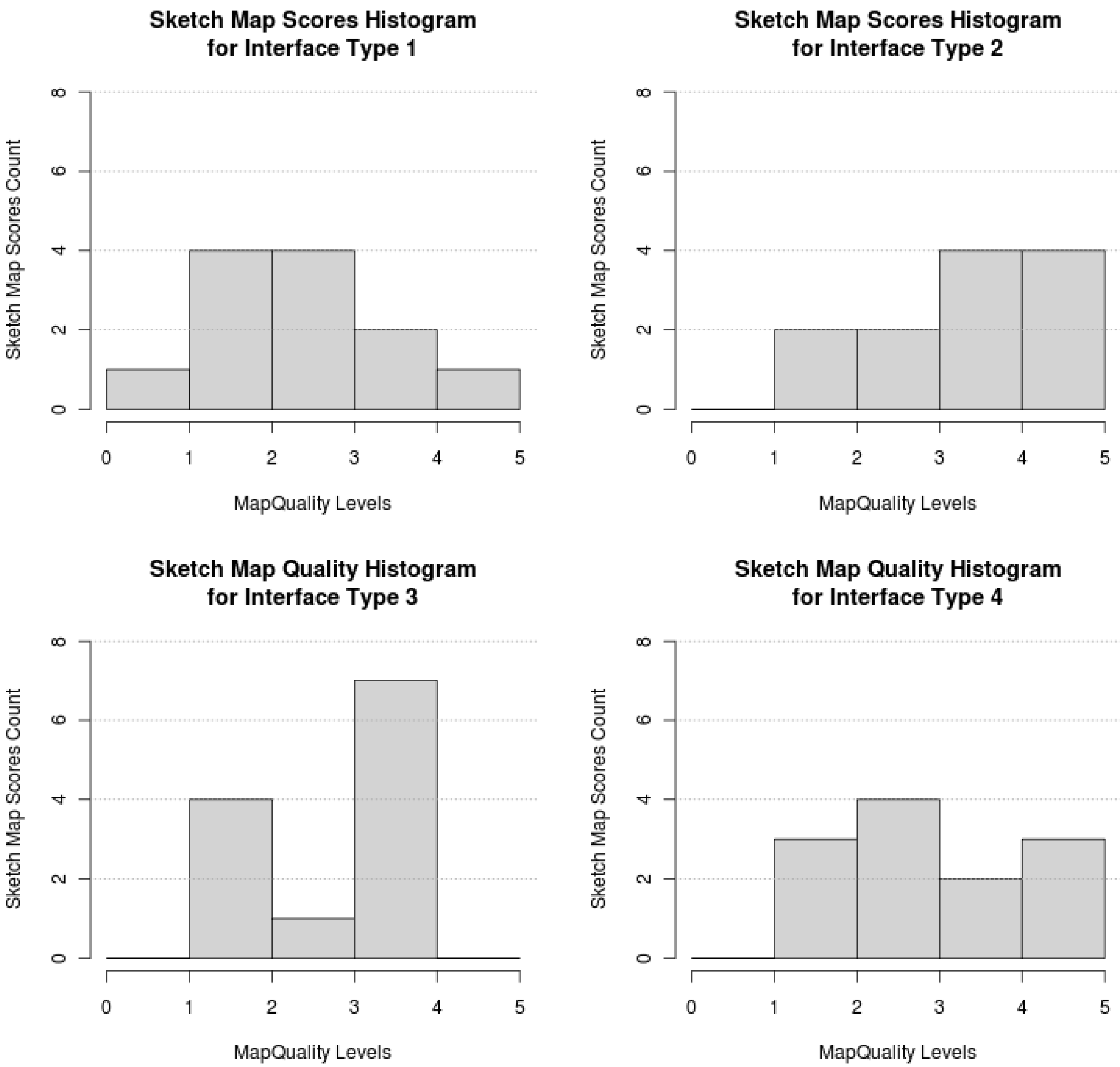


One-way ANOVA: Map Scores vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	5.141	1.714	1.445	0.243
Residuals	44	52.187	1.186		

Map Scores vs. Interface Used Friedman test:	
X^2	4.889
p	0.180
DoF	3

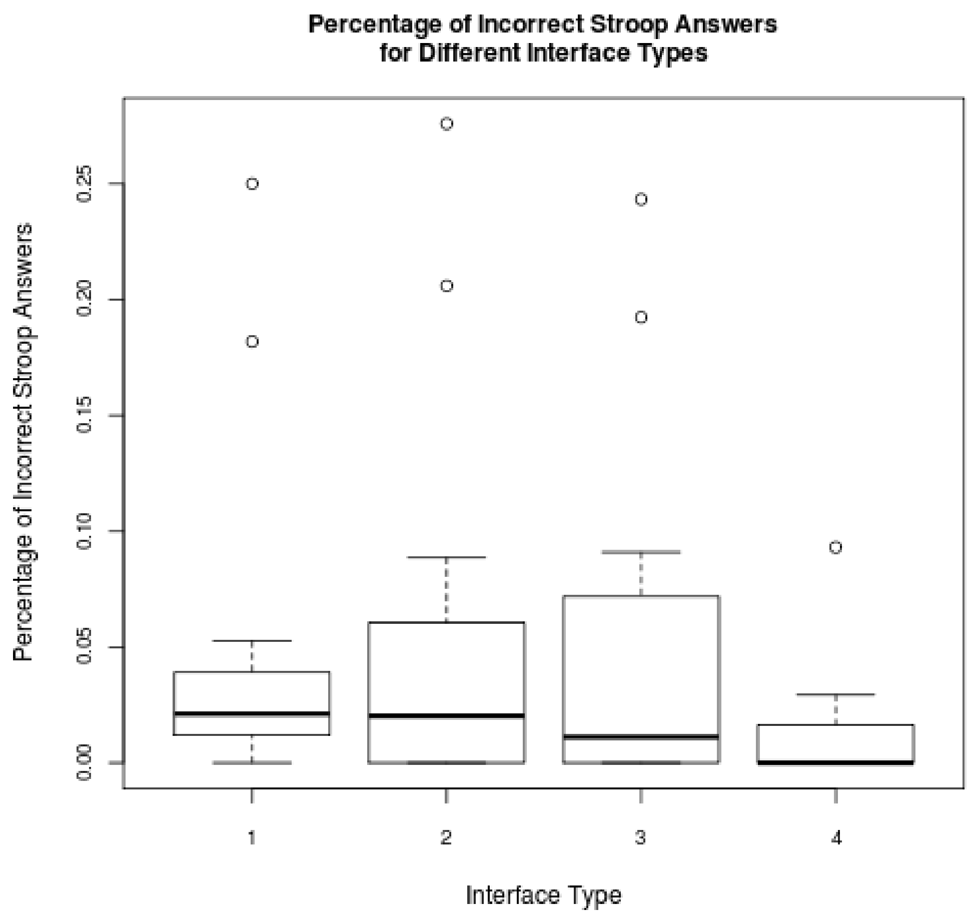
Map Scores vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	11.000	14.000	13.000	38.000	49.000	26.000
Z	-1.616	-1.550	-1.633	0.994	0.797	-0.119
p	0.111	0.139	0.109	0.385	0.458	0.912
R	-0.165	-0.158	-0.167	0.101	0.081	-0.012

Map Scores vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	2.625	1.069	2.500
2	3.542	1.054	4.000
3	3.042	1.010	3.500
4	3.167	1.212	3.000

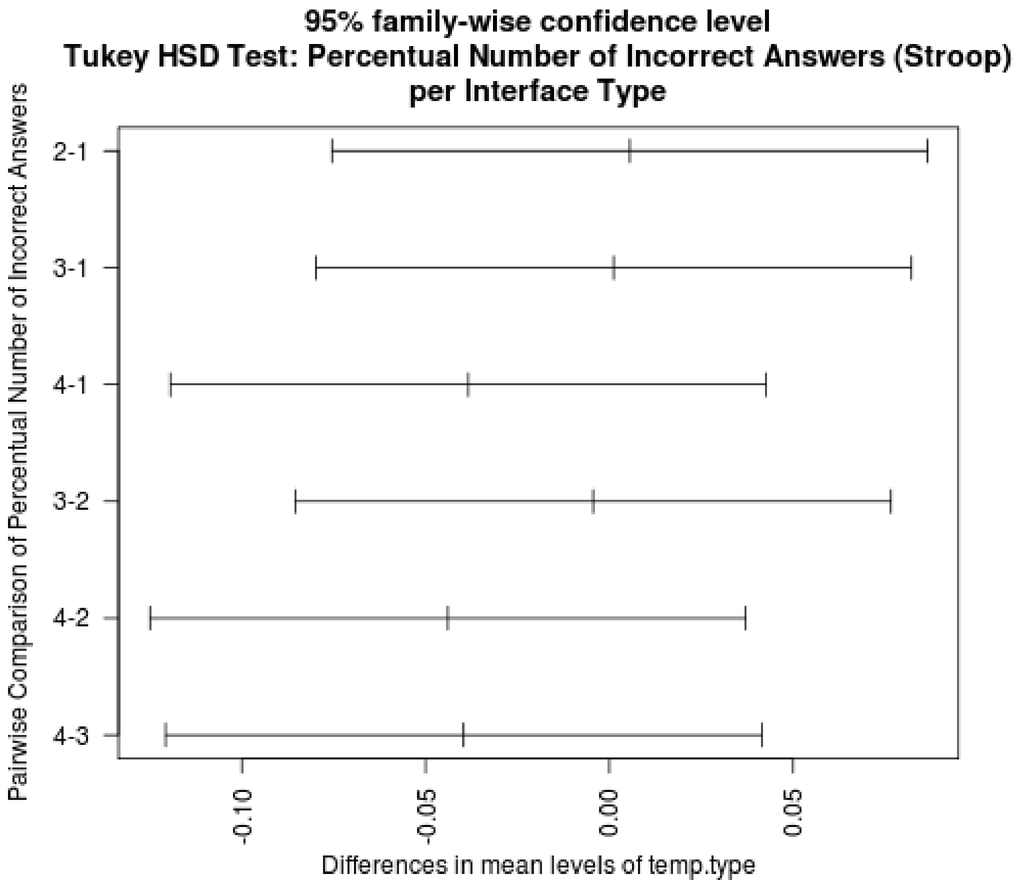


D.2.6 Stroop Task

D.2.6.1 Percentual Number of Incorrect Answers: All Questions



Subject Count	UI1	UI2	UI3	UI4
1	0.000	0.030	0.000	0.000
2	0.011	0.276	0.243	0.000
3	0.016	0.206	0.053	0.000
4	0.021	0.000	0.000	0.020
5	0.182	0.000	0.000	0.093
6	0.024	0.000	0.000	0.000
7	0.013	0.032	0.000	0.000
8	0.000	0.000	0.192	0.000
9	0.026	0.089	0.000	0.029
10	0.250	0.020	0.029	0.013
11	0.053	0.010	0.022	0.000
12	0.021	0.021	0.091	0.000

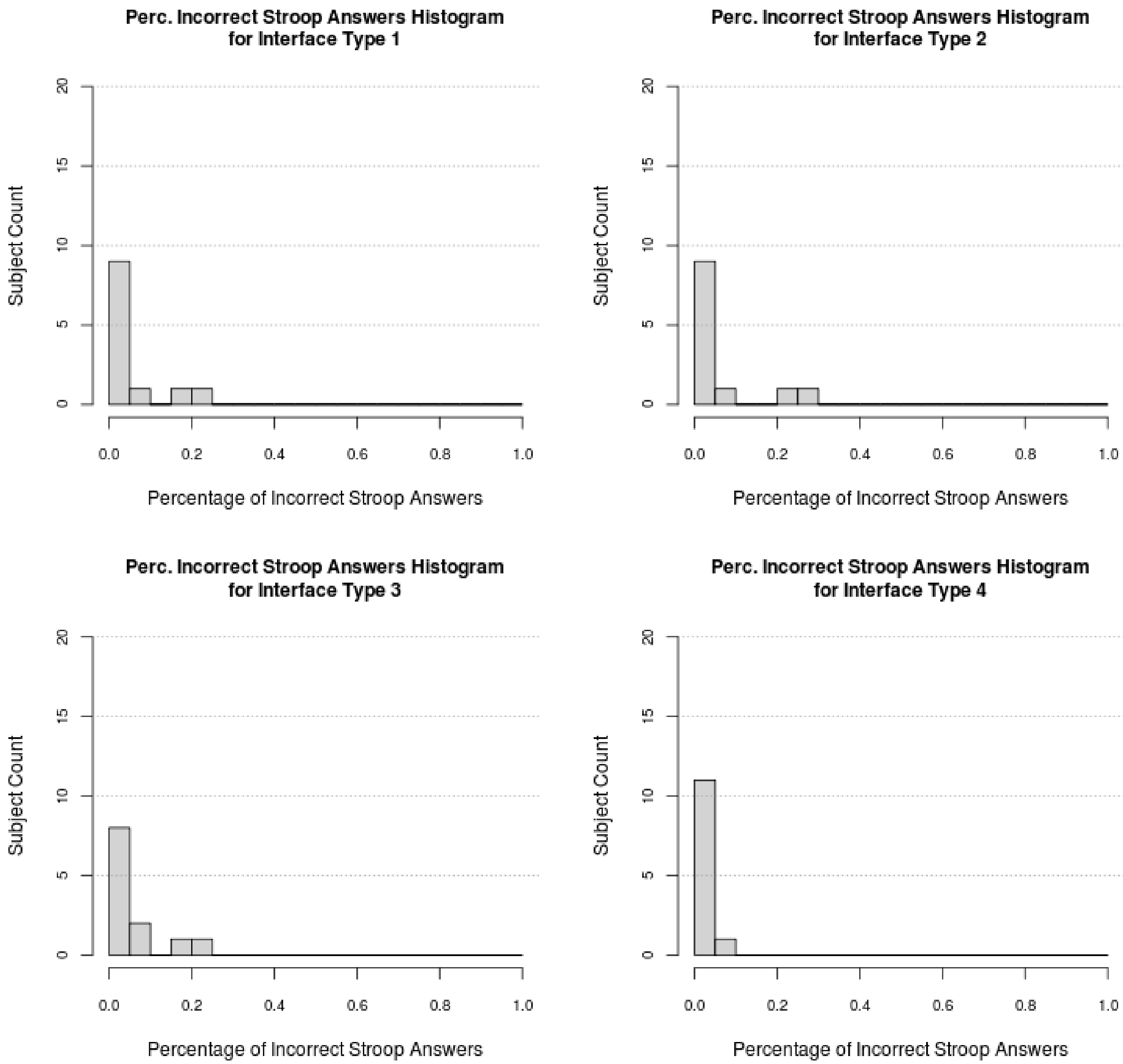


One-way ANOVA: Percentual of Incorrect Strrop Answers vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.015	0.005	0.910	0.444
Residuals	44	0.243	0.006		

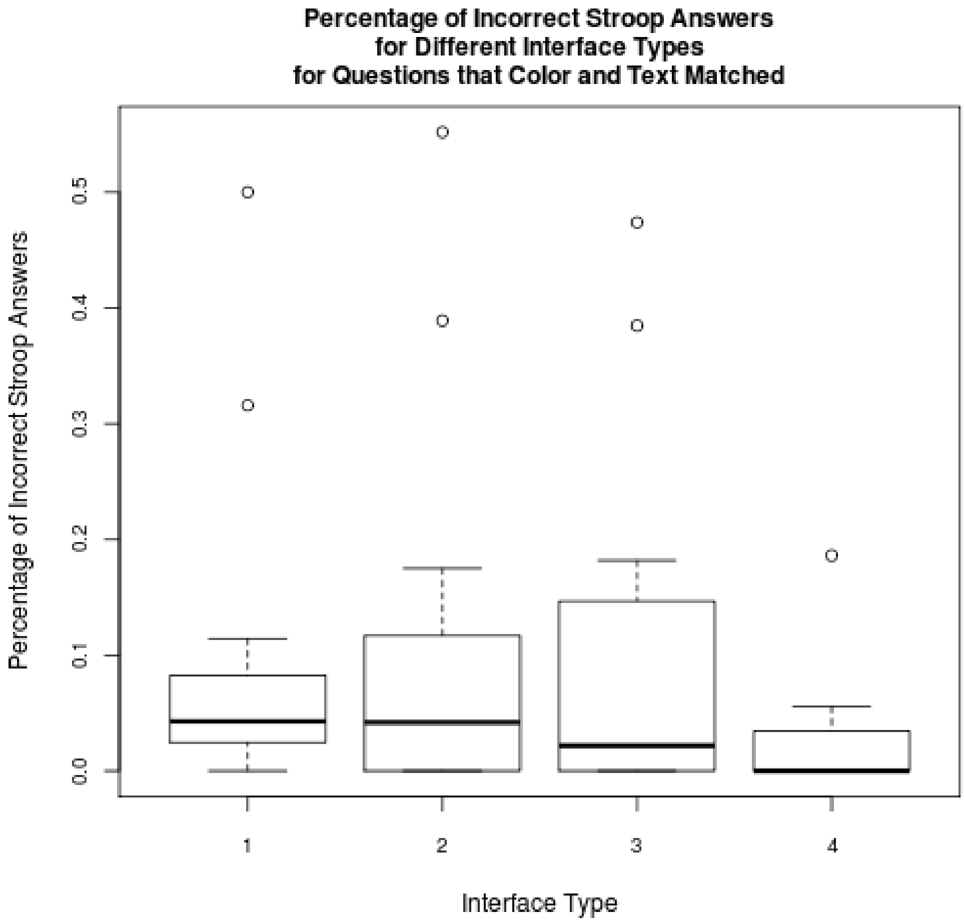
Percentual of Incorrect Strrop Answers vs. Interface Used Friedman test:	
X^2	6.714
p	0.082
DoF	3

Percentual of Incorrect Strrop Answers vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	32.000	33.000	53.000	27.000	44.000	32.000
Z	-0.039	0.118	2.638	0.476	1.772	1.110
p	1.000	0.939	0.006	0.676	0.084	0.297
R	-0.004	0.012	0.269	0.049	0.181	0.113

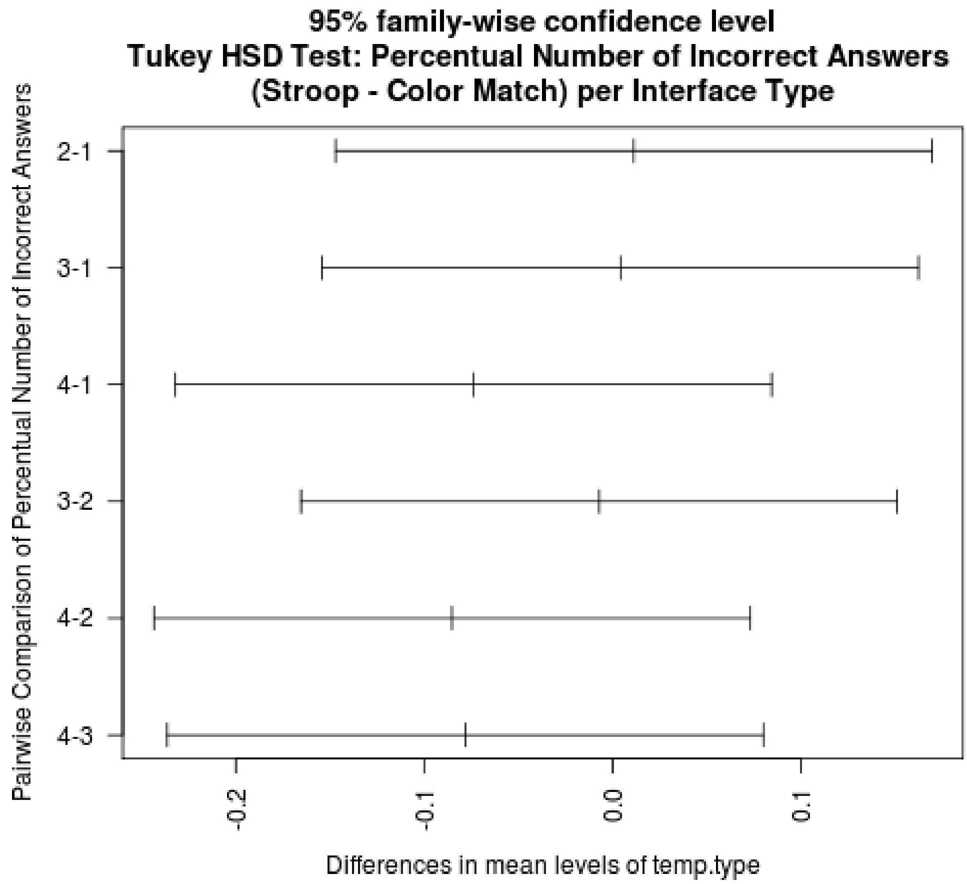
Percentual of Incorrect Strrop Answers vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.051	0.079	0.021
2	0.057	0.091	0.020
3	0.053	0.083	0.011
4	0.013	0.027	0.000



D.2.6.1.1 Percentual Number of Incorrect Answers – Questions Where Color Matched



UI1	UI2	UI3	UI4
0.000	0.059	0.000	0.000
0.023	0.552	0.474	0.000
0.032	0.389	0.111	0.000
0.042	0.000	0.000	0.042
0.316	0.000	0.000	0.186
0.050	0.000	0.000	0.000
0.026	0.056	0.000	0.000
0.000	0.000	0.385	0.000
0.050	0.175	0.000	0.056
0.500	0.040	0.053	0.027
0.114	0.019	0.043	0.000
0.043	0.043	0.182	0.000

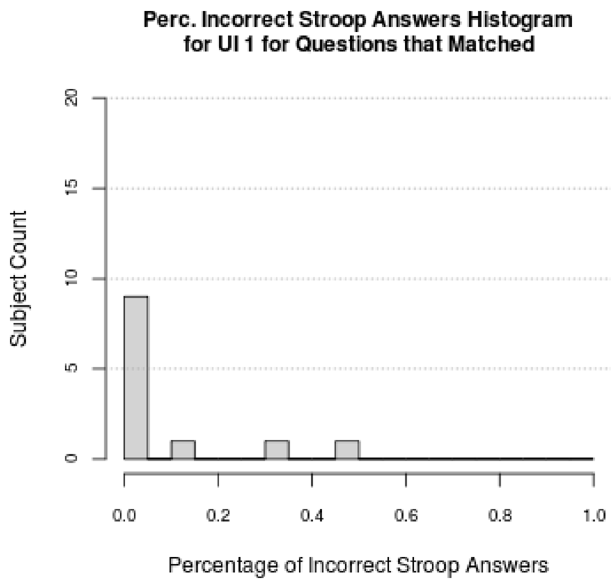


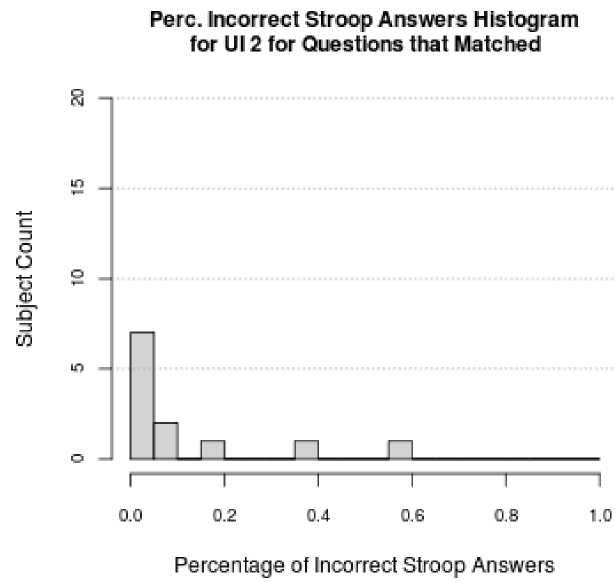
One-way ANOVA: Percentual of Incorrect Strrop Answers (Color Match) vs. Interface Used					
	DoF	*Sum Sq.*	*Mean Sq.*	*F-value*	*Pr(>F)*
interface type	3	0.057	0.019	0.901	0.448
Residuals	44	0.928	0.021		

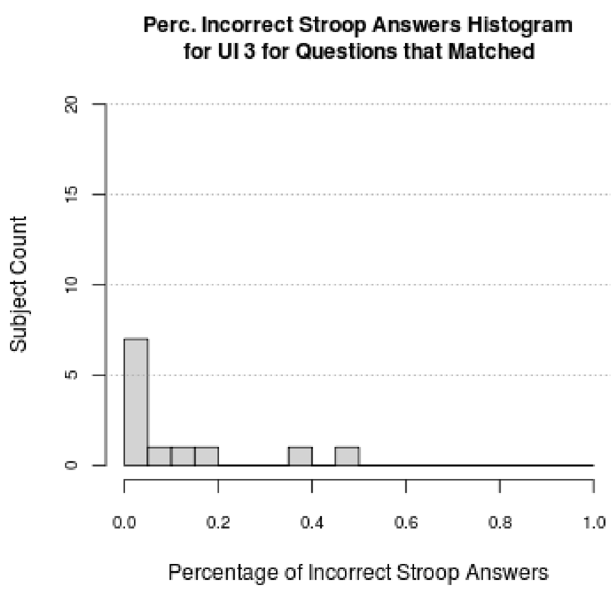
Percentual of Incorrect Strrop Answers (Color Match) vs. Interface Used Friedman test:	
X^2	5.913
p	0.116
DoF	3

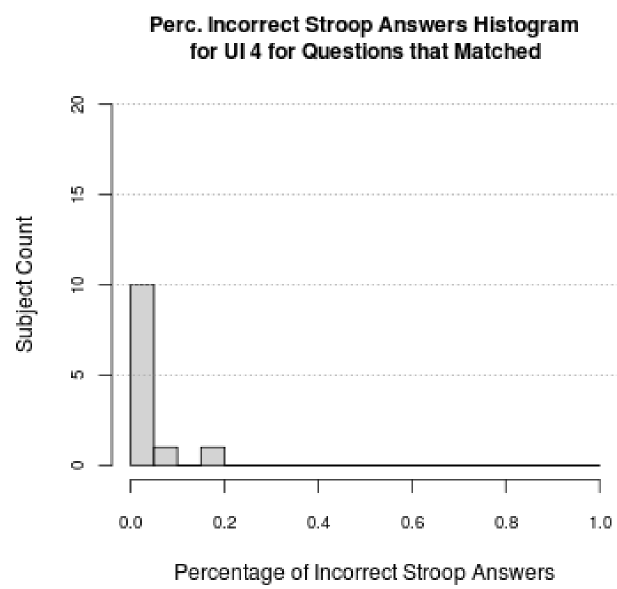
Percentual of Incorrect Strrop Answers (Color Match) vs. Interface Used Wilcoxon test:						
	UI1 – UI2	UI1 – UI3	UI1 – UI4	UI2 – UI3	UI2 – UI4	UI3 – UI4
W	26.000	33.000	44.000	27.000	44.000	32.000
Z	-0.118	0.118	2.538	0.476	1.772	1.110
p	0.939	0.925	0.008	0.676	0.084	0.297
R	-0.012	0.012	0.259	0.049	0.181	0.113

Percentual of Incorrect Strrop Answers (Color Match) vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.100	0.152	0.043
2	0.111	0.178	0.042
3	0.104	0.163	0.022
4	0.026	0.054	0.000

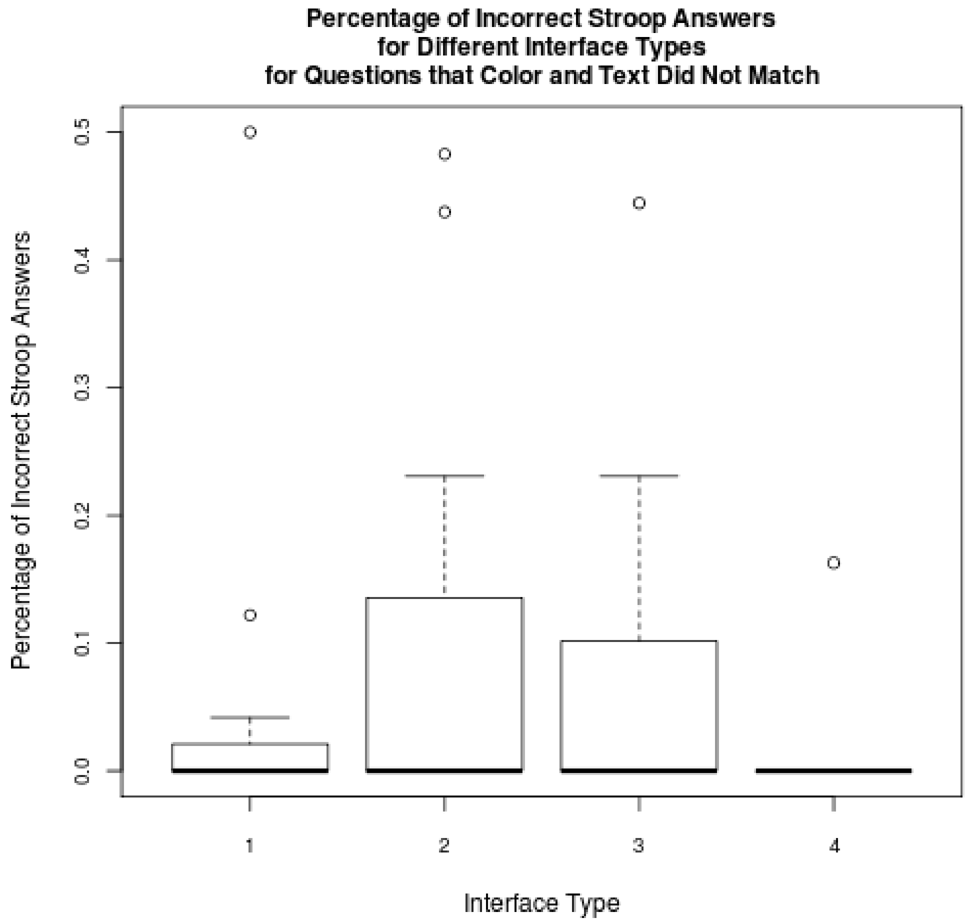




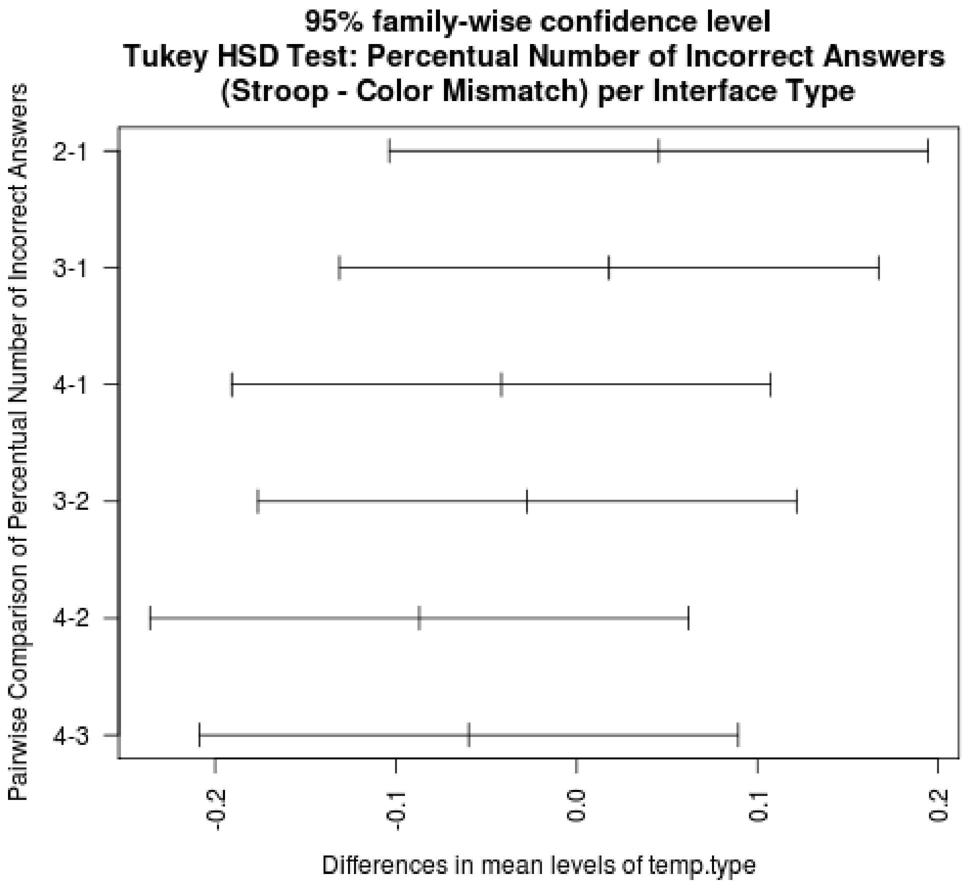




D.2.6.1.2 Percentual Number of Incorrect Answers – Questions Where Color Mismatched



Subject Count	UI1	UI2	UI3	UI4
1	0.000	0.000	0.000	0.000
2	0.000	0.483	0.444	0.000
3	0.000	0.438	0.000	0.000
4	0.000	0.000	0.000	0.000
5	0.000	0.016	0.000	0.163
6	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000
8	0.000	0.000	0.231	0.000
9	0.000	0.231	0.000	0.000
10	0.500	0.000	0.067	0.000
11	0.122	0.000	0.000	0.000
12	0.042	0.040	0.136	0.000

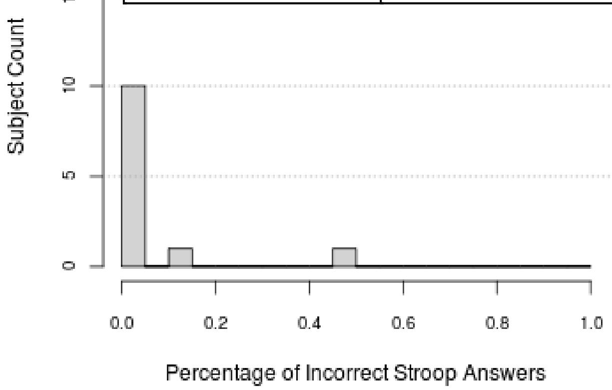


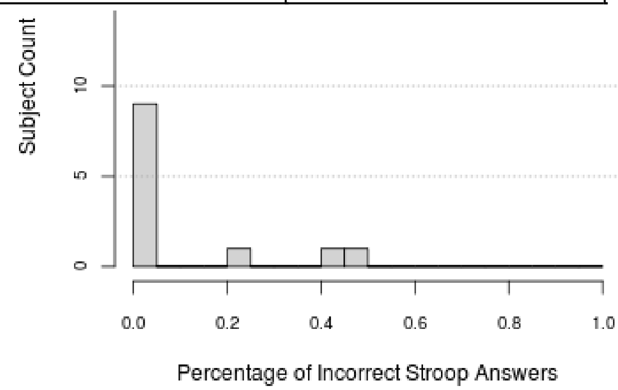
One-way ANOVA: Percentual of Incorrect Strrop Answers (Color Mismatch) vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.048	0.016	0.856	0.471
Residuals	44	0.822	0.019		

Percentual of Incorrect Strrop Answers (Color Mismatch) vs. Interface Used Friedman test:	
X^2	5.913
p	0.116
DoF	3

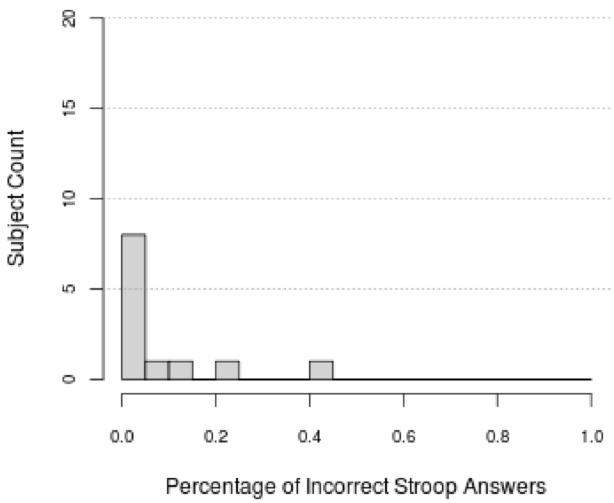
Percentual of Incorrect Strrop Answers (Color Mismatch) vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	11.000	6.000	7.000	15.500	13.000	12.000
Z	-0.451	-0.443	0.947	0.328	1.417	1.328
p	0.688	0.750	0.500	0.781	0.188	0.250
R	-0.046	-0.045	0.097	0.033	0.145	0.136

Percentual of Incorrect Strrop Answers (Color Mismatch) vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.055	0.145	0.000
2	0.101	0.180	0.000
3	0.073	0.138	0.000
4	0.014	0.047	0.000

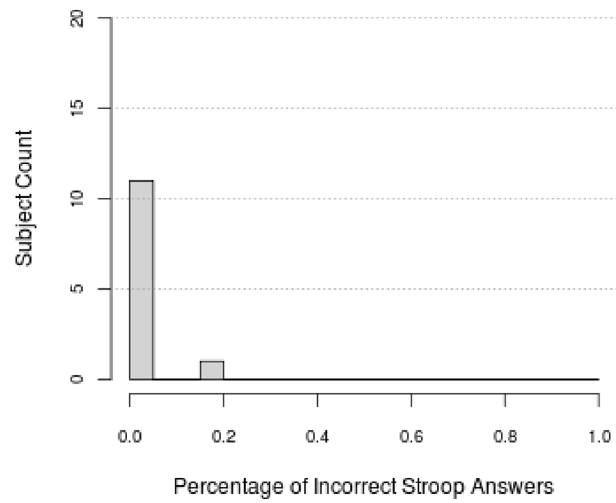




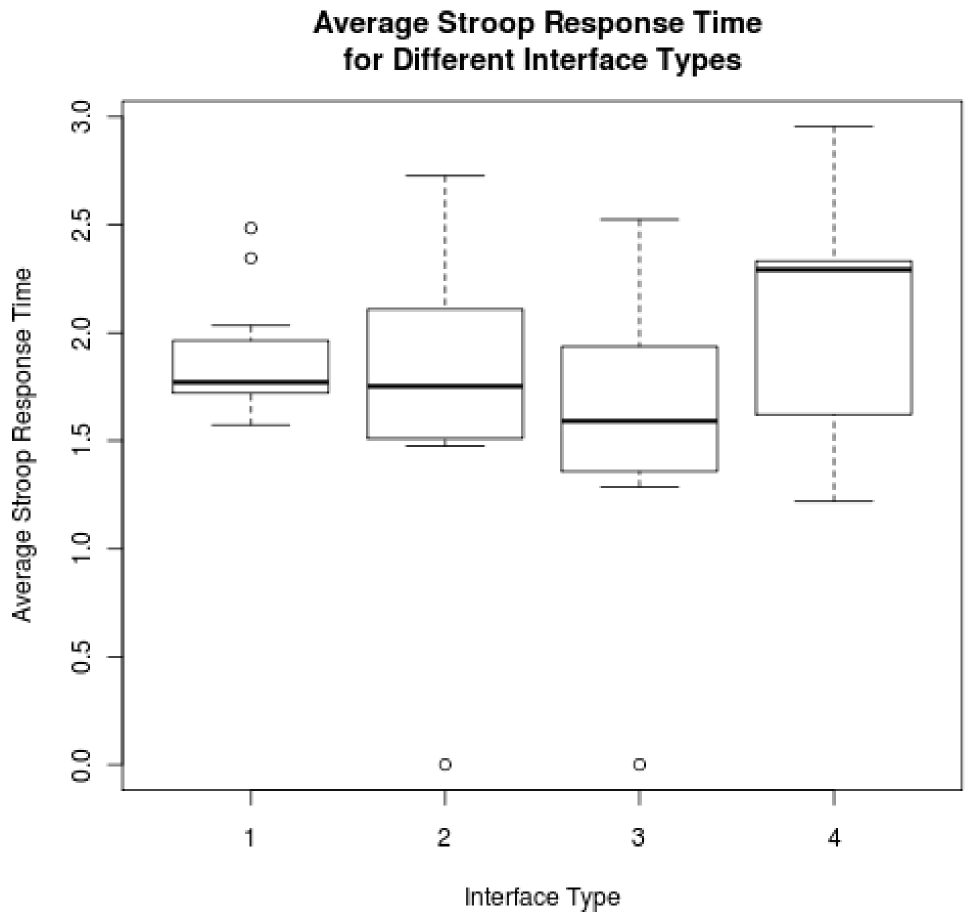
Perc. Incorrect Stroop Answers Histogram for UI 3 for Non-Matching Questions



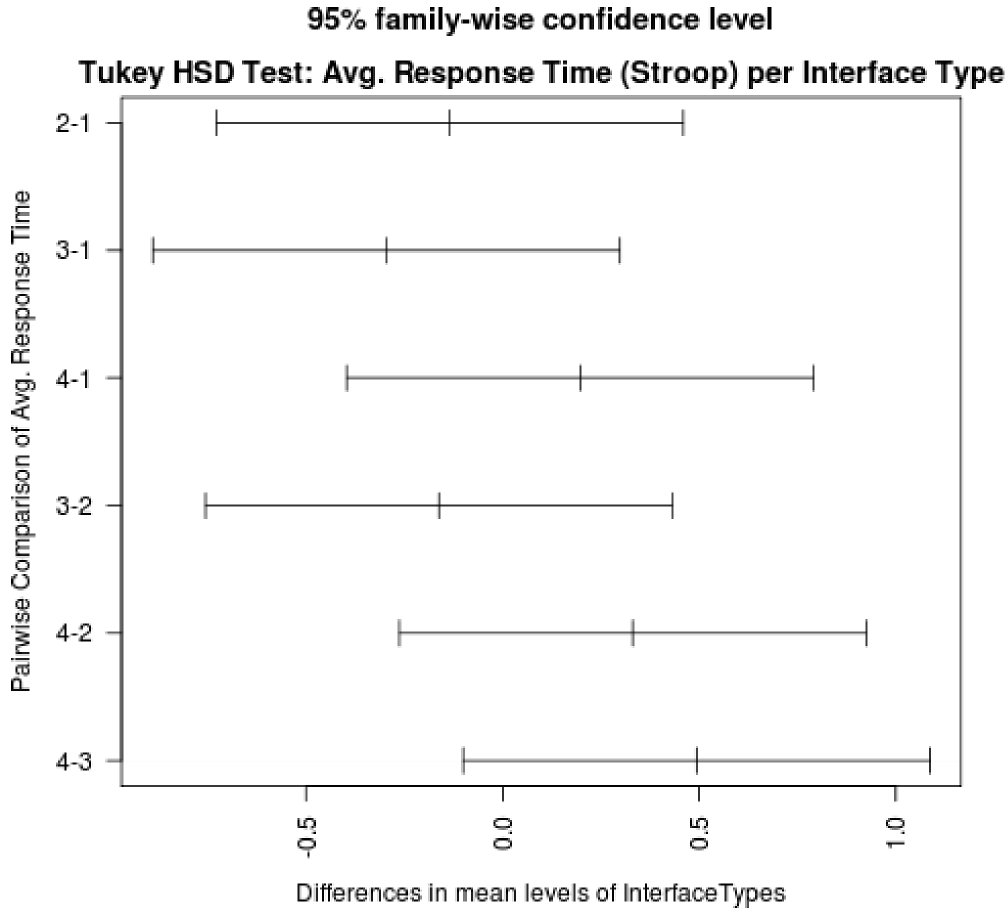
Perc. Incorrect Stroop Answers Histogram for UI 4 for Non-Matching Questions



D.2.6.2 Response Time: All Questions



Subject Count	UI1	UI2	UI3	UI4
1	1.726	2.226	1.303	1.218
2	1.737	1.633	2.058	2.283
3	2.485	1.475	2.524	2.956
4	2.033	2.727	1.534	2.309
5	2.345	1.690	1.287	1.639
6	1.714	0.000	1.413	1.879
7	1.573	1.813	0.000	1.472
8	1.588	1.991	1.770	2.551
9	1.871	1.515	1.434	2.336
10	1.735	2.488	1.650	2.302
11	1.896	1.837	2.171	1.603
12	1.805	1.505	1.814	2.328

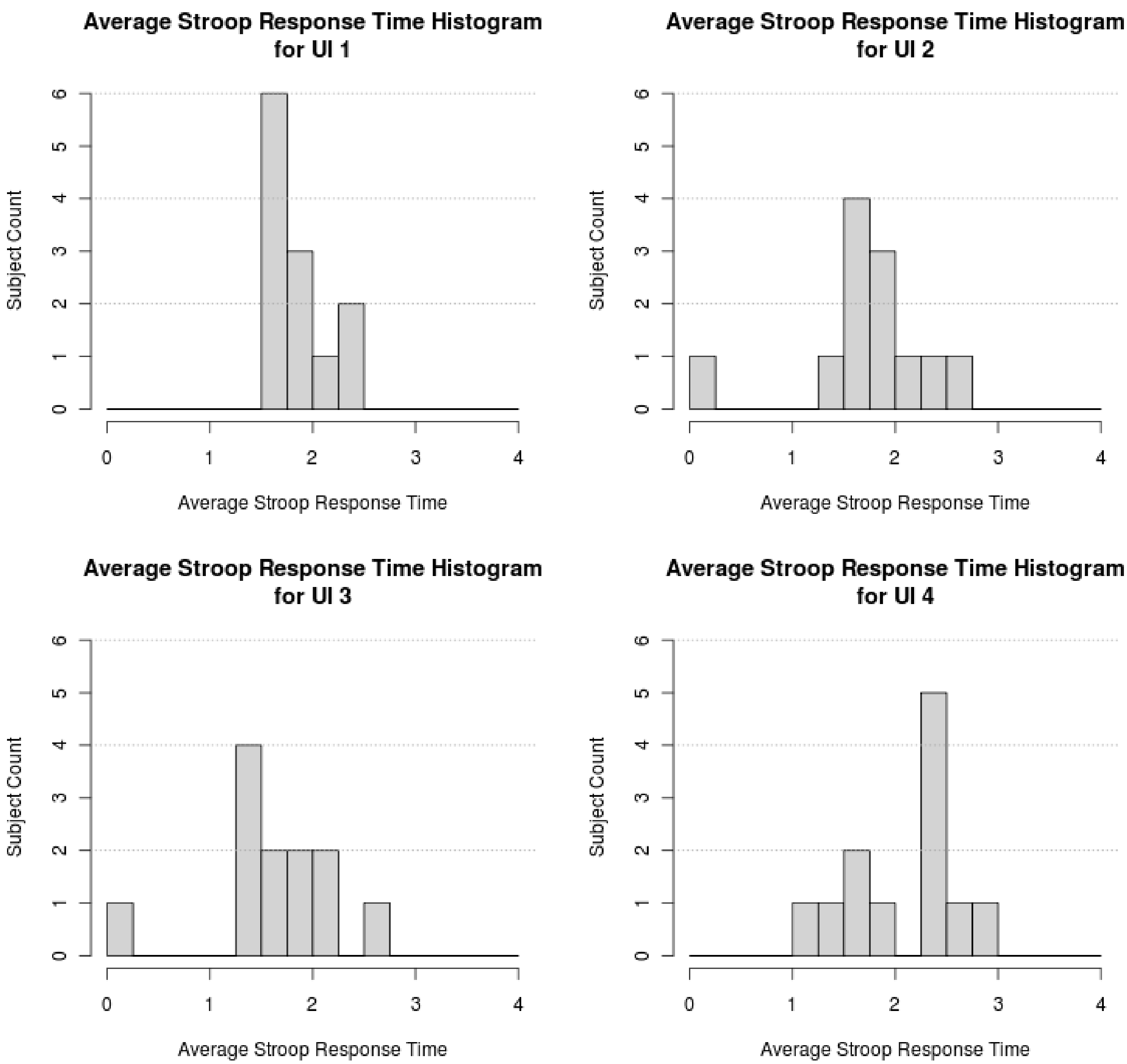


One-way ANOVA: Response Time vs. Interface Used					
	DoF	*Sum Sq.*	*Mean Sq.*	*F-value*	*Pr(>F)*
interface type	3	1.572	0.524	1.766	0.168
Residuals	44	13.056	0.297		

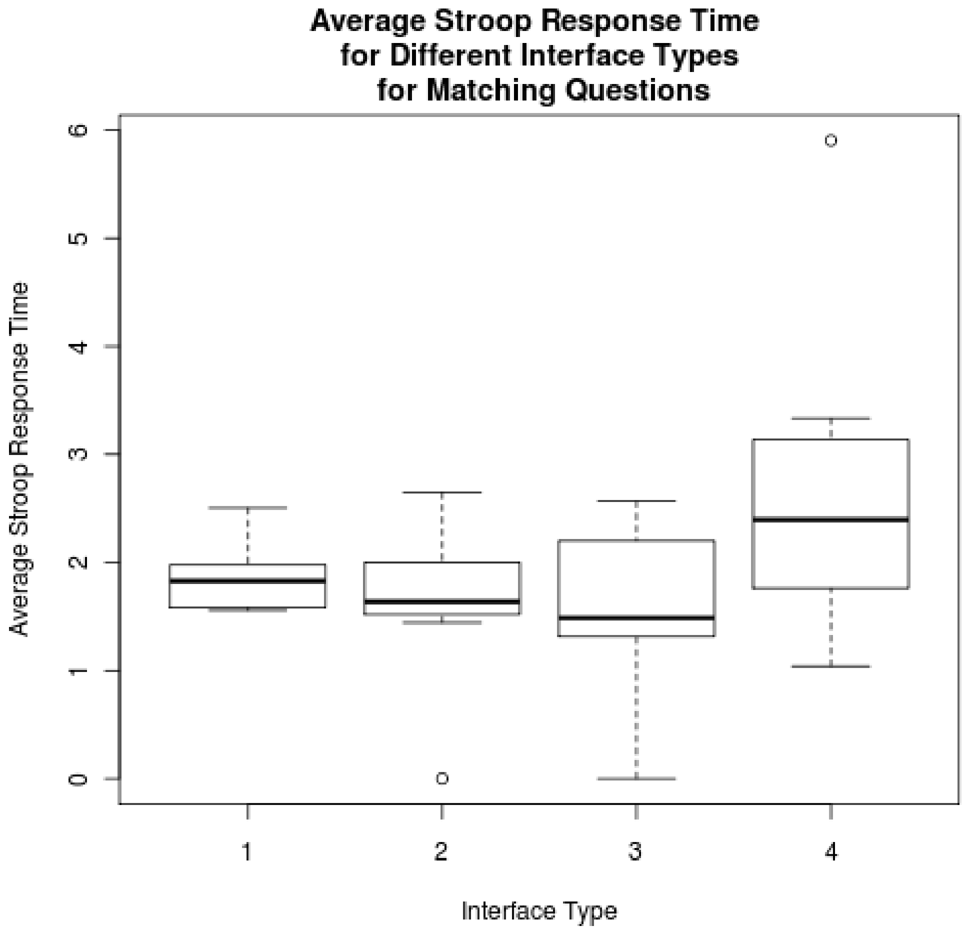
Response Time vs. Interface Used Kurskal-Wallis test:	
X^2	4.685
DoF	3
p	0.196

Response Time vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	UI1 – UI3	UI1 – UI4	UI2 – UI3	UI2 – UI4	UI3 – UI4
X^2	0.403	2.083	0.653	0.908	1.333	3.853
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	0.525	0.149	0.419	0.341	0.284	0.050

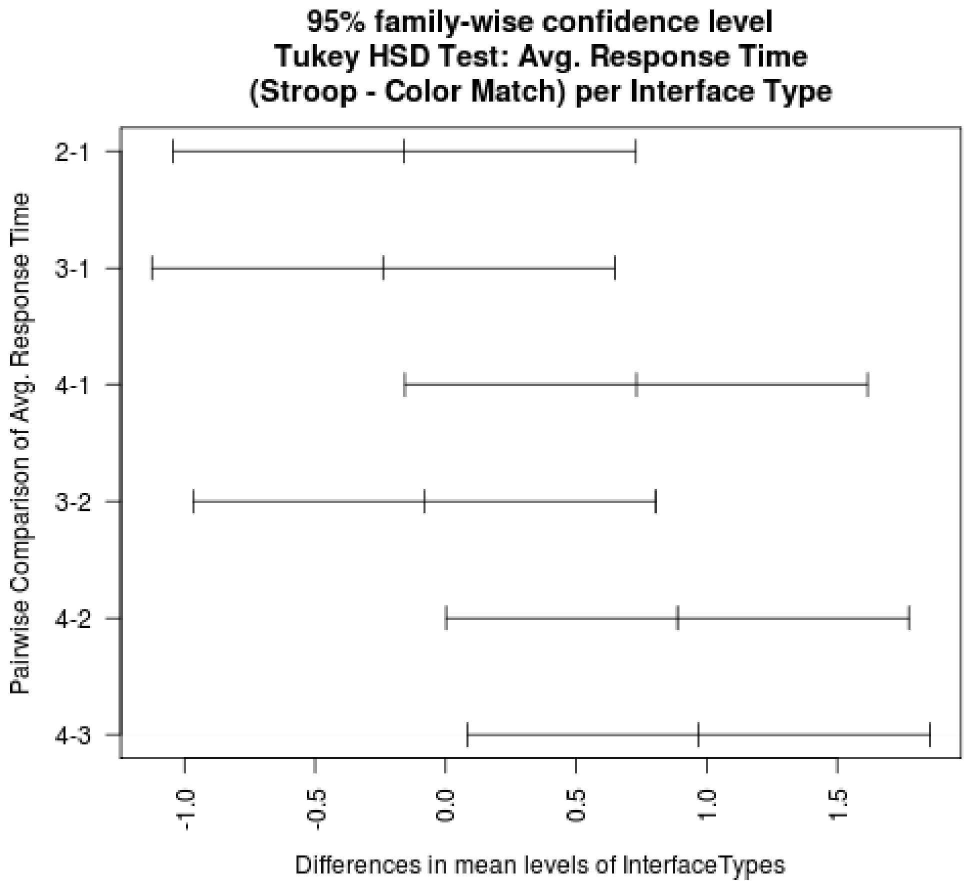
Response Time vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	1.876	0.283	1.771
2	1.742	0.679	1.752
3	1.580	0.623	1.592
4	2.073	0.508	2.292



D.2.6.2.1 Response Time – Questions Where Color Matched



Subject Count	UI1	UI2	UI3	UI4
1	1.785	1.933	1.332	1.040
2	1.557	1.643	2.442	5.905
3	2.504	1.443	2.567	3.111
4	2.003	2.648	1.410	2.896
5	2.283	1.614	1.296	1.893
6	1.827	0.000	1.509	1.915
7	1.575	1.904	0.000	1.480
8	1.580	2.073	1.972	3.334
9	1.955	1.576	1.462	2.432
10	1.830	2.566	1.287	2.360
11	1.903	1.630	2.434	1.630
12	1.587	1.461	1.809	3.160

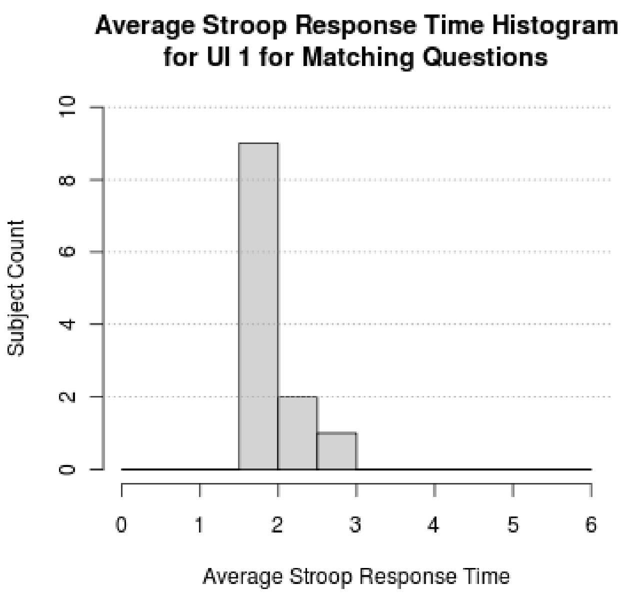


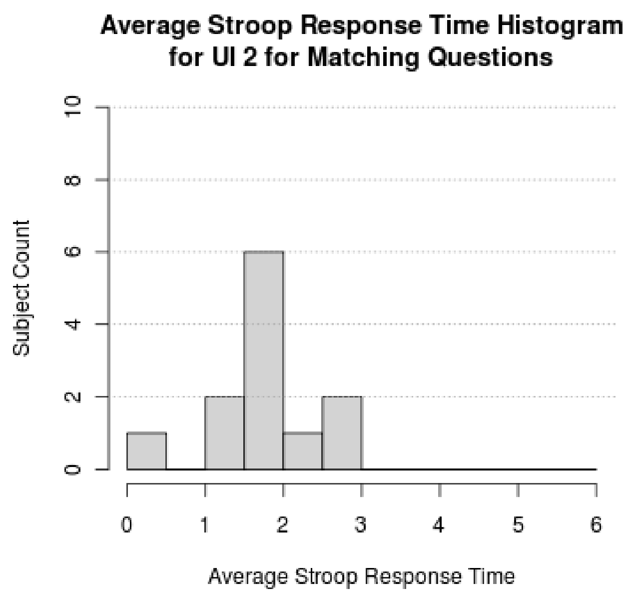
One-way ANOVA: Response Time (Color Match) vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	7.058	2.353	3.558	0.022
Residuals	44	29.092	0.661		

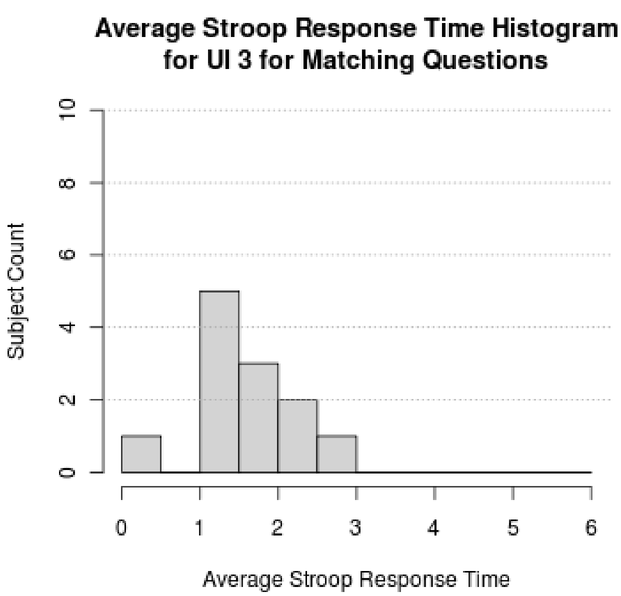
Response Time (Color Match) vs. Interface Used Kurskal-Wallis test:	
X^2	6.641
DoF	3
p	0.084

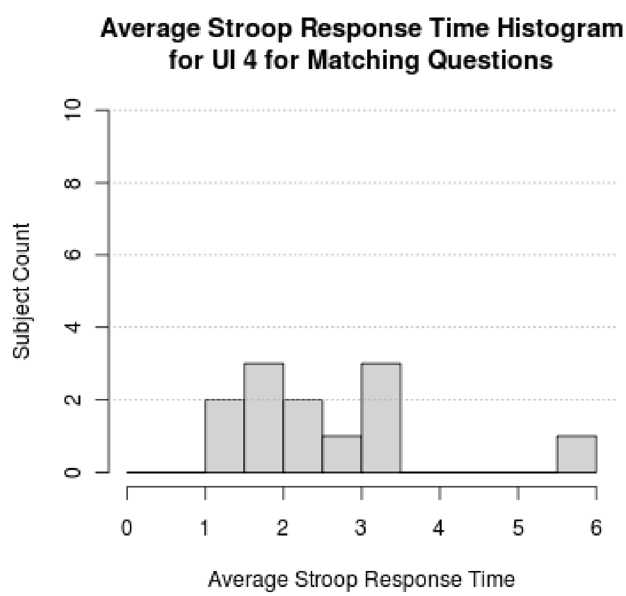
Response Time (Color Match) vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	0.213	1.920	2.803	0.701	3.413	4.320
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	0.644	0.166	0.094	0.402	0.065	0.038

Response Time (Color Match) vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	1.866	0.295	1.828
2	1.708	0.669	1.637
3	1.627	0.700	1.486
4	2.596	1.272	2.396

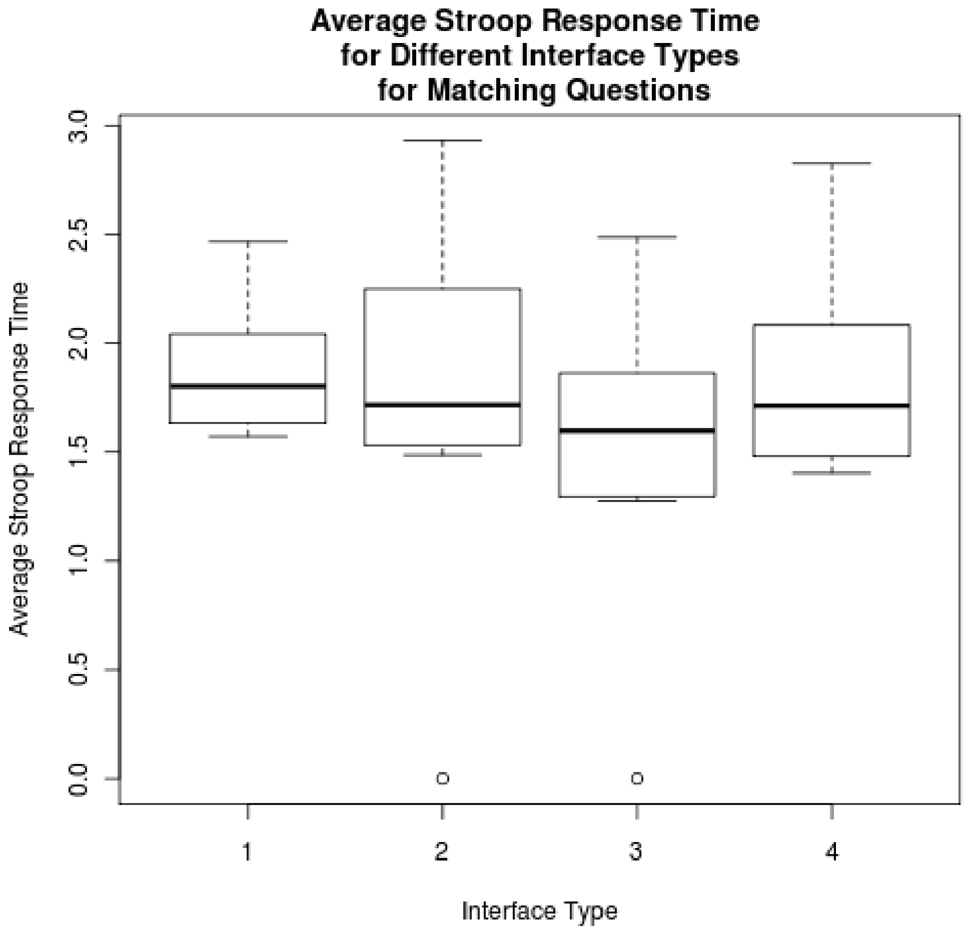




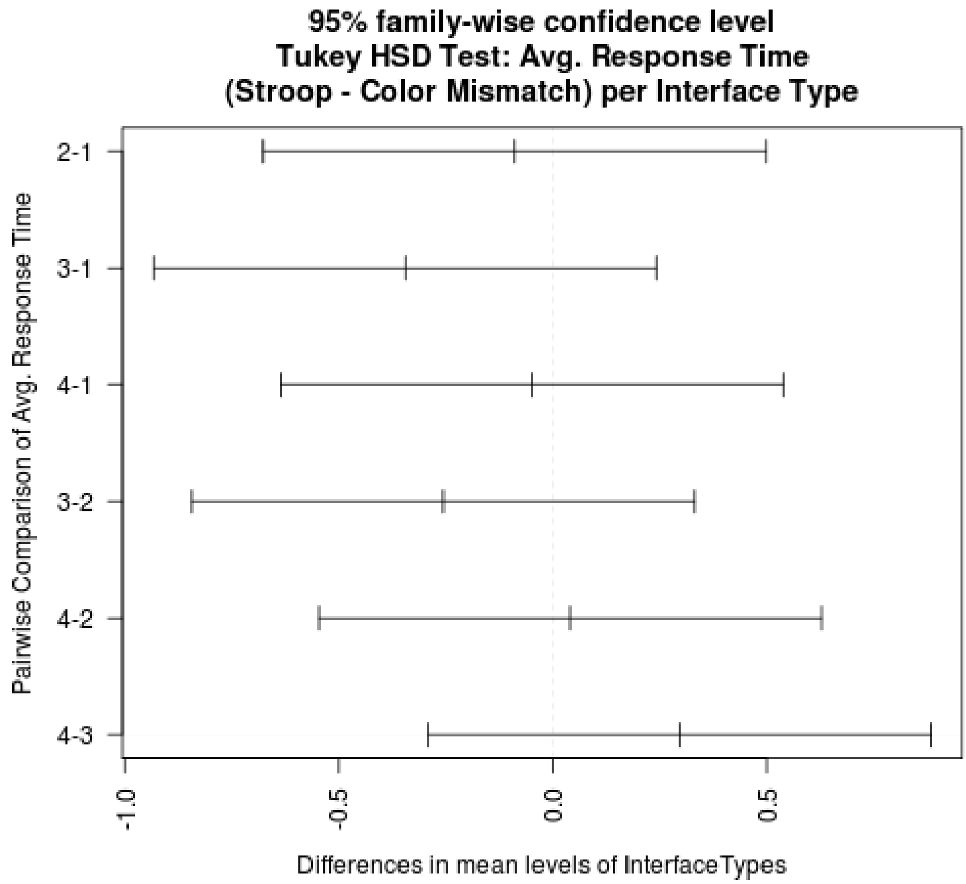




D.2.6.2.2 Response Time – Questions Where Color Mismatched



Subject Count	UI1	UI2	UI3	UI4
1	1.648	2.490	1.275	1.422
2	1.844	1.623	1.629	1.880
3	2.468	1.514	2.487	2.826
4	2.052	2.932	1.658	1.974
5	2.390	1.751	1.278	1.404
6	1.619	0.000	1.315	1.813
7	1.572	1.681	0.000	1.466
8	1.597	1.916	1.568	1.611
9	1.762	1.487	1.400	2.193
10	1.645	2.428	2.037	2.275
11	1.885	2.073	1.907	1.577
12	2.033	1.550	1.820	1.496

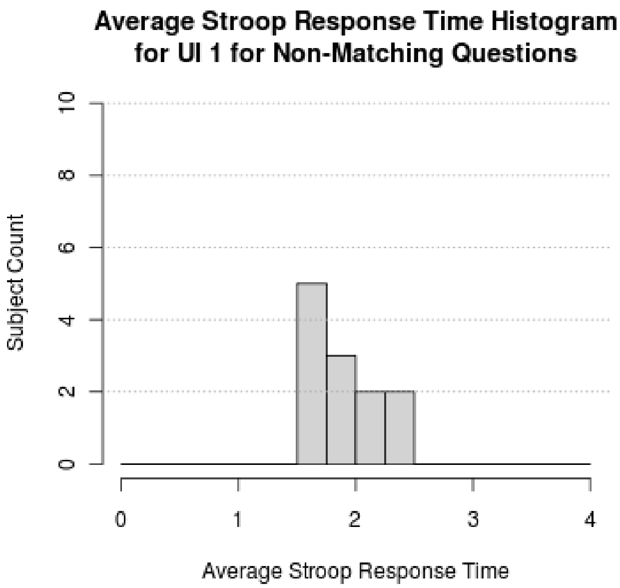


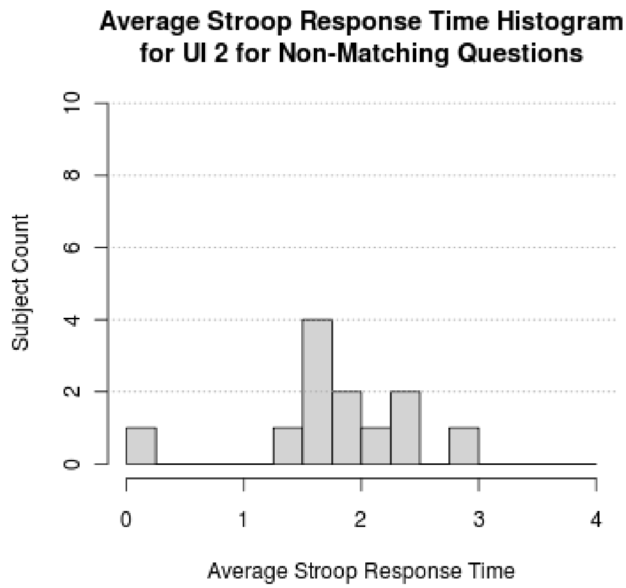
One-way ANOVA: Response Time (Color Mismatch) vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.855	0.285	0.979	0.411
Residuals	44	12.802	0.291		

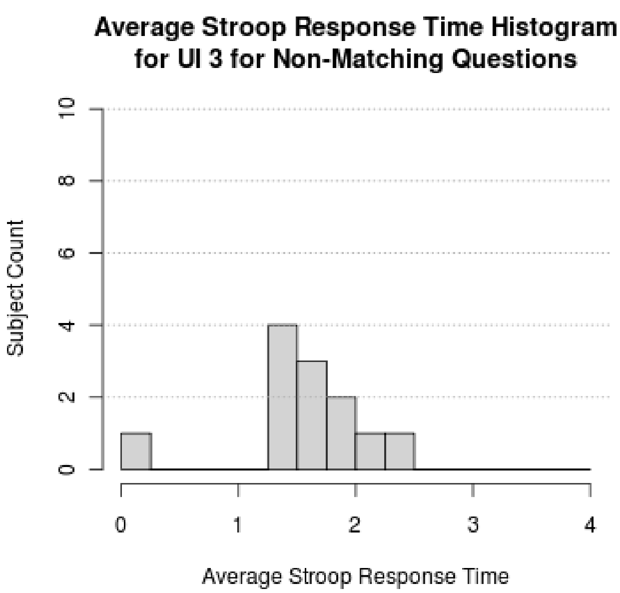
Response Time (Color Mismatch) vs. Interface Used Kurskal-Wallis test:	
X^2	3.518
DoF	3
p	0.318

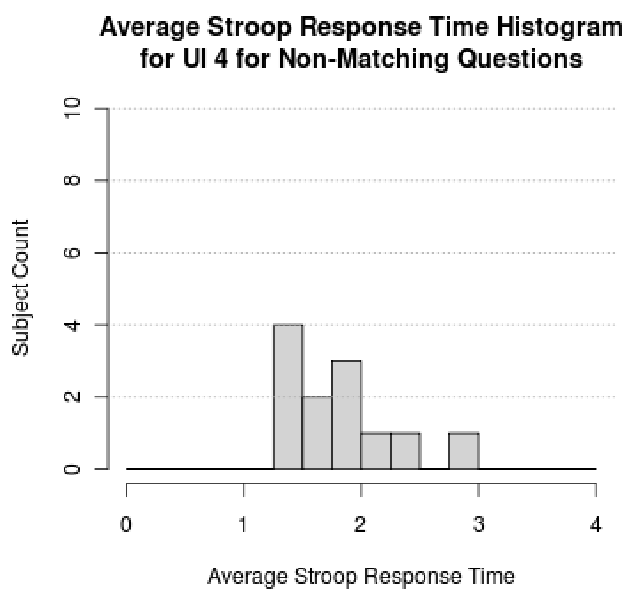
Response Time (Color Mismatch) vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	0.120	2.803	0.853	1.542	0.213	1.470
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	0.729	0.094	0.356	0.214	0.644	0.225

Response Time (Color Mismatch) vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	1.876	0.305	1.803
2	1.787	0.724	1.716
3	1.531	0.600	1.598
4	1.828	0.432	1.712

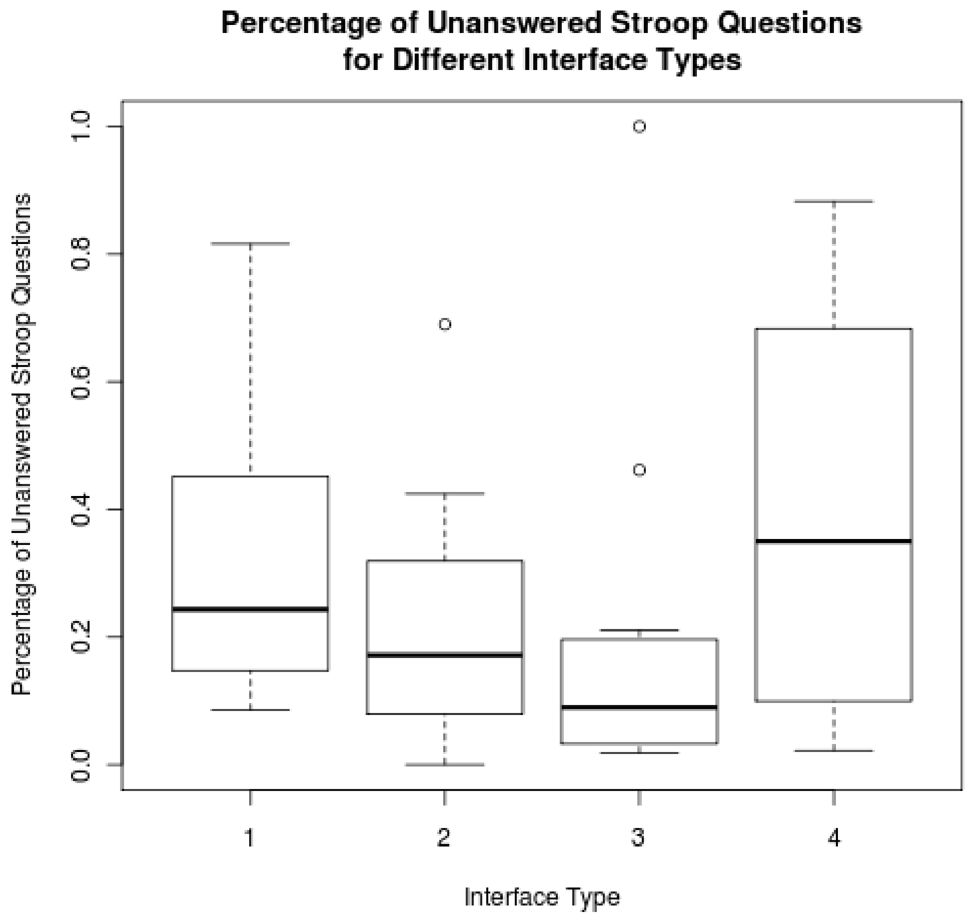




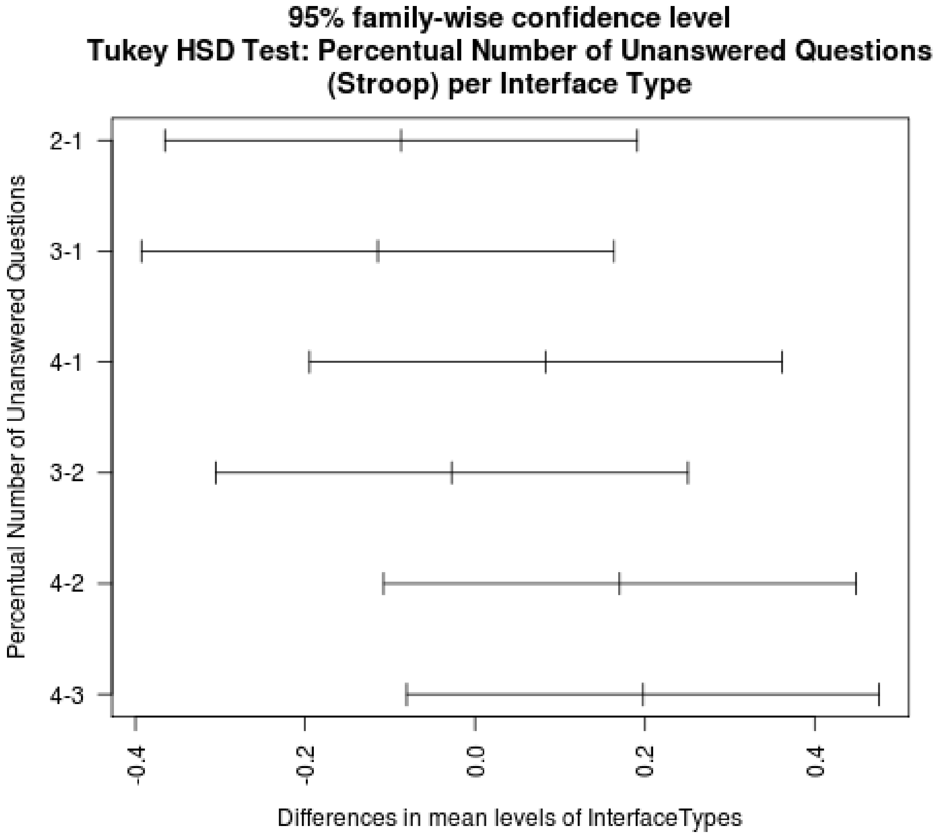




D.2.6.3 Number of Unanswered Questions



Subject Count	UI1	UI2	UI3	UI4
1	0.571	0.424	0.091	0.022
2	0.213	0.069	0.027	0.655
3	0.492	0.088	0.211	0.738
4	0.292	0.690	0.038	0.560
5	0.273	0.271	0.018	0.081
6	0.146	0.000	0.058	0.340
7	0.113	0.129	1.000	0.232
8	0.148	0.200	0.462	0.711
9	0.410	0.367	0.152	0.118
10	0.164	0.235	0.088	0.359
11	0.816	0.143	0.022	0.025
12	0.085	0.063	0.182	0.882

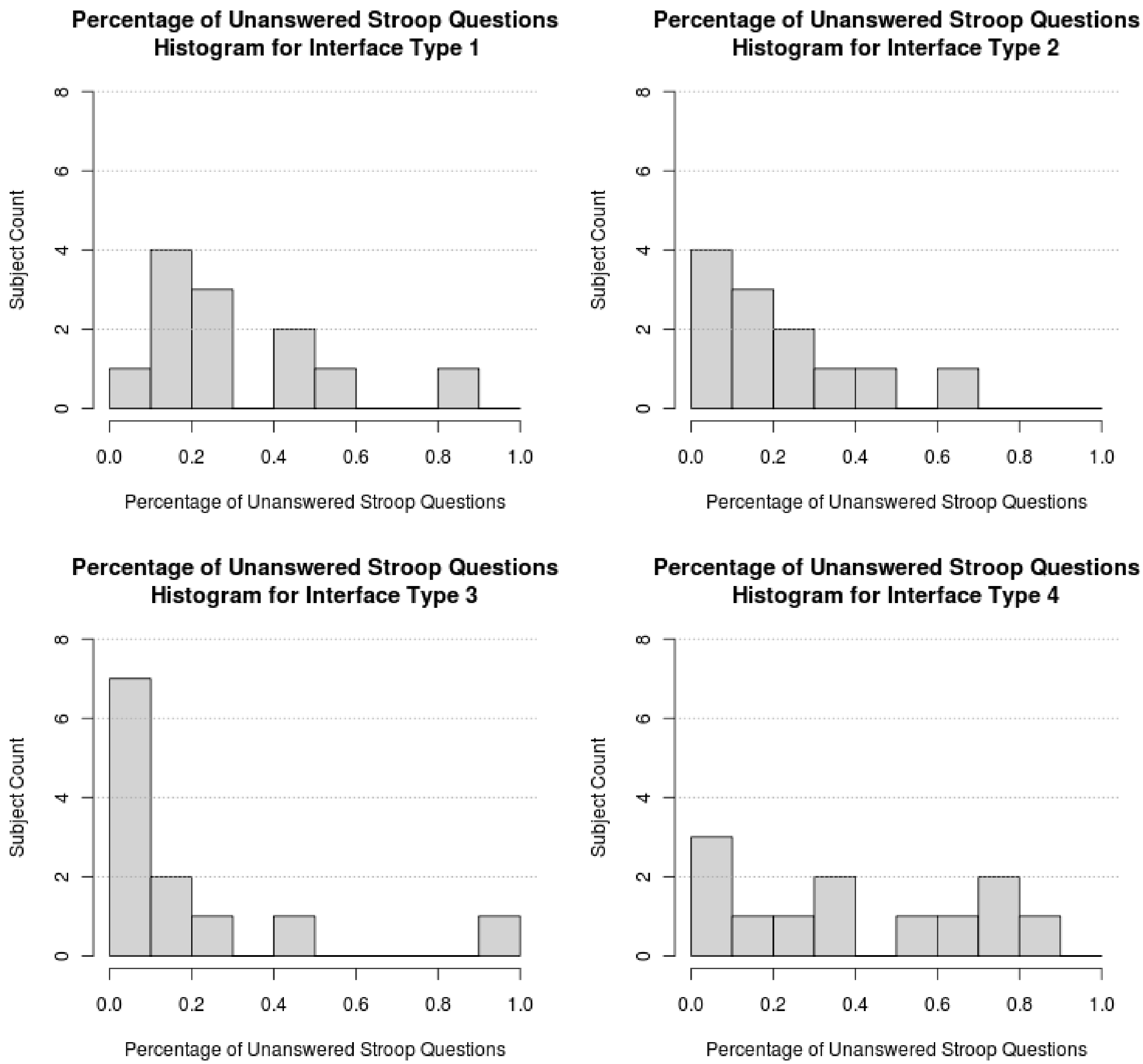


One-way ANOVA: Unanswered Questions vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.290	0.097	1.483	0.232
Residuals	44	2.865	0.065		

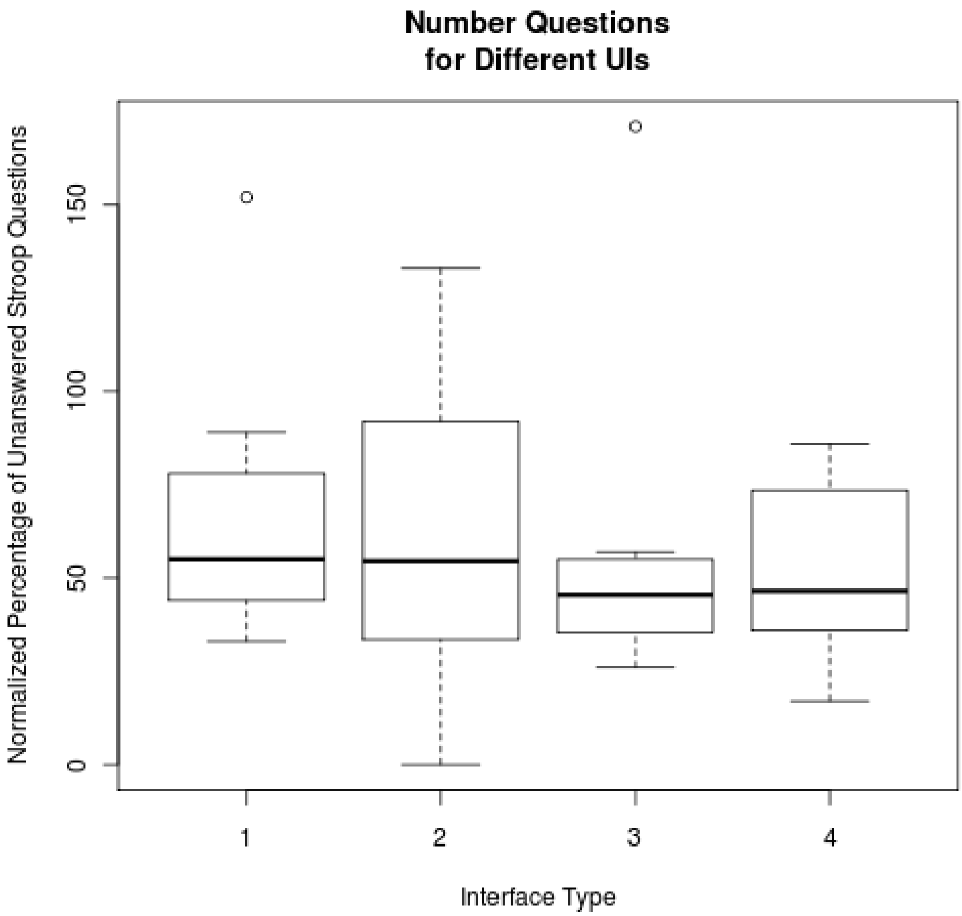
Num. Unanswered Questions vs. Interface Used Kurskal-Wallis test:	
X^2	5.360
DoF	3
p	0.147

Num. Unanswered Questions vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	1.613	4.083	0.163	1.021	1.333	2.613
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	0.204	0.043	0.686	0.312	0.248	0.106

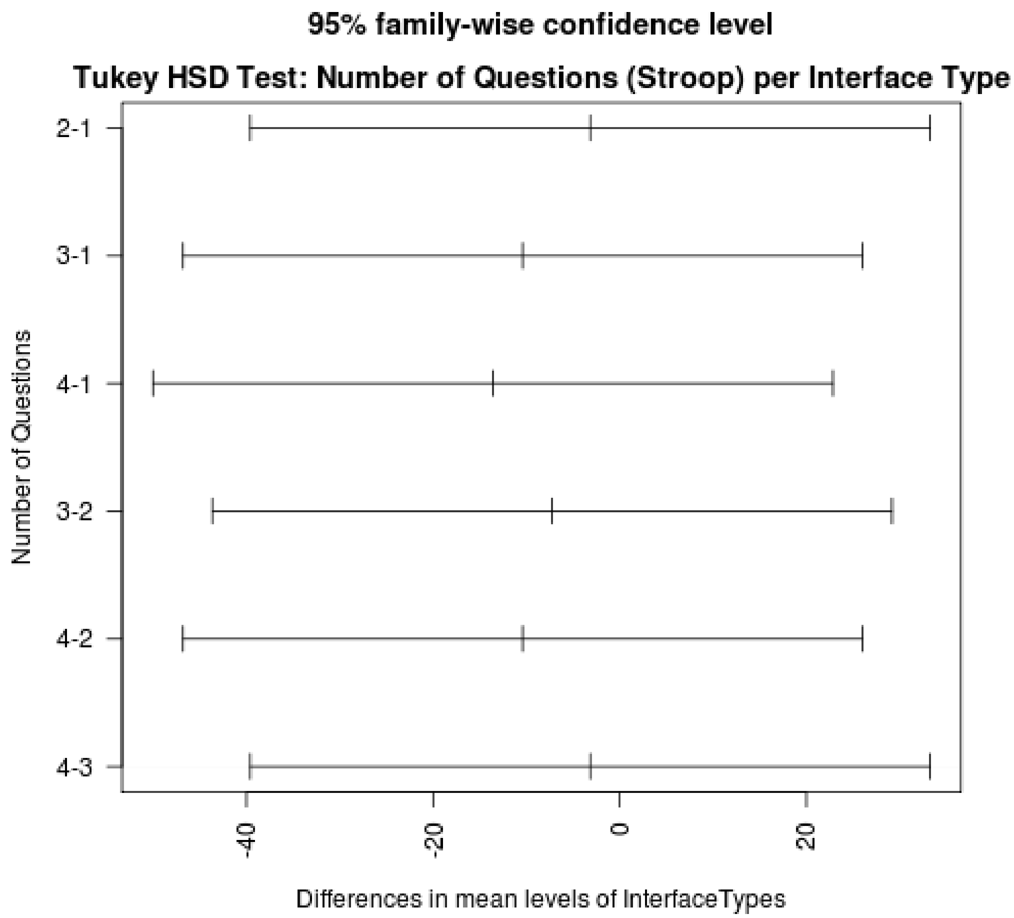
Unanswered Questions vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.310	0.222	0.243
2	0.223	0.194	0.171
3	0.196	0.282	0.090
4	0.394	0.306	0.350



D.2.6.4 Analysis of Fairness of Stroop Questions Distribution Amongst Treatments

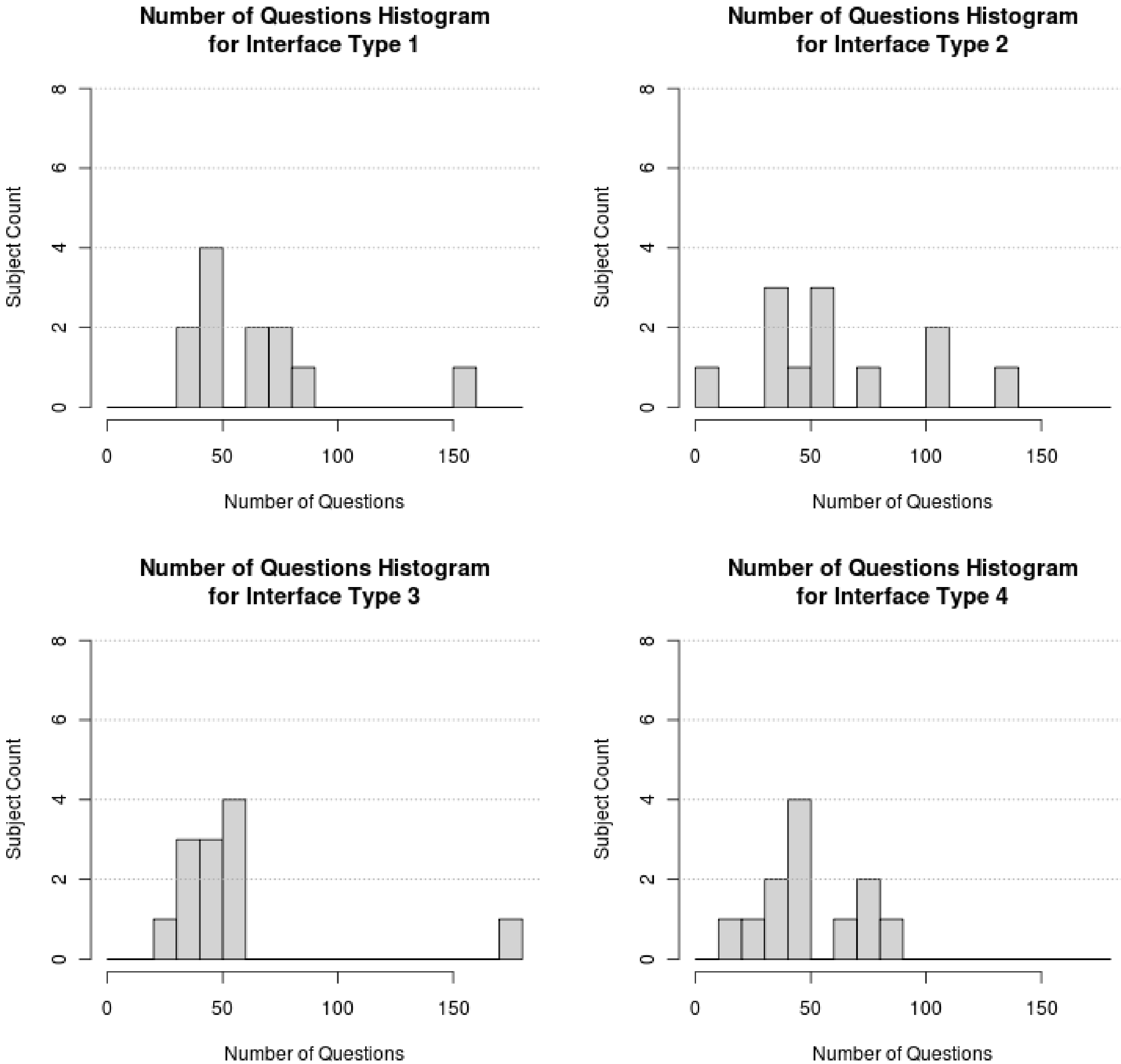


Subject Count	UI1	UI2	UI3	UI4
1	49	33	55	46
2	89	58	37	29
3	63	34	57	42
4	48	58	52	50
5	33	133	55	86
6	41	0	171	47
7	80	31	31	69
8	61	110	26	38
9	39	79	46	34
10	152	51	34	78
11	76	105	45	79
12	47	48	44	17



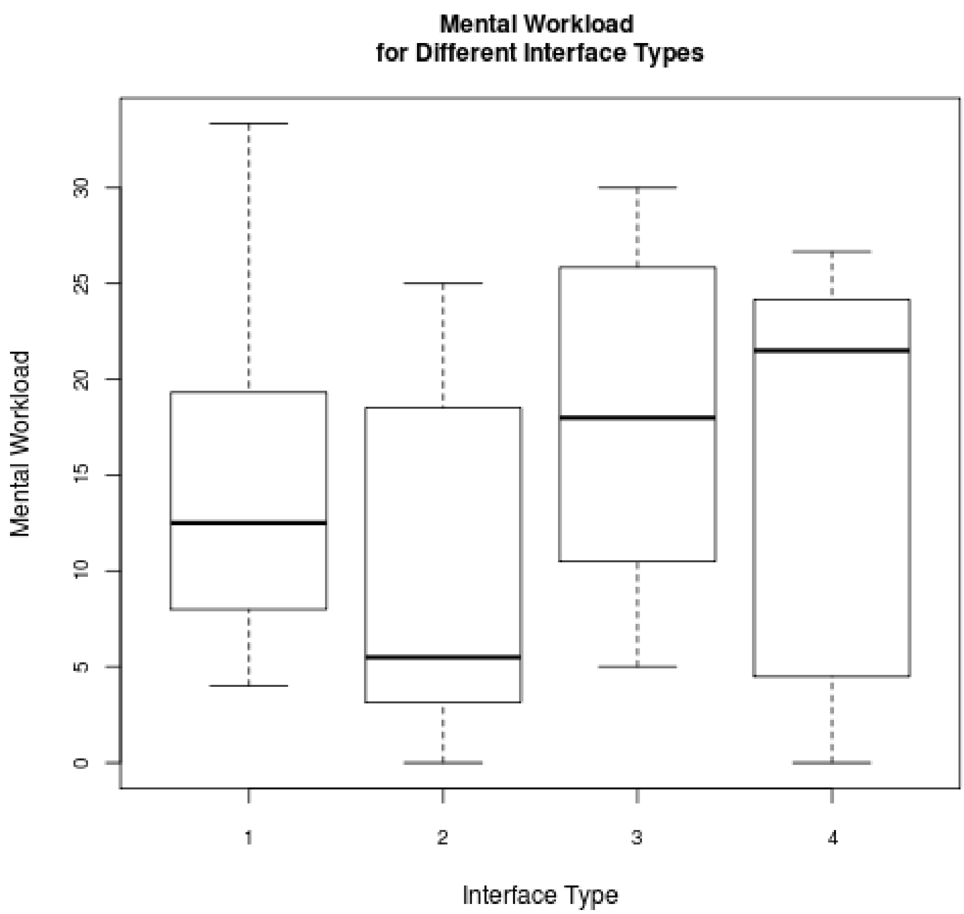
One-way ANOVA: Number of Questions vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	1422.000	474.140	0.425	0.736
Residuals	44	49148.000	1116.990		

Number of Questions vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	64.833	32.552	55.000
2	61.667	38.448	54.500
3	54.417	38.078	45.500
4	51.250	21.914	46.500

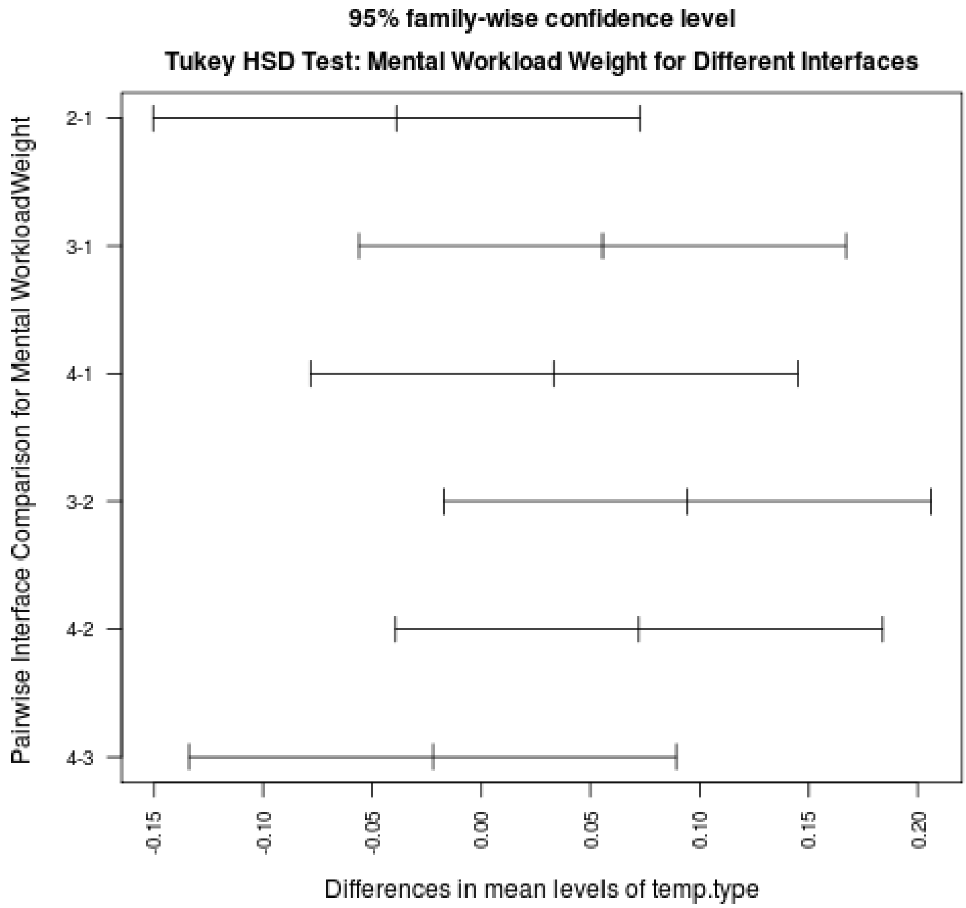

Number of Questions Histogram
for Interface Type 1
Subject Count
Number of Questions
0
50
100
150
0
2
4
6
8
Number of Questions Histogram
for Interface Type 2
Subject Count
Number of Questions
Number of Questions Histogram
for Interface Type 3
Subject Count
Number of Questions
Number of Questions Histogram
for Interface Type 4
Subject Count
Number of Questions

D.2.7 Workload (NASA-TLX)

D.2.7.1 Mental Workload



Subject Count	UI1	UI2	UI3	UI4
1	10.000	4.000	30.000	26.667
2	6.667	13.333	28.333	4.000
3	12.000	5.333	14.000	25.000
4	17.333	0.000	5.000	0.000
5	4.000	18.333	17.333	21.333
6	14.000	1.667	23.333	5.000
7	4.667	5.667	9.333	2.667
8	33.333	25.000	30.000	14.000
9	26.667	4.333	18.667	21.667
10	13.000	20.000	18.667	21.667
11	9.333	18.667	11.667	23.333
12	21.333	2.333	7.333	26.667

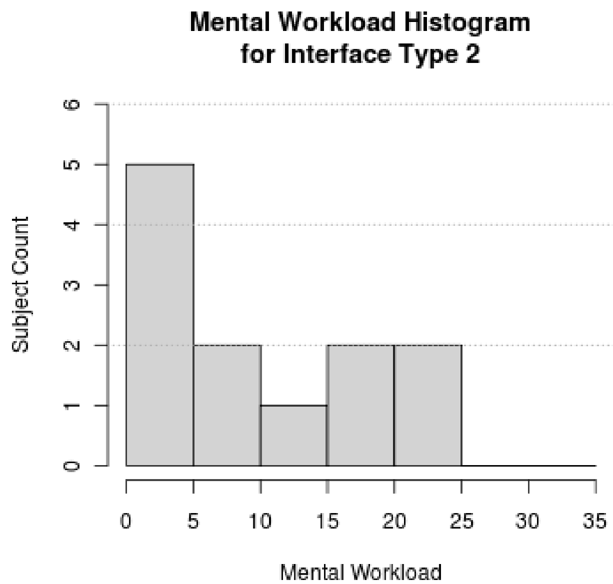


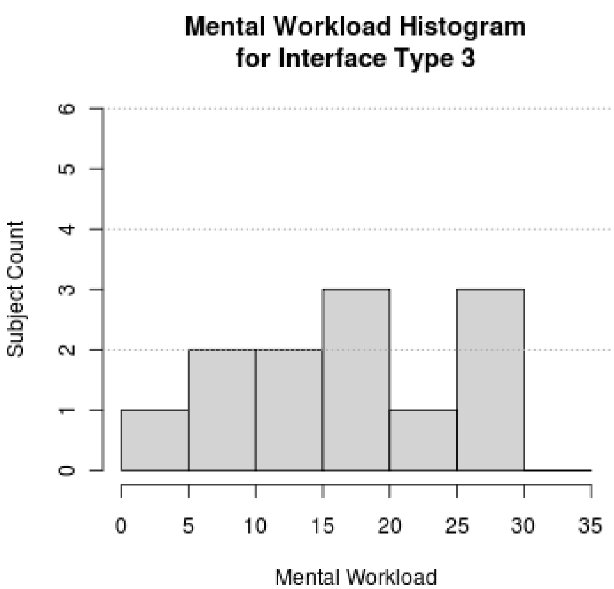
One-way ANOVA: Mental Workload vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	413.500	137.830	1.642	0.194
Residuals	44	3694.500	83.966		

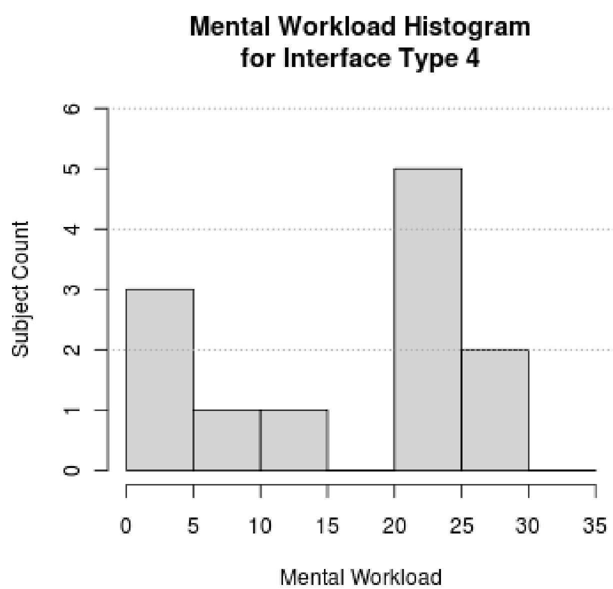
Mental Workload vs. Interface Used Friedman test:	
X^2	5.654
p	0.13
DoF	3

Mental Workload vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	35.000	9.000	23.000	2.000	6.000	28.500
Z	0.748	-1.431	-0.905	-2.643	-1.610	0.596
p	0.479	0.176	0.386	0.008	0.117	0.574
R	0.076	-0.146	-0.092	-0.270	-0.164	0.061

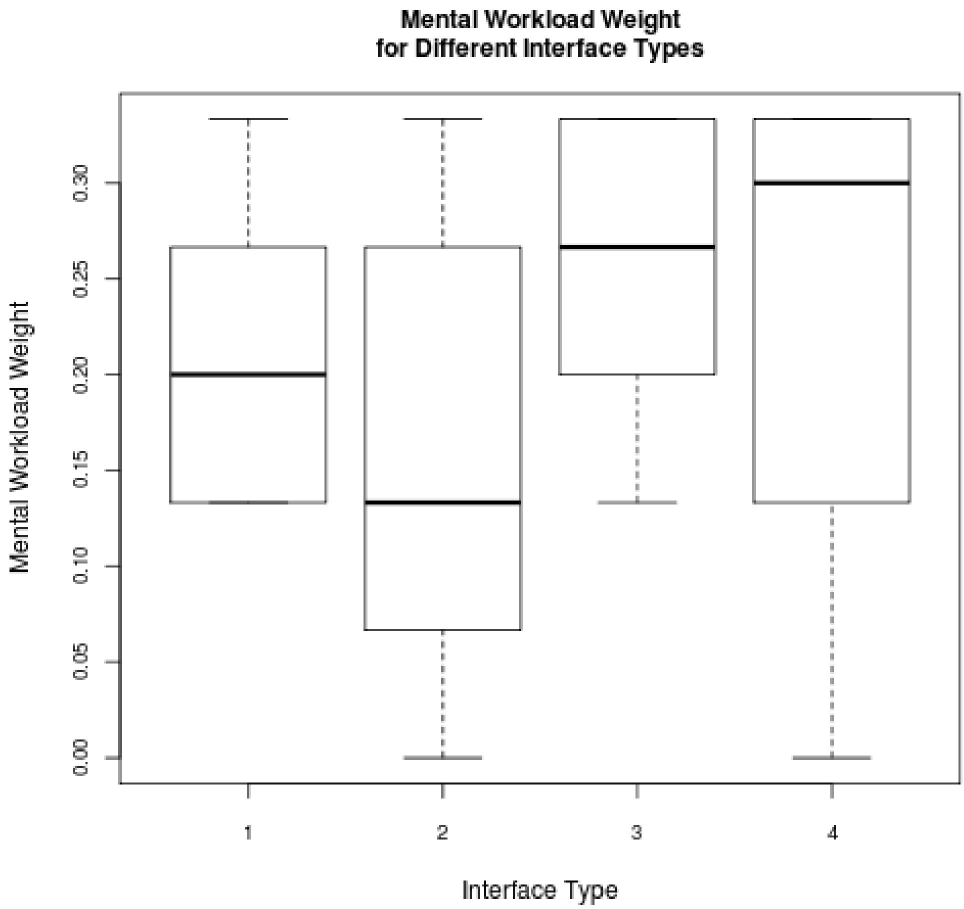
Mental Workload vs. Interface Used Summary:			
Interface	Mean	Std. Dev.	Median
1	14.361	8.950	12.500
2	9.889	8.620	5.500
3	17.806	8.729	18.000
4	16.000	10.259	21.500



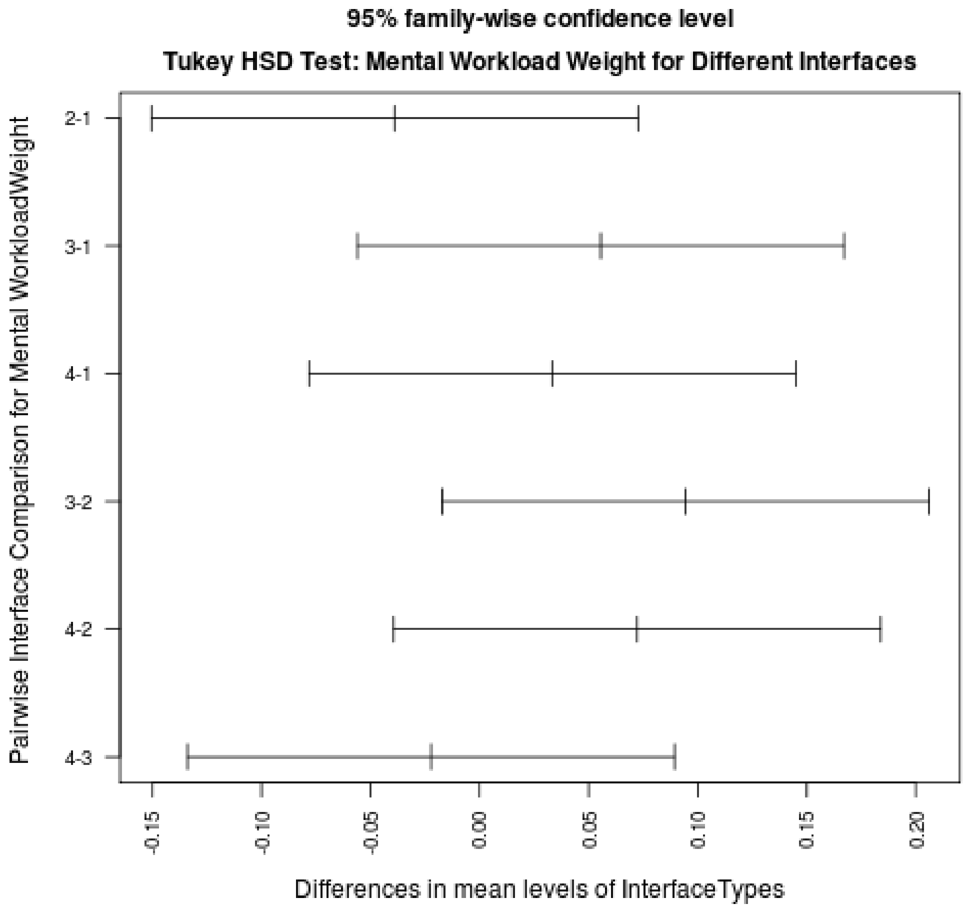




D.2.7.1.1 Mental Workload Weight



Subject Count	UI1	UI2	UI3	UI4
1	0.133	0.133	0.333	0.333
2	0.133	0.267	0.333	0.267
3	0.200	0.133	0.200	0.333
4	0.267	0.000	0.200	0.000
5	0.133	0.333	0.267	0.267
6	0.200	0.067	0.333	0.067
7	0.133	0.067	0.133	0.067
8	0.333	0.333	0.333	0.200
9	0.333	0.067	0.267	0.333
10	0.200	0.267	0.267	0.333
11	0.133	0.267	0.333	0.333
12	0.267	0.067	0.133	0.333

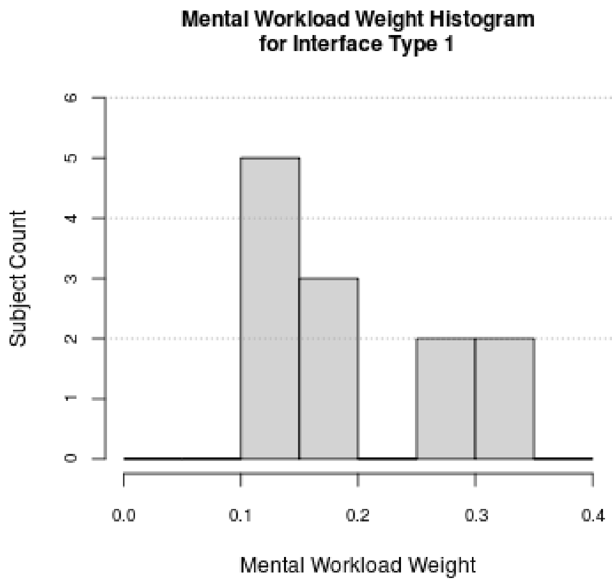


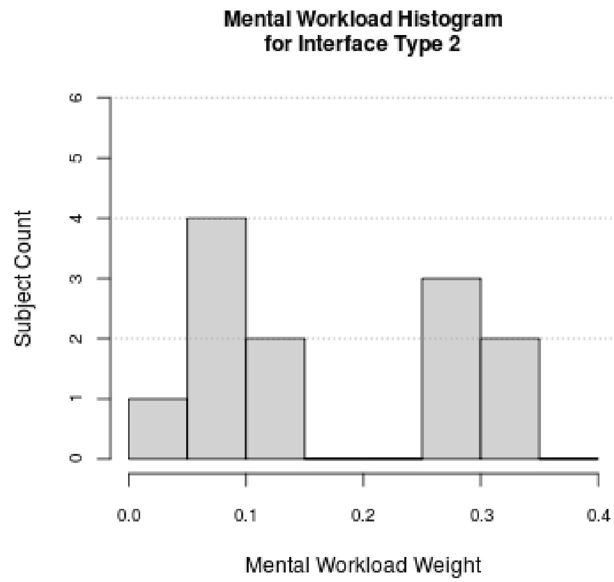
One-way ANOVA: Mental Workload Weight vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.061	0.020	1.941	0.137
Residuals	44	0.461	0.010		

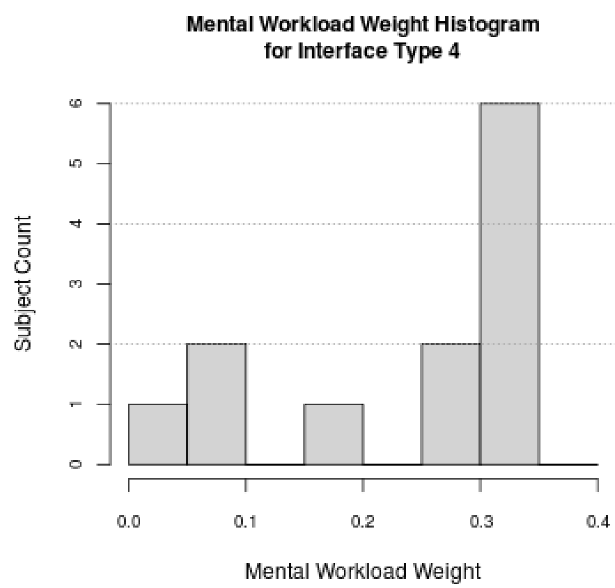
Mental Workload Weight vs. Interface Used Friedman test:	
X^2	5.654
p	0.130
DoF	3

Mental Workload Weight vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	35.000	9.000	23.000	2.000	6.000	28.500
Z	0.748	-1.431	-0.905	-2.643	-1.610	0.596
p	0.479	0.176	0.386	0.008	0.117	0.574
R	0.076	-0.146	-0.092	-0.270	-0.164	0.061

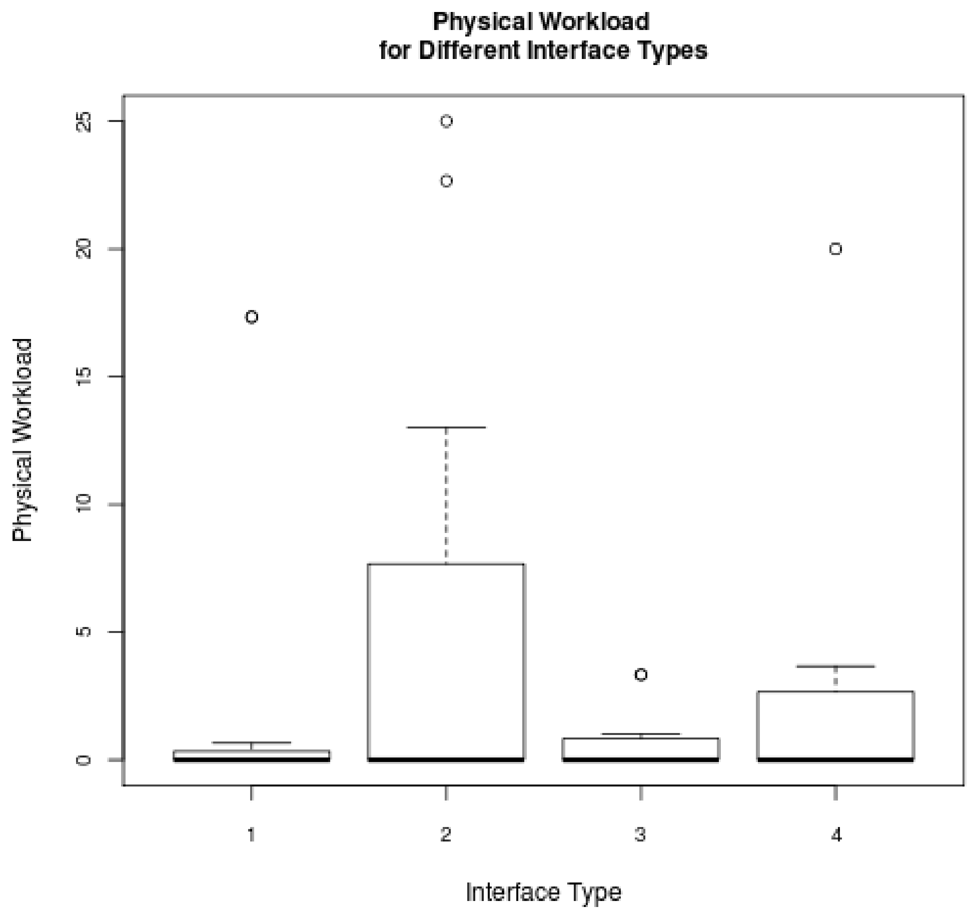
Mental Workload Weight vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.206	0.078	0.200
2	0.167	0.119	0.133
3	0.261	0.078	0.267
4	0.239	0.125	0.300



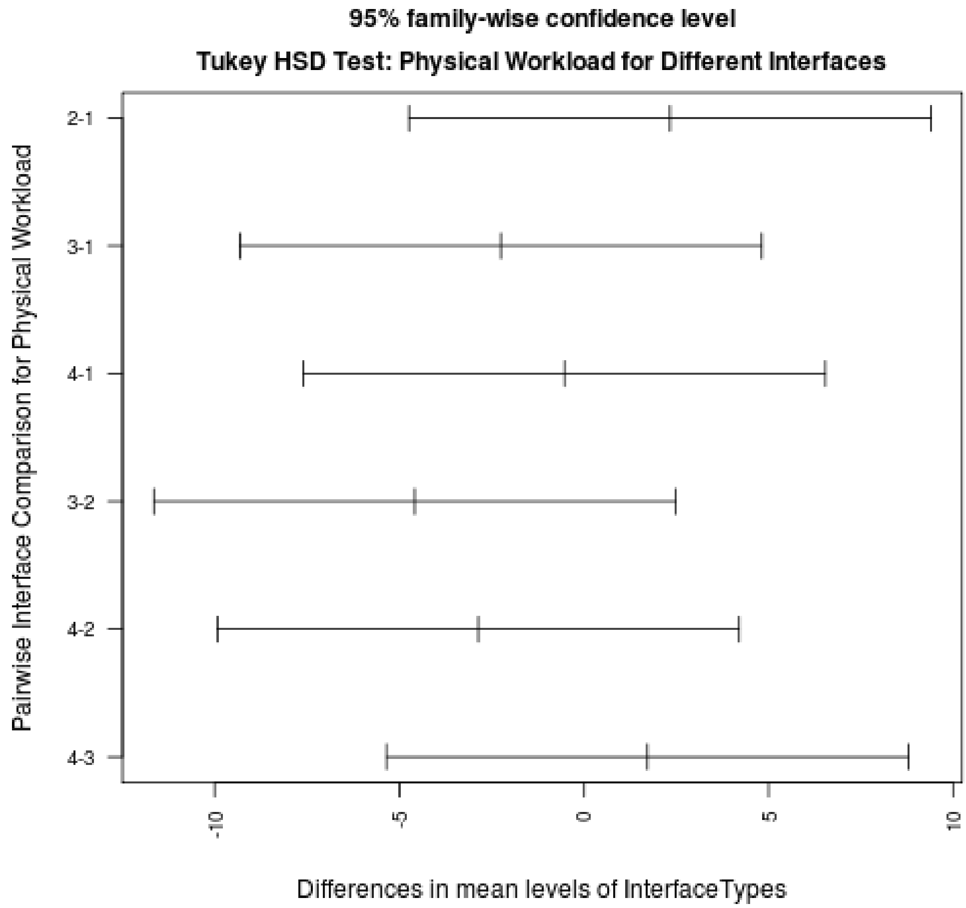




D.2.7.2 Physical Workload



Subject Count	UI1	UI2	UI3	UI4
1	0.000	0.000	0.000	0.000
2	0.000	13.000	0.000	3.000
3	0.000	0.000	0.000	3.667
4	0.000	2.333	0.667	2.333
5	0.000	0.333	0.000	0.000
6	0.000	0.000	3.333	0.000
7	0.000	25.000	0.000	20.000
8	0.667	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000
10	17.333	0.000	1.000	0.000
11	17.333	0.000	3.333	0.000
12	0.000	22.667	0.000	0.000

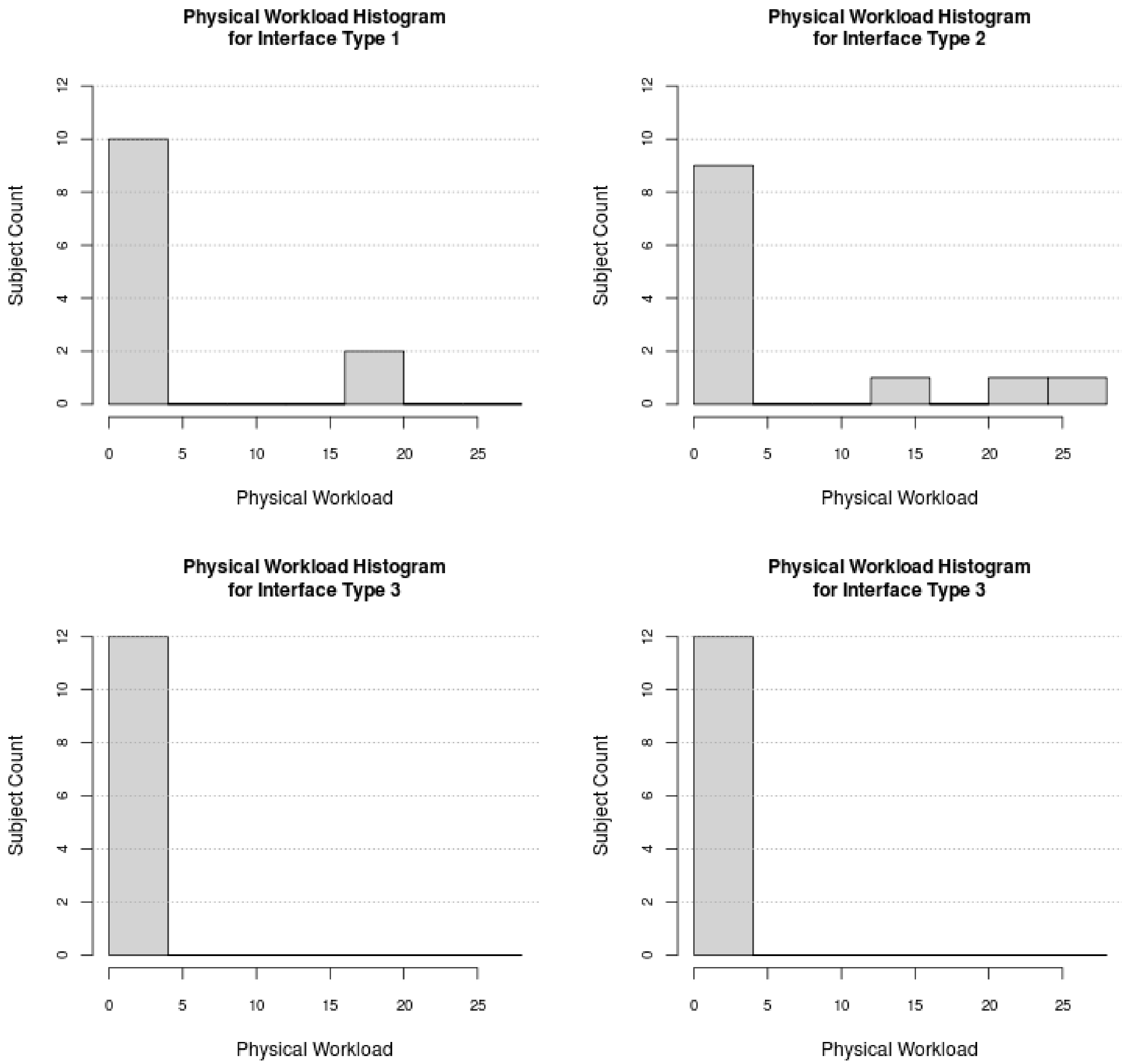


One-way ANOVA: Physical Workload vs. Interface Used					
	DoF	*Sum Sq.*	*Mean Sq.*	*F-value*	*Pr(>F)*
interface type	3	128.830	42.944	1.020	0.393
Residuals	44	1852.060	42.092		

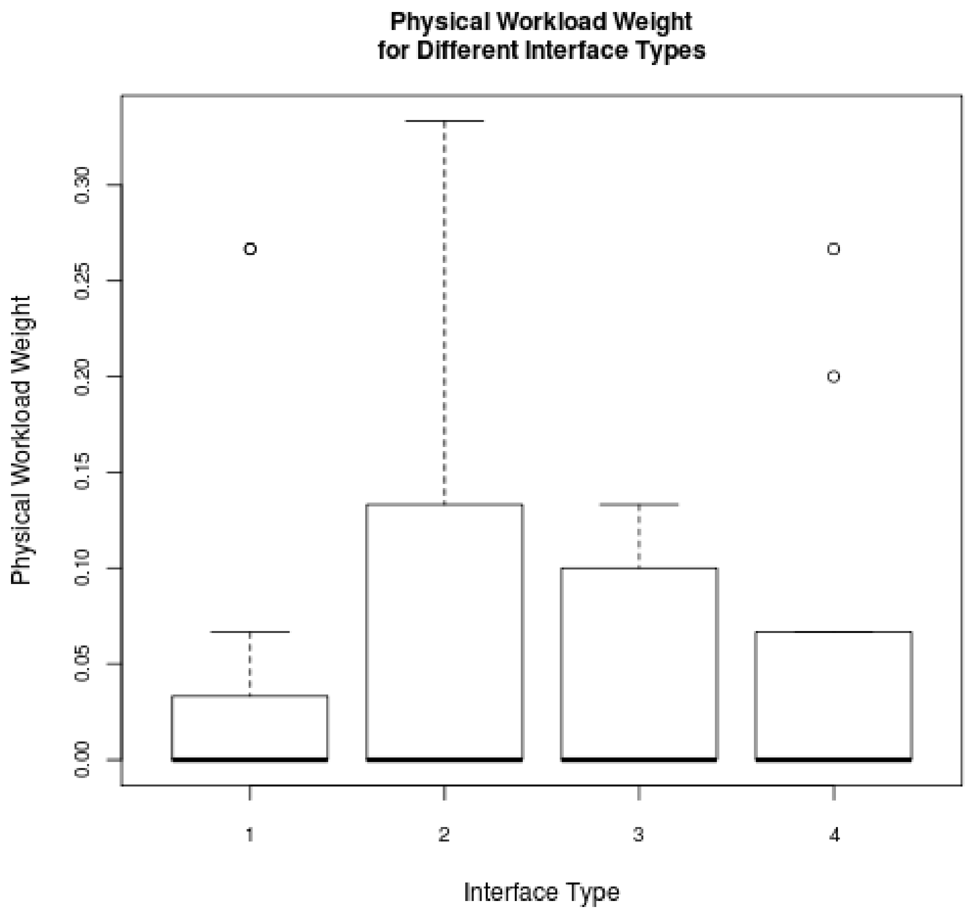
Physical Workload vs. Interface Used Friedman test:	
X^2	1.400
p	0.706
DoF	3

Physical Workload vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	13.000	11.000	12.000	25.000	13.000	10.000
Z	-0.723	0.620	-0.369	0.884	1.417	-0.533
p	0.500	0.500	0.750	0.406	0.188	0.625
R	-0.074	0.063	-0.038	0.090	0.145	-0.054

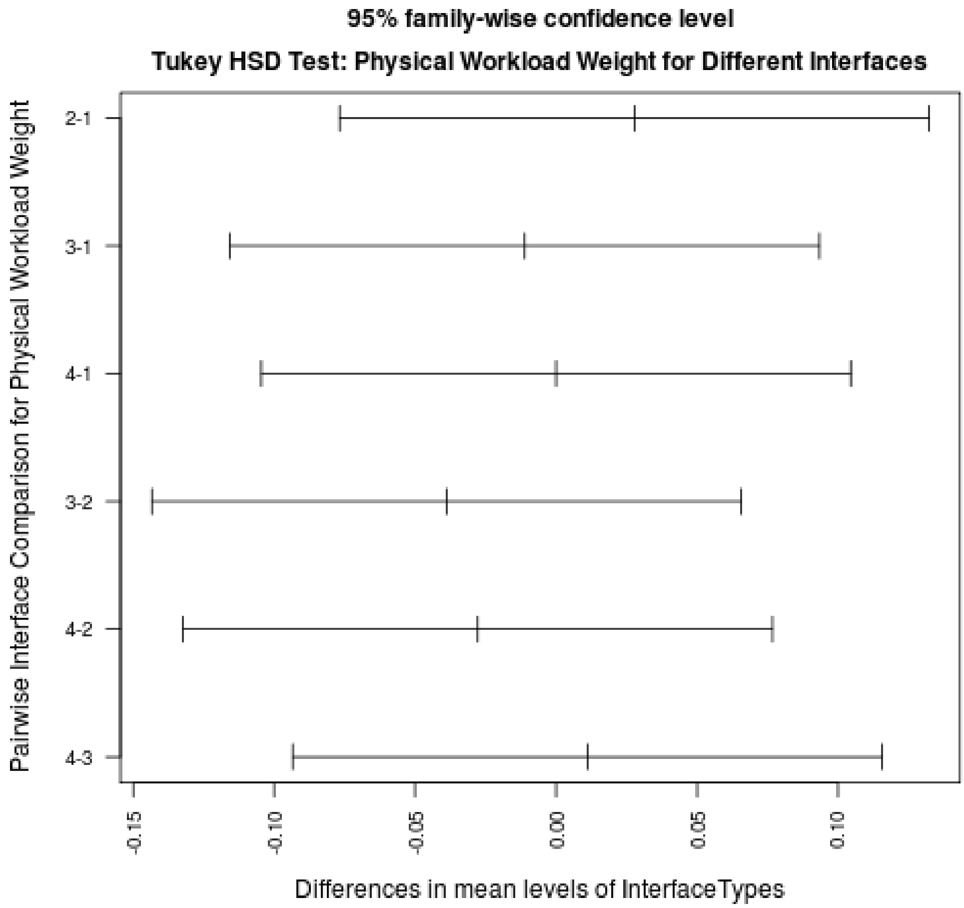
Physical Workload vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	2.944	6.724	0.000
2	5.278	9.434	0.000
3	0.694	1.275	0.000
4	2.417	5.703	0.000



D.2.7.2.1 Physical Workload Weight



Subject Count	UI1	UI2	UI3	UI4
1	0.000	0.000	0.000	0.000
2	0.000	0.200	0.000	0.200
3	0.000	0.000	0.000	0.067
4	0.000	0.067	0.133	0.067
5	0.000	0.067	0.000	0.000
6	0.000	0.000	0.133	0.000
7	0.000	0.333	0.000	0.267
8	0.067	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000
10	0.267	0.000	0.067	0.000
11	0.267	0.000	0.133	0.000
12	0.000	0.267	0.000	0.000

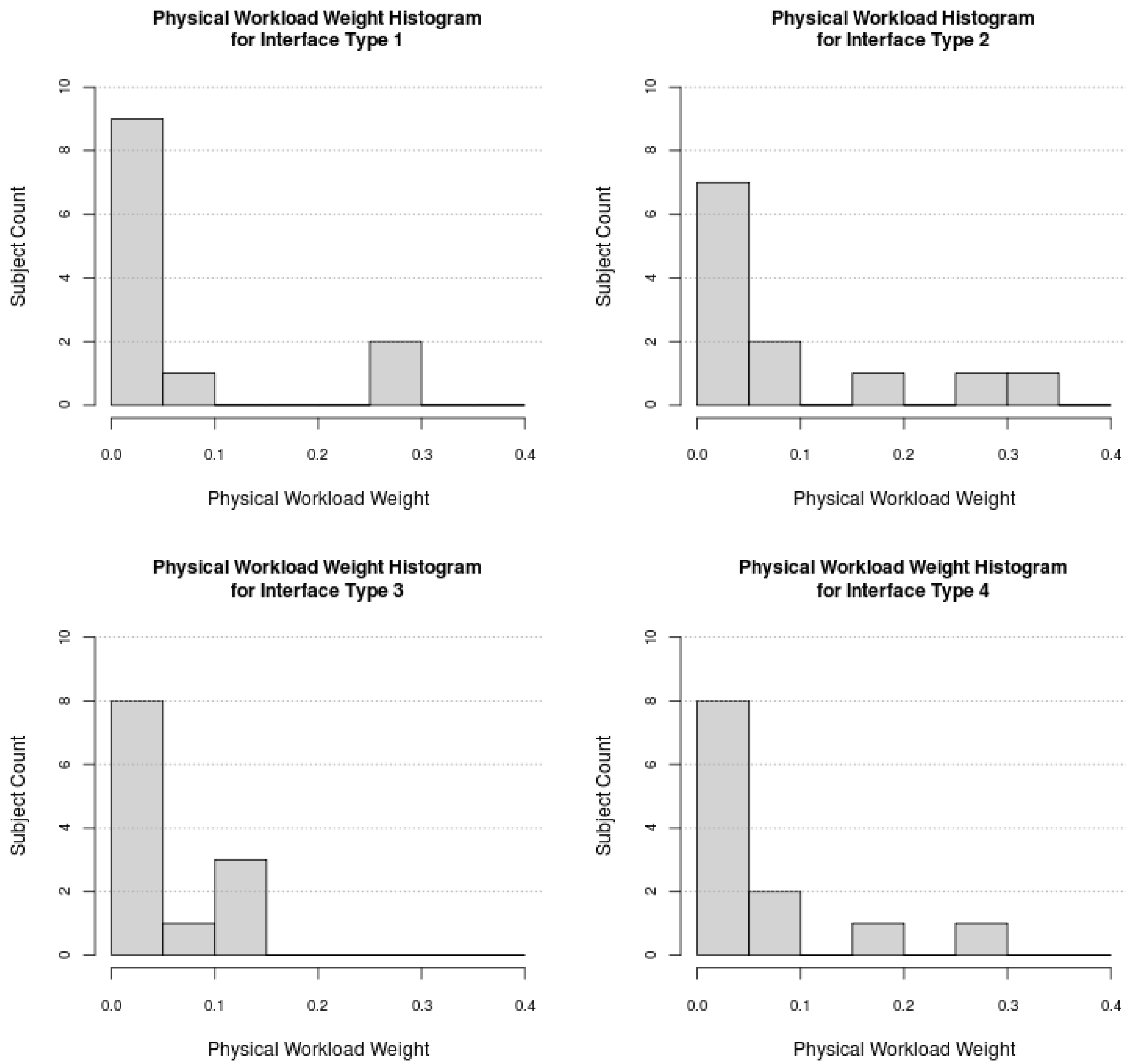


One-way ANOVA: Physical Workload Weight vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.010	0.003	0.359	0.783
Residuals	44	0.405	0.009		

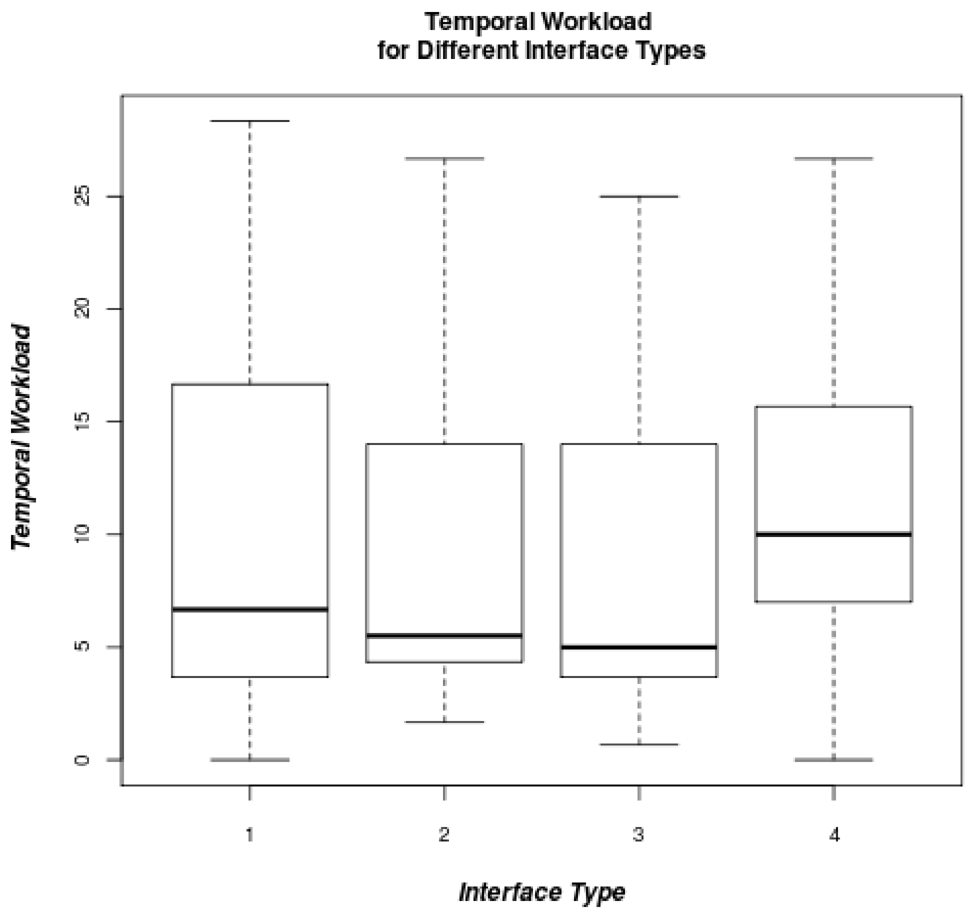
Physical Workload Weight vs. Interface Used Friedman test:	
X^2	0.486
p	0.922
DoF	3

Physical Workload Weight vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	14.000	10.000	14.000	23.500	7.500	12.500
Z	-0.645	0.532	-0.206	0.442	0.995	0.082
p	0.586	0.625	0.938	0.688	0.500	0.984
R	-0.066	0.054	-0.021	0.045	0.102	0.008

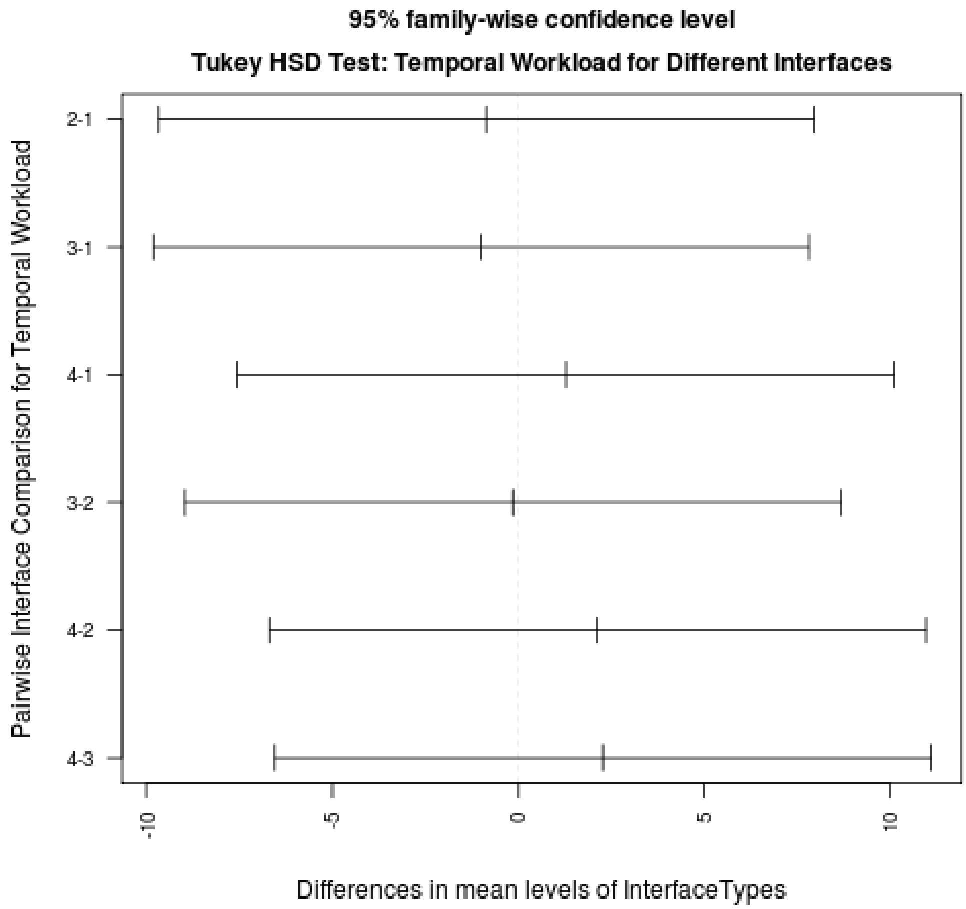
Physical Workload Weight vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.050	0.103	0.000
2	0.078	0.120	0.000
3	0.039	0.060	0.000
4	0.050	0.090	0.000



D.2.7.3 Temporal Workload



Subject Count	UI1	UI2	UI3	UI4
1	4.000	1.667	15.000	26.667
2	9.000	8.000	4.000	10.000
3	18.667	18.667	4.000	10.000
4	3.333	4.000	4.000	20.000
5	23.333	4.667	0.667	20.000
6	5.333	4.667	8.000	11.333
7	28.333	26.667	6.000	0.000
8	8.000	6.000	13.000	11.333
9	4.000	5.000	25.000	4.667
10	0.000	16.000	23.333	6.000
11	14.667	12.000	3.333	8.000
12	2.667	3.667	3.000	8.667

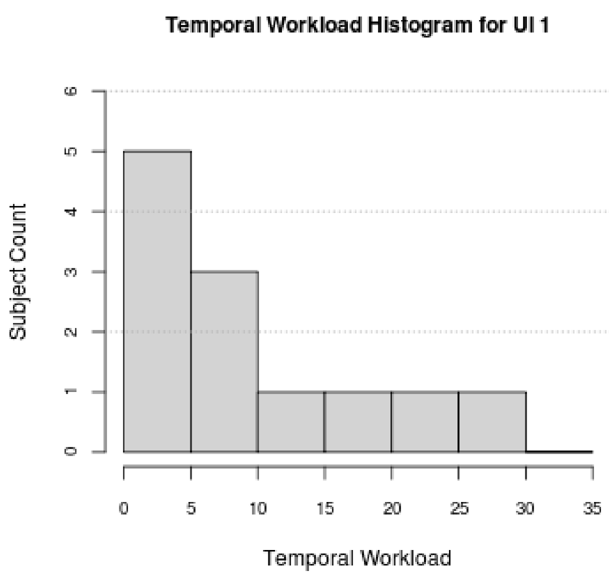


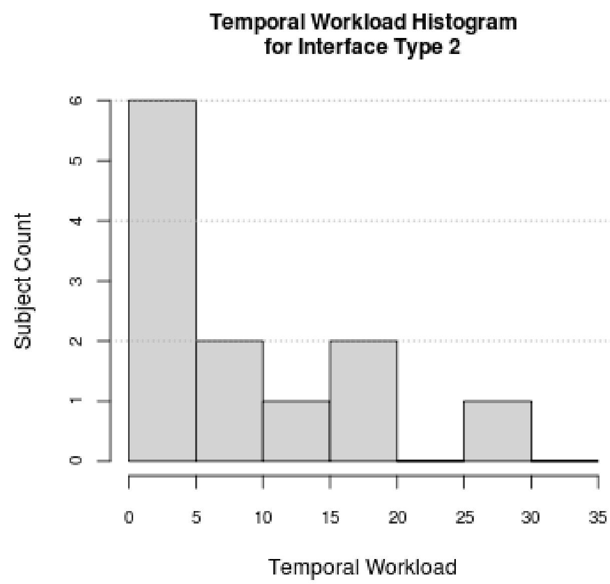
One-way ANOVA: Temporal Workload vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	39.470	13.157	0.201	0.895
Residuals	44	2885.470	65.579		

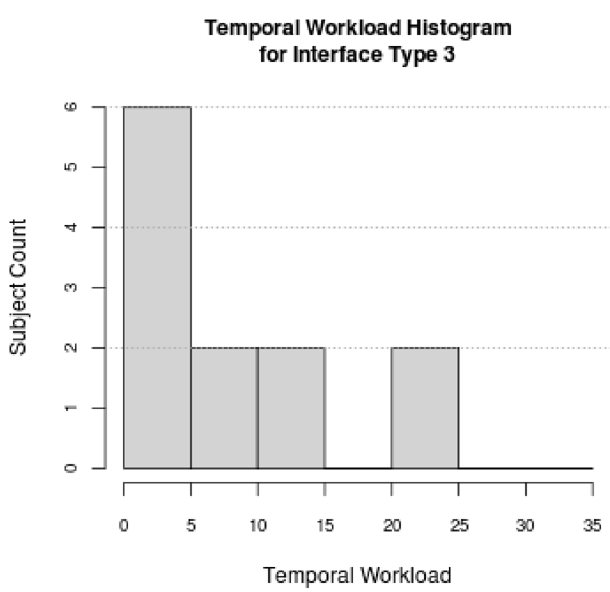
Temporal Workload vs. Interface Used Friedman test:	
X^2	1.739
p	0.628
DoF	3

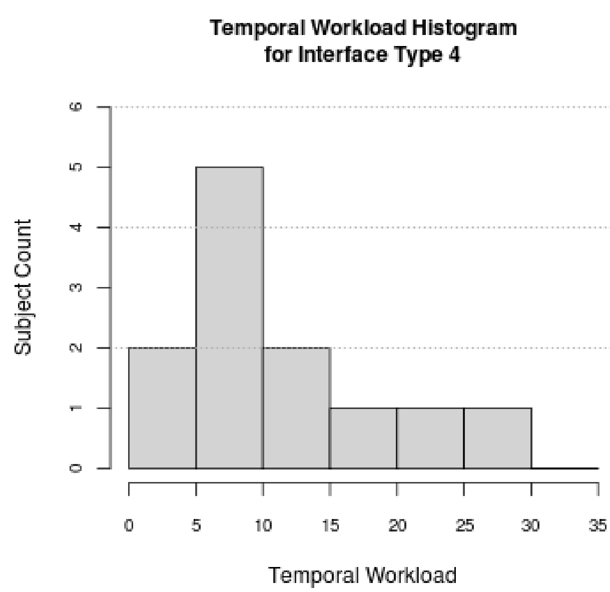
Temporal Workload vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	46.000	40.000	32.000	41.000	31.000	29.500
Z	1.138	0.078	-0.549	0.157	-0.628	-0.746
p	0.283	0.970	0.622	0.910	0.569	0.482
R	0.116	0.008	-0.056	0.016	-0.064	-0.076

Temporal Workload vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	10.111	9.084	6.667
2	9.250	7.589	5.500
3	9.111	8.179	5.000
4	11.389	7.437	10.000

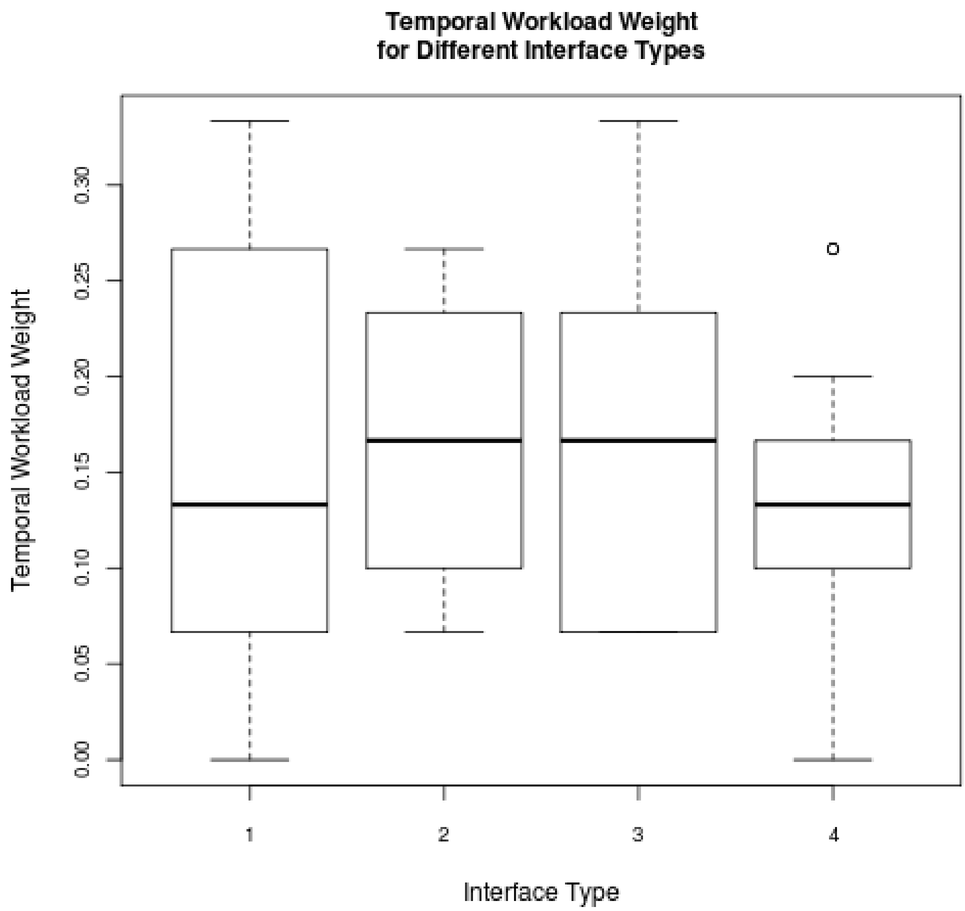




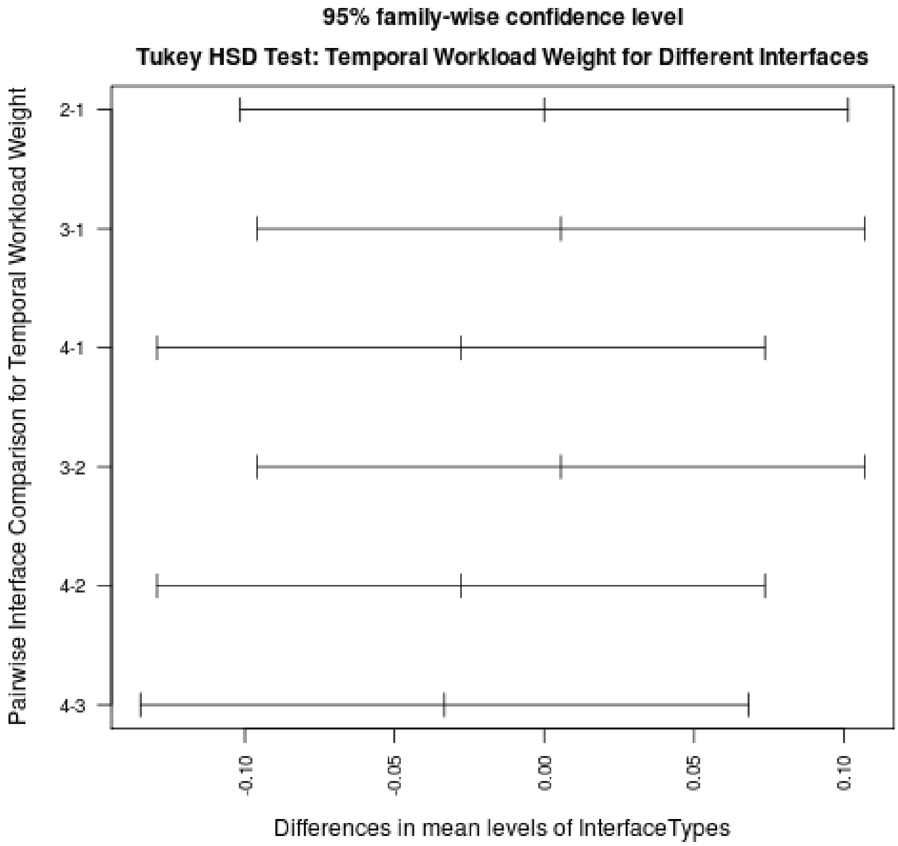




D.2.7.3.1 Temporal Workload Weight



Subject Count	UI1	UI2	UI3	UI4
1	0.067	0.067	0.200	0.267
2	0.200	0.267	0.133	0.133
3	0.267	0.267	0.067	0.133
4	0.067	0.133	0.067	0.267
5	0.333	0.133	0.067	0.200
6	0.133	0.133	0.267	0.133
7	0.333	0.267	0.133	0.000
8	0.133	0.067	0.200	0.133
9	0.133	0.200	0.333	0.067
10	0.000	0.200	0.333	0.067
11	0.267	0.200	0.067	0.133
12	0.067	0.067	0.200	0.133

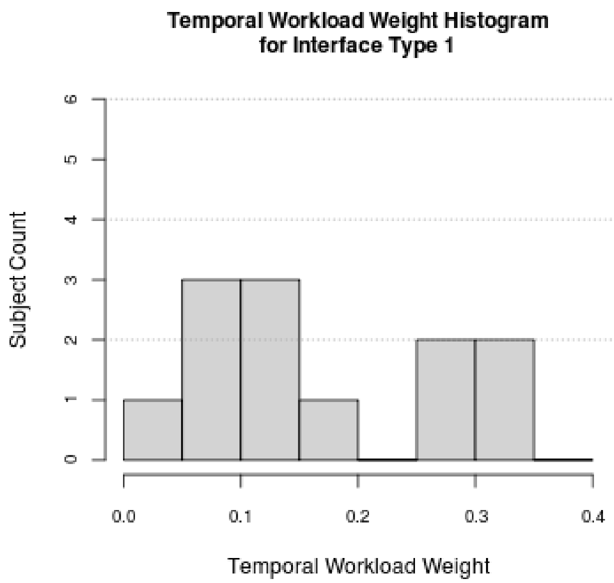


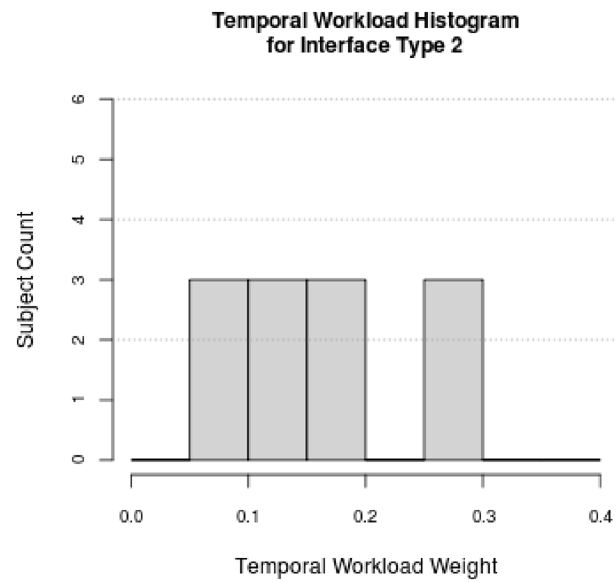
One-way ANOVA: Temporal Workload Weight vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.008	0.003	0.313	0.816
Residuals	44	0.381	0.009		

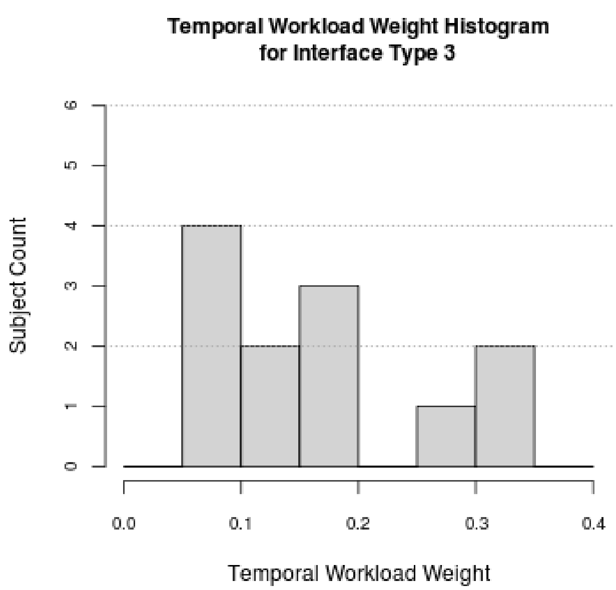
Temporal Workload Weight vs. Interface Used Friedman test:	
X^2	0.300
p	0.960
DoF	3

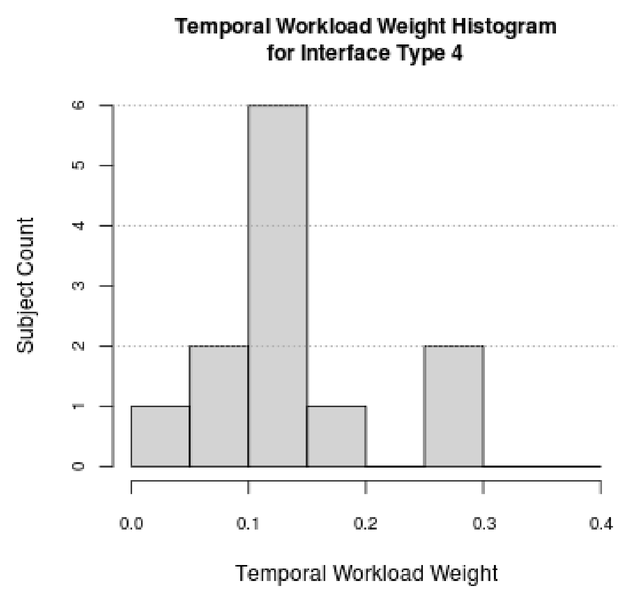
Temporal Workload Weight vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	15.000	35.000	33.500	41.500	41.500	44.000
Z	-0.241	0.118	0.631	0.197	0.708	0.904
p	0.828	0.921	0.557	0.878	0.513	0.391
R	-0.025	0.012	0.064	0.020	0.072	0.092

Temporal Workload Weight vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.167	0.112	0.133
2	0.167	0.078	0.167
3	0.172	0.100	0.167
4	0.139	0.078	0.133

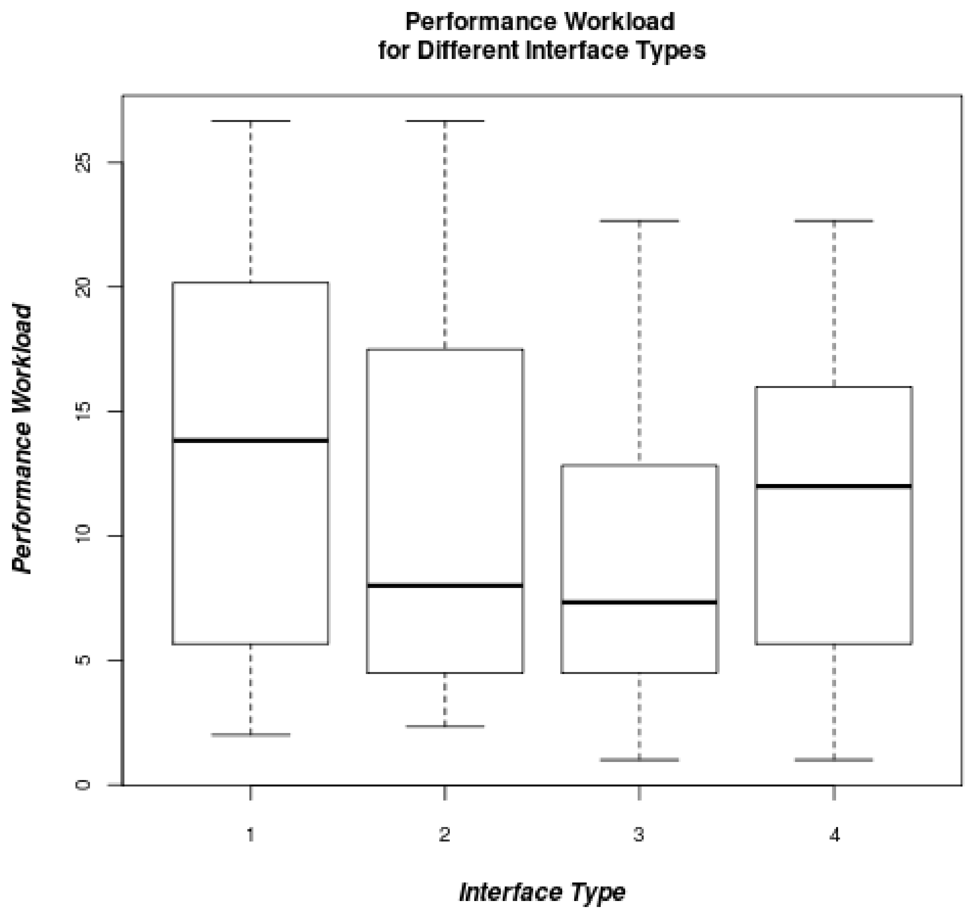




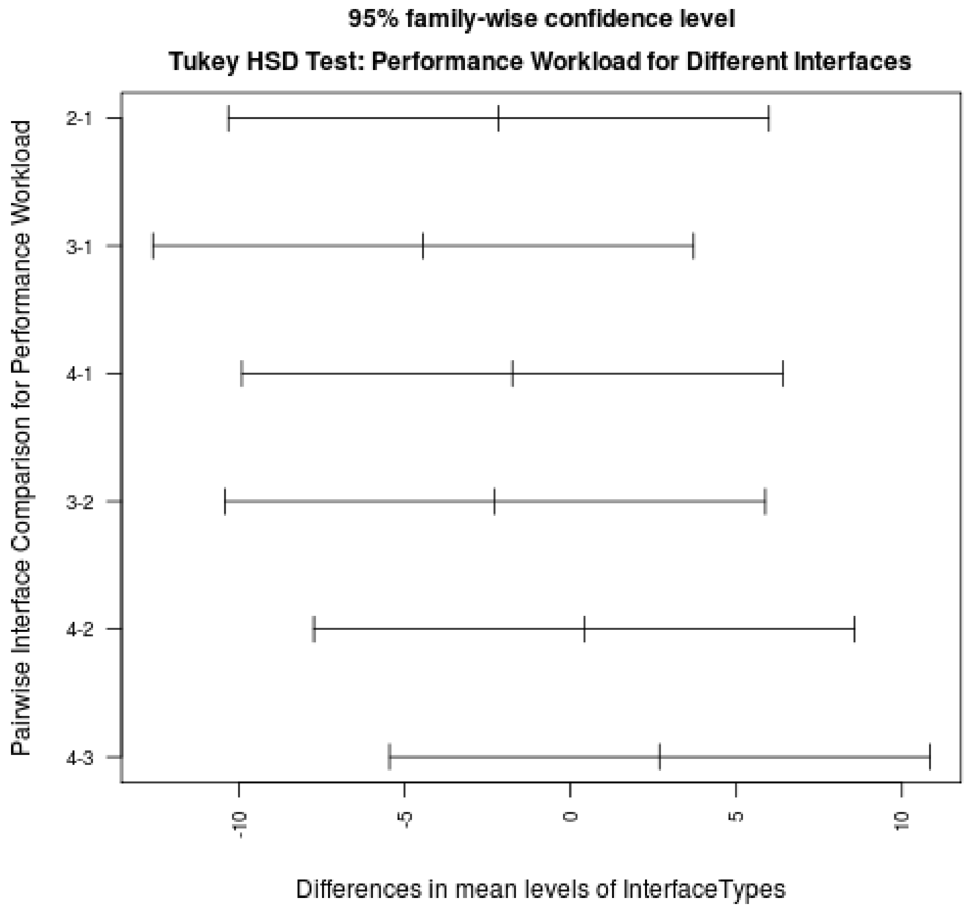




D.2.7.4 Performance Workload



Subject Count	UI1	UI2	UI3	UI4
1	6.000	26.667	1.667	1.333
2	14.667	2.333	4.000	8.000
3	2.000	16.667	22.667	22.667
4	5.000	22.667	6.000	12.000
5	13.000	11.000	8.667	1.000
6	6.667	6.667	8.667	12.000
7	5.333	5.000	16.000	13.333
8	26.667	7.000	5.333	17.000
9	21.333	4.000	5.000	21.333
10	21.333	18.333	11.000	10.000
11	19.000	2.667	14.667	15.000
12	17.000	9.000	1.000	3.333

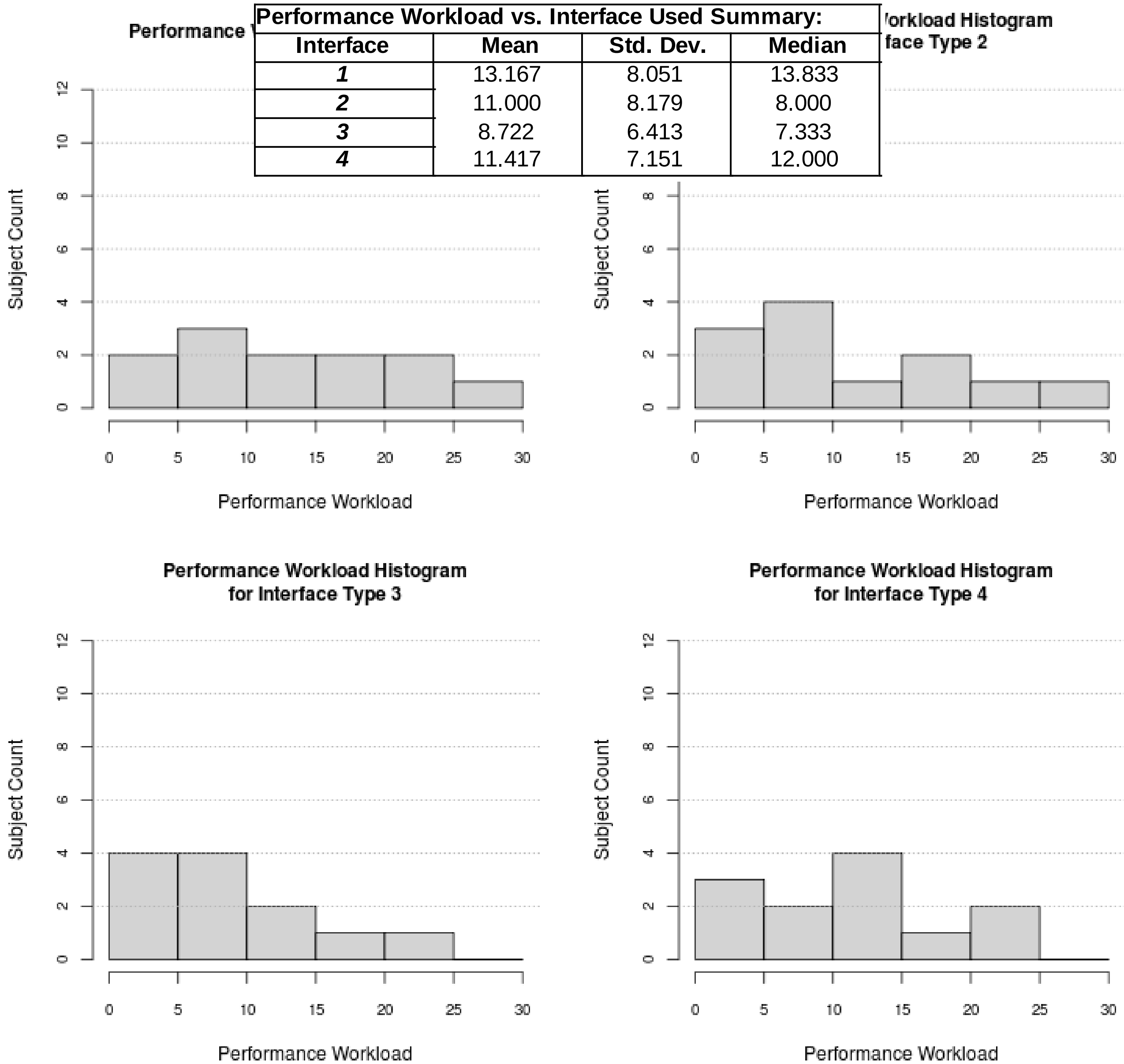


One-way ANOVA: Performance Workload vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	120.400	40.132	0.717	0.547
Residuals	44	2463.700	55.992		

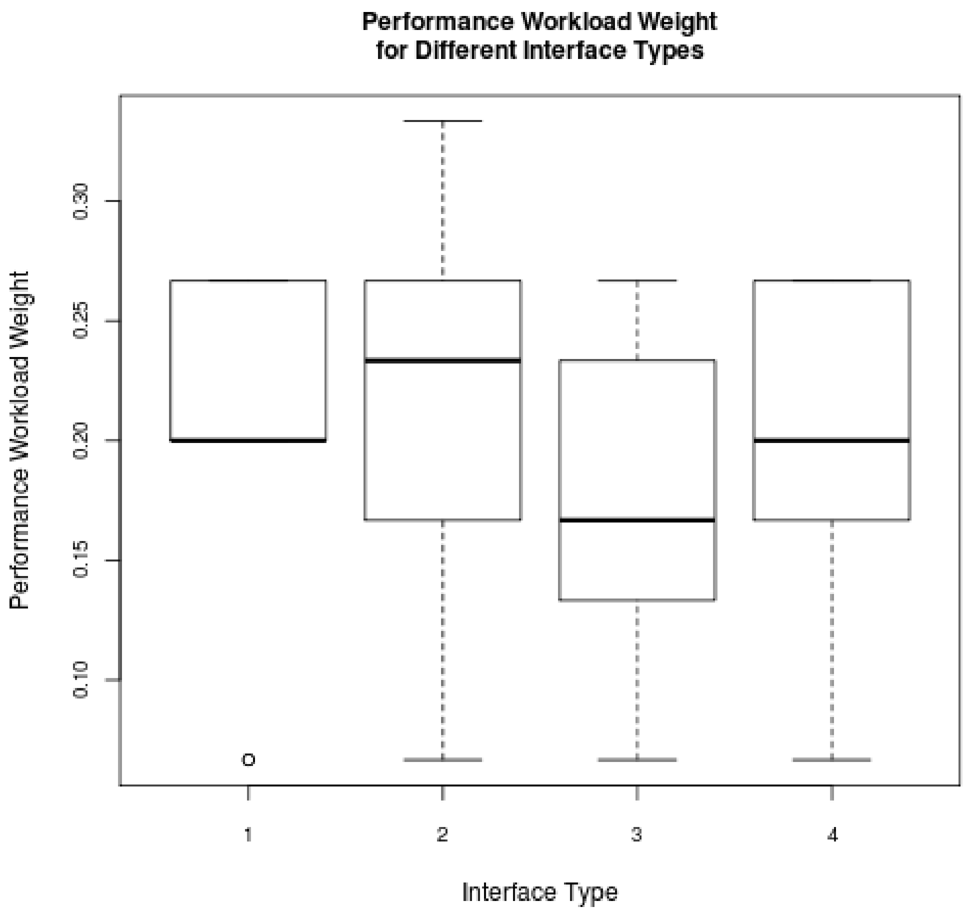
Performance Workload vs. Interface Used Friedman test:	
X^2	3.154
p	0.369
DoF	3

Performance Workload vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	40.000	57.000	41.000	46.000	36.000	19.000
Z	0.746	1.412	0.746	0.549	-0.235	-1.217
p	0.493	0.176	0.493	0.622	0.850	0.249
R	0.076	0.144	0.076	0.056	-0.024	-0.124

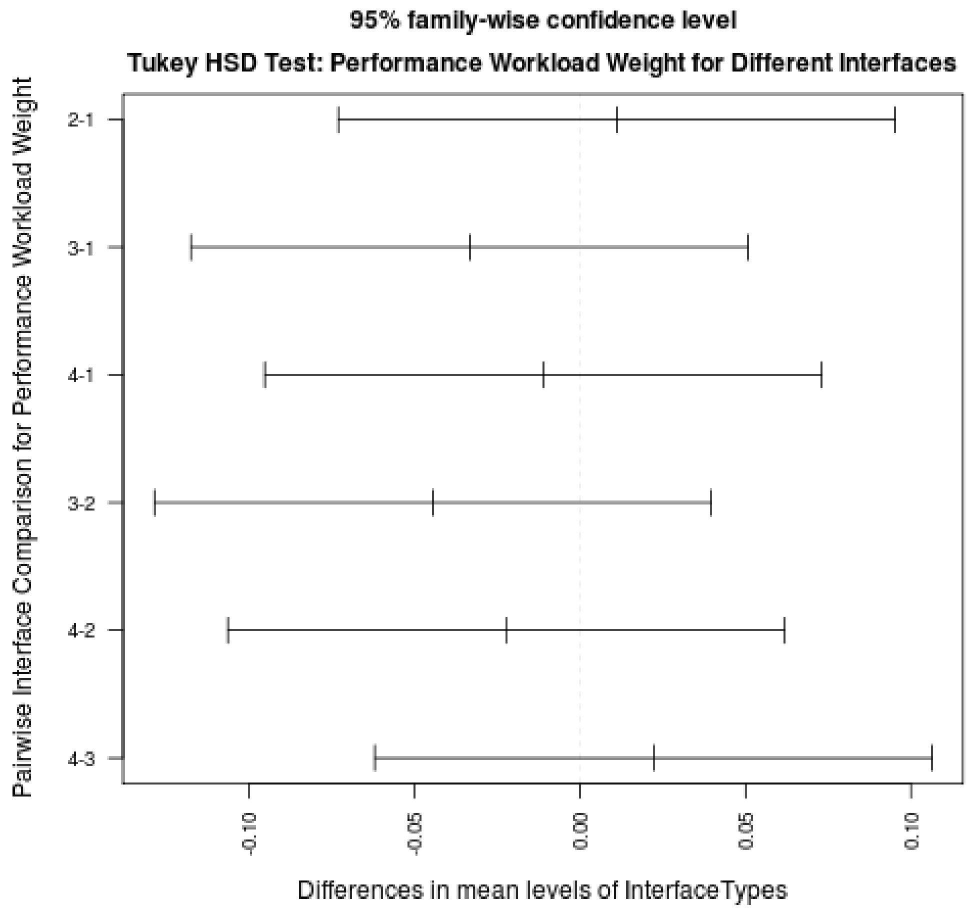
Performance Workload vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	13.167	8.051	13.833
2	11.000	8.179	8.000
3	8.722	6.413	7.333
4	11.417	7.151	12.000



D.2.7.4.1 Performance Workload Weight



Subject Count	UI1	UI2	UI3	UI4
1	0.200	0.267	0.067	0.067
2	0.267	0.067	0.200	0.200
3	0.067	0.333	0.267	0.267
4	0.200	0.267	0.133	0.267
5	0.200	0.200	0.133	0.067
6	0.267	0.267	0.133	0.200
7	0.067	0.067	0.267	0.267
8	0.267	0.200	0.133	0.200
9	0.267	0.267	0.200	0.267
10	0.267	0.333	0.200	0.200
11	0.200	0.133	0.267	0.200
12	0.200	0.200	0.067	0.133

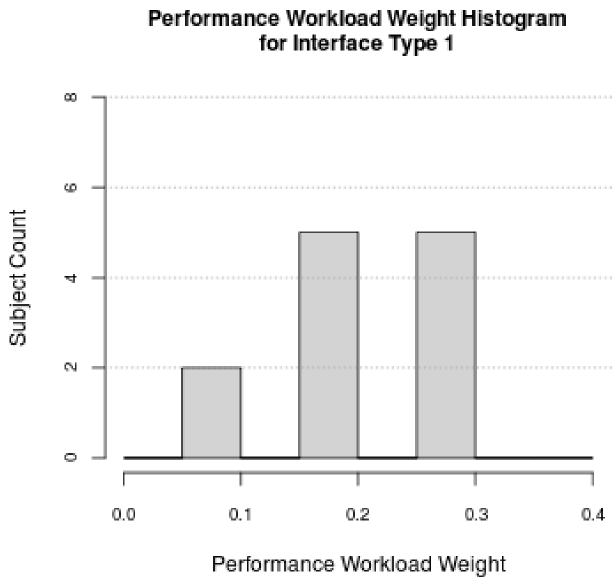


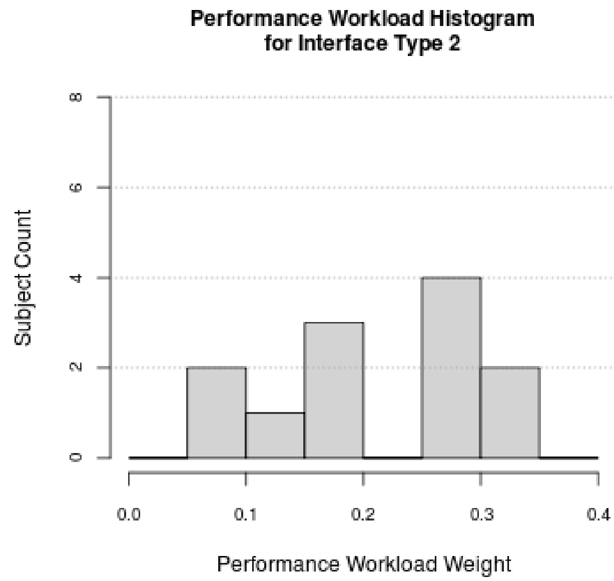
One-way ANOVA: Performance Workload Weight vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.013	0.004	0.725	0.543
Residuals	44	0.262	0.006		

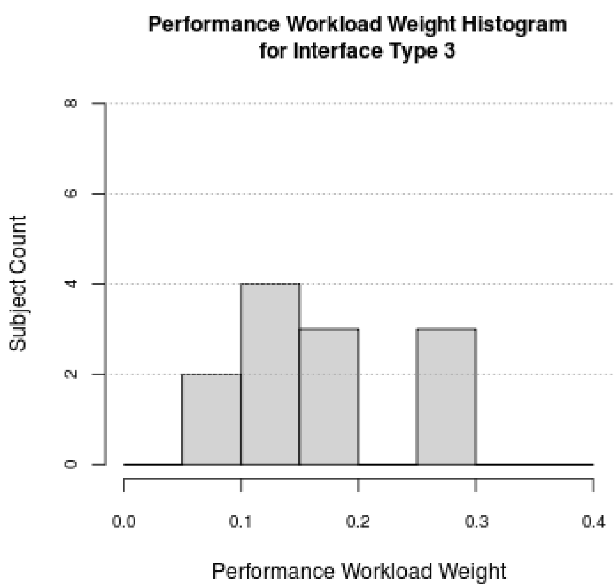
Performance Workload Weight vs. Interface Used Friedman test:	
X^2	6.087
p	0.107
DoF	3

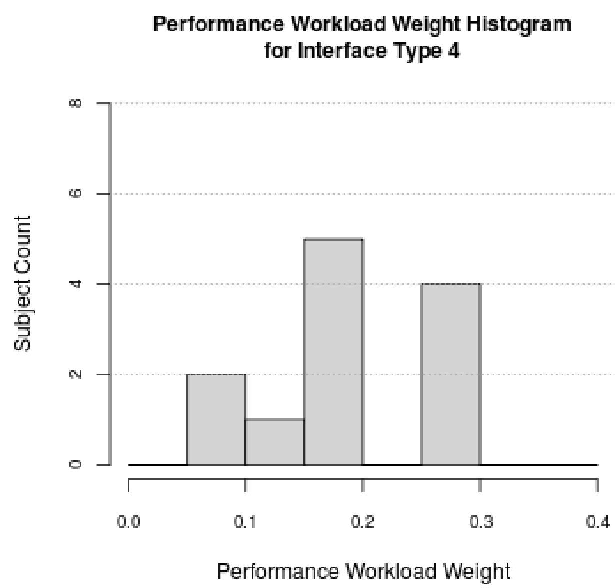
Performance Workload Weight vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	14.000	52.500	33.000	51.000	26.500	5.000
Z	-0.205	1.065	0.755	0.944	0.675	-1.355
p	0.891	0.309	0.484	0.369	0.535	0.203
R	-0.021	0.109	0.077	0.096	0.069	-0.138

Performance Workload Weight vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.206	0.072	0.200
2	0.217	0.090	0.233
3	0.172	0.072	0.167
4	0.194	0.072	0.200

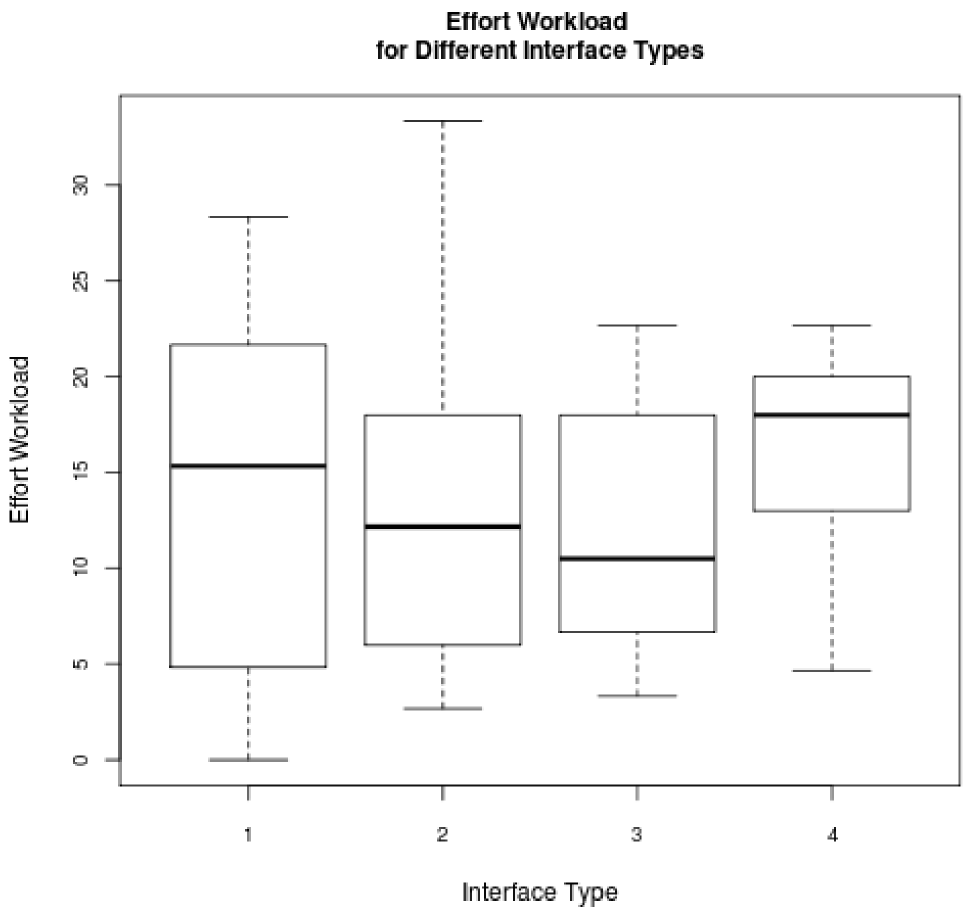




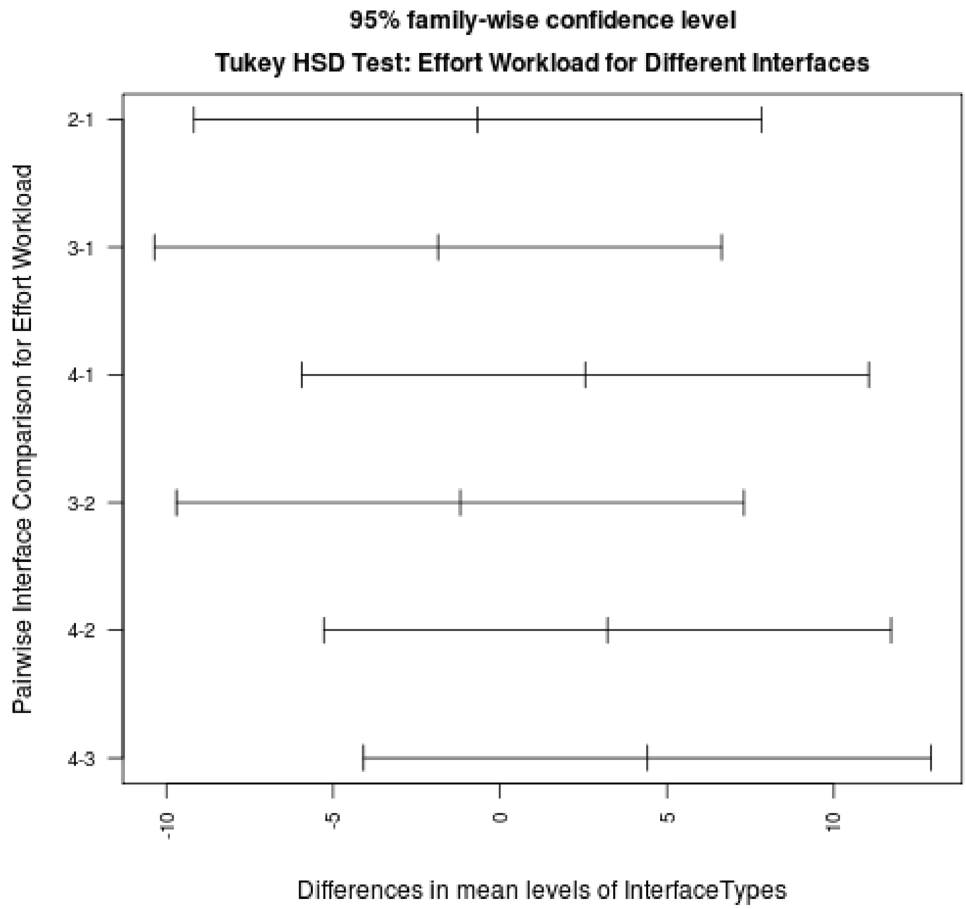




D.2.7.5 Effort Workload



Subject Count	UI1	UI2	UI3	UI4
1	26.667	10.000	21.333	20.000
2	23.333	15.000	22.667	16.000
3	4.667	2.667	9.333	11.000
4	20.000	21.333	11.667	4.667
5	17.333	17.333	18.667	22.667
6	28.333	13.000	7.333	22.667
7	13.333	5.667	9.333	18.667
8	19.000	18.667	5.000	20.000
9	0.667	11.333	3.333	14.000
10	5.000	6.000	6.000	20.000
11	0.000	6.000	14.000	12.000
12	10.000	33.333	17.333	17.333

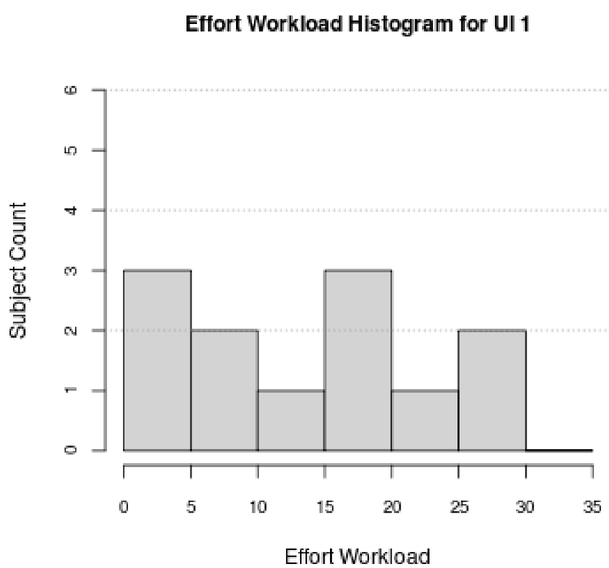


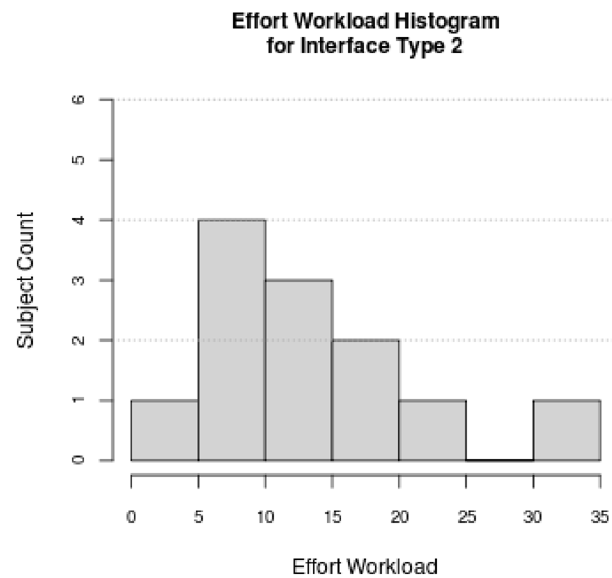
One-way ANOVA: Effort Workload vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	125.270	41.756	0.686	0.566
Residuals	44	2678.790	60.882		

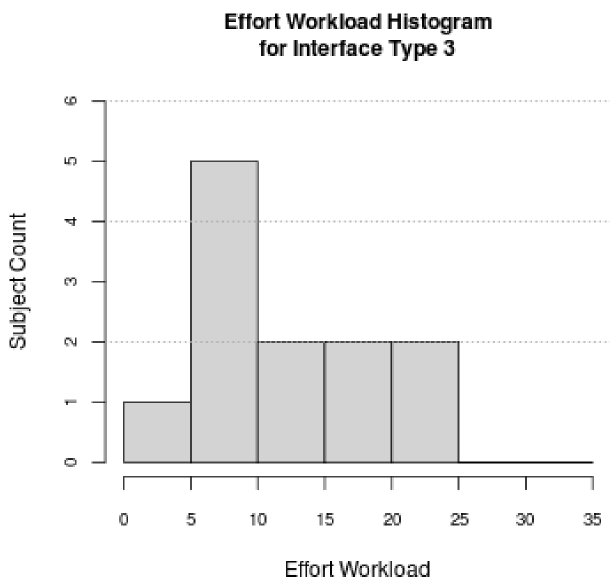
Effort Workload vs. Interface Used Friedman test:	
X^2	4.333
p	0.228
DoF	3

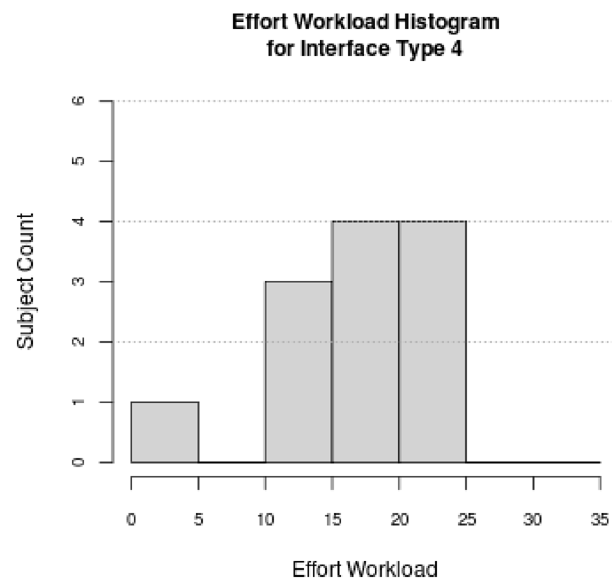
Effort Workload vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	37.000	44.000	29.000	38.000	23.000	15.000
Z	0.353	0.392	-0.785	0.353	-1.255	-1.531
p	0.762	0.733	0.458	0.762	0.233	0.140
R	0.036	0.040	-0.080	0.036	-0.128	-0.156

Effort Workload vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	14.028	9.924	15.333
2	13.361	8.563	12.167
3	12.167	6.562	10.500
4	16.583	5.352	18.000

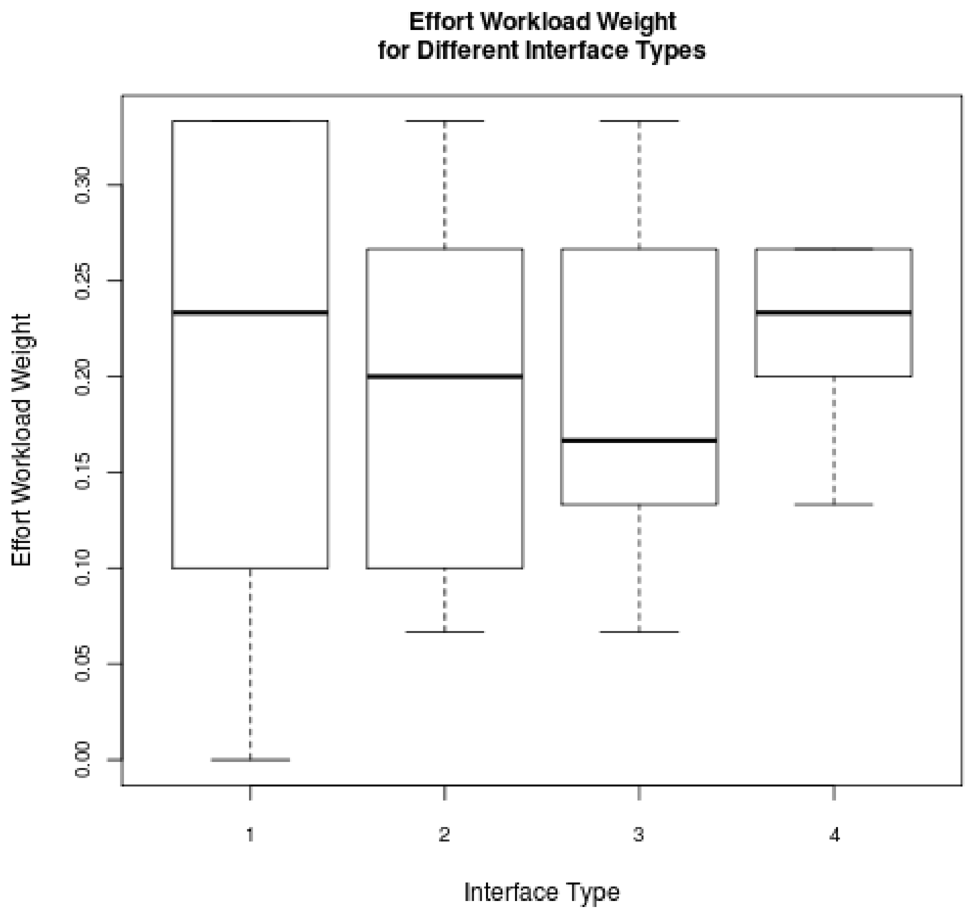




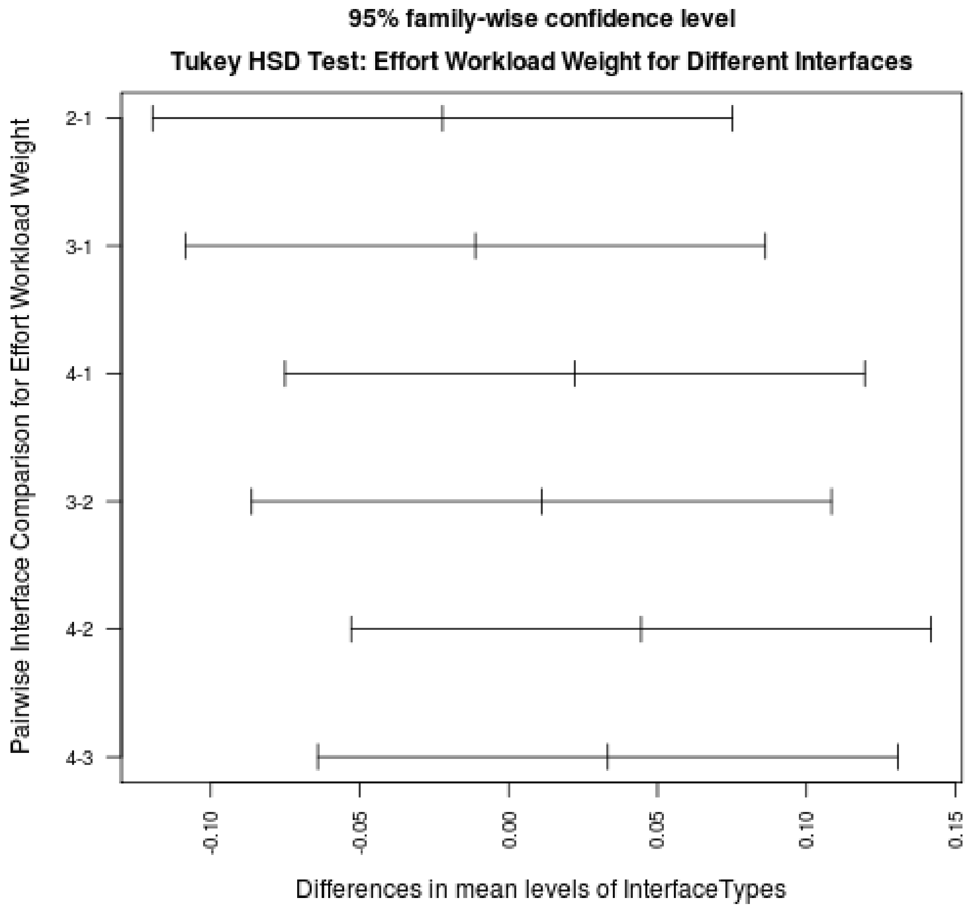




D.2.7.5.1 Effort Workload Weight



Subject Count	UI1	UI2	UI3	UI4
1	0.333	0.200	0.267	0.200
2	0.333	0.200	0.267	0.200
3	0.133	0.067	0.133	0.200
4	0.333	0.267	0.333	0.133
5	0.267	0.267	0.267	0.267
6	0.333	0.200	0.133	0.267
7	0.267	0.067	0.133	0.267
8	0.200	0.267	0.067	0.267
9	0.067	0.133	0.133	0.200
10	0.067	0.133	0.133	0.267
11	0.000	0.067	0.200	0.200
12	0.133	0.333	0.267	0.267

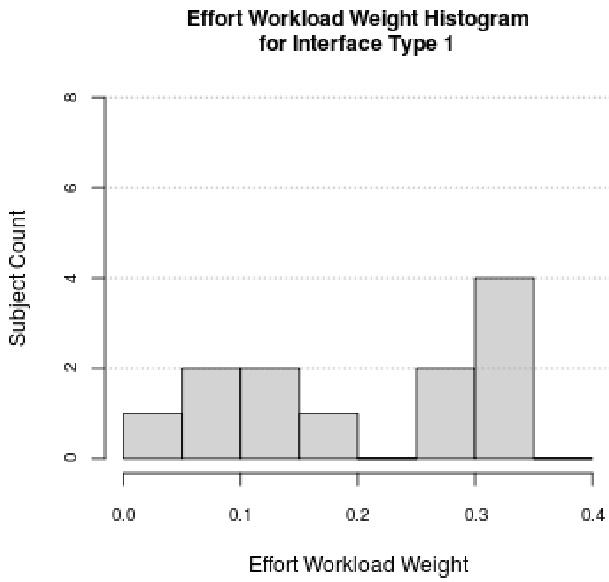


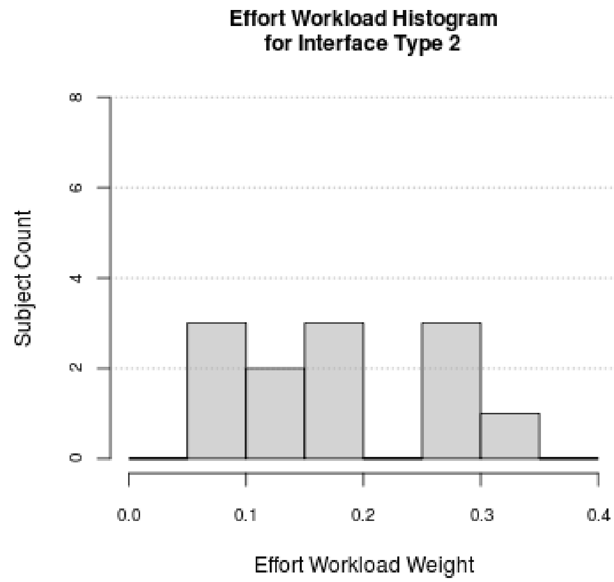
One-way ANOVA: Effort Workload Weight vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.013	0.004	0.542	0.656
Residuals	44	0.351	0.008		

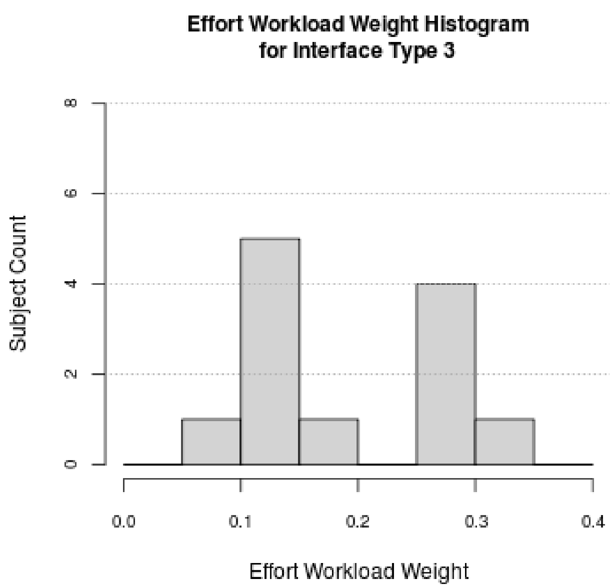
Effort Workload Weight vs. Interface Used Friedman test:	
X^2	2.190
p	0.534
DoF	3

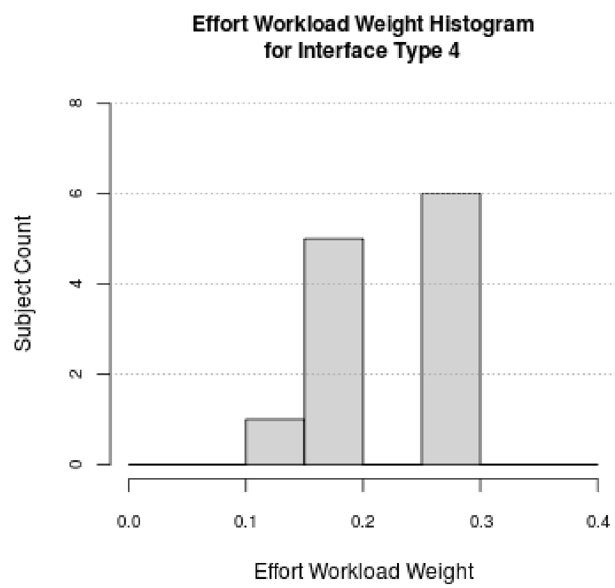
Effort Workload Weight vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	39.000	22.500	18.000	17.500	7.500	11.000
Z	0.512	0.119	-0.906	-0.754	-1.487	-1.272
p	0.647	0.926	0.389	0.477	0.156	0.242
R	0.052	0.012	-0.092	-0.077	-0.152	-0.130

Effort Workload Weight vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.206	0.122	0.233
2	0.183	0.090	0.200
3	0.194	0.083	0.167
4	0.228	0.045	0.233

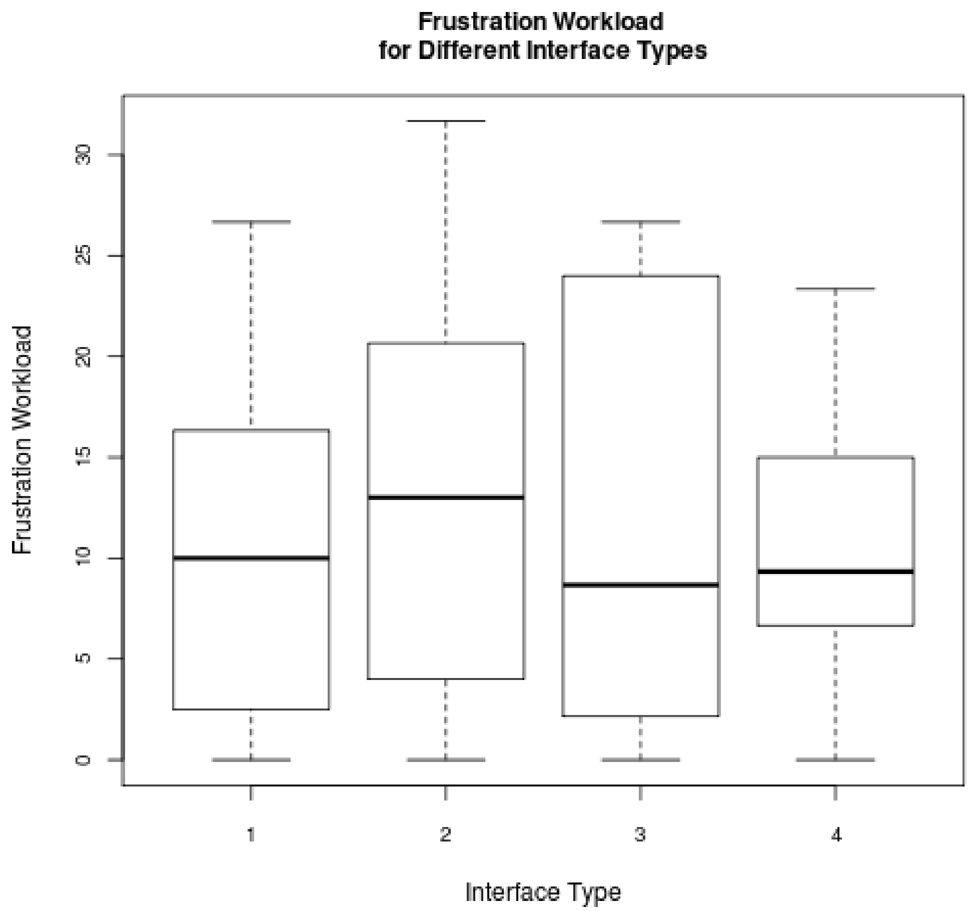




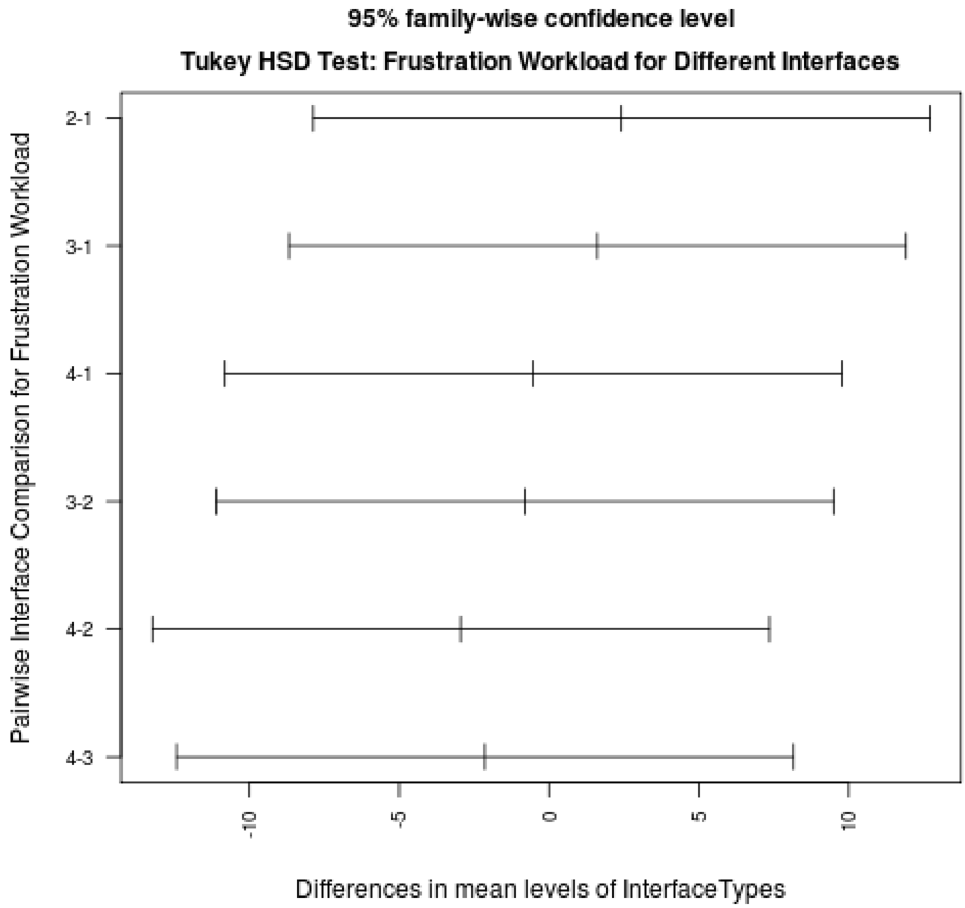




D.2.7.6 Frustration Workload



Subject Count	UI1	UI2	UI3	UI4
1	18.667	26.667	7.333	9.333
2	2.000	0.000	4.333	0.000
3	23.333	13.000	26.667	0.000
4	9.333	21.333	10.000	18.667
5	1.667	0.000	25.333	16.000
6	3.000	20.000	0.000	23.333
7	7.000	13.000	26.667	8.667
8	0.000	10.667	22.667	14.000
9	14.000	31.667	5.000	11.333
10	14.000	3.000	0.000	9.333
11	10.667	15.000	0.000	8.000
12	26.667	5.000	21.667	5.333

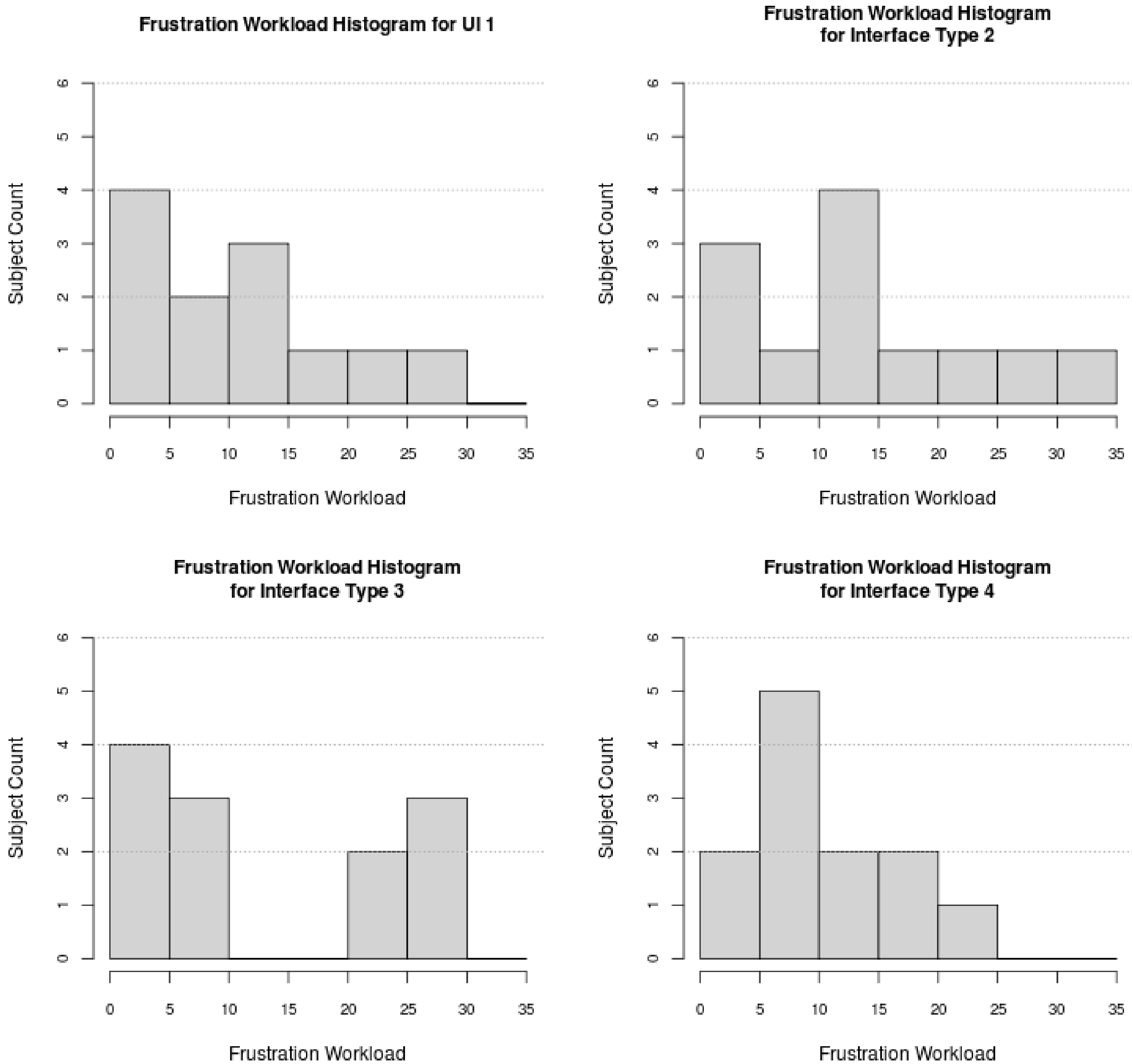


One-way ANOVA: Frustration Workload vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	67.8	22.608	0.2536	0.8583
Residuals	44	3922.2	89.14		

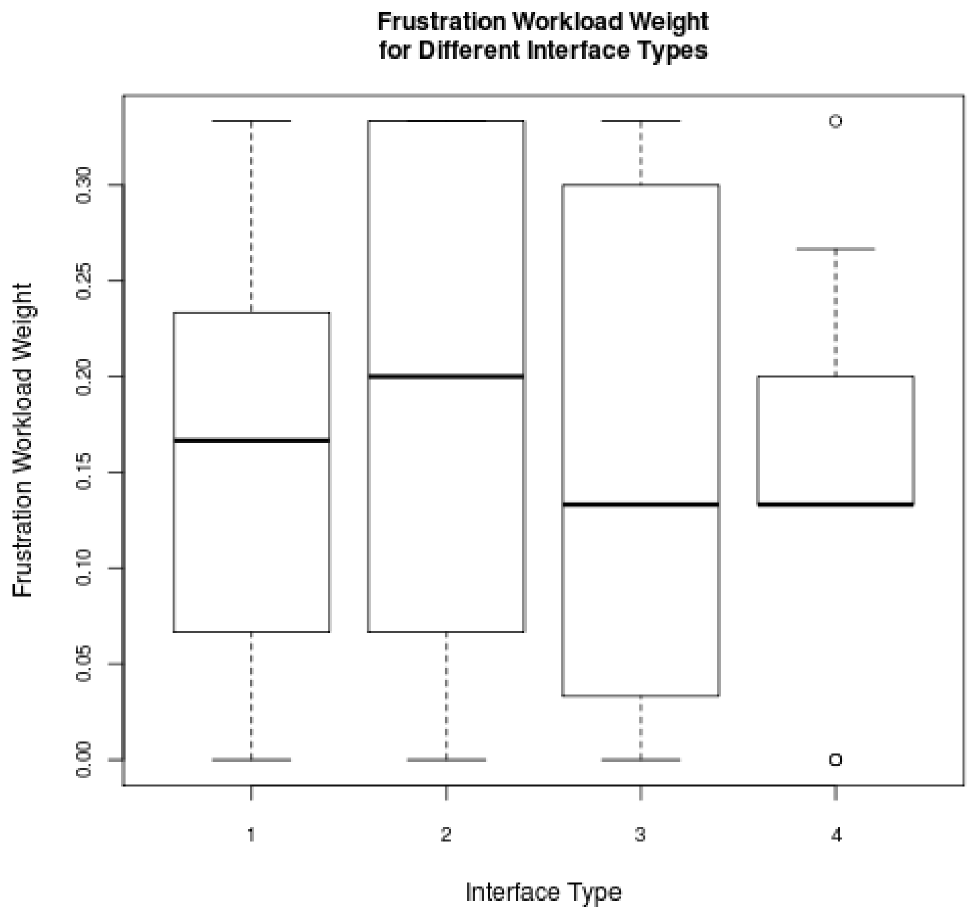
Frustration Workload vs. Interface Used Friedman test:	
X^2	0.227
p	0.973
DoF	3

Frustration Workload vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	29.000	38.000	43.500	42.000	43.000	46.000
Z	-0.784	-0.078	0.353	0.235	0.824	0.549
p	0.470	0.970	0.749	0.834	0.446	0.622
R	-0.080	-0.008	0.036	0.024	0.084	0.056

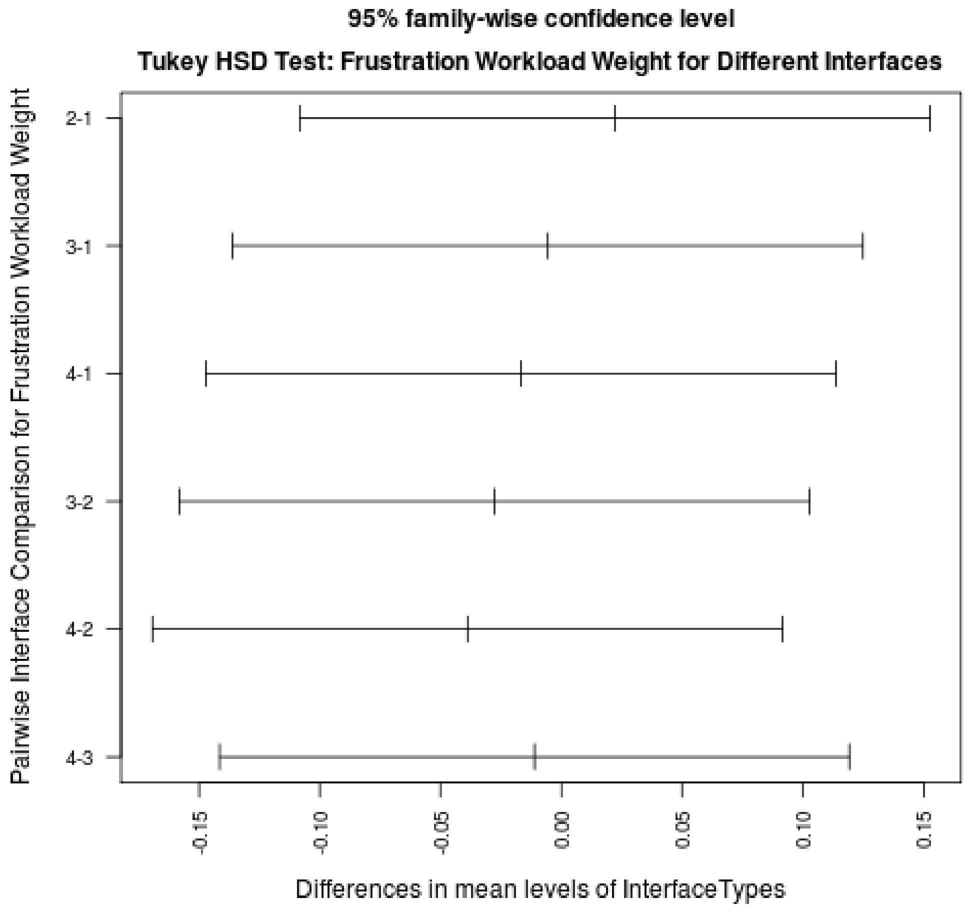
Frustration Workload vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	10.861	8.770	10.000
2	13.278	10.288	13.000
3	12.472	11.193	8.667
4	10.333	6.966	9.333



D.2.7.6.1 Frustration Workload Weight



Subject Count	UI1	UI2	UI3	UI4
1	0.267	0.333	0.133	0.133
2	0.067	0.000	0.067	0.000
3	0.333	0.200	0.333	0.000
4	0.133	0.267	0.133	0.267
5	0.067	0.000	0.267	0.200
6	0.067	0.333	0.000	0.333
7	0.200	0.200	0.333	0.133
8	0.000	0.133	0.267	0.200
9	0.200	0.333	0.067	0.133
10	0.200	0.067	0.000	0.133
11	0.133	0.333	0.000	0.133
12	0.333	0.067	0.333	0.133

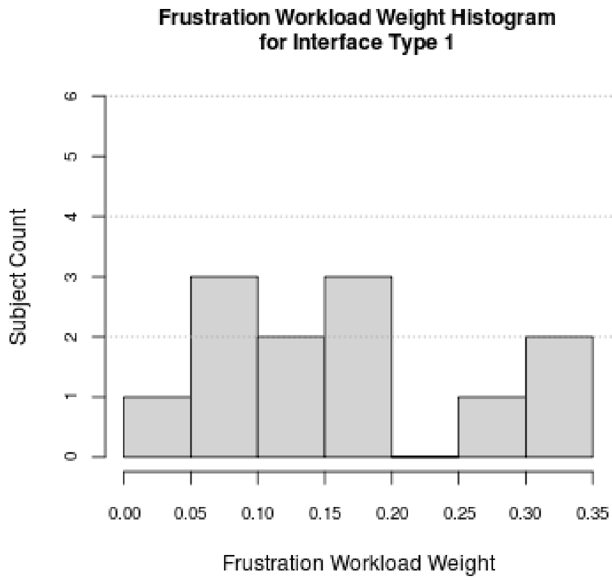


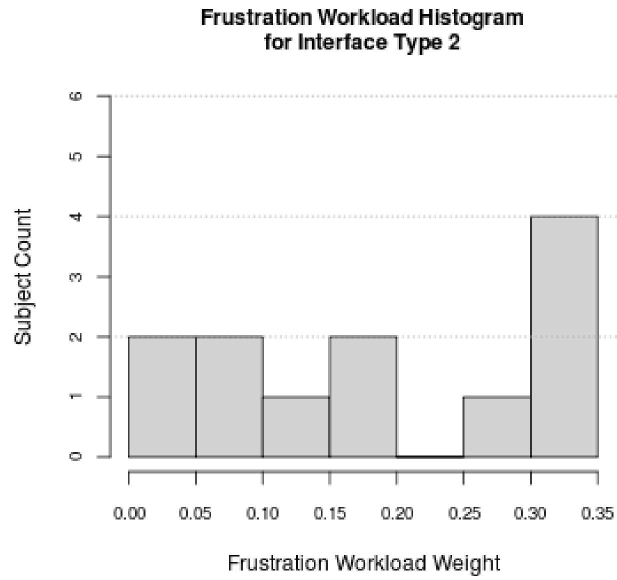
One-way ANOVA: Frustration Workload Weight vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.010	0.003	0.224	0.879
Residuals	44	0.630	0.014		

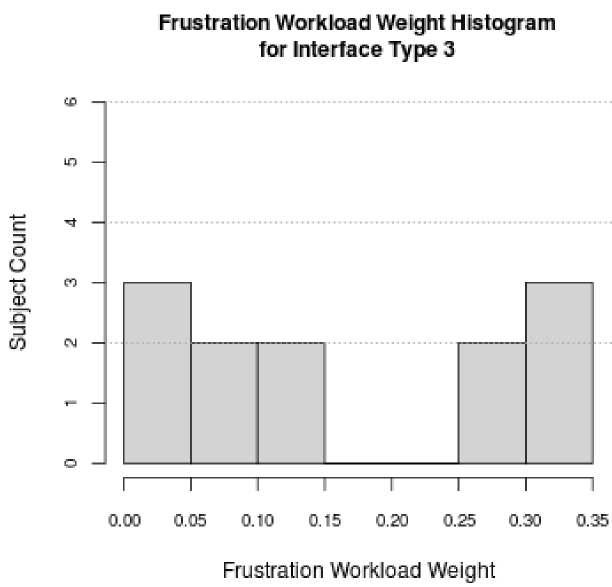
Frustration Workload Weight vs. Interface Used Friedman test:	
X^2	0.627
p	0.890
DoF	3

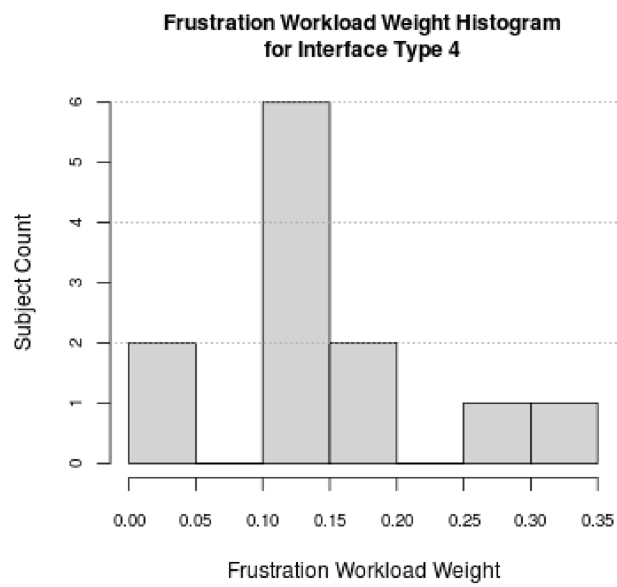
Frustration Workload Weight vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	27.000	19.000	35.500	45.500	30.000	36.500
Z	-0.511	0.402	0.315	0.511	0.716	0.315
p	0.637	0.727	0.779	0.642	0.535	0.766
R	-0.052	0.041	0.032	0.052	0.073	0.032

Frustration Workload Weight vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.167	0.108	0.167
2	0.189	0.133	0.200
3	0.161	0.138	0.133
4	0.150	0.095	0.133



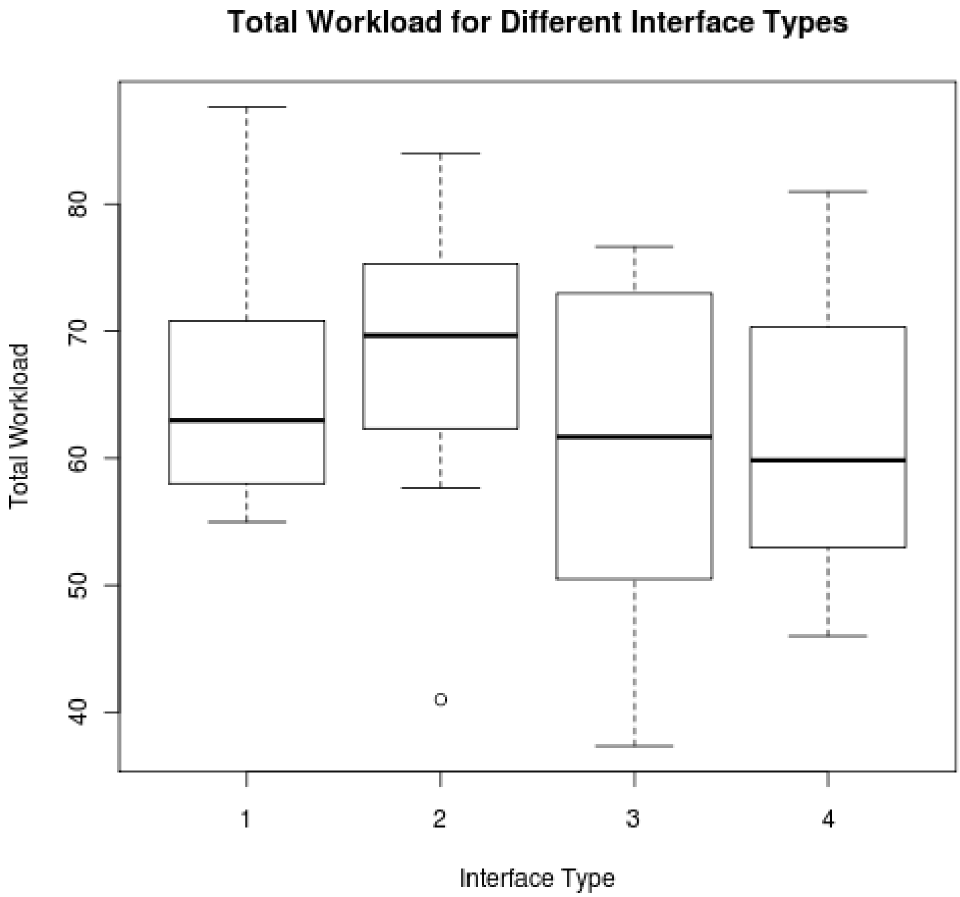




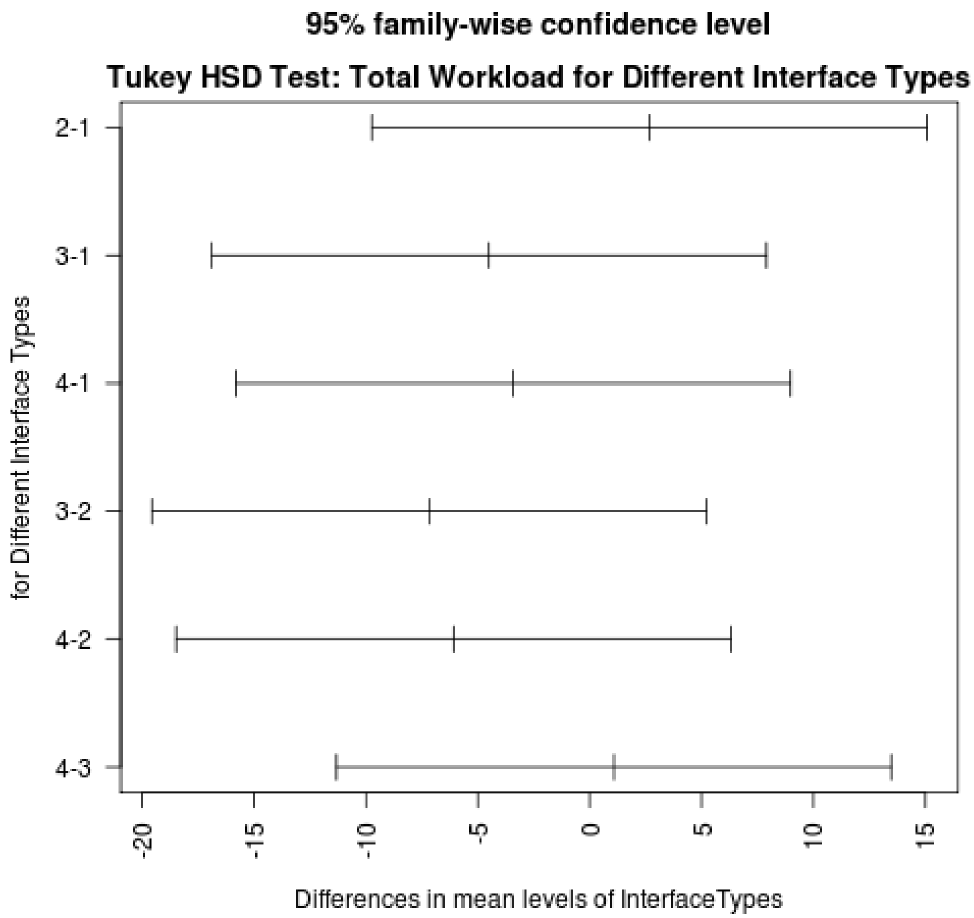


D.2.7.7 Workload Factors (NASA-TLX)

Ratings for each interface taking into consideration all NASA-TLX factors together.



Subject Count	UI1	UI2	UI3	UI4
1	65.333	84.000	75.333	69.000
2	55.667	41.000	63.333	51.667
3	60.667	72.333	76.667	56.333
4	55.000	57.667	37.333	71.667
5	59.333	81.000	70.667	51.667
6	57.333	74.333	50.667	46.000
7	58.667	63.333	67.333	81.000
8	87.667	76.333	76.000	67.333
9	66.667	73.000	57.000	56.333
10	70.667	67.000	60.000	63.333
11	71.000	66.333	47.000	54.333
12	77.667	61.333	50.333	76.000

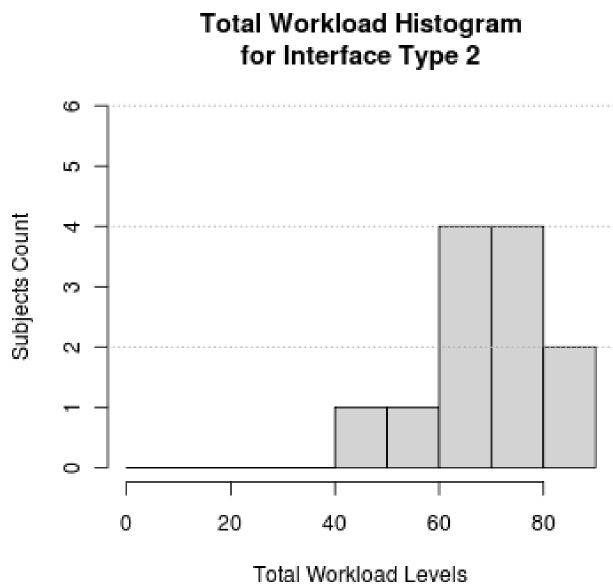


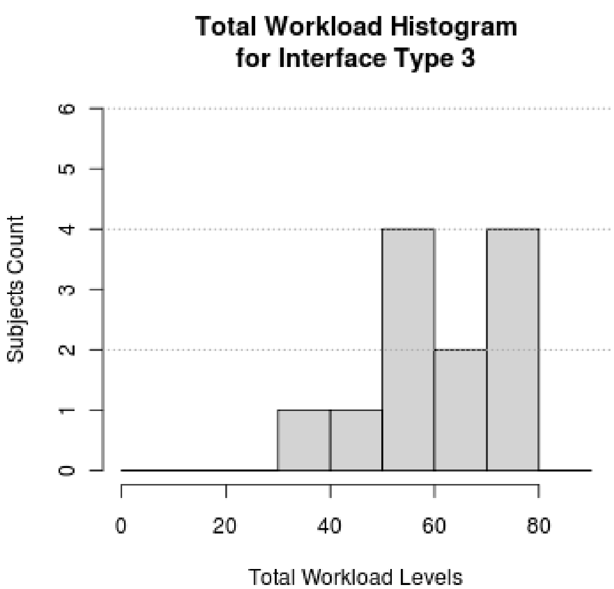
One-way ANOVA: NASA-TLX Total Workload vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	385.700	128.580	0.994	0.405
Residuals	44	5694.000	129.410		

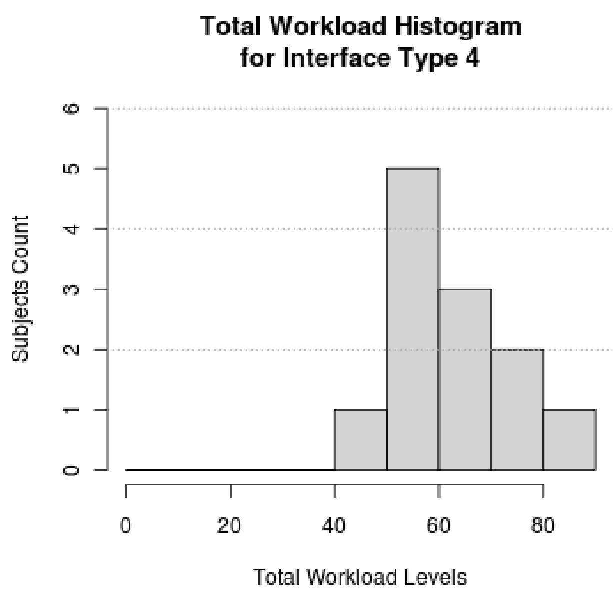
NASA-TLX Total Workload vs. Interface Used Friedman test:	
X^2	4.5
p	0.212
DoF	3

NASA-TLX Total Workload vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	29.000	52.000	54.000	62.000	54.000	40.000
Z	-0.784	1.020	1.177	1.804	1.177	0.078
p	0.470	0.339	0.266	0.077	0.266	0.970
R	-0.080	0.104	0.120	0.184	0.120	0.008

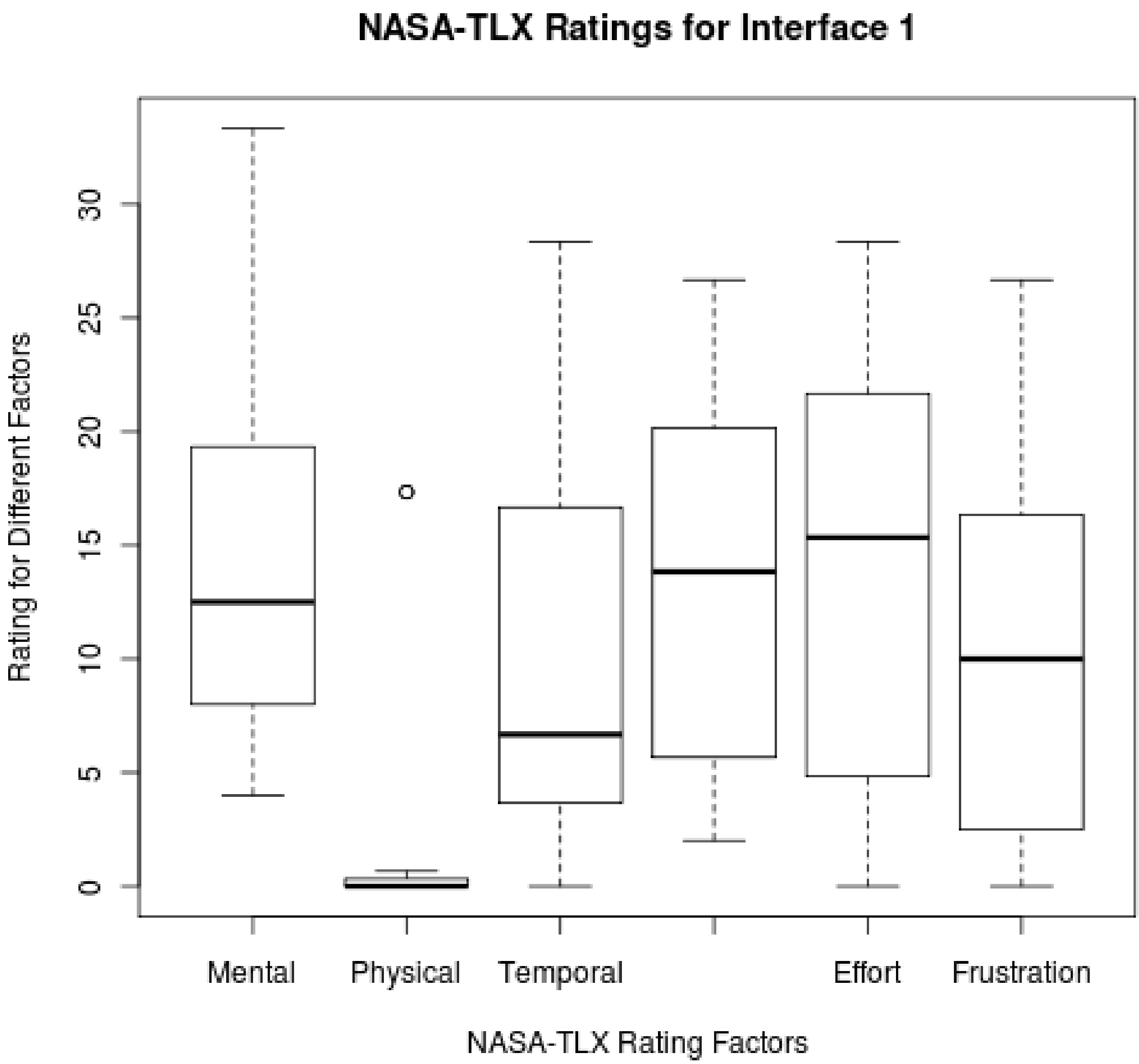
NASA-TLX Total Workload vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	65.472	9.906	63.000
2	68.139	11.615	69.667
3	60.972	12.822	61.667
4	62.056	10.964	59.833

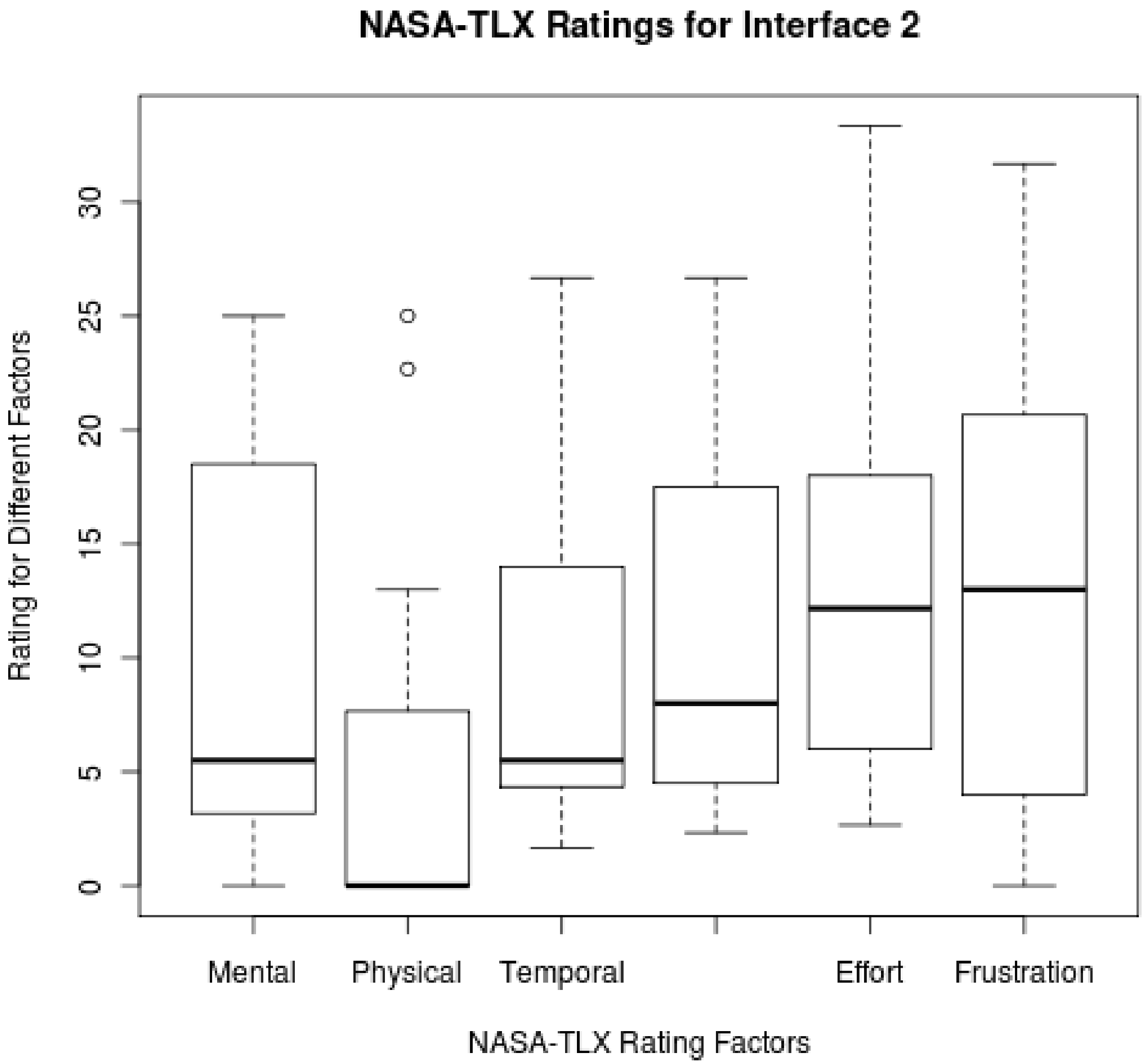


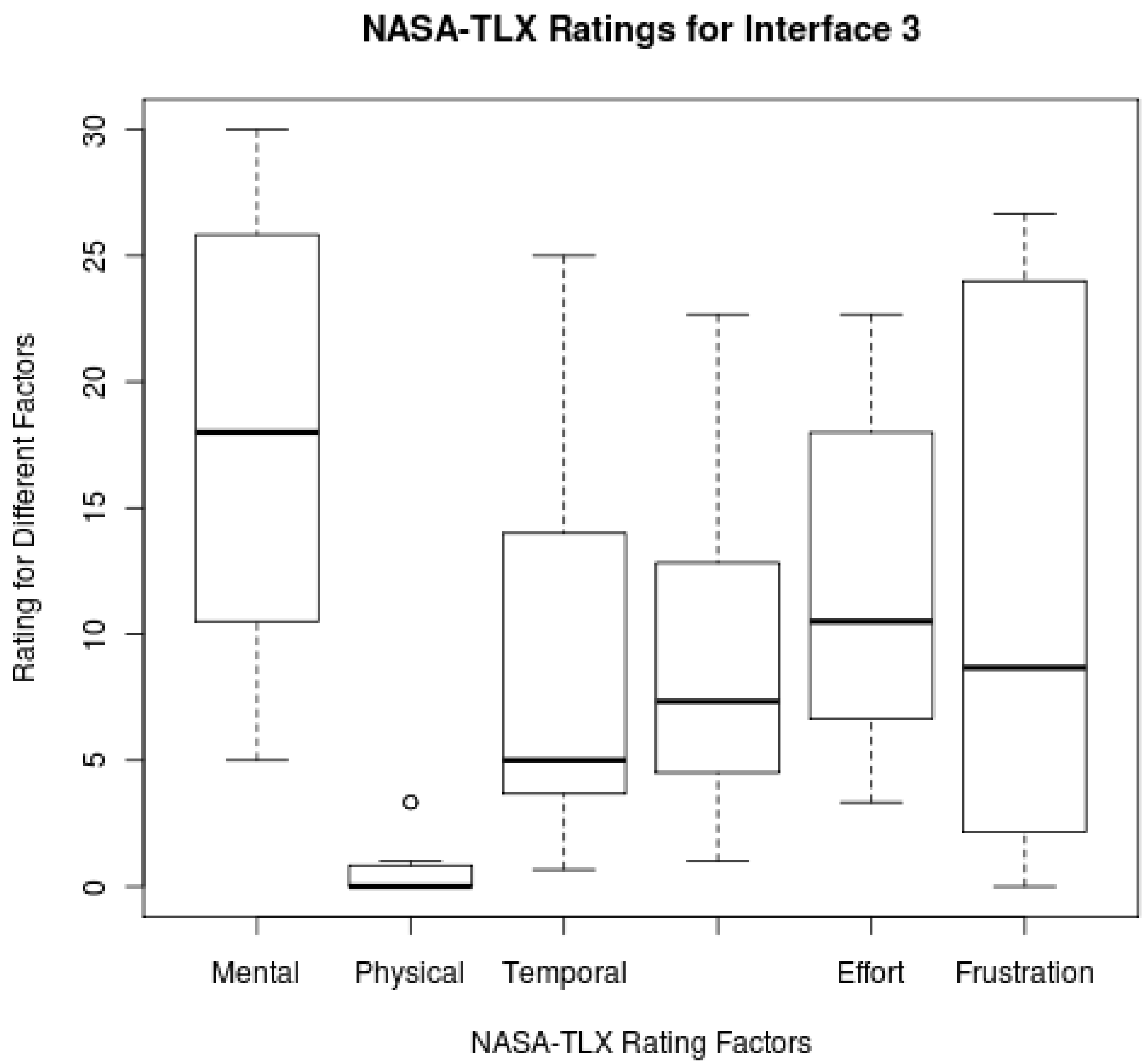


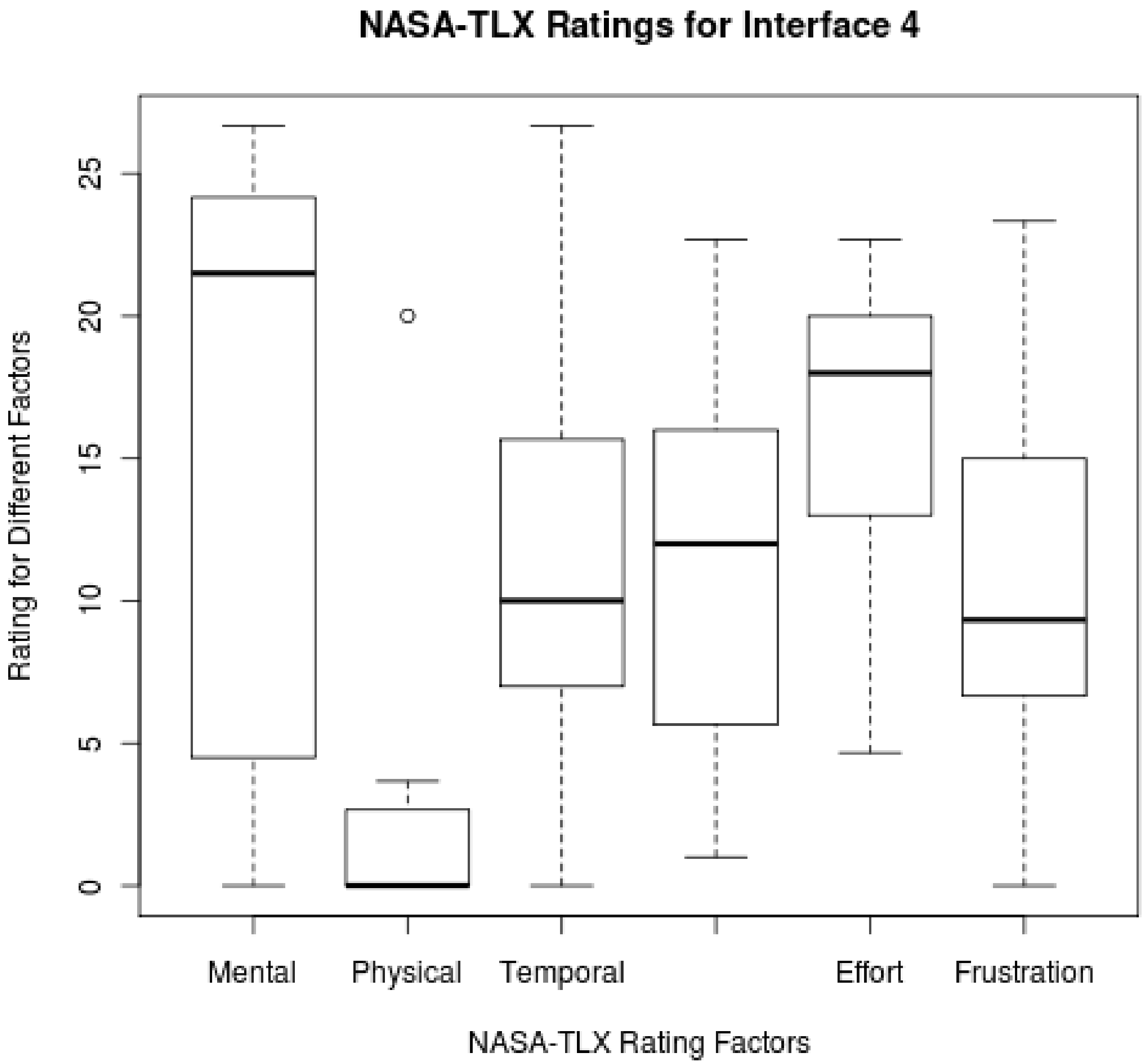


D.2.7.7.1 Ratings for Separate Workload Factors (NASA-TLX) per Interface

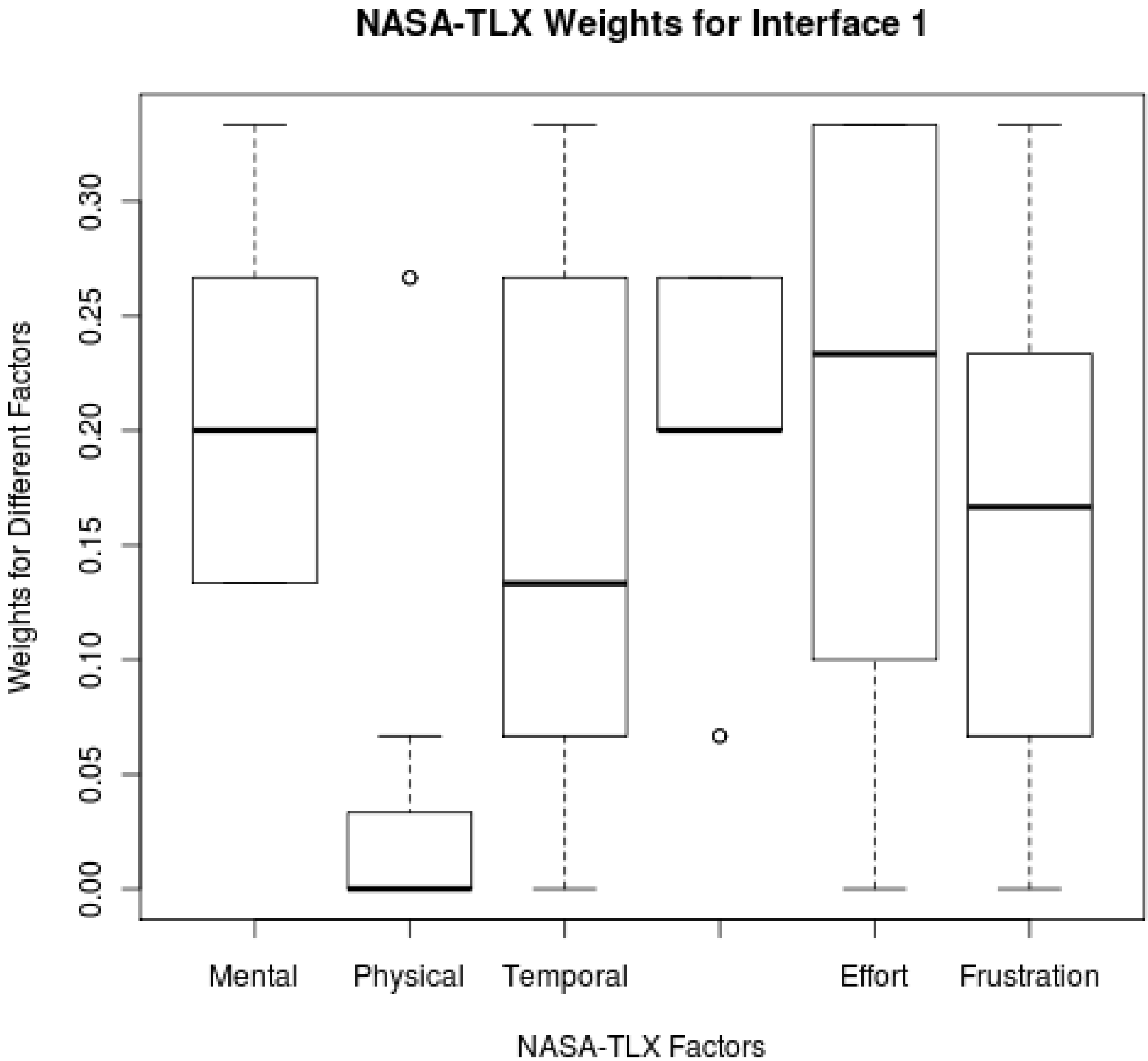


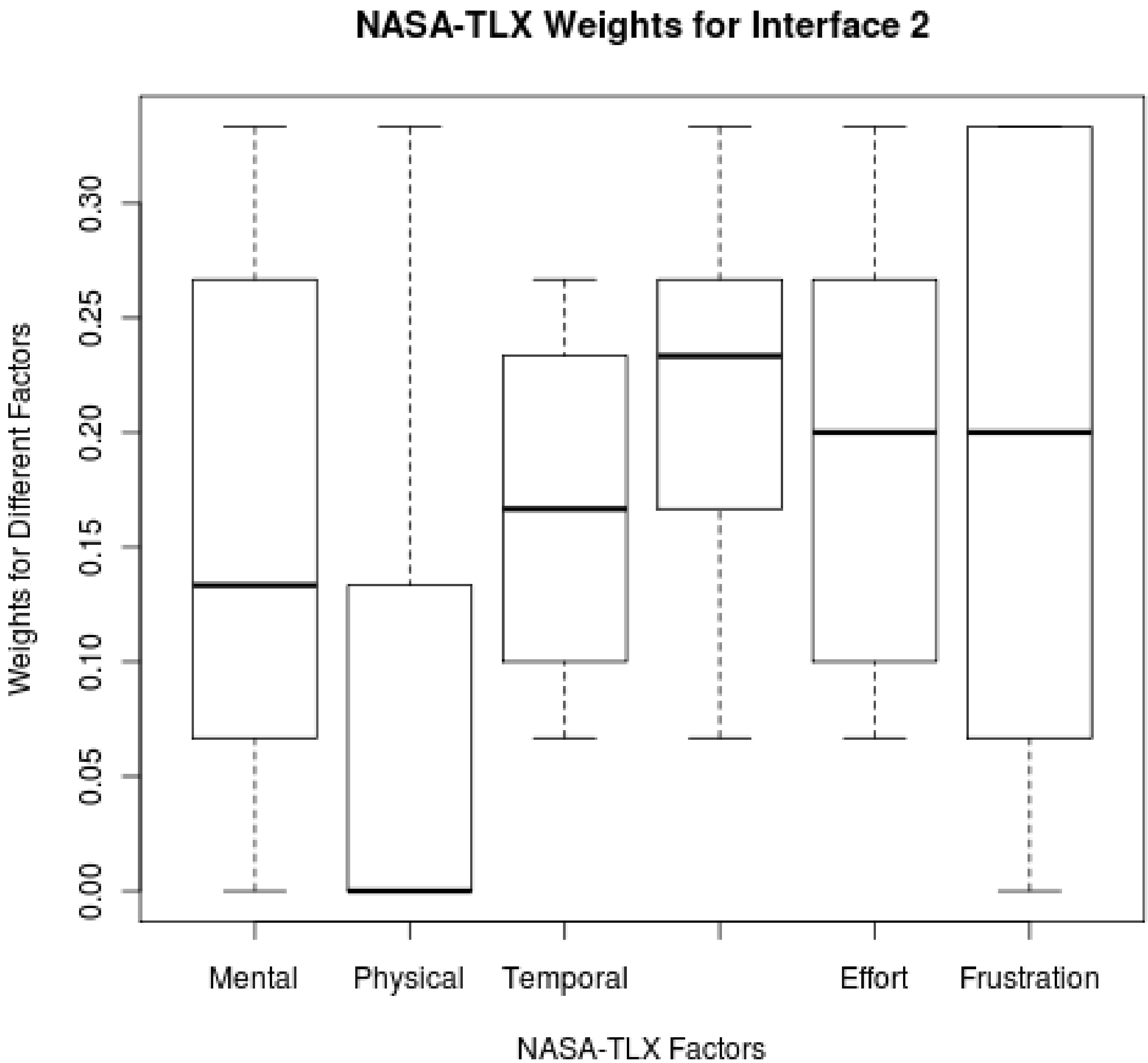

NASA-TLX Ratings for Interface 2
Rating for Different Factors
0
5
10
15
20
25
30
Mental
Physical
Temporal
Effort
Frustration
NASA-TLX Rating Factors


NASA-TLX Ratings for Interface 3
Rating for Different Factors
0
5
10
15
20
25
30
Mental
Physical
Temporal
Effort
Frustration
NASA-TLX Rating Factors

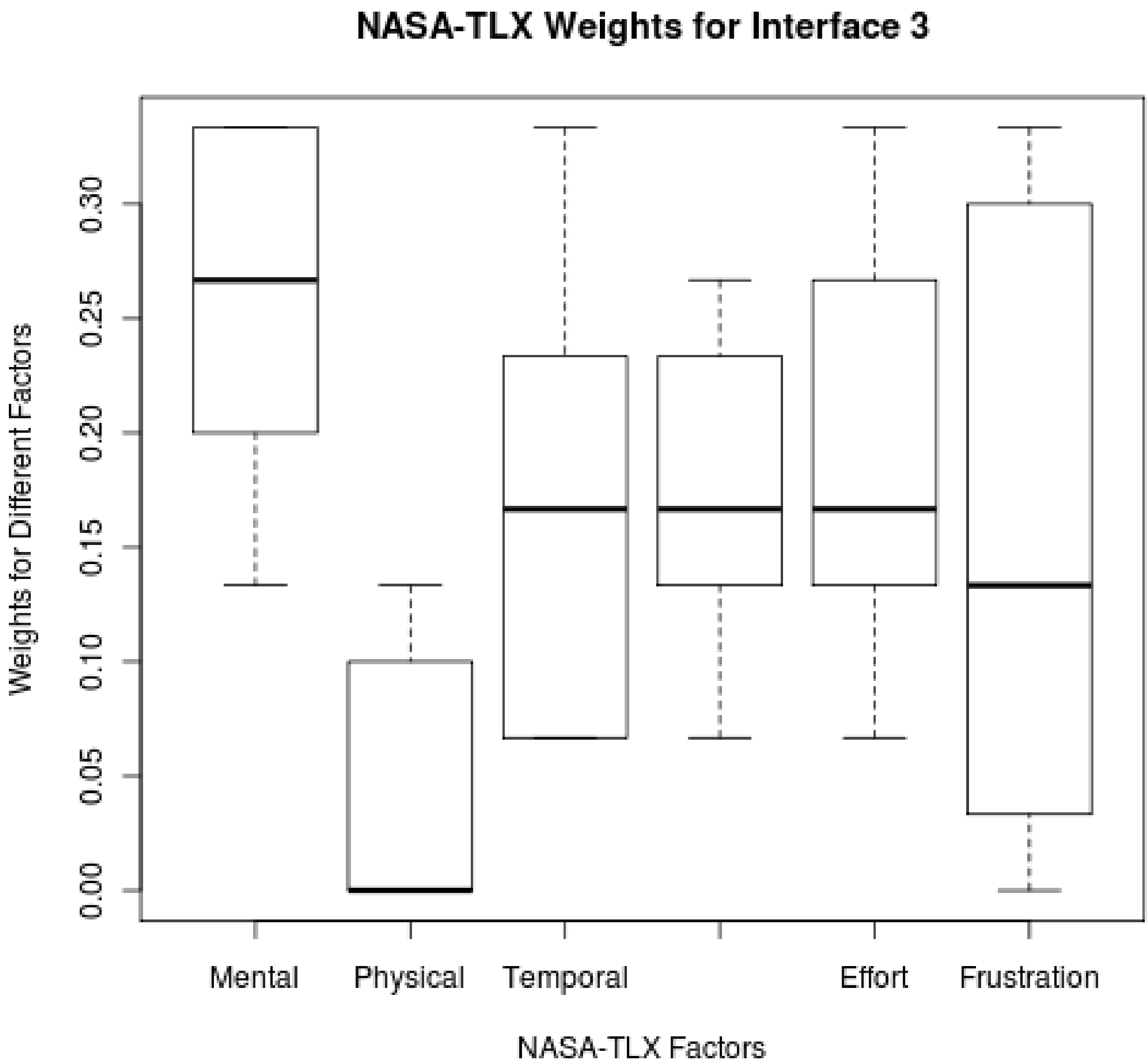

NASA-TLX Ratings for Interface 4
Rating for Different Factors
0
5
10
15
20
25
Mental
Physical
Temporal
Effort
Frustration
NASA-TLX Rating Factors

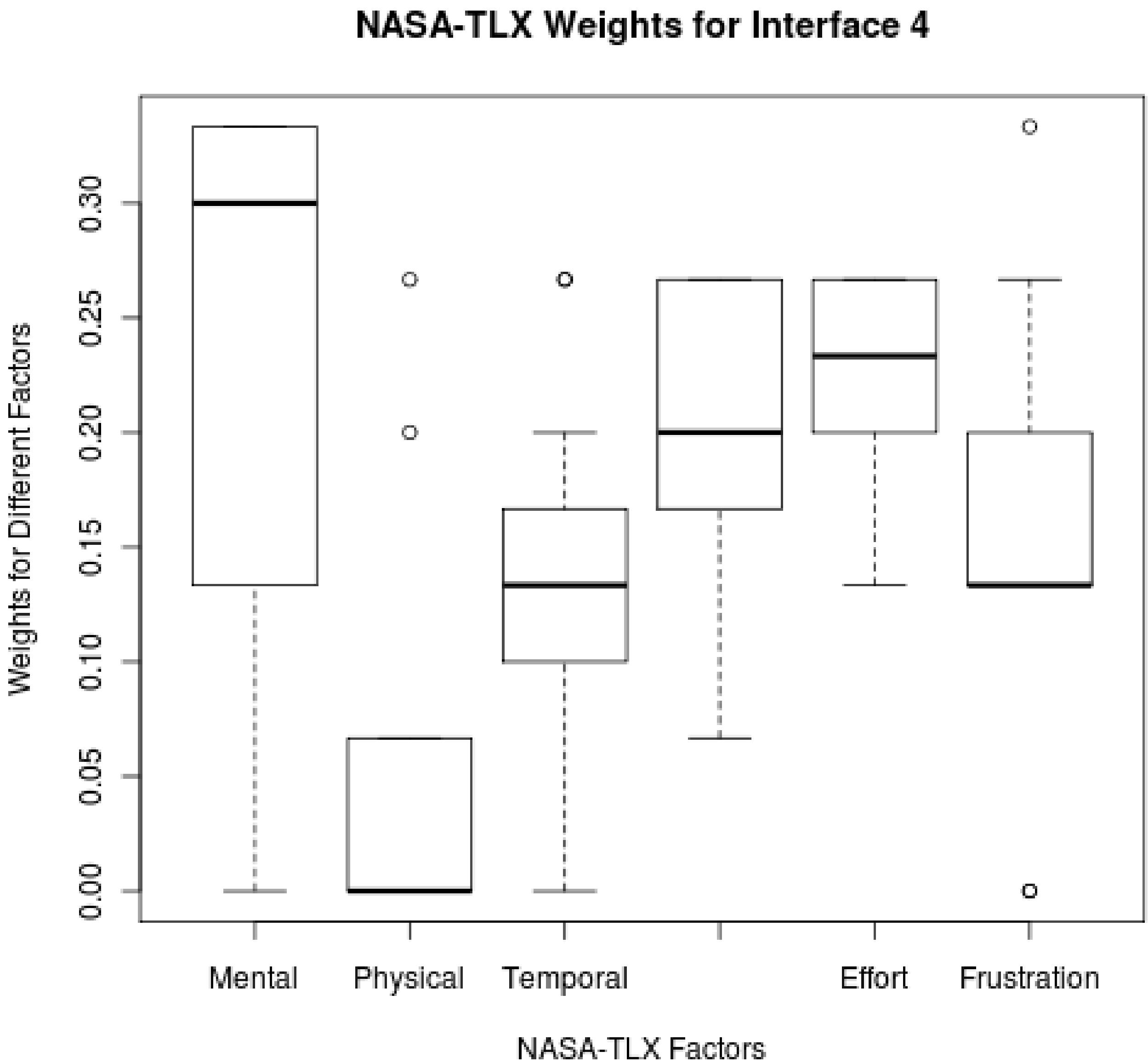
D.2.7.7.2 Weights for Separate Workload Factors (NASA-TLX) per Interface





NASA-TLX Weights for Interface 2
Weights for Different Factors
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Mental
Physical
Temporal
Effort
Frustration
NASA-TLX Factors


NASA-TLX Weights for Interface 3
Weights for Different Factors
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Mental
Physical
Temporal
Effort
Frustration
NASA-TLX Factors

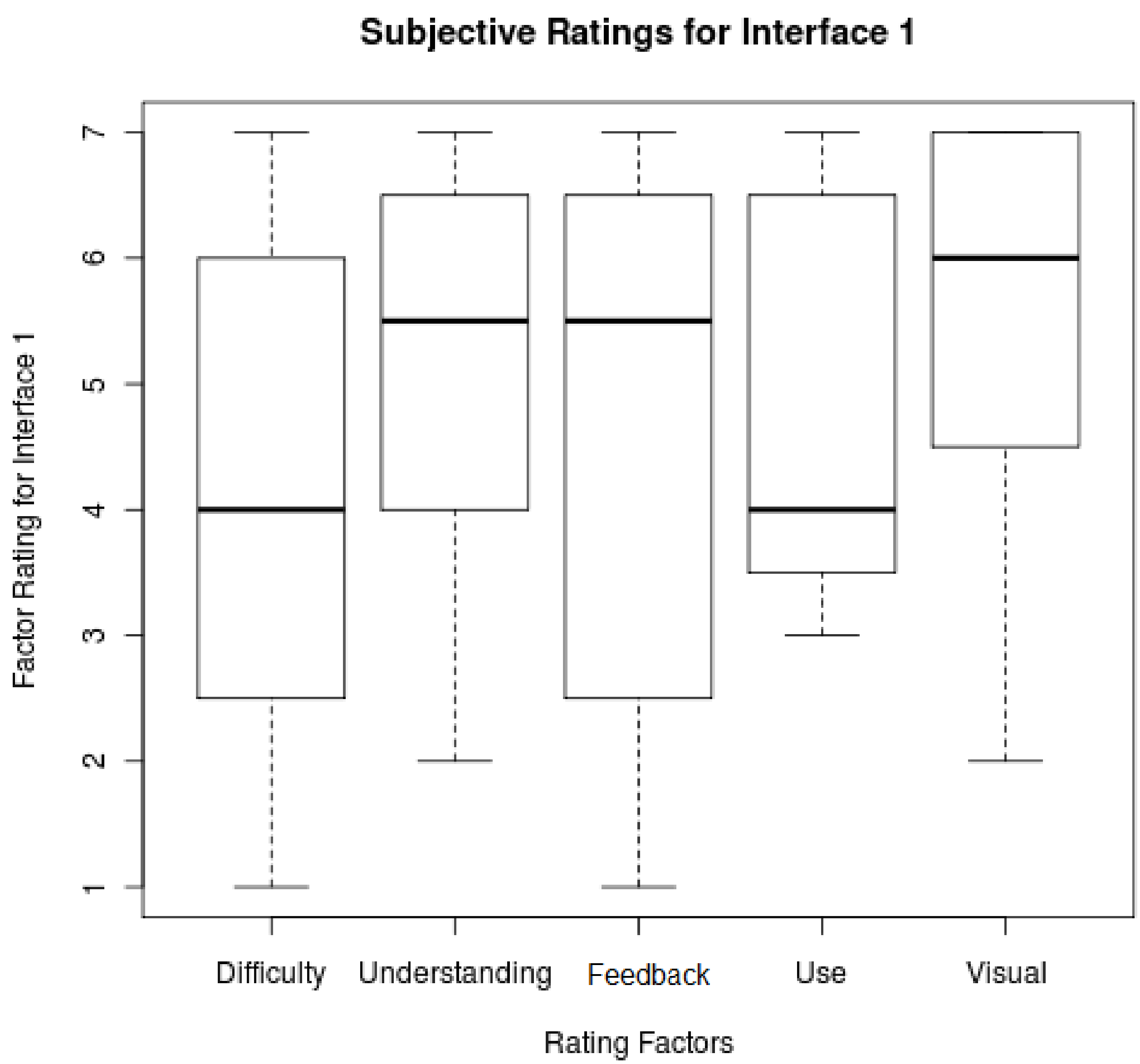

NASA-TLX Weights for Interface 4
Weights for Different Factors
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Mental
Physical
Temporal
Effort
Frustration
NASA-TLX Factors

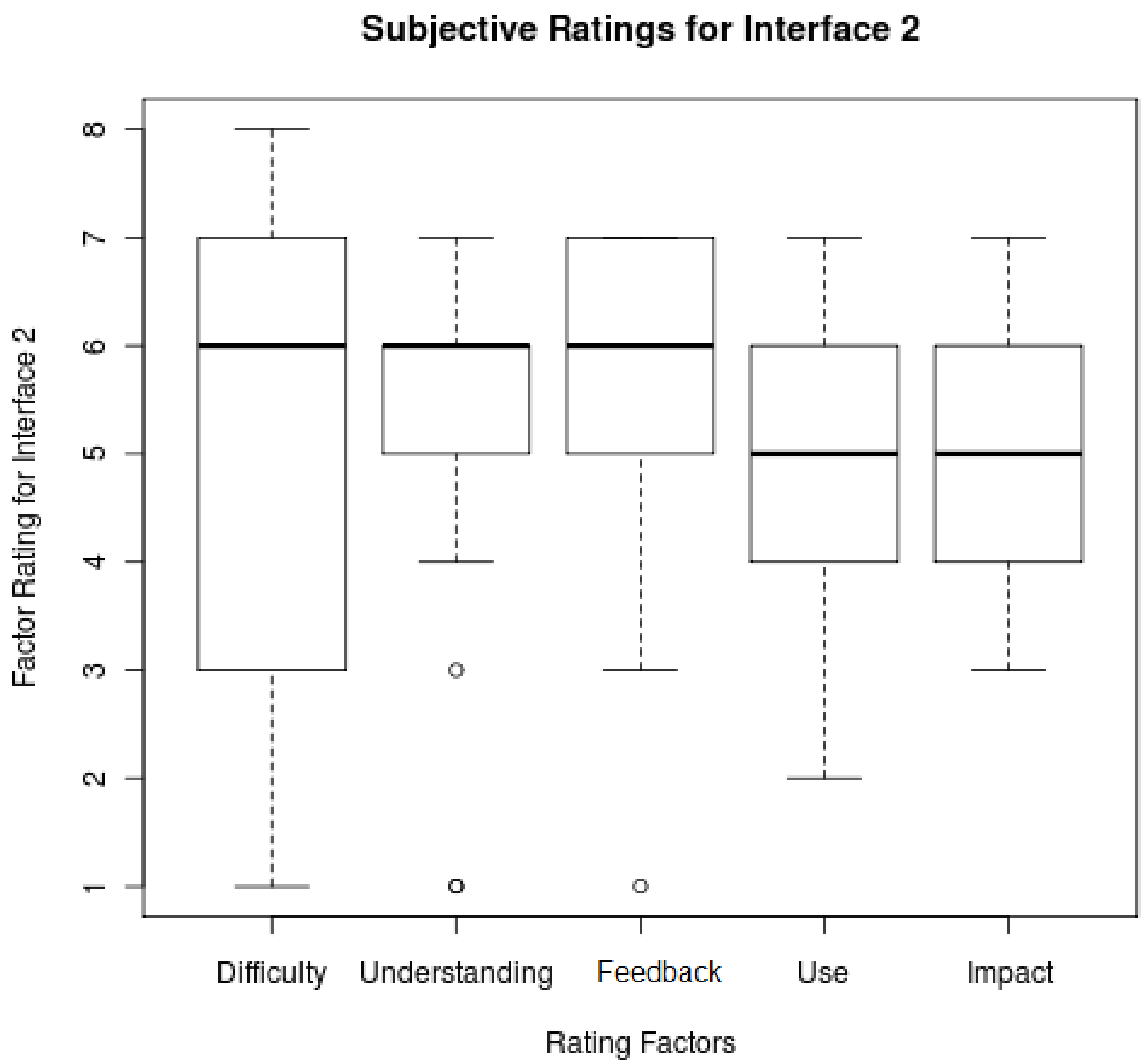
D.2.8 Final questionnaire

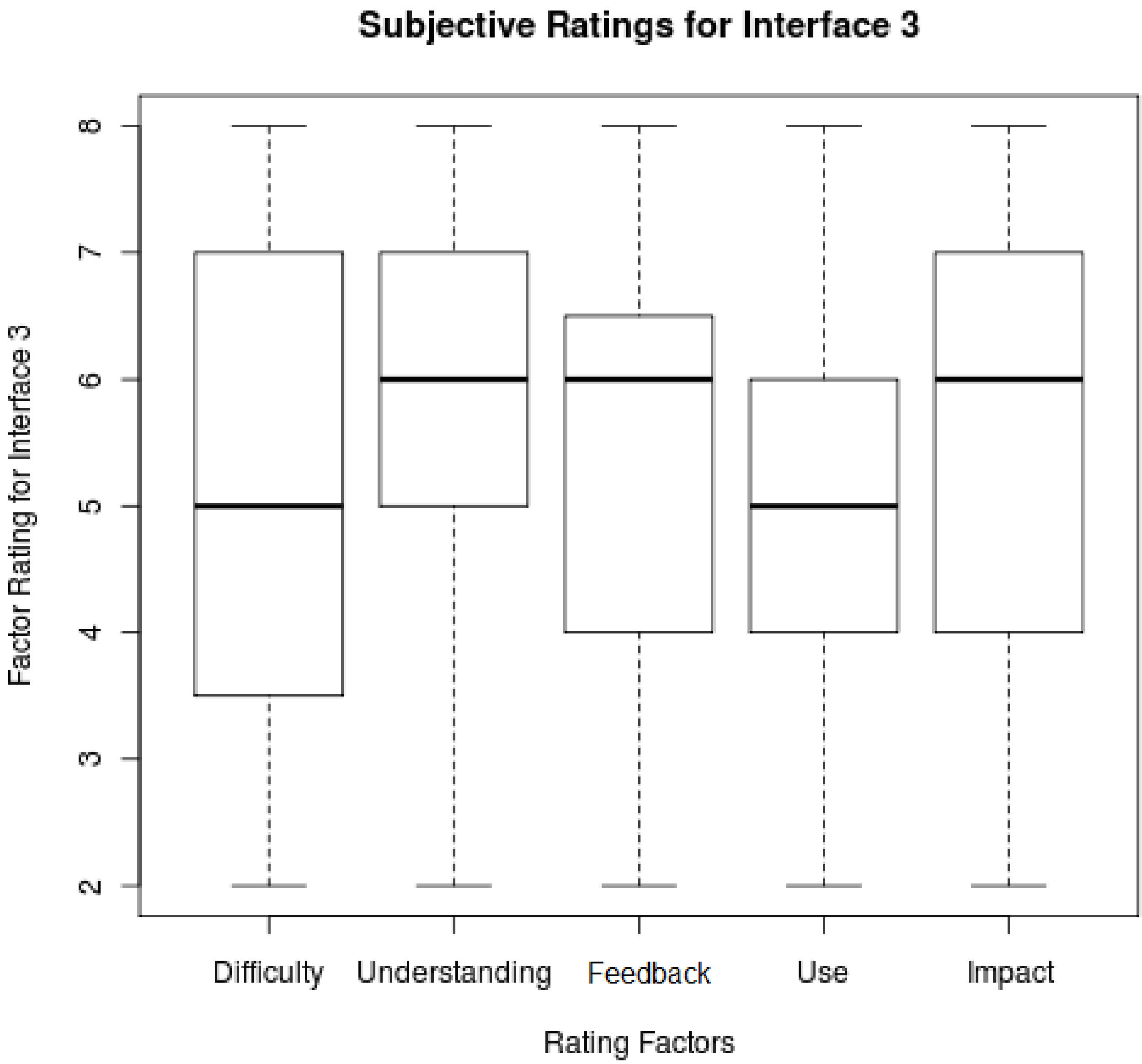
D.2.8.1 Overall Interface Evaluation

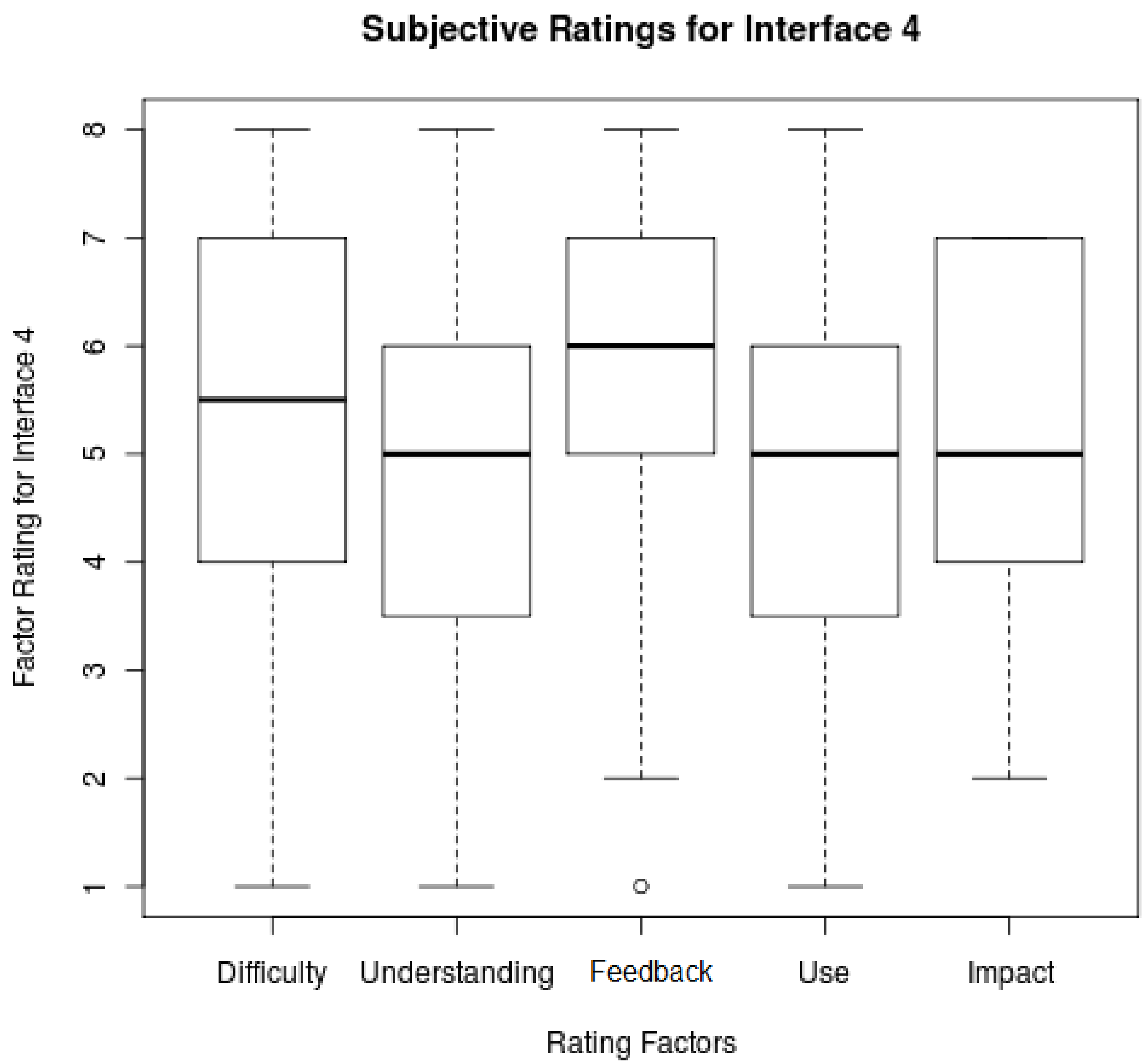
Plots of ratings of different factors for each interface taking all rating factors together into consideration are presented here.

Questionnaire Factors



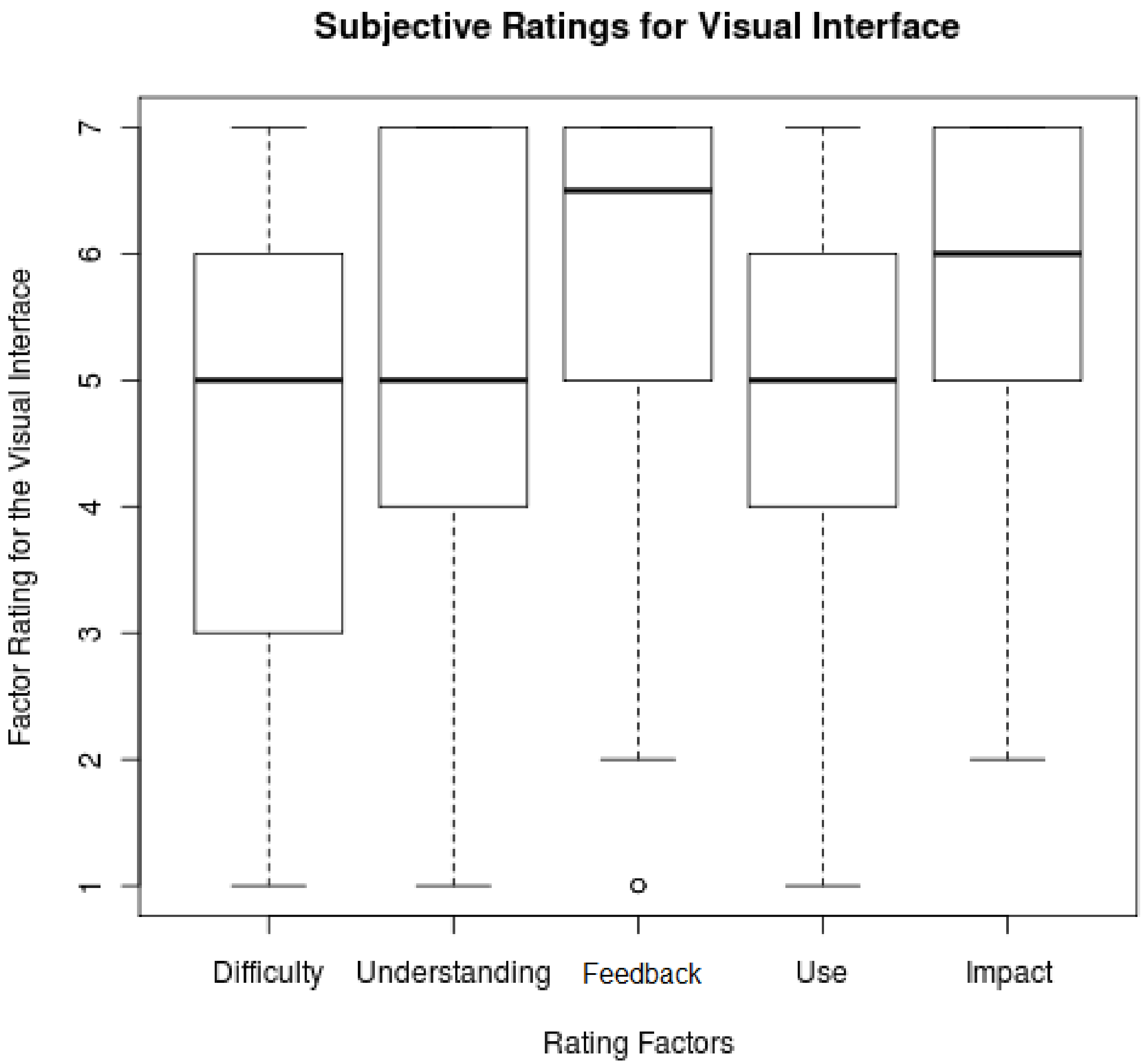

Subjective Ratings for Interface 2
Factor Rating for Interface 2
1
2
3
4
5
6
7
8
Difficulty
Understanding
Feedback
Use
Impact
Rating Factors

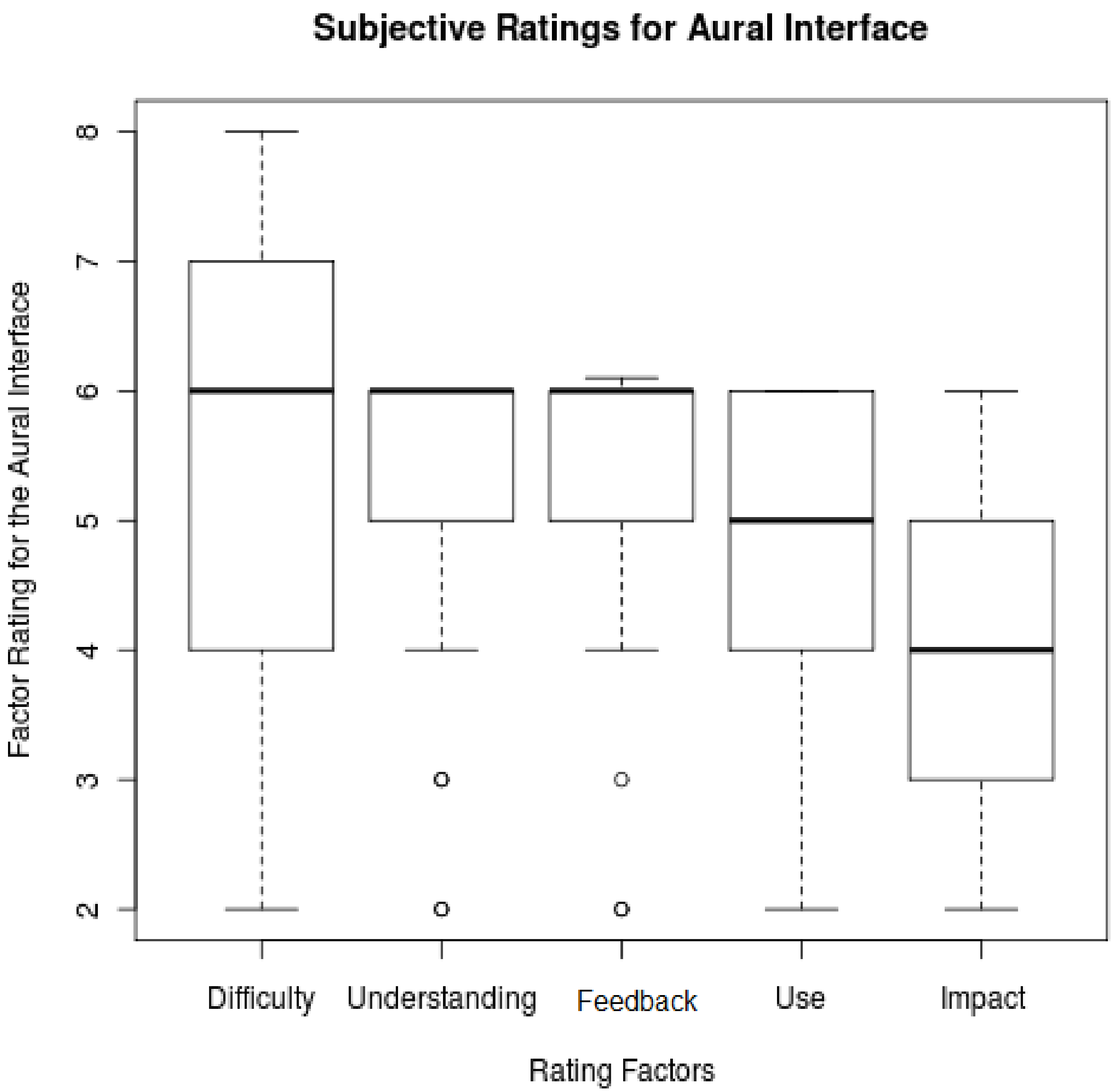

Subjective Ratings for Interface 3
Factor Rating for Interface 3
2
3
4
5
6
7
8
Difficulty
Understanding
Feedback
Use
Impact
Rating Factors

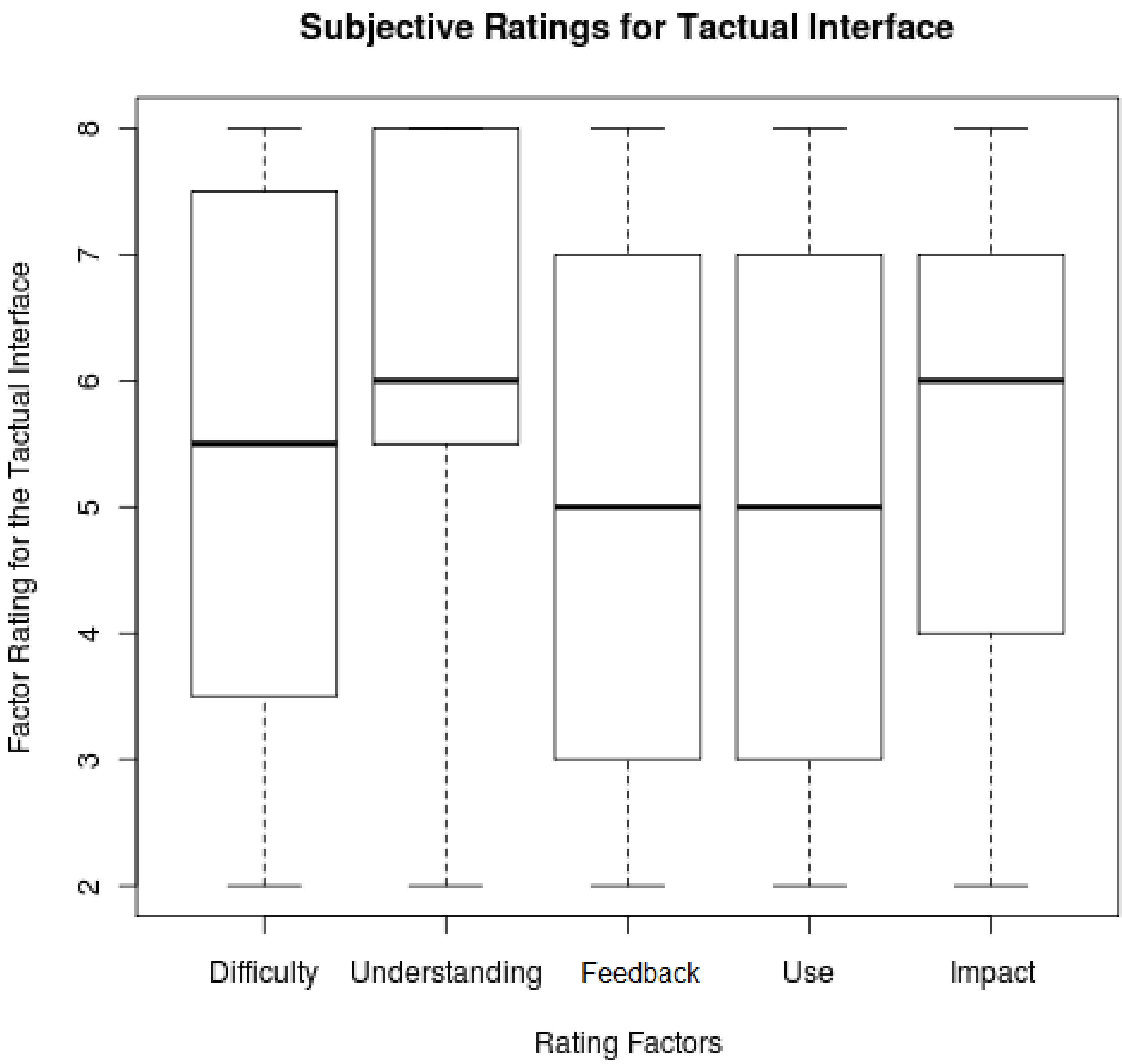

Subjective Ratings for Interface 4
Factor Rating for Interface 4
1
2
3
4
5
6
7
8
Difficulty
Understanding
Feedback
Use
Impact
Rating Factors

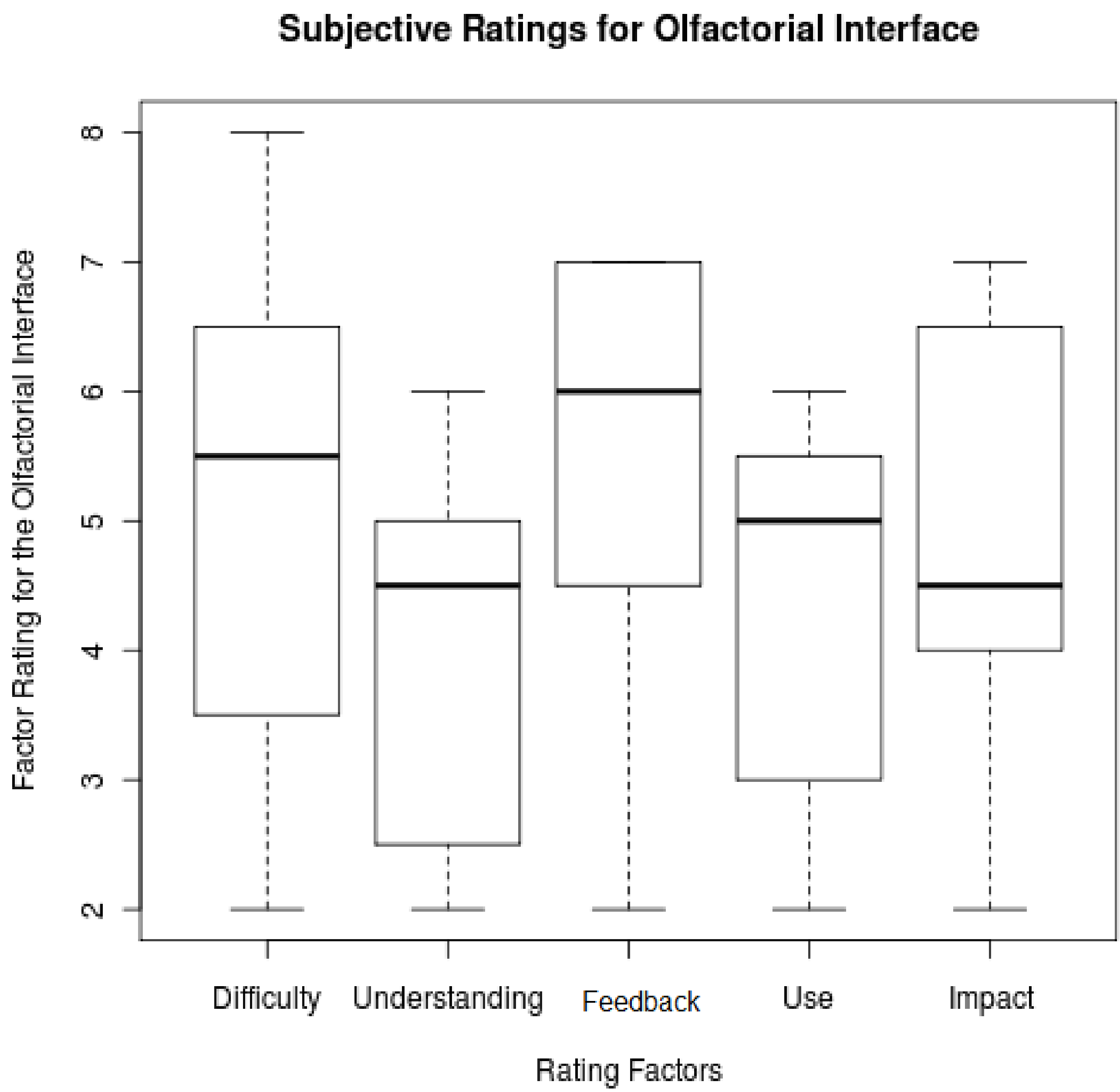
D.2.8.1.1 Overall Feedback Evaluation

Plots of ratings of different factors for visual feedback using all types of interfaces used and for individual interfaces are presented here.

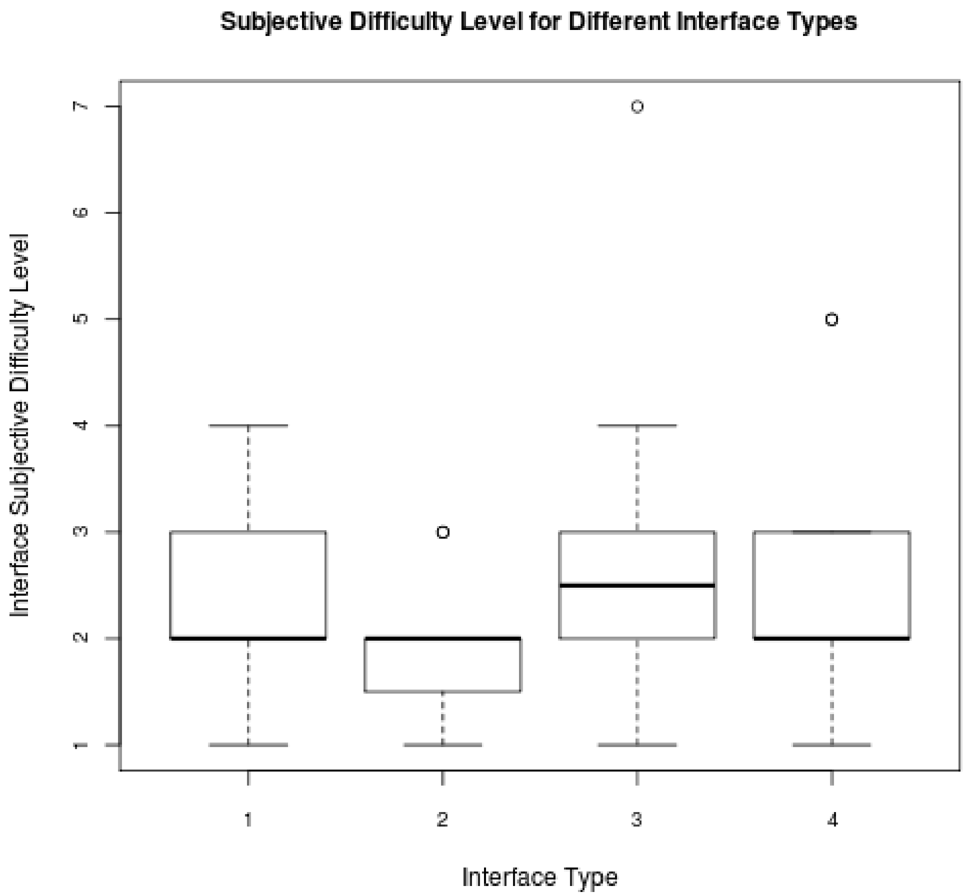



Subjective Ratings for Aural Interface
Factor Rating for the Aural Interface
2
3
4
5
6
7
8
Difficulty
Understanding
Feedback
Use
Impact
Rating Factors

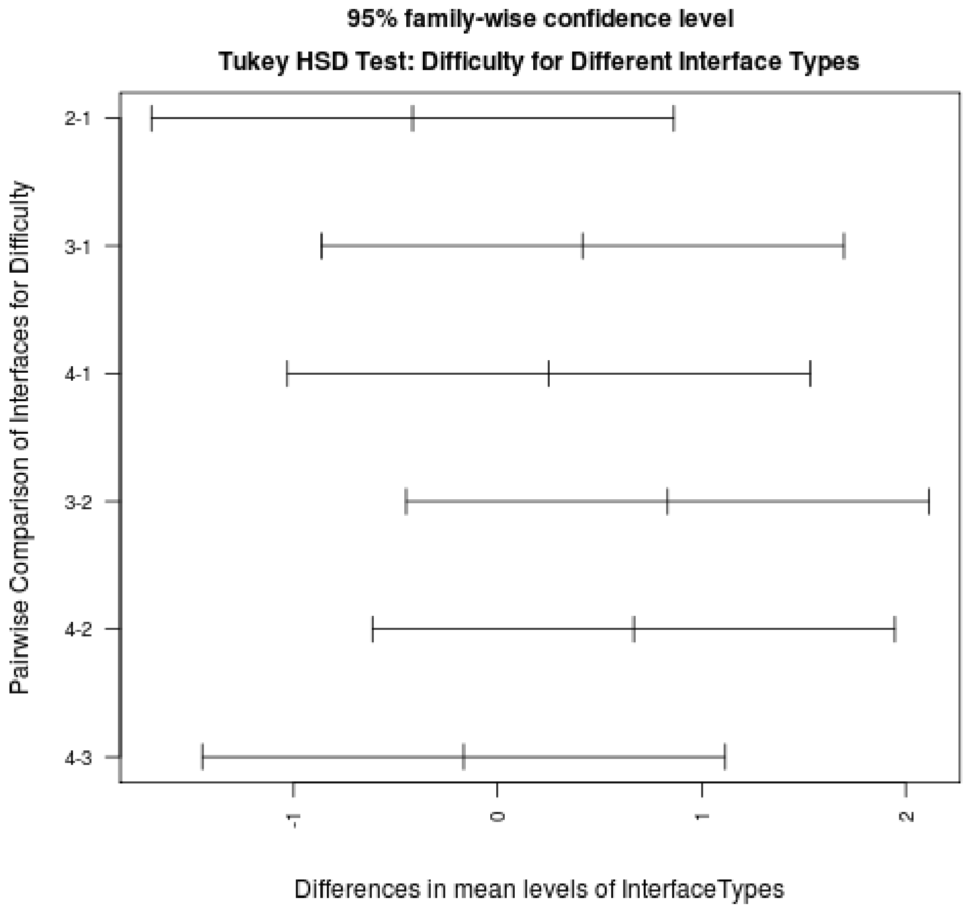

Subjective Ratings for Tactual Interface
Factor Rating for the Tactual Interface
2
3
4
5
6
7
8
Difficulty
Understanding
Feedback
Use
Impact
Rating Factors


Subjective Ratings for Olfactorial Interface
Factor Rating for the Olfactorial Interface
2
3
4
5
6
7
8
Difficulty
Understanding
Feedback
Use
Impact
Rating Factors

D.2.8.2 Difficulty



Subject Count	UI1	UI2	UI3	UI4
1	4	1	7	1
2	3	2	1	1
3	2	3	2	5
4	3	1	2	2
5	3	2	1	5
6	3	3	2	2
7	2	1	3	3
8	2	2	3	2
9	1	2	3	3
10	2	2	4	3
11	2	2	3	2
12	1	2	2	2

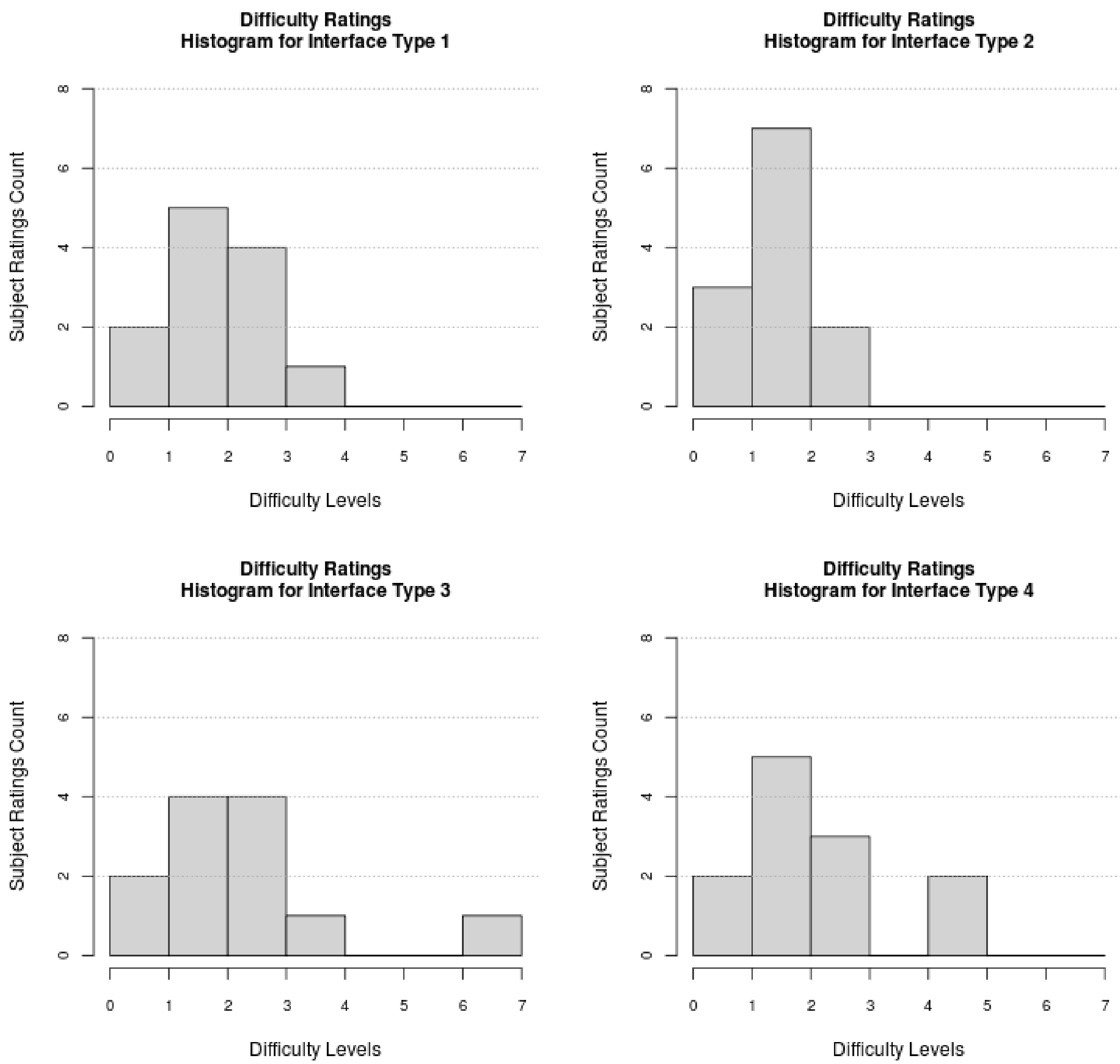


One-way ANOVA: Difficulty vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	4.729	1.576	1.142	0.343
Residuals	44	60.750	1.381		

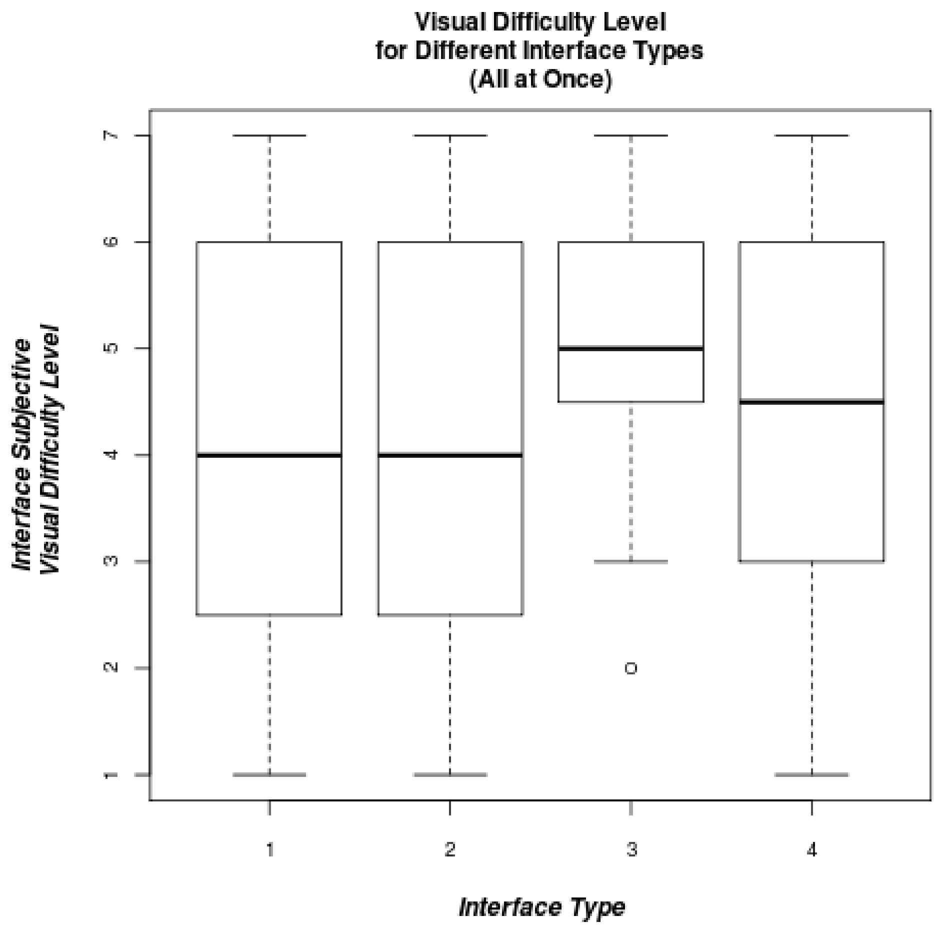
Difficulty vs. Interface Used Friedman test:	
X^2	2.576
p	0.462
DoF	3

Difficulty vs. Interface Used Wicoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	25.500	24.000	22.500	18.000	6.000	12.000
Z	0.937	-0.839	-0.557	-1.340	-1.620	0.636
p	0.438	0.482	0.652	0.241	0.148	0.625
R	0.096	-0.086	-0.057	-0.137	-0.165	0.065

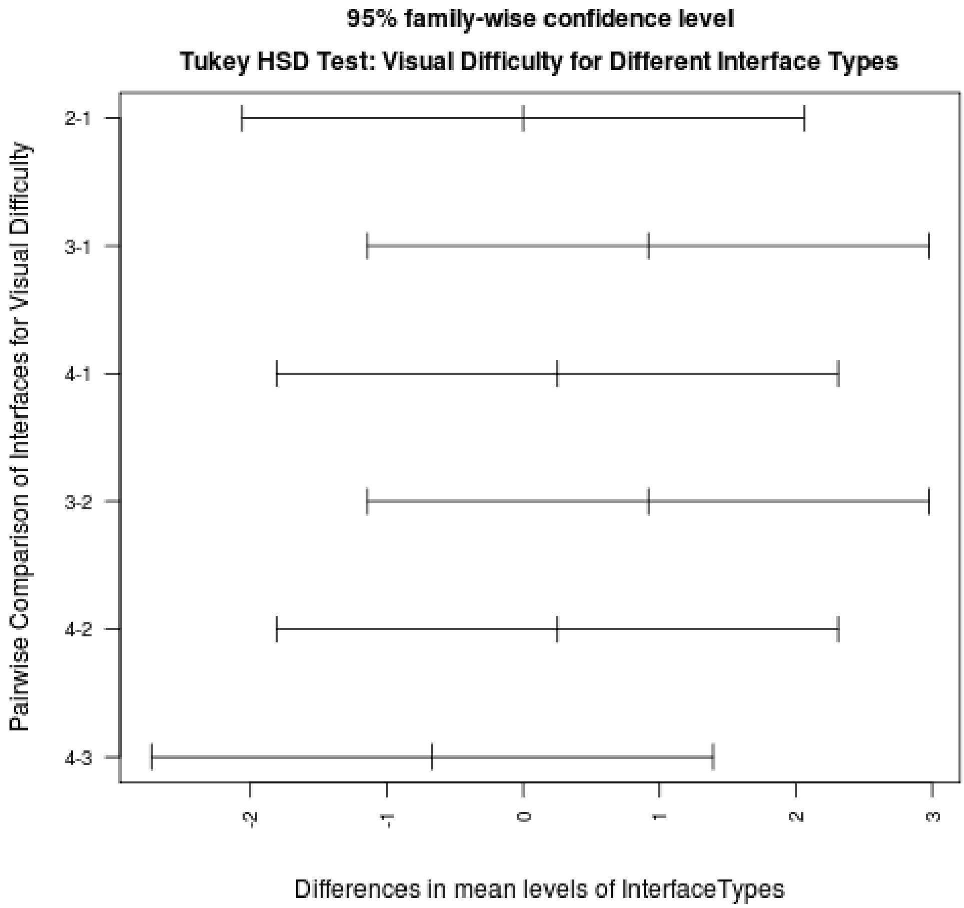
Difficulty vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	2.333	0.888	2.000
2	1.917	0.669	2.000
3	2.750	1.603	2.500
4	2.583	1.311	2.000



D.2.8.2.1 Difficulty: Visual Only



Subject Count	UI1	UI2	UI3	UI4
1	2	2	2	1
2	5	7	5	6
3	4	6	6	7
4	7	6	6	2
5	3	3	4	4
6	4	3	7	3
7	7	6	5	3
8	6	2	6	5
9	2	1	5	5
10	3	6	5	4
11	1	3	3	6
12	6	5	7	7

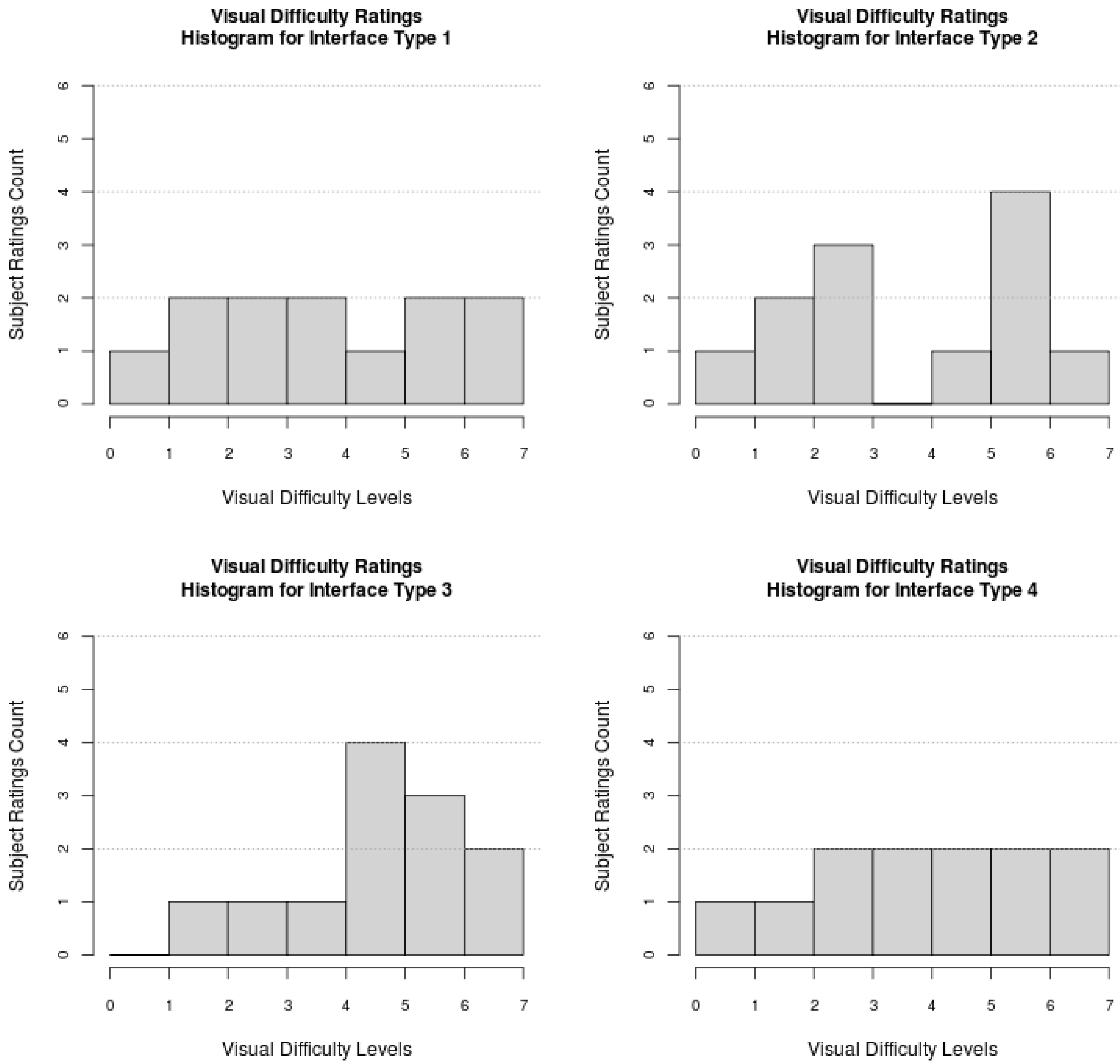


One-way ANOVA: Difficulty Visual vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	6.750	2.250	0.630	0.600
Residuals	44	157.170	3.570		

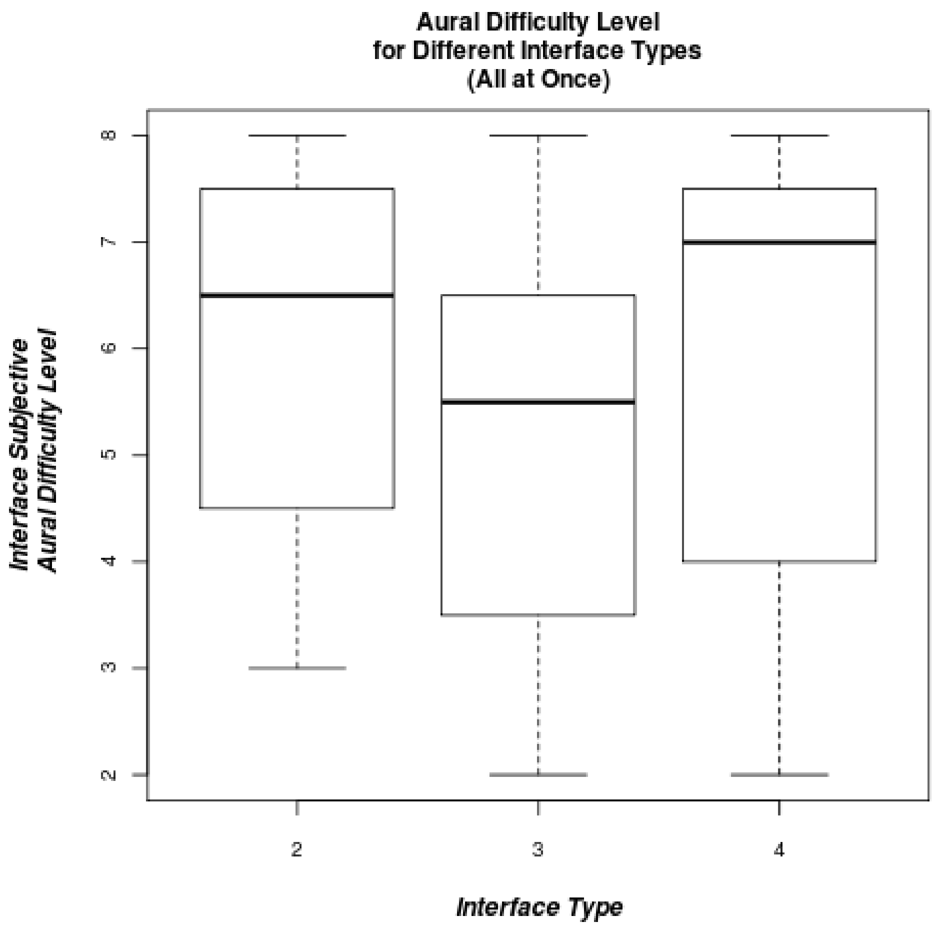
Difficulty Visual vs. Interface Used Friedman test:	
X^2	2.123
p	0.547
DoF	3

Difficulty Visual vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	25	7.5	33.5	8.5	29	32
Z	-0.04	-1.795	-0.441	-1.088	-0.355	1.12
p	1	0.098	0.69	0.32	0.769	0.293
R	-0.004	-0.183	-0.045	-0.111	-0.036	0.114

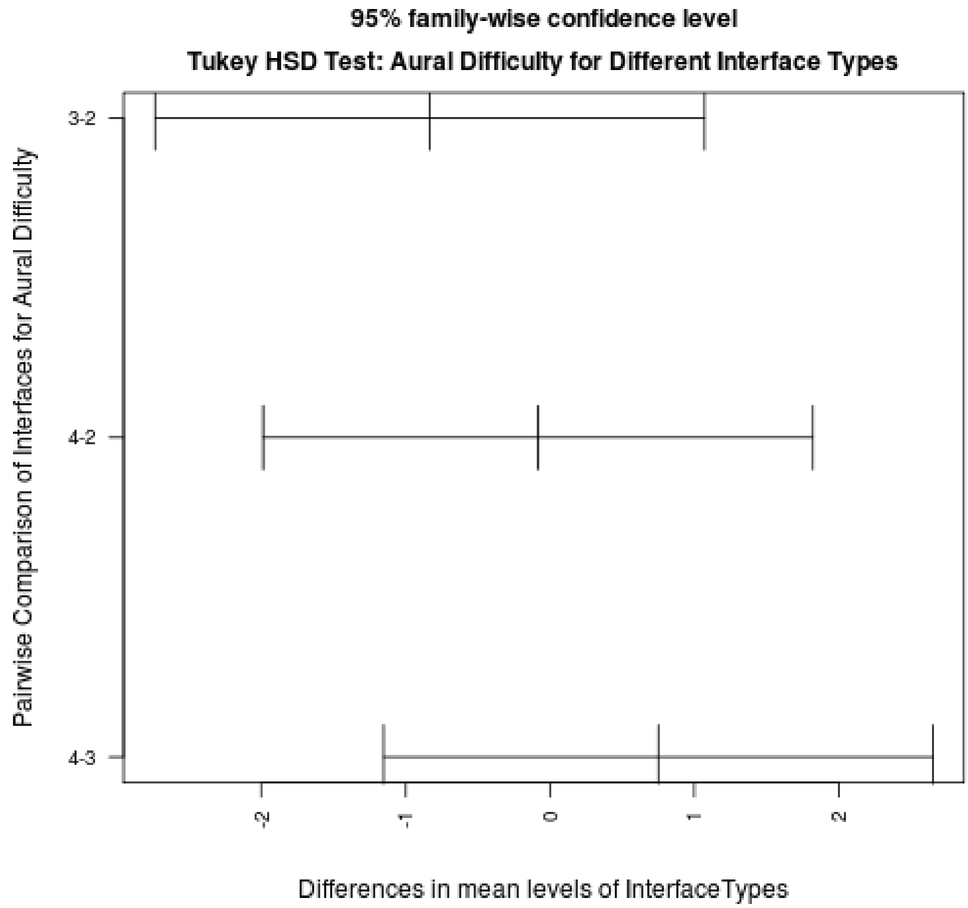
Difficulty Visual vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	4.167	2.038	4.000
2	4.167	2.038	4.000
3	5.083	1.505	5.000
4	4.417	1.929	4.500



D.2.8.2.2 Difficulty: Aural Only



Subject Count	UI1	UI2	UI3	UI4
1		4	5	2
2		6	3	7
3		6	6	4
4		7	8	6
5		8	8	4
6		5	3	7
7		7	4	4
8		4	6	8
9		3	7	8
10		8	5	7
11		7	2	7
12		8	6	8

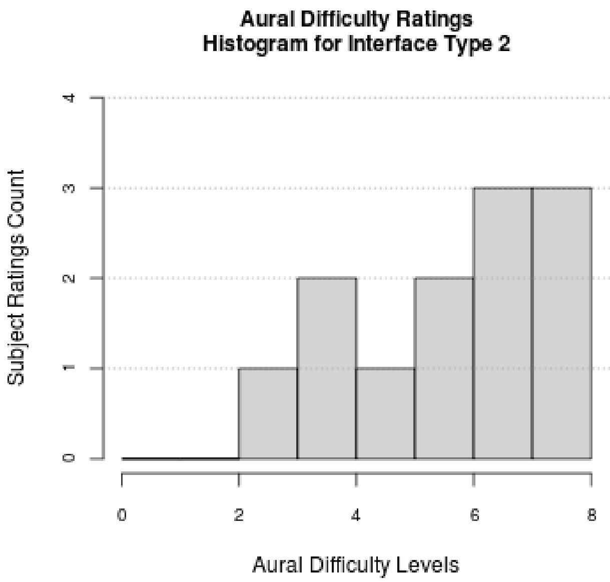


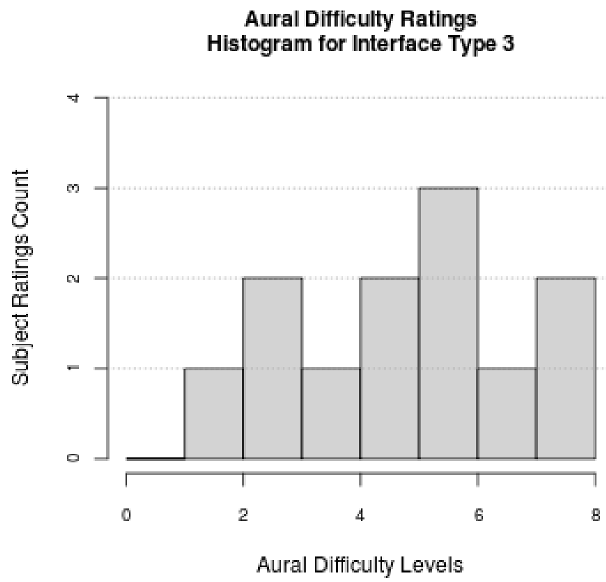
One-way ANOVA: Difficulty Aural vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	2	5.056	2.5278	0.7	0.5038
Residuals	33	119.167	3.6111		

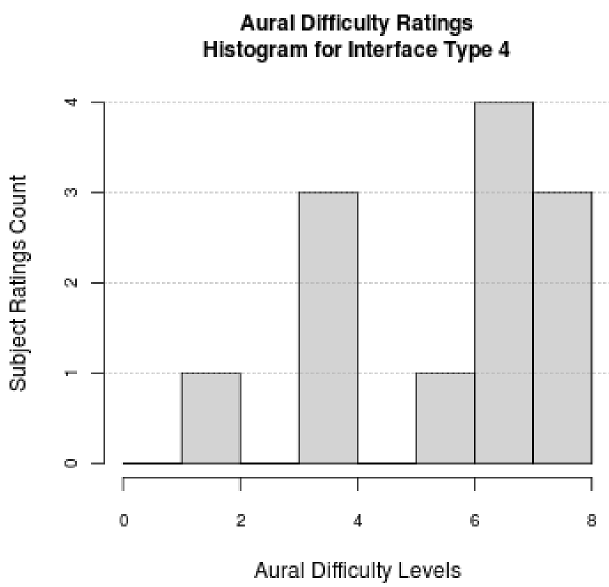
Difficulty Aural vs. Interface Used Friedman test:	
X^2	0.977
p	0.614
DoF	2

Difficulty Aural vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W				39.000	29.500	24.000
Z				1.067	0.316	-0.832
p				0.301	0.779	0.446
R				0.109	0.032	-0.085

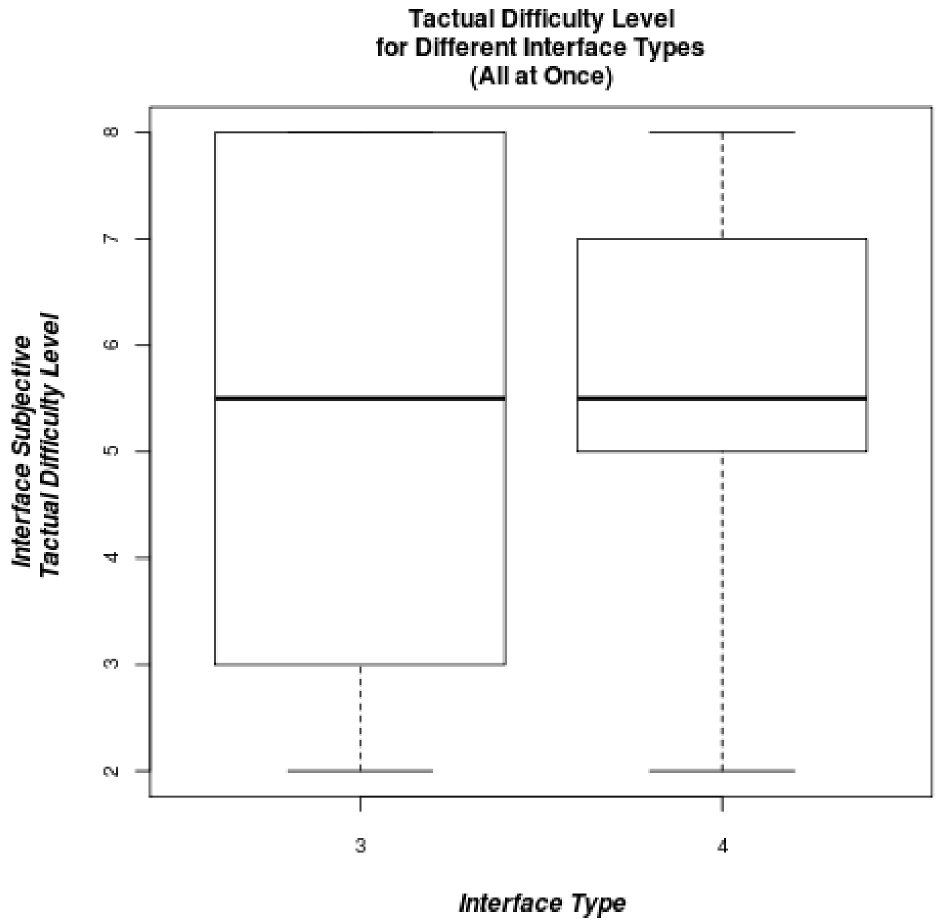
Difficulty Aural vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1			
2	6.083	1.730	6.500
3	5.250	1.960	5.500
4	6.000	2.000	7.000



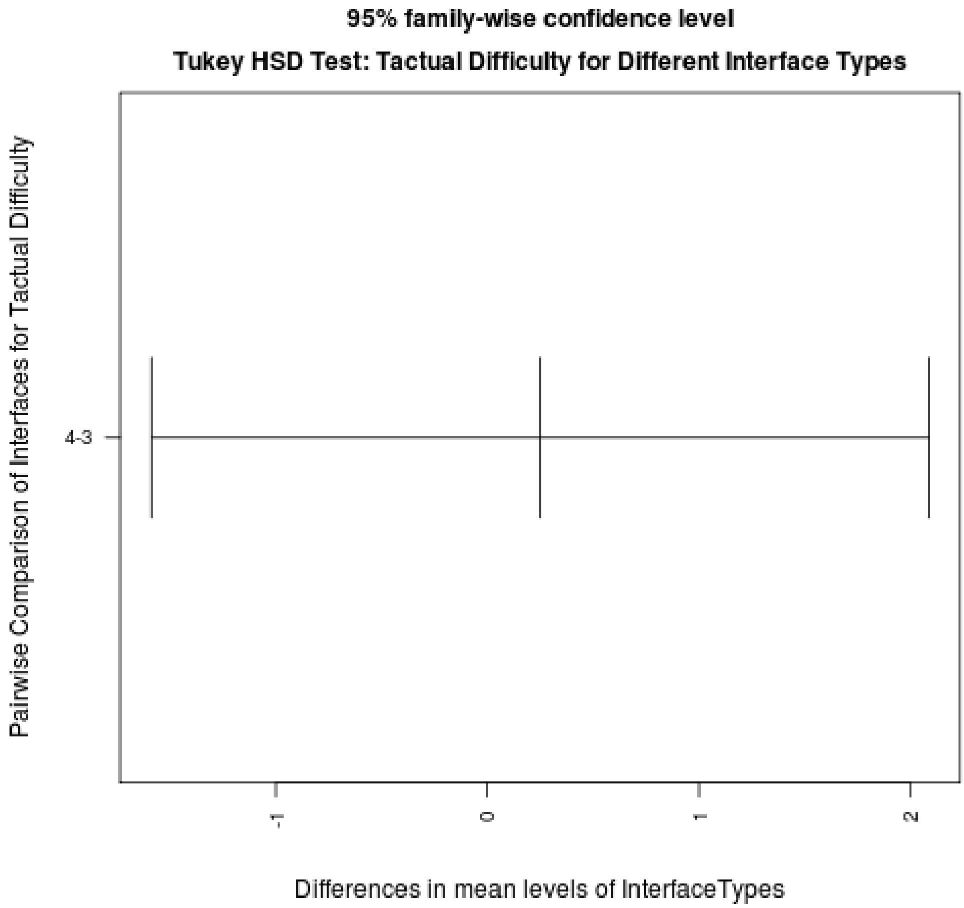




D.2.8.2.3 Difficulty: Tactual Only



Subject Count	UI1	UI2	UI3	UI4
1			4	8
2			2	7
3			8	5
4			8	5
5			8	2
6			7	3
7			4	8
8			3	5
9			8	5
10			7	6
11			3	7
12			3	7

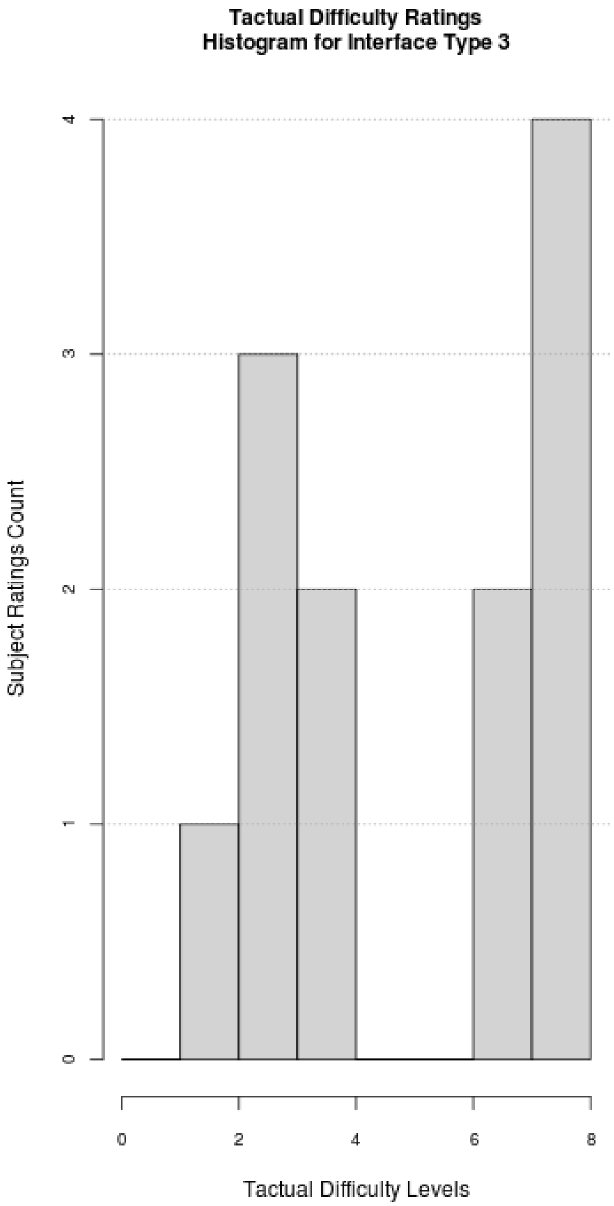


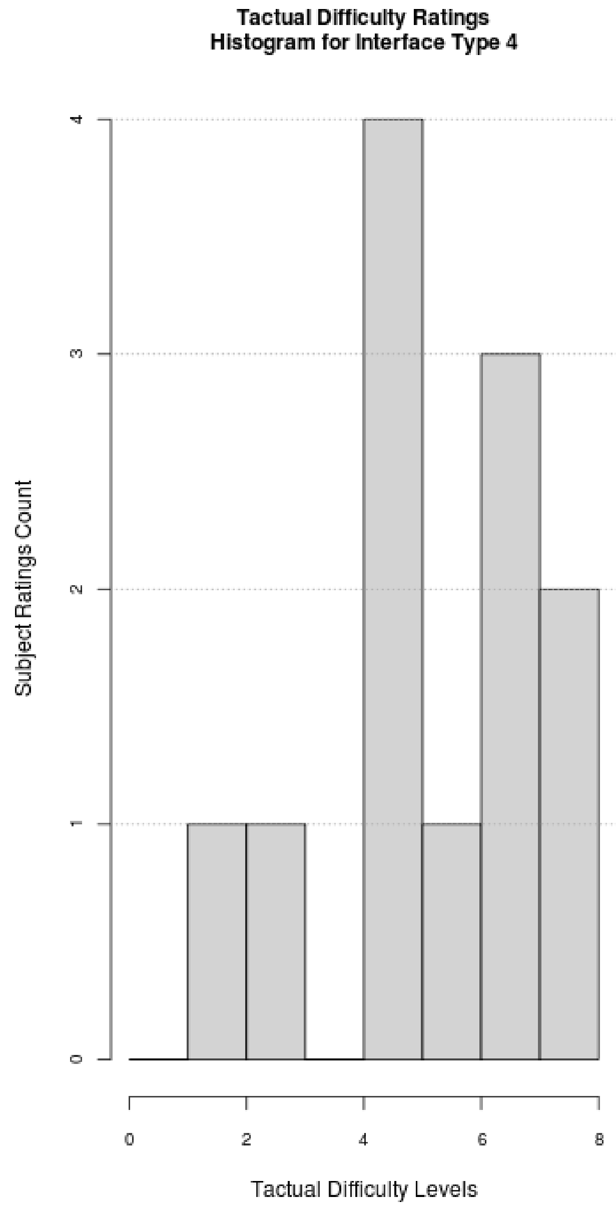
One-way ANOVA: Difficulty Tactual vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	0.375	0.375	0.080	0.780
Residuals	22	103.583	4.708		

Difficulty Tactual vs. Interface Used Friedman test:	
X^2	0.000
p	1.000
DoF	1

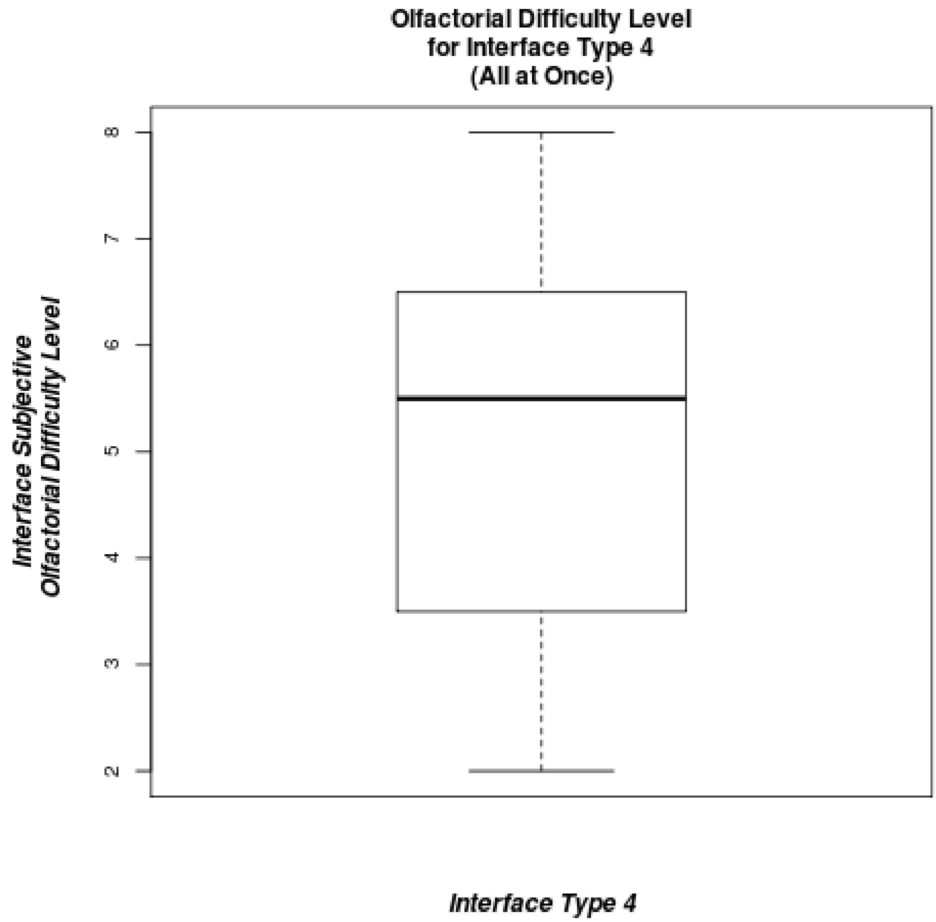
Difficulty Tactual vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W						33.000
Z						-0.475
p						0.674
R						-0.048

Difficulty Tactual vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1			
2			
3	5.417	2.429	5.500
4	5.667	1.875	5.500

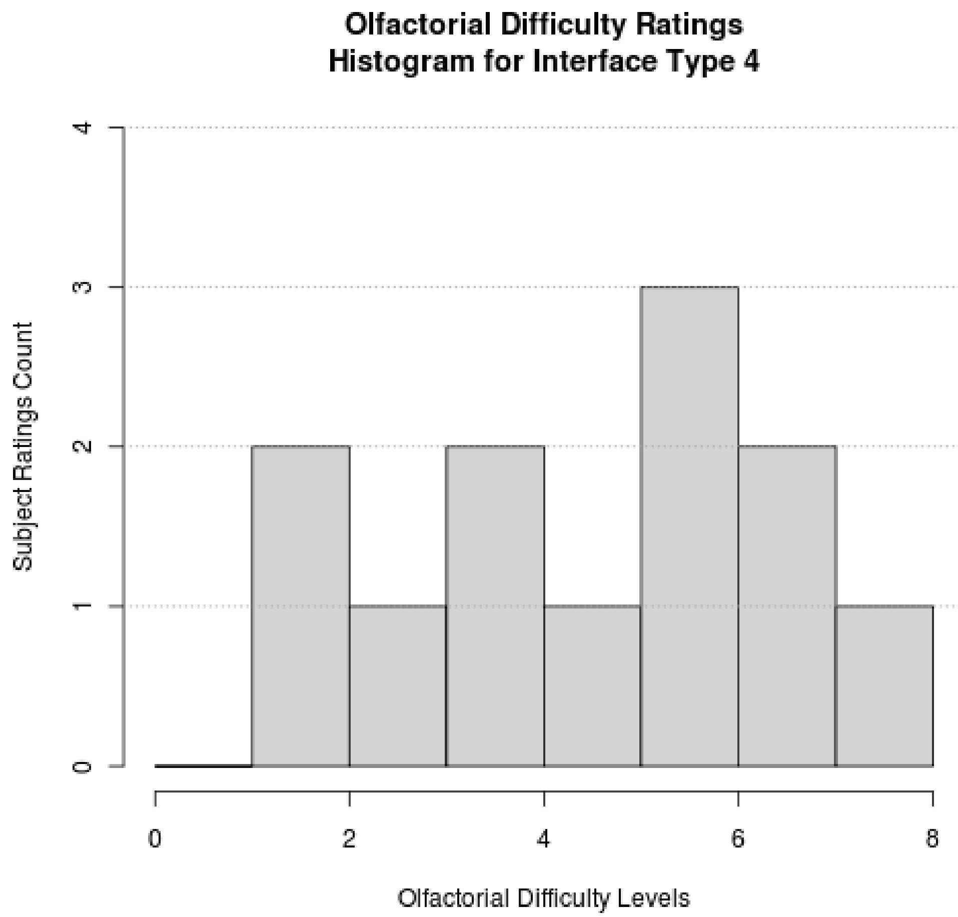




D.2.8.2.4 Difficulty: Olfactorial Only

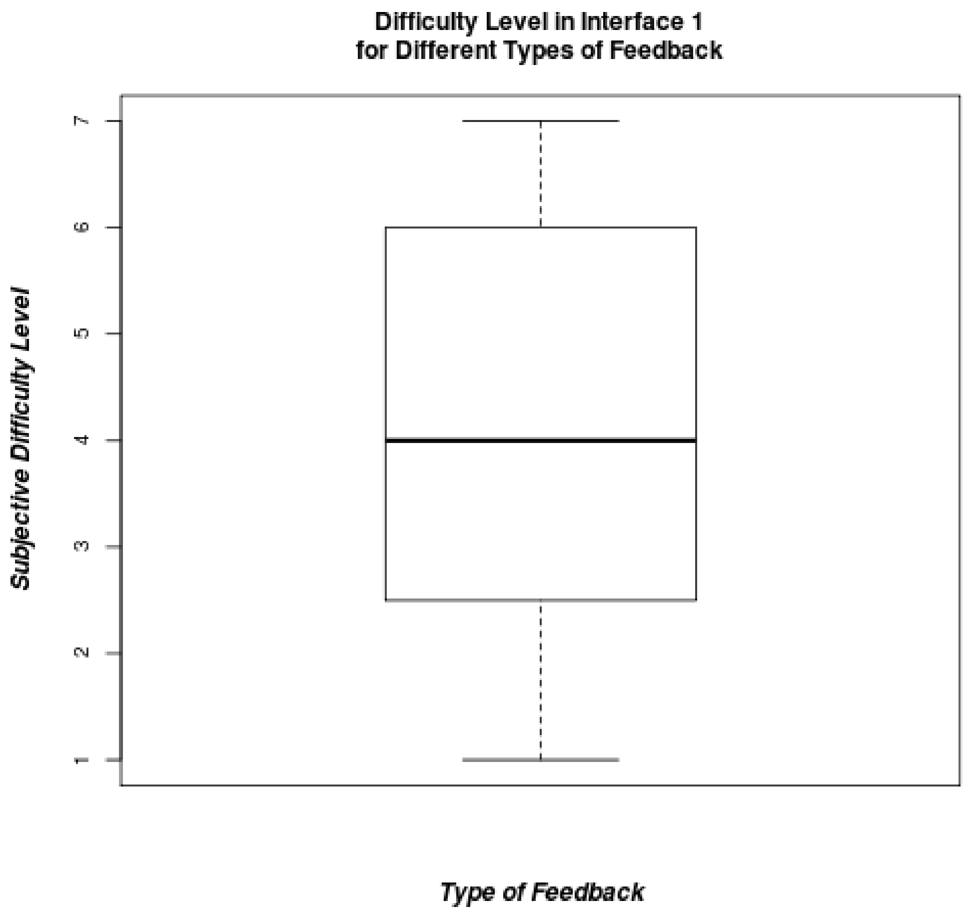


Subject Count	UI1	UI2	UI3	UI4
1				6
2				7
3				4
4				4
5				8
6				3
7				2
8				6
9				5
10				6
11				2
12				7

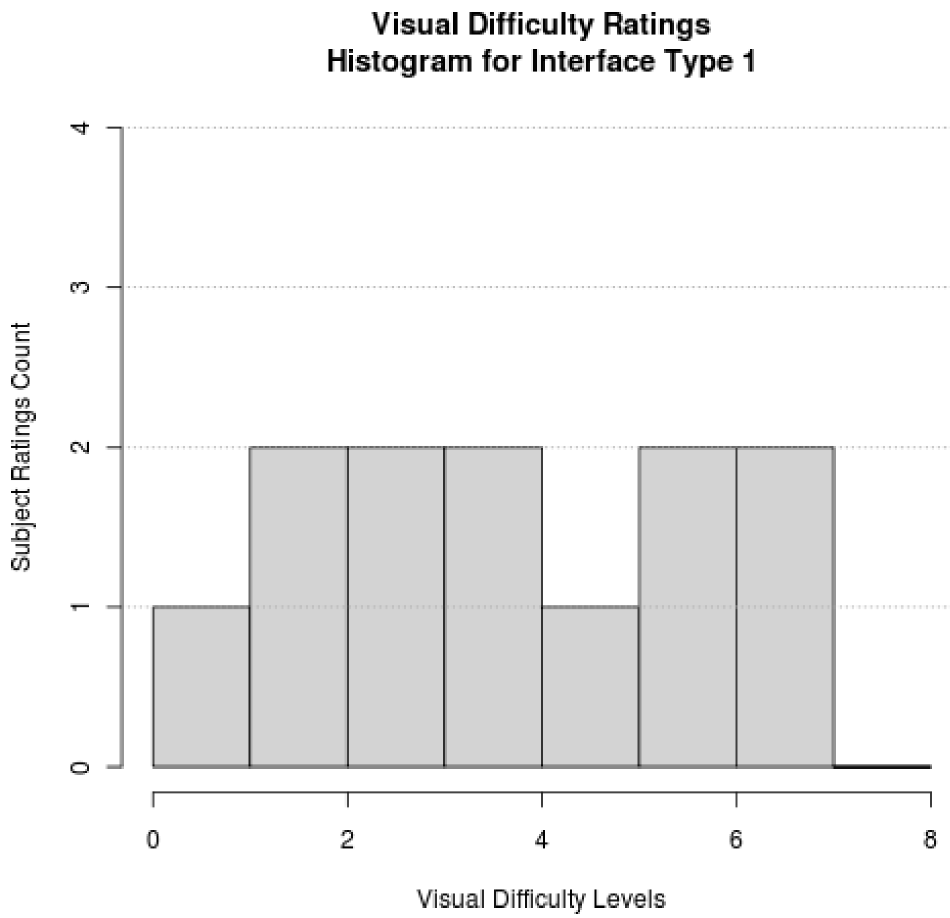


Difficulty Olfactorial vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1			
2			
3			
4	5.000	2.000	5.500

D.2.8.2.5 Difficulty Ratings for Each Type of Feedback: Interface 1

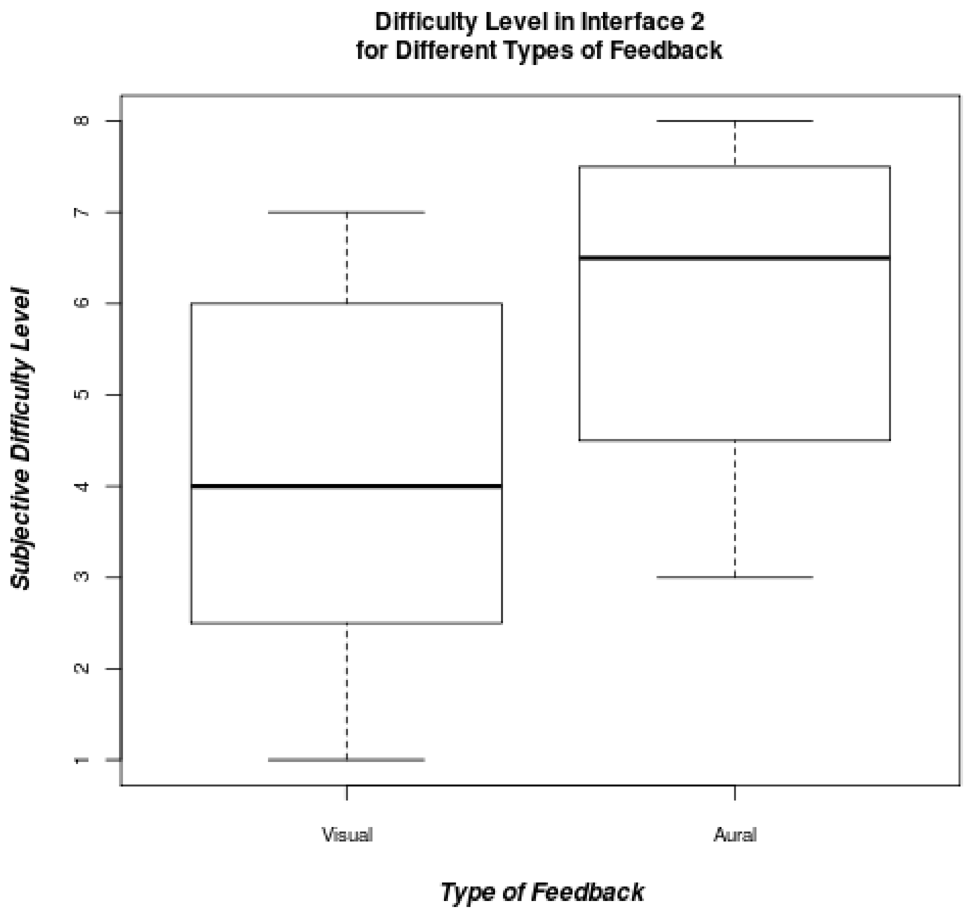


Subject Count	Visual	Aural	Tactual	Olfactorial
1	2			
2	5			
3	4			
4	7			
5	3			
6	4			
7	7			
8	6			
9	2			
10	3			
11	1			
12	6			

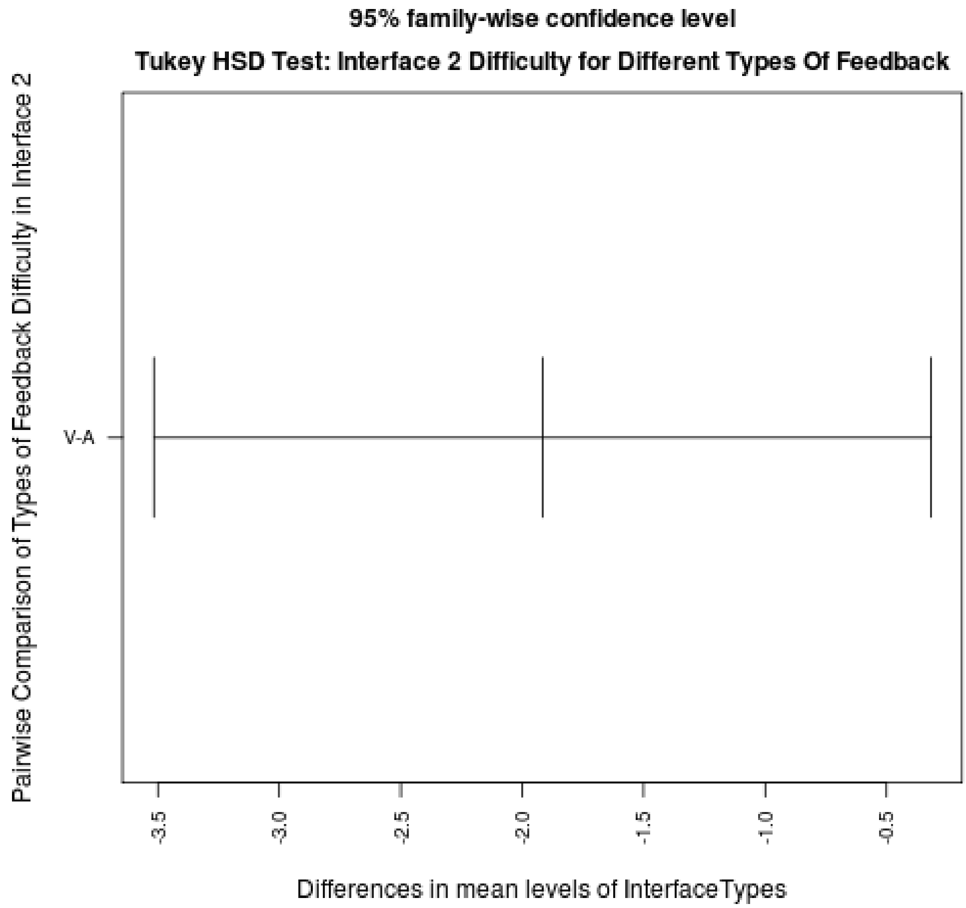


Difficulty vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	4.167	2.038	4.000
Aural			
Tactual			
Olfactorial			

D.2.8.2.6 Difficulty Ratings for Each Type of Feedback: Interface 2



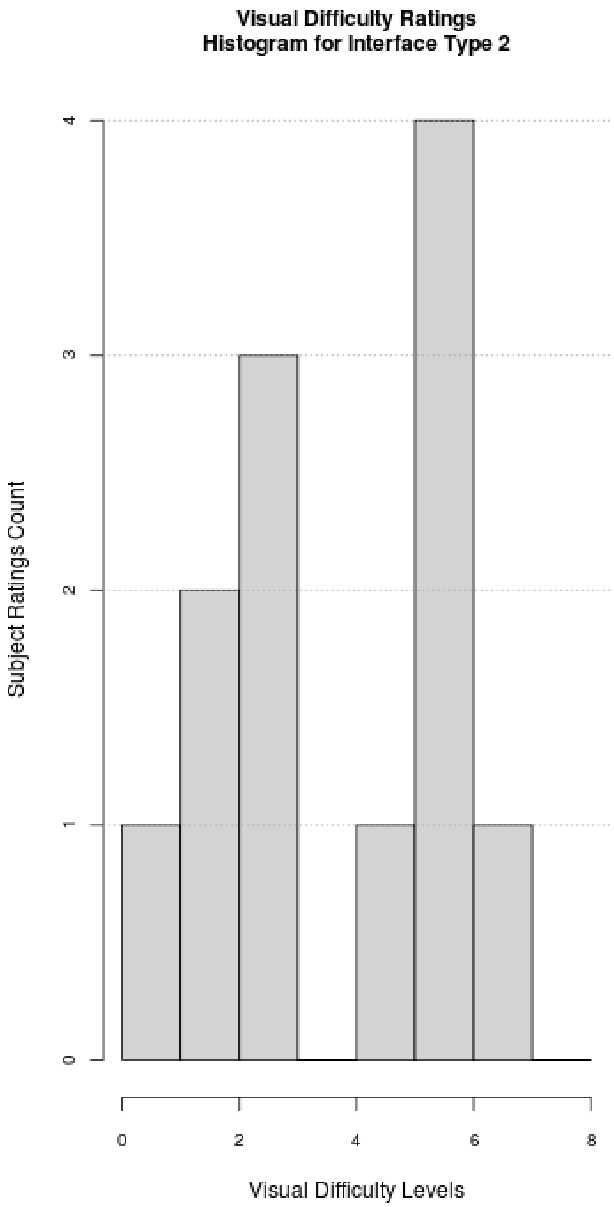
Subject Count	Visual	Aural	Tactual	Olfactorial
1	2	4		
2	7	6		
3	6	6		
4	6	7		
5	3	8		
6	3	5		
7	6	7		
8	2	4		
9	1	3		
10	6	8		
11	3	7		
12	5	8		

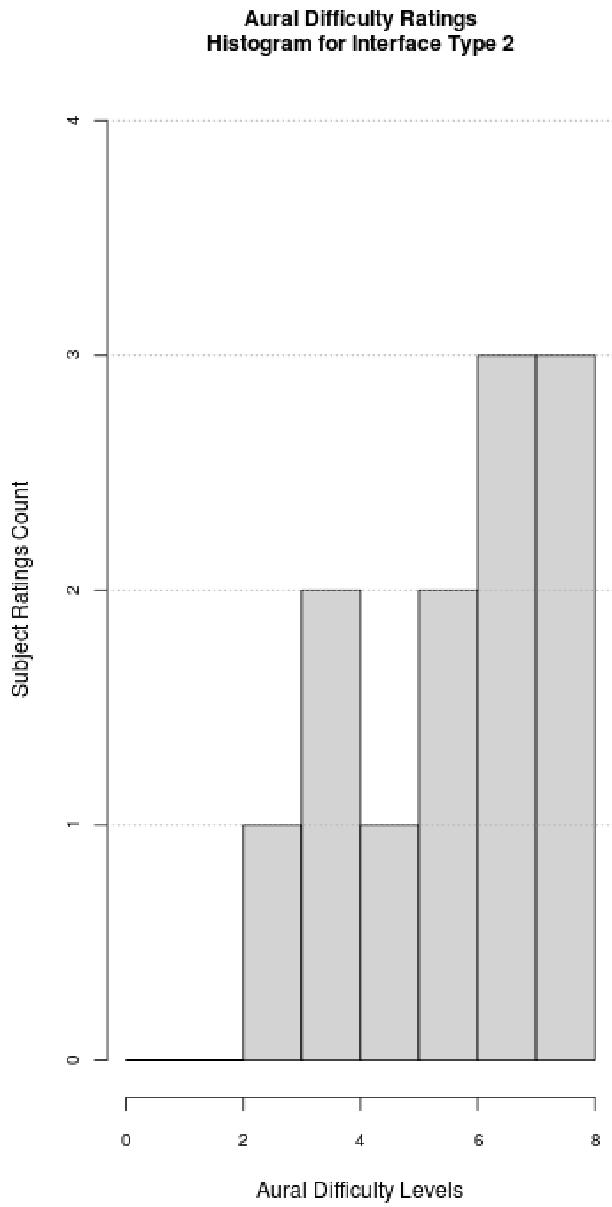


One-way ANOVA: Difficulty vs. Type of Feedback					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	22.042	22.042	6.171	0.021
Residuals	22	78.583	3.572		

Difficulty vs. Type of Feedback Friedman test:	
X^2	7.364
p	0.007
DoF	1

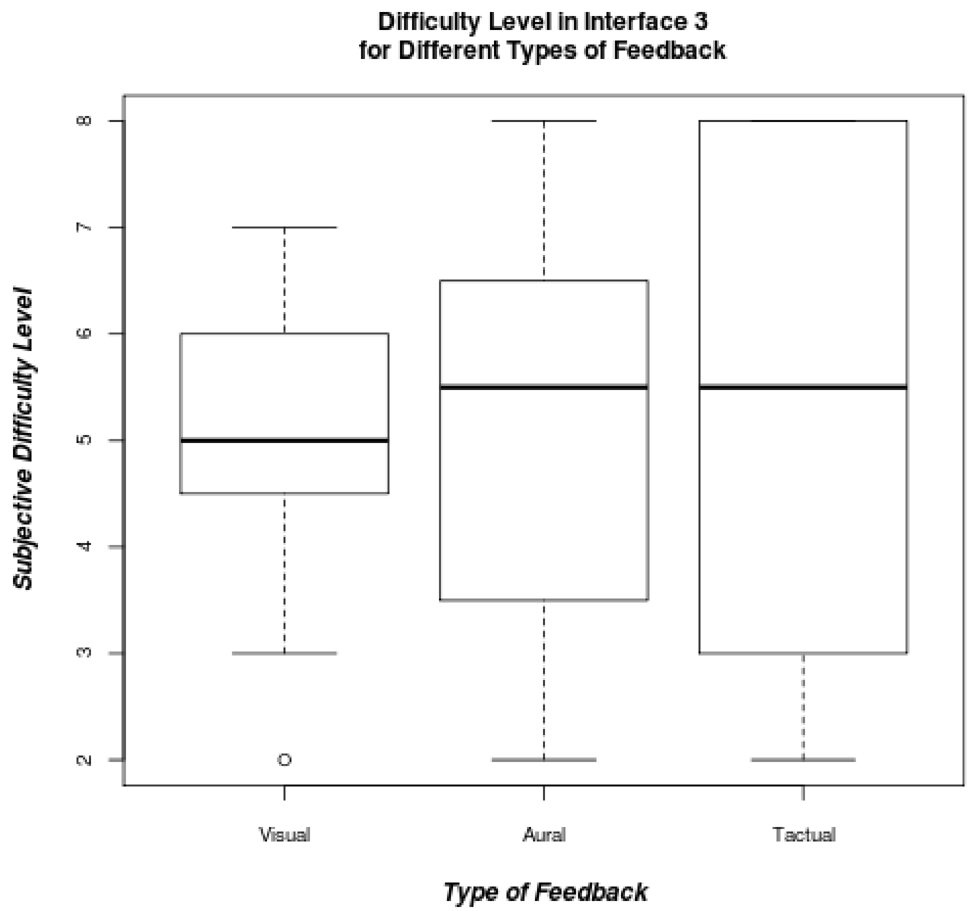
Difficulty vs. Type of Feedback Wilcoxon test:						
	Visual – Aural	**Visual – Tactual**	**Visual – Olfact.**	**Aural – Tactual**	**Aural – Olfact.**	**Tactual – Olfact.**
W	2.000					
Z	-2.813					
p	0.004					
R	-0.287					



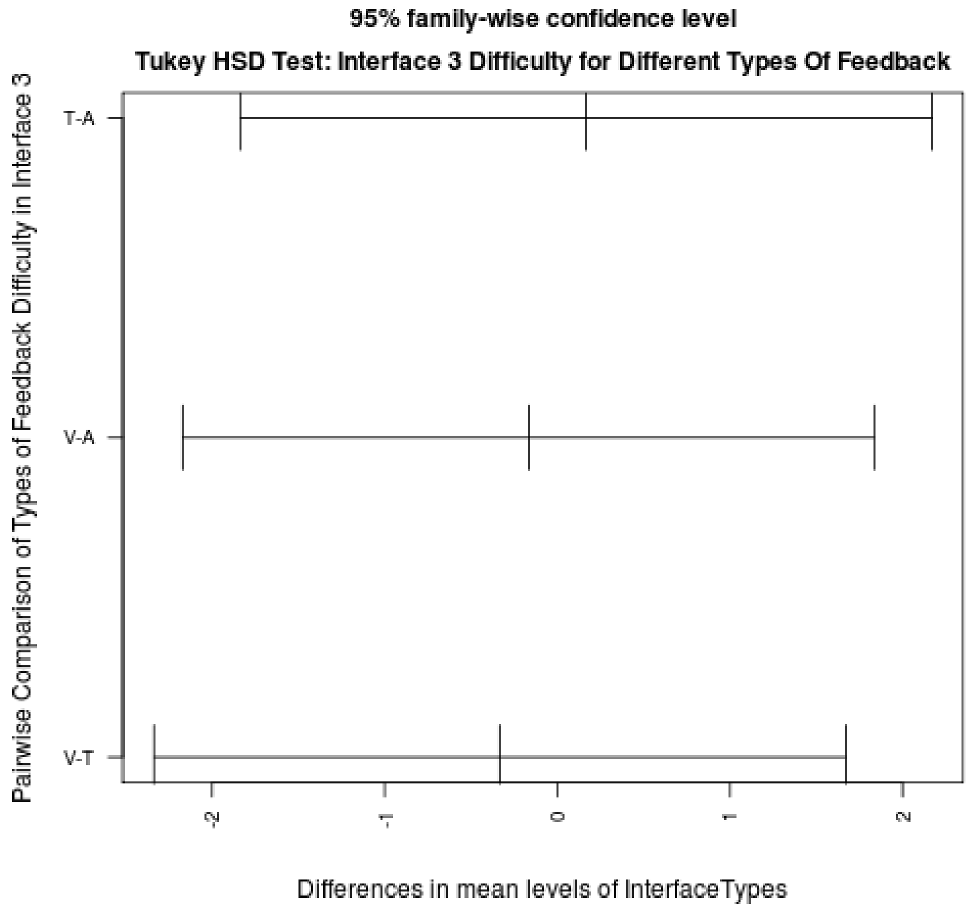


Difficulty vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	4.167	2.038	4.000
Aural	6.083	1.730	6.500
Tactual			
Olfactorial			

D.2.8.2.7 Difficulty Ratings for Each Type of Feedback: Interface 3



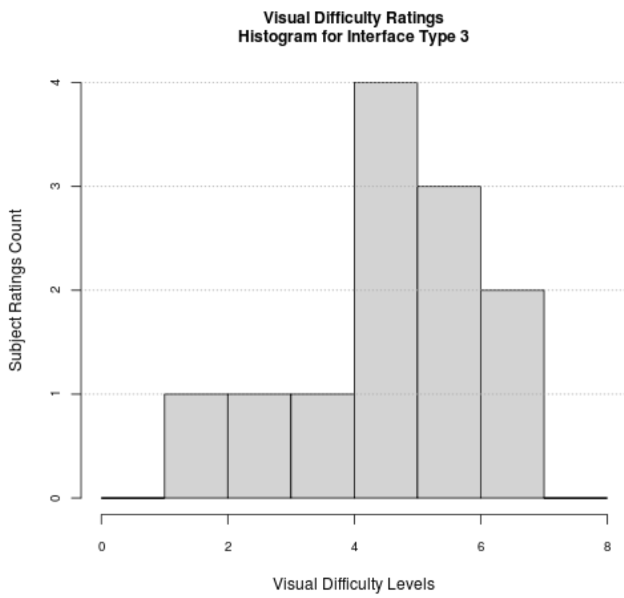
Subject Count	Visual	Aural	Tactual	Olfactorial
1	2	5	4	
2	5	3	2	
3	6	6	8	
4	6	8	8	
5	4	8	8	
6	7	3	7	
7	5	4	4	
8	6	6	3	
9	5	7	8	
10	5	5	7	
11	3	2	3	
12	7	6	3	

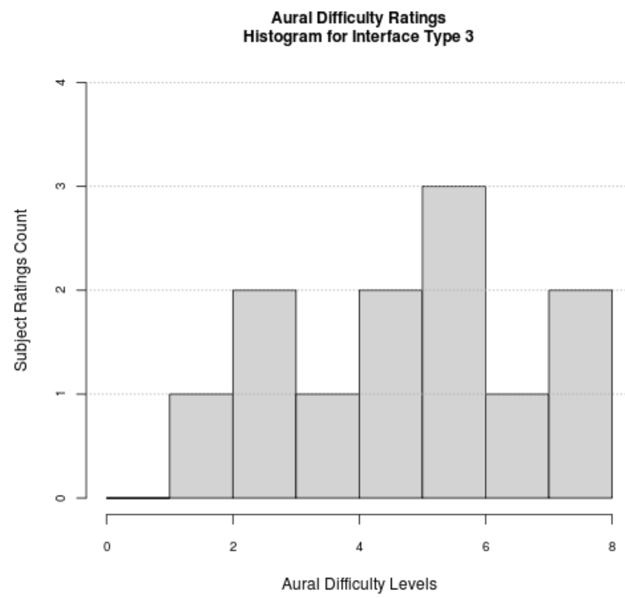


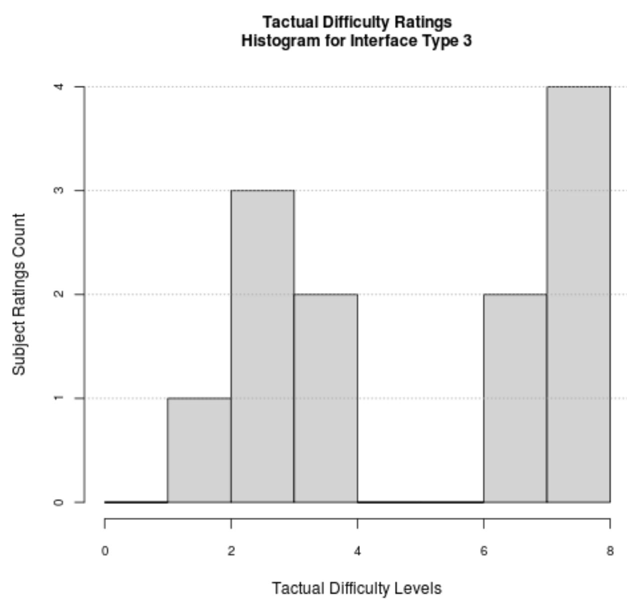
One-way ANOVA: Difficulty vs. Type of Feedback					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	2	0.667	0.333	0.083	0.920
Residuals	33	132.083	4.003		

Difficulty vs. Type of Feedback Friedman test:	
X^2	0.350
p	0.839
DoF	2

Difficulty vs. Type of Feedback Wilcoxon test:						
	Visual – Aural	**Visual – Tactual**	**Visual – Olfact.**	**Aural – Tactual**	**Aural – Olfact.**	**Tactual – Olfact.**
W	19.500	24.500		20.000		
Z	-0.119	-0.396		-0.319		
p	0.957	0.738		0.781		
R	-0.012	-0.040		-0.033		

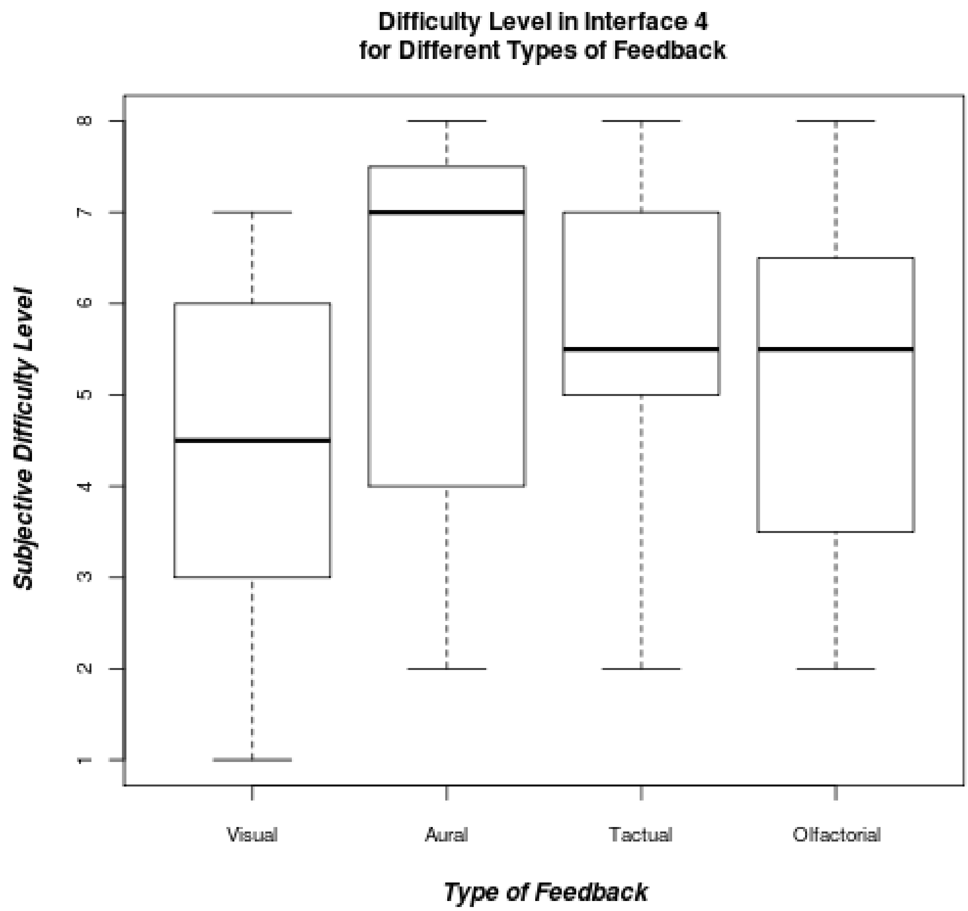




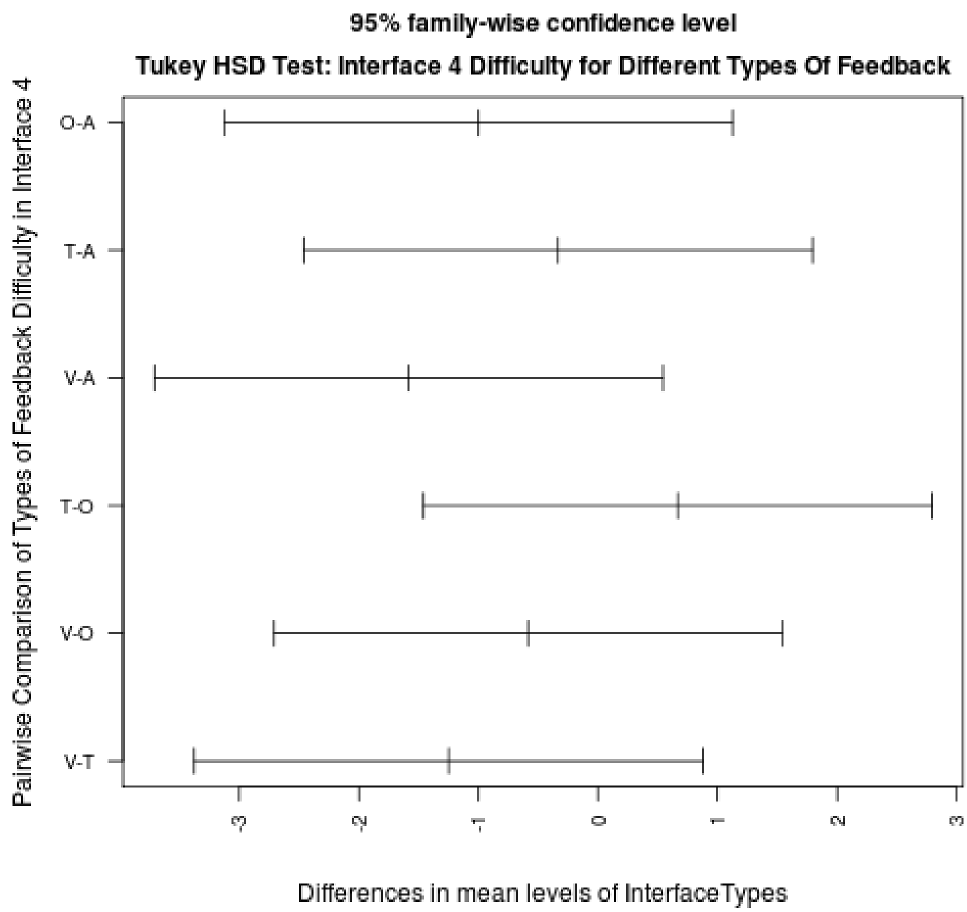


Difficulty vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	5.083	1.505	5.000
Aural	5.250	1.960	5.500
Tactual	5.417	2.429	5.500
Olfactorial			

D.2.8.2.8 Difficulty Ratings for Each Type of Feedback: Interface 4



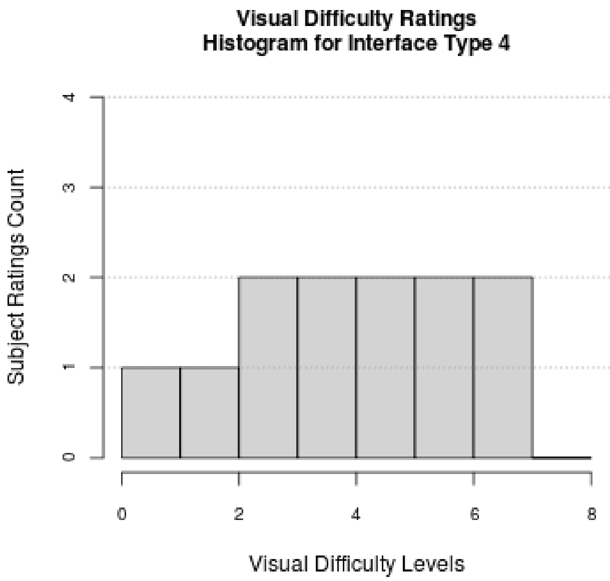
Subject Count	Visual	Aural	Tactual	Olfactorial
1	1	2	8	6
2	6	7	7	7
3	7	4	5	4
4	2	6	5	4
5	4	4	2	8
6	3	7	3	3
7	3	4	8	2
8	5	8	5	6
9	5	8	5	5
10	4	7	6	6
11	6	7	7	2
12	7	8	7	7

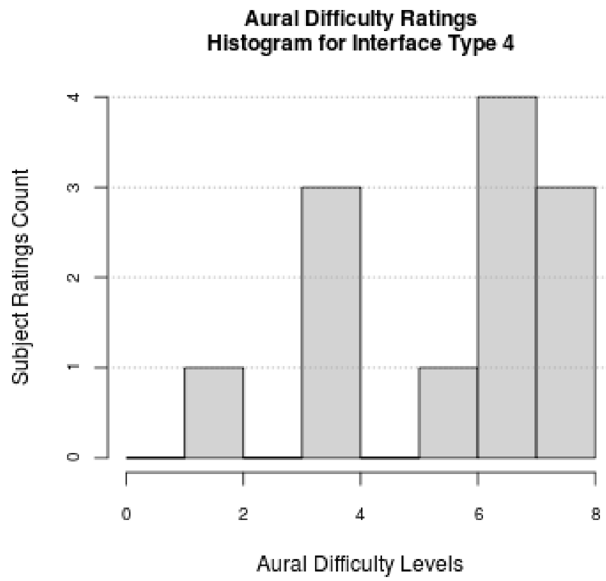


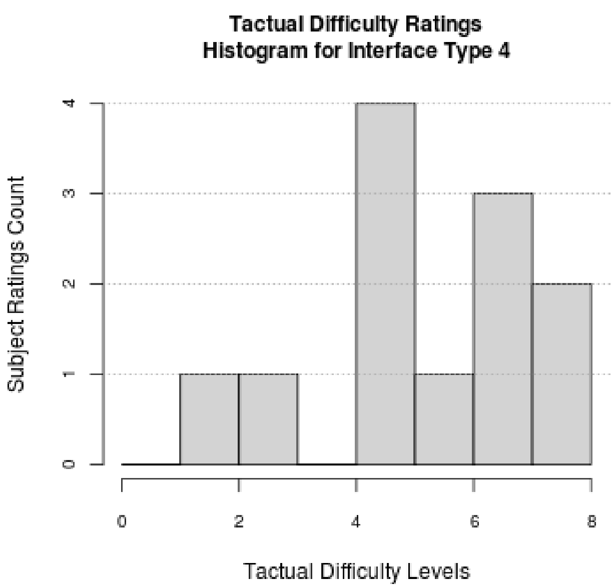
One-way ANOVA: Difficulty vs. Type of Feedback					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	f	5.965	1.566	0.211
Residuals	44	167.583	3.809		

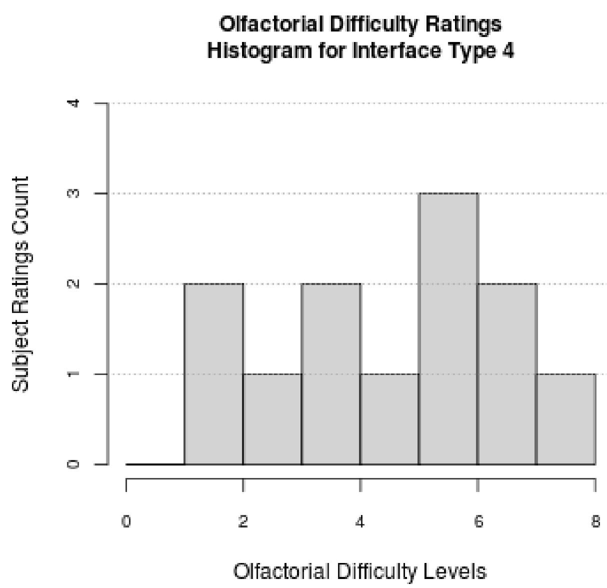
Difficulty vs. Type of Feedback Friedman test:	
X^2	10.03
p	0.018
DoF	3

Difficulty vs. Type of Feedback Wilcoxon test:						
	Visual – Aural	**Visual – Tactual**	**Visual – Olfact.**	**Aural – Tactual**	**Aural – Olfact.**	**Tactual – Olfact.**
W	7.500	8.000	15.500	34.000	39.000	19.500
Z	-2.384	-1.449	-0.914	0.831	1.383	1.068
p	0.020	0.164	0.398	0.428	0.191	0.359
R	-0.243	-0.148	-0.093	0.085	0.141	0.109



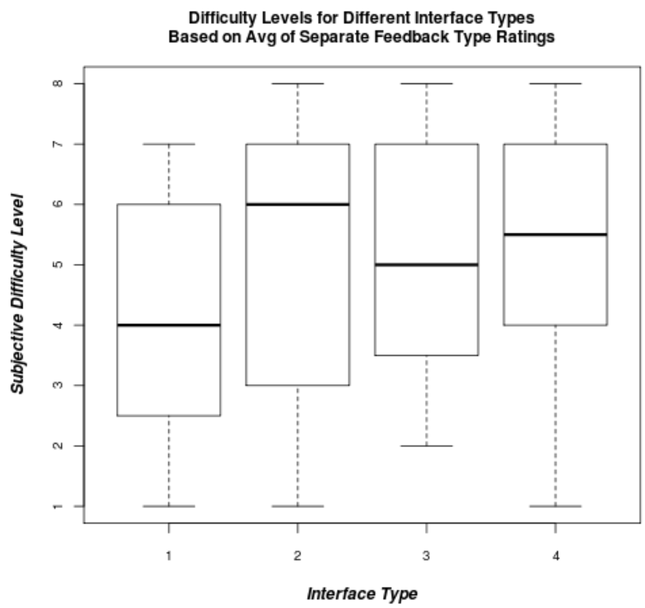


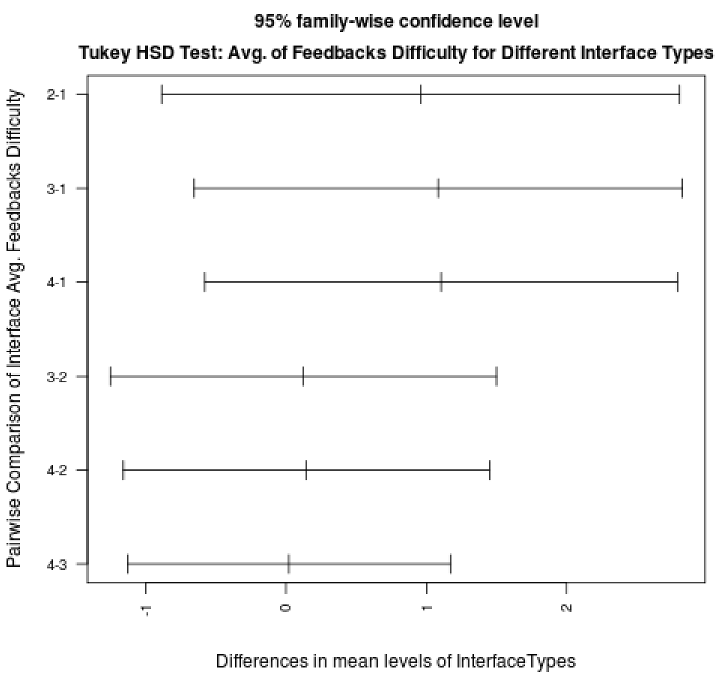




Difficulty vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	4.417	1.929	4.500
Aural	6.000	2.000	7.000
Tactual	5.667	1.875	5.500
Olfactorial	5.000	2.000	5.500

D.2.8.2.9 Overall Interface Difficulty – Average of Individual Feedback Ratings

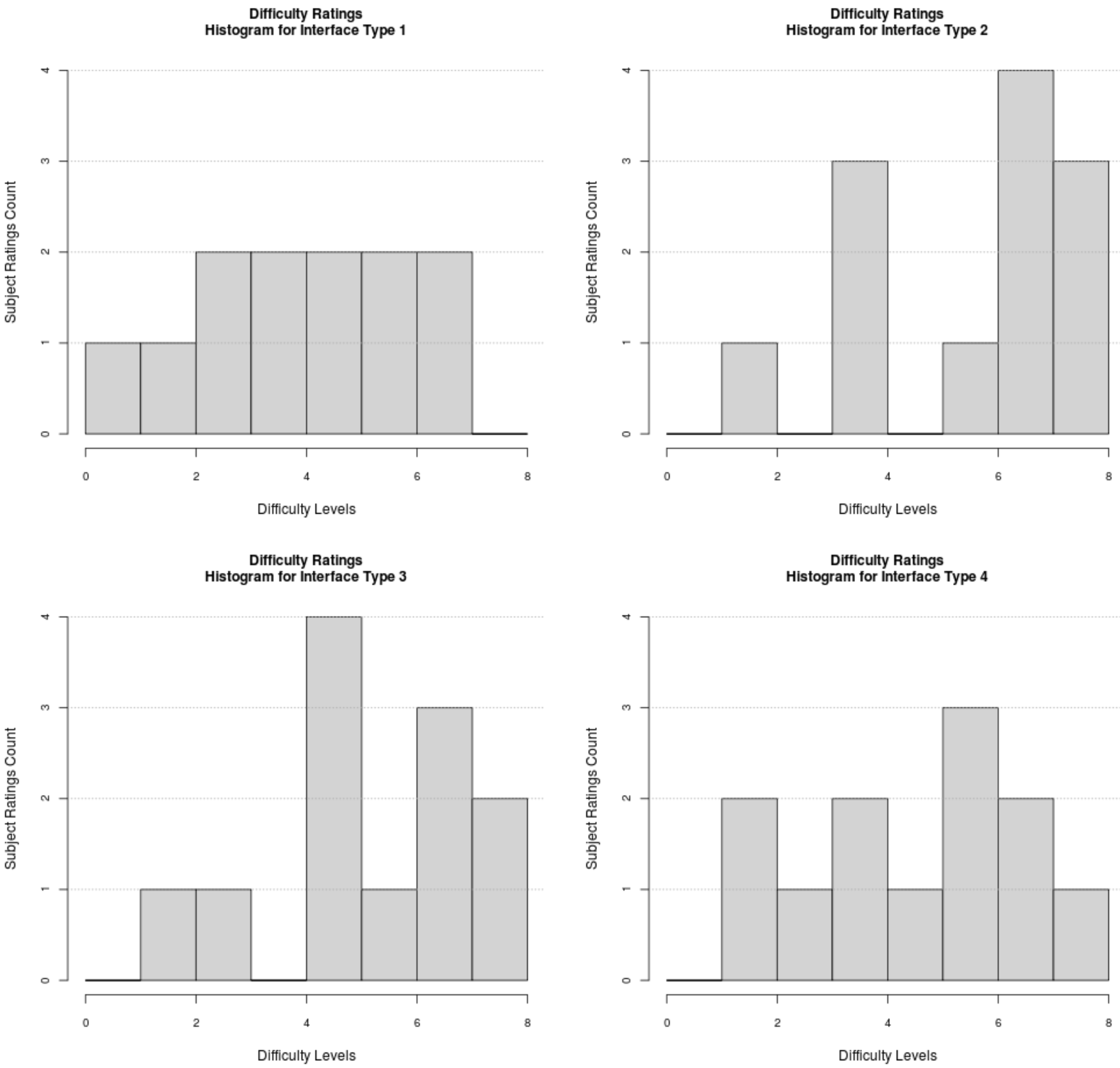




Avg. of Feedbacks Difficulty vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	4.167	2.038	4.000
2	5.125	2.092	6.000
3	5.250	1.948	5.000
4	5.271	1.987	5.500

Subject Count	UI1	UI2	UI3	UI4
1	2	2	2	1
2	5	7	5	6
3	4	6	6	7
4	7	6	6	2
5	3	3	4	4
6	4	3	7	3
7	7	6	5	3
8	6	2	6	5
9	2	1	5	5
10	3	6	5	4
11	1	3	3	6
12	6	5	7	7
13		4	5	2
14		6	3	7
15		6	6	4
16		7	8	6
17		8	8	4
18		5	3	7
19		7	4	4
20		4	6	8
21		3	7	8
22		8	5	7
23		7	2	7
24		8	6	8
25			4	8
26			2	7
27			8	5
28			8	5
29			8	2
30			7	3
31			4	8
32			3	5
33			8	5
34			7	6
35			3	7
36			3	7
37				6
38				7
39				4
40				4
41				8
42				3
43				2
44				6
45				5
46				6
47				2
48				7

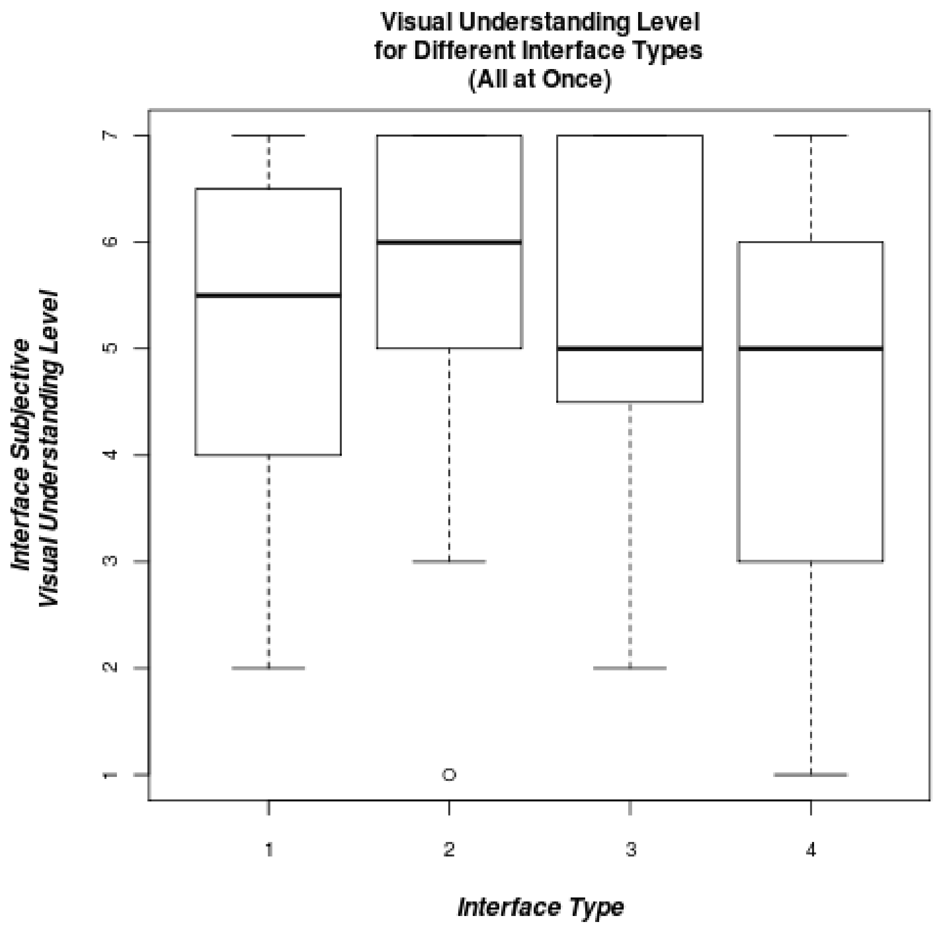
One-way ANOVA: Avg. of Feedbacks Difficulty vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	12.600	4.201	1.049	0.374
Residuals	116	464.520	4.005		



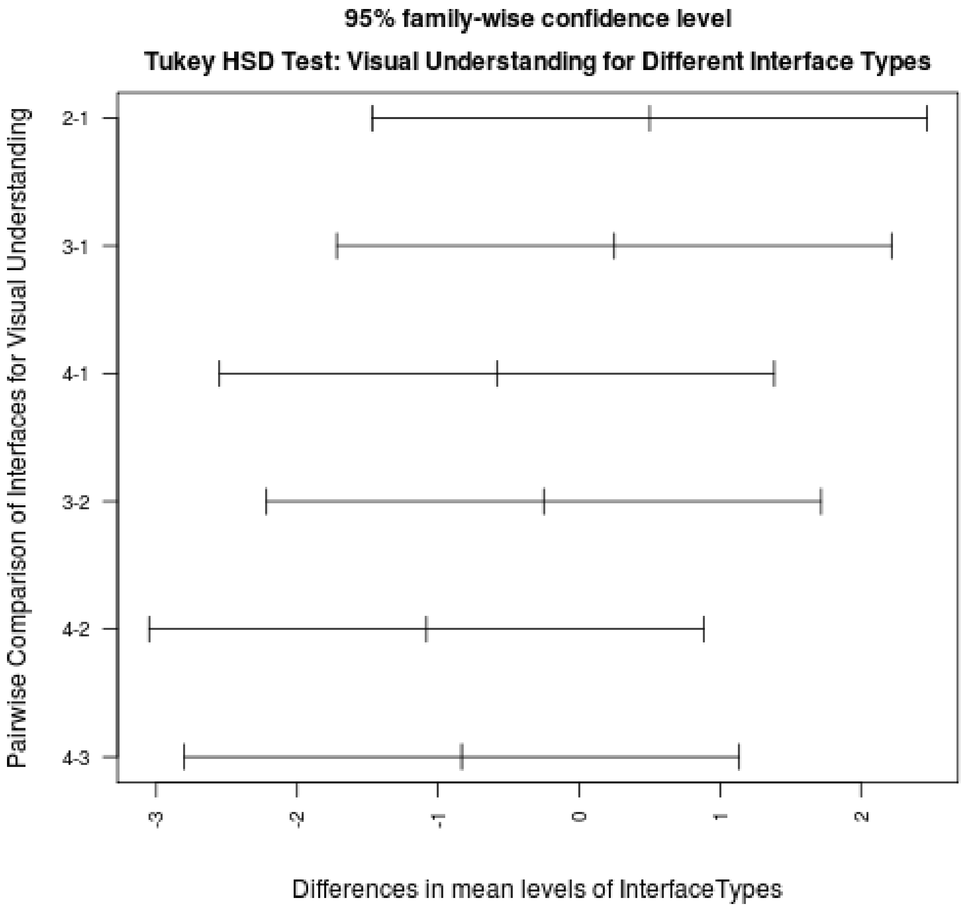
Avg. of Feedbacks Difficulty vs. Interface Used Friedman test:	
X^2	2.123
p	0.547
DoF	3

D.2.8.3 Understanding

D.2.8.3.1 Understanding: Visual Only



Subject Count	UI1	UI2	UI3	UI4
1	6	1	2	1
2	5	7	5	6
3	2	5	5	7
4	7	7	6	2
5	6	5	4	5
6	7	6	7	5
7	7	7	7	3
8	5	7	4	5
9	3	6	7	3
10	5	7	5	4
11	2	3	5	7
12	6	6	7	6

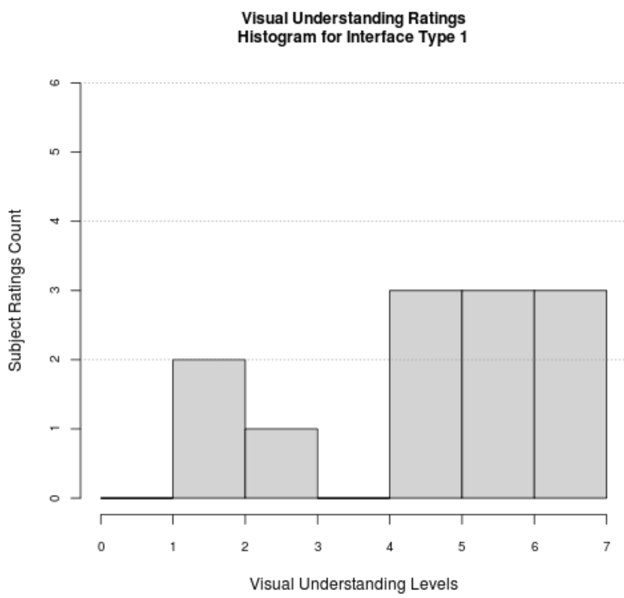


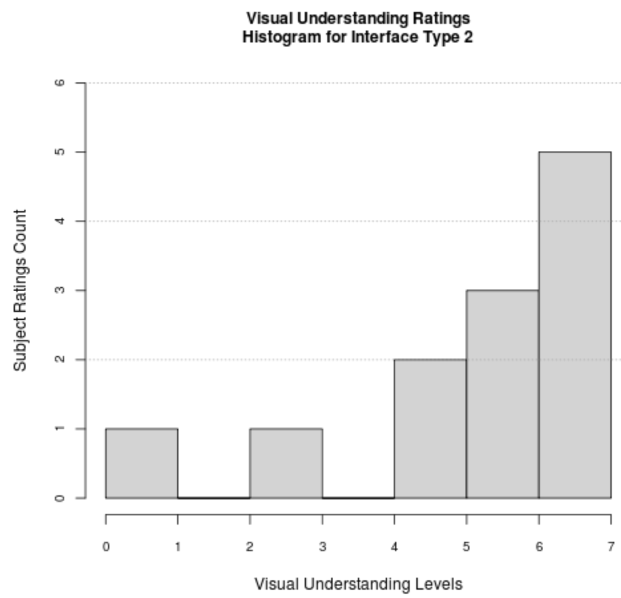
One-way ANOVA: Understanding Visual vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	7.750	2.583	0.792	0.505
Residuals	44	143.500	3.261		

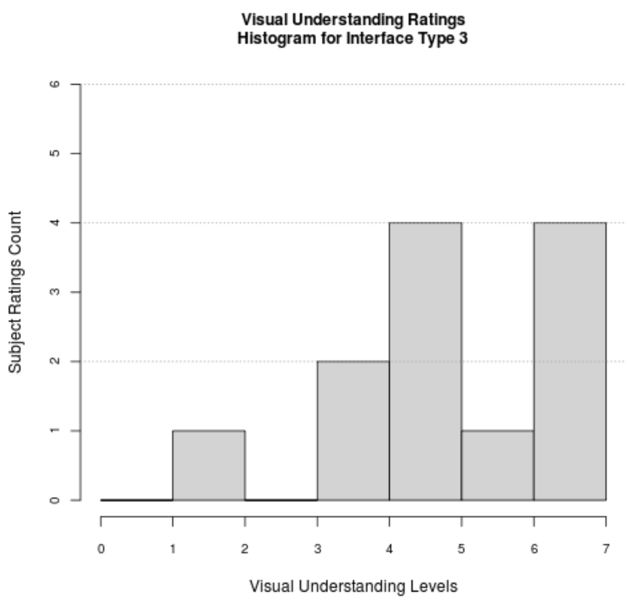
Understanding Visual vs. Interface Used Friedman test:	
X^2	2.447
p	0.485
DoF	3

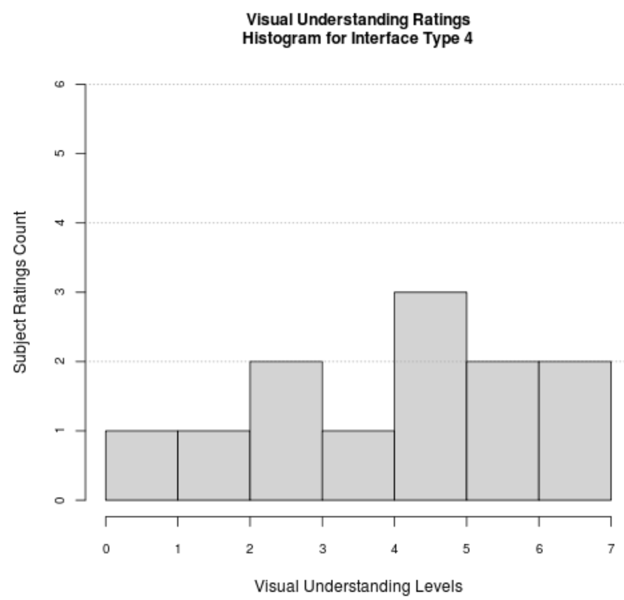
Understanding Visual vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	13.000	15.500	28.000	33.000	34.000	51.500
Z	-1.114	-0.201	0.797	0.440	1.509	0.997
p	0.281	0.867	0.480	0.717	0.145	0.376
R	-0.114	-0.021	0.081	0.045	0.154	0.102

Understanding Visual vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	5.083	1.832	5.500
2	5.583	1.881	6.000
3	5.333	1.557	5.000
4	4.500	1.931	5.000

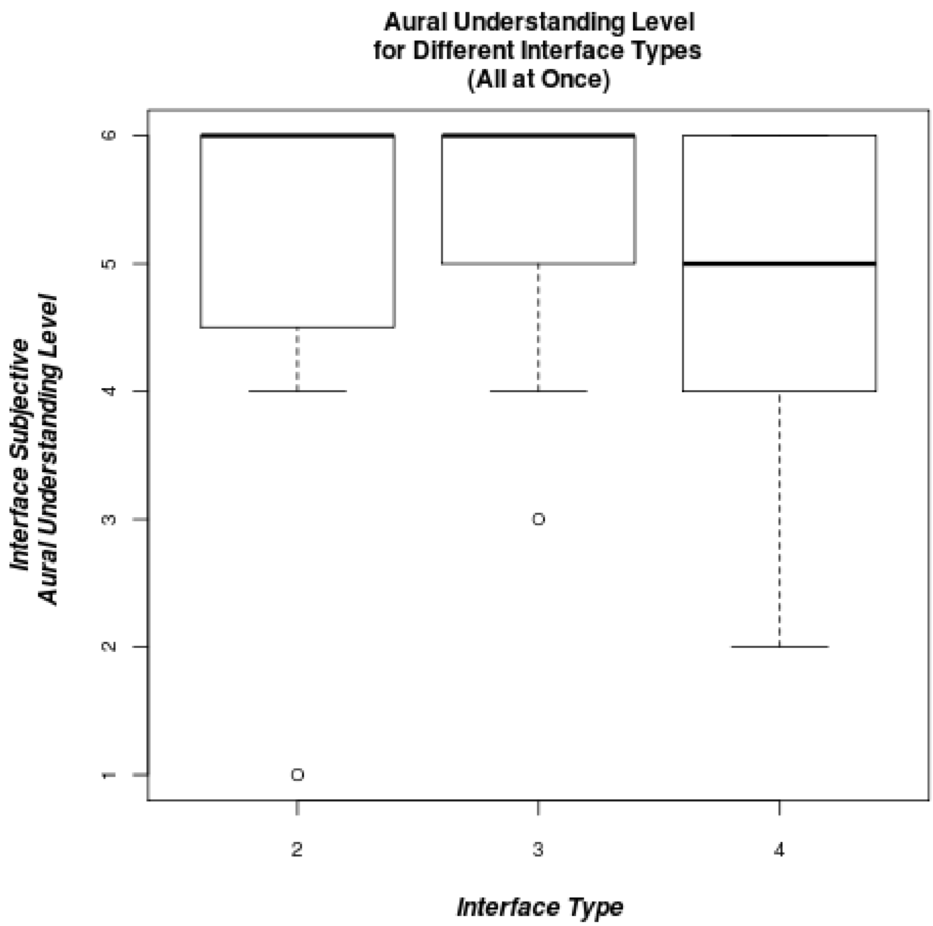




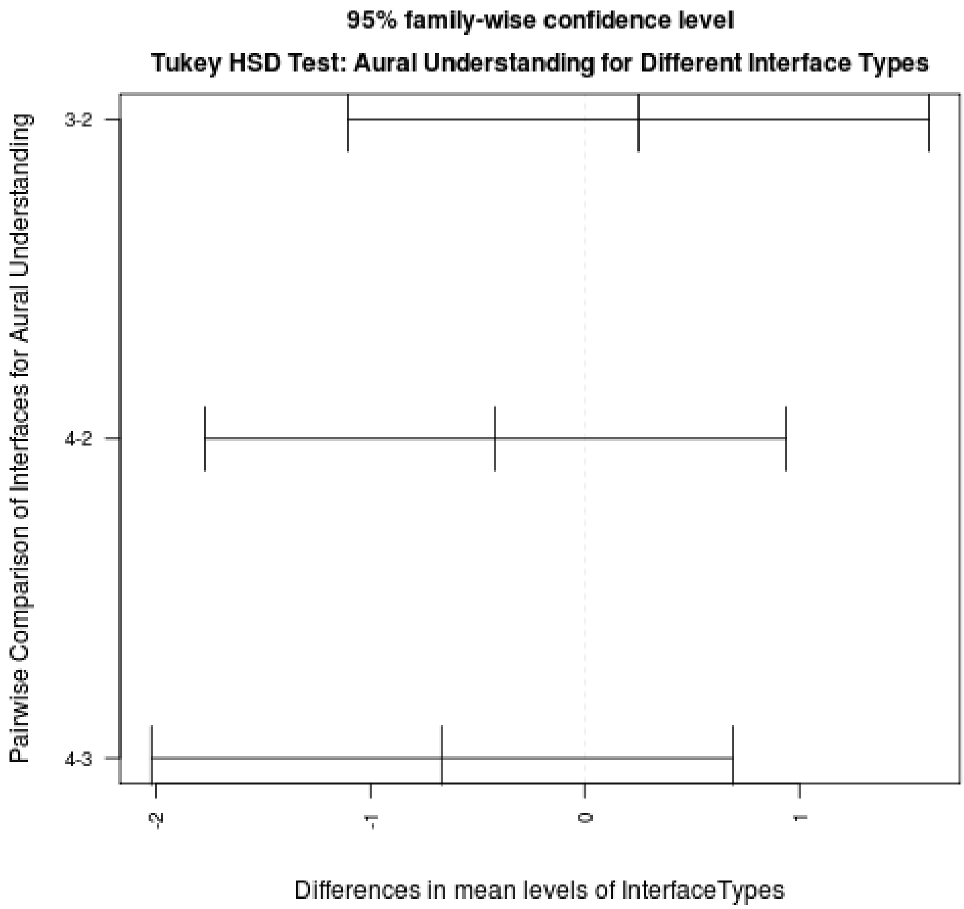




D.2.8.3.2 Understanding: Aural Only



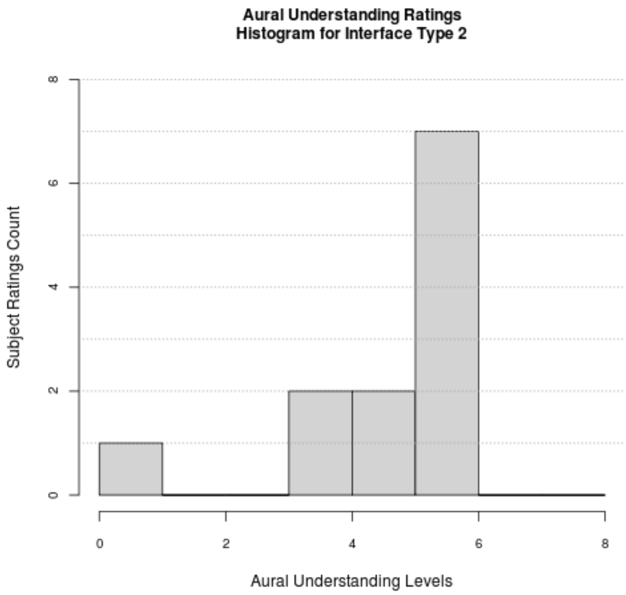
Subject Count	UI1	UI2	UI3	UI4
1		4	6	3
2		4	5	5
3		6	3	2
4		6	6	5
5		6	5	2
6		5	4	6
7		6	6	6
8		6	5	6
9		5	6	5
10		6	6	5
11		1	6	5
12		6	6	6

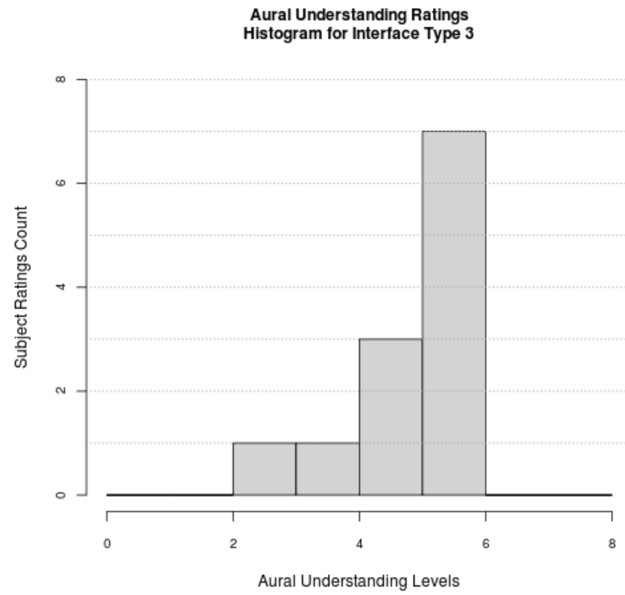


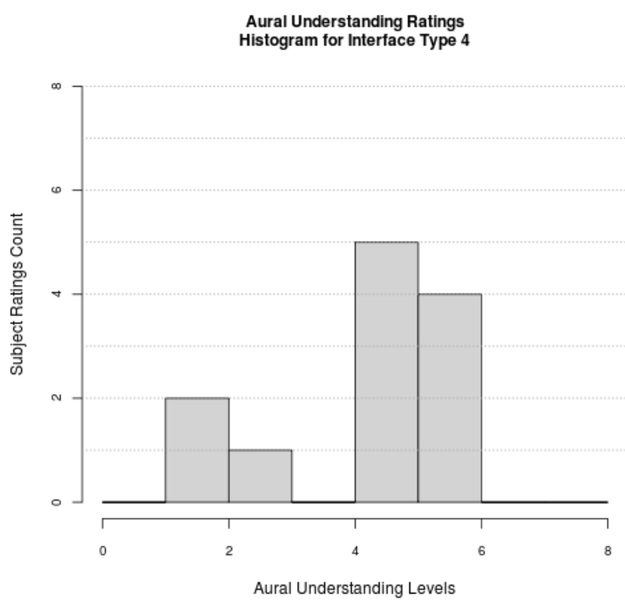
One-way ANOVA: Understanding Aural vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	2	2.722	1.361	0.746	0.482
Residuals	33	60.250	1.826		

Understanding Aural vs. Interface Used Friedman test:	
X^2	2.229
p	0.328
DoF	2

Understanding Aural vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W				16.000	23.000	34.500
Z				-0.162	0.730	1.569
p				0.914	0.602	0.121
R				-0.017	0.075	0.160

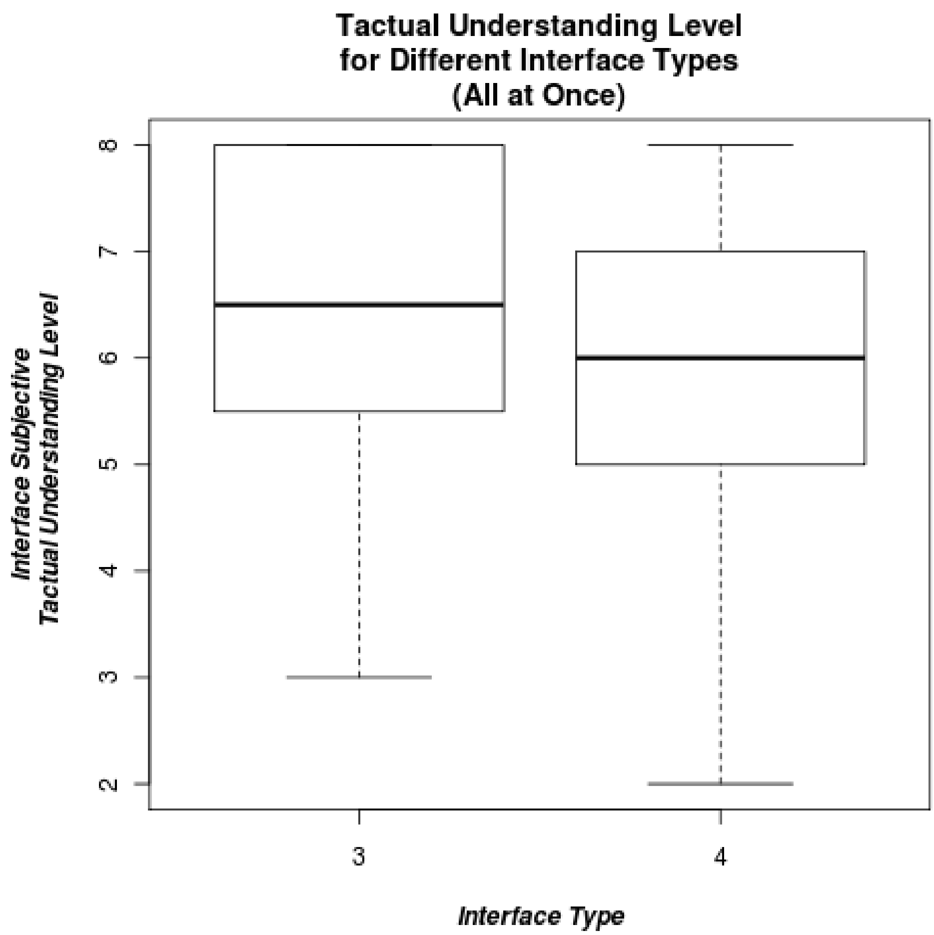




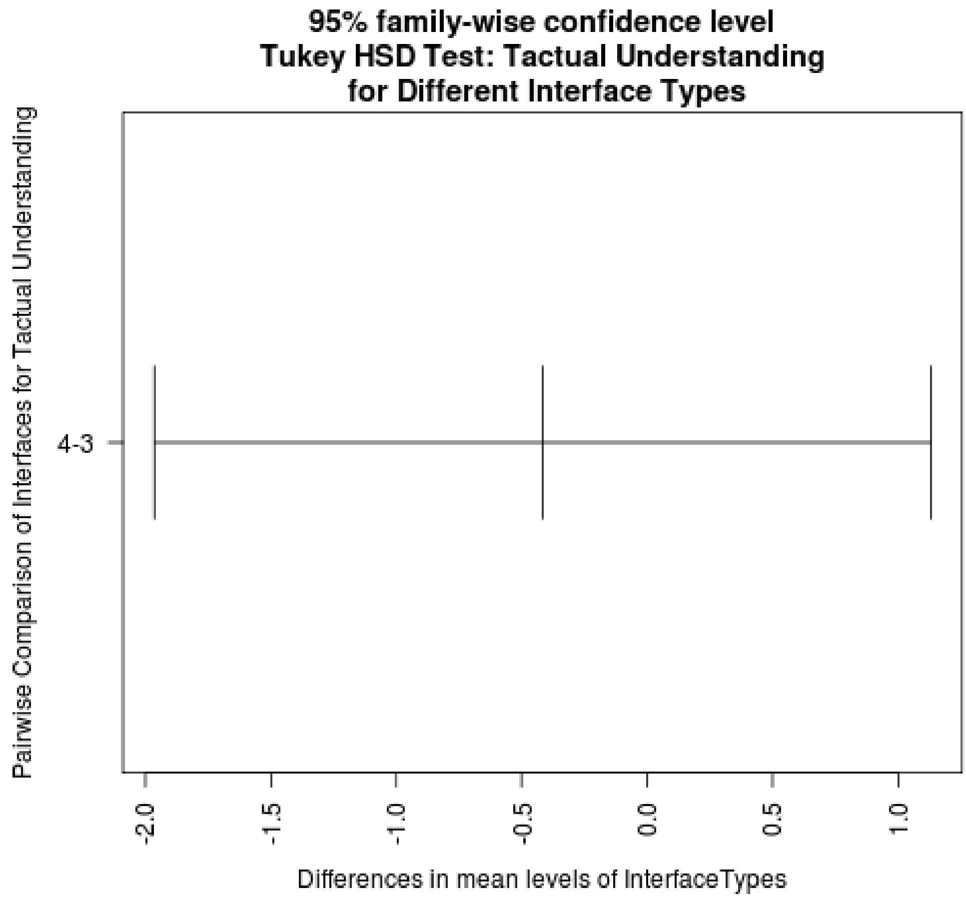


Understanding Aural vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1			
2	5.083	1.505	6.000
3	5.333	0.985	6.000
4	4.667	1.497	5.000

D.2.8.3.3 Understanding: Tactual Only



Subject Count	UI1	UI2	UI3	UI4
1			6	8
2			3	7
3			6	6
4			6	6
5			7	2
6			8	4
7			8	6
8			3	4
9			8	6
10			8	7
11			8	7
12			5	8

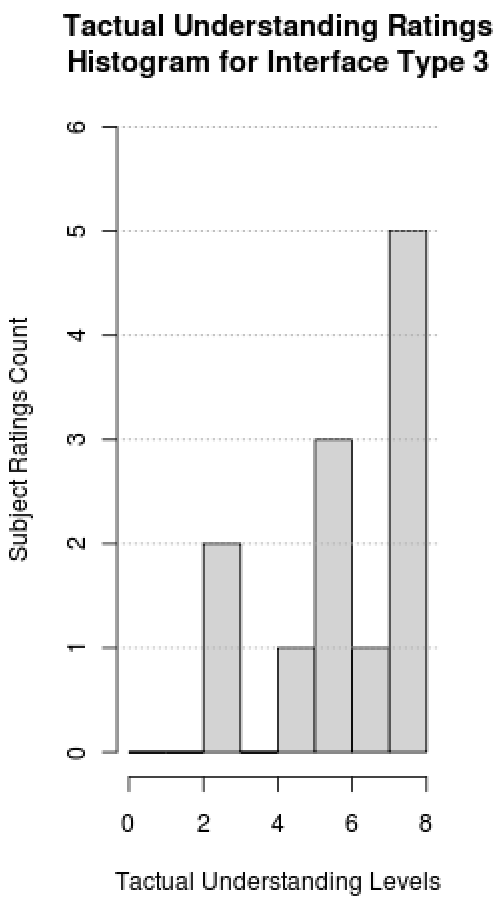


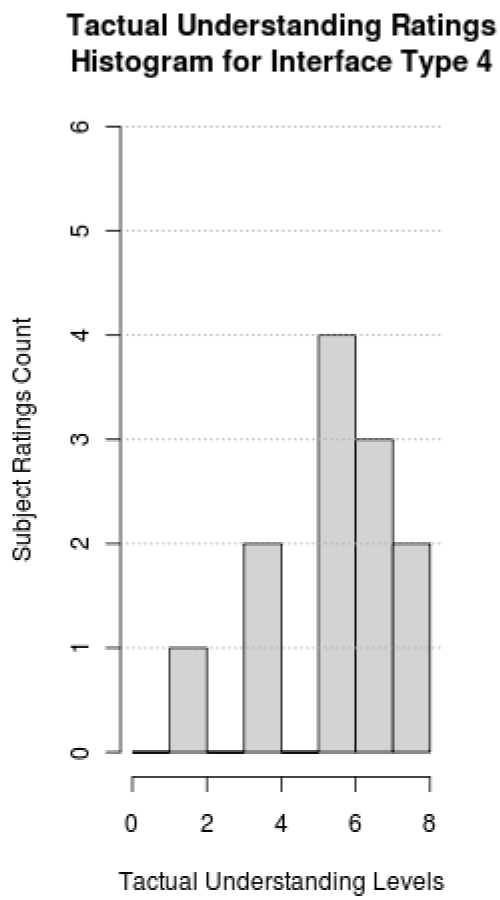
One-way ANOVA: Understanding Tactual vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	1.042	1.042	0.311	0.582
Residuals	22	73.583	3.345		

Understanding Tactual vs. Interface Used Friedman test:	
X^2	0.400
p	0.527
DoF	1

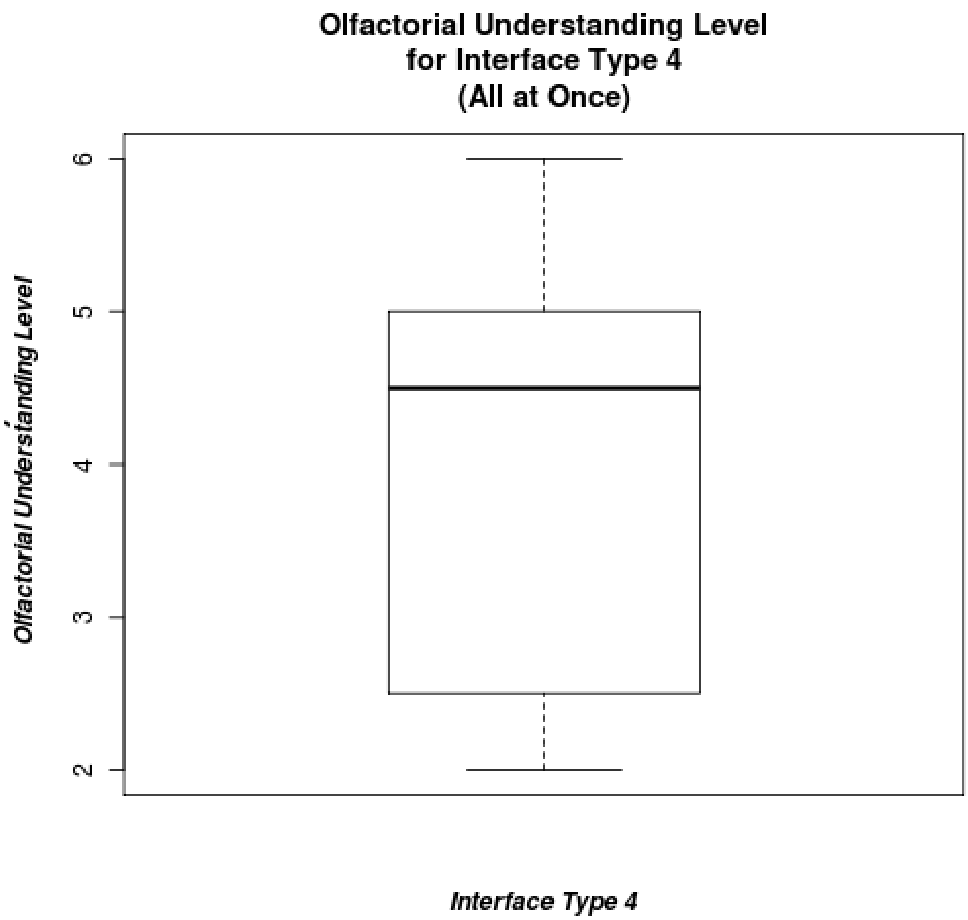
Understanding Tactual vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W						32.500
Z						0.553
p						0.617
R						0.056

Understanding Tactual vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1			
2			
3	6.333	1.875	6.500
4	5.917	1.782	6.000

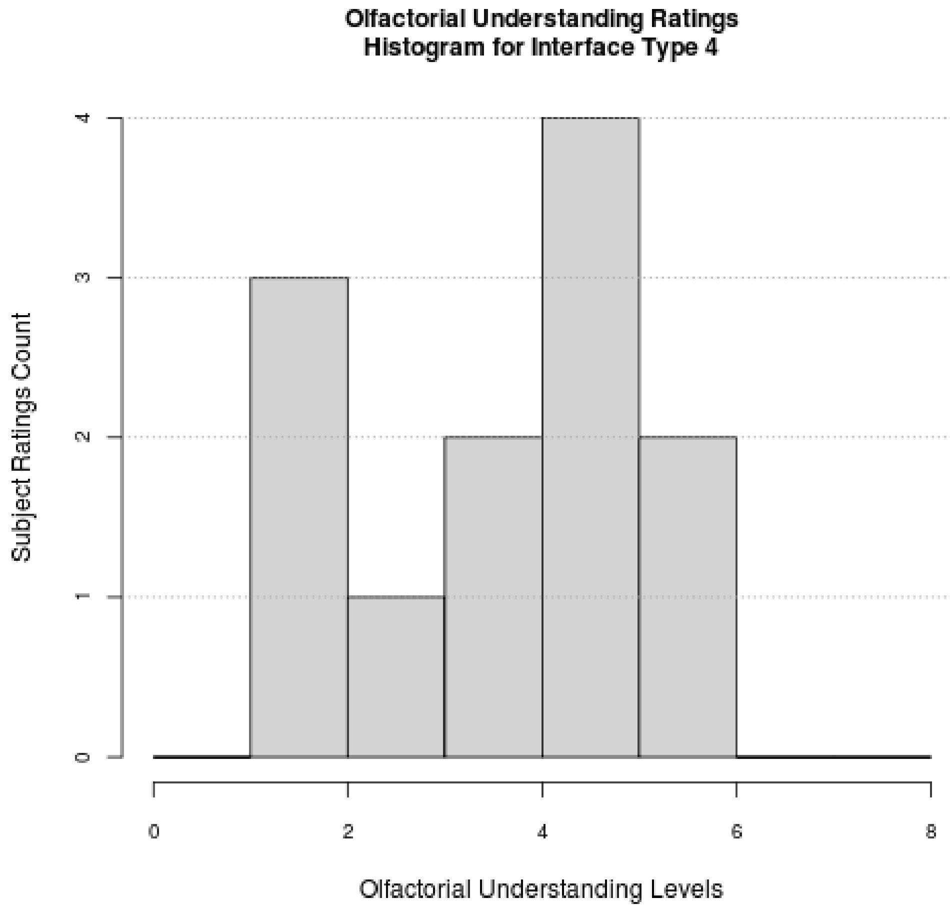




D.2.8.3.4 Understanding: Olfactorial Only

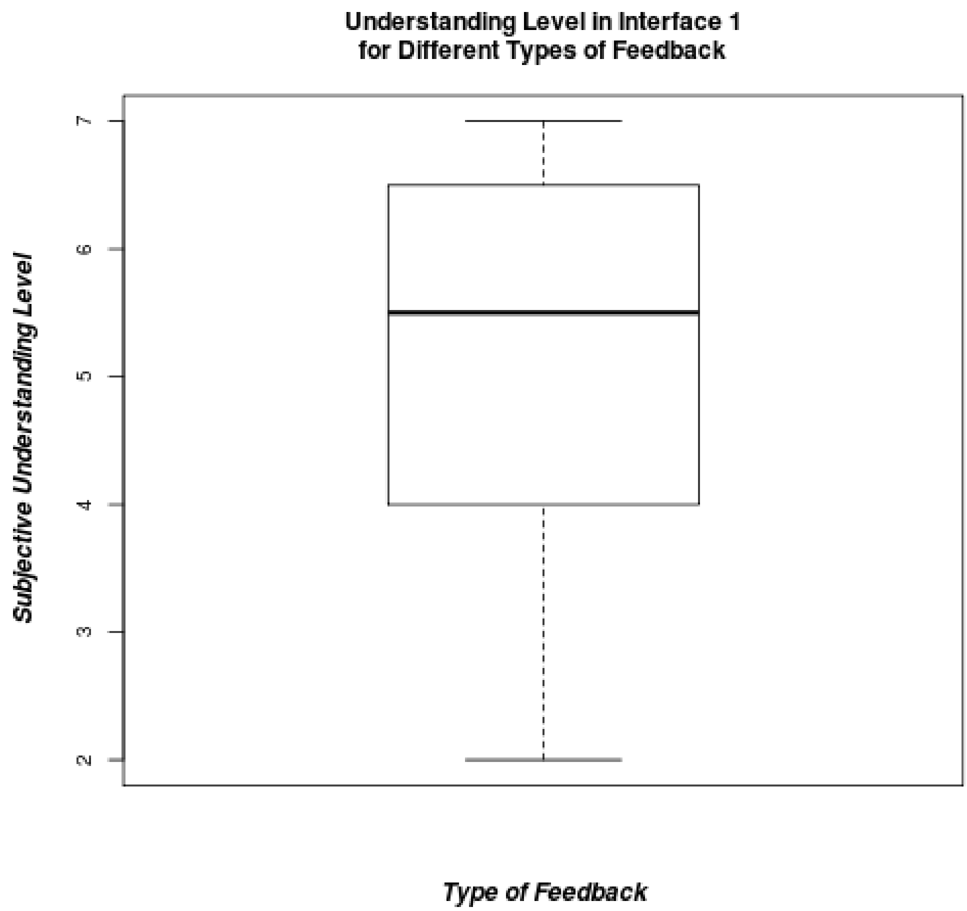


Subject Count	UI1	UI2	UI3	UI4
1				4
2				5
3				2
4				2
5				6
6				4
7				3
8				5
9				2
10				5
11				6
12				5

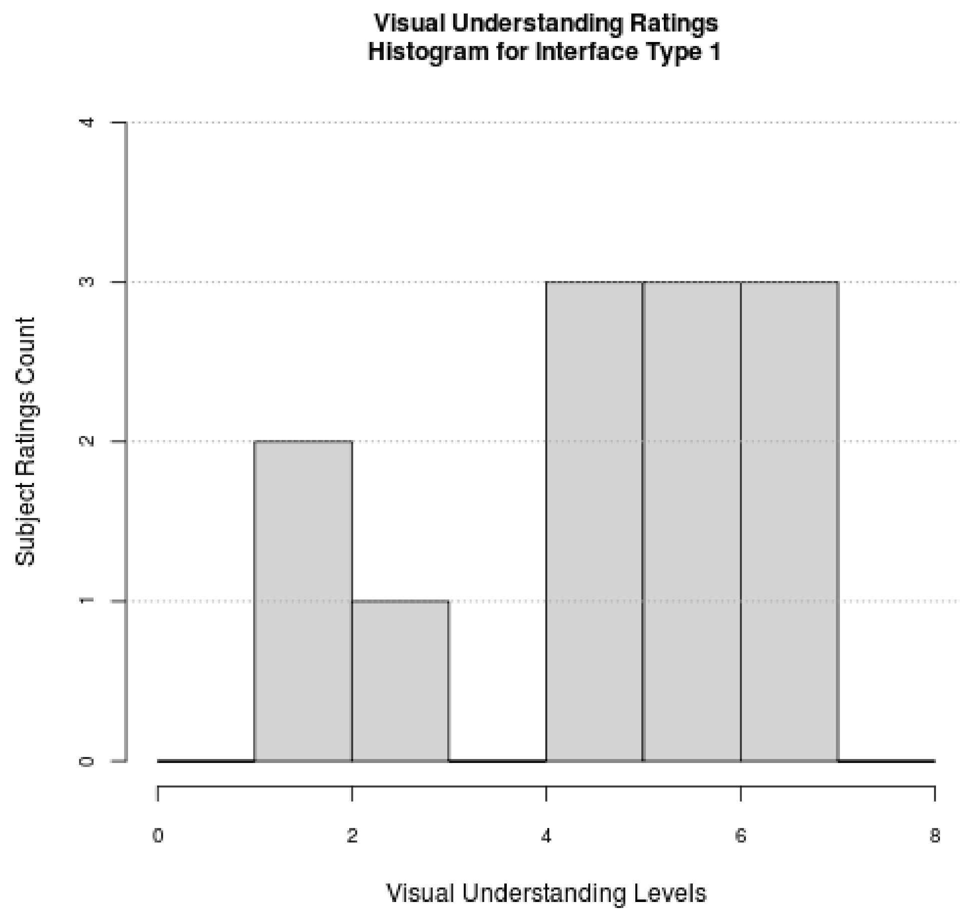


Understanding Olfactorial vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1			
2			
3			
4	4.083	1.505	4.500

D.2.8.3.5 Understanding Ratings for Each Type of Feedback: Interface 1

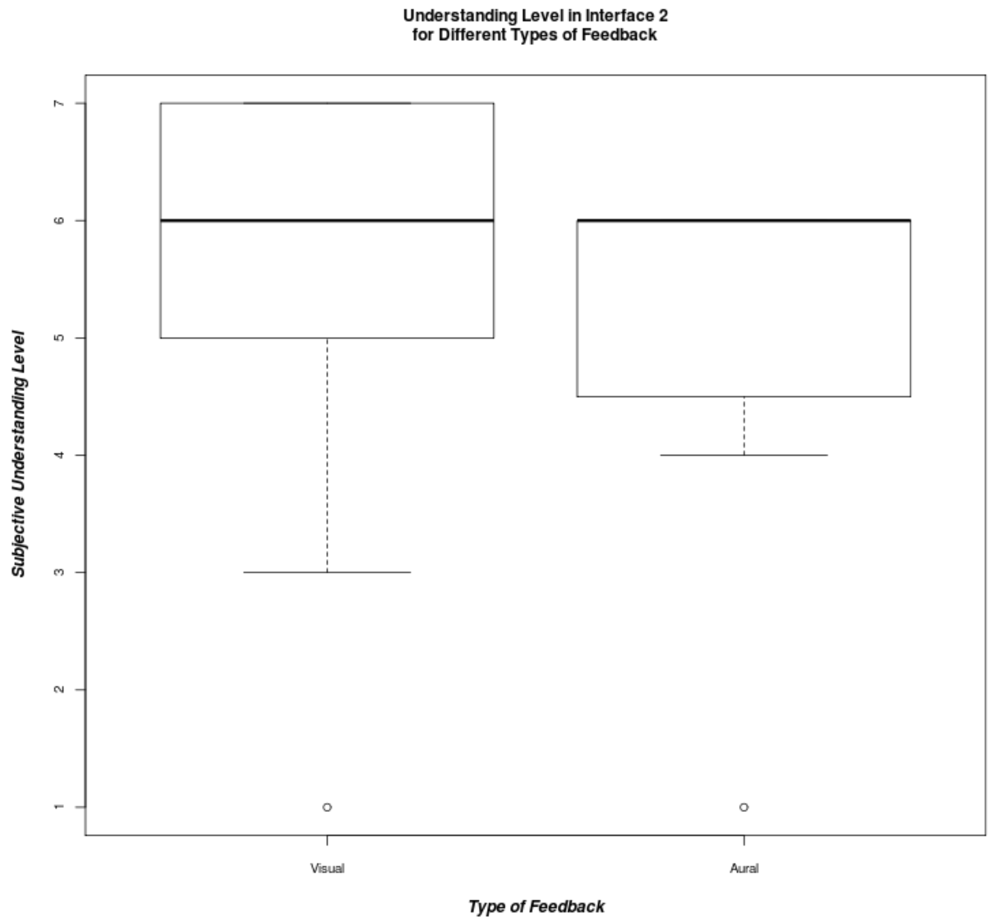


Subject Count	Visual	Aural	Tactual	Olfactorial
1	6			
2	5			
3	2			
4	7			
5	6			
6	7			
7	7			
8	5			
9	3			
10	5			
11	2			
12	6			

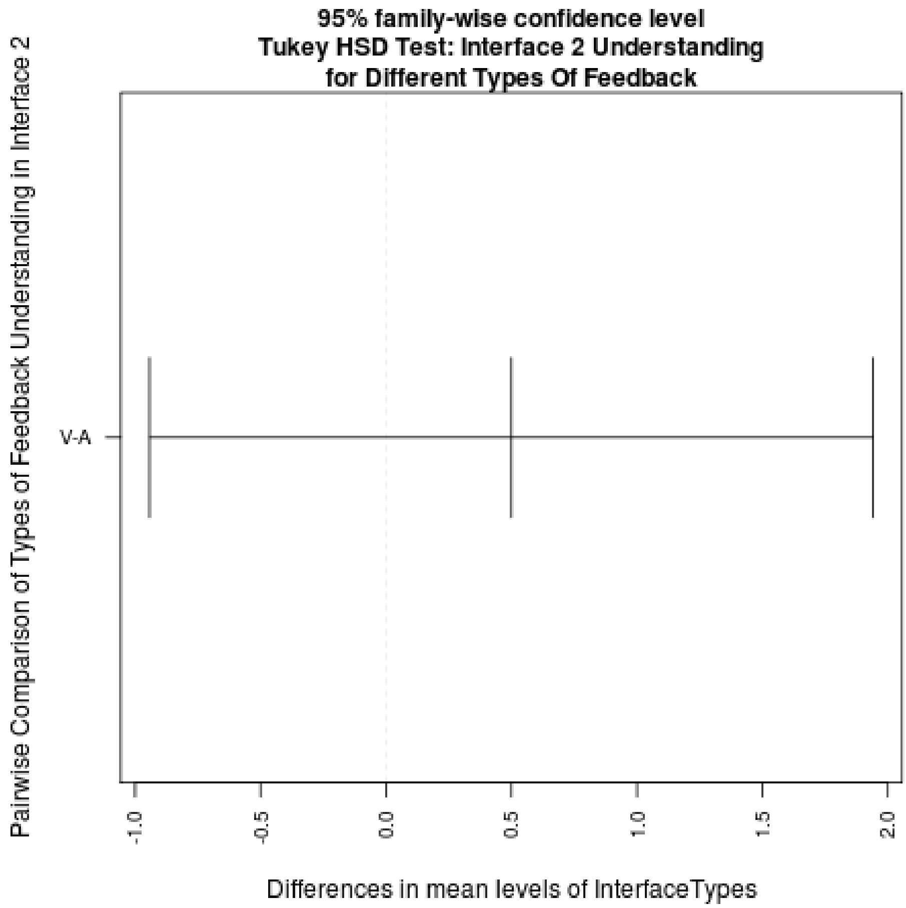


Understanding vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	5.083	1.832	5.500
Aural			
Tactual			
Olfactorial			

D.2.8.3.6 Understanding Ratings for Each Type of Feedback: Interface 2



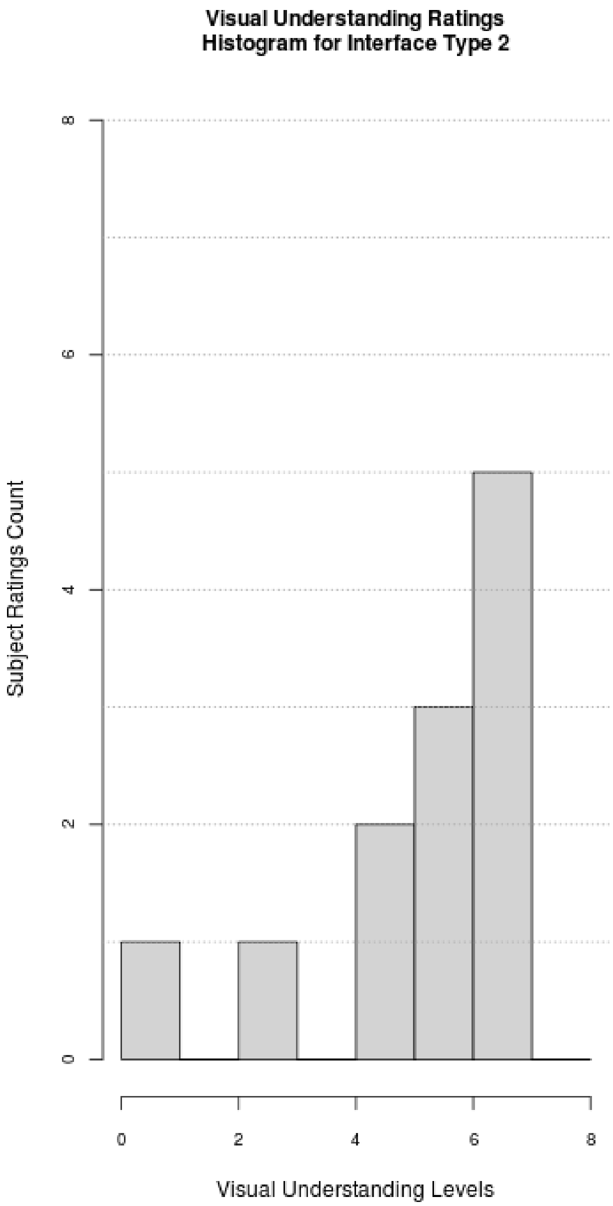
Subject Count	Visual	Aural	Tactual	Olfactorial
1	1	4		
2	7	4		
3	5	6		
4	7	6		
5	5	6		
6	6	5		
7	7	6		
8	7	6		
9	6	5		
10	7	6		
11	3	1		
12	6	6		

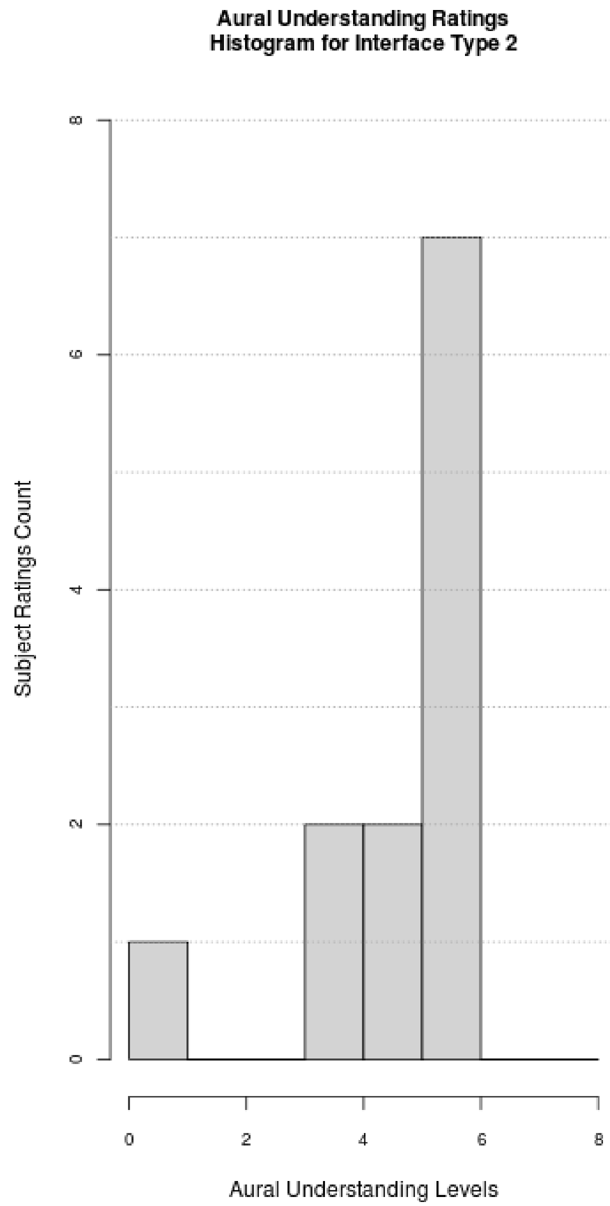


One-way ANOVA: Understanding vs. Type of Feedback					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	1.500	1.500	0.517	0.480
Residuals	22	63.833	2.902		

Understanding vs. Type of Feedback Friedman test:	
X^2	2.273
p	0.132
DoF	1

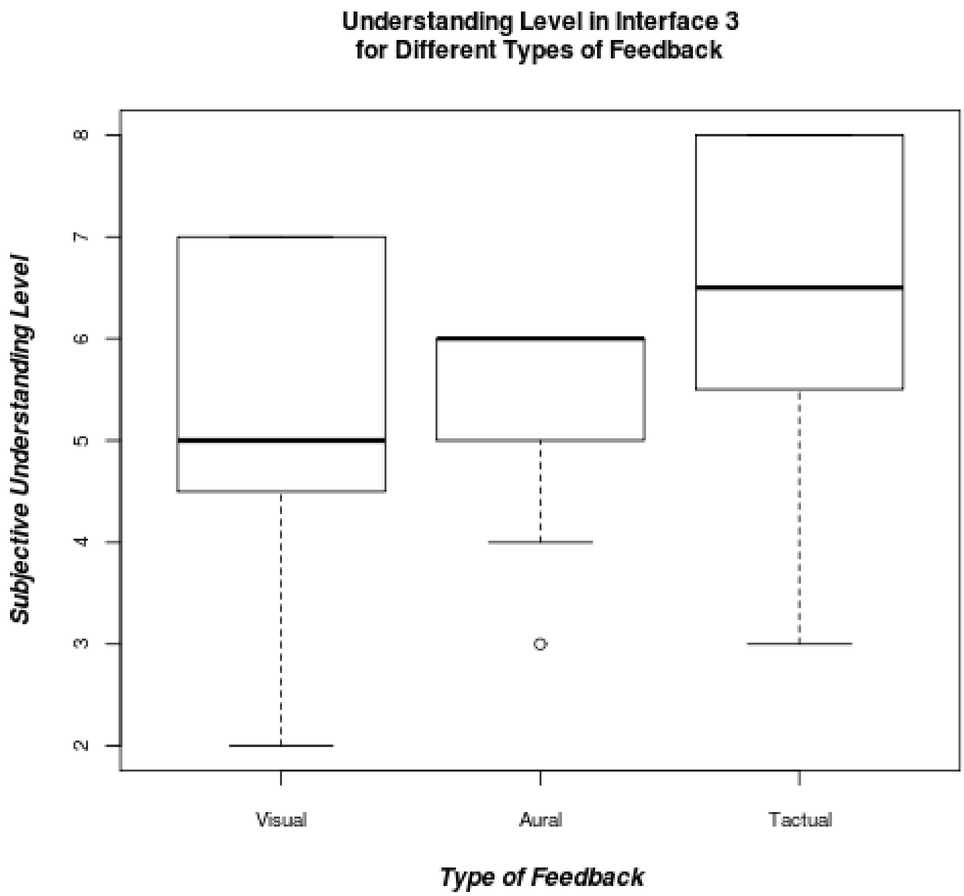
Understanding vs. Type of Feedback Wilcoxon test:						
	Visual – Aural	**Visual – Tactual**	**Visual – Olfact.**	**Aural – Tactual**	**Aural – Olfact.**	**Tactual – Olfact.**
W	46.500					
Z	1.299					
p	0.270					
R	0.133					



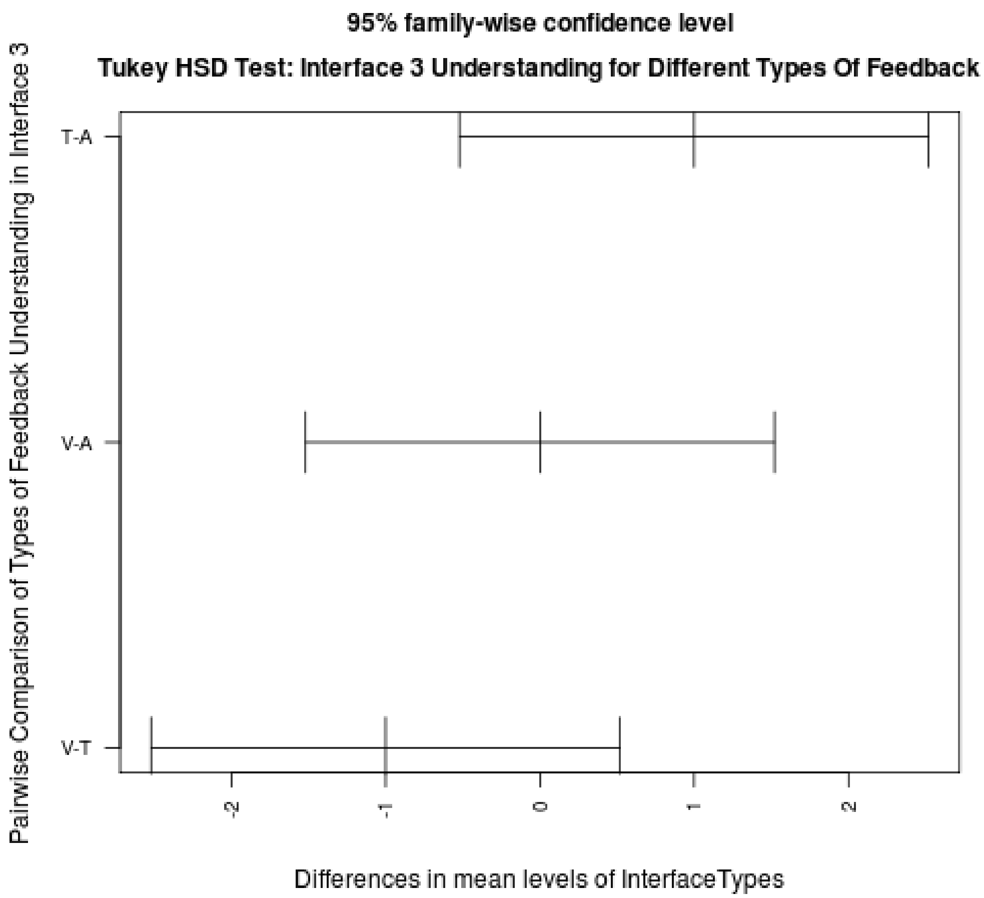


Understanding vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	5.583	1.881	6.000
Aural	5.083	1.505	6.000
Tactual			
Olfactorial			

D.2.8.3.7 Understanding Ratings for Each Type of Feedback: Interface 3



Subject Count	Visual	Aural	Tactual	Olfactorial
1	2	6	6	
2	5	5	3	
3	5	3	6	
4	6	6	6	
5	4	5	7	
6	7	4	8	
7	7	6	8	
8	4	5	3	
9	7	6	8	
10	5	6	8	
11	5	6	8	
12	7	6	5	

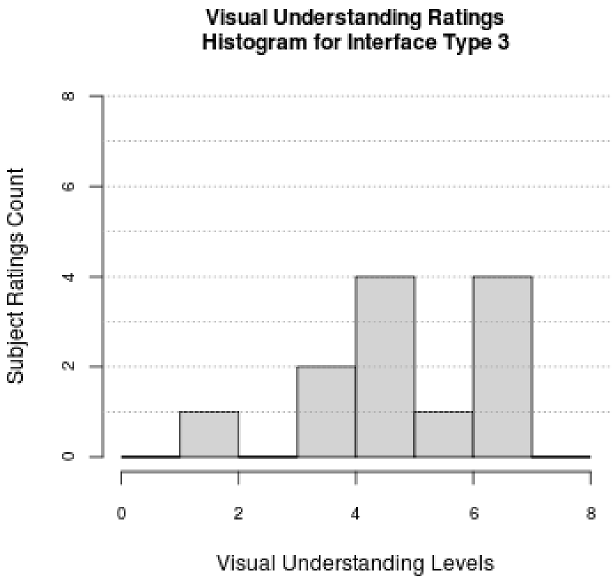


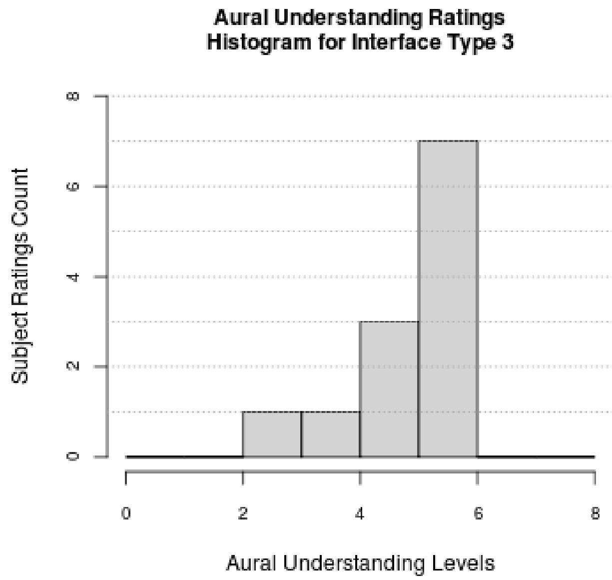
One-way ANOVA: Understanding vs. Type of Feedback					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	2	8.000	4.000	1.737	0.192
Residuals	33	76.000	2.303		

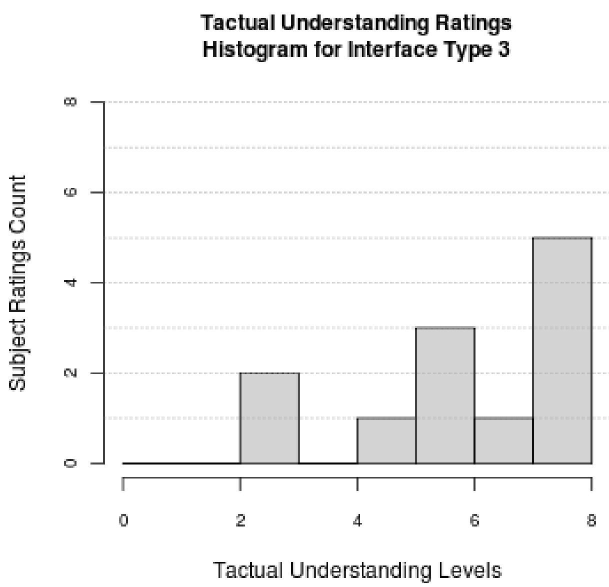
Understanding vs. Type of Feedback Friedman test:	
X^2	2.905
p	0.234
DoF	2

Understanding vs. Type of Feedback Wilcoxon test:						
	Visual – Aural	**Visual – Tactual**	**Visual – Olfact.**	**Aural – Tactual**	**Aural – Olfact.**	**Tactual – Olfact.**
W	29.000	16.000		11.000		
Z	0.121	-1.546		-1.651		
p	1.000	0.126		0.121		
R	0.012	-0.158		-0.168		

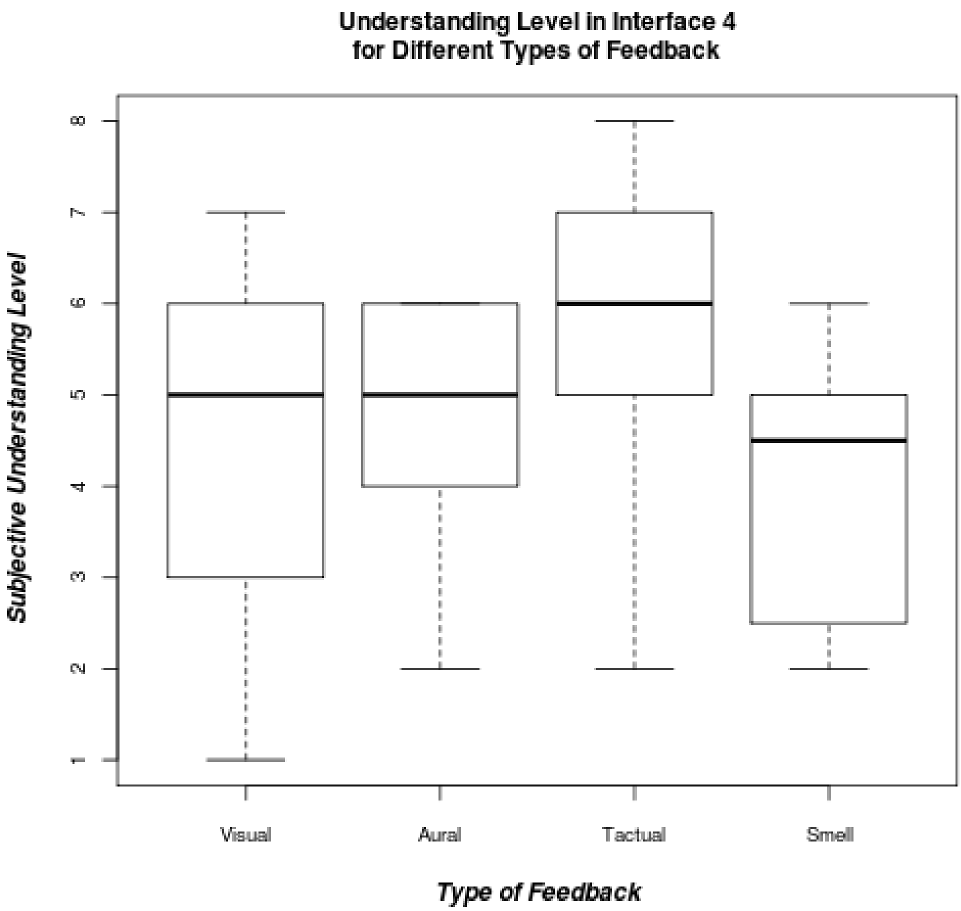
Understanding vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	5.333	1.557	5.000
Aural	5.333	0.985	6.000
Tactual	6.333	1.875	6.500
Olfactorial			



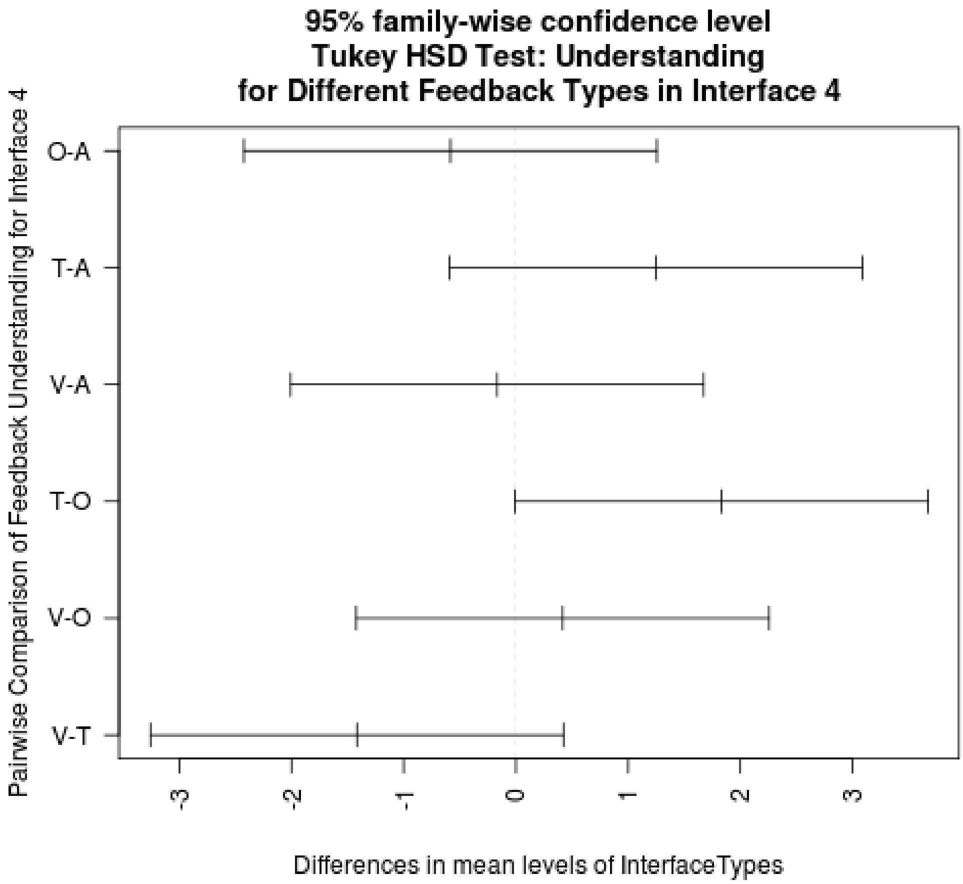




D.2.8.3.8 Understanding Ratings for Each Type of Feedback: Interface 4



Subject Count	Visual	Aural	Tactual	Olfactorial
1	1	3	8	4
2	6	5	7	5
3	7	2	6	2
4	2	5	6	2
5	5	2	2	6
6	5	6	4	4
7	3	6	6	3
8	5	6	4	5
9	3	5	6	2
10	4	5	7	5
11	7	5	7	6
12	6	6	8	5

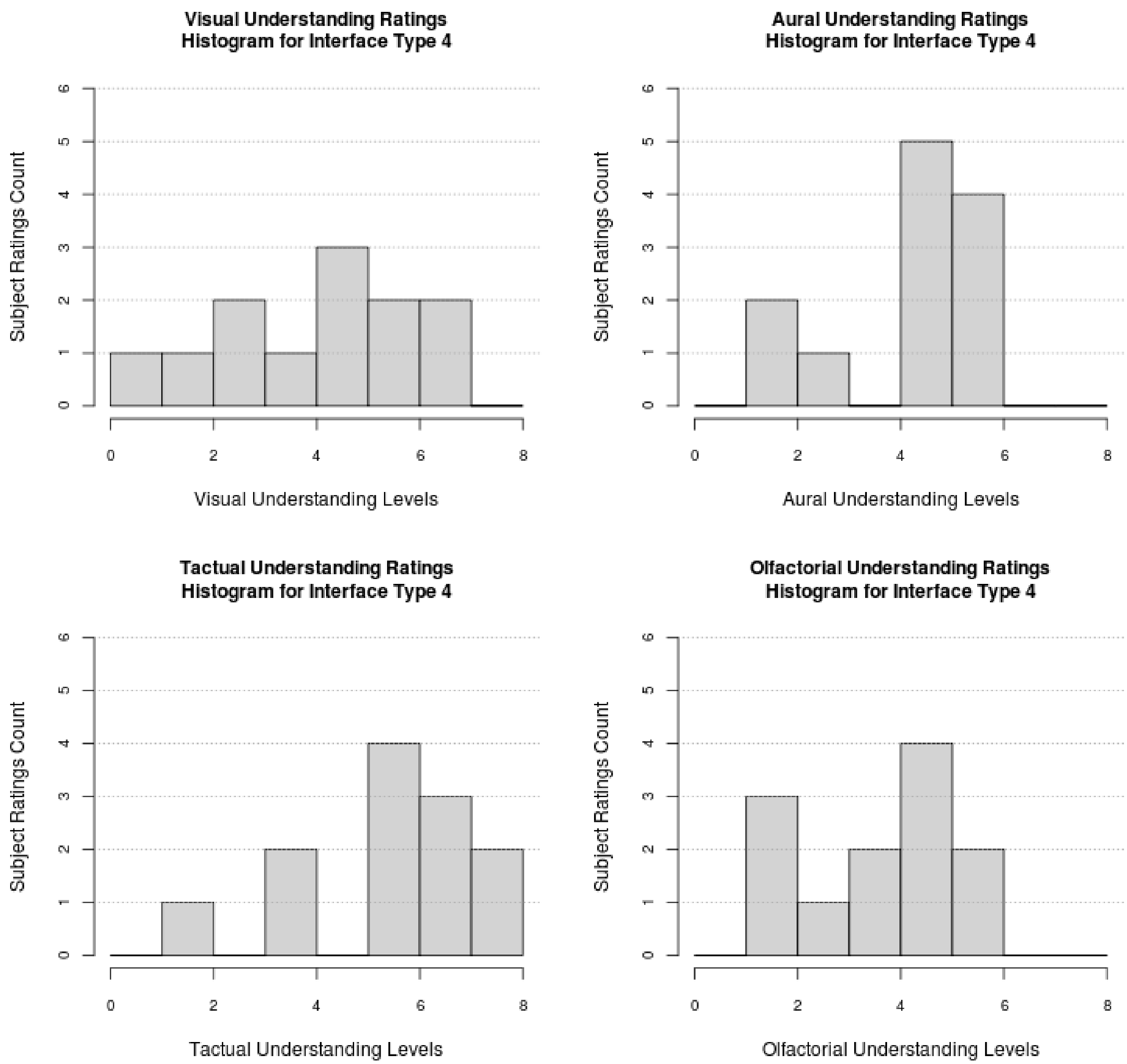


One-way ANOVA: Understanding vs. Type of Feedback					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	22.417	7.472	2.620	0.063
Residuals	44	125.500	2.852		

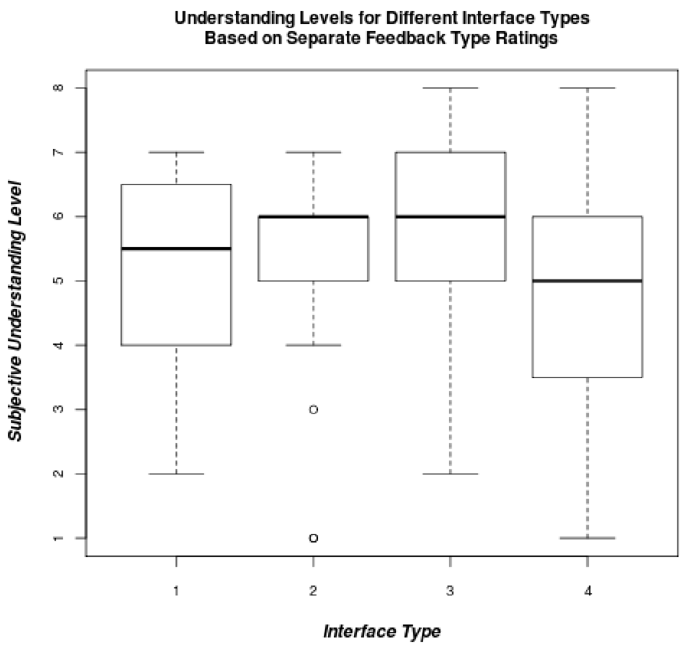
Understanding vs. Type of Feedback Friedman test:	
X^2	5.972
p	0.113
DoF	3

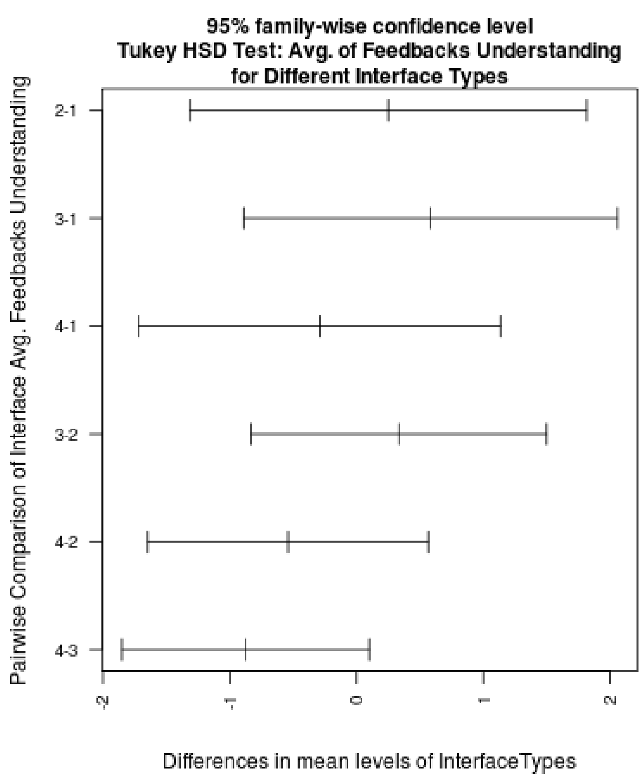
Understanding vs. Type of Feedback Wilcoxon test:						
	Visual – Aural	**Visual – Tactual**	**Visual – Olfact.**	**Aural – Tactual**	**Aural – Olfact.**	**Tactual – Olfact.**
W	28.500	15.000	29.000	11.000	31.000	55.500
Z	-0.474	-1.543	0.892	-1.797	1.037	2.060
p	0.665	0.138	0.398	0.092	0.316	0.041
R	-0.048	-0.157	0.091	-0.183	0.106	0.210

Understanding vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	4.500	1.931	5.000
Aural	4.667	1.497	5.000
Tactual	5.917	1.782	6.000
Olfactorial	4.083	1.505	4.500



D.2.8.3.9 Overall Interface Understanding – Average of Individual Feedback Ratings



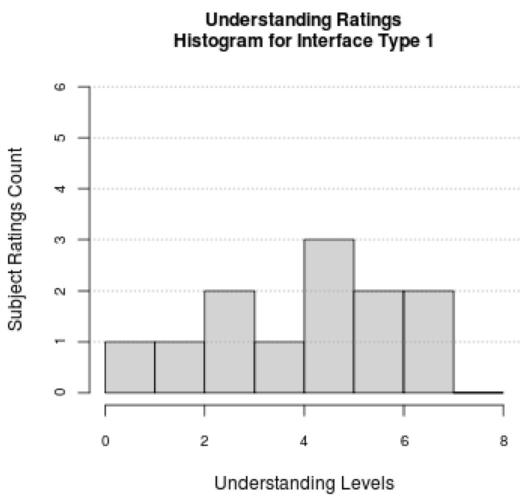


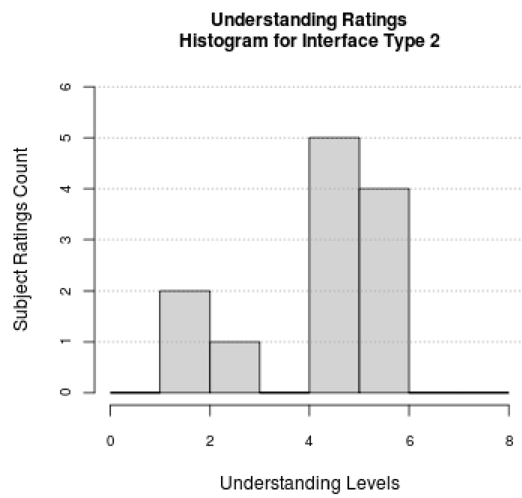
Subject Count	UI1	UI2	UI3	UI4
1	6	1	2	1
2	5	7	5	6
3	2	5	5	7
4	7	7	6	2
5	6	5	4	5
6	7	6	7	5
7	7	7	7	3
8	5	7	4	5
9	3	6	7	3
10	5	7	5	4
11	2	3	5	7
12	6	6	7	6
13		4	6	3
14		4	5	5
15		6	3	2
16		6	6	5
17		6	5	2
18		5	4	6
19		6	6	6
20		6	5	6
21		5	6	5
22		6	6	5
23		1	6	5
24		6	6	6
25			6	8
26			3	7
27			6	6
28			6	6
29			7	2
30			8	4
31			8	6
32			3	4
33			8	6
34			8	7
35			8	7
36			5	8
37				4
38				5
39				2
40				2
41				6
42				4
43				3
44				5
45				2
46				5
47				6
48				5

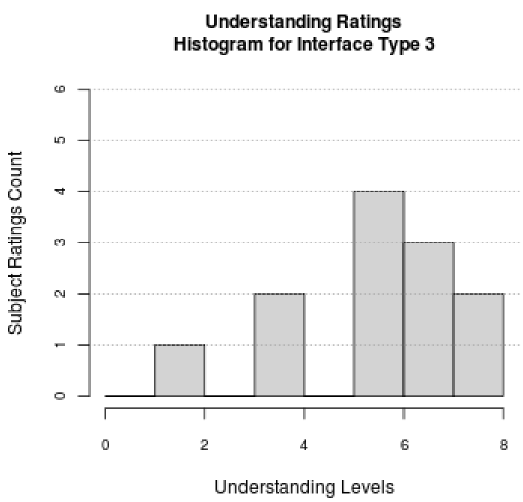
One-way ANOVA: Avg. of Feedbacks Understanding vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	16.430	5.475	1.901	0.133
Residuals	116	334.170	2.880		

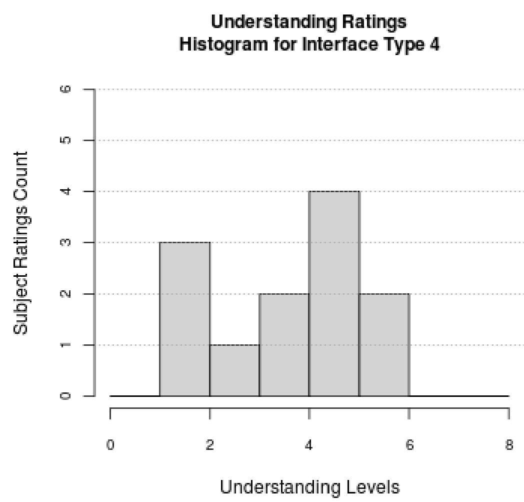
Avg. of Feedbacks Understanding vs. Interface Used Friedman test:	
X^2	2.447
p	0.485
DoF	3

Avg. of Feedbacks Understanding vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	5.083	1.832	5.500
2	5.333	1.685	6.000
3	5.667	1.549	6.000
4	4.792	1.774	5.000



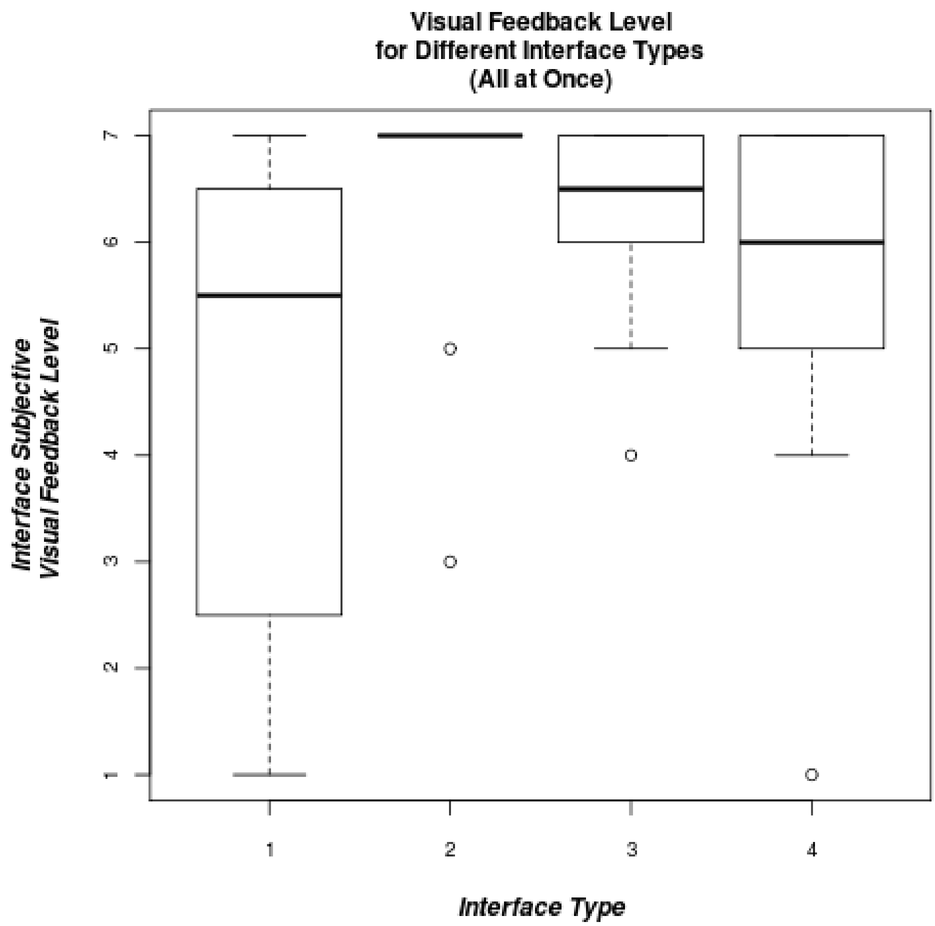




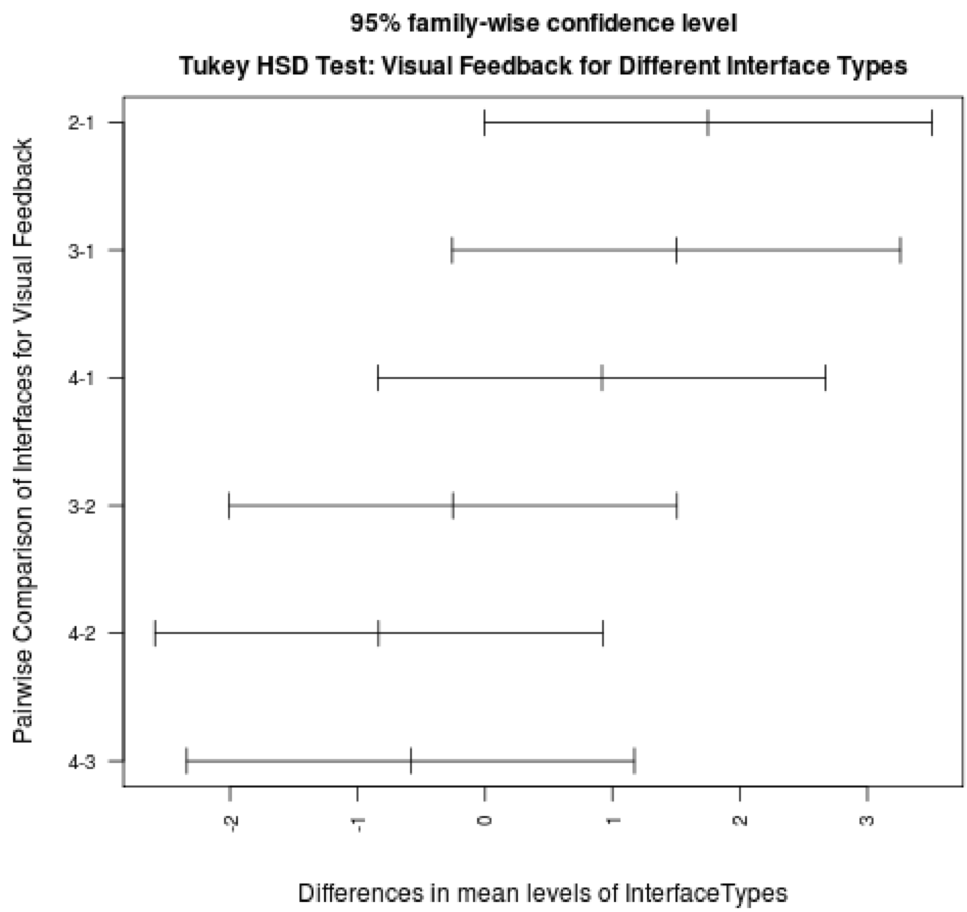


D.2.8.4 Feedback

D.2.8.4.1 Feedback: Visual Only



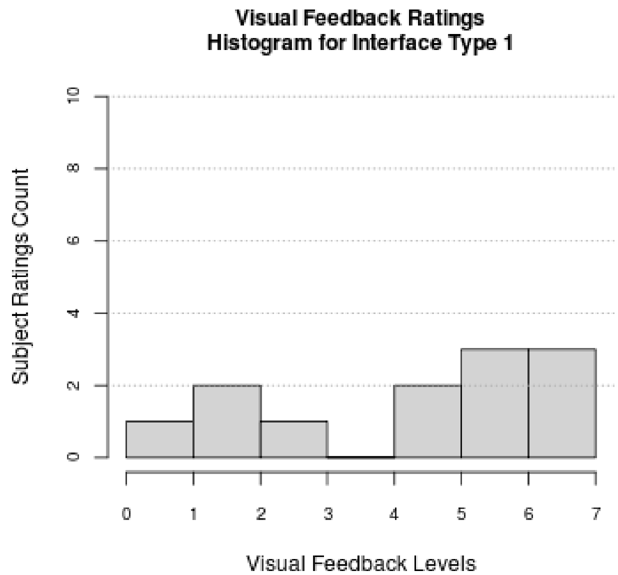
Subject Count	UI1	UI2	UI3	UI4
1	1	7	7	1
2	6	7	6	6
3	5	7	7	7
4	7	7	6	7
5	2	5	6	5
6	6	7	7	7
7	6	7	7	7
8	7	7	5	7
9	3	7	6	5
10	5	3	4	4
11	2	7	7	6
12	7	7	7	6

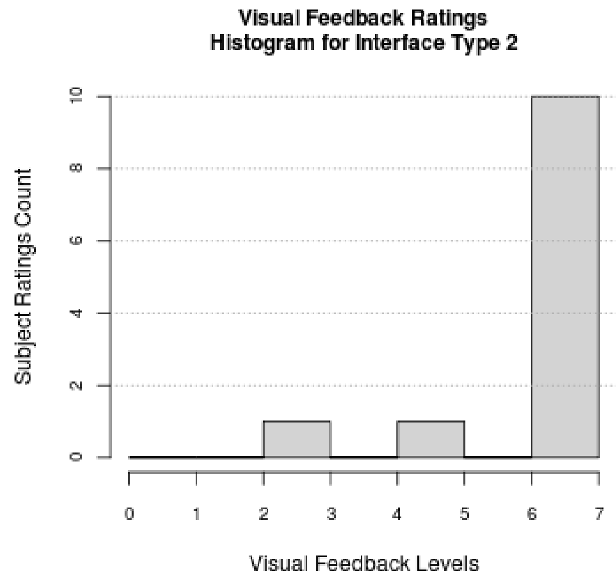


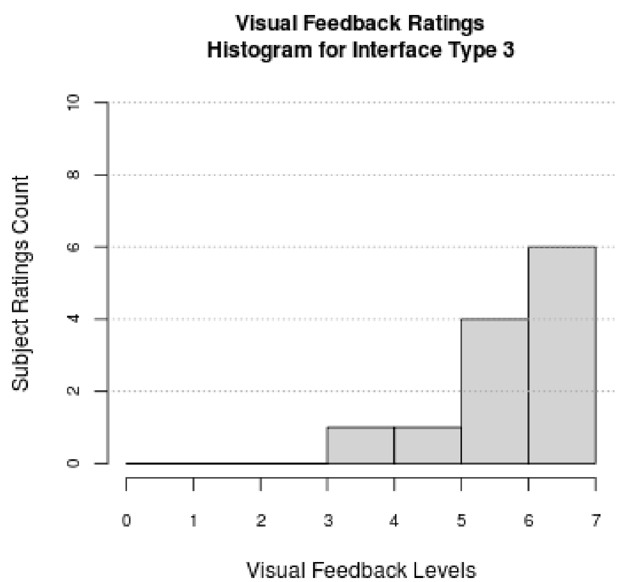
One-way ANOVA: Feedback Visual vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	21.750	7.250	2.794	0.051
Residuals	44	114.170	2.595		

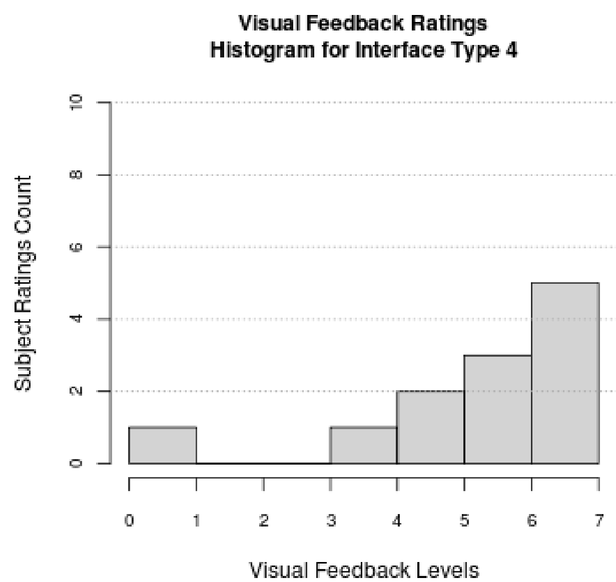
Feedback Visual vs. Interface Used Friedman test:	
X^2	7.379
p	0.061
DoF	3

Feedback Visual vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	4.500	10.500	5.000	15.000	18.500	19.000
Z	-2.265	-1.661	-1.694	0.896	1.699	1.034
p	0.023	0.117	0.117	0.531	0.156	0.359
R	-0.231	-0.170	-0.173	0.091	0.173	0.105



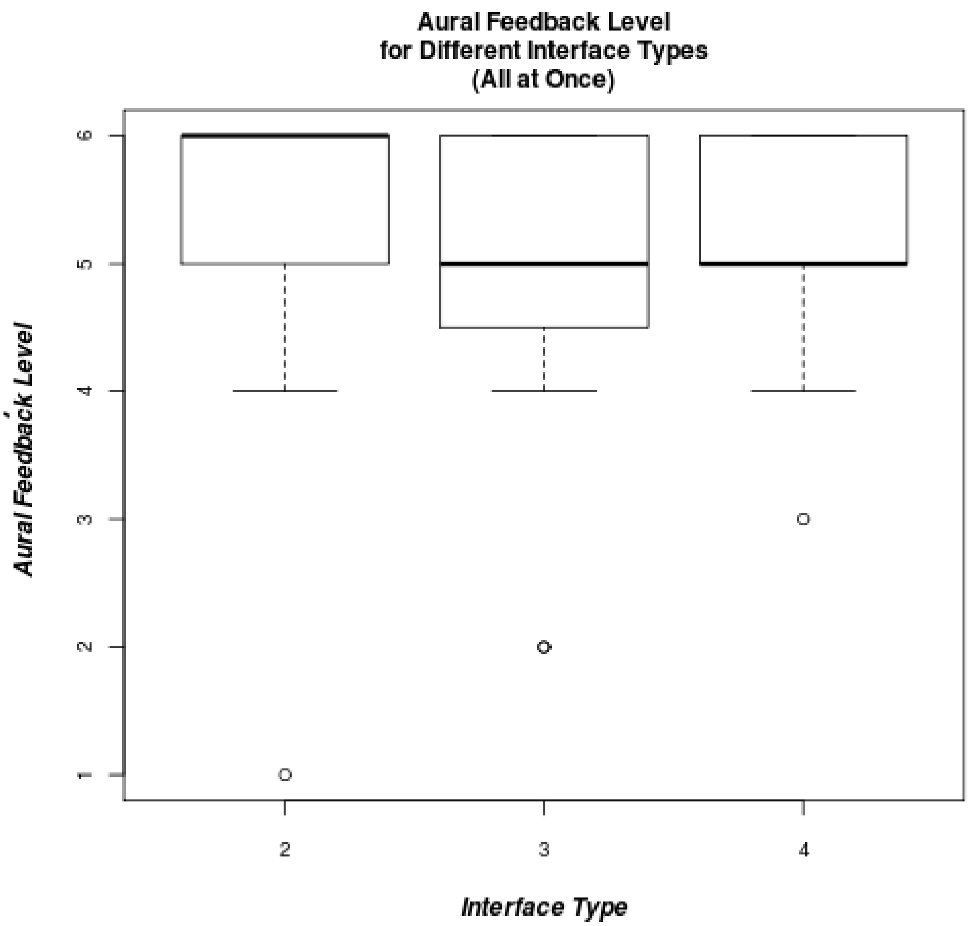




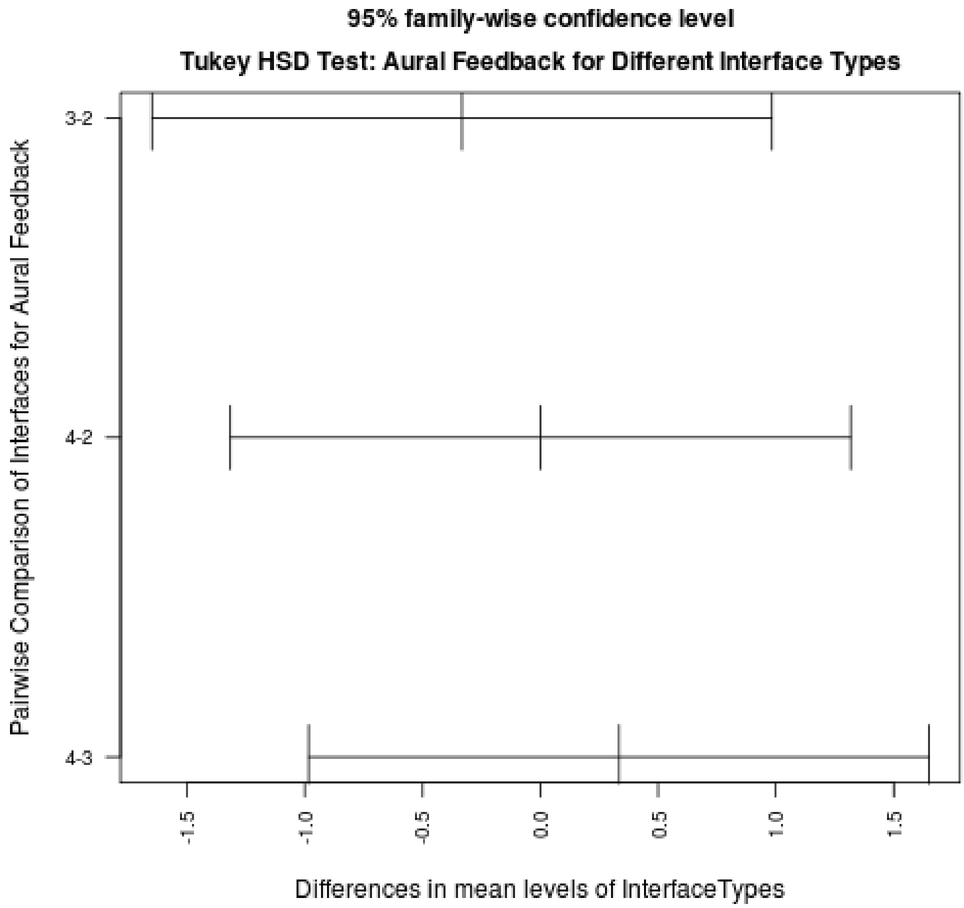


Feedback Visual vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	4.750	2.179	5.500
2	6.500	1.243	7.000
3	6.250	0.965	6.500
4	5.667	1.775	6.000

D.2.8.4.2 Feedback: Aural Only



Subject Count	UI1	UI2	UI3	UI4
1		4	4	3
2		6	5	5
3		5	2	6
4		6	6	5
5		6	5	6
6		6	6	5
7		6	2	6
8		5	5	6
9		1	5	5
10		5	6	4
11		6	6	5
12		6	6	6

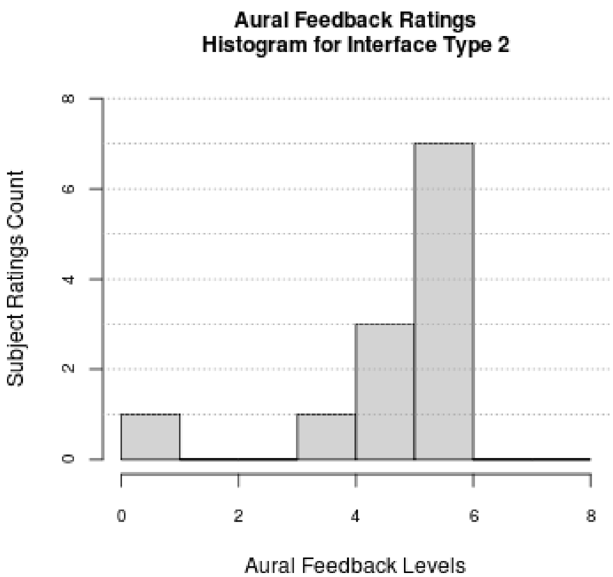


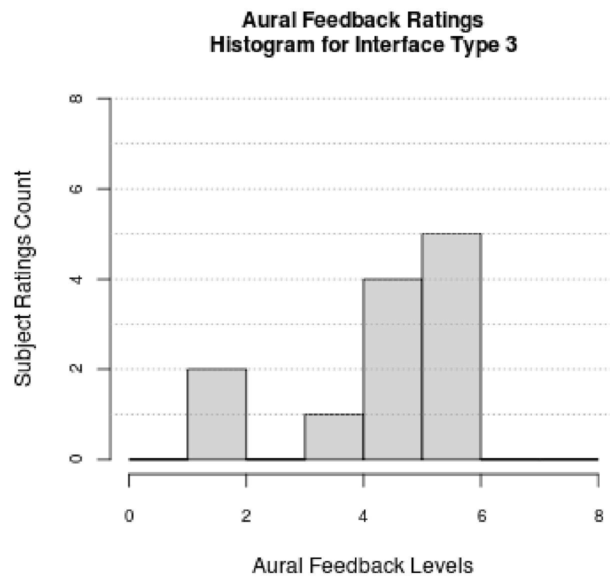
One-way ANOVA: Feedback Aural vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	2	0.889	0.444	0.257	0.775
Residuals	33	57.000	1.727		

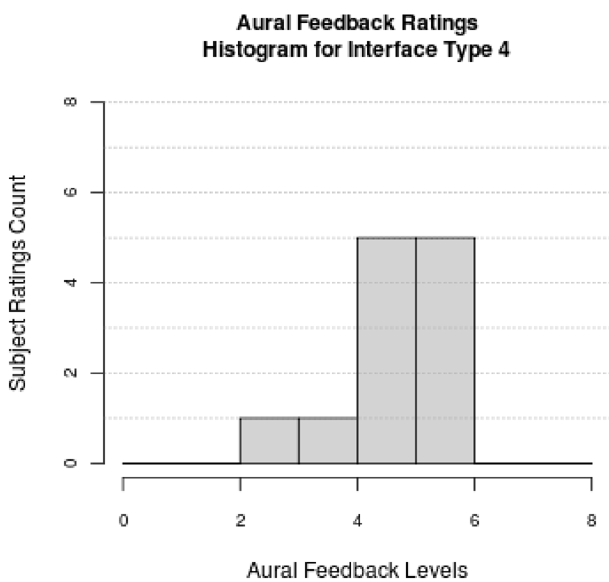
Feedback Aural vs. Interface Used Friedman test:	
X^2	1.200
p	0.549
DoF	2

Feedback Aural vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W				13.500	27.000	21.000
Z				0.763	0.739	0.000
p				0.594	0.508	1.000
R				0.078	0.075	0.000

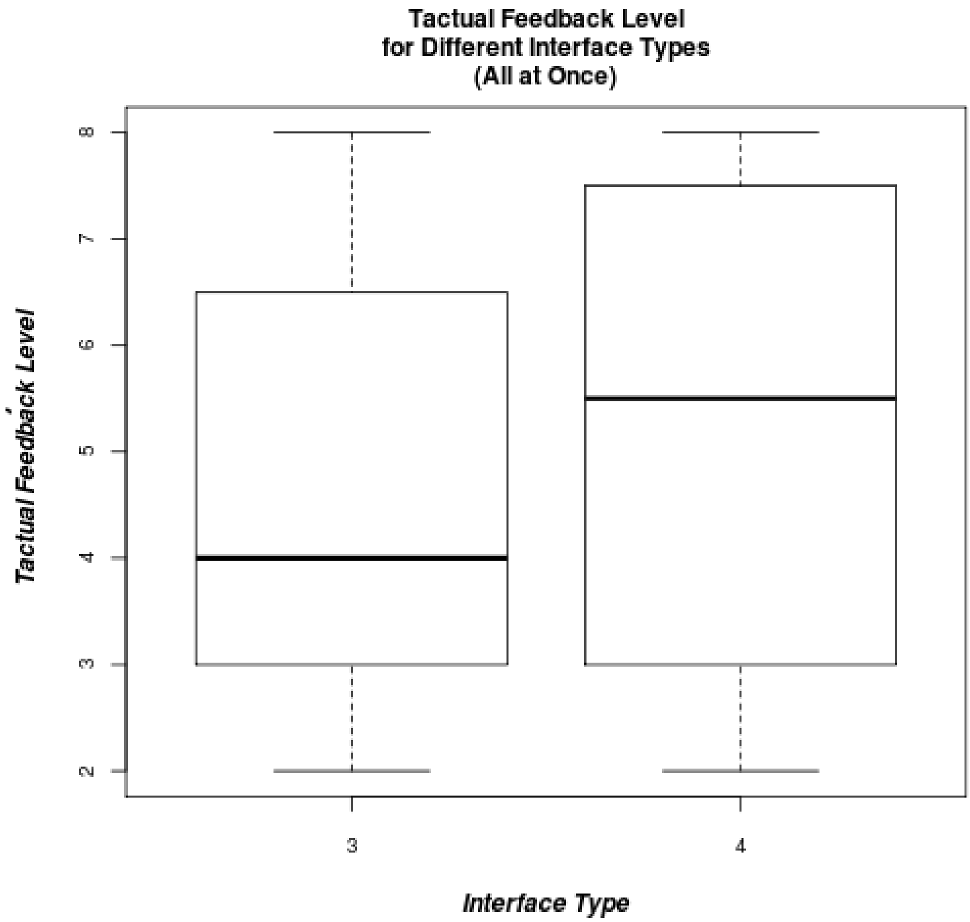
Feedback Aural vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1			
2	5.167	1.467	6.000
3	4.833	1.467	5.000
4	5.167	0.937	5.000



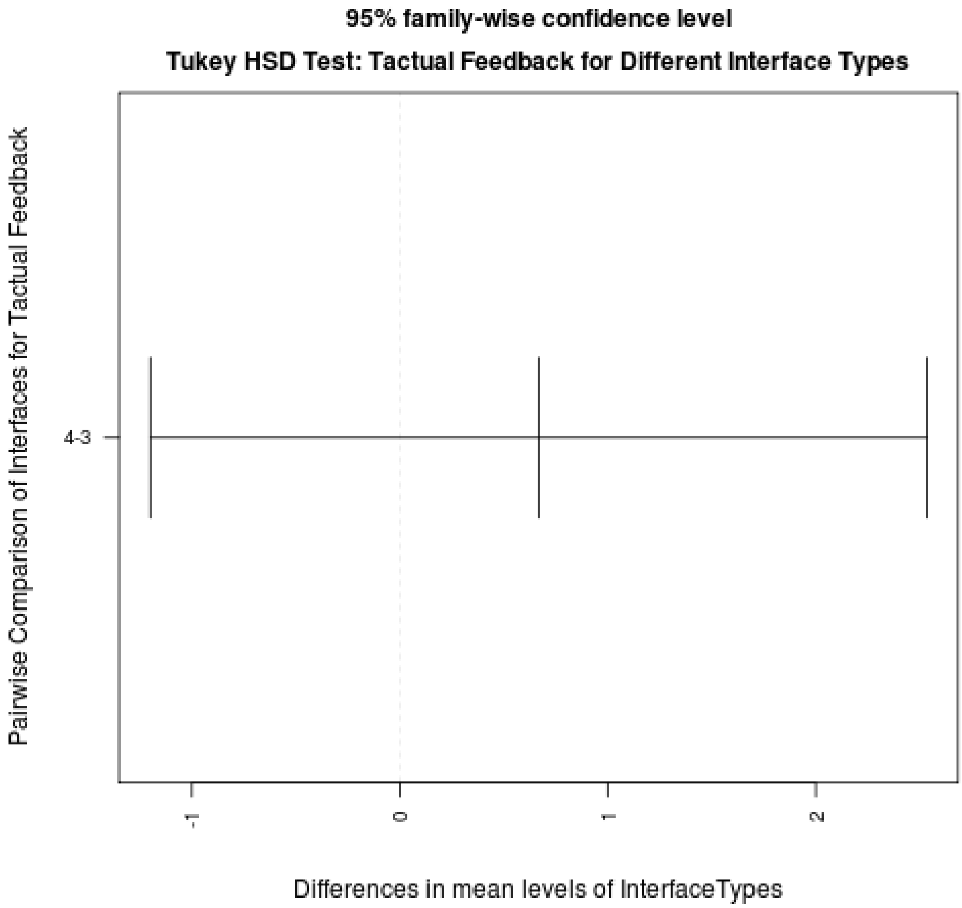




D.2.8.4.3 Feedback: Tactual Only



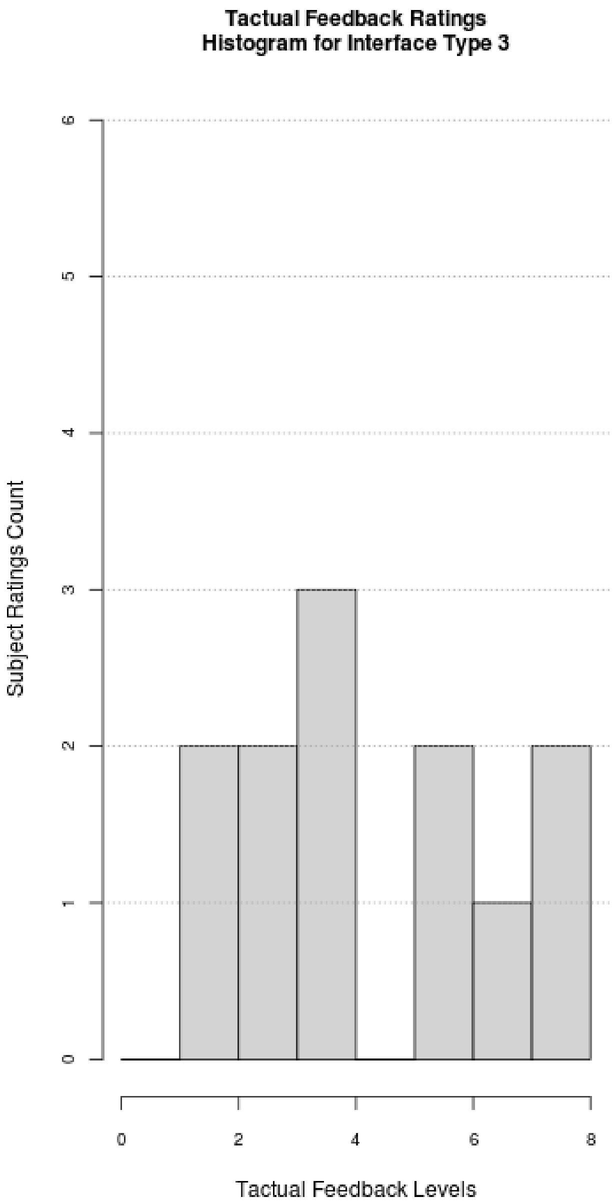
Subject Count	UI1	UI2	UI3	UI4
1			4	6
2			2	7
3			4	8
4			3	3
5			7	8
6			3	2
7			6	8
8			2	3
9			6	3
10			8	5
11			8	5
12			4	7

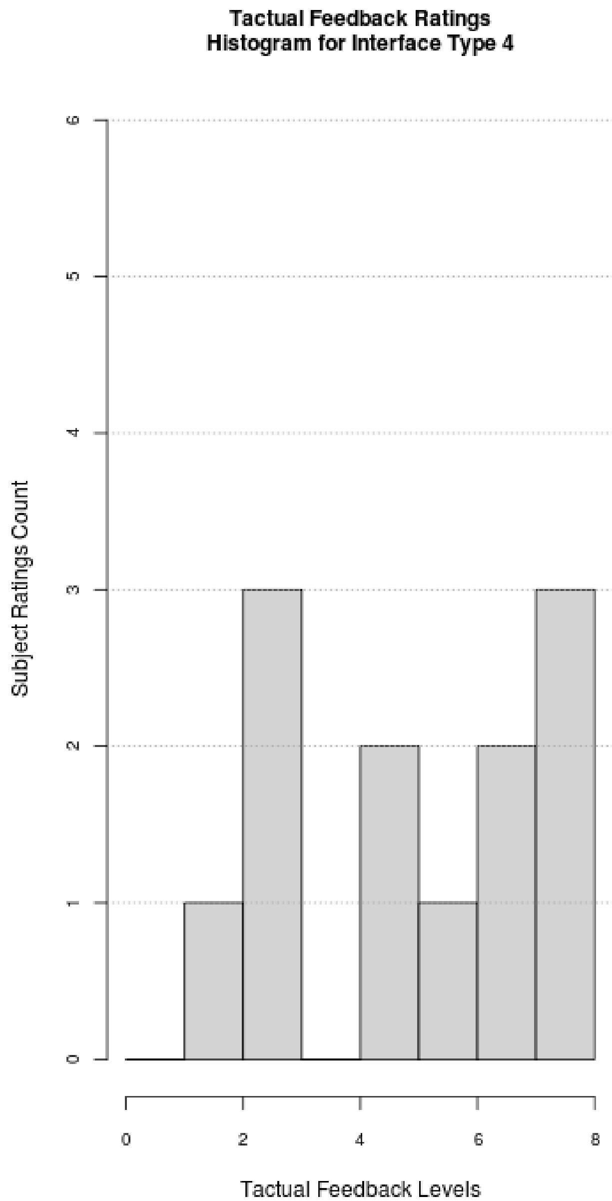


One-way ANOVA: Feedback Tactual vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	2.667	2.667	0.547	0.467
Residuals	22	107.167	4.871		

Feedback Tactual vs. Interface Used Friedman test:	
X^2	0.818
p	0.366
DoF	1

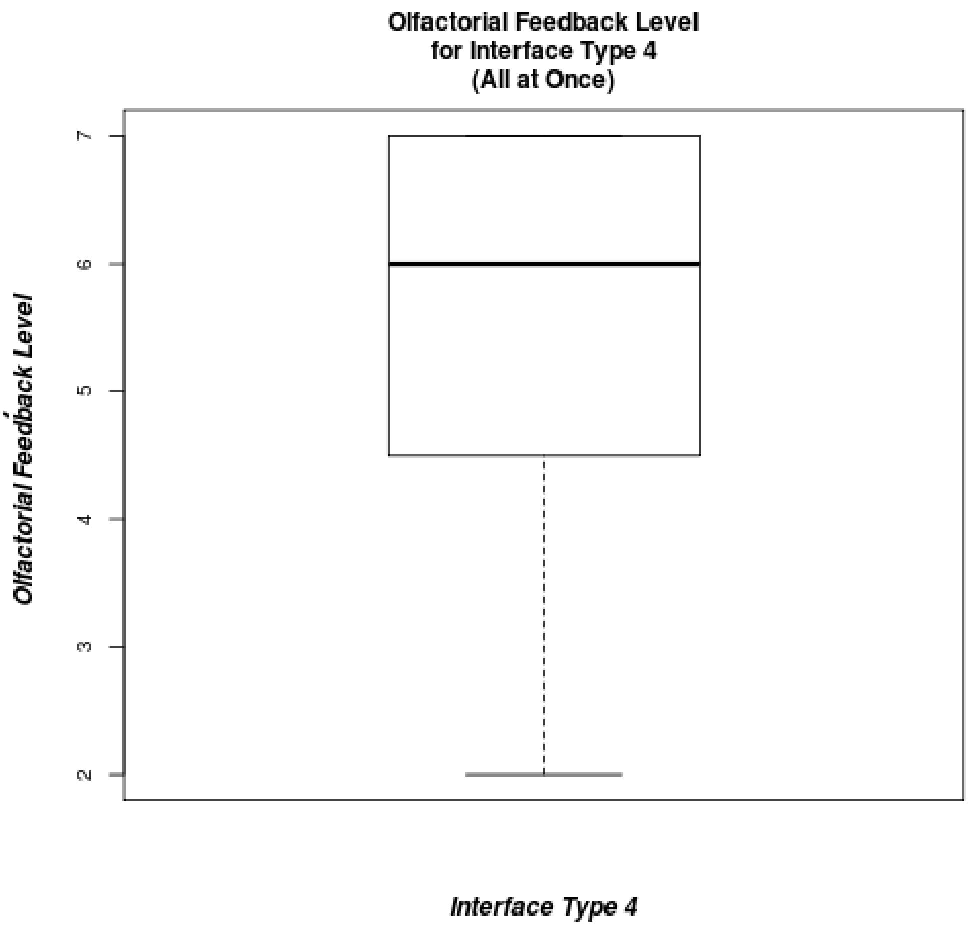
Feedback Tactual vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W						24.500
Z						-0.790
p						0.474
R						-0.081



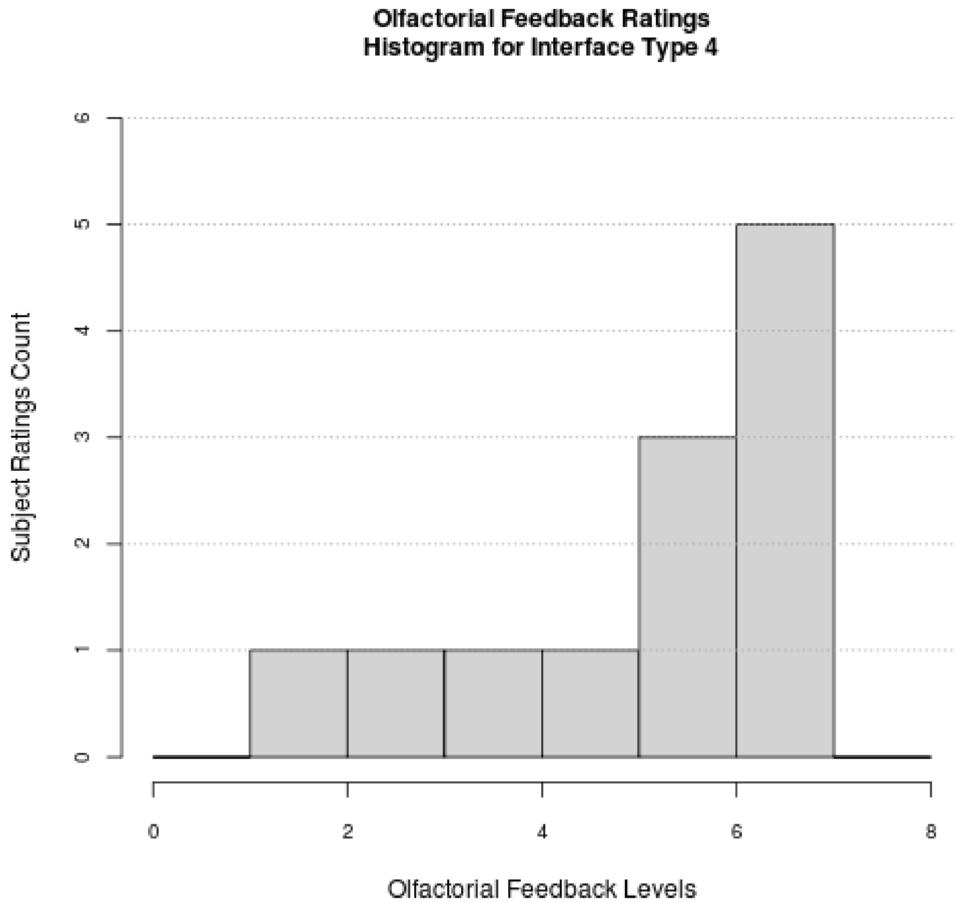


Feedback Tactual vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1			
2			
3	4.750	2.179	4.000
4	5.417	2.234	5.500

D.2.8.4.4 Feedback: Olfactorial Only

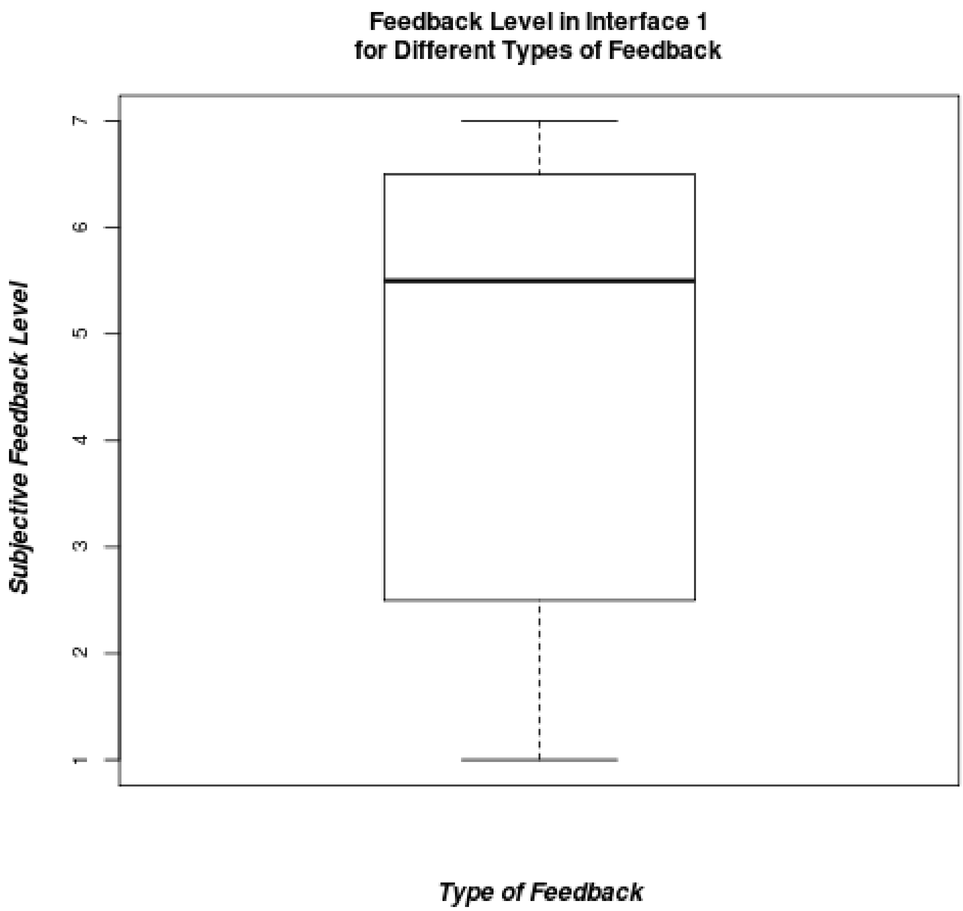


Subject Count	UI1	UI2	UI3	UI4
1				7
2				6
3				7
4				3
5				4
6				2
7				7
8				6
9				6
10				7
11				7
12				5

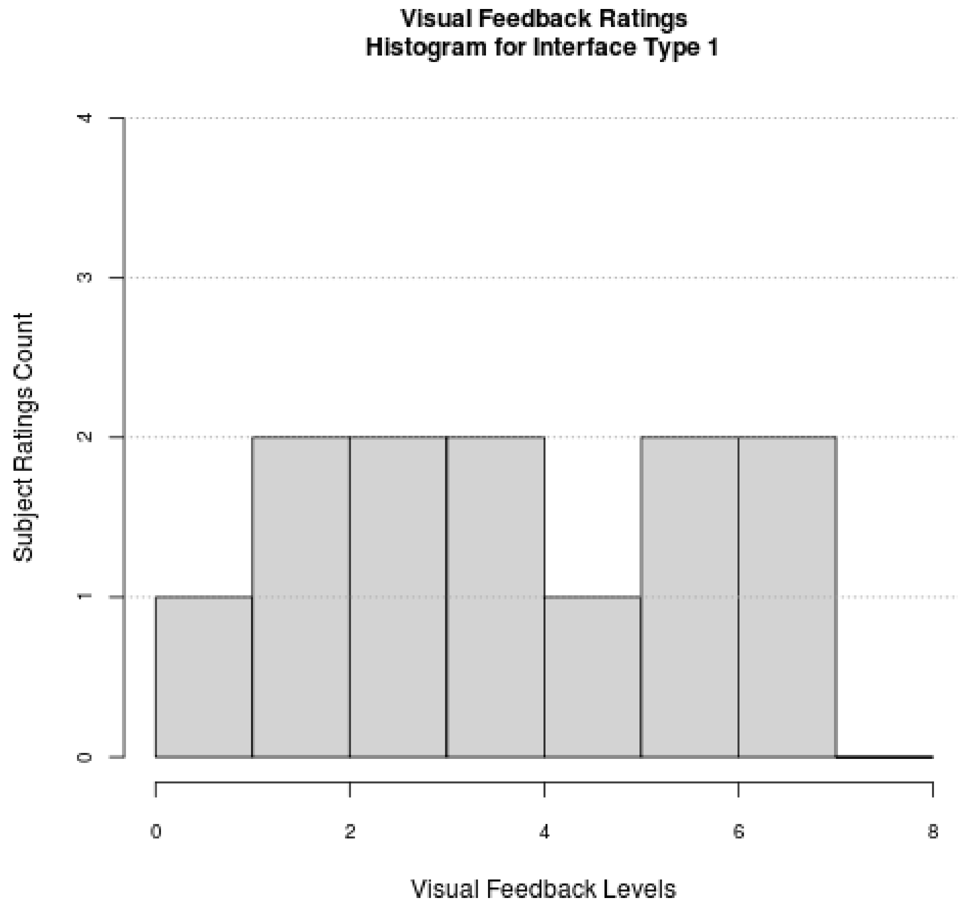


Feedback Olfacorial vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1			
2			
3			
4	5.583	1.730	6.000

D.2.8.4.5 Feedback Ratings for Each Type of Feedback: Interface 1

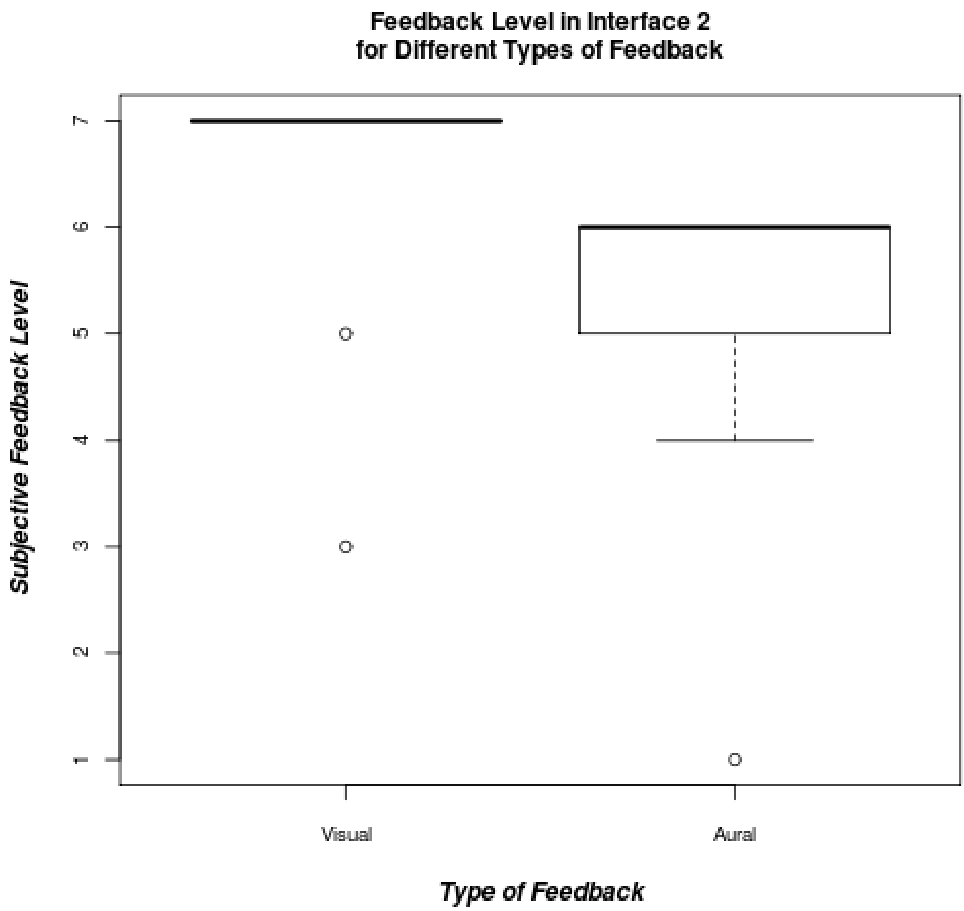


Subject Count	Visual	Aural	Tactual	Olfactorial
1	1			
2	6			
3	5			
4	7			
5	2			
6	6			
7	6			
8	7			
9	3			
10	5			
11	2			
12	7			

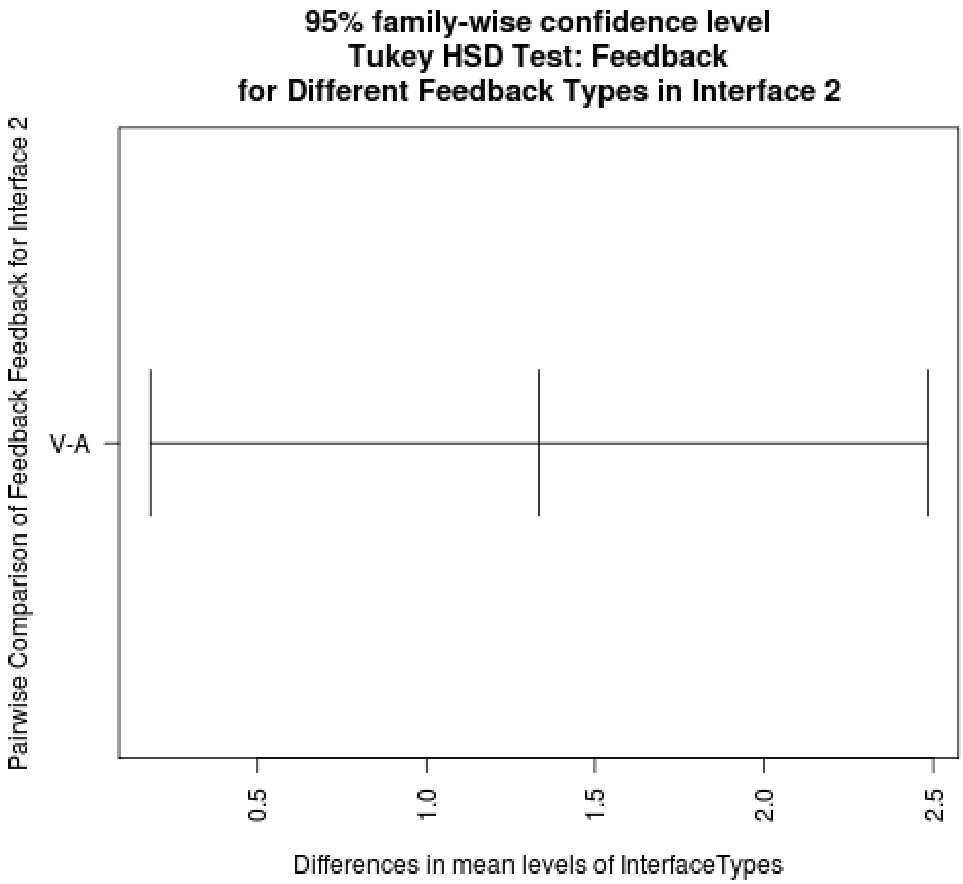


Feedback vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	4.750	2.179	5.500
Aural			
Tactual			
Olfactorial			

D.2.8.4.6 Feedback Ratings for Each Type of Feedback: Interface 2



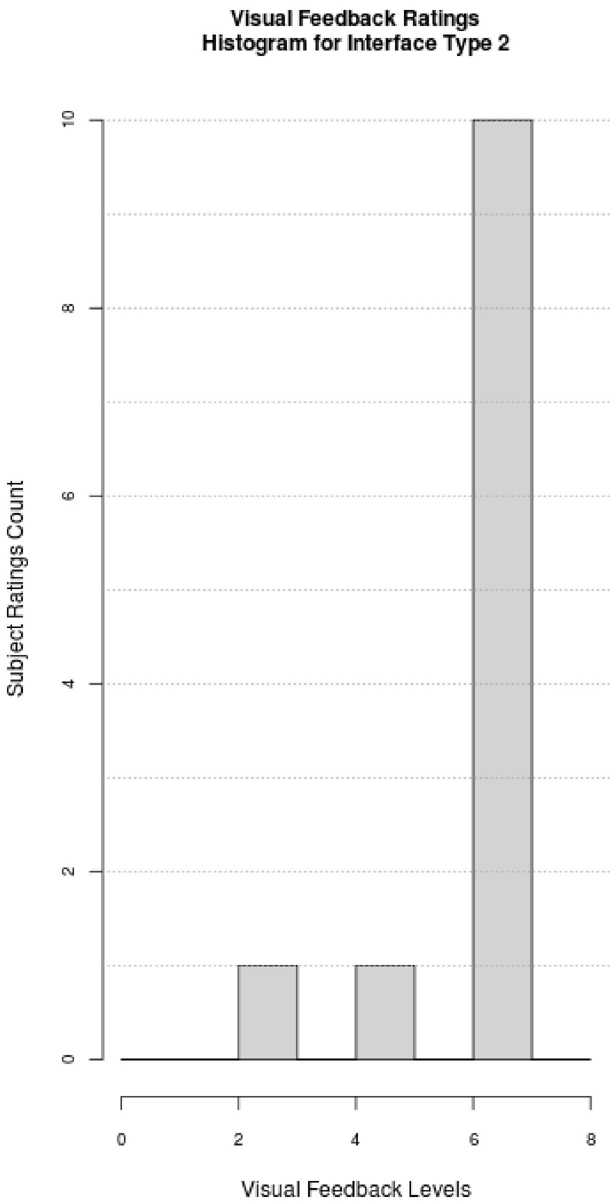
Subject Count	Visual	Aural	Tactual	Olfactorial
1	7	4		
2	7	6		
3	7	5		
4	7	6		
5	5	6		
6	7	6		
7	7	6		
8	7	5		
9	7	1		
10	3	5		
11	7	6		
12	7	6		

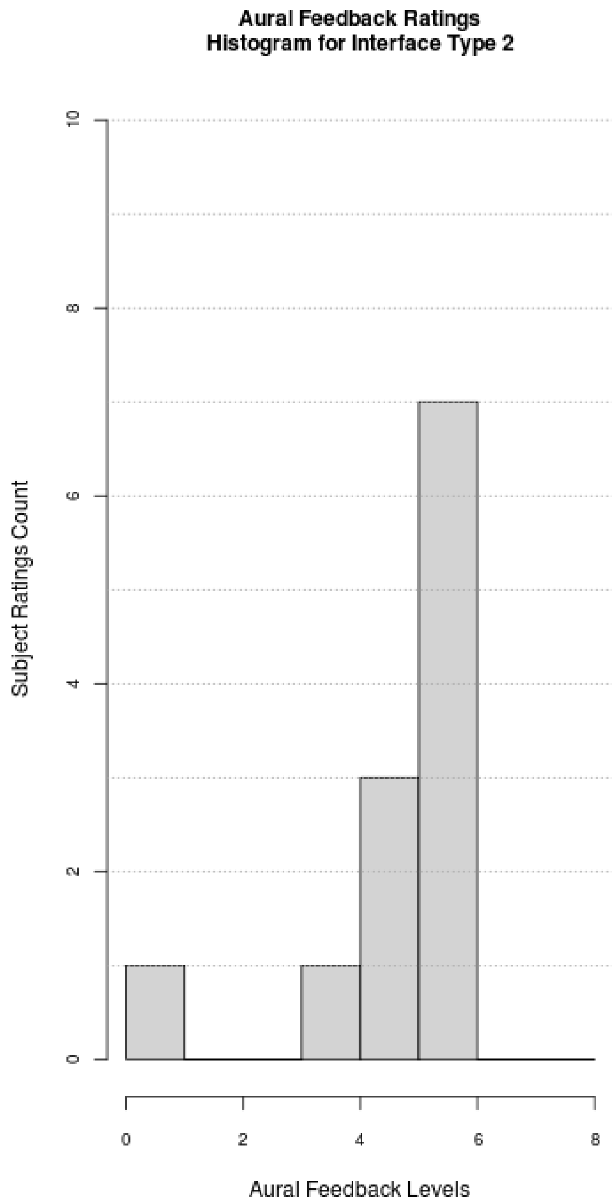


One-way ANOVA: Feedback vs. Type of Feedback					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	10.667	10.667	5.771	0.025
Residuals	22	40.667	1.849		

Feedback vs. Type of Feedback Friedman test:	
X^2	5.333
p	0.021
DoF	1

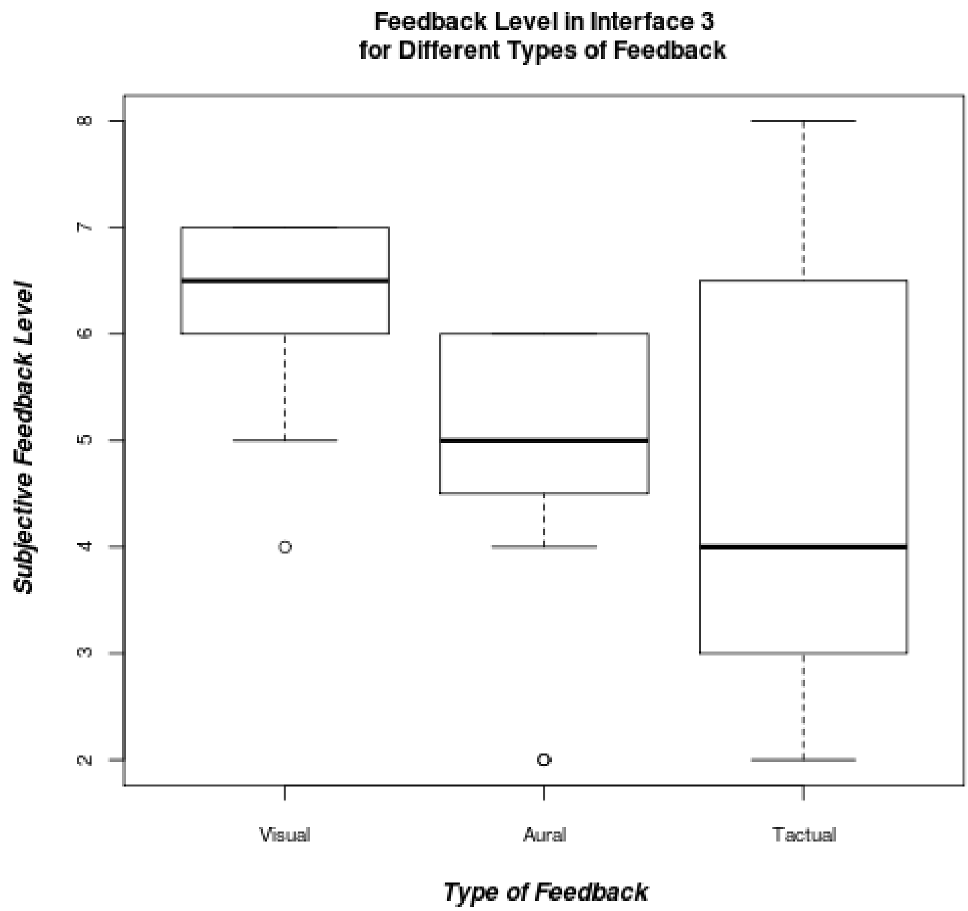
Feedback vs. Type of Feedback Wilcoxon test:						
	Visual – Aural	**Visual – Tactual**	**Visual – Olfact.**	**Aural – Tactual**	**Aural – Olfact.**	**Tactual – Olfact.**
W	57.500					
Z	2.291					
p	0.016					
R	0.234					



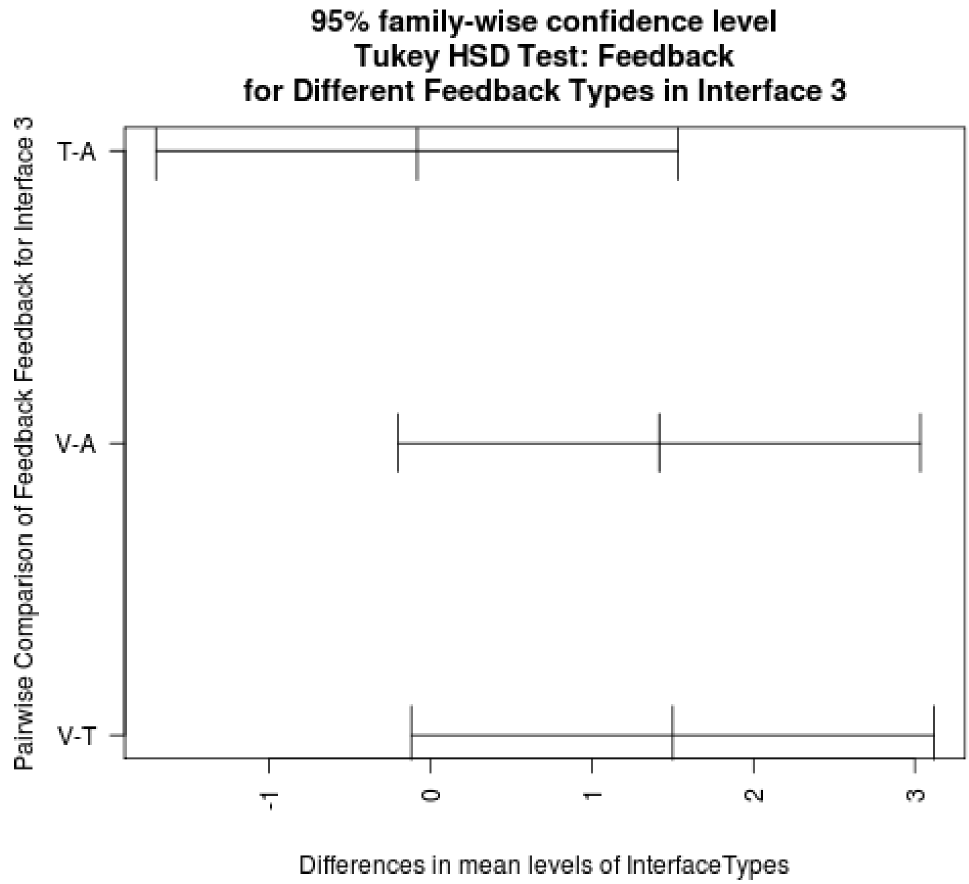


Feedback vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	6.500	1.243	7.000
Aural	5.167	1.467	6.000
Tactual			
Olfactorial			

D.2.8.4.7 Feedback Ratings for Each Type of Feedback: Interface 3



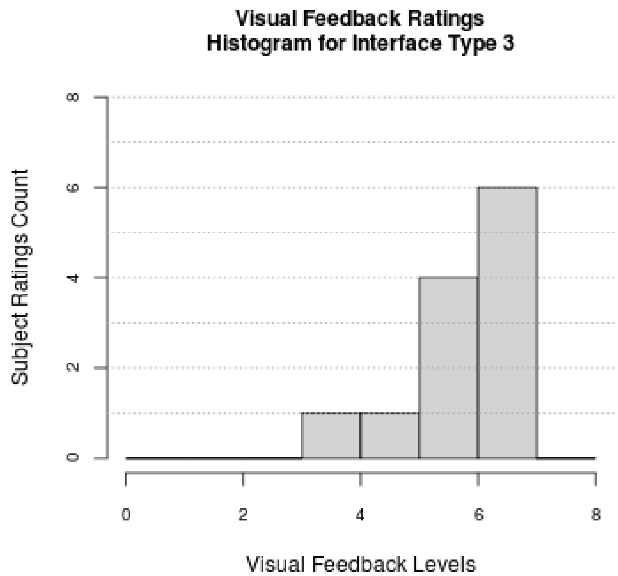
Subject Count	Visual	Aural	Tactual	Olfactorial
1	7	4	4	
2	6	5	2	
3	7	2	4	
4	6	6	3	
5	6	5	7	
6	7	6	3	
7	7	2	6	
8	5	5	2	
9	6	5	6	
10	4	6	8	
11	7	6	8	
12	7	6	4	

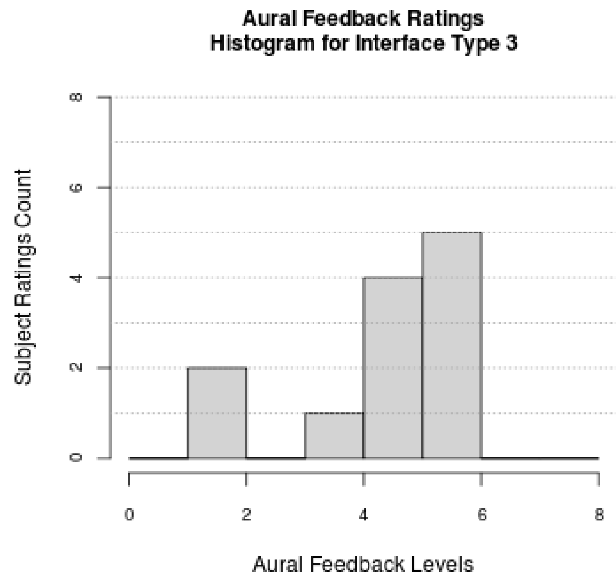


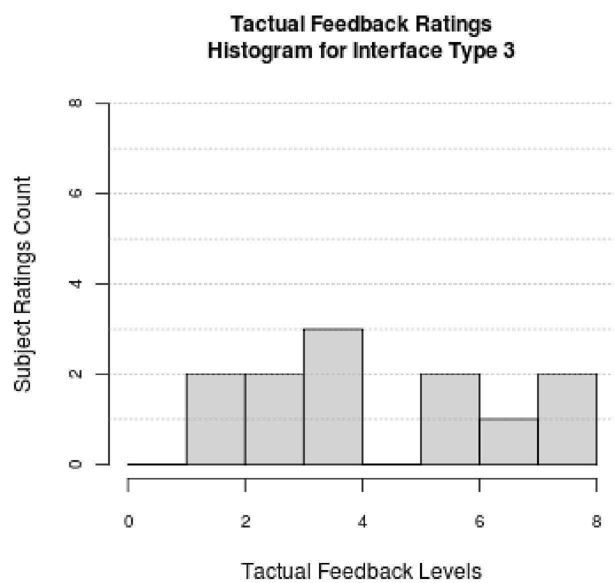
One-way ANOVA: Feedback vs. Type of Feedback					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	2	17.056	8.528	3.266	0.051
Residuals	33	86.167	2.611		

Feedback vs. Type of Feedback Friedman test:	
X^2	6.045
p	0.049
DoF	2

Feedback vs. Type of Feedback Wilcoxon test:						
	Visual – Aural	**Visual – Tactual**	**Visual – Olfact.**	**Aural – Tactual**	**Aural – Olfact.**	**Tactual – Olfact.**
W	48.000	52.000		38.000		
Z	2.276	1.706		0.357		
p	0.016	0.106		0.775		
R	0.232	0.174		0.036		

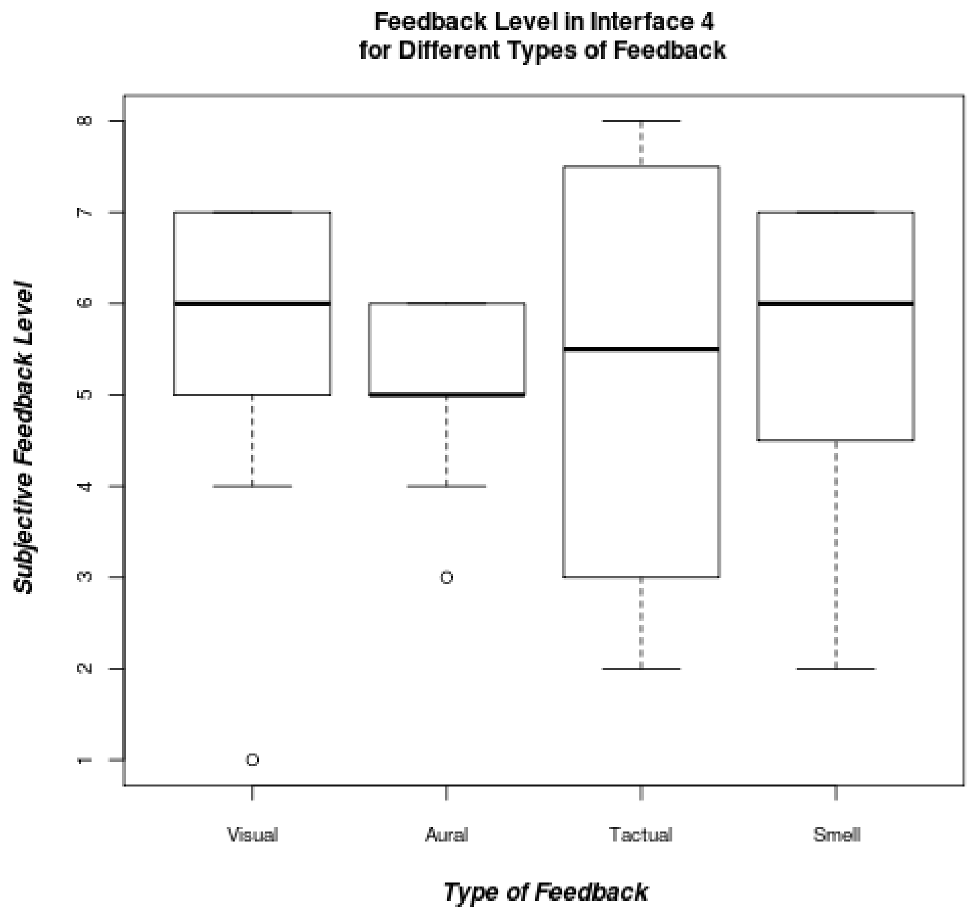




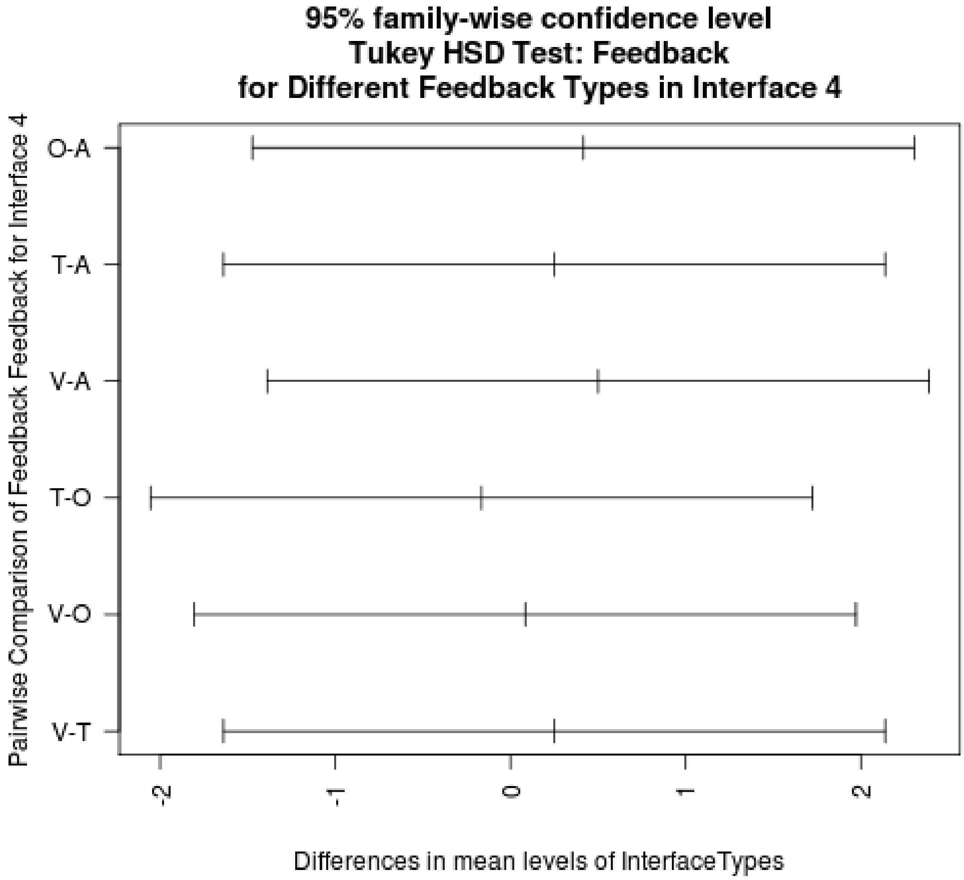


Feedback vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	6.250	0.965	6.500
Aural	4.833	1.467	5.000
Tactual	4.750	2.179	4.000
Olfactorial			

D.2.8.4.8 Feedback Ratings for Each Type of Feedback: Interface 4



Subject Count	Visual	Aural	Tactual	Olfactorial
1	1	3	6	7
2	6	5	7	6
3	7	6	8	7
4	7	5	3	3
5	5	6	8	4
6	7	5	2	2
7	7	6	8	7
8	7	6	3	6
9	5	5	3	6
10	4	4	5	7
11	6	5	5	7
12	6	6	7	5

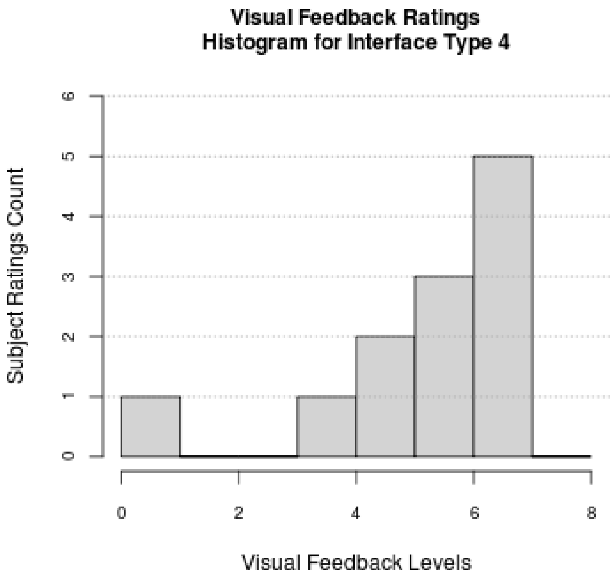


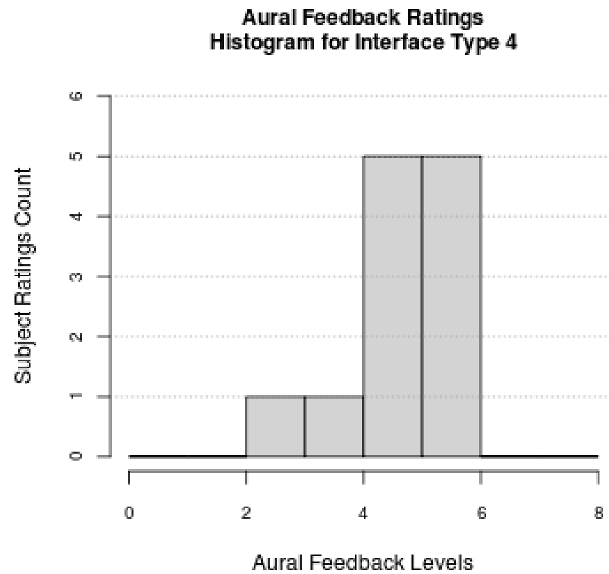
One-way ANOVA: Feedback vs. Type of Feedback					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	1.750	0.583	0.194	0.900
Residuals	44	132.170	3.004		

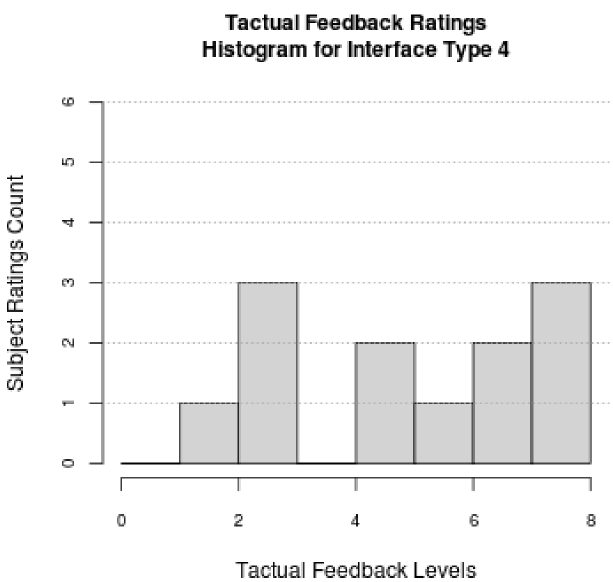
Feedback vs. Type of Feedback Friedman test:	
X^2	2.264
p	0.52
DoF	3

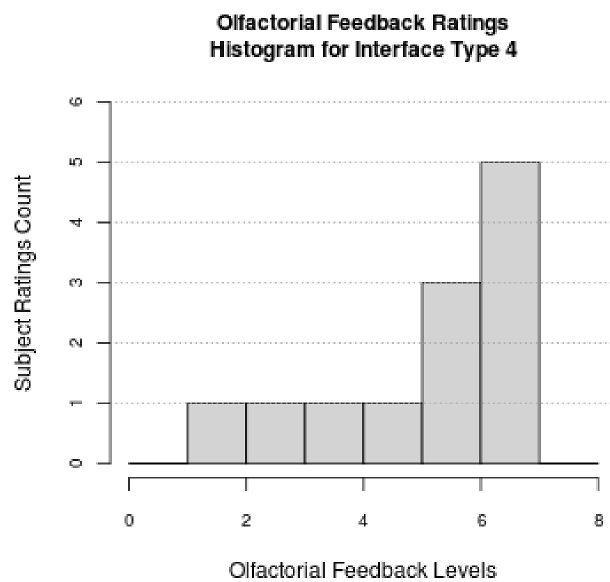
Feedback vs. Type of Feedback Wilcoxon test:						
	Visual – Aural	**Visual – Tactual**	**Visual – Olfact.**	**Aural – Tactual**	**Aural – Olfact.**	**Tactual – Olfact.**
W	33.500	41.000	24.000	31.000	26.500	23.500
Z	1.490	0.159	0.240	-0.279	-0.634	-0.317
p	0.168	0.896	0.863	0.801	0.593	0.787
R	0.152	0.016	0.024	-0.028	-0.065	-0.032

Feedback vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	5.667	1.775	6.000
Aural	5.167	0.937	5.000
Tactual	5.417	2.234	5.500
Olfactorial	5.583	1.730	6.000

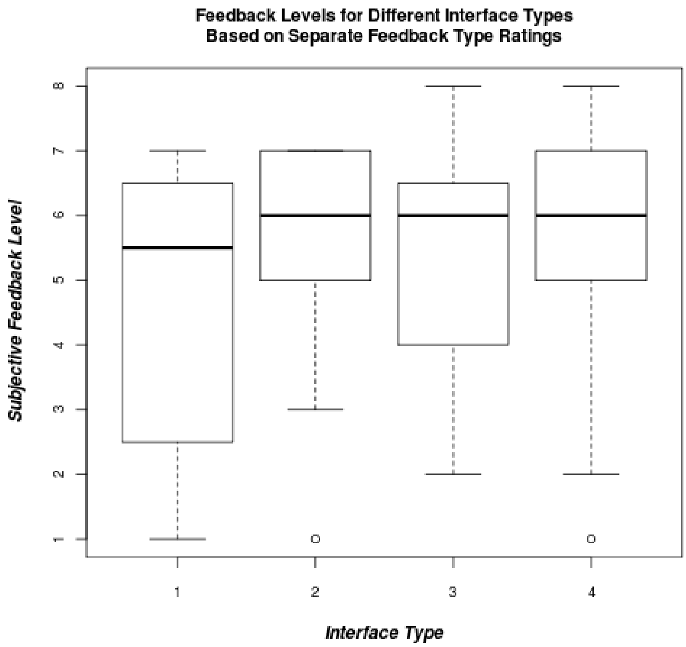


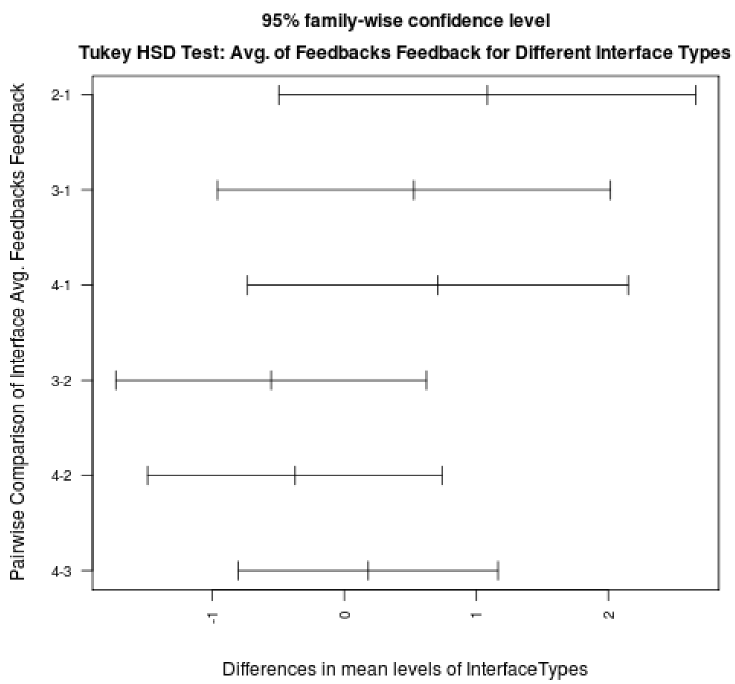






D.2.8.4.9 Overall Interface Feedback – Average of Individual Feedback Ratings





Subject Count	UI1	UI2	UI3	UI4
1	1	7	7	1
2	6	7	6	6
3	5	7	7	7
4	7	7	6	7
5	2	5	6	5
6	6	7	7	7
7	6	7	7	7
8	7	7	5	7
9	3	7	6	5
10	5	3	4	4
11	2	7	7	6
12	7	7	7	6
13		4	4	3
14		6	5	5
15		5	2	6
16		6	6	5
17		6	5	6
18		6	6	5
19		6	2	6
20		5	5	6
21		1	5	5
22		5	6	4
23		6	6	5
24		6	6	6
25			4	6
26			2	7
27			4	8
28			3	3
29			7	8
30			3	2
31			6	8
32			2	3
33			6	3
34			8	5
35			8	5
36			4	7
37				7
38				6
39				7
40				3
41				4
42				2
43				7
44				6
45				6
46				7
47				7
48				5

One-way ANOVA: Avg. of Feedbacks Feedback vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	10.270	3.423	1.165	0.326
Residuals	116	340.720	2.937		

Avg. of Feedbacks Feedback vs. Interface Used Friedman test:	
X^2	7.379
p	0.061
DoF	3

Avg. of Feedbacks Feedback vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	4.750	2.179	5.500
2	5.833	1.494	6.000
3	5.278	1.717	6.000
4	5.458	1.688	6.000

One-way ANOVA: Avg. of Feedbacks Feedback – Interfaces 1 and 2					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	9.389	9.389	3.082	0.088
Residuals	34	103.583	3.047		

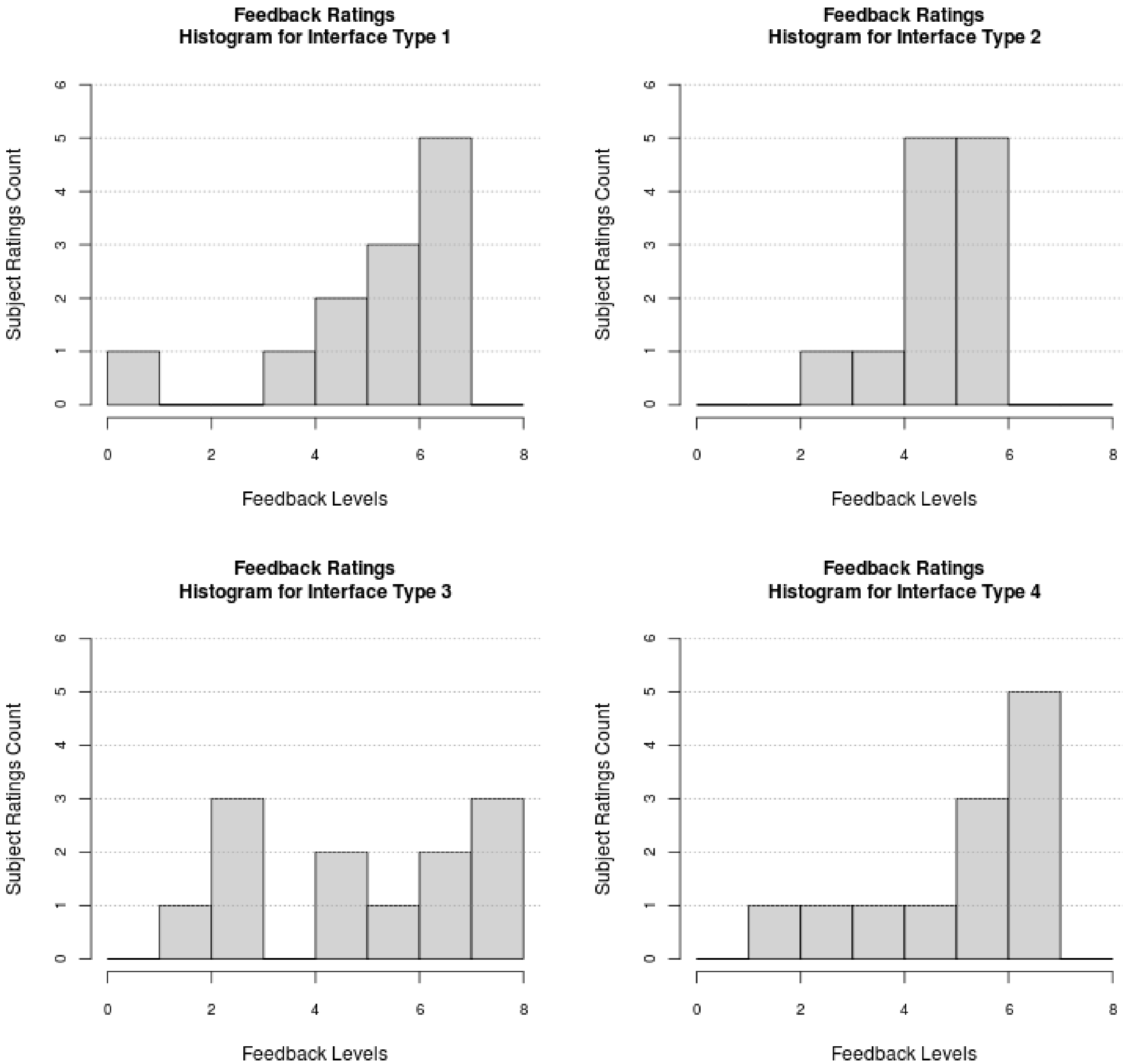
One-way ANOVA: Avg. of Feedbacks Feedback – Interfaces 1 and 3					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	2.507	2.507	0.742	0.394
Residuals	46	155.472	3.380		

One-way ANOVA: Avg. of Feedbacks Feedback – Interfaces 1 and 4					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	4.817	4.817	1.501	0.226
Residuals	58	186.167	3.210		

One-way ANOVA: Avg. of Feedbacks Feedback – Interfaces 2 and 3					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	0.469	0.469	0.143	0.707
Residuals	58	190.514	3.285		

One-way ANOVA: Avg. of Feedbacks Feedback – Interfaces 2 and 4					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	2.250	2.250	0.850	0.360
Residuals	70	185.250	2.646		

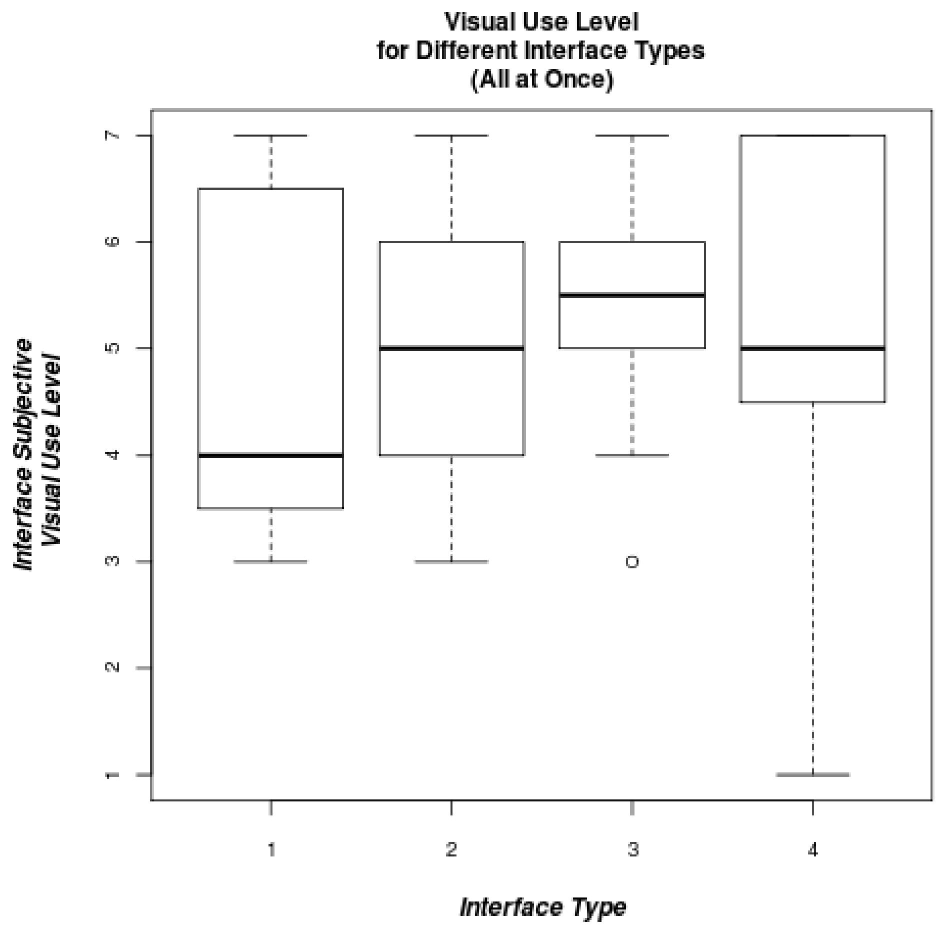
One-way ANOVA: Avg. of Feedbacks Feedback – Interfaces 3 and 4					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	0.671	0.671	0.232	0.631
Residuals	82	237.139	2.892		



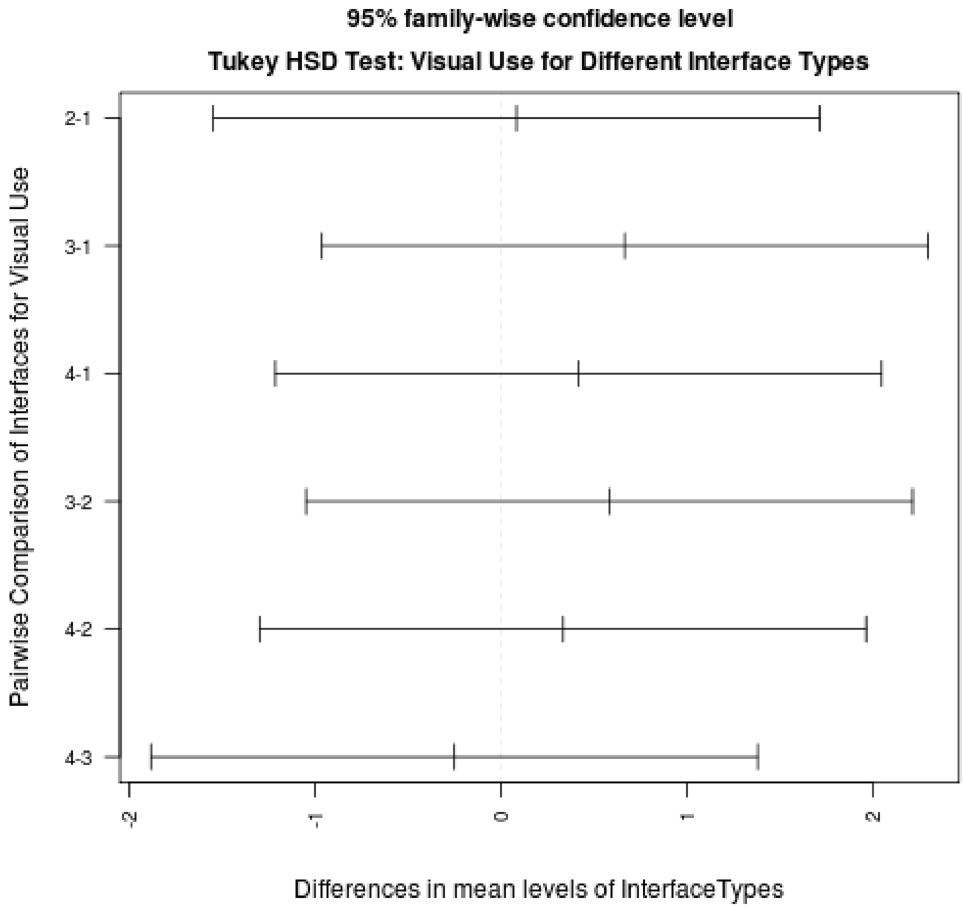
Feedback Ratings
Histogram for Interface Type 1
Subject Ratings Count
Feedback Levels
Feedback Ratings
Histogram for Interface Type 2
Subject Ratings Count
Feedback Levels
Feedback Ratings
Histogram for Interface Type 3
Subject Ratings Count
Feedback Levels
Feedback Ratings
Histogram for Interface Type 4
Subject Ratings Count
Feedback Levels

D.2.8.5 Use

D.2.8.5.1 Use: Visual Only



Subject Count	UI1	UI2	UI3	UI4
1	7	7	3	1
2	4	6	6	6
3	3	5	6	7
4	7	6	7	4
5	4	4	4	3
6	7	6	6	5
7	5	5	5	7
8	4	3	5	5
9	3	3	6	5
10	4	4	5	5
11	3	4	5	7
12	6	5	7	7

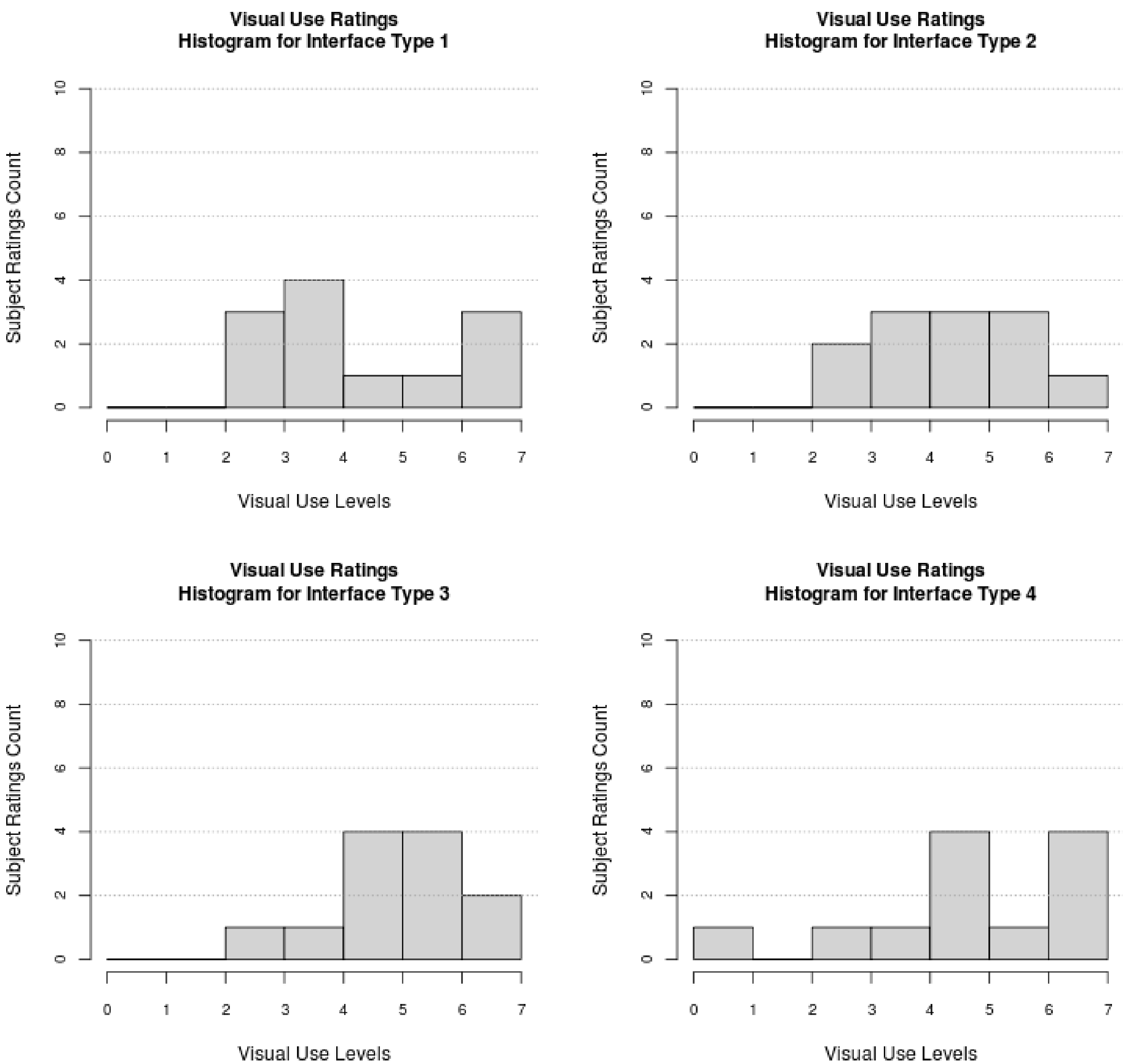


One-way ANOVA: Use Visual vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	3.417	1.1389	0.5087	0.6783
Residuals	44	98.5	2.2386		

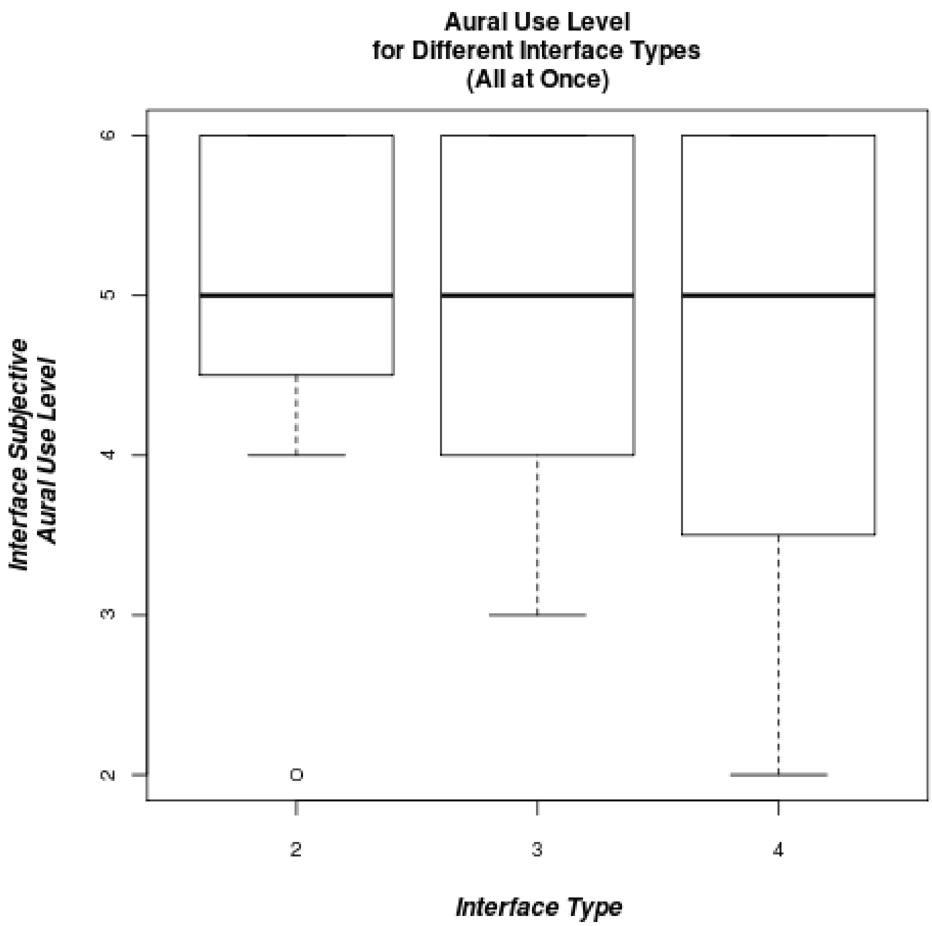
Use Visual vs. Interface Used Friedman test:	
X^2	5.370
p	0.147
DoF	3

Use Visual vs. Interface UsedUse Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	12.000	11.500	30.000	8.000	21.500	21.500
Z	0.041	-1.474	-0.712	-1.775	-1.036	0.606
p	1.000	0.160	0.511	0.070	0.349	0.609
R	0.004	-0.150	-0.073	-0.181	-0.106	0.062

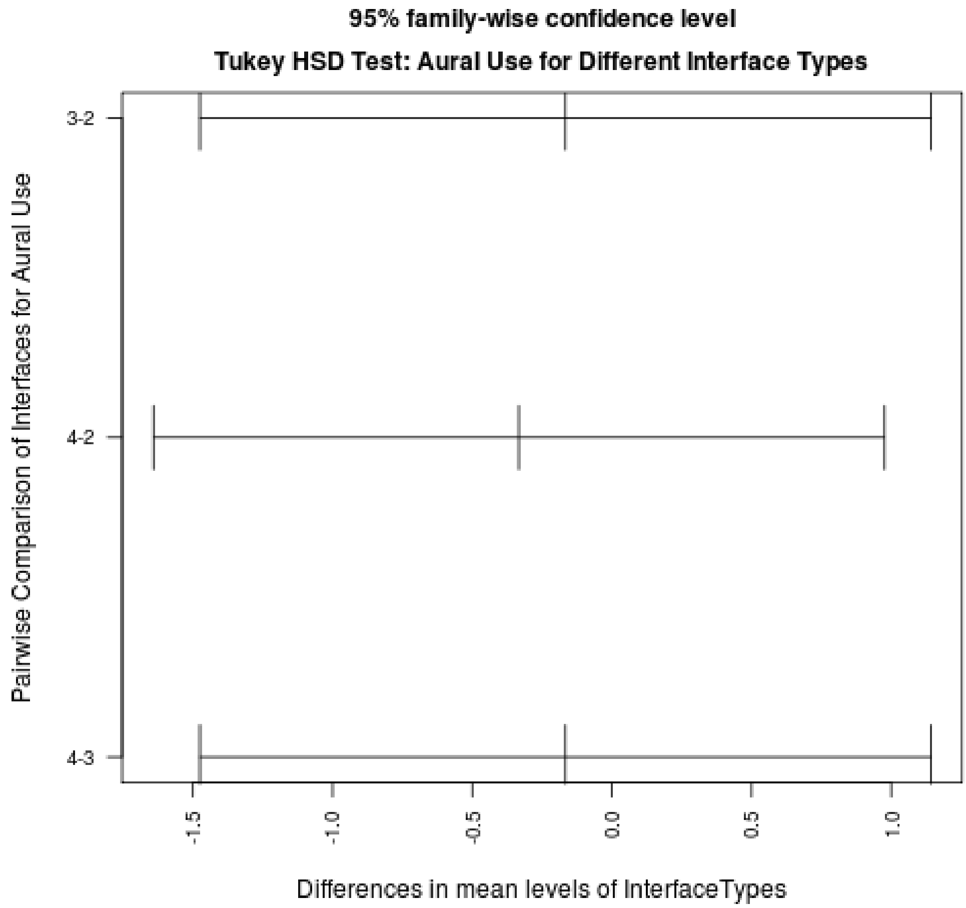
Use Visual vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	4.750	1.603	4.000
2	4.833	1.267	5.000
3	5.417	1.165	5.500
4	5.167	1.850	5.000



D.2.8.5.2 Use: Aural Only



Subject Count	UI1	UI2	UI3	UI4
1		4	3	3
2		5	5	5
3		6	4	2
4		5	6	5
5		6	3	6
6		5	5	4
7		4	5	6
8		2	5	6
9		6	6	5
10		5	4	2
11		6	6	6
12		6	6	6

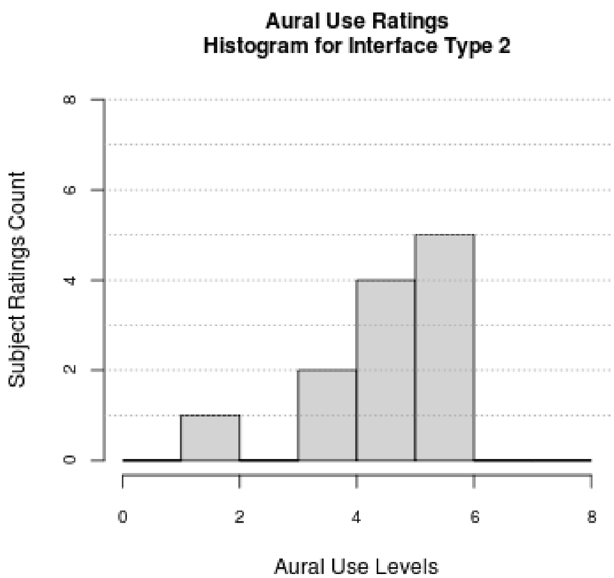


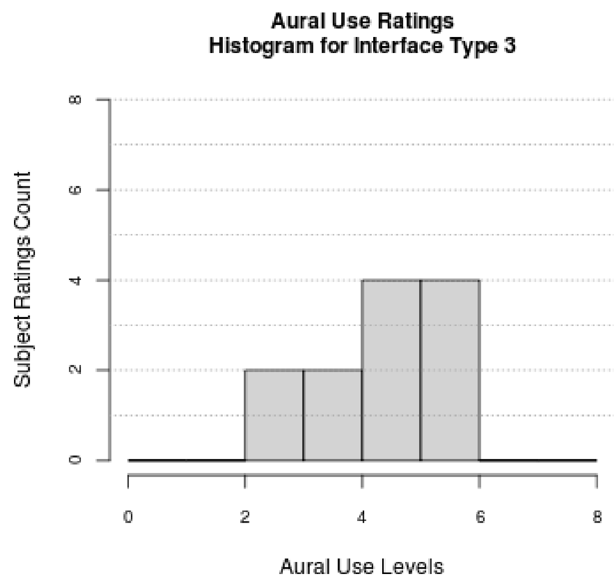
One-way ANOVA: Use Aural vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	2	0.667	0.333	0.195	0.824
Residuals	33	56.333	1.707		

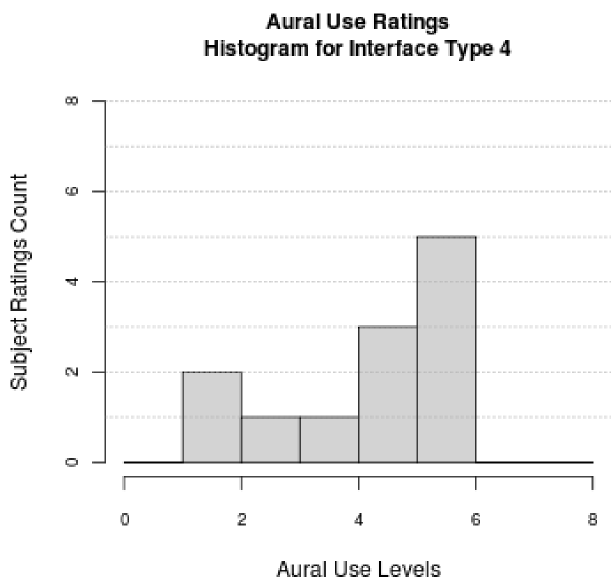
Use Aural vs. Interface Used Friedman test:	
X^2	1.355
p	0.508
DoF	2

Use Aural vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W				16.500	17.500	22.000
Z				0.412	0.904	0.648
p				0.797	0.406	0.602
R				0.042	0.092	0.066

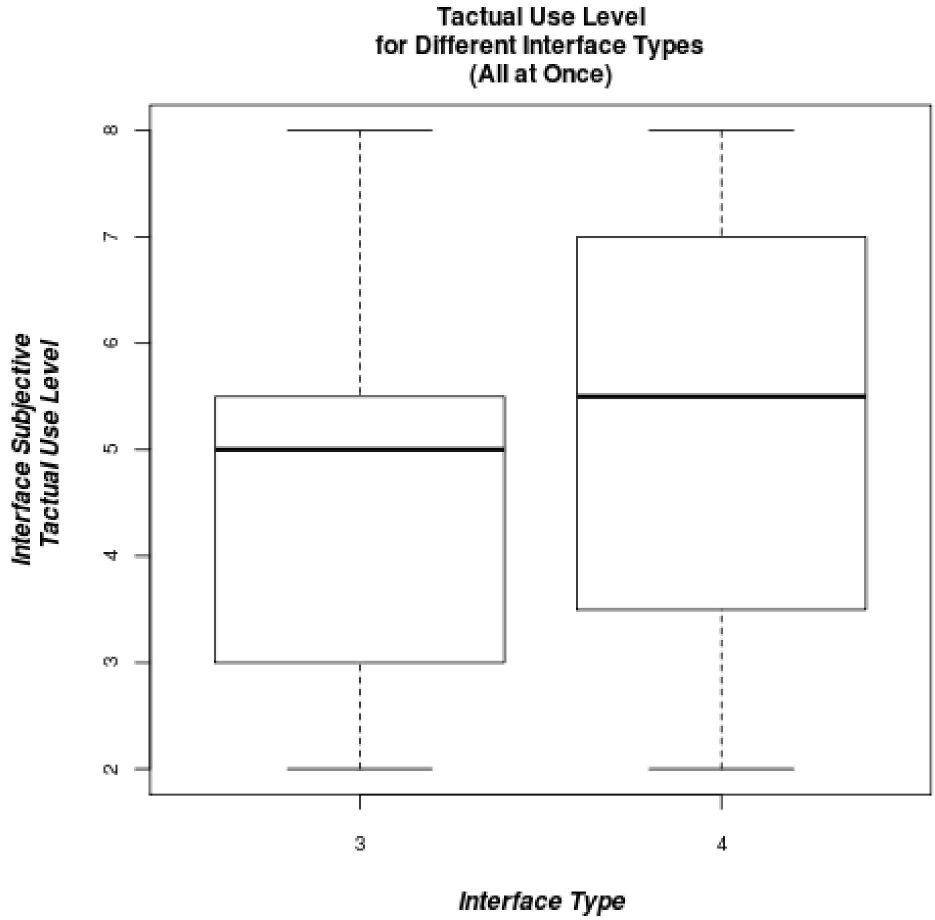
Use Aural vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1			
2	5.000	1.206	5.000
3	4.833	1.115	5.000
4	4.667	1.557	5.000



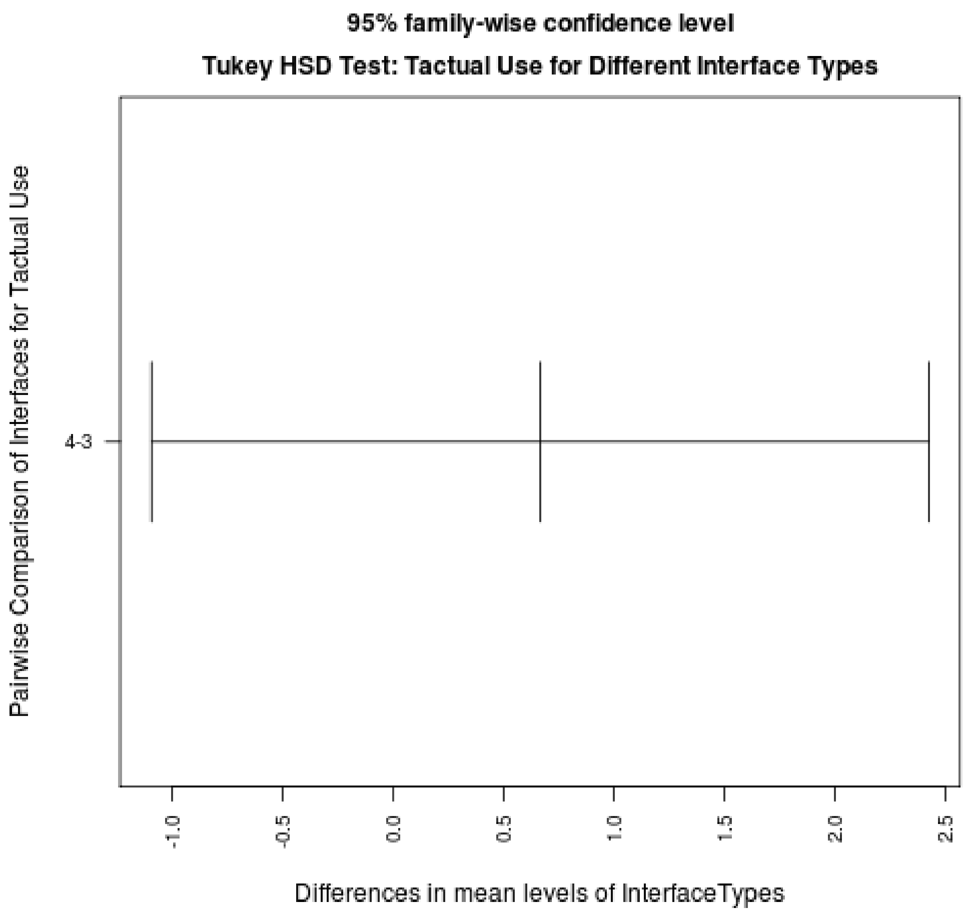




D.2.8.5.3 Use: Tactual Only



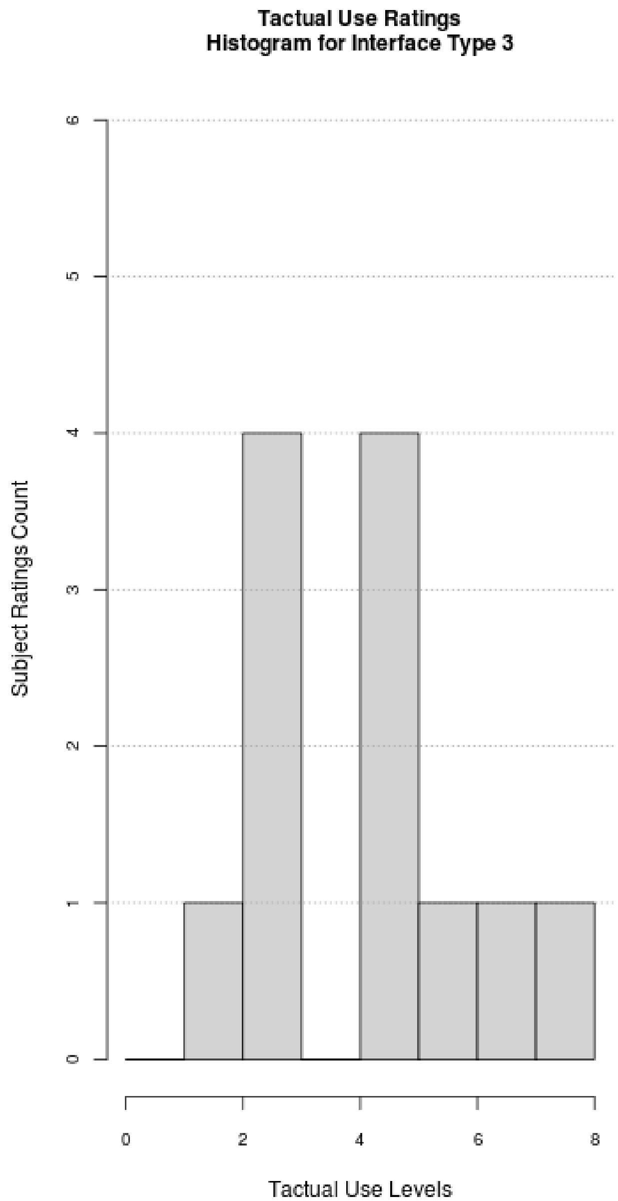
Subject Count	UI1	UI2	UI3	UI4
1			5	7
2			2	7
3			3	8
4			3	2
5			5	8
6			5	4
7			7	4
8			3	2
9			6	3
10			5	4
11			8	7
12			3	7

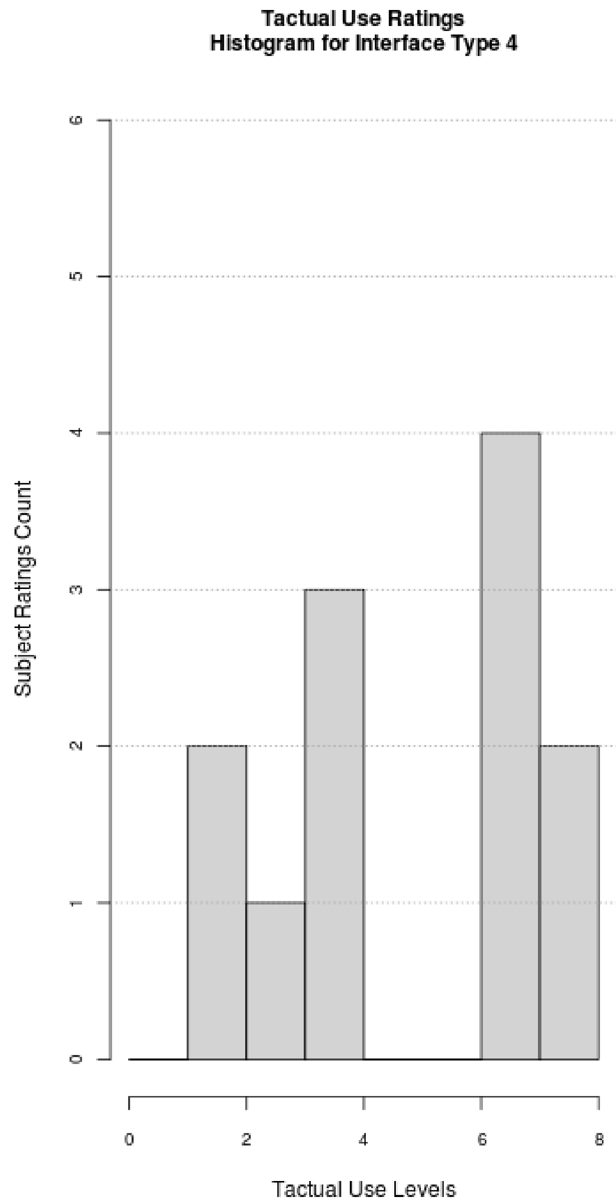


One-way ANOVA: Use Tactual vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	2.667	2.667	0.617	0.441
Residuals	22	95.167	4.326		

Use Tactual vs. Interface Used Friedman test:	
X^2	0.333
p	0.564
DoF	1

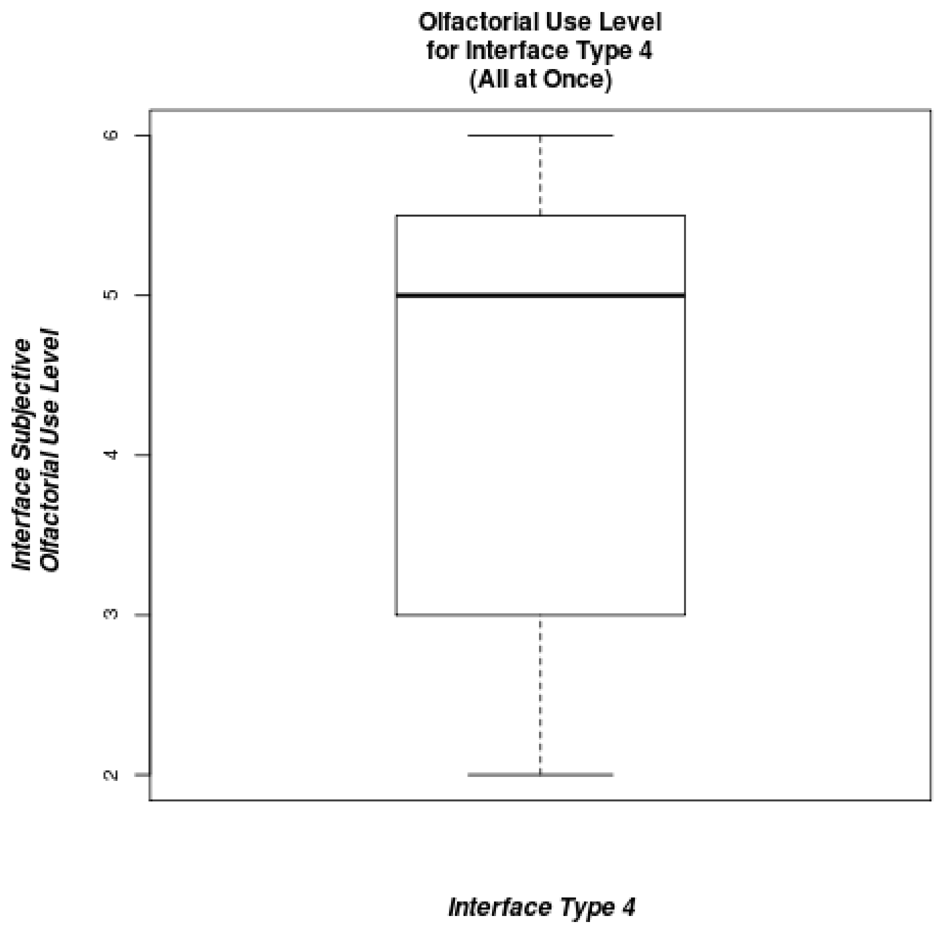
Use Tactual vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W						31.000
Z						-0.634
p						0.544
R						-0.065



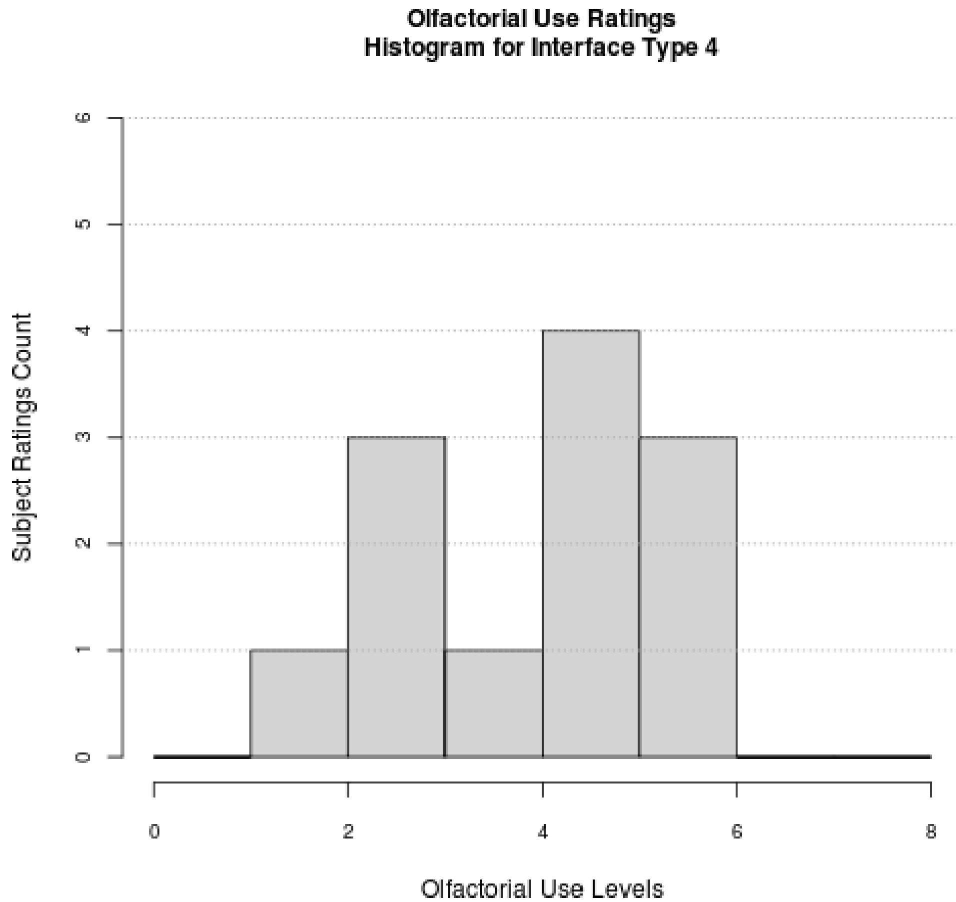


Use Tactual vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1			
2			
3	4.583	1.832	5
4	5.25	2.301	5.5

D.2.8.5.4 Use: Olfactorial Only

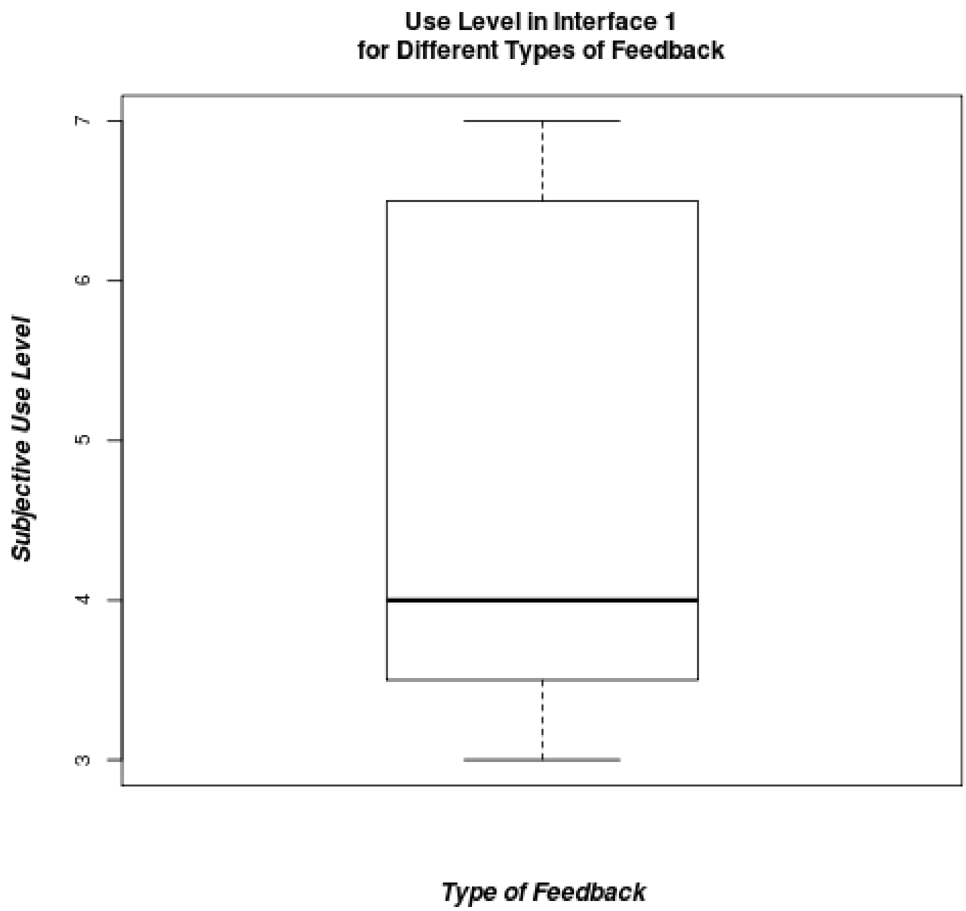


Subject Count	UI1	UI2	UI3	UI4
1				6
2				5
3				3
4				4
5				5
6				2
7				3
8				5
9				3
10				6
11				6
12				5

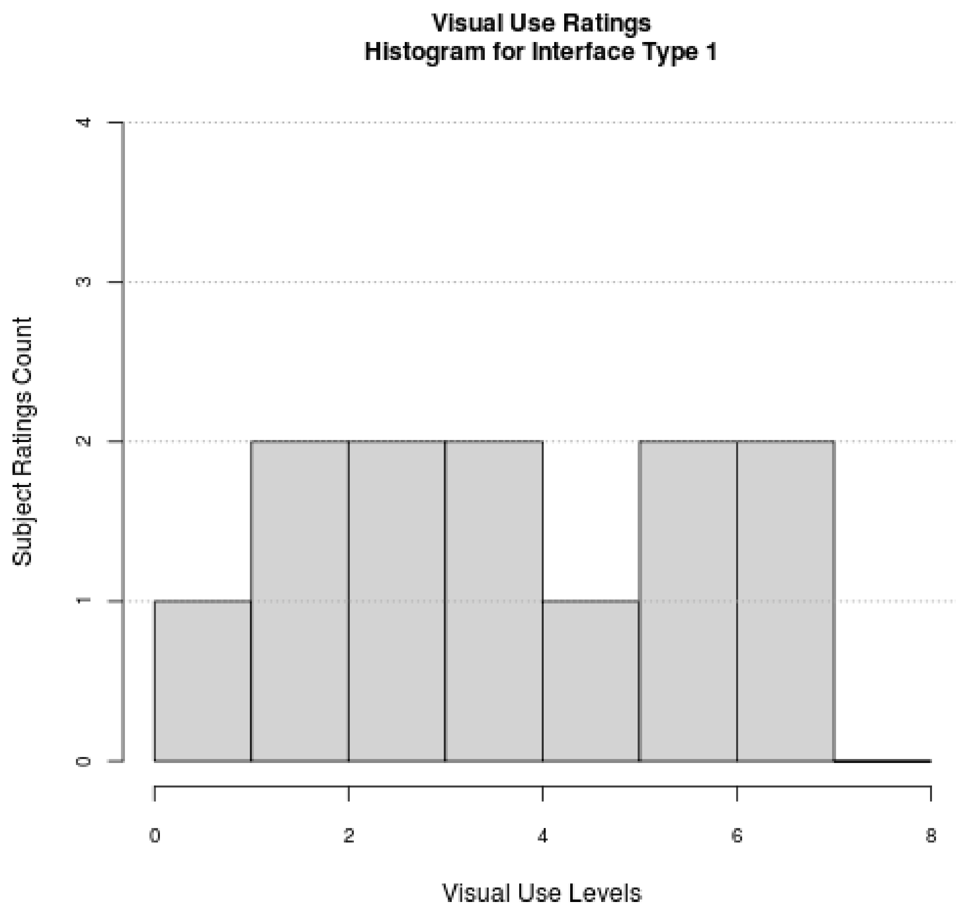


Use Olfacorial vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1			
2			
3			
4	4.417	1.379	5

D.2.8.5.5 Use Ratings for Each Type of Feedback: Interface 1

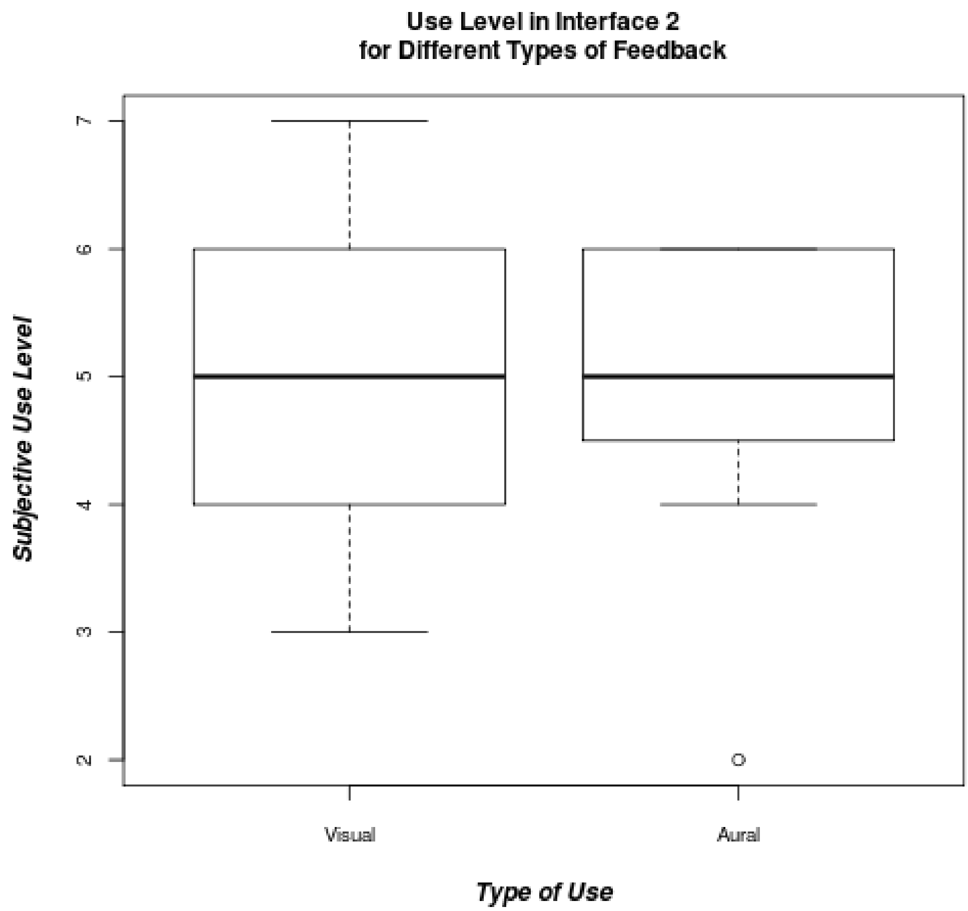


Subject Count	Visual	Aural	Tactual	Olfactorial
1	7			
2	4			
3	3			
4	7			
5	4			
6	7			
7	5			
8	4			
9	3			
10	4			
11	3			
12	6			

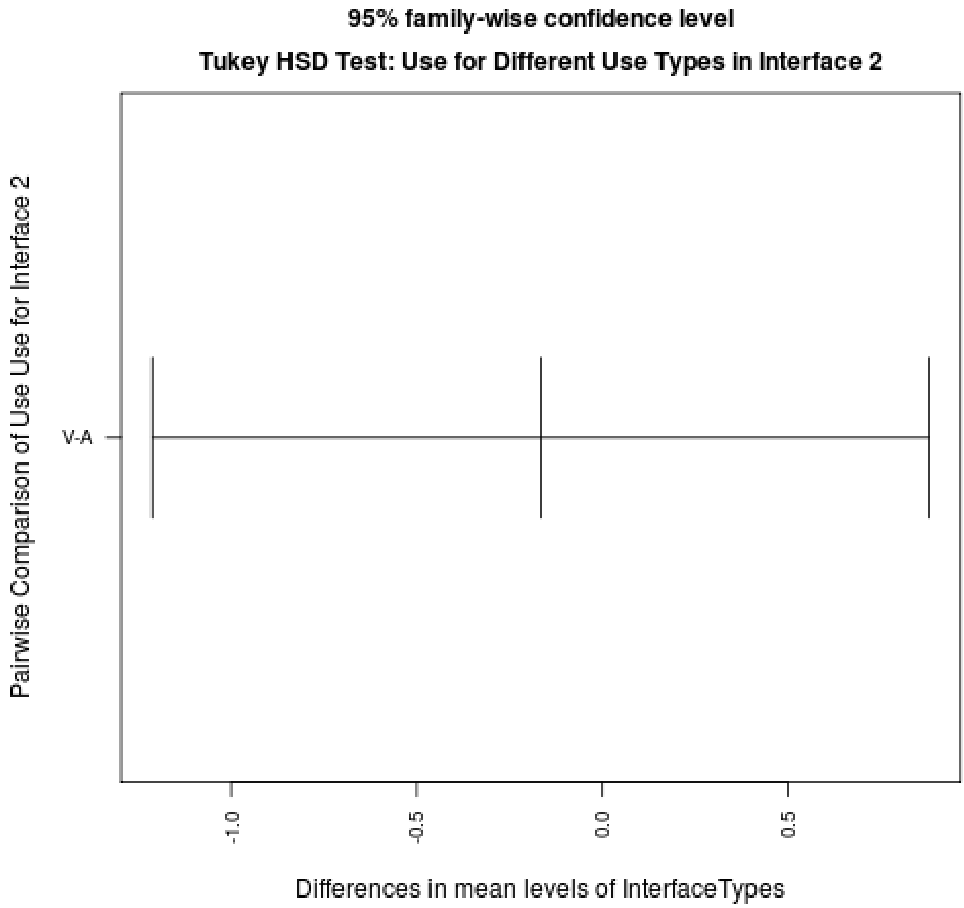


Use vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	4.750	1.603	4.000
Aural			
Tactual			
Olfactorial			

D.2.8.5.6 Use Ratings for Each Type of Feedback: Interface 2



Subject Count	Visual	Aural	Tactual	Olfactorial
1	7	4		
2	6	5		
3	5	6		
4	6	5		
5	4	6		
6	6	5		
7	5	4		
8	3	2		
9	3	6		
10	4	5		
11	4	6		
12	5	6		

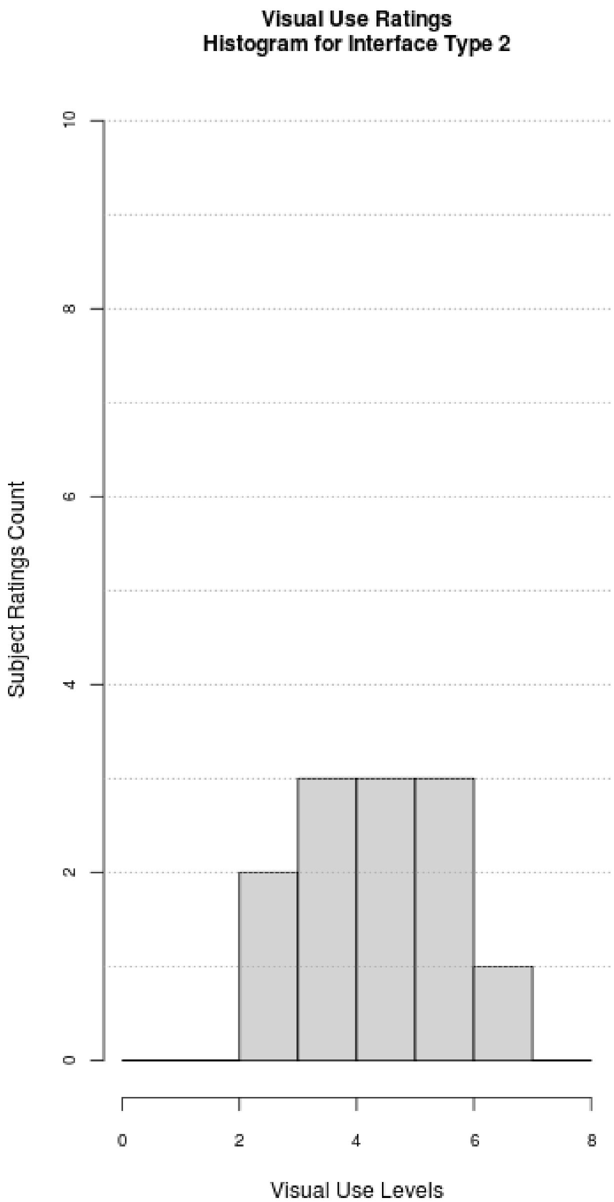


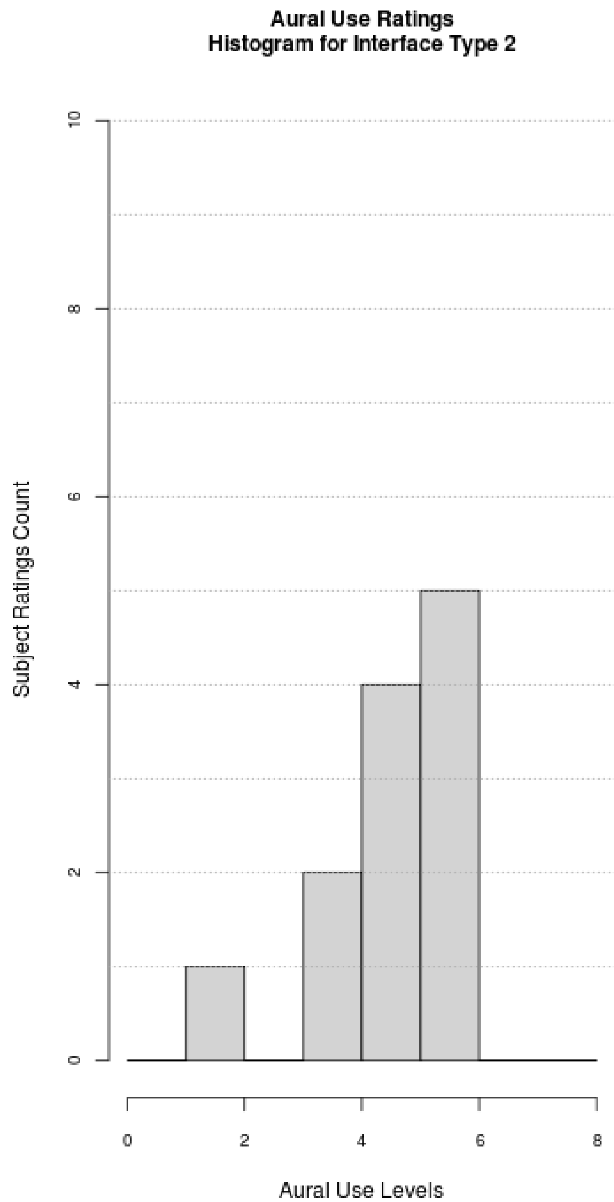
One-way ANOVA: Use vs. Type of Feedback					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	0.167	0.167	0.109	0.745
Residuals	22	33.667	1.530		

Use vs. Type of Feedback Friedman test:	
X^2	0.000
p	1.000
DoF	1

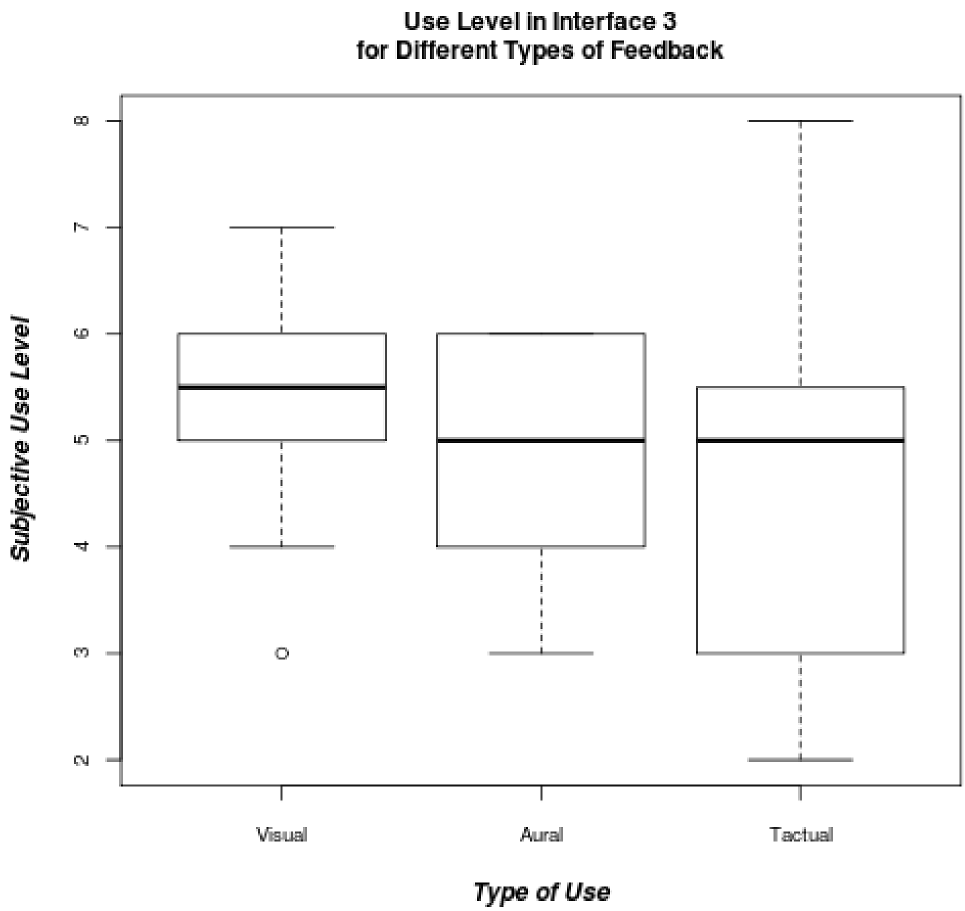
Use vs. Type of Feedback Wilcoxon test:						
	Visual – Aural	**Visual – Tactual**	**Visual – Olfact.**	**Aural – Tactual**	**Aural – Olfact.**	**Tactual – Olfact.**
W	34.000					
Z	-0.406					
p	0.690					
R	-0.041					

Use vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	4.833	1.267	5
Aural	5	1.206	5
Tactual			
Olfactorial			

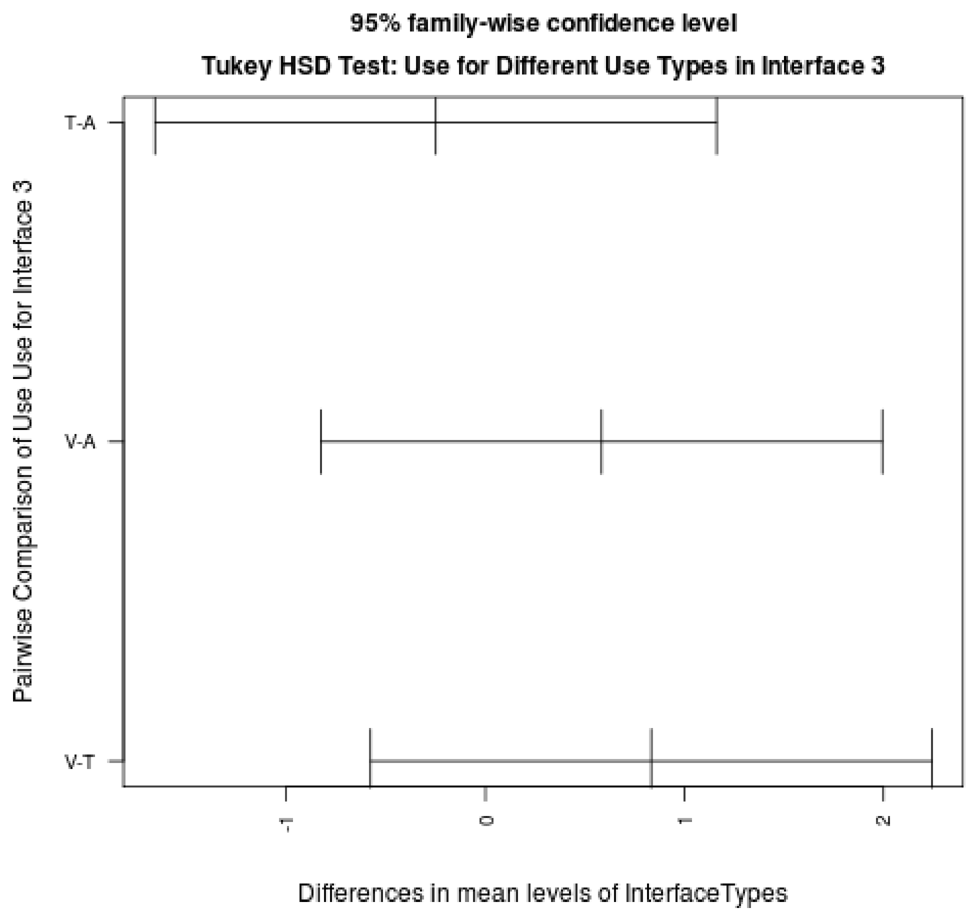




D.2.8.5.7 Use Ratings for Each Type of Feedback: Interface 3



Subject Count	Visual	Aural	Tactual	Olfactorial
1	3	3	5	
2	6	5	2	
3	6	4	3	
4	7	6	3	
5	4	3	5	
6	6	5	5	
7	5	5	7	
8	5	5	3	
9	6	6	6	
10	5	4	5	
11	5	6	8	
12	7	6	3	

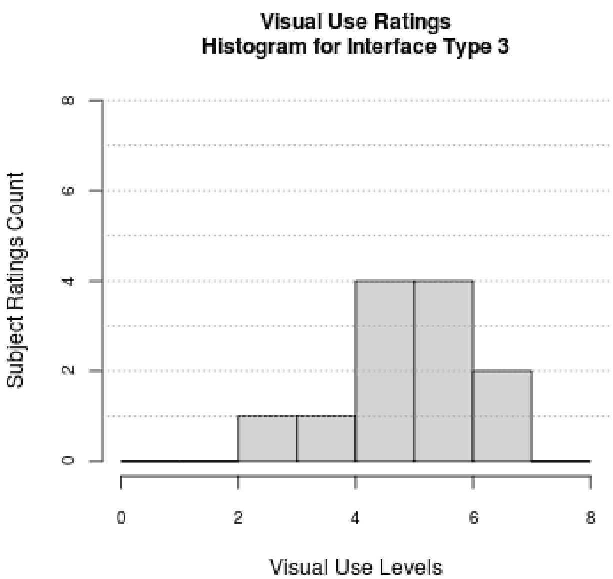


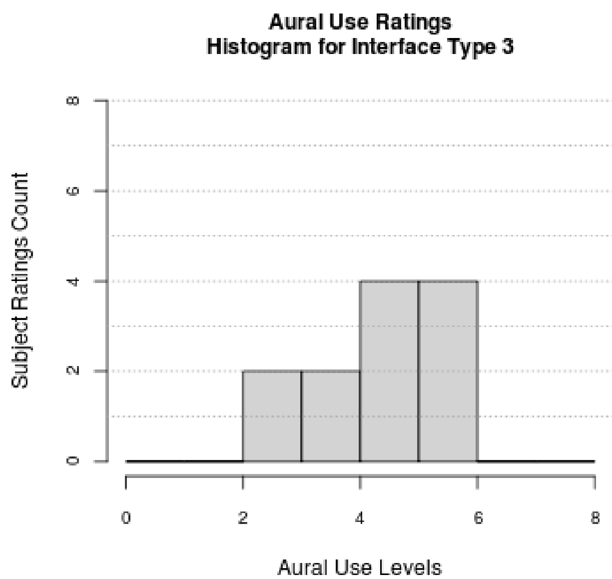
One-way ANOVA: Use vs. Type of Feedback					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	2	4.389	2.194	1.106	0.343
Residuals	33	65.500	1.985		

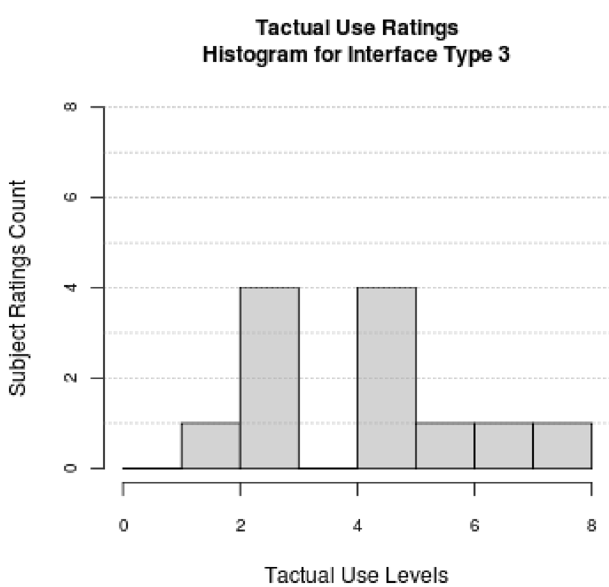
Use vs. Type of Feedback Friedman test:	
X^2	2.667
p	0.264
DoF	2

Use vs. Type of Feedback Wilcoxon test:						
	Visual – Aural	**Visual – Tactual**	**Visual – Olfact.**	**Aural – Tactual**	**Aural – Olfact.**	**Tactual – Olfact.**
W	32.000	39.000		33.500		
Z	2.137	1.067		0.477		
p	0.062	0.324		0.602		
R	0.218	0.109		0.049		

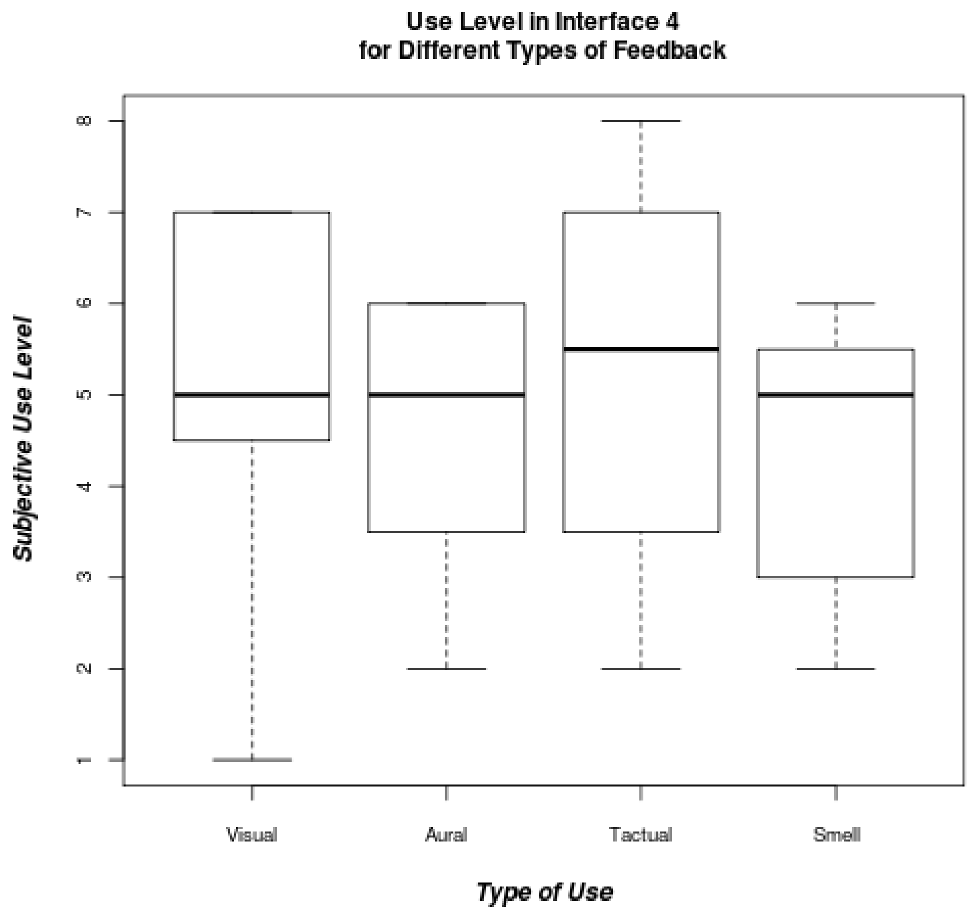
Use vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	5.417	1.165	5.500
Aural	4.833	1.115	5.000
Tactual	4.583	1.832	5.000
Olfactorial			



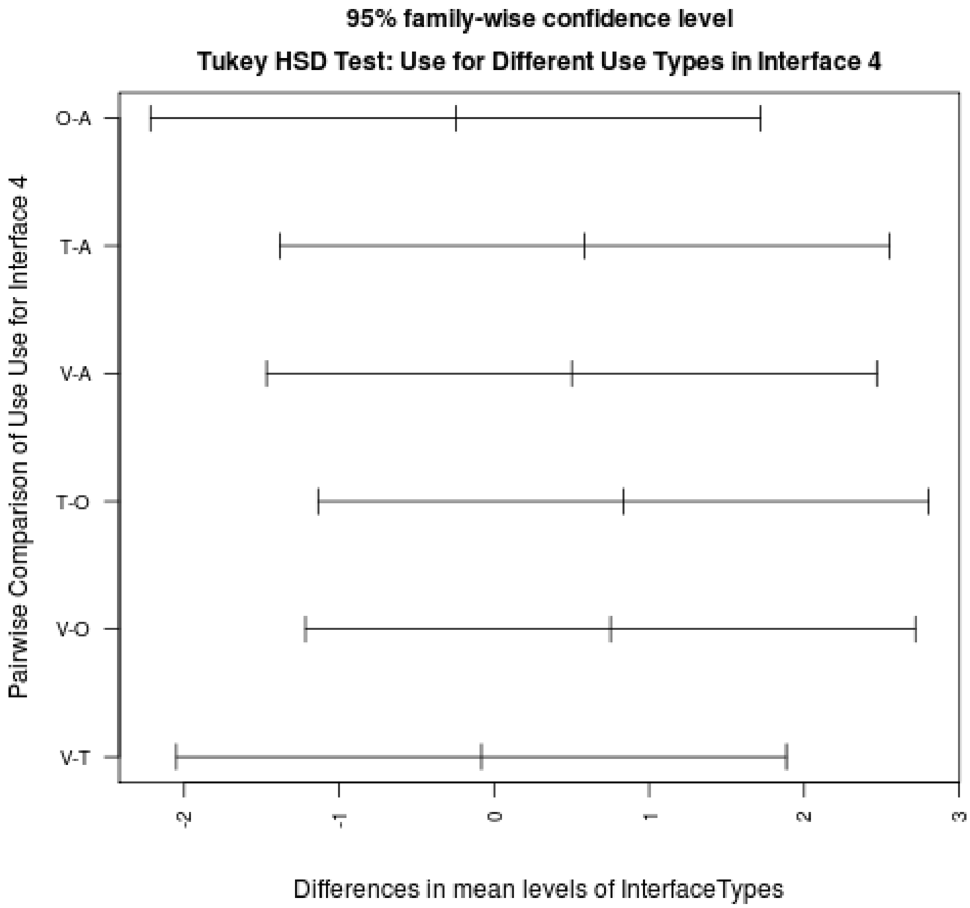




D.2.8.5.8 Use Ratings for Each Type of Feedback: Interface 4



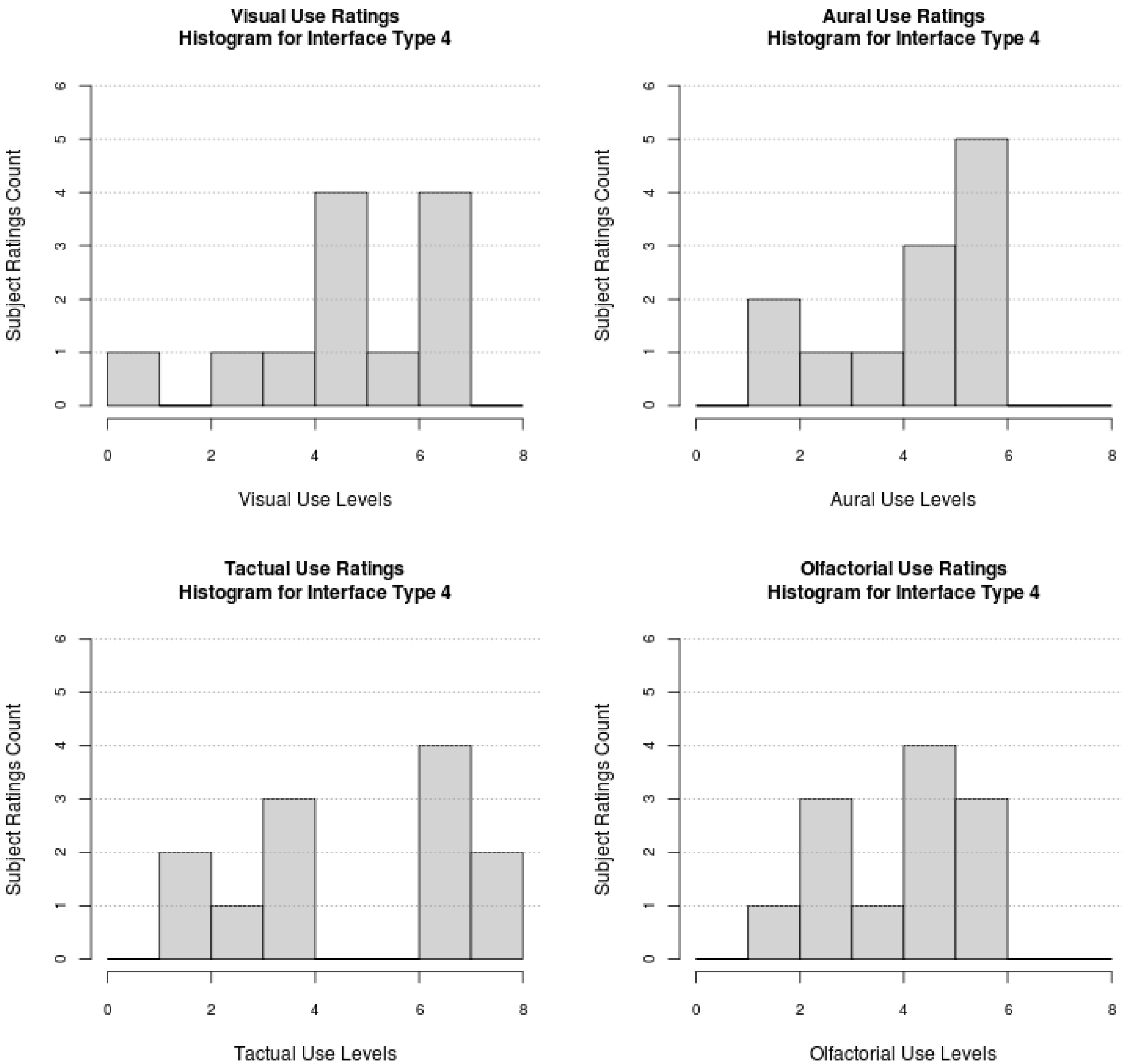
Subject Count	Visual	Aural	Tactual	Olfactorial
1	1	3	7	6
2	6	5	7	5
3	7	2	8	3
4	4	5	2	4
5	3	6	8	5
6	5	4	4	2
7	7	6	4	3
8	5	6	2	5
9	5	5	3	3
10	5	2	4	6
11	7	6	7	6
12	7	6	7	5



One-way ANOVA: Use vs. Type of Feedback					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	5.750	1.917	0.588	0.626
Residuals	44	143.500	3.261		

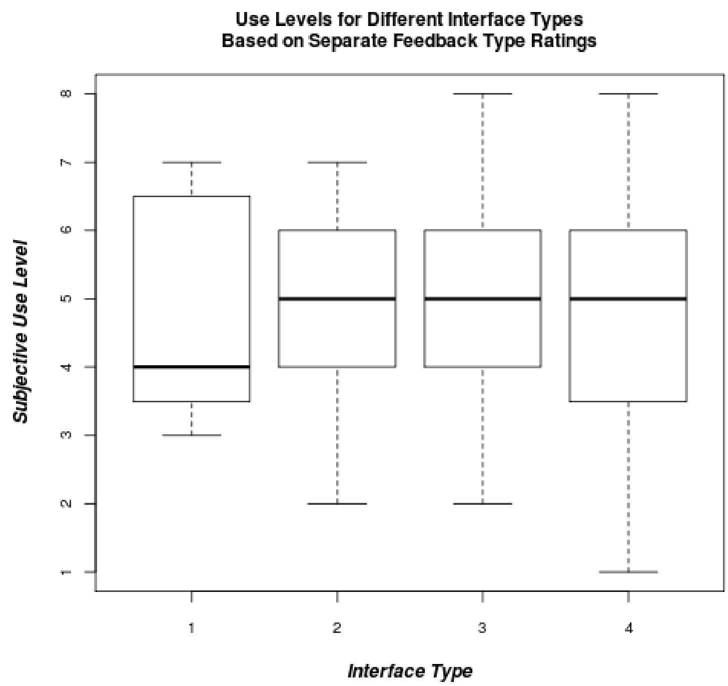
Use vs. Type of Feedback Friedman test:	
X^2	3.919
p	0.270
DoF	3

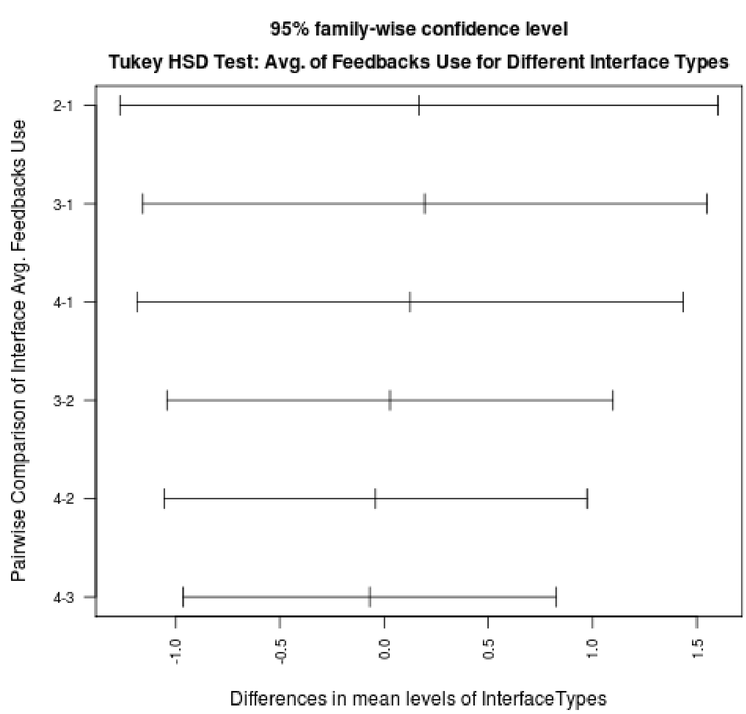
Use vs. Type of Feedback Wilcoxon test:						
	Visual – Aural	**Visual – Tactual**	**Visual – Olfact.**	**Aural – Tactual**	**Aural – Olfact.**	**Tactual – Olfact.**
W	40.500	31.000	38.000	27.500	33.500	44.500
Z	0.723	0.435	1.146	-0.554	0.794	1.110
p	0.489	0.678	0.277	0.613	0.457	0.301
R	0.074	0.044	0.117	-0.057	0.081	0.113



Use vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	5.167	1.850	5.000
Aural	4.667	1.557	5.000
Tactual	5.250	2.301	5.500
Olfactorial	4.417	1.379	5.000

D.2.8.5.9 Overall Interface Use – Average of Individual Feedback Ratings



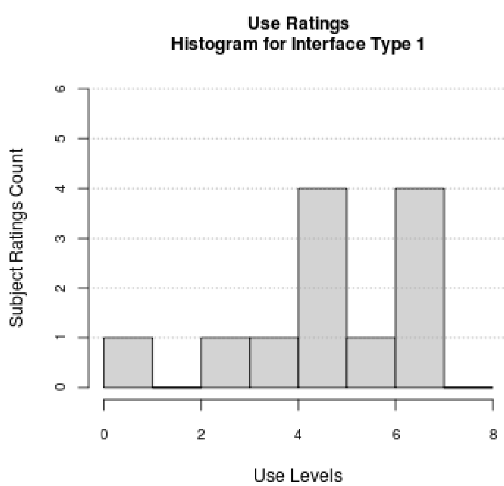


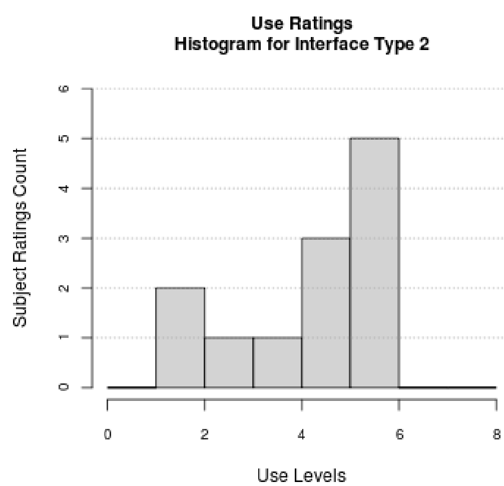
Subject Count	UI1	UI2	UI3	UI4
1	7	7	3	1
2	4	6	6	6
3	3	5	6	7
4	7	6	7	4
5	4	4	4	3
6	7	6	6	5
7	5	5	5	7
8	4	3	5	5
9	3	3	6	5
10	4	4	5	5
11	3	4	5	7
12	6	5	7	7
13		4	3	3
14		5	5	5
15		6	4	2
16		5	6	5
17		6	3	6
18		5	5	4
19		4	5	6
20		2	5	6
21		6	6	5
22		5	4	2
23		6	6	6
24		6	6	6
25			5	7
26			2	7
27			3	8
28			3	2
29			5	8
30			5	4
31			7	4
32			3	2
33			6	3
34			5	4
35			8	7
36			3	7
37				6
38				5
39				3
40				4
41				5
42				2
43				3
44				5
45				3
46				6
47				6
48				5

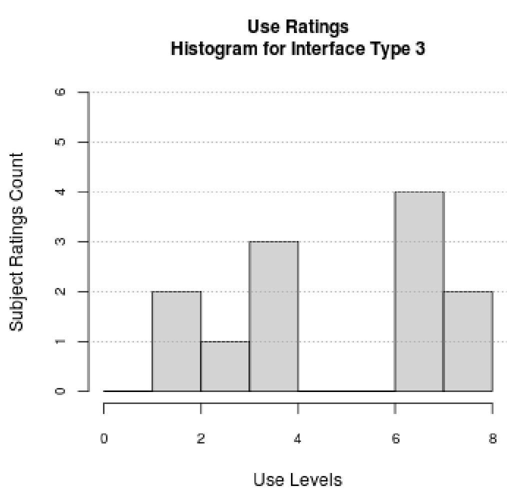
One-way ANOVA: Avg. of Feedbacks Use vs. Interface Used					
	DoF	*Sum Sq.*	*Mean Sq.*	*F-value*	*Pr(>F)*
interface type	3	0.369	0.123	0.051	0.985
Residuals	116	281.222	2.424		

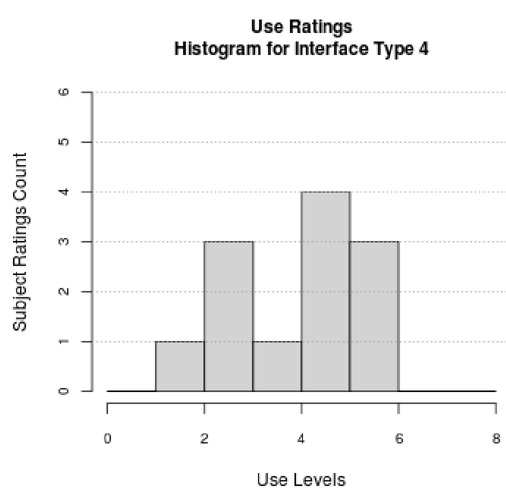
Avg. of Feedbacks Use vs. Interface Used Friedman test:	
X^2	5.370
p	0.147
DoF	3

Avg. of Feedbacks Use vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	4.750	1.603	4.000
2	4.917	1.213	5.000
3	4.944	1.413	5.000
4	4.875	1.782	5.000



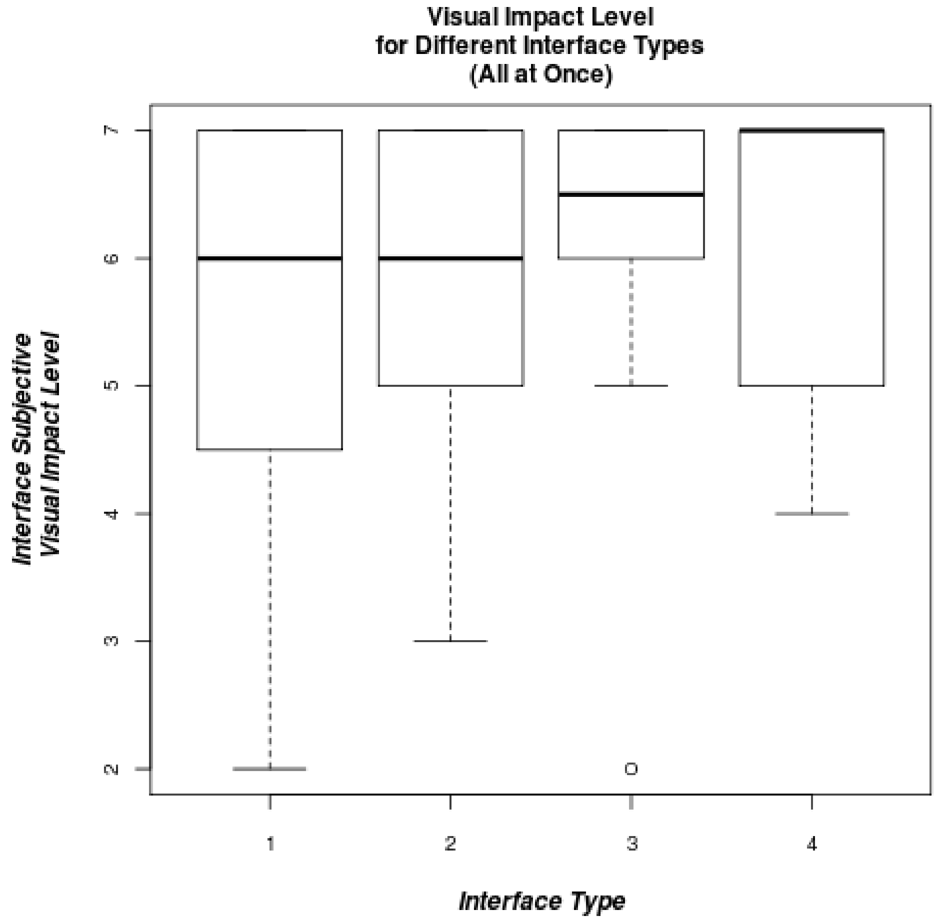




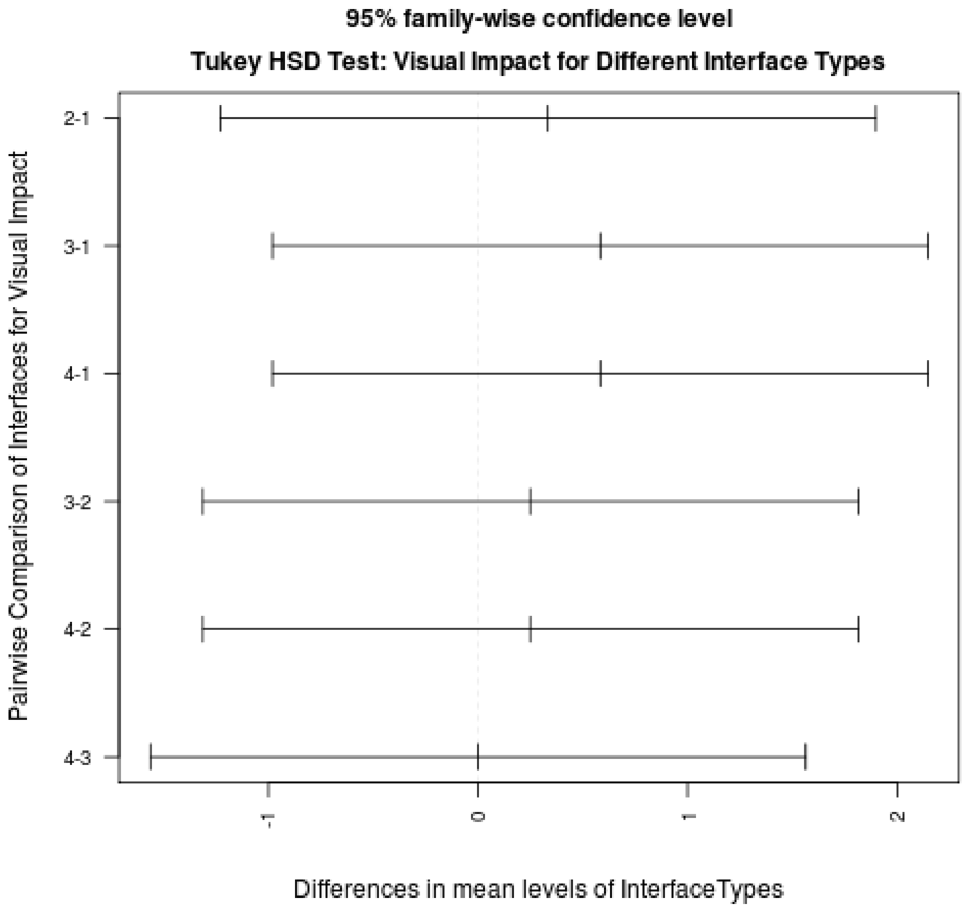


D.2.8.6 Impact

D.2.8.6.1 Impact: Visual Only



Subject Count	UI1	UI2	UI3	UI4
1	7	3	7	4
2	6	7	6	7
3	6	7	7	7
4	6	6	7	6
5	4	5	2	7
6	7	5	7	6
7	6	7	6	4
8	7	5	6	7
9	3	6	5	7
10	5	7	7	4
11	2	5	6	7
12	7	7	7	7

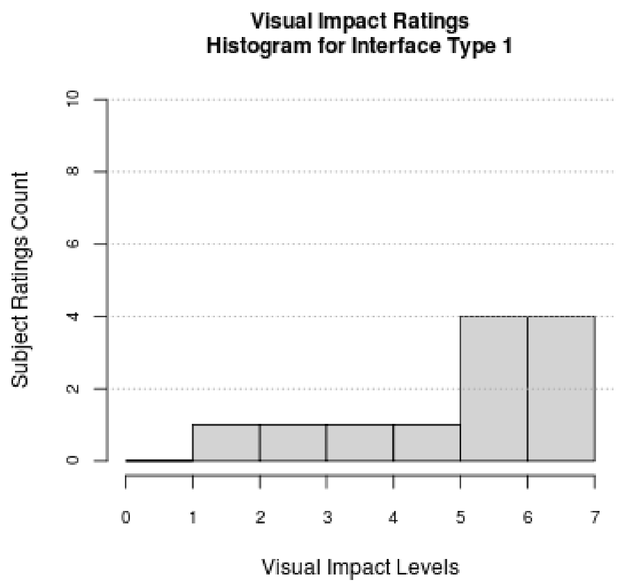


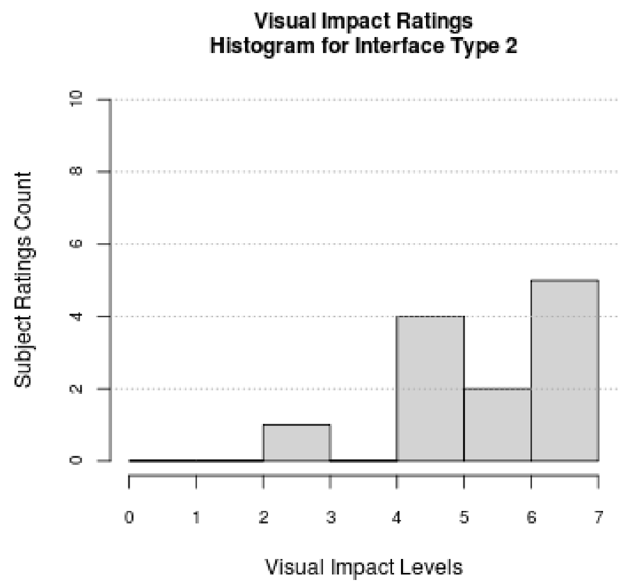
One-way ANOVA: Impact Visual vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	2.750	0.917	0.446	0.722
Residuals	44	90.500	2.057		

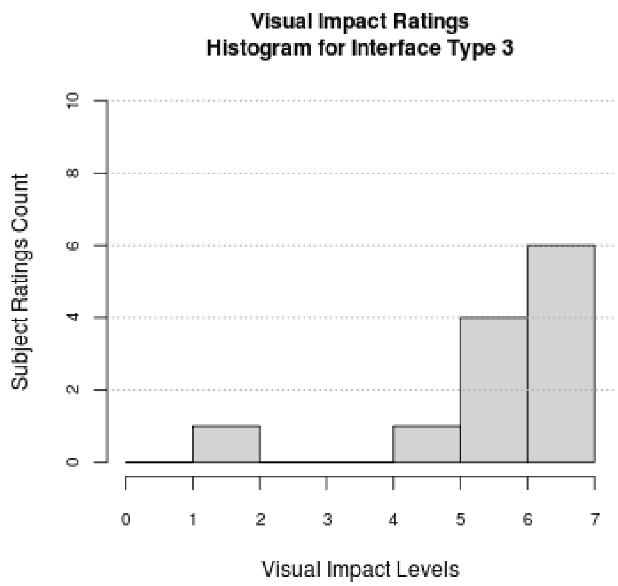
Impact Visual vs. Interface Used Friedman test:	
X^2	1.674
p	0.643
DoF	3

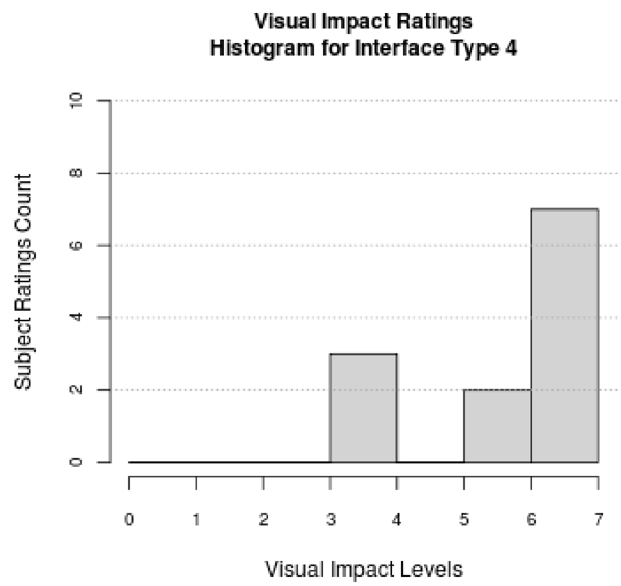
Impact Visual vs. Interface UsedUse Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	22.000	7.000	16.500	18.500	15.000	29.500
Z	-0.753	-1.193	-0.597	-0.442	-0.887	0.159
p	0.484	0.312	0.609	0.719	0.367	0.891
R	-0.077	-0.122	-0.061	-0.045	-0.091	0.016

Impact Visual vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	5.500	1.679	6.000
2	5.833	1.267	6.000
3	6.083	1.443	6.500
4	6.083	1.311	7.000

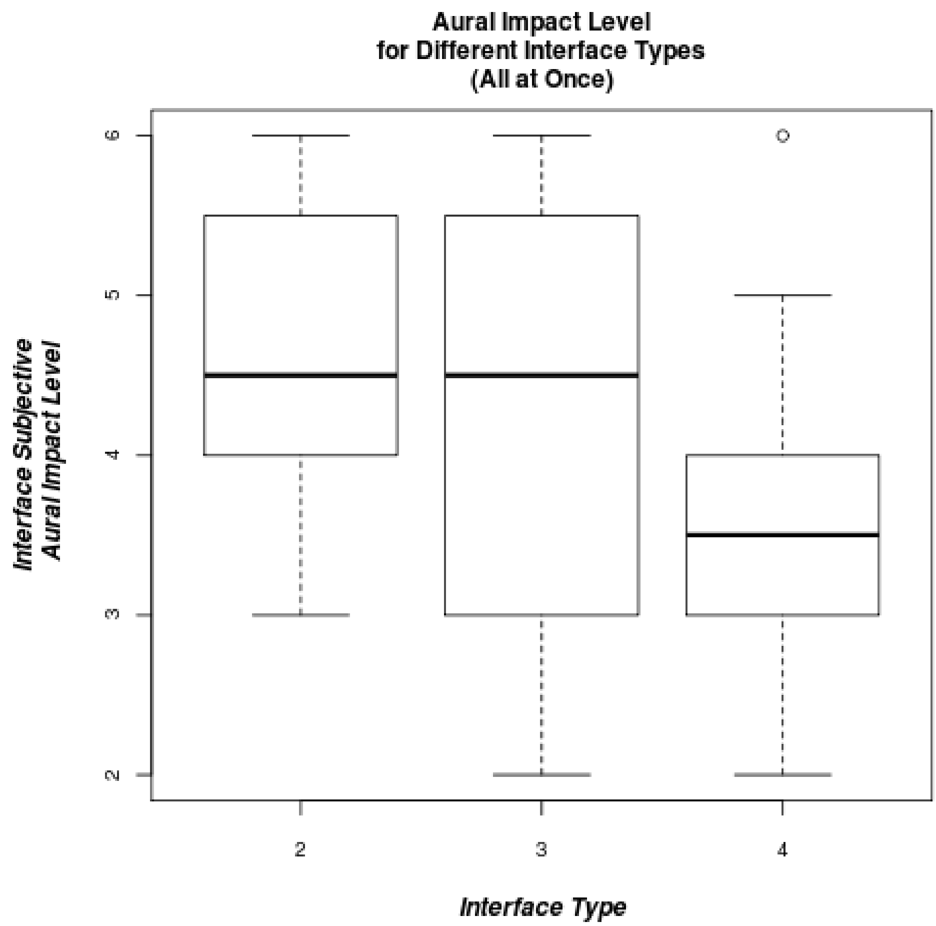




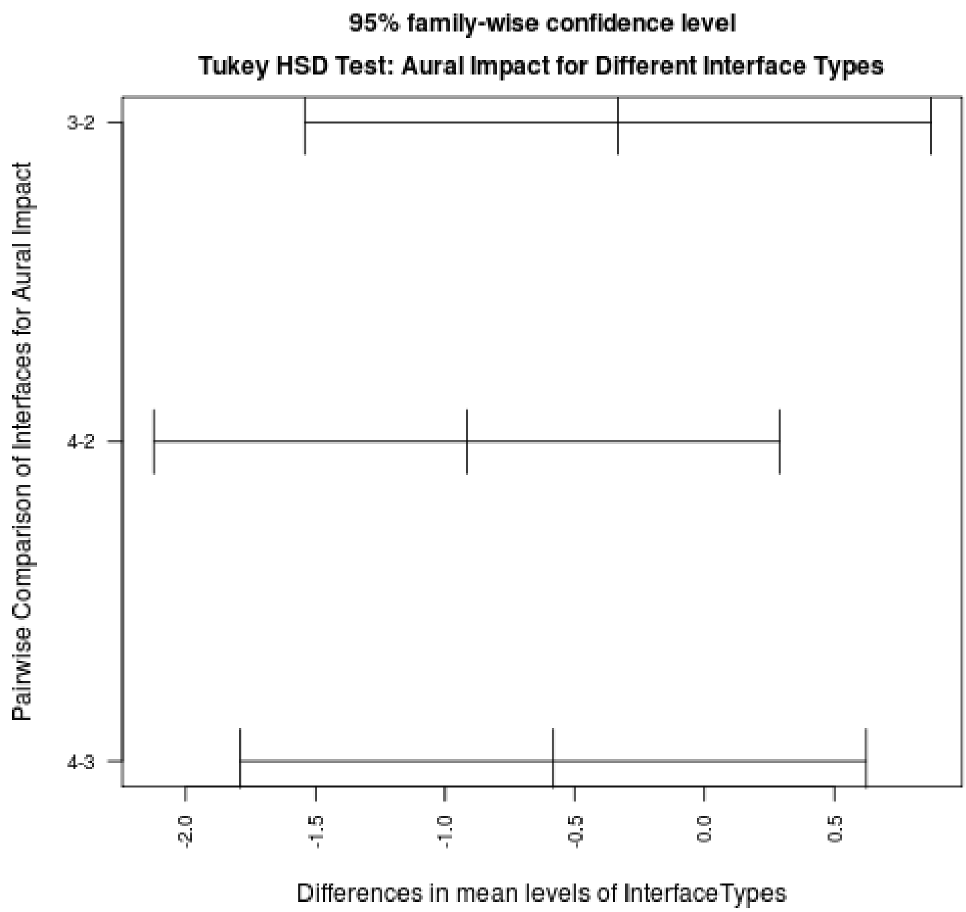




D.2.8.6.2 Impact: Aural Only



Subject Count	UI1	UI2	UI3	UI4
1		4	3	4
2		6	5	4
3		4	2	2
4		5	5	3
5		5	3	3
6		4	3	4
7		5	5	4
8		3	4	3
9		6	6	3
10		3	3	5
11		4	6	6
12		6	6	3

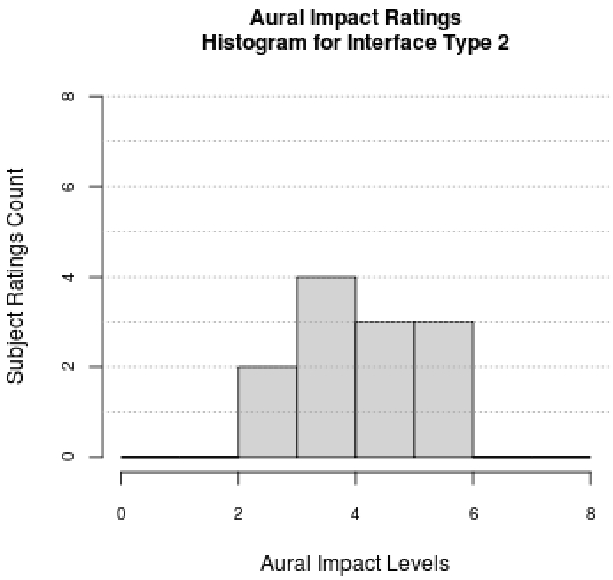


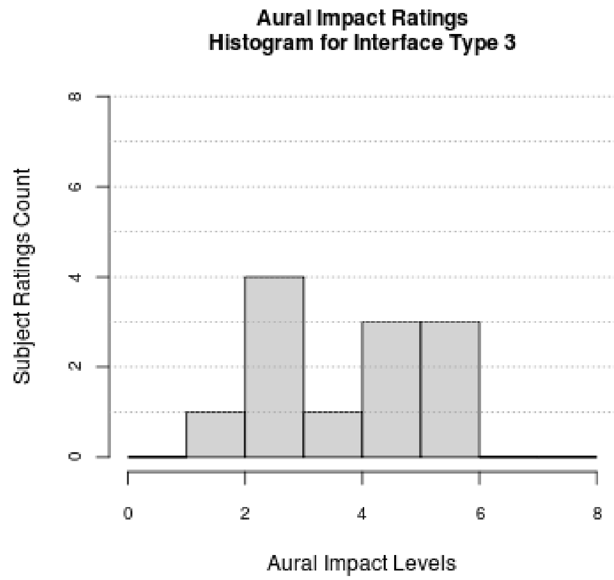
One-way ANOVA: Impact Aural vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	2	5.167	2.583	1.782	0.184
Residuals	33	47.833	1.450		

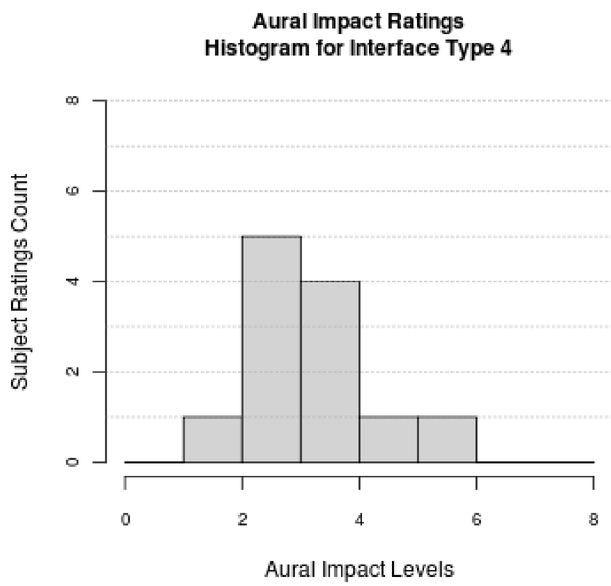
Impact Aural vs. Interface Used Friedman test:	
X^2	3.459
p	0.177
DoF	2

Impact Aural vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W				19.500	36.000	32.500
Z				1.072	1.689	1.160
p				0.406	0.121	0.293
R				0.109	0.172	0.118

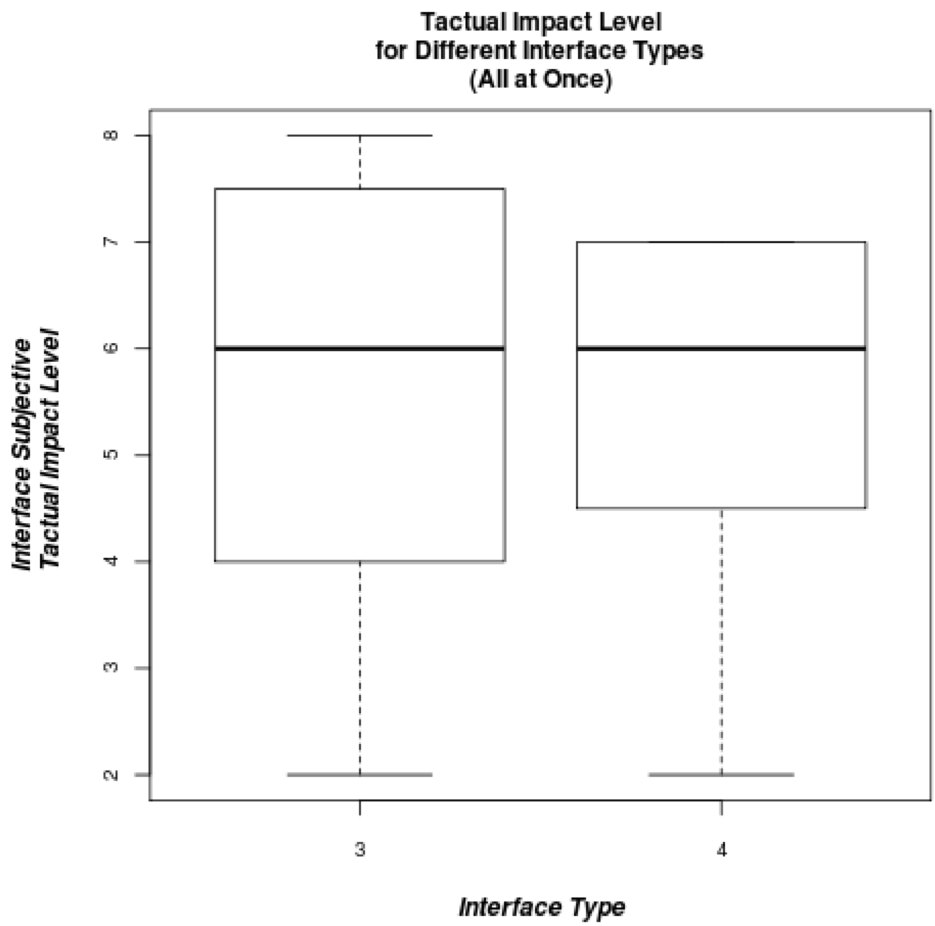
Impact Aural vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1			
2	4.583	1.084	4.500
3	4.250	1.422	4.500
4	3.667	1.073	3.500



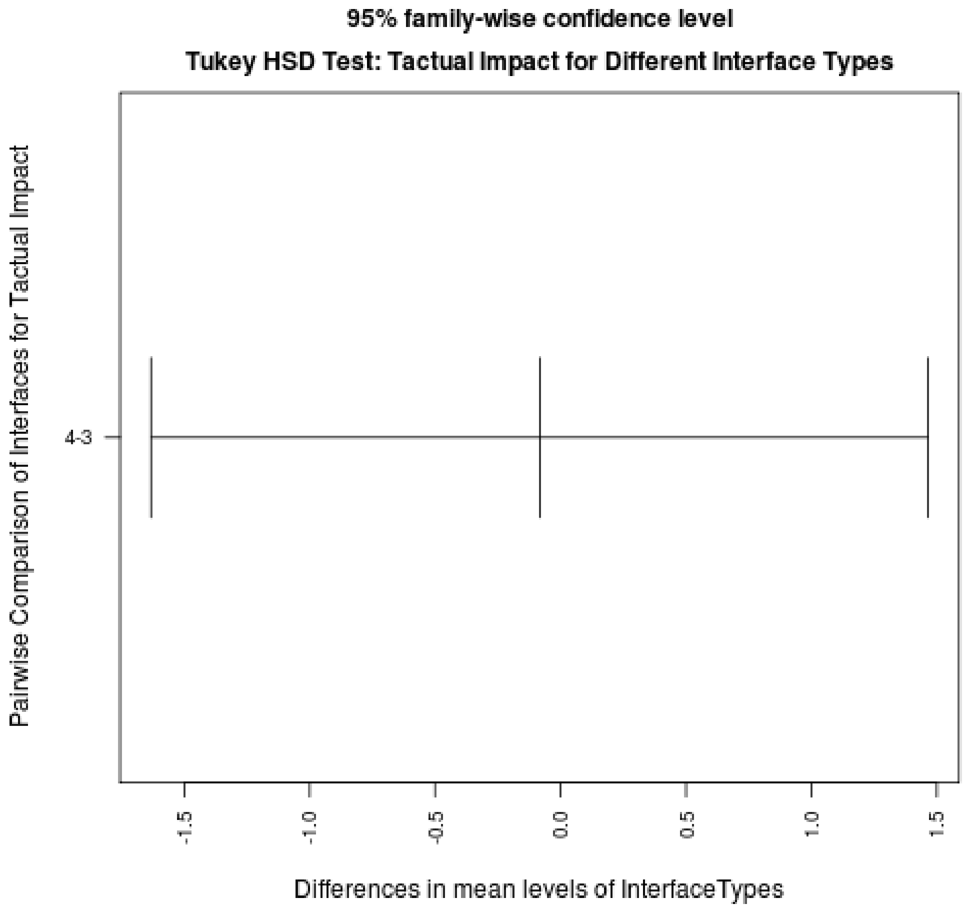




D.2.8.6.3 Impact: Tactual Only



Subject Count	UI1	UI2	UI3	UI4
1			6	7
2			2	7
3			6	7
4			4	5
5			5	2
6			7	4
7			7	6
8			4	4
9			8	6
10			8	6
11			8	7
12			3	6

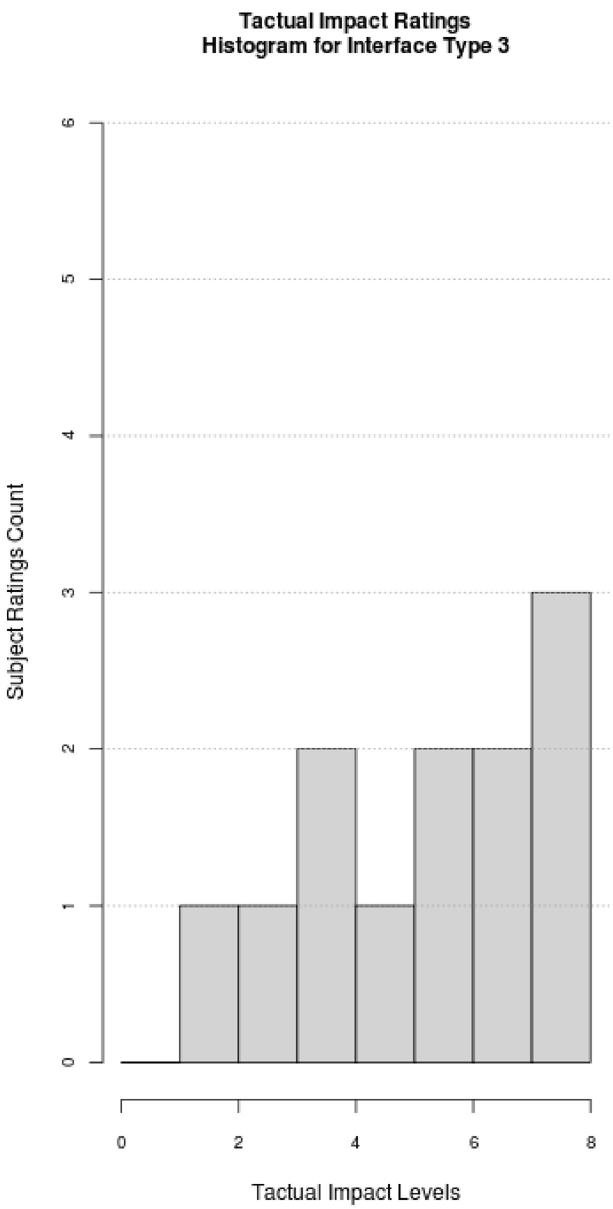


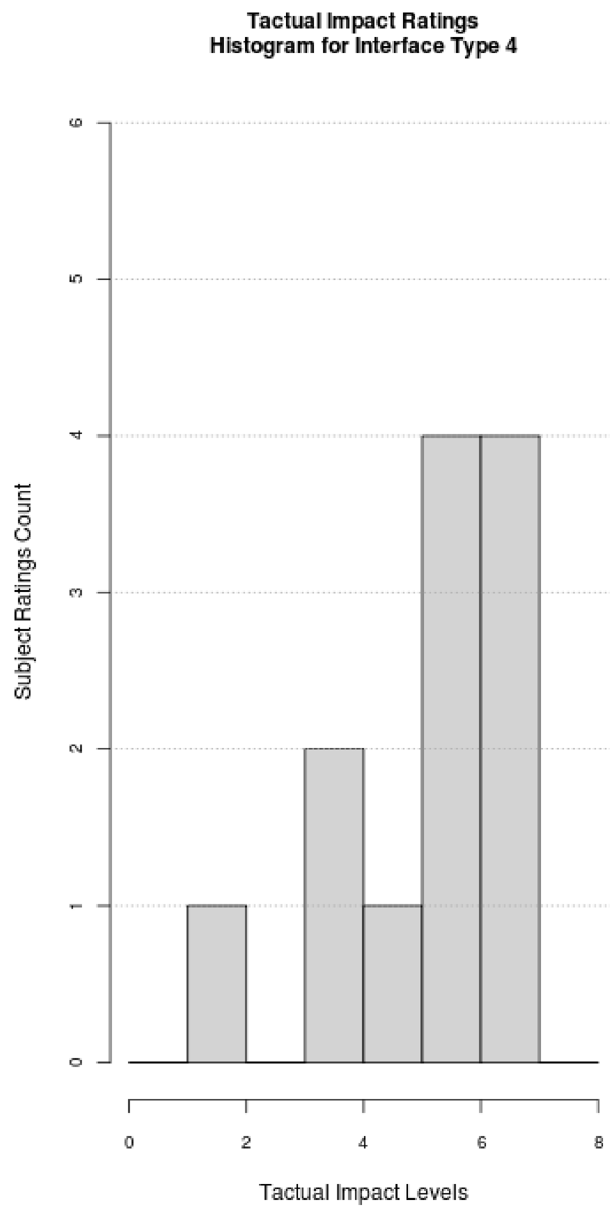
One-way ANOVA: Impact Tactual vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	0.042	0.042	0.013	0.912
Residuals	22	73.583	3.345		

Impact Tactual vs. Interface Used Friedman test:	
X^2	0.091
p	0.763
DoF	1

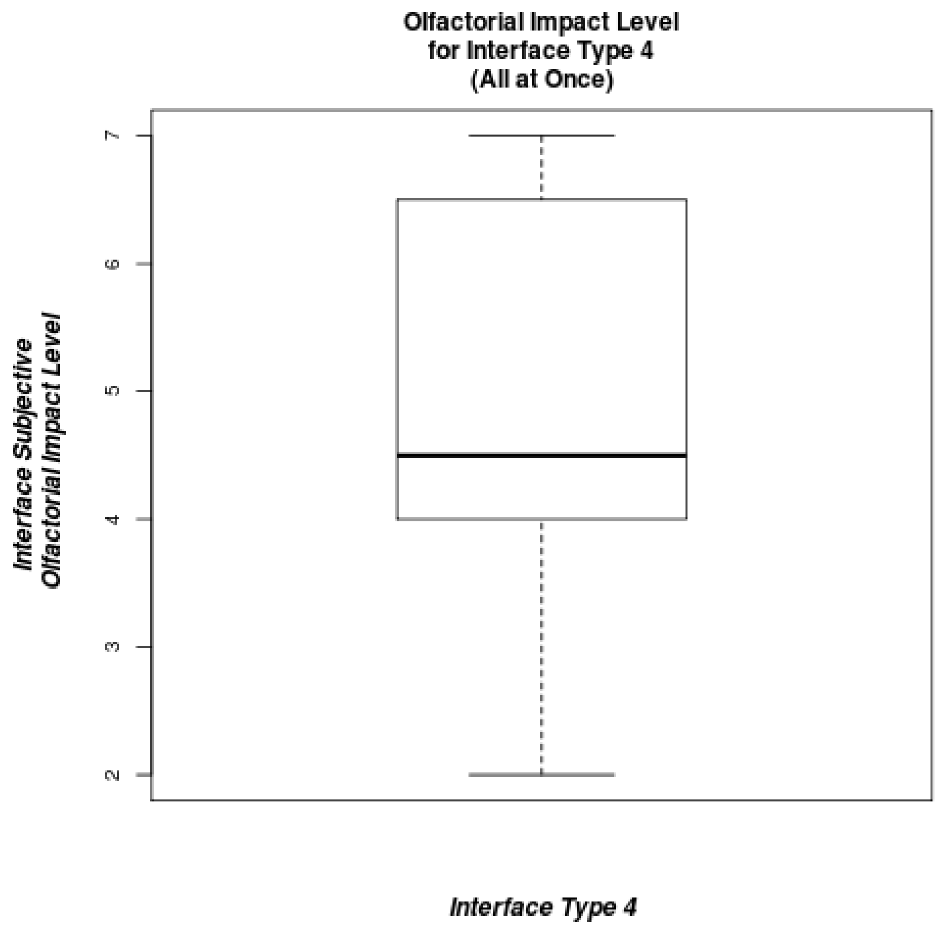
Impact Tactual vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W						37.000
Z						0.357
p						0.766
R						0.036

Impact Tactual vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1			
2			
3	5.667	2.060	6.000
4	5.583	1.564	6.000

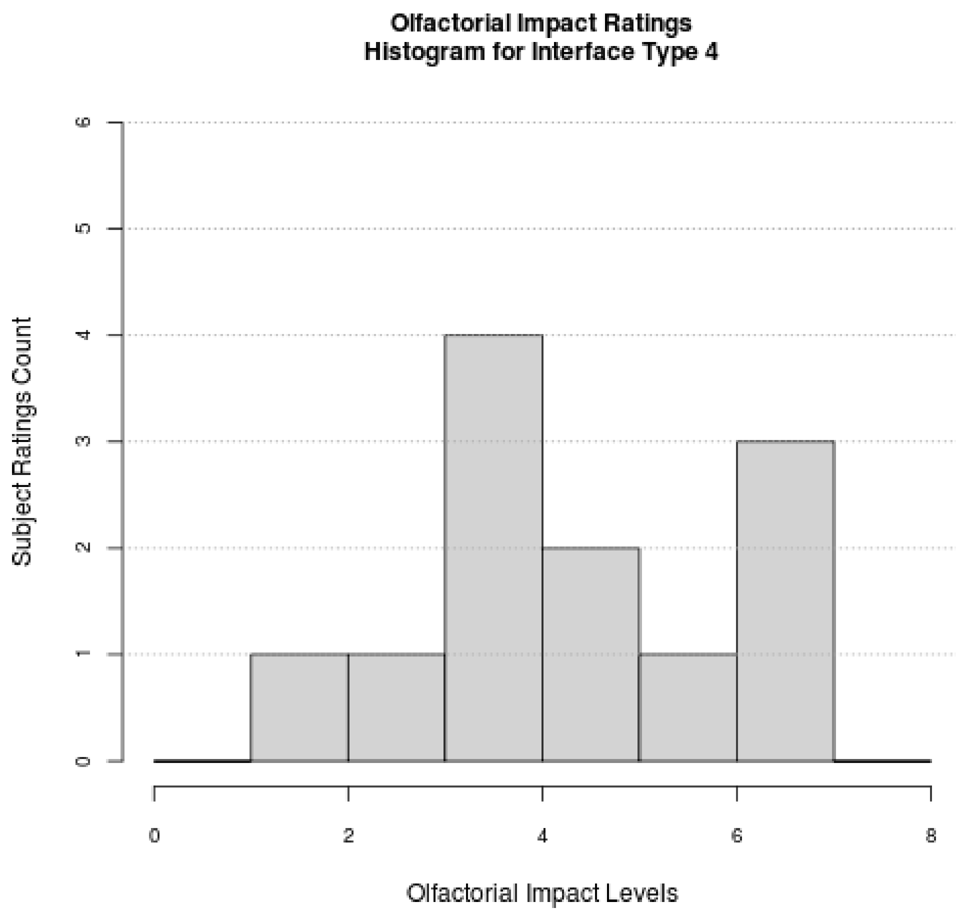




D.2.8.6.4 Impact: Olfactorial Only

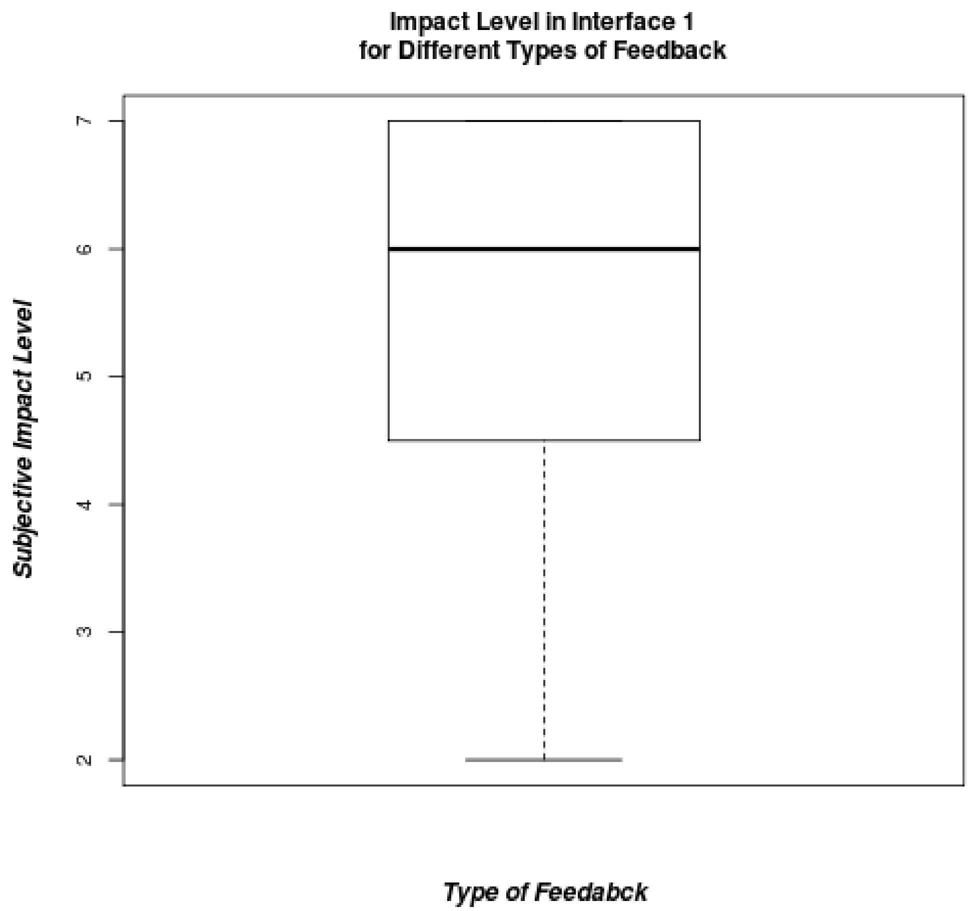


Subject Count	UI1	UI2	UI3	UI4
1				4
2				7
3				4
4				4
5				5
6				4
7				3
8				6
9				2
10				7
11				7
12				5

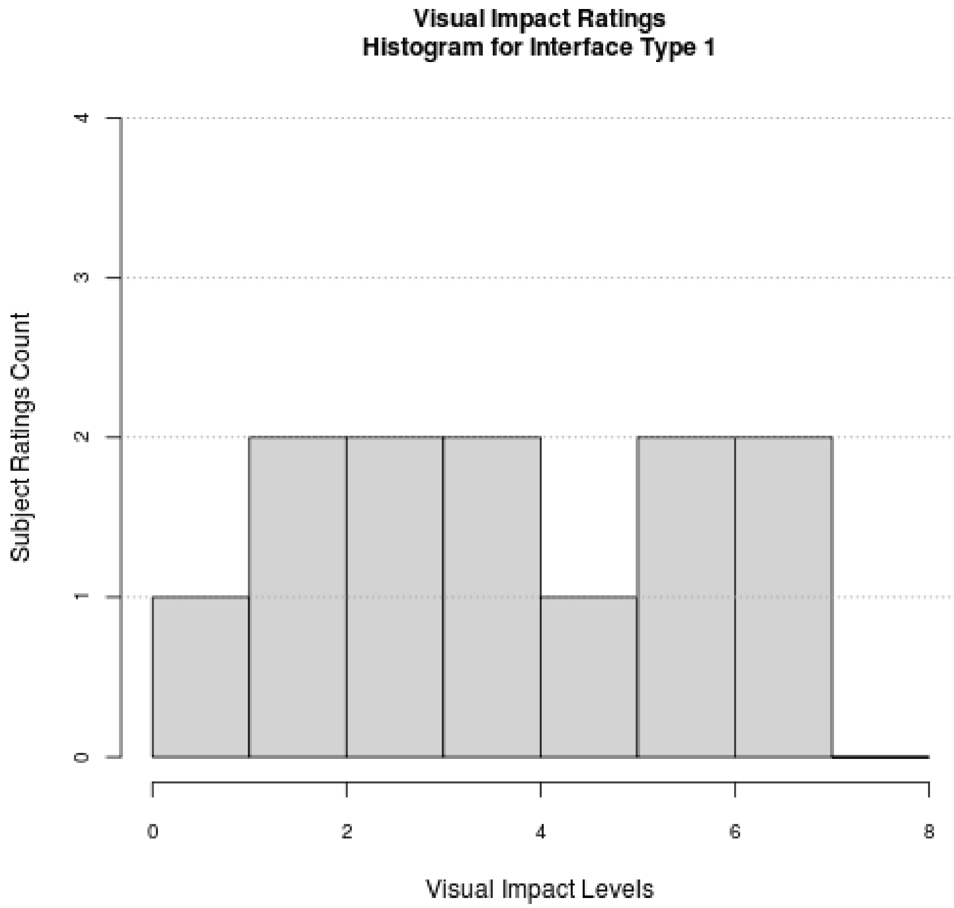


Impact Olfacorial vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1			
2			
3			
4	4.833	1.642	4.500

D.2.8.6.5 Impact Ratings for Each Type of Feedback: Interface 1

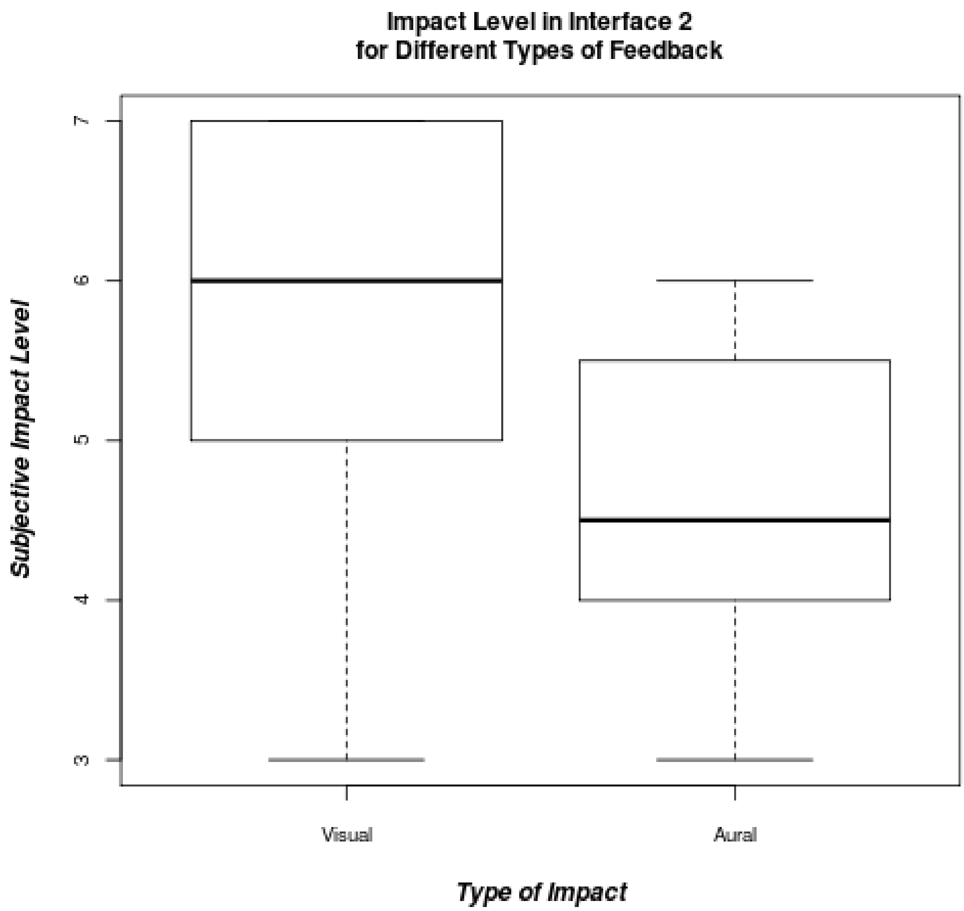


Subject Count	Visual	Aural	Tactual	Olfactorial
1	7			
2	6			
3	6			
4	6			
5	4			
6	7			
7	6			
8	7			
9	3			
10	5			
11	2			
12	7			

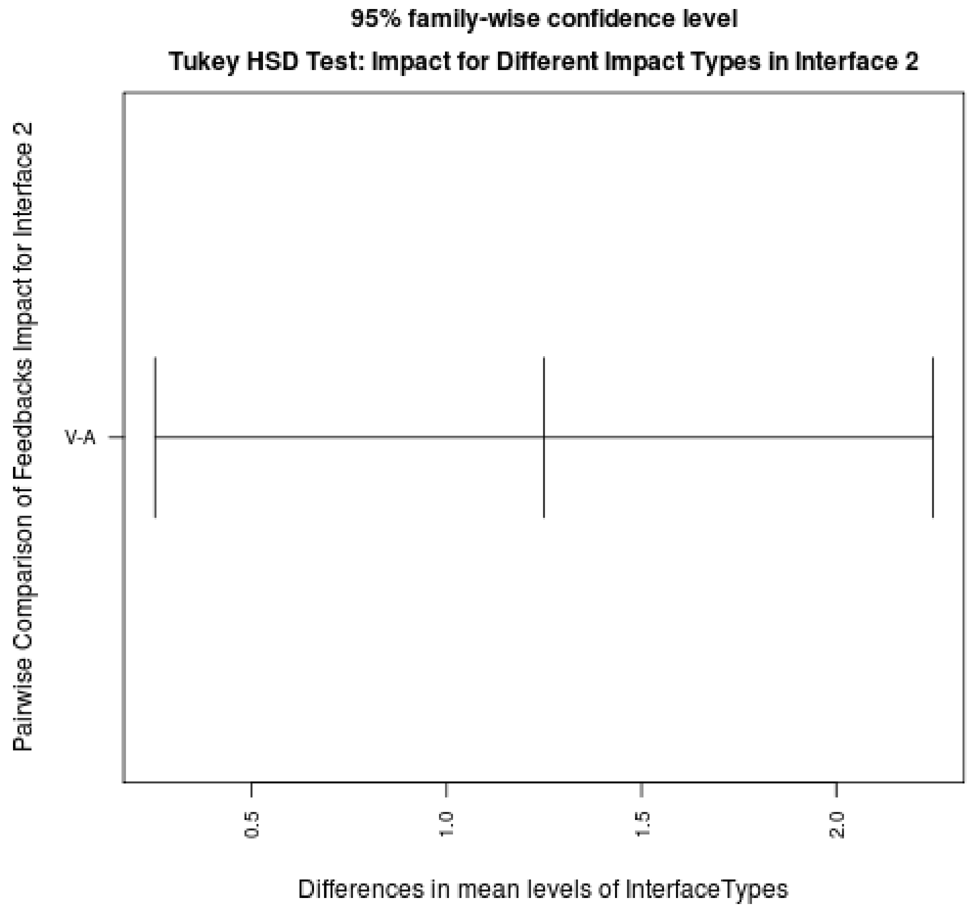


Impact vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	5.500	1.679	6.000
Aural			
Tactual			
Olfactorial			

D.2.8.6.6 Impact Ratings for Each Type of Feedback: Interface 2



Subject Count	Visual	Aural	Tactual	Olfactorial
1	3	4		
2	7	6		
3	7	4		
4	6	5		
5	5	5		
6	5	4		
7	7	5		
8	5	3		
9	6	6		
10	7	3		
11	5	4		
12	7	6		

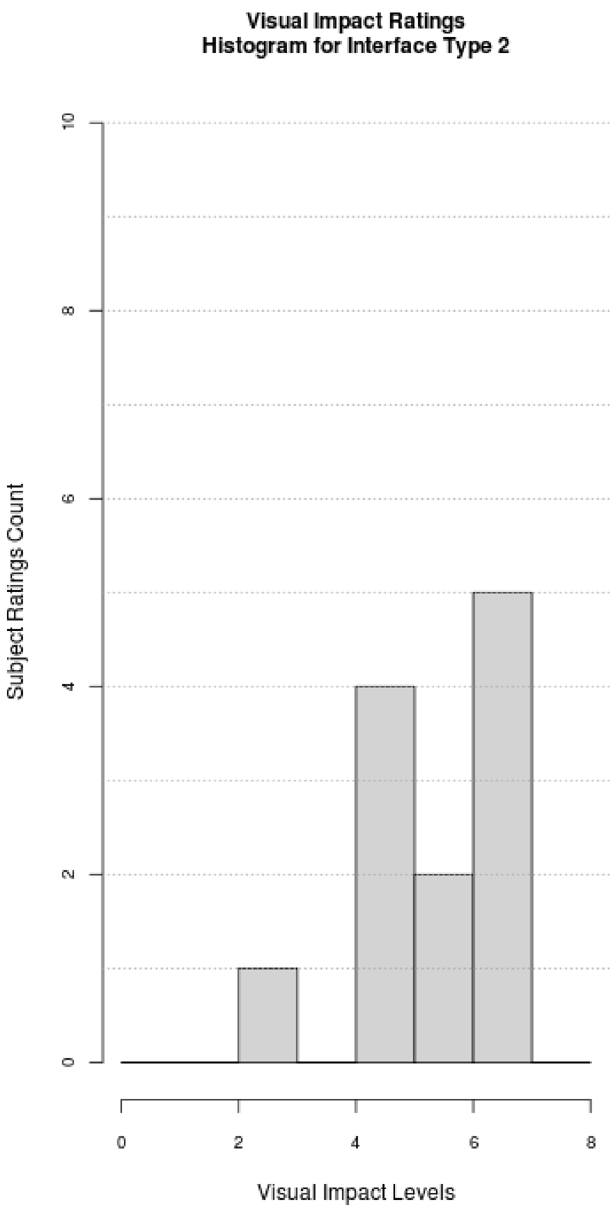


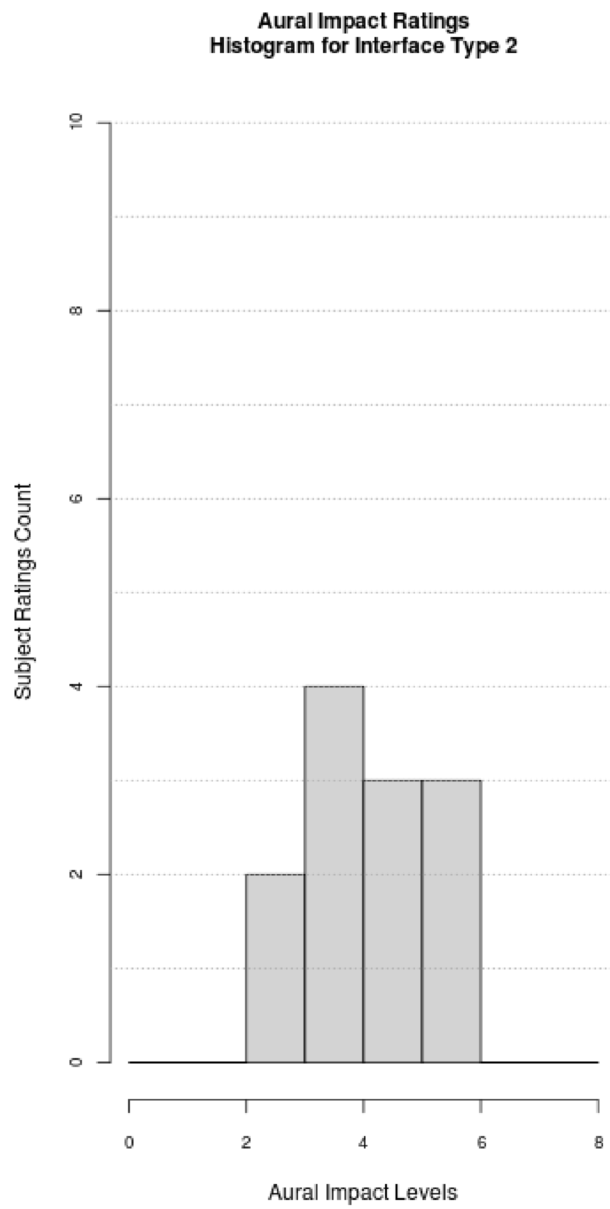
One-way ANOVA: Impact vs. Type of Feedback					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	1	9.375	9.375	6.744	0.016
Residuals	22	30.583	1.390		

Impact vs. Type of Feedback Friedman test:	
X^2	6.400
p	0.011
DoF	1

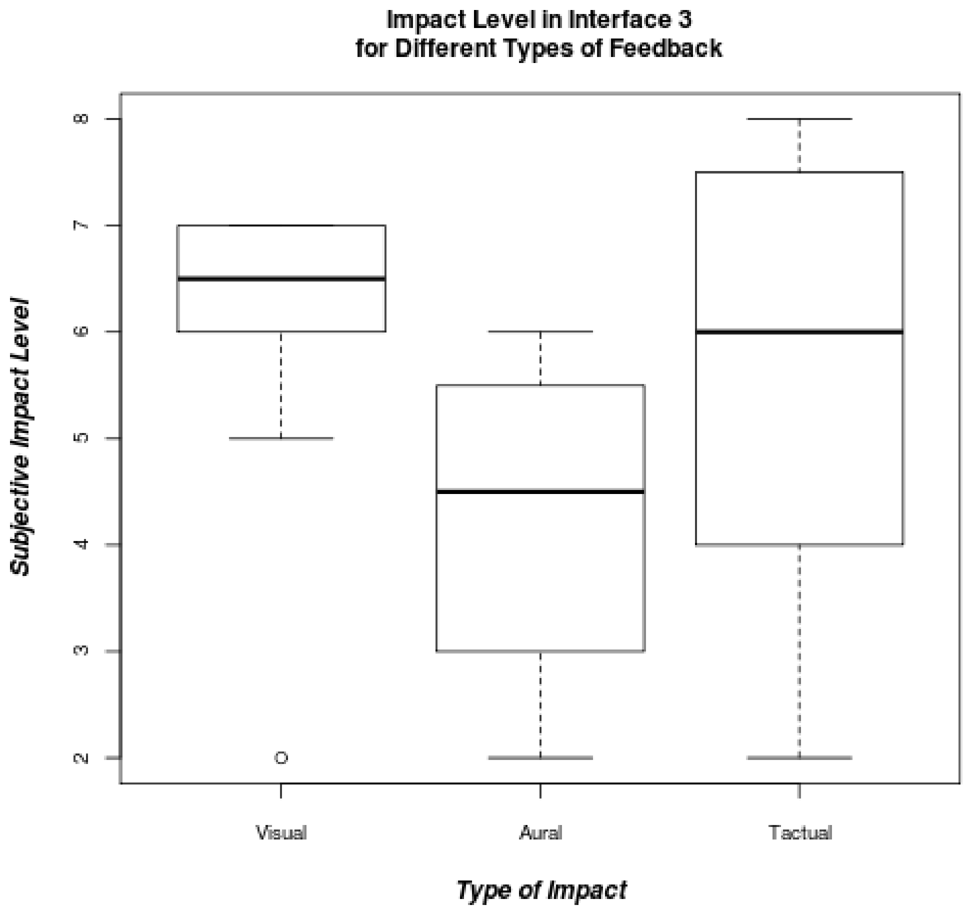
Impact vs. Type of Feedback Wilcoxon test:						
	Visual – Aural	**Visual – Tactual**	**Visual – Olfact.**	**Aural – Tactual**	**Aural – Olfact.**	**Tactual – Olfact.**
W						51.500
Z						2.556
p						0.014
R						0.261

Impact vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	5.833	1.267	6.000
Aural	4.583	1.084	4.500
Tactual			
Olfactorial			

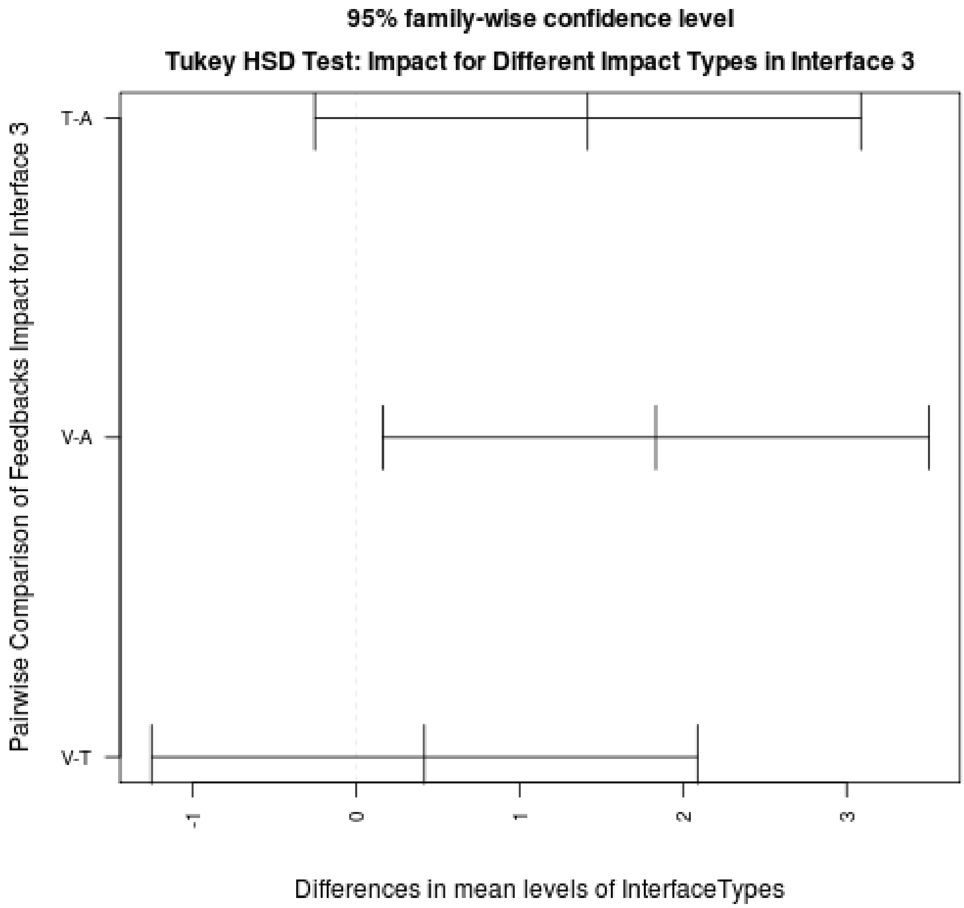




D.2.8.6.7 Impact Ratings for Each Type of Feedback: Interface 3



Subject Count	Visual	Aural	Tactual	Olfactorial
1	7	3	6	
2	6	5	2	
3	7	2	6	
4	7	5	4	
5	2	3	5	
6	7	3	7	
7	6	5	7	
8	6	4	4	
9	5	6	8	
10	7	3	8	
11	6	6	8	
12	7	6	3	

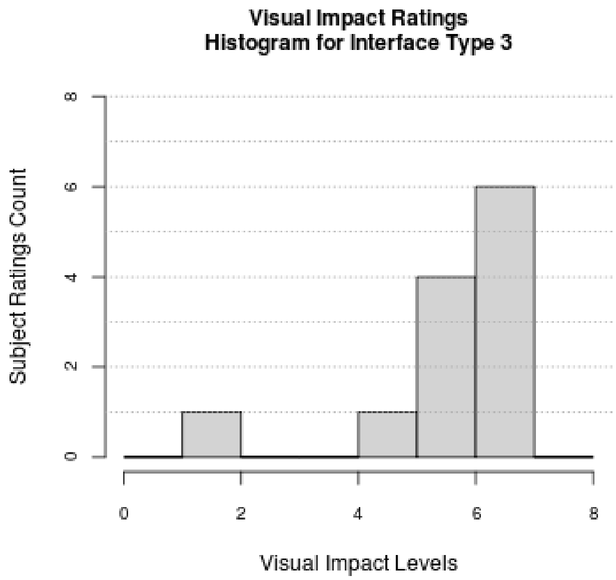


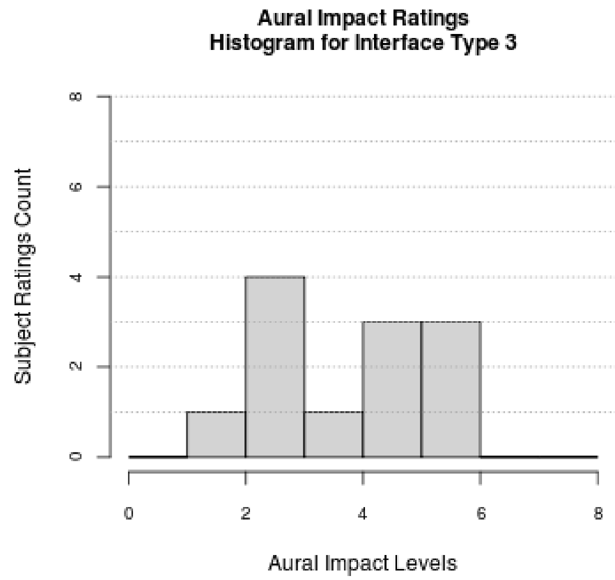
One-way ANOVA: Impact vs. Type of Feedback					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	2	22.167	11.083	3.983	0.028
Residuals	33	91.833	2.783		

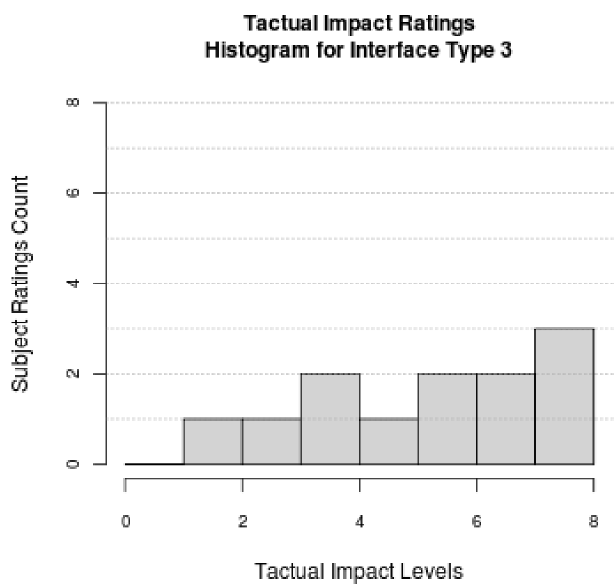
Impact vs. Type of Feedback Friedman test:	
X^2	4.978
p	0.083
DoF	2

Impact vs. Type of Feedback Wilcoxon test:						
	Visual – Aural	**Visual – Tactual**	**Visual – Olfact.**	**Aural – Tactual**	**Aural – Olfact.**	**Tactual – Olfact.**
W	60.000	39.500		15.000		
Z	2.418	0.553		-1.619		
p	0.018	0.628		0.108		
R	0.247	0.056		-0.165		

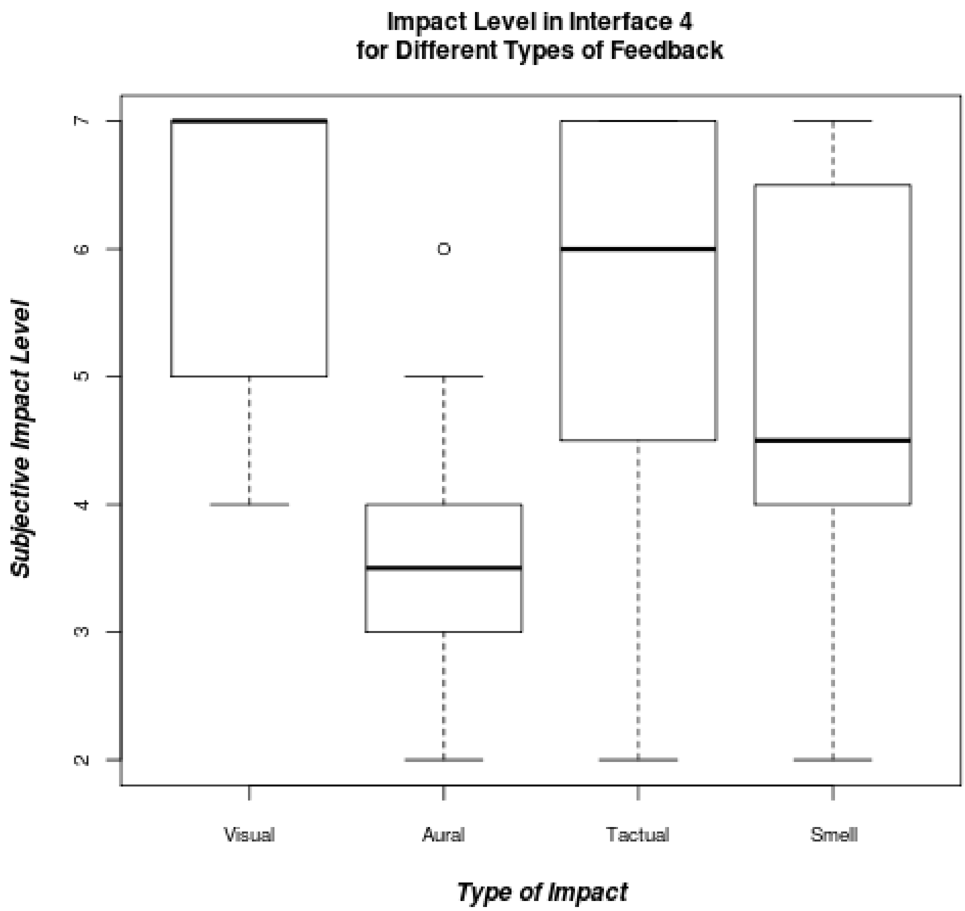
Impact vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	6.083	1.443	6.500
Aural	4.250	1.422	4.500
Tactual	5.667	2.060	6.000
Olfactorial			



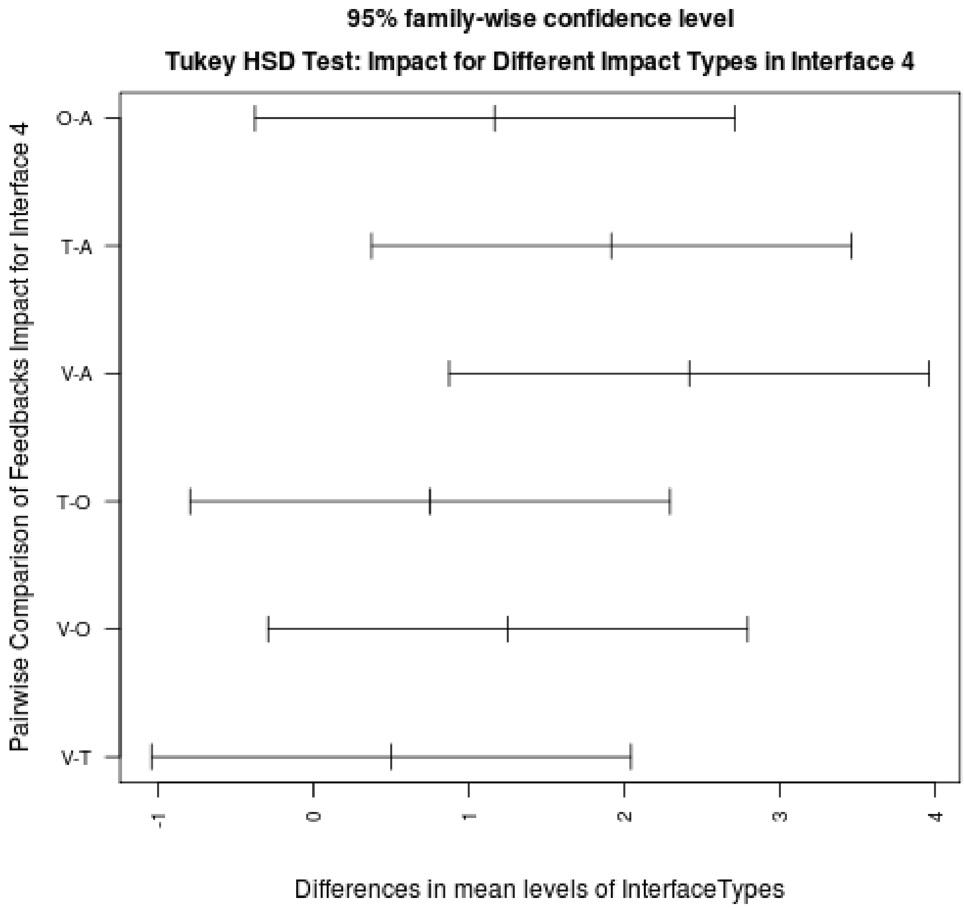




D.2.8.6.8 Impact Ratings for Each Type of Feedback: Interface 4



Subject Count	Visual	Aural	Tactual	Olfactorial
1	4	4	7	4
2	7	4	7	7
3	7	2	7	4
4	6	3	5	4
5	7	3	2	5
6	6	4	4	4
7	4	4	6	3
8	7	3	4	6
9	7	3	6	2
10	4	5	6	7
11	7	6	7	7
12	7	3	6	5

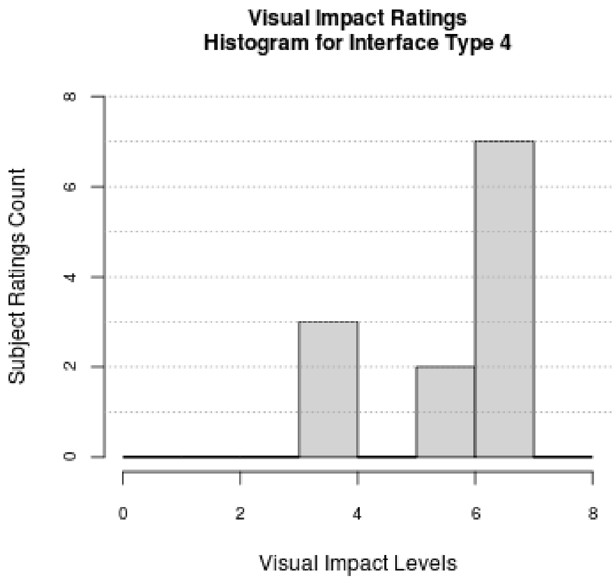


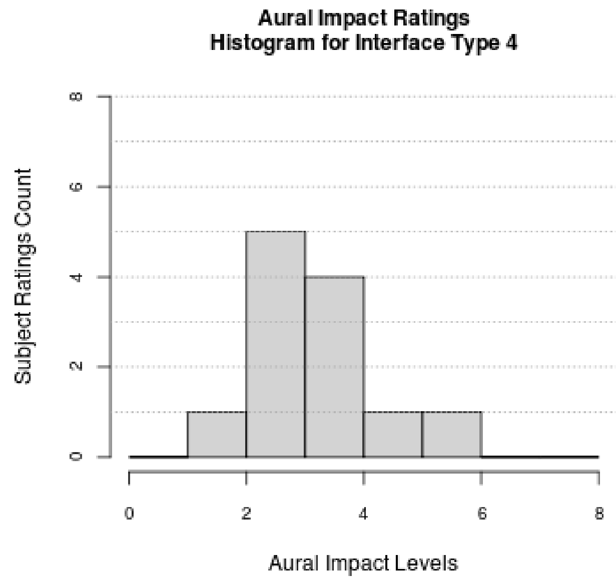
One-way ANOVA: Impact vs. Type of Feedback					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	39.750	13.250	6.613	0.001
Residuals	44	88.167	2.004		

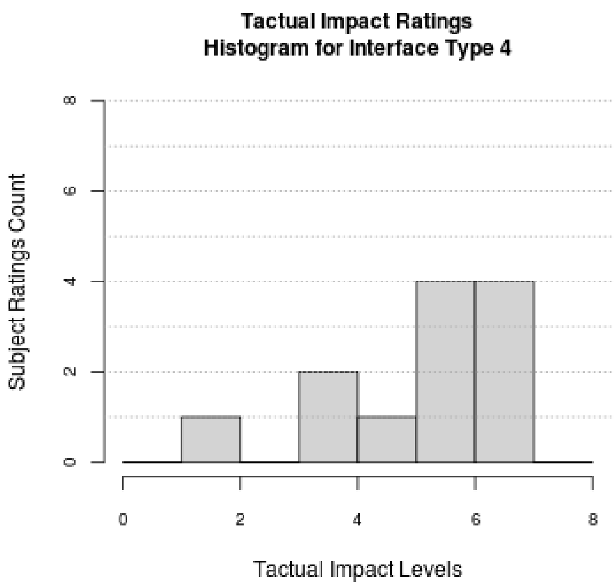
Impact vs. Type of Feedback Friedman test:	
X^2	13.971
p	0.003
DoF	3

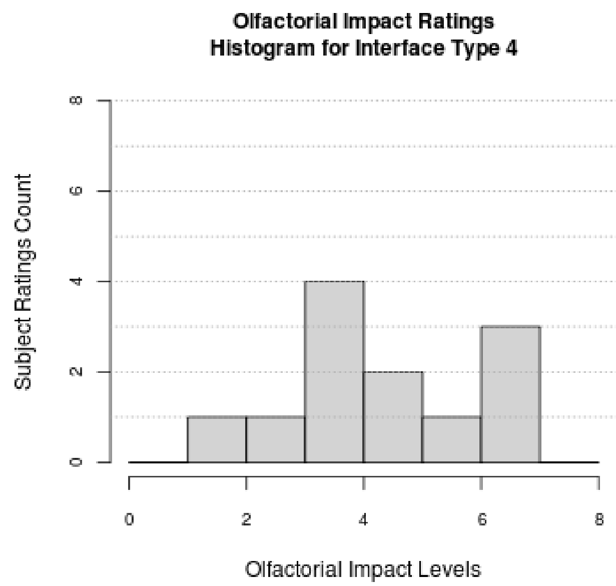
Impact vs. Type of Feedback Wilcoxon test:						
	Visual – Aural	**Visual – Tactual**	**Visual – Olfact.**	**Aural – Tactual**	**Aural – Olfact.**	**Tactual – Olfact.**
W	53.500	27.500	37.500	2.500	5.000	32.500
Z	2.690	0.756	2.032	-2.770	-2.263	1.156
p	0.006	0.488	0.039	0.005	0.029	0.289
R	0.275	0.077	0.207	-0.283	-0.231	0.118

Impact vs. Type of Feedback Summary:			
Feedback	**Mean**	**Std. Dev.**	**Median**
Visual	6.083	1.311	7.000
Aural	3.667	1.073	3.500
Tactual	5.583	1.564	6.000
Olfactorial	4.833	1.642	4.500

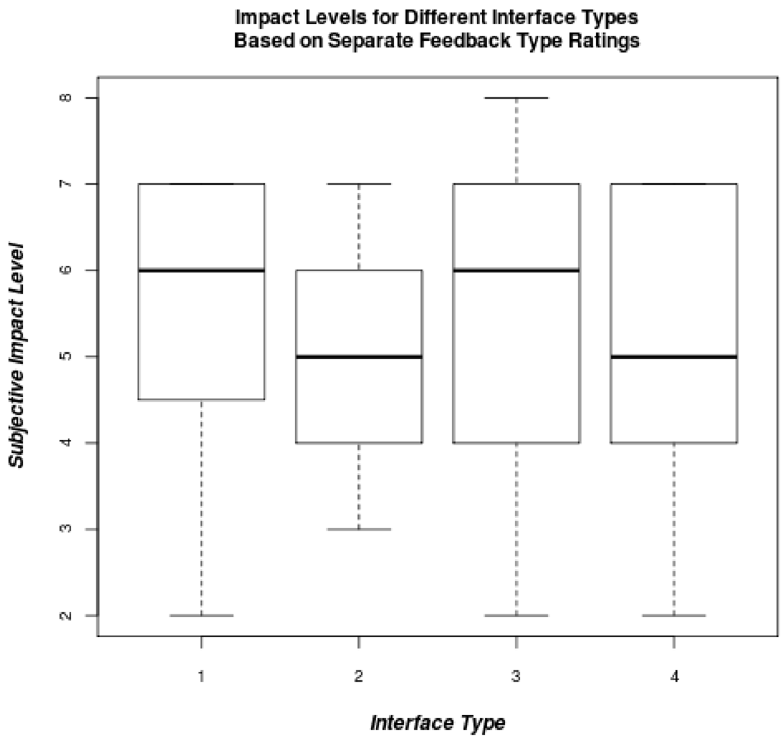


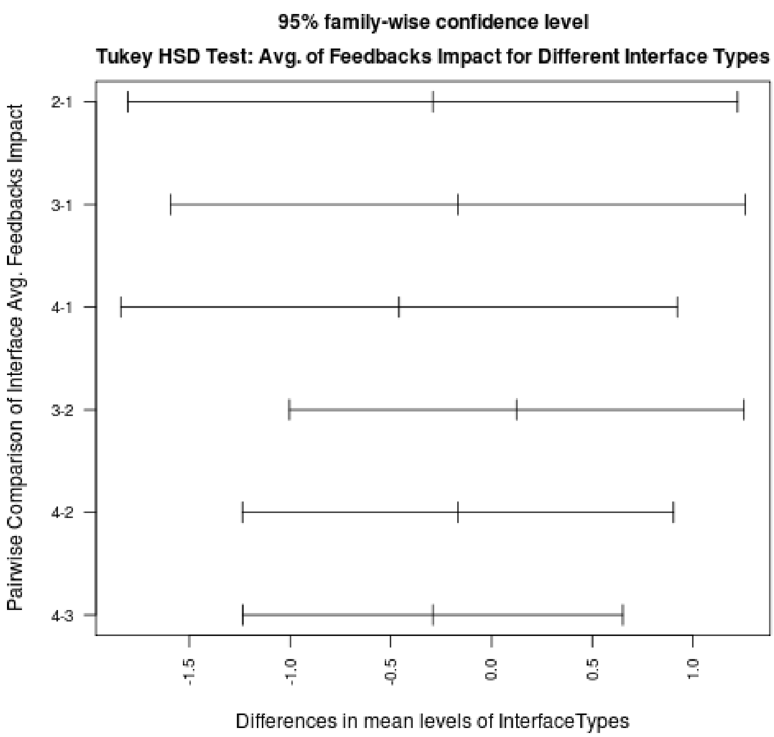






D.2.8.6.9 Overall Interface Impact – Average of Individual Feedback Ratings



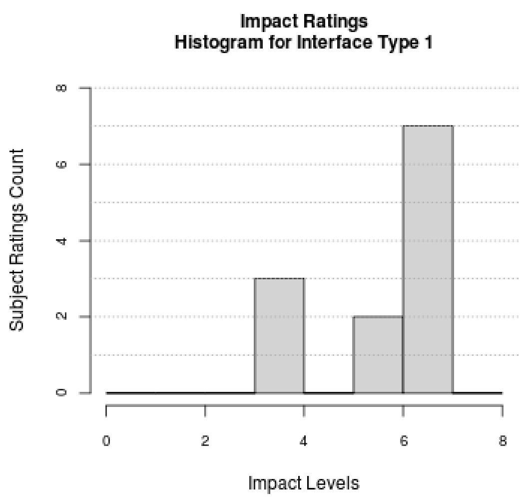


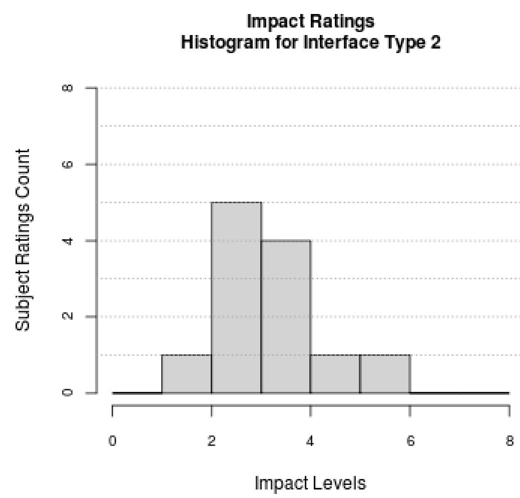
Subject Count	UI1	UI2	UI3	UI4
1	7	3	7	4
2	6	7	6	7
3	6	7	7	7
4	6	6	7	6
5	4	5	2	7
6	7	5	7	6
7	6	7	6	4
8	7	5	6	7
9	3	6	5	7
10	5	7	7	4
11	2	5	6	7
12	7	7	7	7
13		4	3	4
14		6	5	4
15		4	2	2
16		5	5	3
17		5	3	3
18		4	3	4
19		5	5	4
20		3	4	3
21		6	6	3
22		3	3	5
23		4	6	6
24		6	6	3
25			6	7
26			2	7
27			6	7
28			4	5
29			5	2
30			7	4
31			7	6
32			4	4
33			8	6
34			8	6
35			8	7
36			3	6
37				4
38				7
39				4
40				4
41				5
42				4
43				3
44				6
45				2
46				7
47				7
48				5

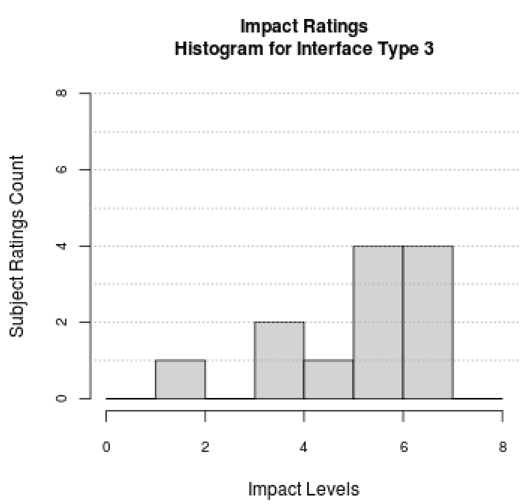
One-way ANOVA: Avg. of Feedbacks Impact vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	2.917	0.972	0.361	0.782
Residuals	116	312.875	2.697		

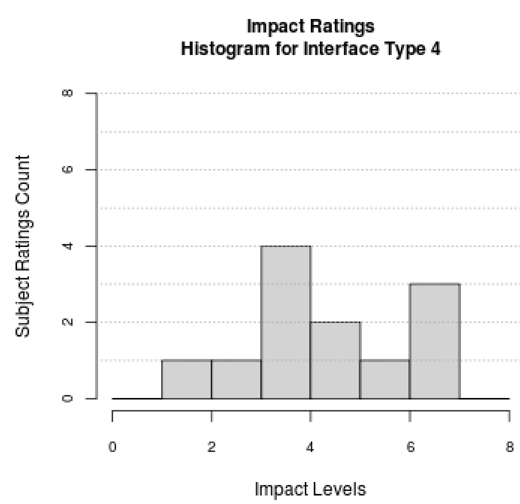
Avg. of Feedbacks Impact vs. Interface Used Friedman test:	
X^2	1.674
p	0.643
DoF	3

Avg. of Feedbacks Impact vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	5.500	1.679	6.000
2	5.208	1.318	5.000
3	5.333	1.805	6.000

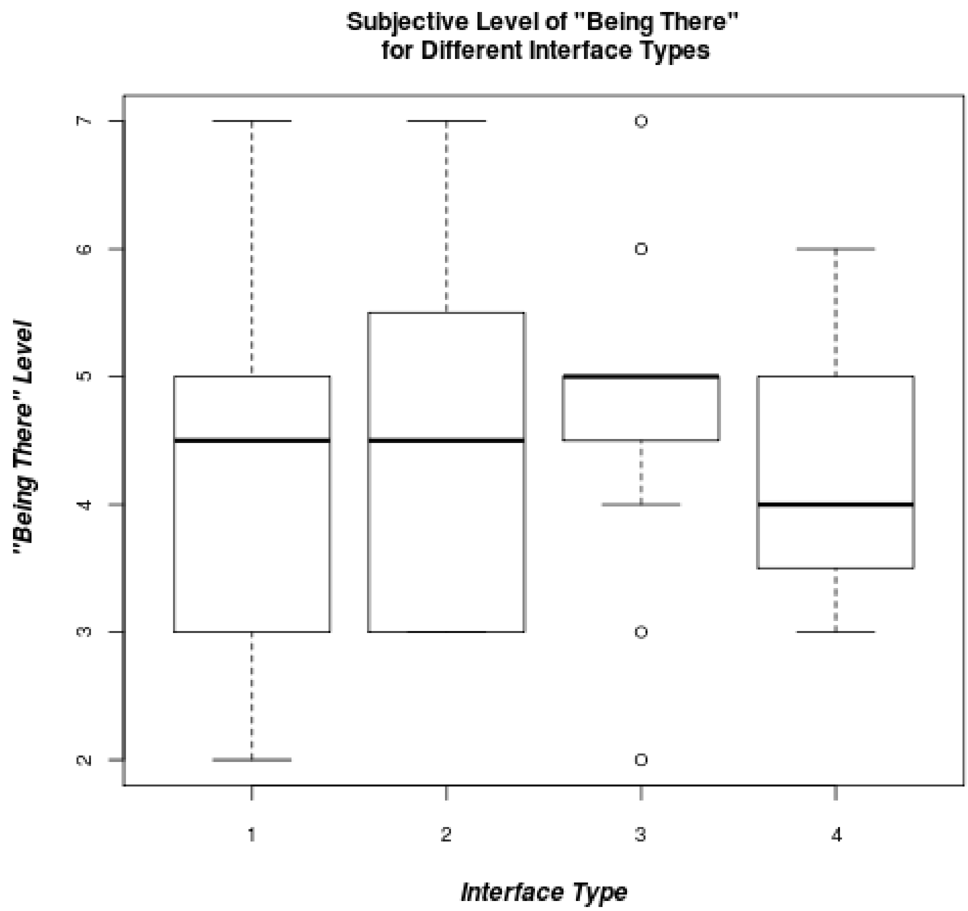




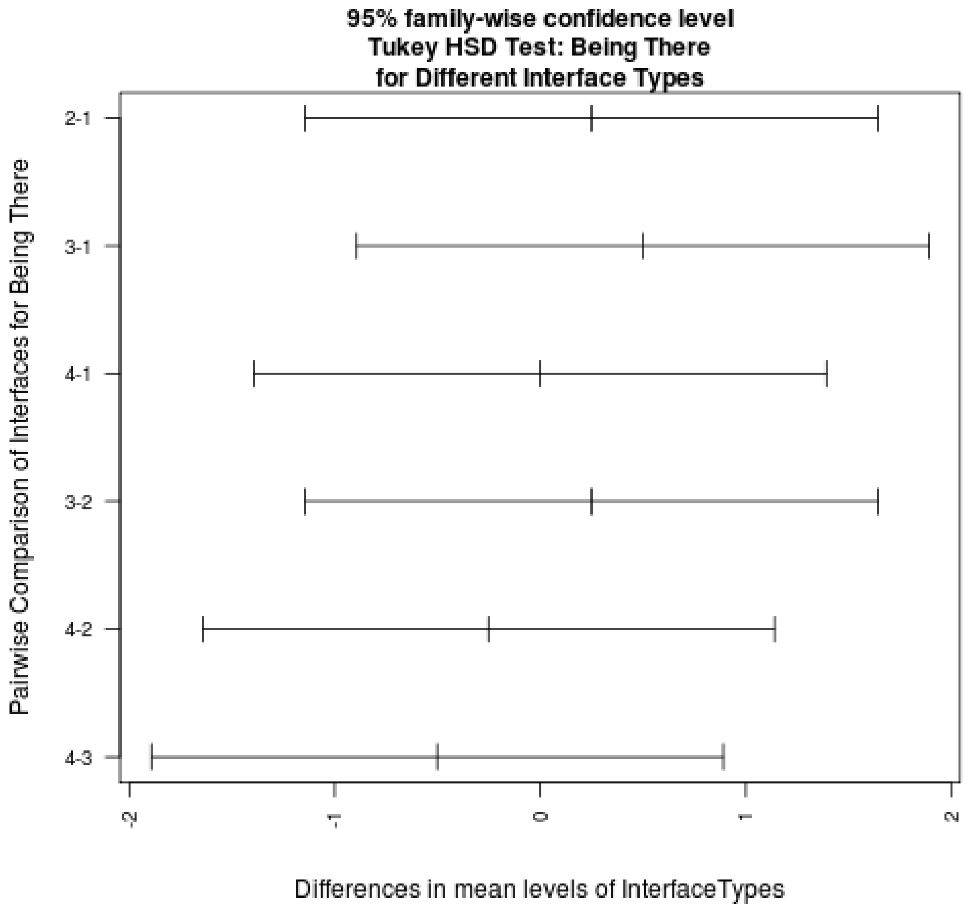




D.2.8.7 Being There



Subject Count	UI1	UI2	UI3	UI4
1	5	3	5	4
2	5	7	5	6
3	5	6	5	4
4	4	5	6	5
5	3	5	2	3
6	7	6	5	3
7	5	3	3	3
8	5	4	5	4
9	4	3	5	4
10	2	5	5	5
11	3	3	7	4
12	3	4	4	6

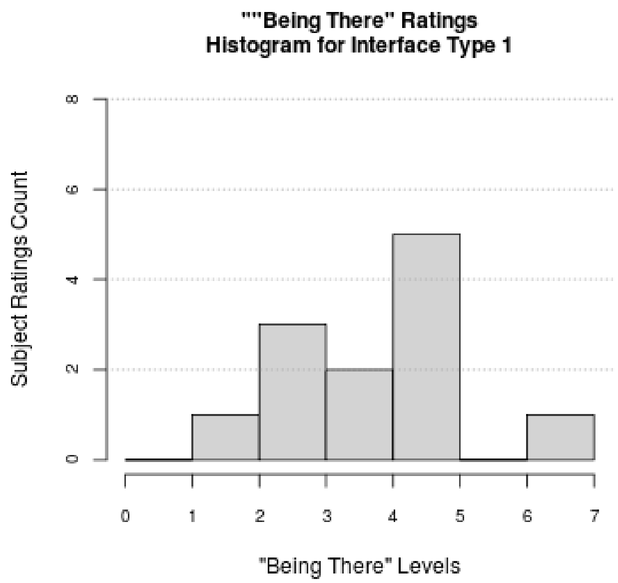


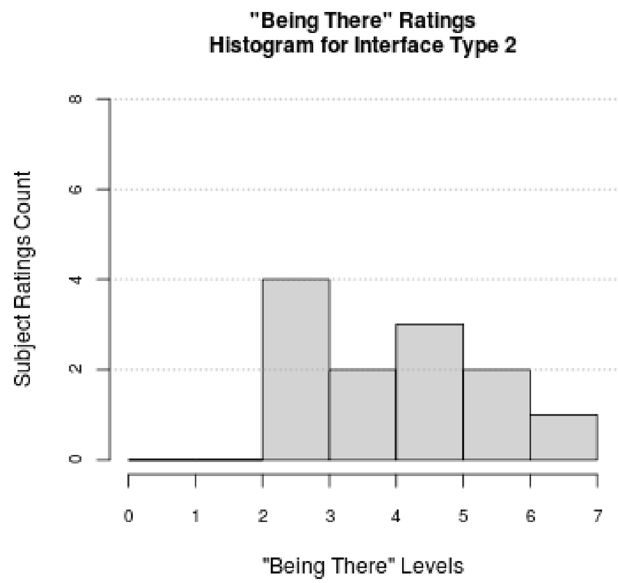
One-way ANOVA: Being There vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	2.063	0.688	0.422	0.738
Residuals	44	71.750	1.631		

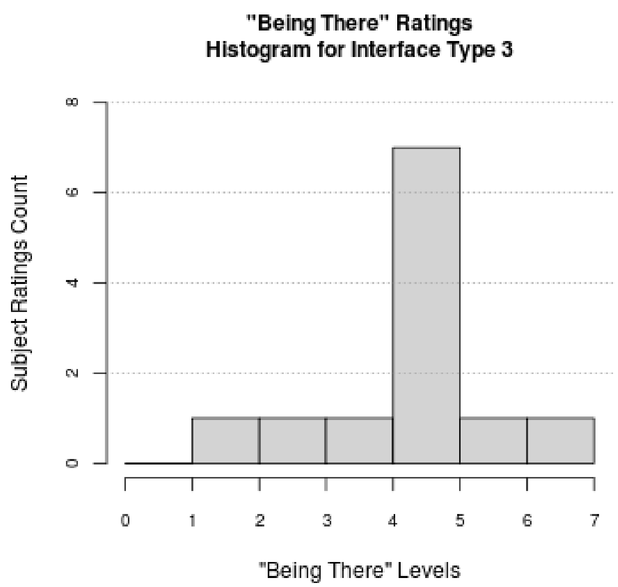
Being There vs. Interface Used Friedman test:	
X^2	1.088
p	0.780
DoF	3

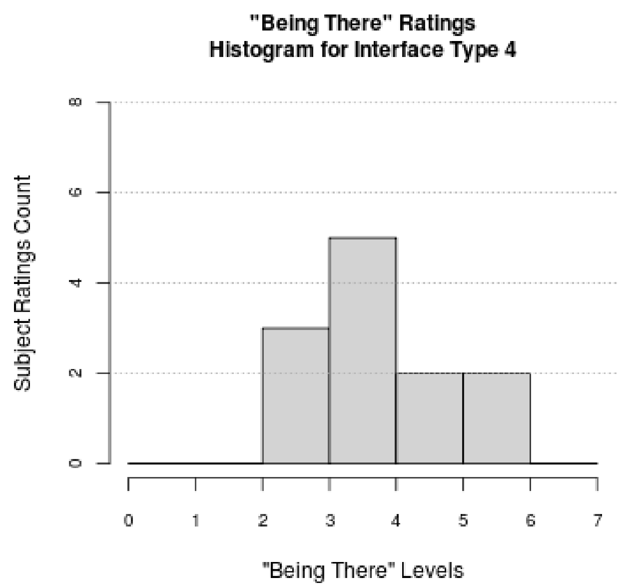
Being There vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	27.500	12.000	27.500	19.000	22.500	38.500
Z	-0.479	-0.806	0.000	-0.399	0.364	1.208
p	0.706	0.484	1.000	0.730	0.797	0.260
R	-0.049	-0.082	0.000	-0.041	0.037	0.123

Being There vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	4.250	1.357	4.500
2	4.500	1.382	4.500
3	4.750	1.288	5.000
4	4.250	1.055	4.000

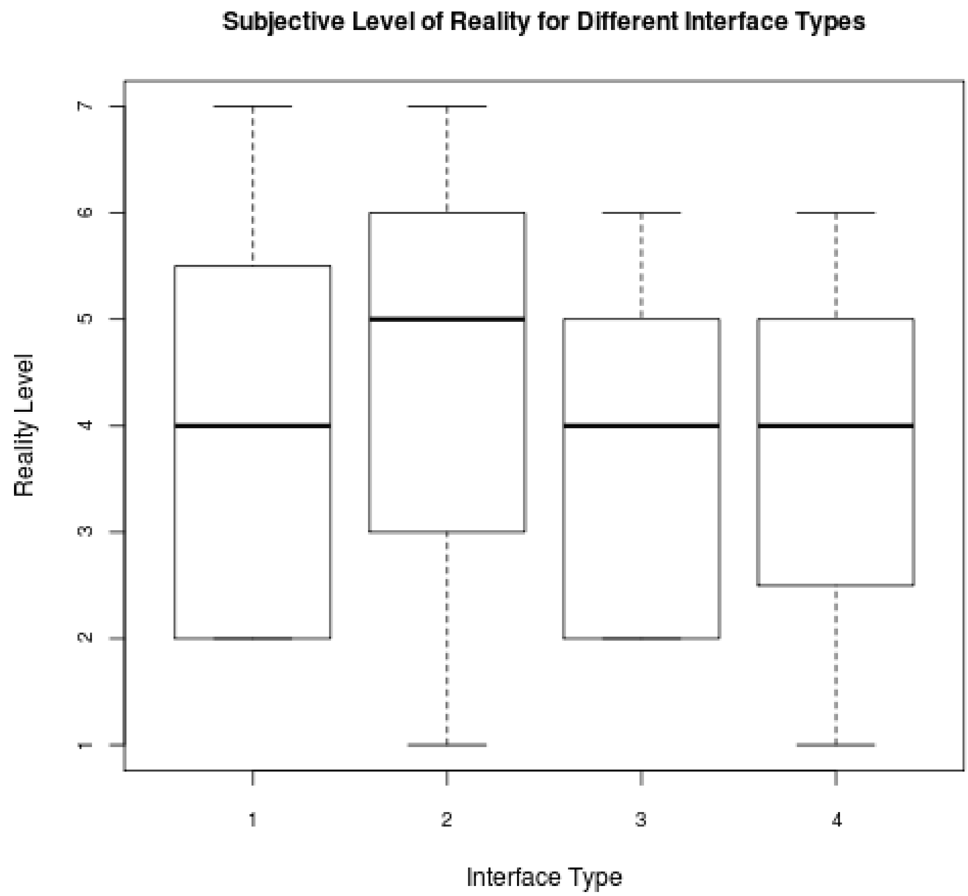




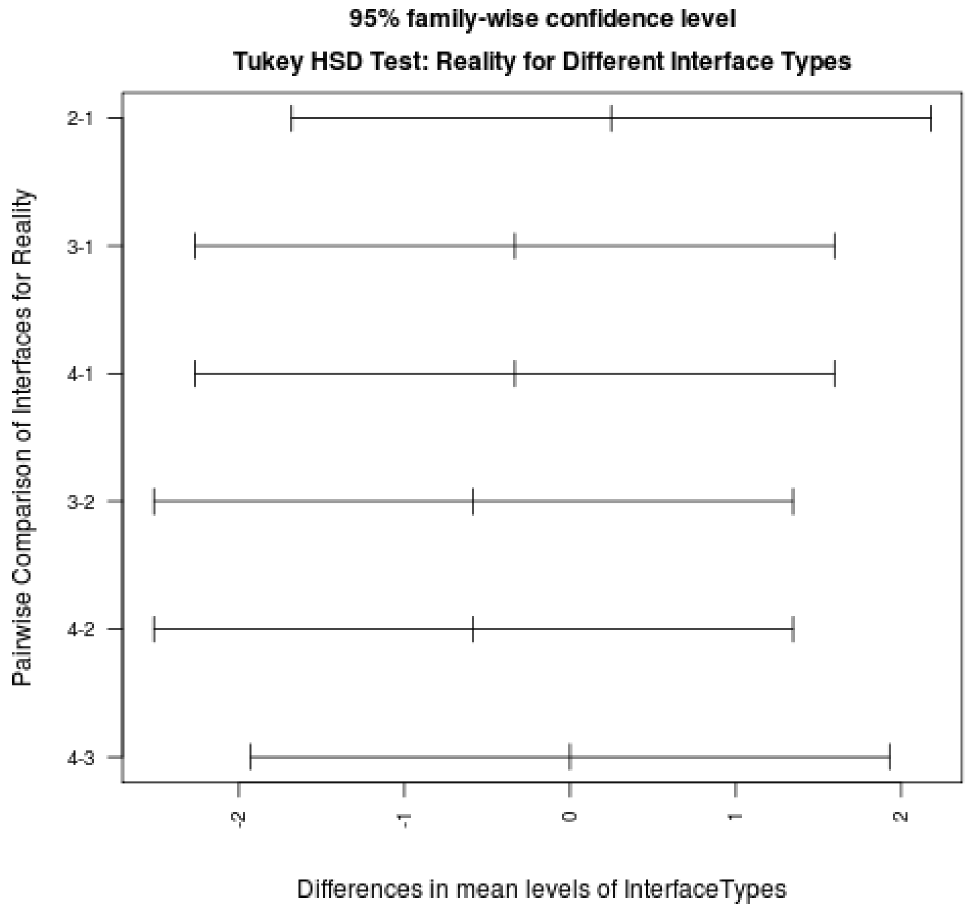




D.2.8.8 Reality



Subject Count	UI1	UI2	UI3	UI4
1	6	1	3	1
2	5	6	5	6
3	2	7	2	5
4	2	5	4	4
5	5	4	2	2
6	7	6	2	3
7	4	3	4	1
8	2	5	5	5
9	2	1	2	4
10	4	5	5	5
11	3	6	6	5
12	7	3	5	4

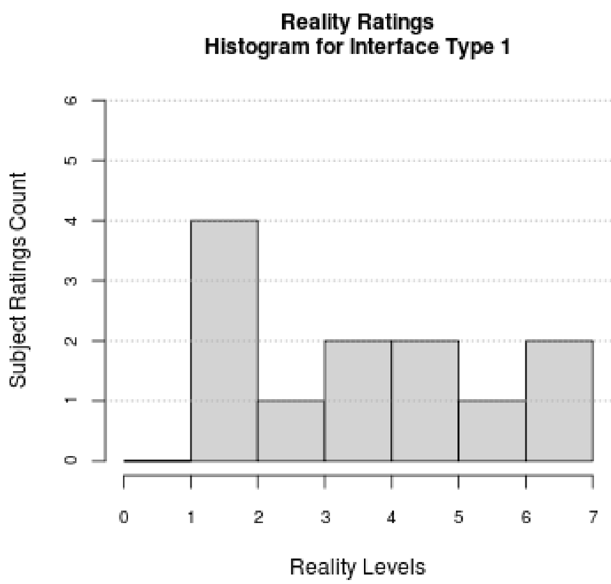


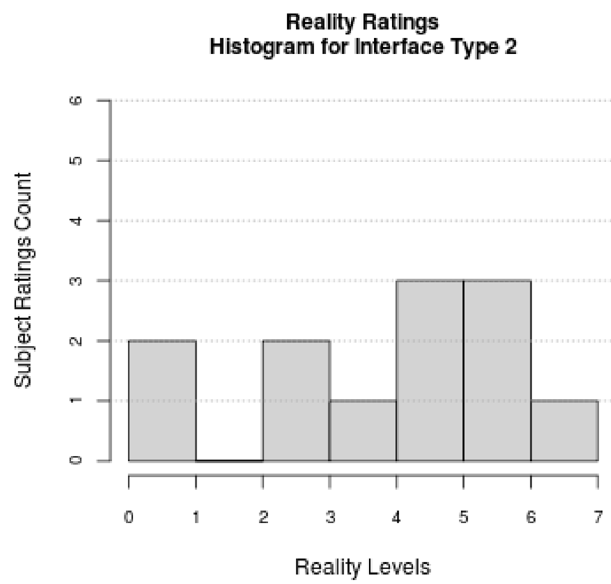
One-way ANOVA: Reality vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	2.896	0.965	0.308	0.820
Residuals	44	138.083	3.138		

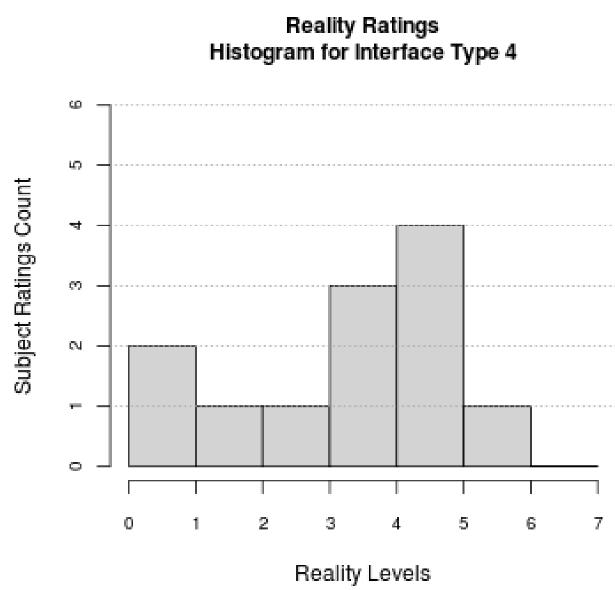
Reality vs. Interface Used Friedman test:	
X^2	0.495
p	0.920
DoF	3

Reality vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	35.500	21.500	47.000	28.000	26.500	18.000
Z	-0.279	0.282	0.634	0.558	1.330	0.000
p	0.796	0.812	0.564	0.637	0.211	1.000
R	-0.028	0.029	0.065	0.057	0.136	0.000

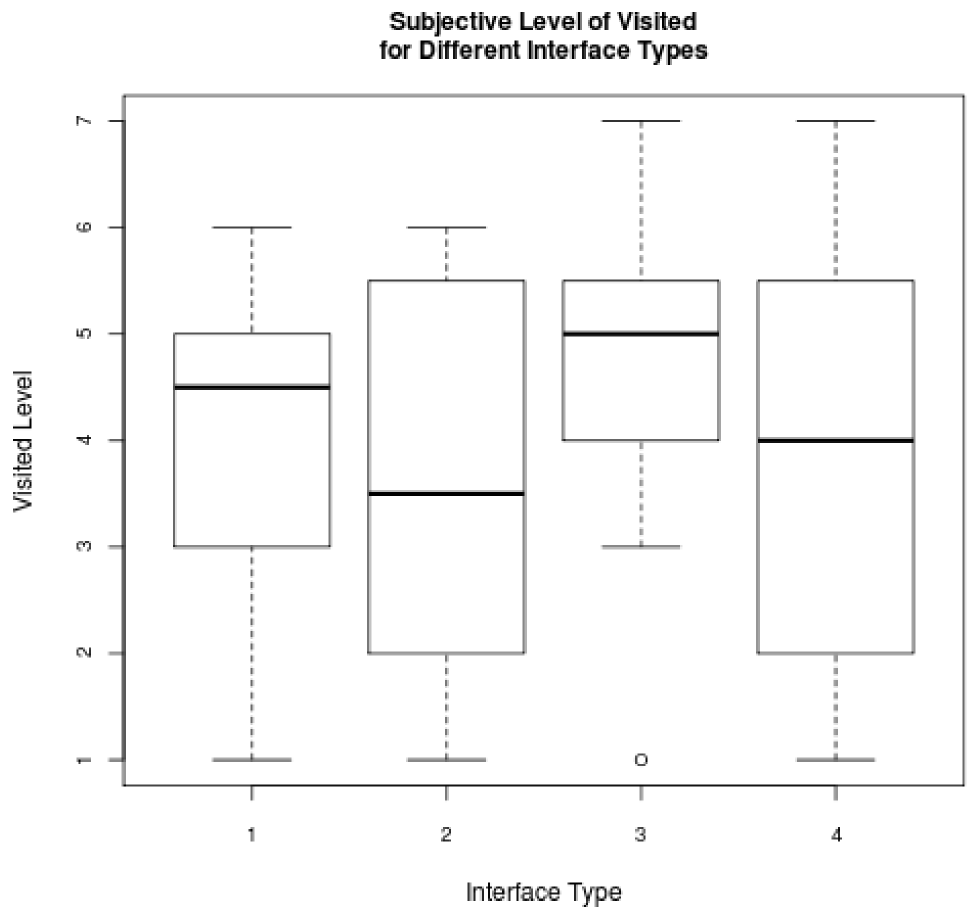
Reality vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	4.083	1.929	4.000
2	4.333	1.969	5.000
3	3.750	1.485	4.000
4	3.750	1.658	4.000



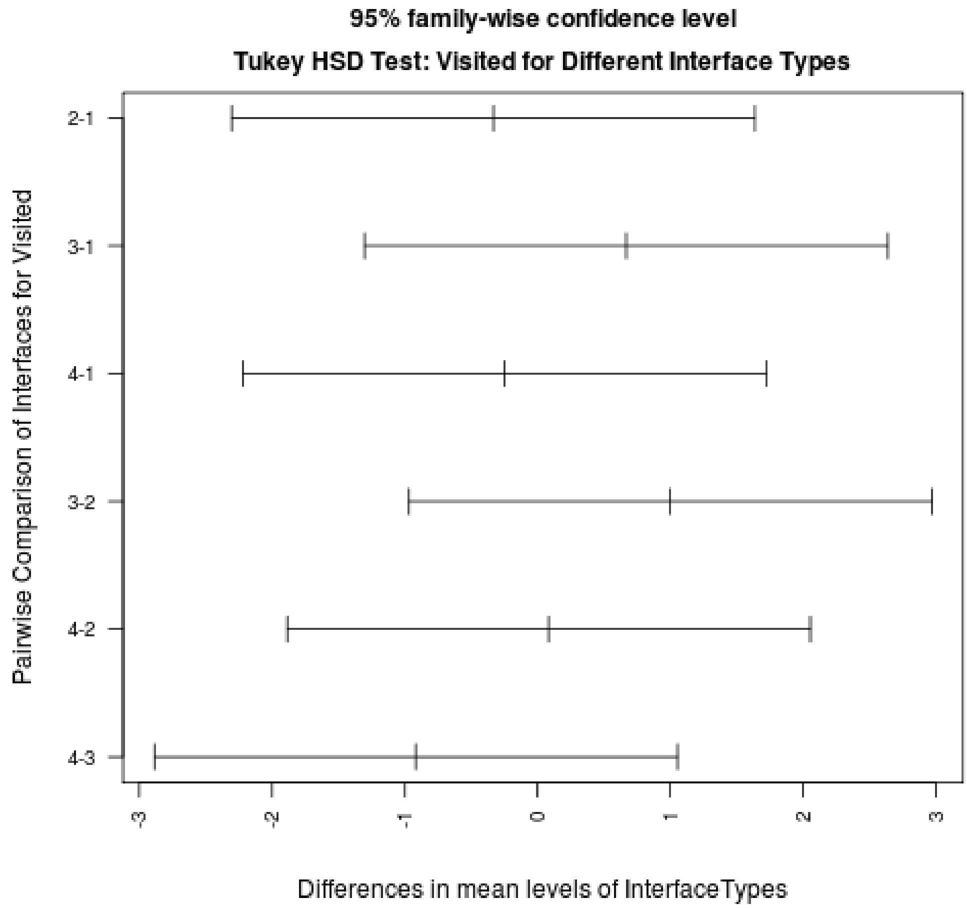




D.2.8.9 Visited



Subject Count	UI1	UI2	UI3	UI4
1	1	3	5	1
2	5	4	5	6
3	5	6	4	6
4	1	6	6	5
5	5	3	1	2
6	5	2	6	1
7	6	2	5	2
8	6	2	4	5
9	3	4	5	2
10	4	6	3	3
11	4	1	5	5
12	3	5	7	7

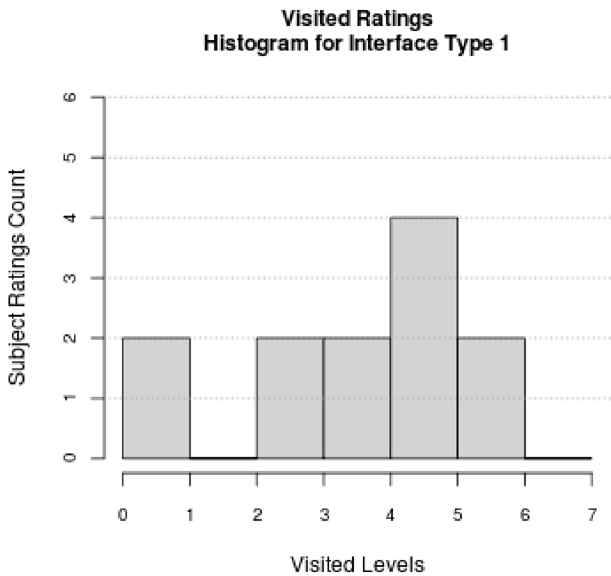


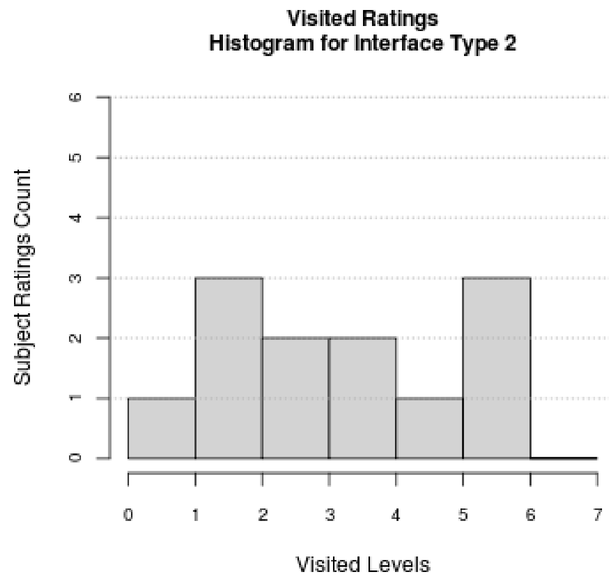
One-way ANOVA: Visited vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	7.396	2.465	0.756	0.525
Residuals	44	143.583	3.263		

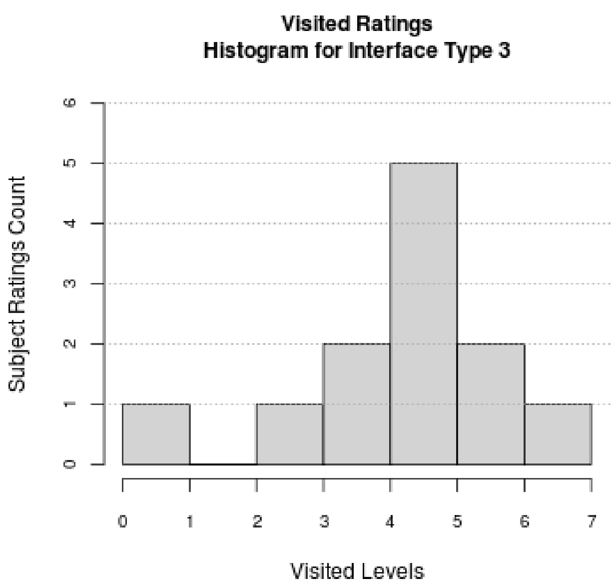
Visited vs. Interface Used Friedman test:	
X^2	0.991
p	0.803
DoF	3

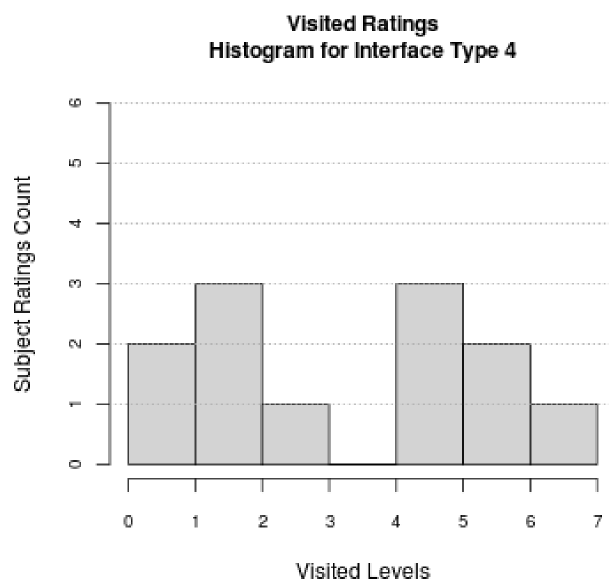
Visited vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	45.500	24.500	36.500	18.500	25.500	32.500
Z	0.513	-0.713	0.320	-1.347	0.000	0.916
p	0.637	0.519	0.825	0.202	1.000	0.395
R	0.052	-0.073	0.033	-0.137	0.000	0.093

Visited vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	4.000	1.706	4.500
2	3.667	1.775	3.500
3	4.667	1.557	5.000
4	3.750	2.137	4.000

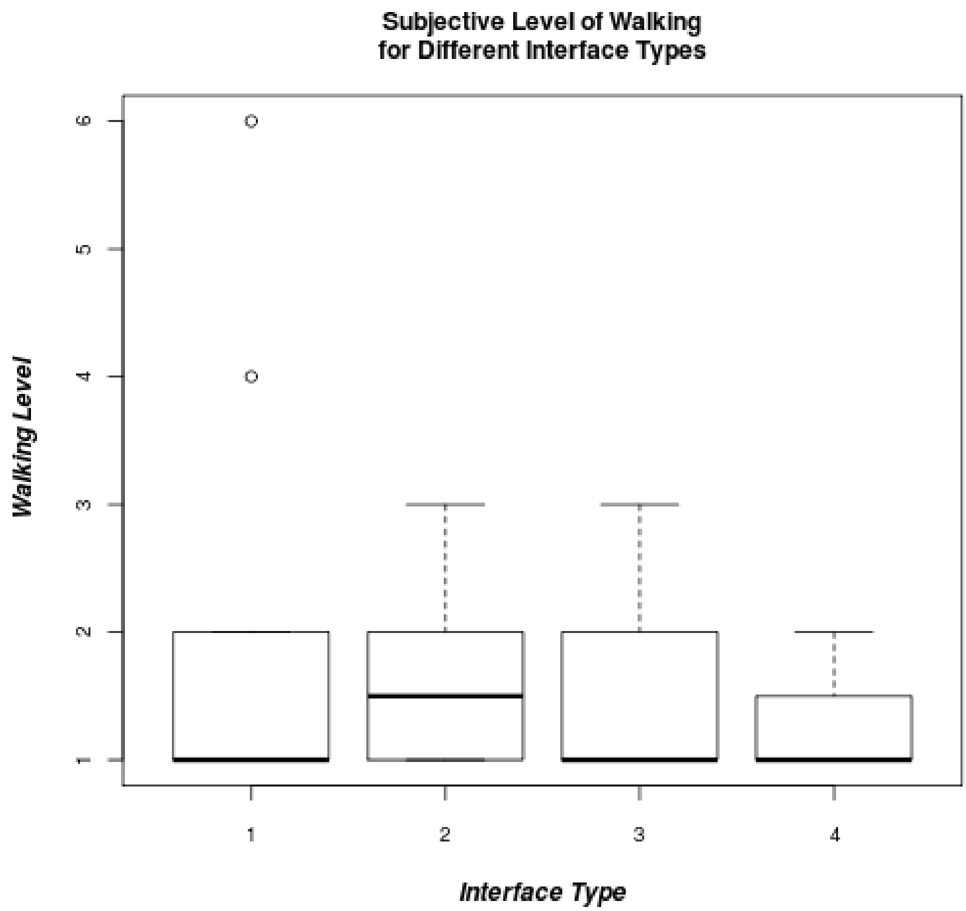




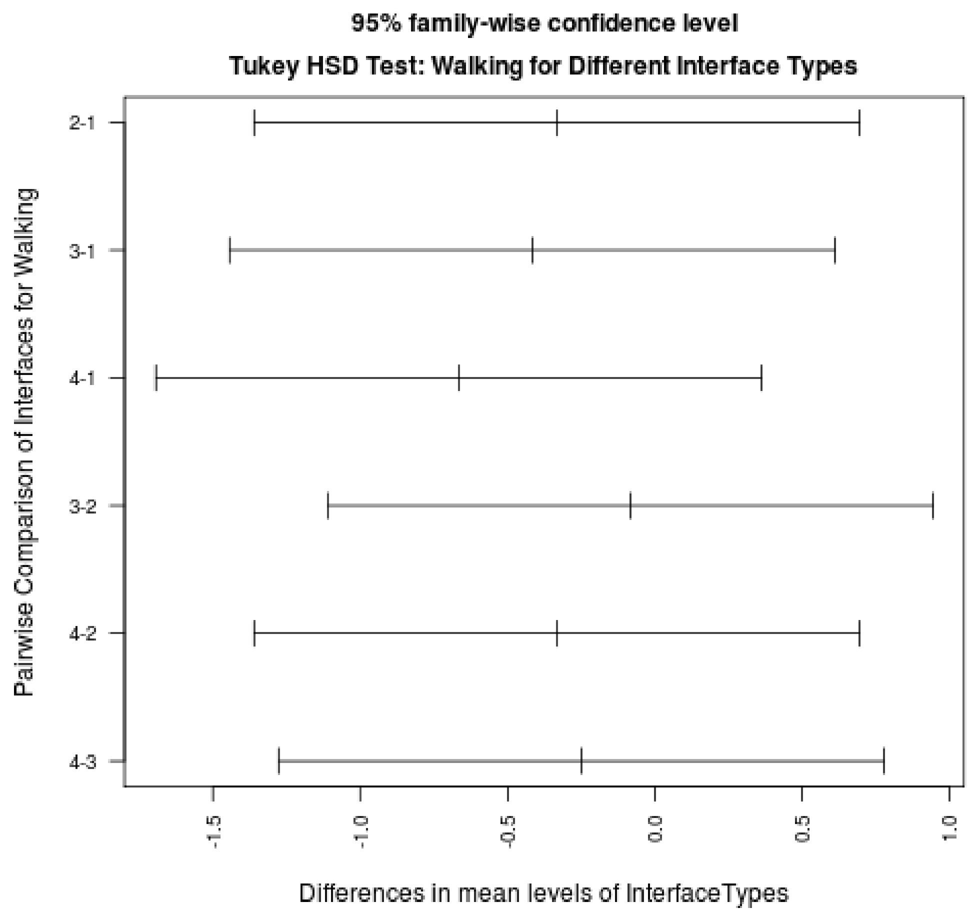




D.2.8.10 Walking



Subject Count	UI1	UI2	UI3	UI4
1	1	1	2	1
2	2	1	1	1
3	1	2	1	1
4	1	1	1	2
5	1	2	1	1
6	2	2	2	1
7	1	2	1	1
8	1	1	2	2
9	4	1	3	2
10	6	3	2	1
11	1	2	1	1
12	2	1	1	1



One-way ANOVA: Walking vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	2.729	0.910	1.024	0.391
Residuals	44	39.083	0.888		

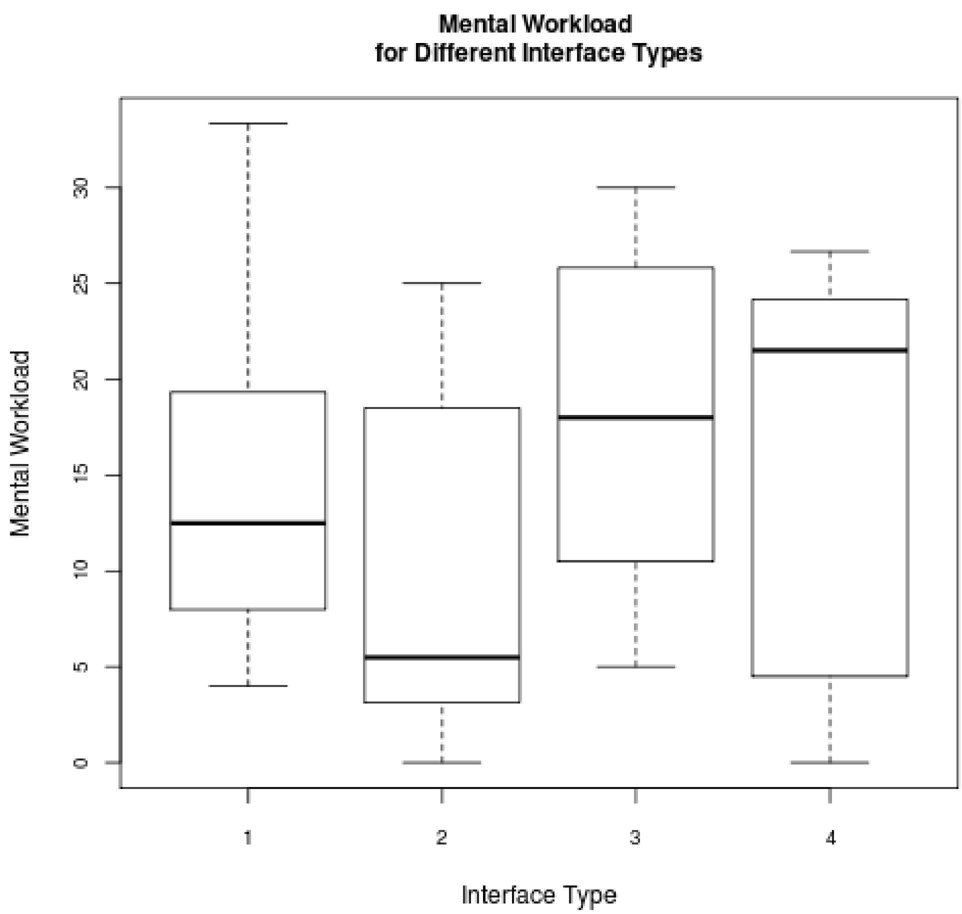
Walking vs. Interface Used Friedman test:	
X^2	2.415
p	0.491
DoF	3

Walking vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	22.000	15.000	22.000	20.000	31.500	12.000
Z	0.326	0.896	1.282	0.493	1.108	1.342
p	0.797	0.531	0.281	0.727	0.398	0.375
R	0.033	0.091	0.131	0.050	0.113	0.137

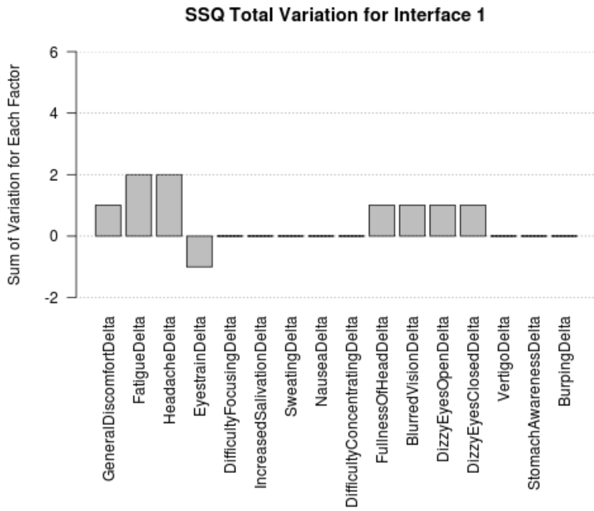
Walking vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	1.917	1.564	1.000
2	1.583	0.669	1.500
3	1.500	0.674	1.000
4	1.250	0.452	1.000

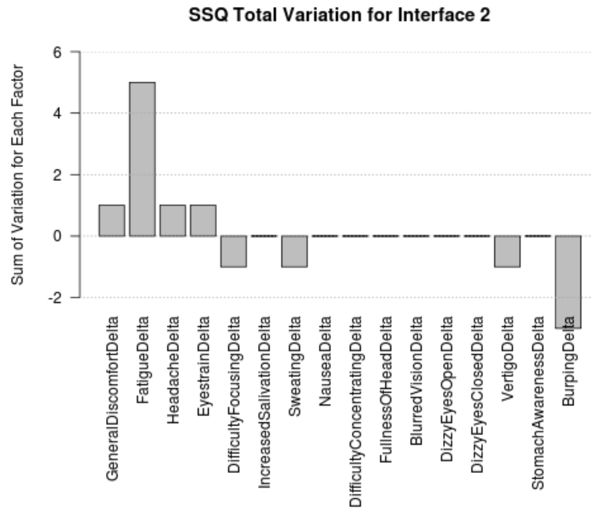
D.2.9 SSQ

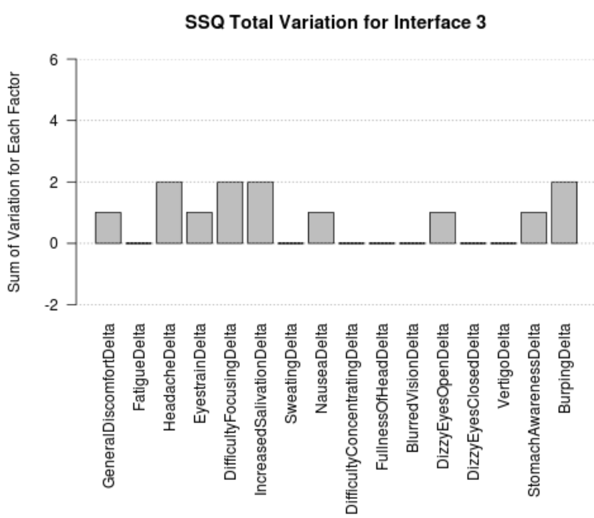
D.2.9.1 Changes in Health State for All Interfaces

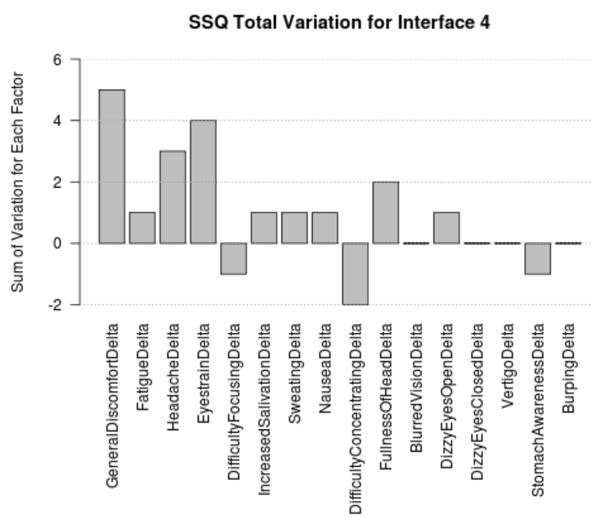


D.2.9.2 Changes in Health State for Per Interface

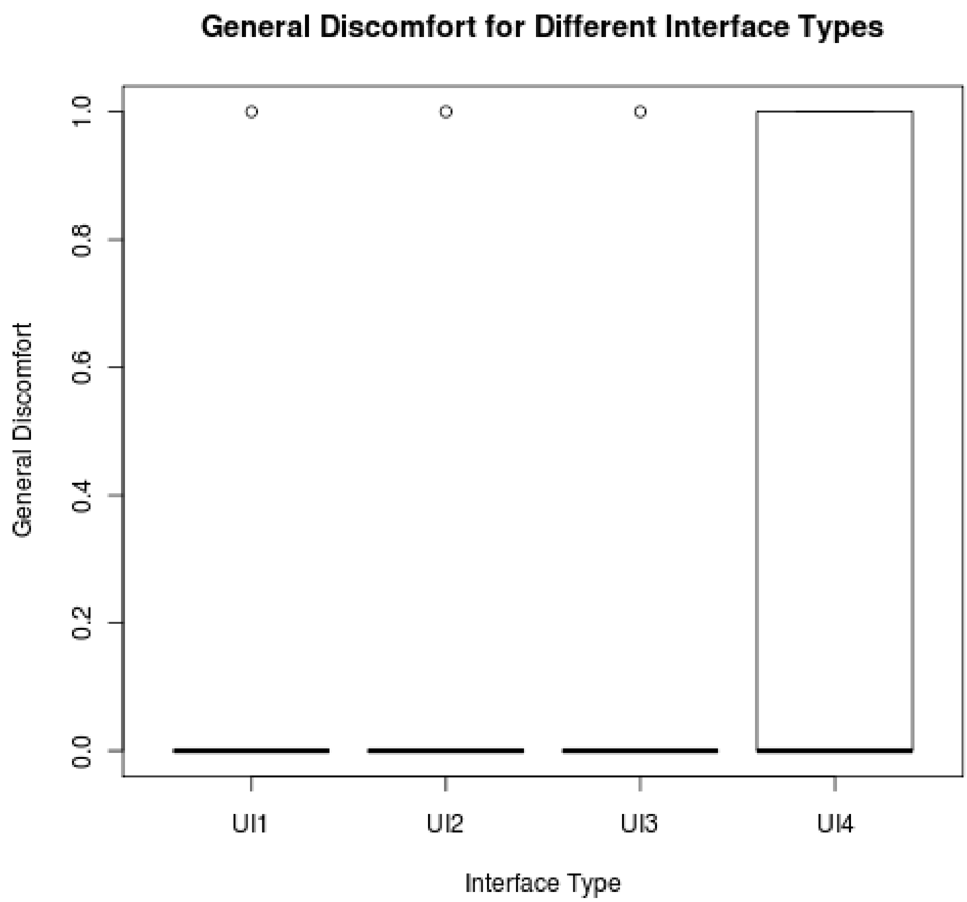




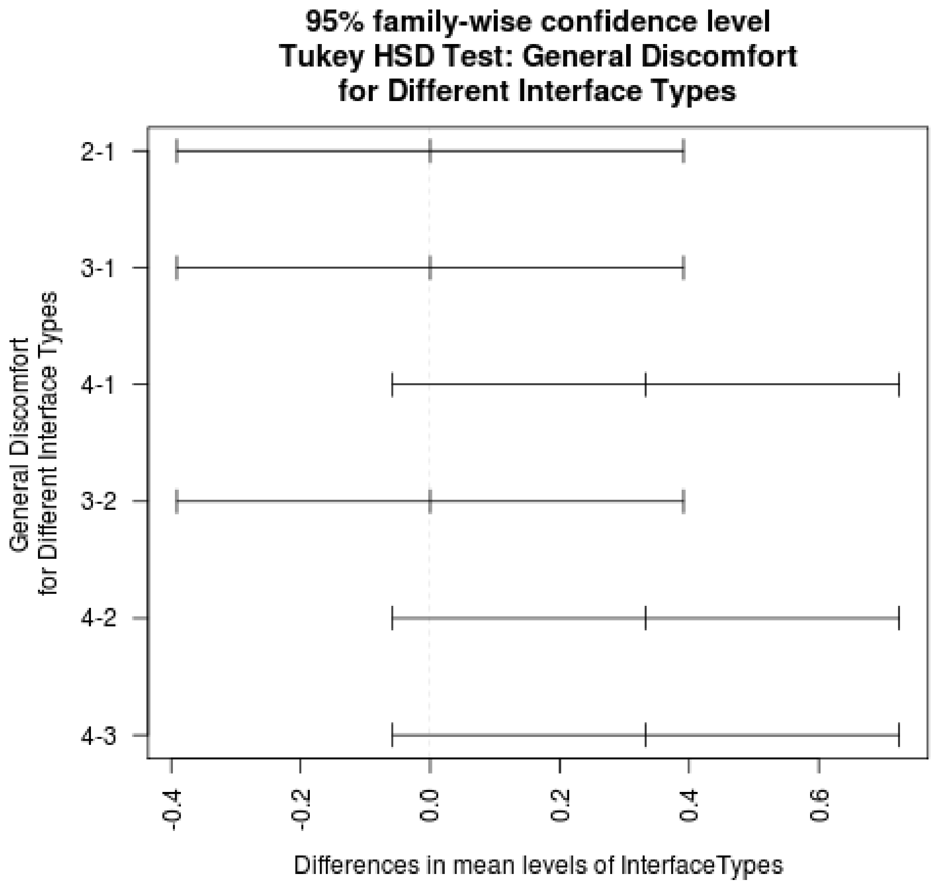




D.2.9.3 General Discomfort



Subject Count	UI1	UI2	UI3	UI4
1	0	1	0	1
2	0	0	0	0
3	0	0	1	0
4	0	0	0	1
5	0	0	0	0
6	0	0	0	0
7	0	0	0	1
8	0	0	0	0
9	0	0	0	1
10	1	0	0	0
11	0	0	0	0
12	0	0	0	1



One-way ANOVA: General Discomfort vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	1.000	0.333	2.588	0.065
Residuals	44	5.667	0.129		

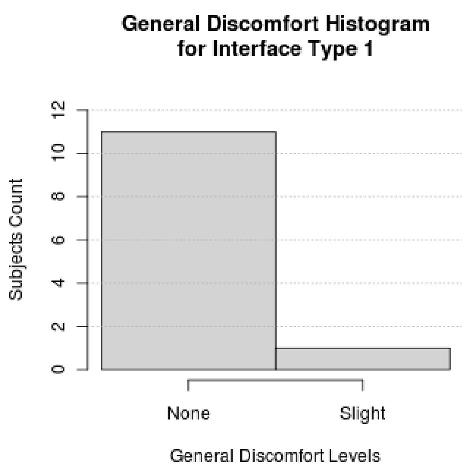
General Discomfort vs. Interface Used Friedman test:	
X^2	6.545
p	0.088
DoF	3

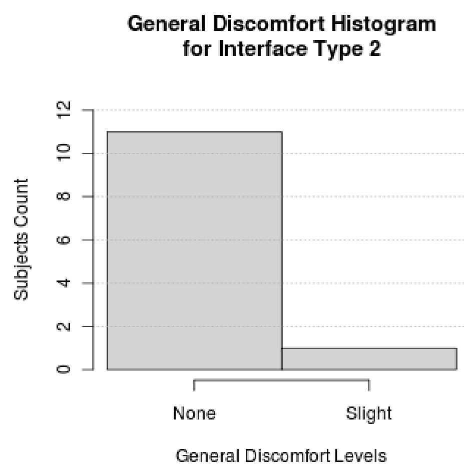
General Discomfort vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	1.500	3.500	3.500	1.500	0.000	3.500
Z	0.000	-1.633	-1.633	0.000	-2.000	-1.633
p	1.000	0.219	0.219	1.000	0.125	0.219
R	0.000	-0.167	-0.167	0.000	-0.204	-0.167

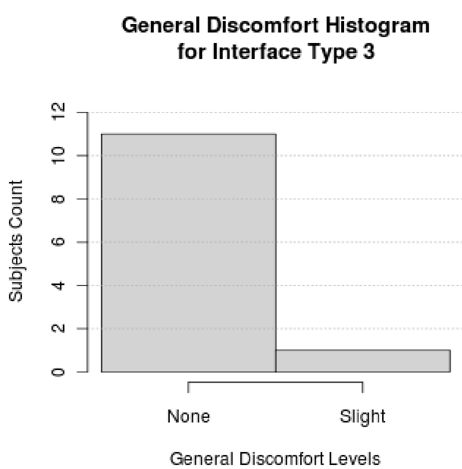
General Discomfort vs. Interface Used Kurskal-Wallis test:	
X^2	7050.000
DoF	3
p	0.070

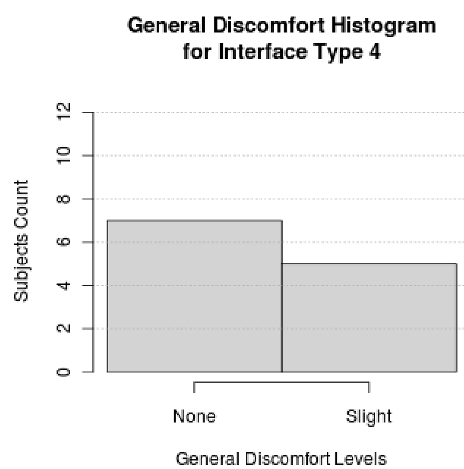
General Discomfort vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	0.000	0.000	3.407	0.000	3.407	3.407
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	1.000	1.000	0.065	1.000	0.065	0.065

General Discomfort vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.083	0.289	0.000
2	0.083	0.289	0.000
3	0.083	0.289	0.000
4	0.417	0.515	0.000

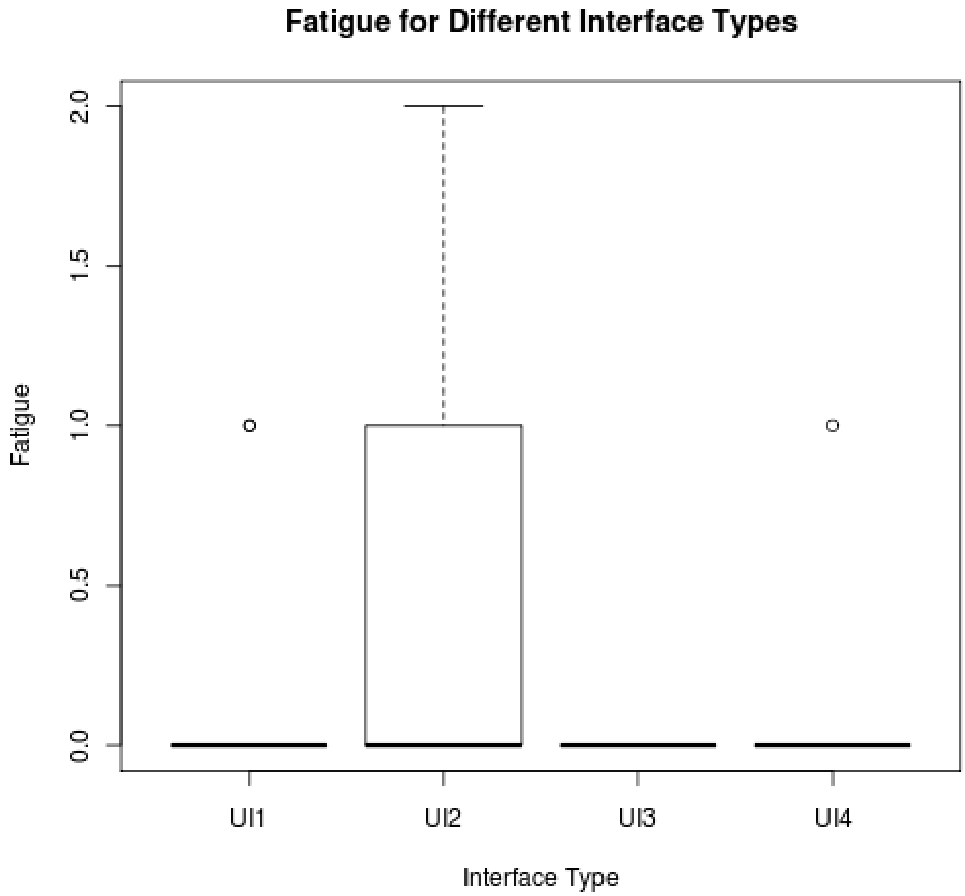




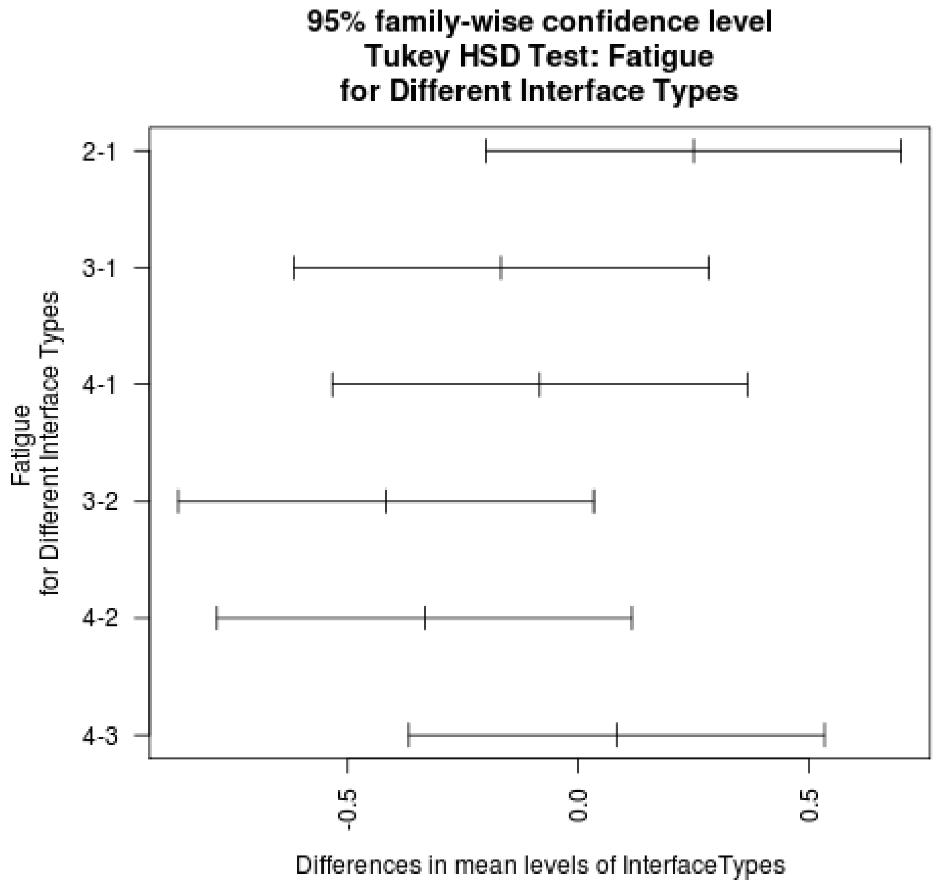




D.2.9.4 Fatigue



Subject Count	UI1	UI2	UI3	UI4
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	1	0	0
5	0	2	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	1	1	0	0
11	1	0	0	0
12	0	1	0	1



One-way ANOVA: Fatigue vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	1.167	0.389	2.282	0.092
Residuals	44	7.500	0.170		

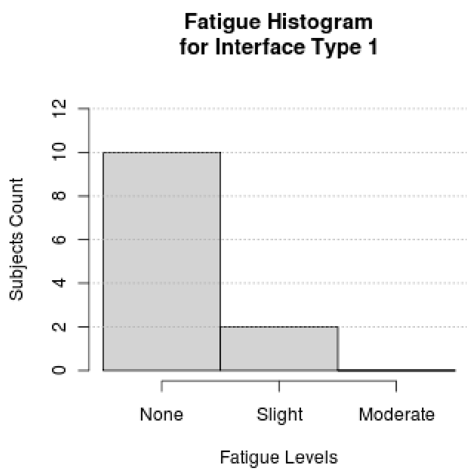
Fatigue vs. Interface Used Friedman test:	
X^2	6.176
p	0.103
DoF	3

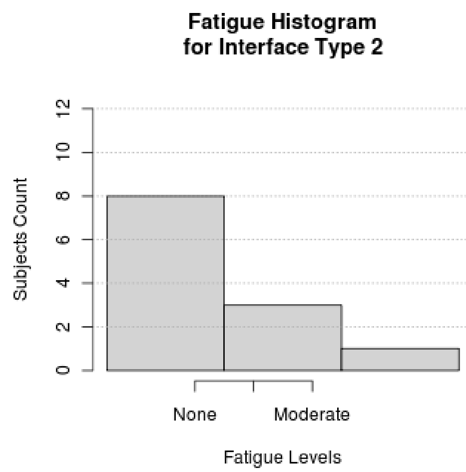
Fatigue vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	2.000	3.000	4.000	10.000	6.000	0.000
Z	-1.044	1.414	0.577	1.993	1.728	-1.000
p	0.500	0.500	1.000	0.125	0.250	1.000
R	-0.107	0.144	0.059	0.203	0.176	-0.102

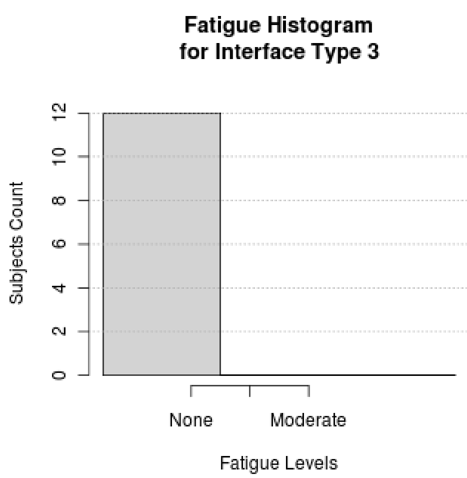
Fatigue vs. Interface Used Kurskal-Wallis test:	
X^2	5.908
DoF	3
p	0.116

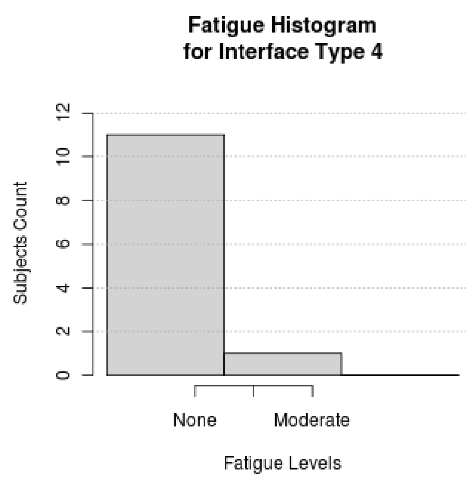
Fatigue vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	0.988	2.091	0.365	4.571	2.281	1.000
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	0.320	0.148	0.546	0.032	0.131	0.314

Fatigue vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.167	0.389	0.000
2	0.417	0.669	0.000
3	0.000	0.000	0.000
4	0.083	0.289	0.000

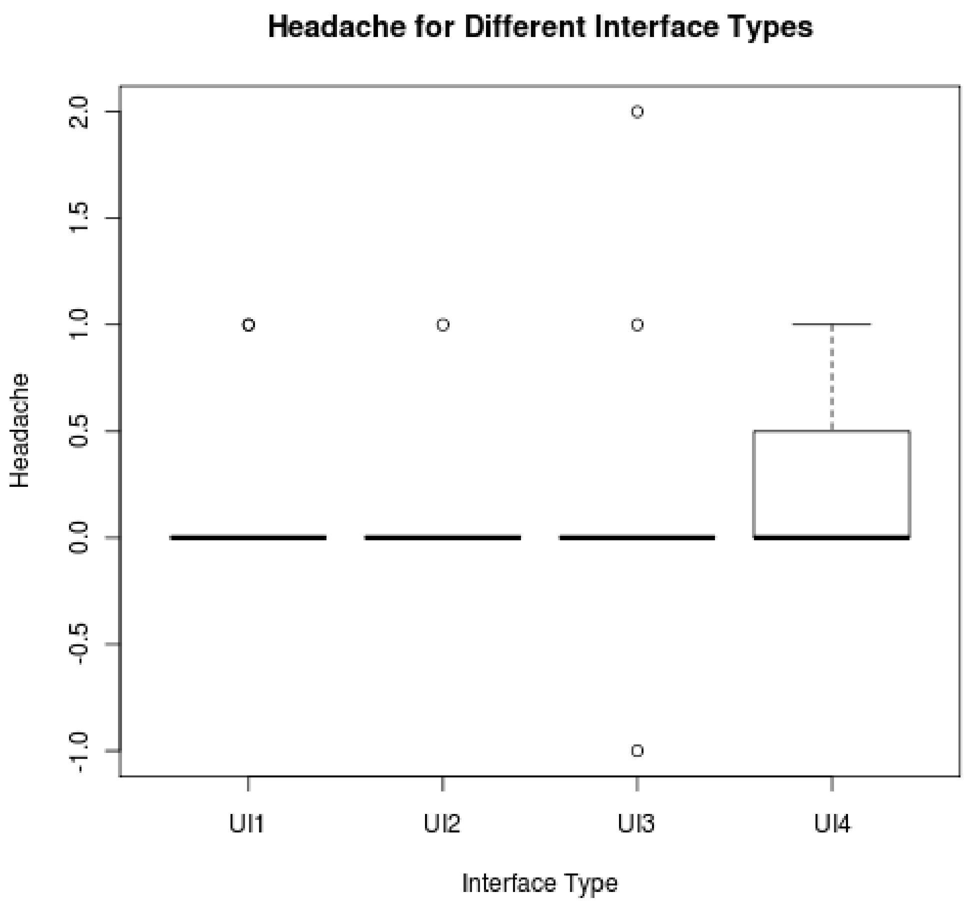




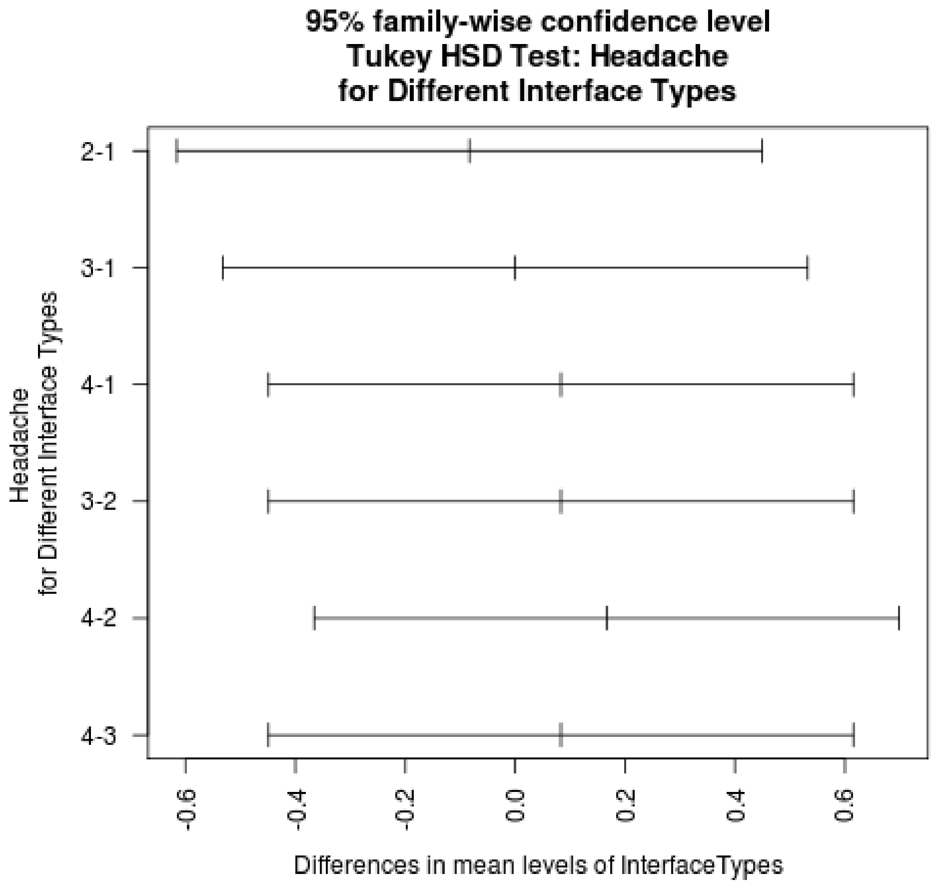




D.2.9.5 Headache



Subject Count	UI1	UI2	UI3	UI4
1	0	0	0	0
2	1	0	0	0
3	0	0	2	0
4	0	0	0	0
5	0	0	1	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	1
10	0	0	0	1
11	1	0	-1	0
12	0	1	0	1



One-way ANOVA: Headache vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.167	0.056	0.233	0.873
Residuals	44	10.500	0.239		

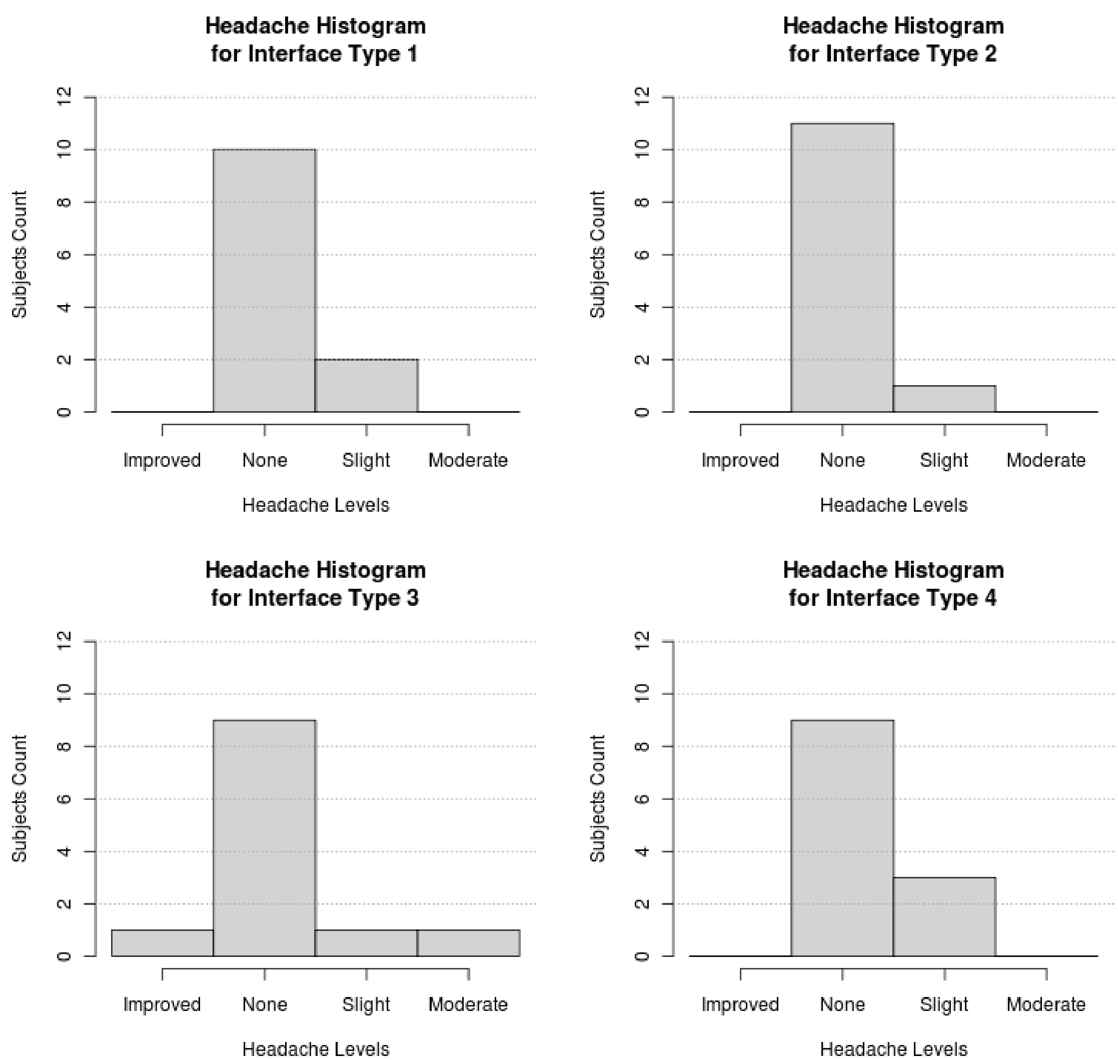
Headache vs. Interface Used Friedman test:	
X^2	1.213
p	0.75
DoF	3

Headache vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	4.000	5.000	6.000	4.000	0.000	9.000
Z	0.577	0.000	-0.447	-0.095	-1.414	-0.640
p	1.000	1.000	1.000	1.000	0.500	0.688
R	0.059	0.000	-0.046	-0.010	-0.144	-0.065

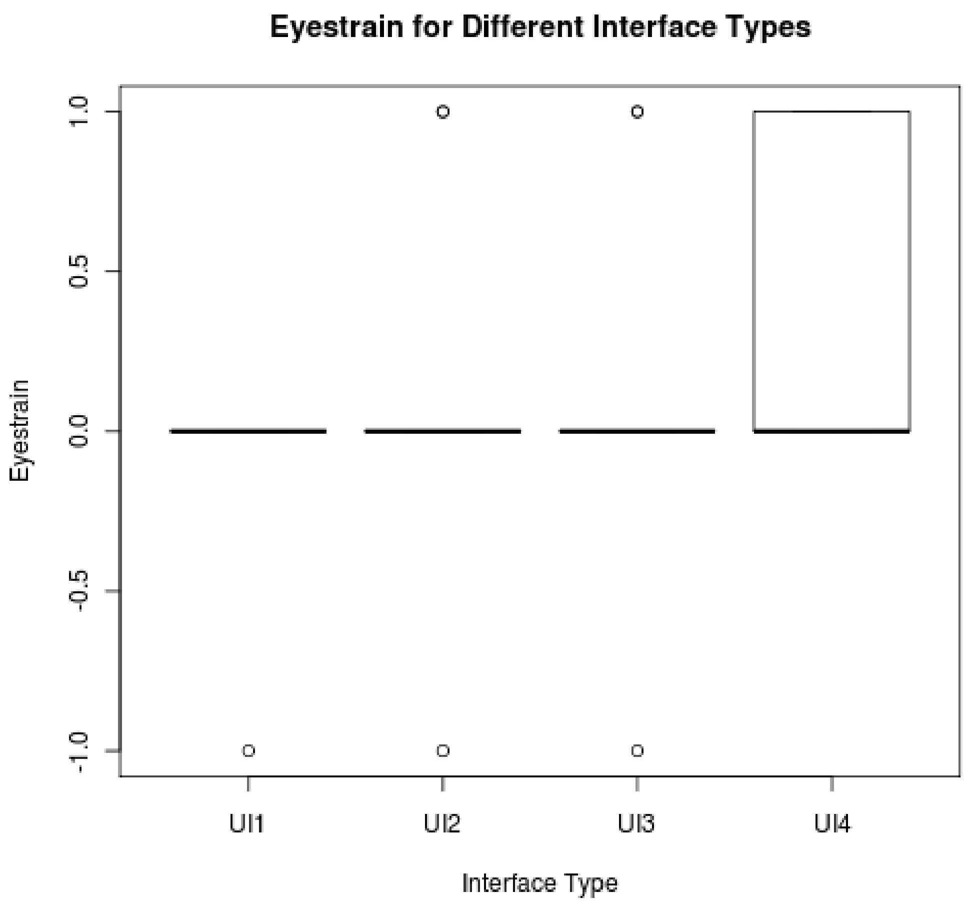
Headache vs. Interface Used Kurskal-Wallis test:	
X^2	1.154
DoF	3
p	0.764

Headache vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	0.365	0.106	0.242	0.008	1.150	0.470
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	0.546	0.745	0.623	0.929	0.283	0.493

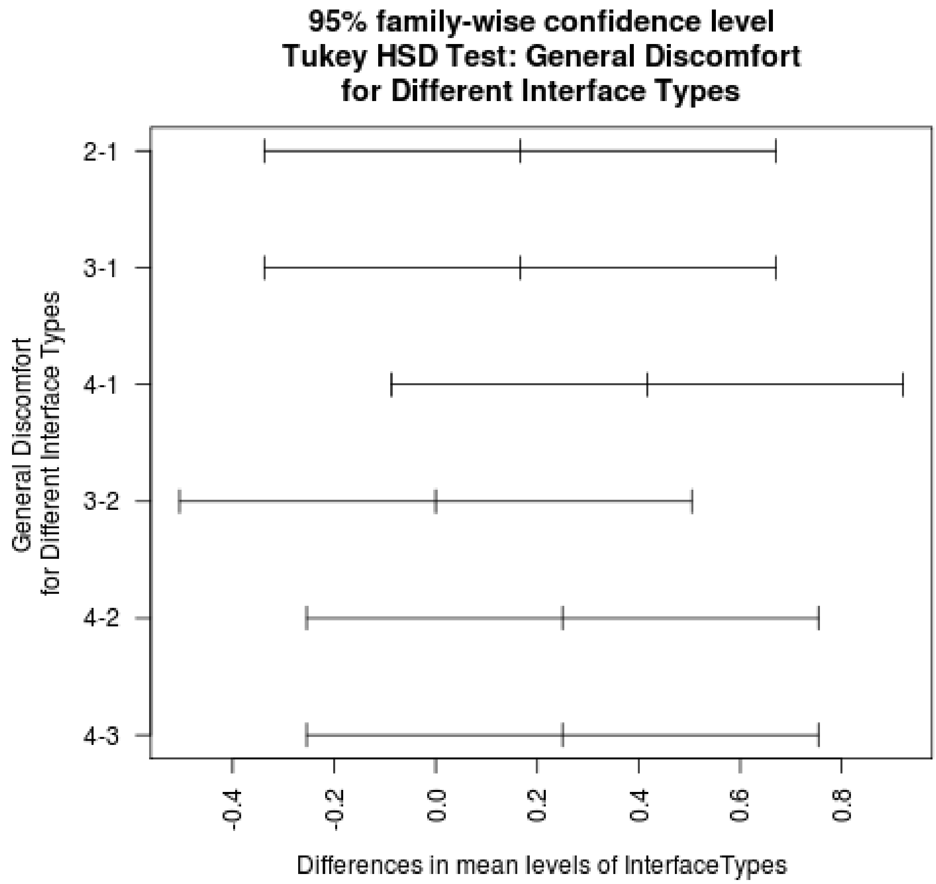
Interface	Mean	Std. Dev.	Median
1	0.167	0.389	0.000
2	0.083	0.289	0.000
3	0.167	0.718	0.000
4	0.250	0.452	0.000



D.2.9.6 Eyestrain



Subject Count	UI1	UI2	UI3	UI4
1	0	0	-1	0
2	0	0	0	1
3	0	1	1	0
4	0	-1	0	0
5	0	0	1	1
6	0	0	0	0
7	0	0	0	1
8	0	0	0	0
9	0	0	0	0
10	0	1	0	1
11	-1	0	0	0
12	0	0	0	0



One-way ANOVA: Eyestrain vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	1.063	0.354	1.655	0.191
Residuals	44	9.417	0.214		

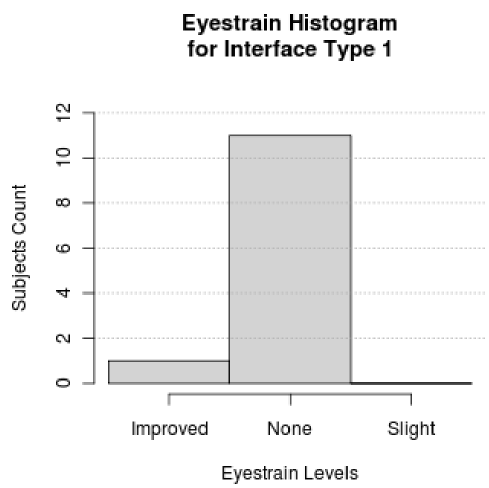
Eyestrain vs. Interface Used Friedman test:	
X^2	5.667
p	0.129
DoF	3

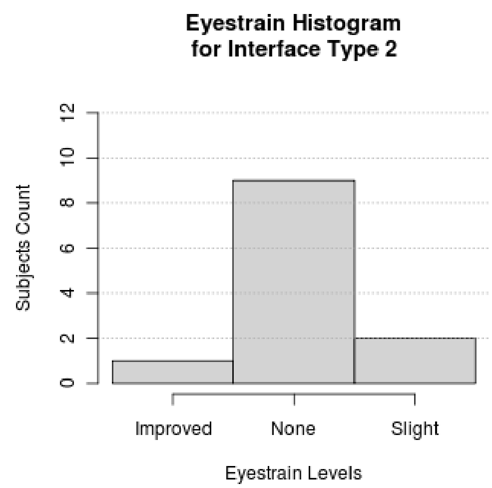
Eyestrain vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	2.500	2.500	0.000	5.000	3.000	3.000
Z	-1.000	-1.000	-2.236	0.000	-1.342	-1.342
p	0.625	0.625	0.062	1.000	0.375	0.375
R	-0.102	-0.102	-0.228	0.000	-0.137	-0.137

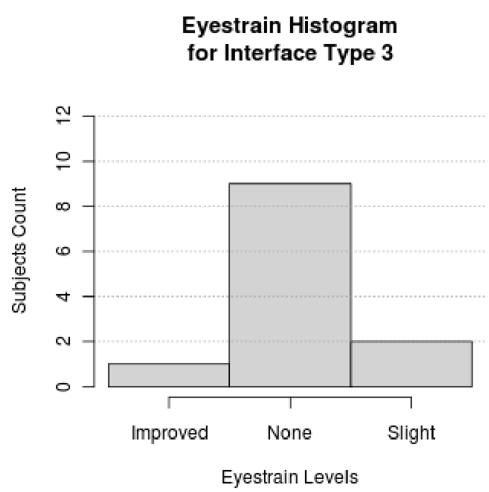
Eyestrain vs. Interface Used Kurskal-Wallis test:	
X^2	4.866
DoF	3
p	0.182

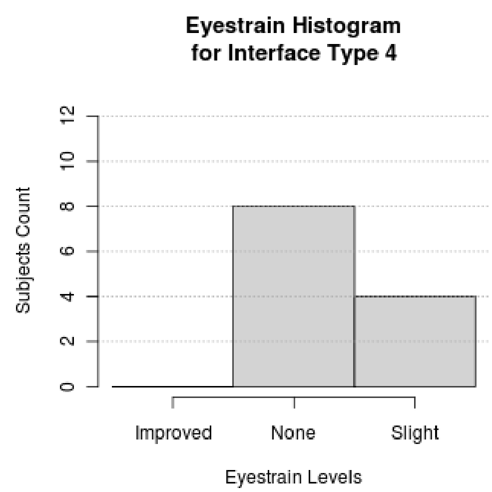
Eyestrain vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	0.958	0.958	5.227	0.000	1.354	1.354
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	0.328	0.328	0.022	1.000	0.244	0.244

Interface	Mean	Std. Dev.	Median
1	-0.083	0.289	0.000
2	0.083	0.515	0.000
3	0.083	0.515	0.000
4	0.333	0.492	0.000

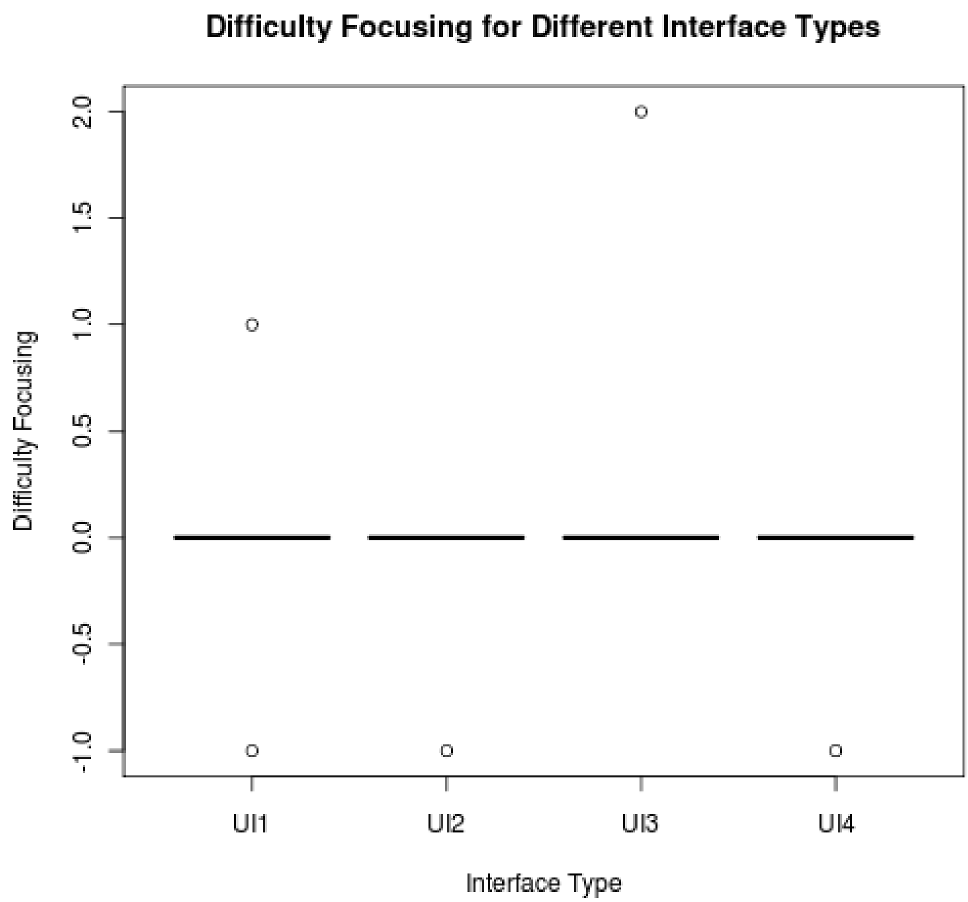




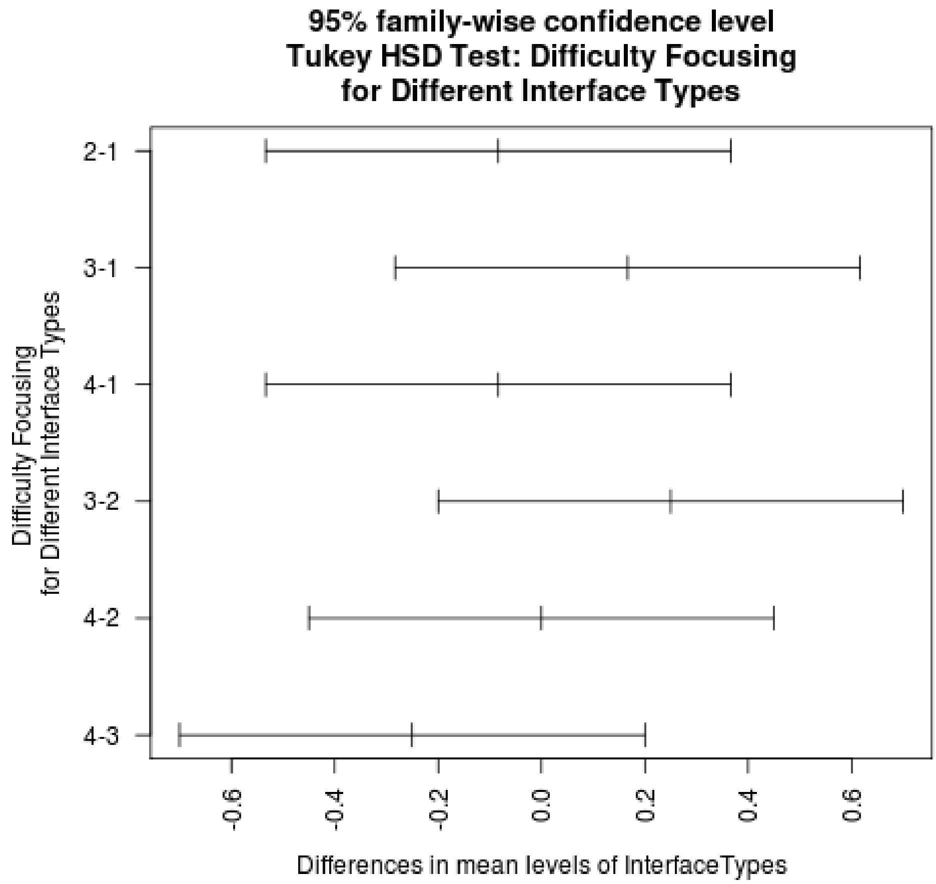




D.2.9.7 Difficulty Focusing



Subject Count	UI1	UI2	UI3	UI4
1	0	-1	0	0
2	0	0	0	0
3	0	0	0	0
4	-1	0	0	0
5	0	0	2	0
6	0	0	0	0
7	0	0	0	-1
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	1	0	0	0
12	0	0	0	0



One-way ANOVA: Difficulty Focusing vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.500	0.167	0.978	0.412
Residuals	44	7.500	0.170		

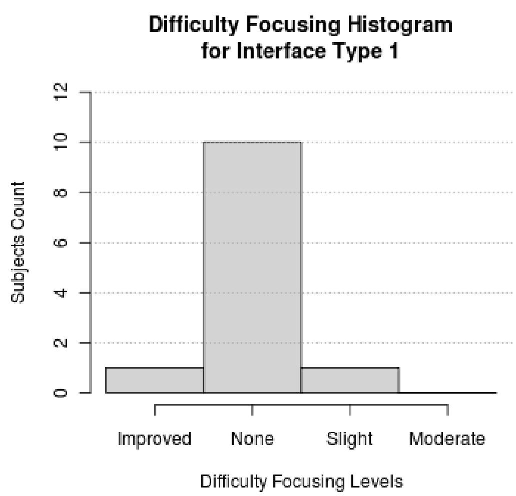
Difficulty Focusing vs. Interface Used Friedman test:	
X^2	2.200
p	0.532
DoF	3

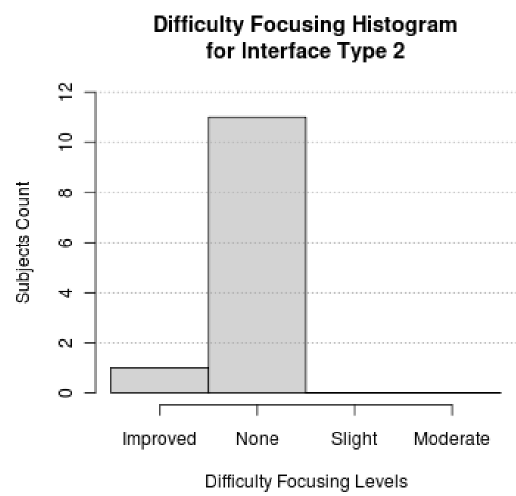
Difficulty Focusing vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	4.000	1.500	4.000	0.000	1.500	3.000
Z	0.577	-0.629	0.577	-1.413	0.000	1.413
p	1.000	0.750	1.000	0.500	1.000	0.500
R	0.059	-0.064	0.059	-0.144	0.000	0.144

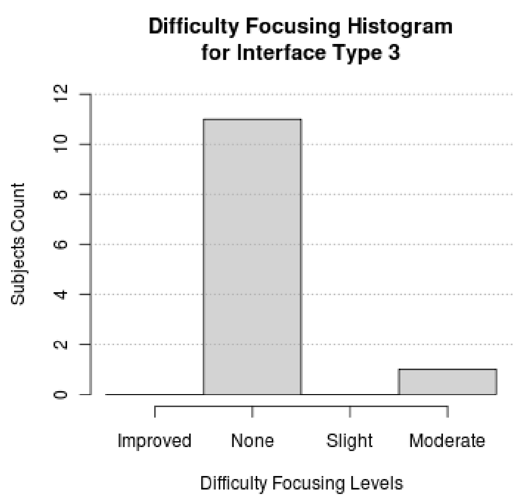
Difficulty Focusing vs. Interface Used Kurskal-Wallis test:	
X^2	2.185
DoF	3
p	0.535

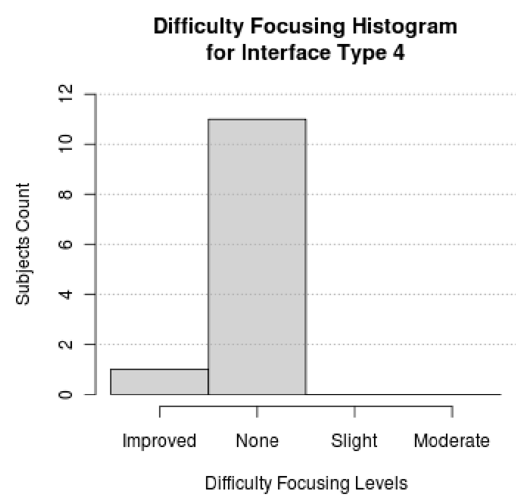
Difficulty Focusing vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	0.306	0.363	0.306	1.917	0.000	1.917
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	0.580	0.547	0.580	0.166	1.000	0.166

Difficulty Focusing vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.000	0.426	0.000
2	-0.083	0.289	0.000
3	0.167	0.577	0.000
4	-0.083	0.289	0.000

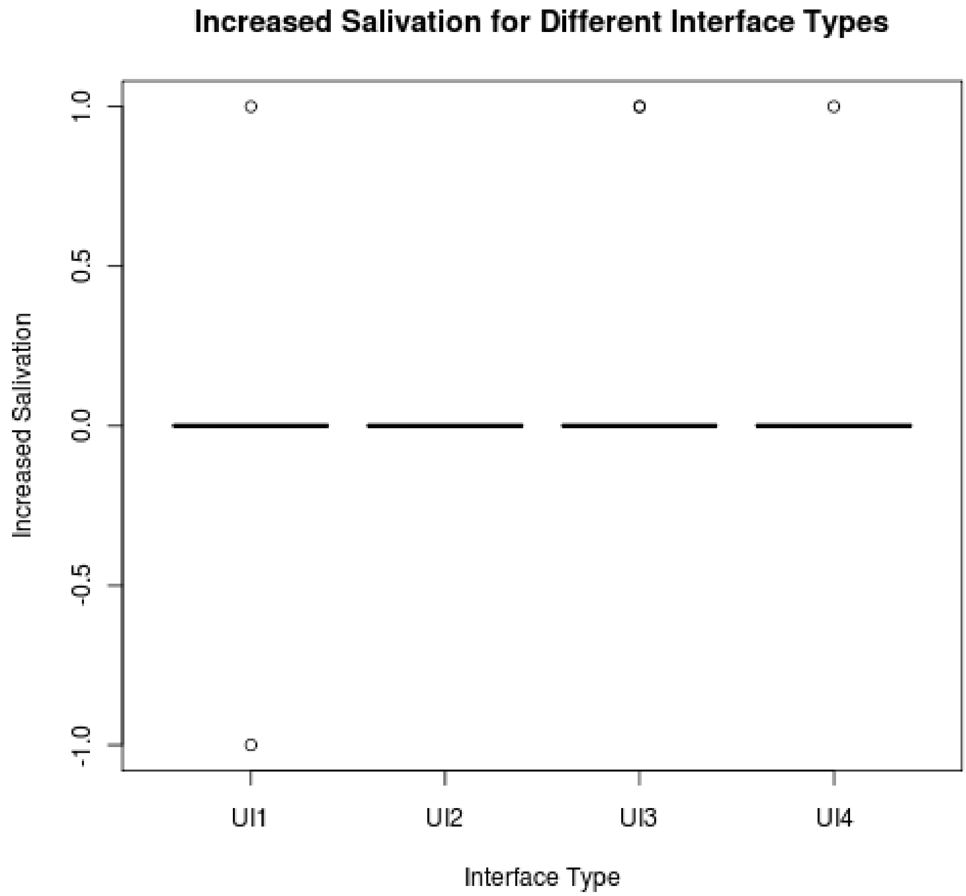




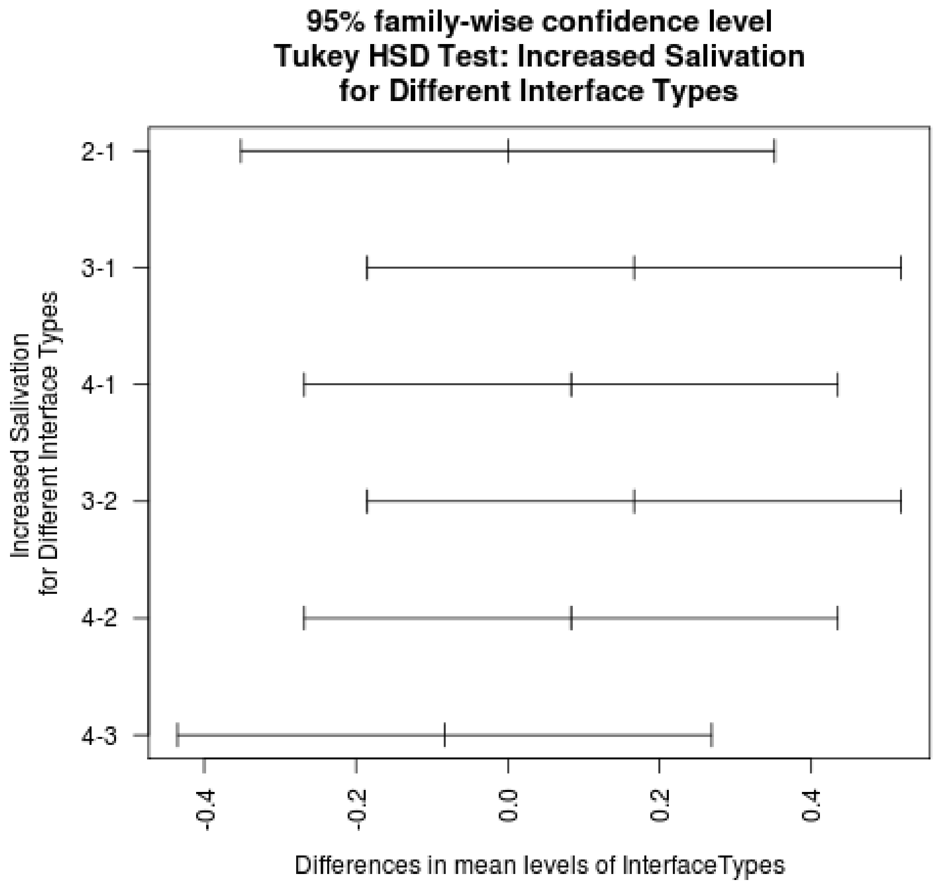




D.2.9.8 Increased Salivation



Subject Count	UI1	UI2	UI3	UI4
1	0	0	1	0
2	0	0	0	0
3	0	0	0	1
4	0	0	0	0
5	0	0	1	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	1	0	0	0
11	-1	0	0	0
12	0	0	0	0



One-way ANOVA: Increased Salivation vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.229	0.076	0.733	0.538
Residuals	44	4.583	0.104		

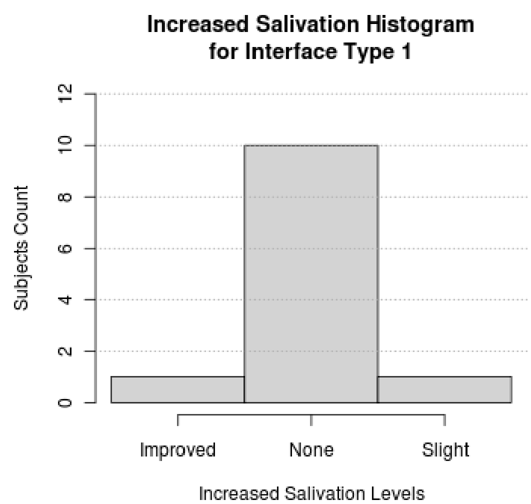
Increased Salivation vs. Interface Used Friedman test:	
X^2	2.200
p	0.532
DoF	3

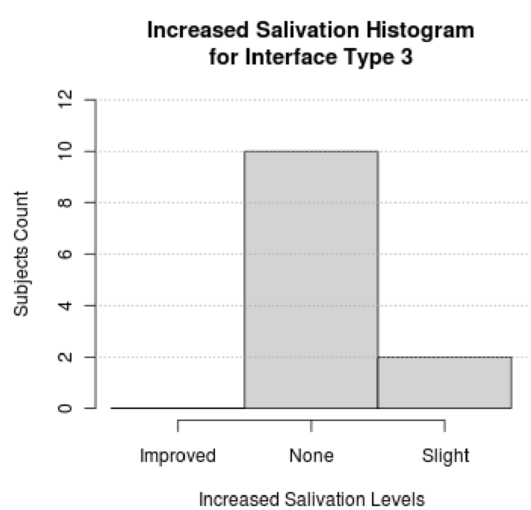
Increased Salivation vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	1.500	2.500	2.000	0.000	0.000	4.000
Z	0.000	-1.000	-0.577	-1.414	-1.000	0.577
p	1.000	0.625	1.000	0.500	1.000	1.000
R	0.000	-0.102	-0.059	-0.144	-0.102	0.059

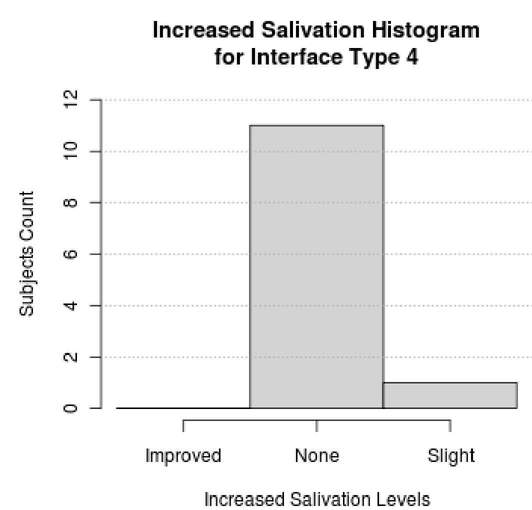
Increased Salivation vs. Interface Used Kurskal-Wallis test:	
X^2	2.223
DoF	3
p	0.527

Increased Salivation vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	0.000	0.960	0.306	2.091	1.000	0.365
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	1.000	0.327	0.580	0.148	0.317	0.546

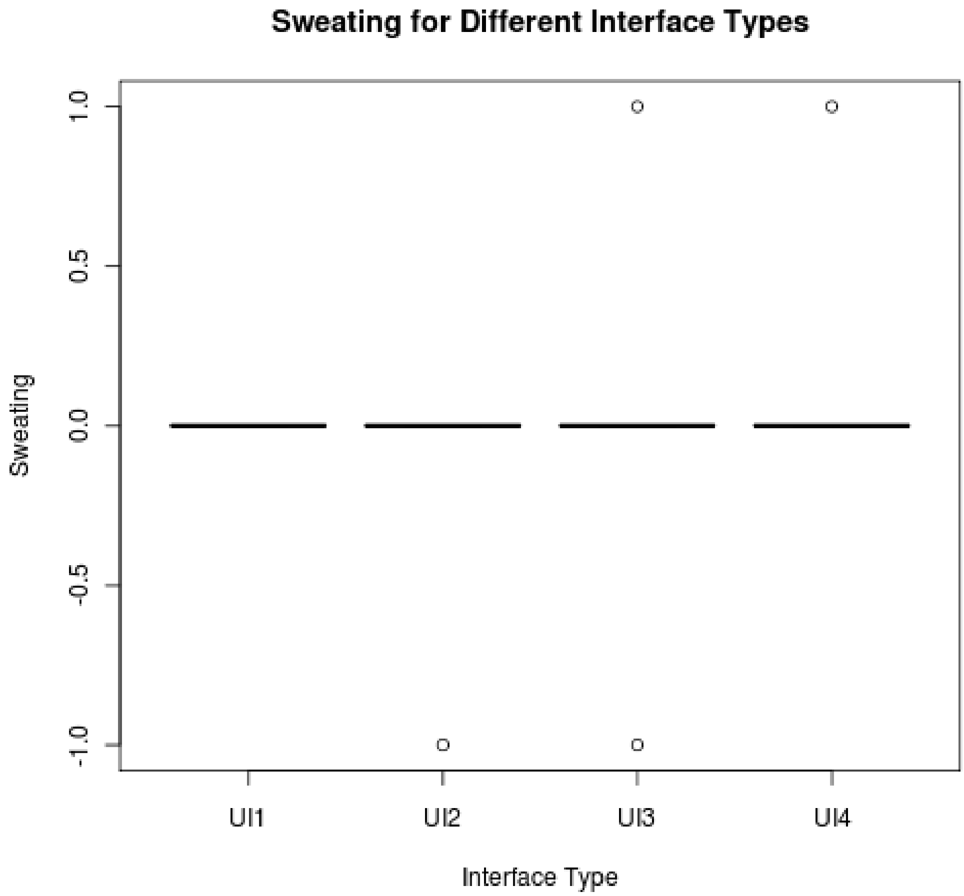
Increased Salivation vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.000	0.426	0.000
2	0.000	0.000	0.000
3	0.167	0.389	0.000
4	0.083	0.289	0.000



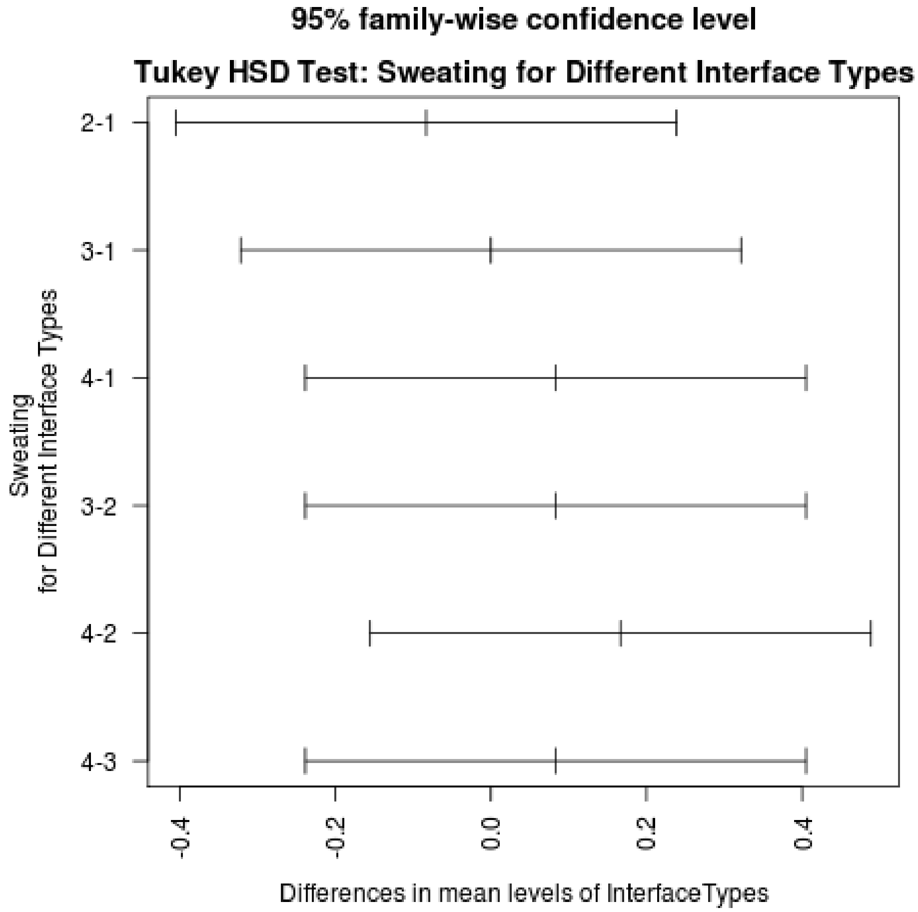




D.2.9.9 Sweating



Subject Count	UI1	UI2	UI3	UI4
1	0	0	0	0
2	0	0	1	0
3	0	0	0	1
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	-1	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	-1	0



One-way ANOVA: Sweating vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.167	0.056	0.638	0.595
Residuals	44	3.833	0.087		

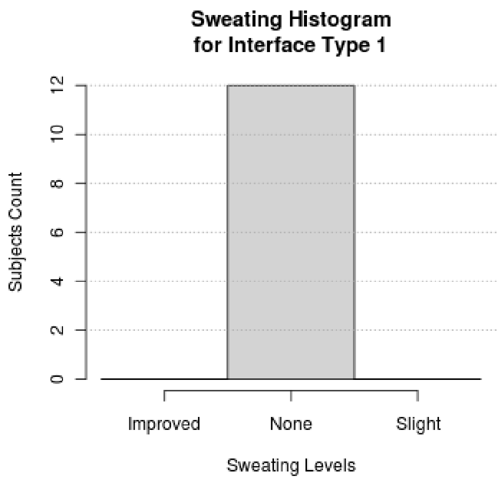
Sweating vs. Interface Used Friedman test:	
X^2	2.000
p	0.572
DoF	3

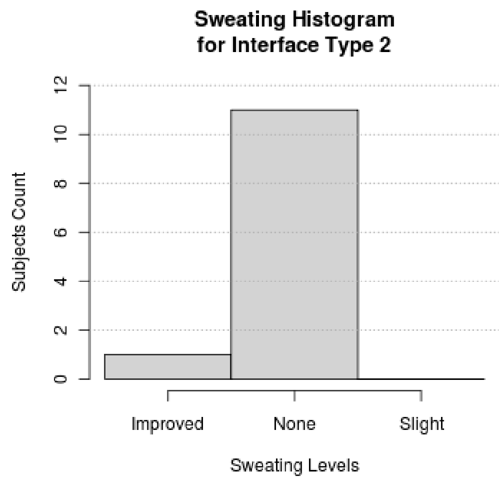
Sweating vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	1.000	1.500	0.000	2.000	0.000	2.000
Z	1.000	0.000	-1.000	-0.577	-1.414	-0.577
p	1.000	1.000	1.000	1.000	0.500	1.000
R	0.102	0.000	-0.102	-0.059	-0.144	-0.059

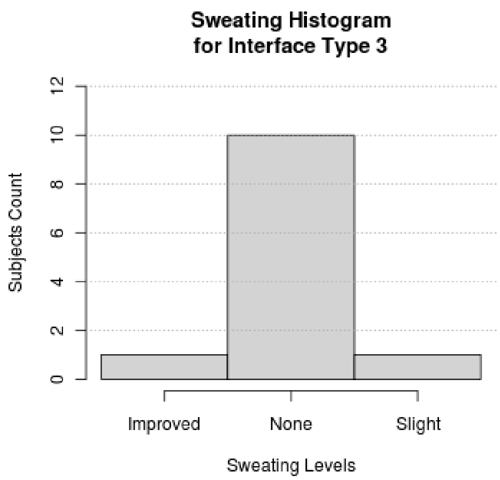
Sweating vs. Interface Used Kurskal-Wallis test:	
X^2	1.958
DoF	3
p	0.581

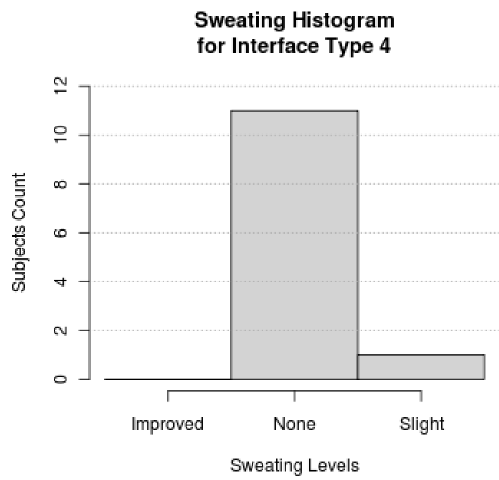
Sweating vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	1.000	0.000	1.000	0.306	1.917	0.306
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	0.317	1.000	0.317	0.580	0.166	0.580

Sweating vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.000	0.000	0.000
2	-0.083	0.289	0.000
3	0.000	0.426	0.000
4	0.083	0.289	0.000

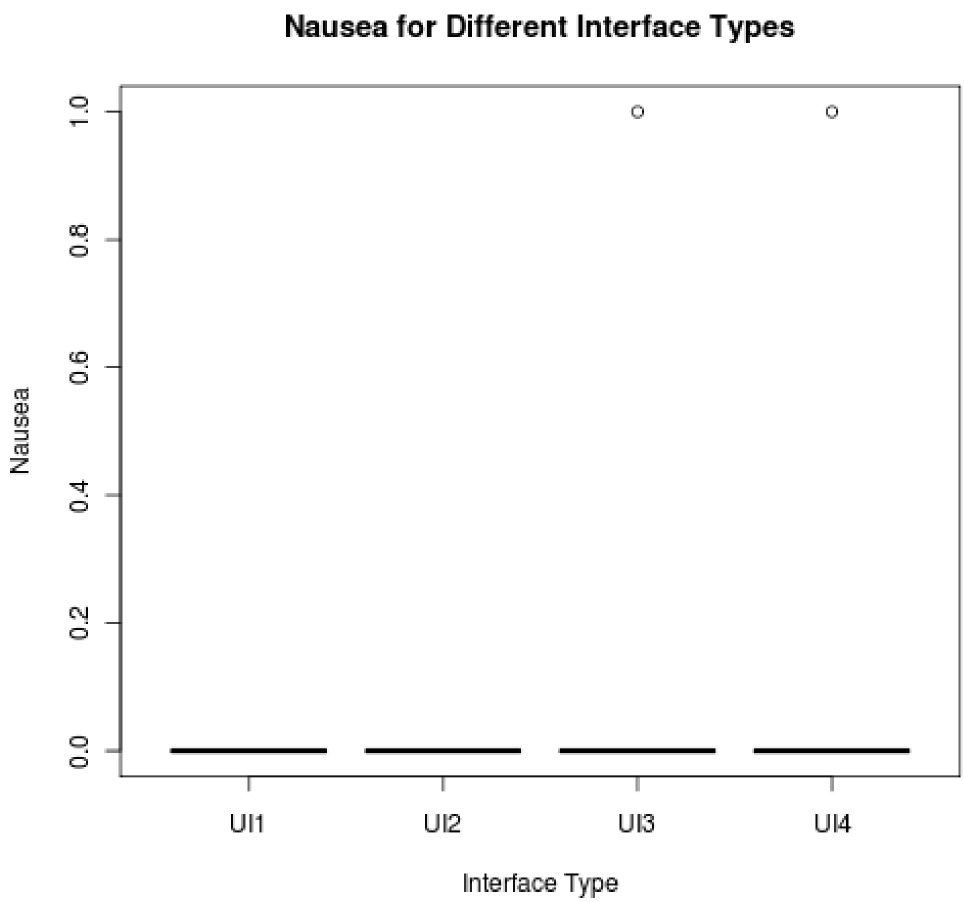




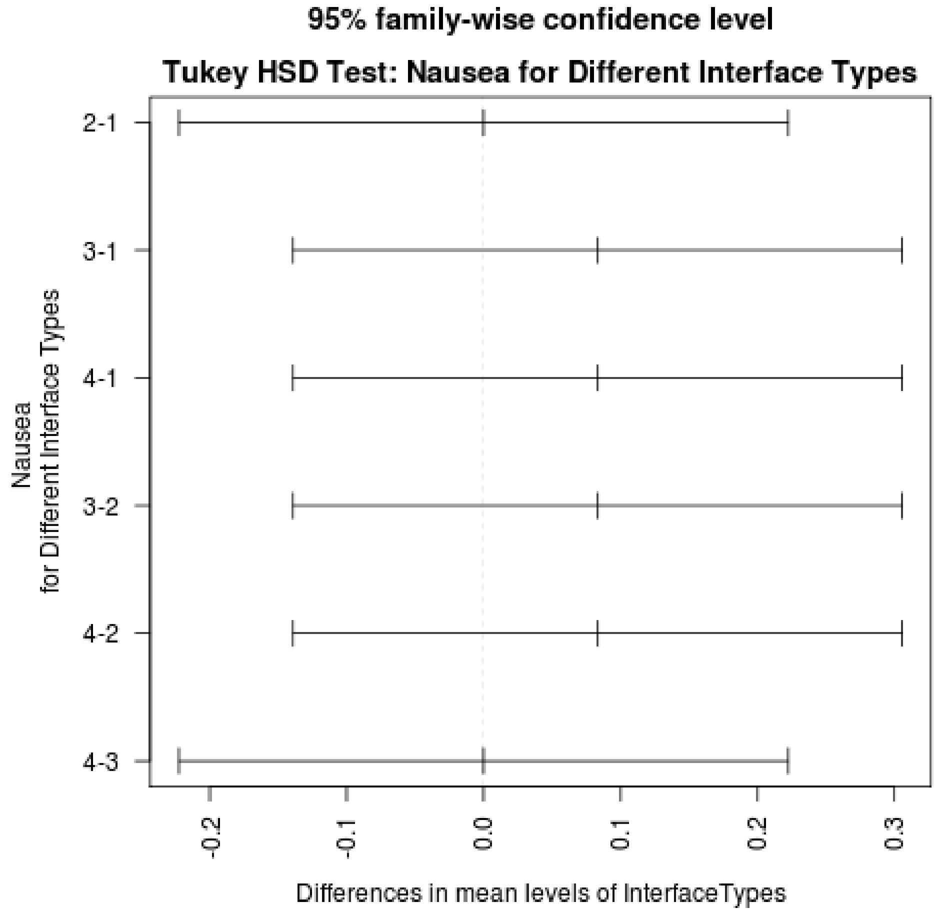




D.2.9.10 Nausea



Subject Count	UI1	UI2	UI3	UI4
1	0	0	0	0
2	0	0	0	0
3	0	0	1	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	1



One-way ANOVA: Nausea vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.083	0.028	0.667	0.577
Residuals	44	1.833	0.042		

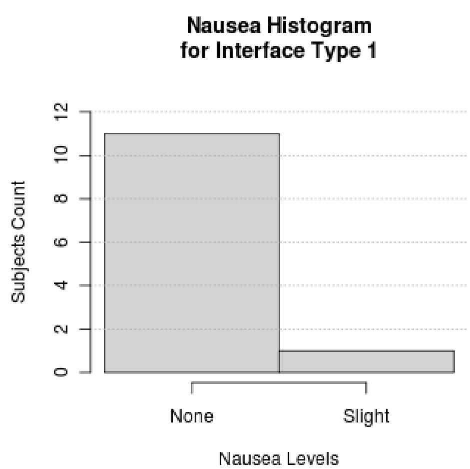
Nausea vs. Interface Used Friedman test:	
X^2	2.000
p	0.572
DoF	3

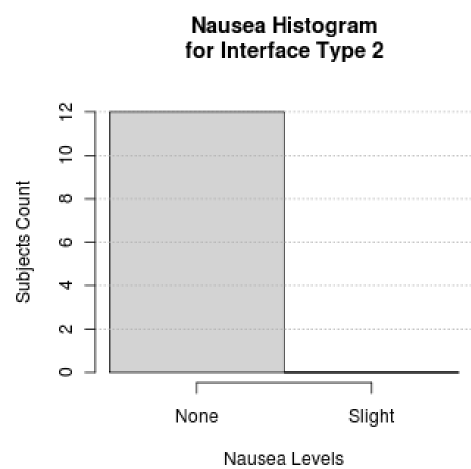
Nausea vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	eq.	0.000	0.000	0.000	0.000	1.500
Z	eq.	-1.000	-1.000	-1.000	-1.000	0.000
p	eq.	1.000	1.000	1.000	1.000	1.000
R	eq.	-0.102	-0.102	-0.102	-0.102	0.000

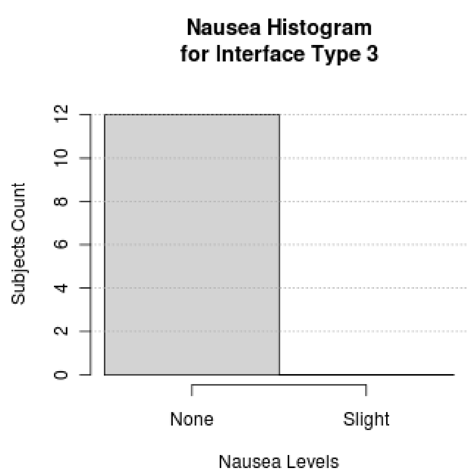
Nausea vs. Interface Used Kurskal-Wallis test:	
X^2	2.043
DoF	3
p	0.563

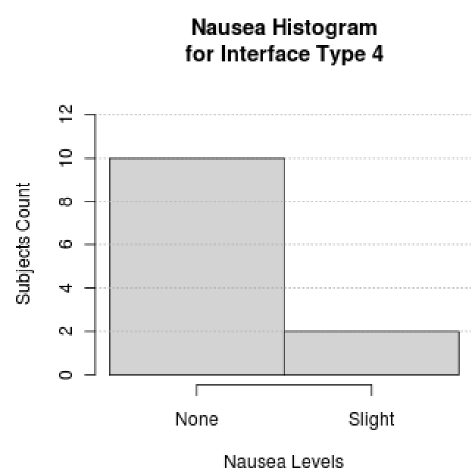
Nausea vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	na	1.000	1.000	1.000	1.000	0.000
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	na	0.317	0.317	0.317	0.317	1.000

Nausea vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.000	0.000	0.000
2	0.000	0.000	0.000
3	0.083	0.289	0.000
4	0.083	0.289	0.000

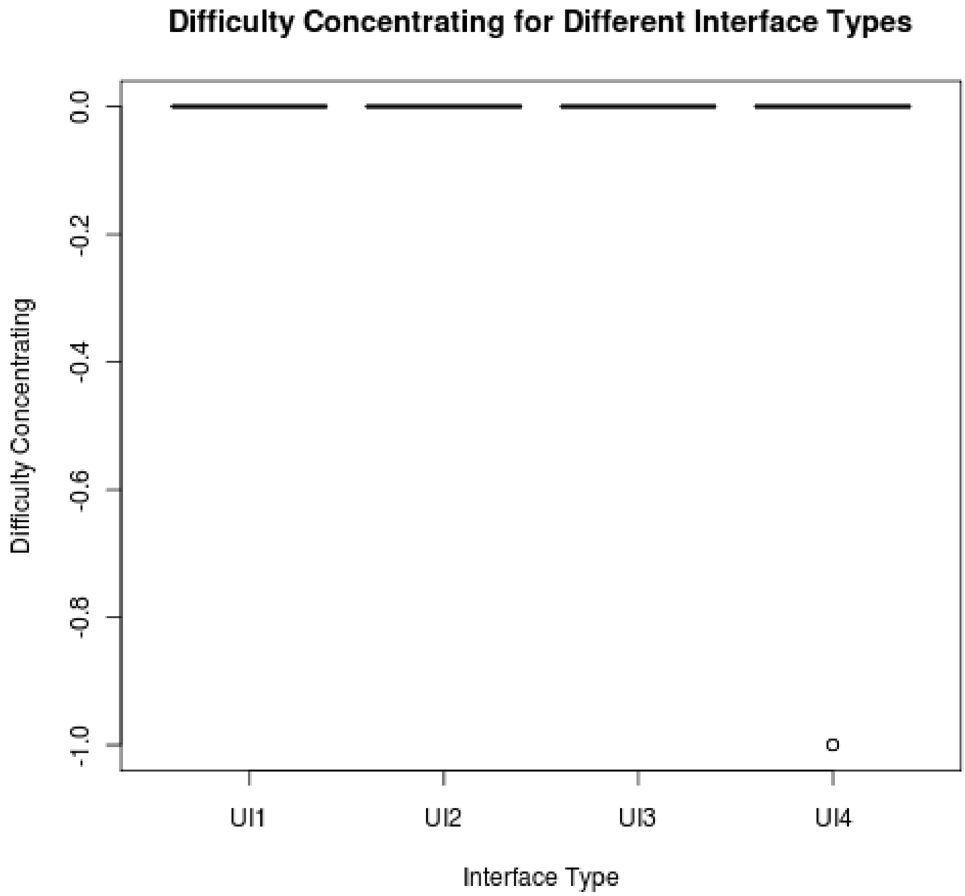




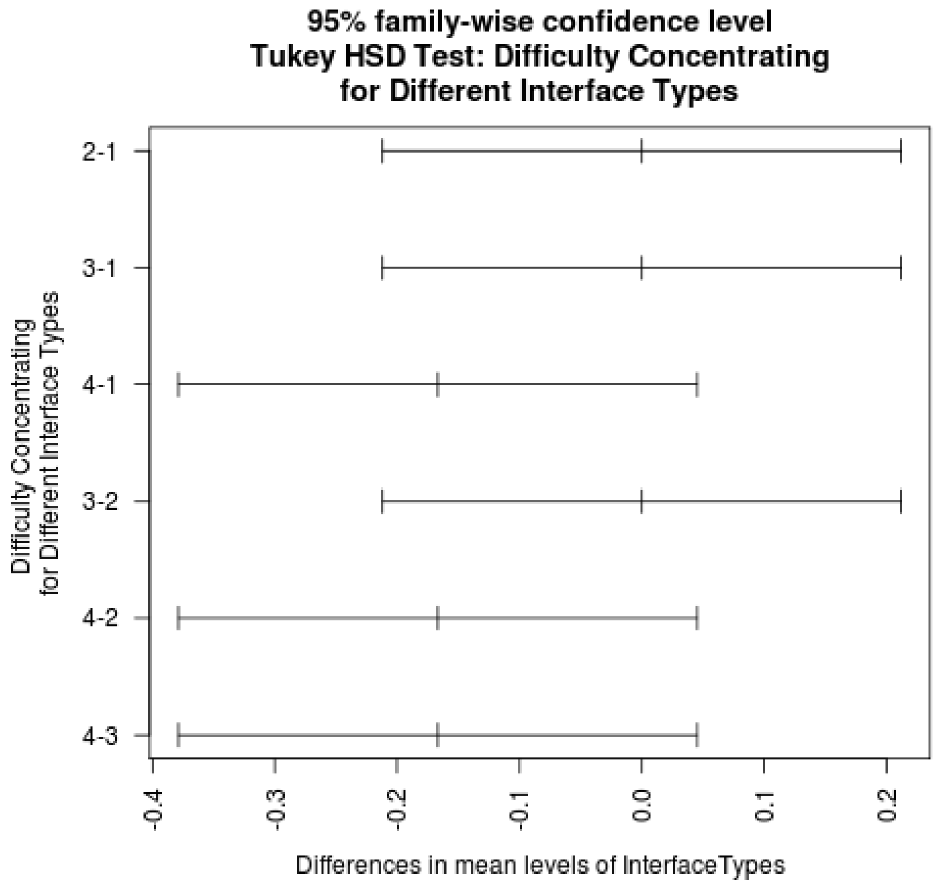




D.2.9.11 Difficulty Concentrating



Subject Count	UI1	UI2	UI3	UI4
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	-1
6	0	0	0	0
7	0	0	0	-1
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0



One-way ANOVA: Difficulty Concentrating vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.250	0.083	2.200	0.102
Residuals	44	1.667	0.038		

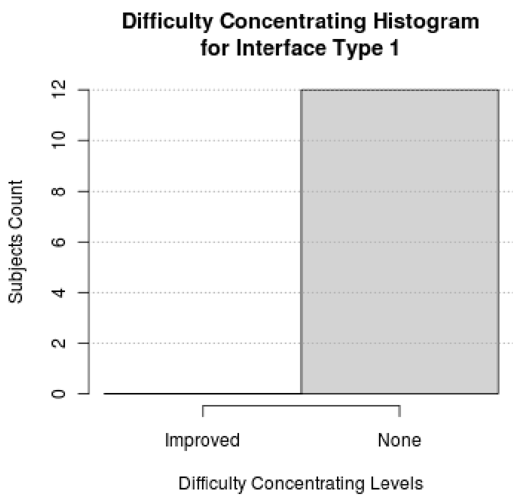
Difficulty Concentrating vs. Interface Used Friedman test:	
X^2	6.000
p	0.112
DoF	3

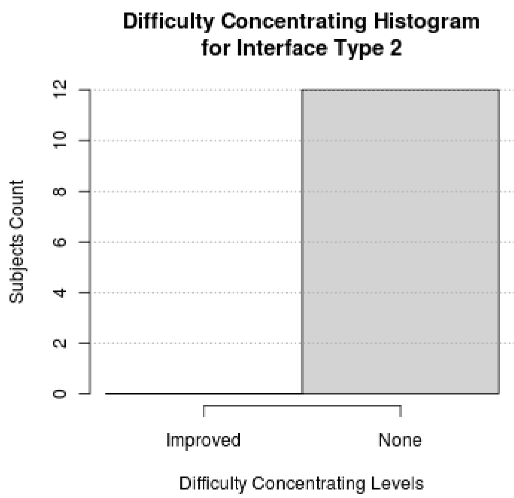
Difficulty Concentrating vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	eq.	eq.	3.000	eq.	3.000	3.000
Z	eq.	eq.	1.414	eq.	1.414	1.414
p	eq.	eq.	0.500	eq.	0.500	0.500
R	eq.	eq.	0.144	eq.	0.144	0.144

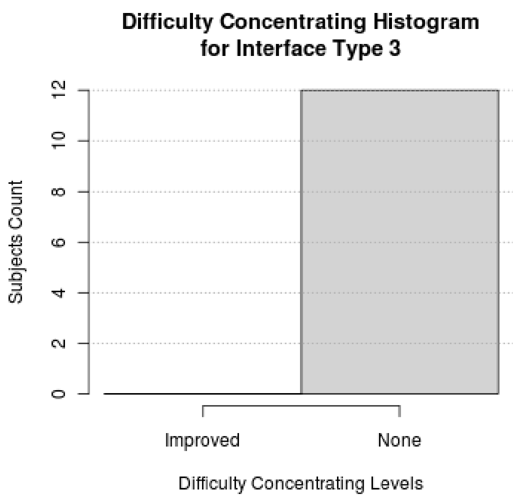
Difficulty Concentrating vs. Interface Used Kurskal-Wallis test:	
X^2	6.13
DoF	3
p	0.105

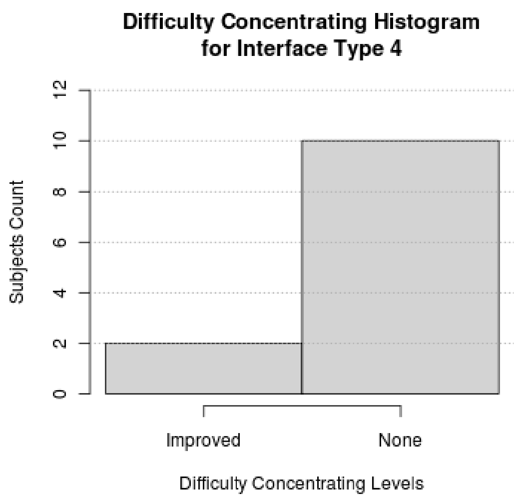
Difficulty Concentrating vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	na	na	2.091	na	2.091	2.091
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	na	na	0.148	na	0.148	0.148

Difficulty Concentrating vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.000	0.000	0.000
2	0.000	0.000	0.000
3	0.000	0.000	0.000
4	-0.167	0.389	0.000

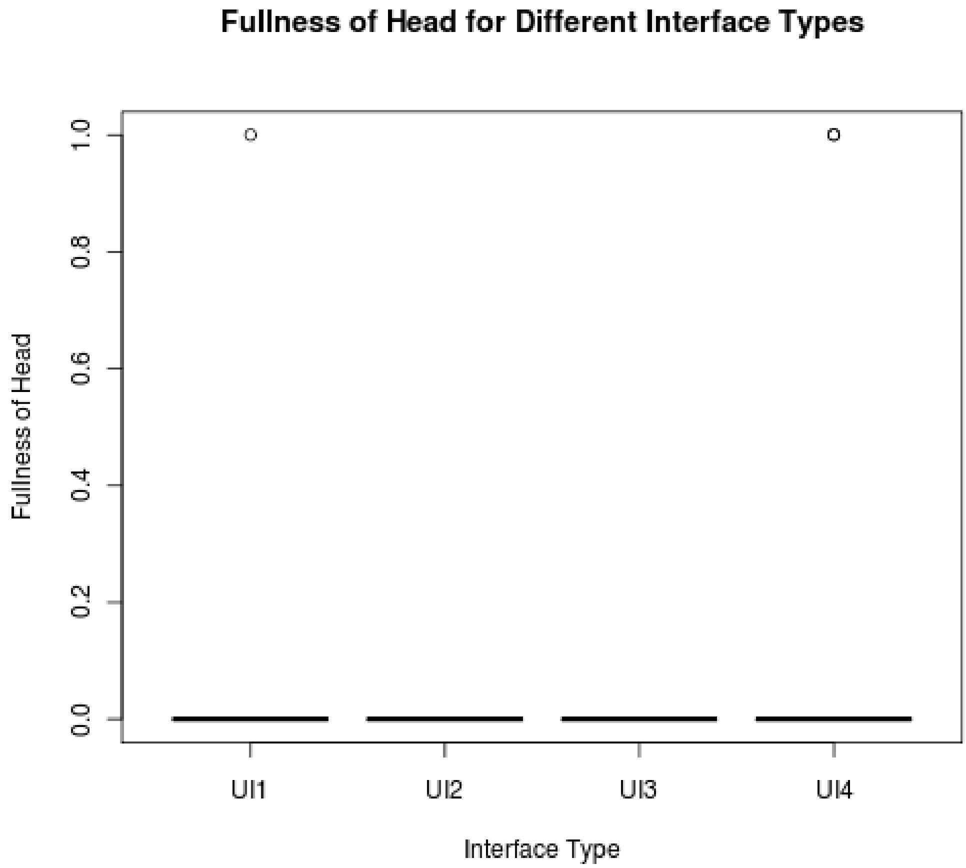




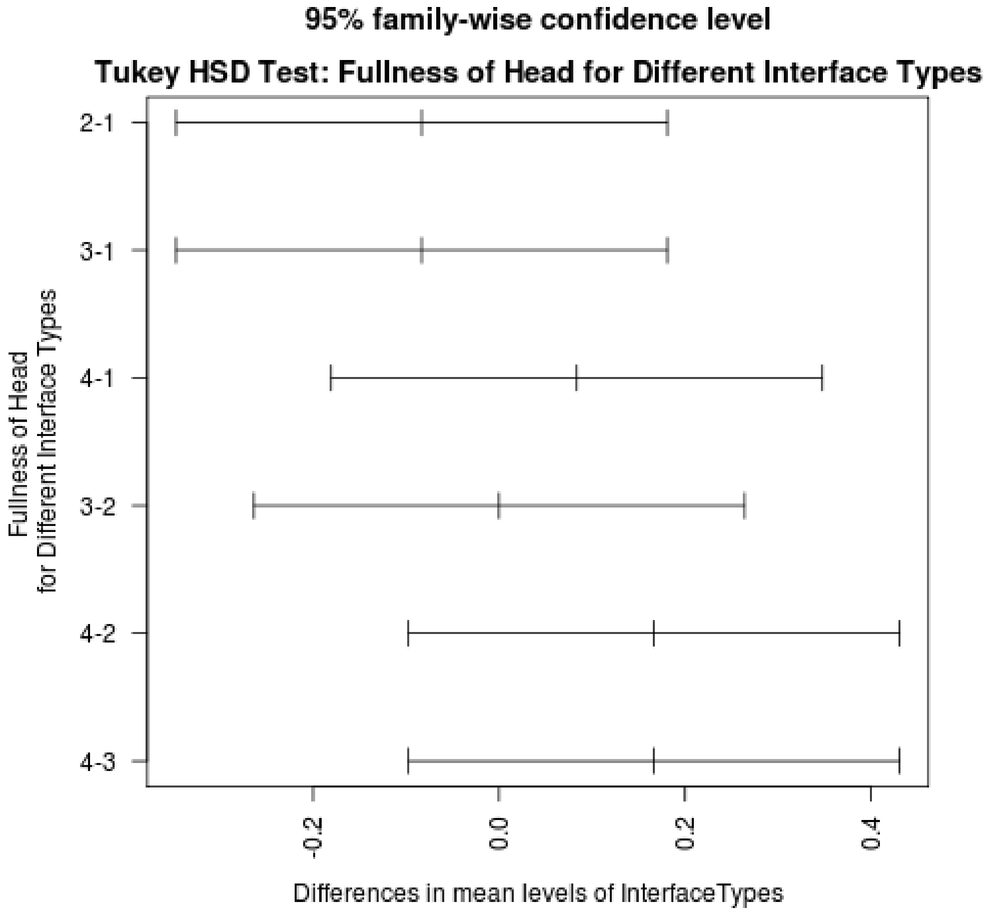




D.2.9.12 Fullness of Head



Subject Count	UI1	UI2	UI3	UI4
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	1
8	0	0	0	0
9	0	0	0	0
10	1	0	0	0
11	0	0	0	0
12	0	0	0	1



One-way ANOVA: Fullness of Head vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.229	0.076	1.301	0.286
Residuals	44	2.583	0.059		

Fullness of Head vs. Interface Used Friedman test:	
X^2	3.667
p	0.300
DoF	3

Fullness of Head vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	1.000	1.000	2.000	eq.	0.000	0.000
Z	1.000	1.000	-0.577	eq.	-1.414	-1.414
p	1.000	1.000	1.000	eq.	0.500	0.500
R	0.102	0.102	-0.059	eq.	-0.144	-0.144

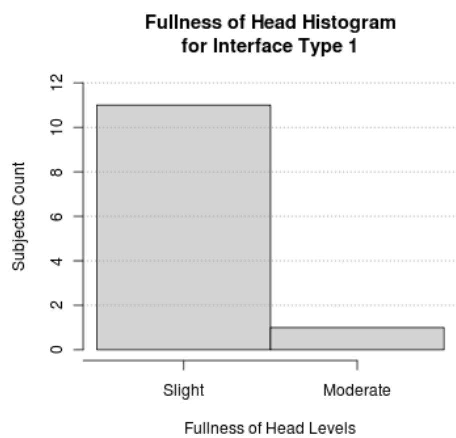
Fullness of Head vs. Interface Used Kurskal-Wallis test:	
X^2	3.830
DoF	3
p	0.280

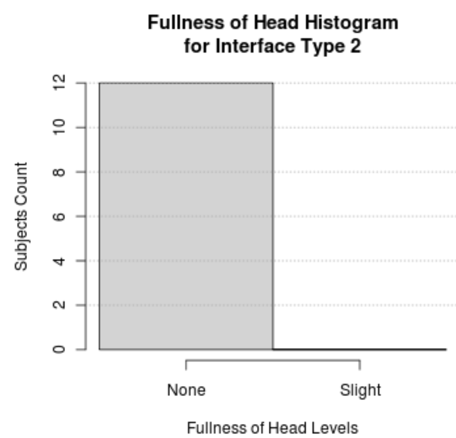
Fullness of Head vs. Interface Used Kruskal-Wallis test:

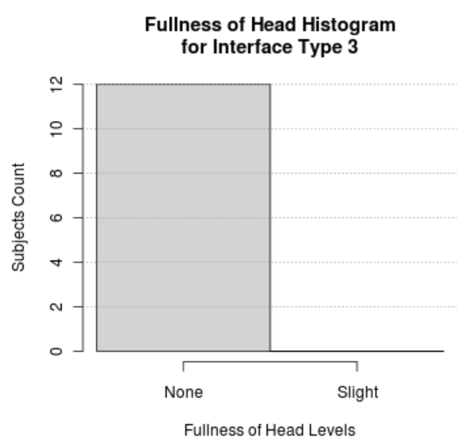
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	1.000	1.000	0.365	na	2.091	2.091
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	0.317	0.317	0.546	na	0.148	0.148

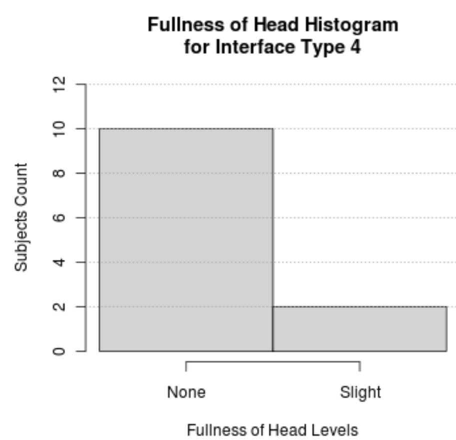
Fullness of Head vs. Interface Used Summary:

Interface	**Mean**	**Std. Dev.**	**Median**
1	0.083	0.289	0.000
2	0.000	0.000	0.000
3	0.000	0.000	0.000
4	0.167	0.389	0.000

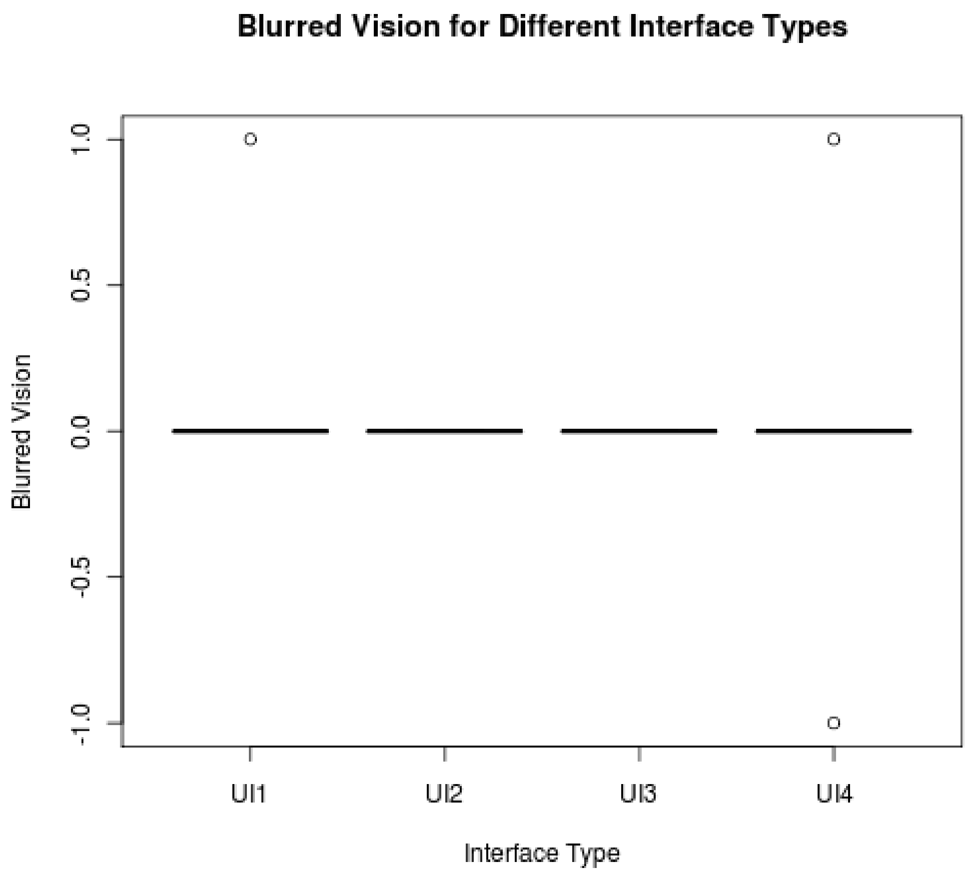




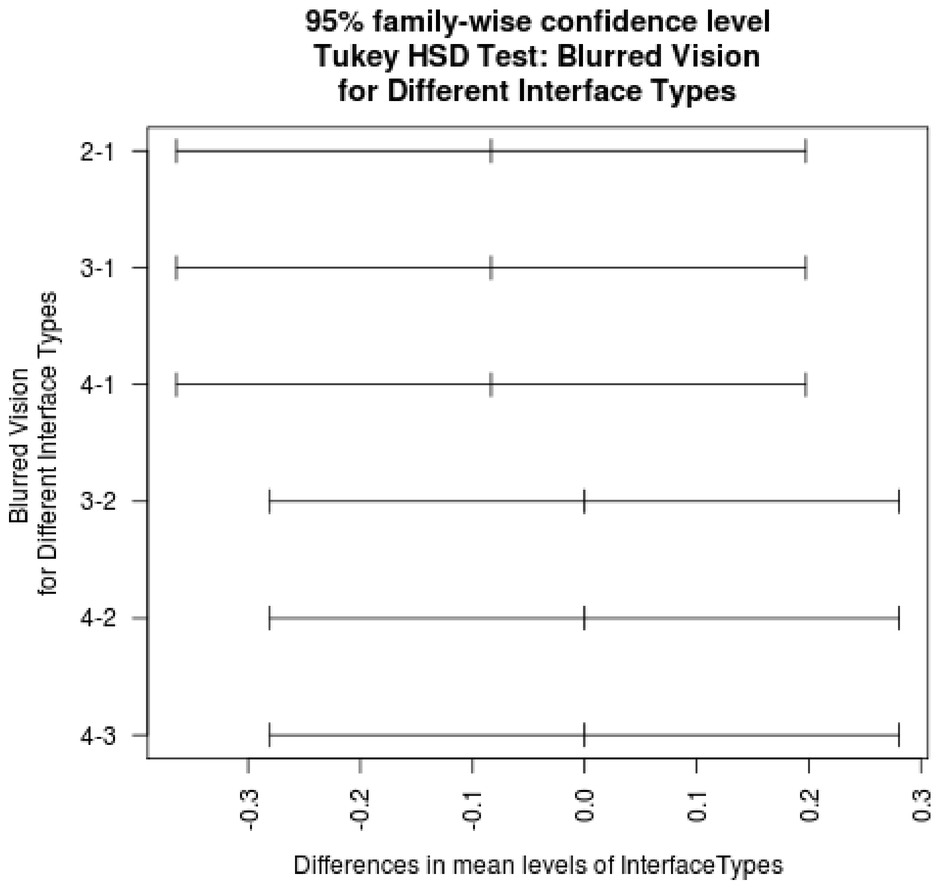




D.2.9.13 Blurred Vision



Subject Count	UI1	UI2	UI3	UI4
1	0	0	0	0
2	0	0	0	1
3	0	0	0	-1
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	1	0	0	0
12	0	0	0	0



One-way ANOVA: Blurred Vision vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.063	0.021	0.314	0.815
Residuals	44	2.917	0.066		

Blurred Vision vs. Interface Used Friedman test:	
X^2	1.000
p	0.801
DoF	3

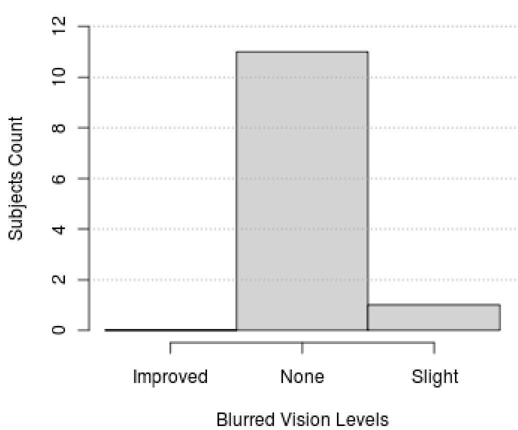
Blurred Vision vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	1.000	1.000	4.000	eq.	1.500	1.500
Z	1.000	1.000	0.577	eq.	0.000	0.000
p	1.000	1.000	1.000	eq.	1.000	1.000
R	0.102	0.102	0.059	eq.	0.000	0.000

Blurred Vision vs. Interface Used Kurskal-Wallis test:	
X^2	3.830
DoF	3
p	0.280

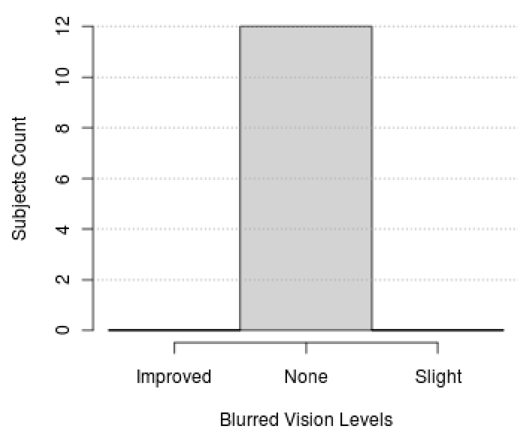
Blurred Vision vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	1.000	1.000	0.306	na	0.000	0.000
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	0.317	0.317	0.580	na	1.000	1.000

Blurred Vision vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.083	0.289	0.000
2	0.000	0.000	0.000
3	0.000	0.000	0.000
4	0.000	0.426	0.000

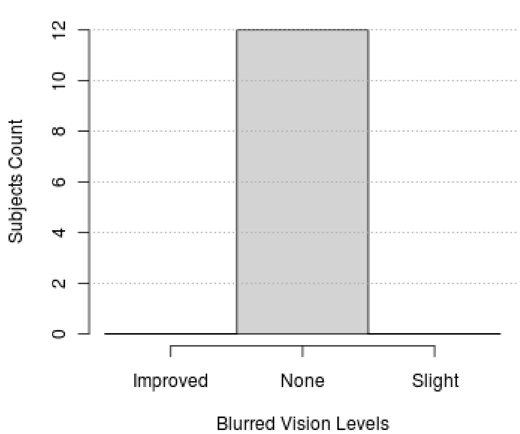
Blurred Vision Histogram for Interface Type 1



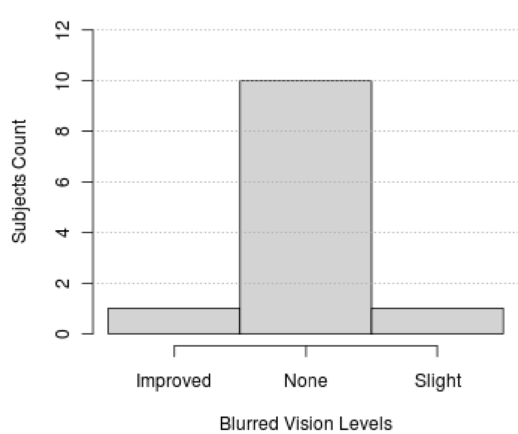
Blurred Vision Histogram for Interface Type 2



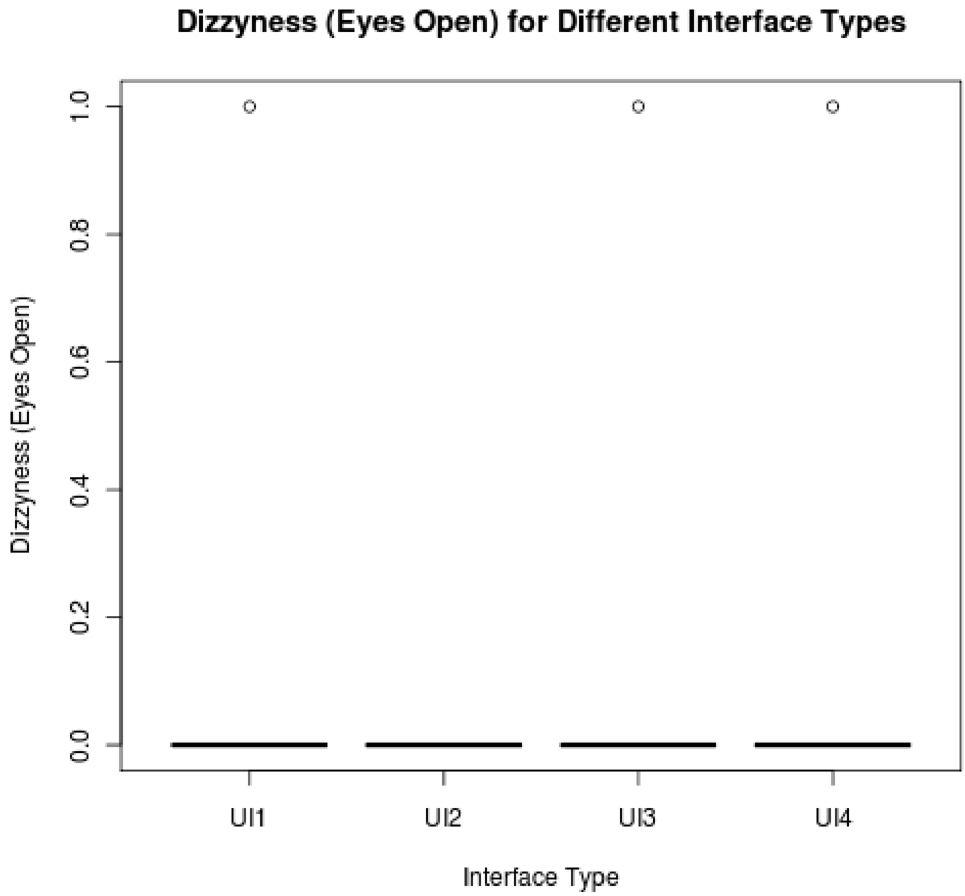
Blurred Vision Histogram for Interface Type 3



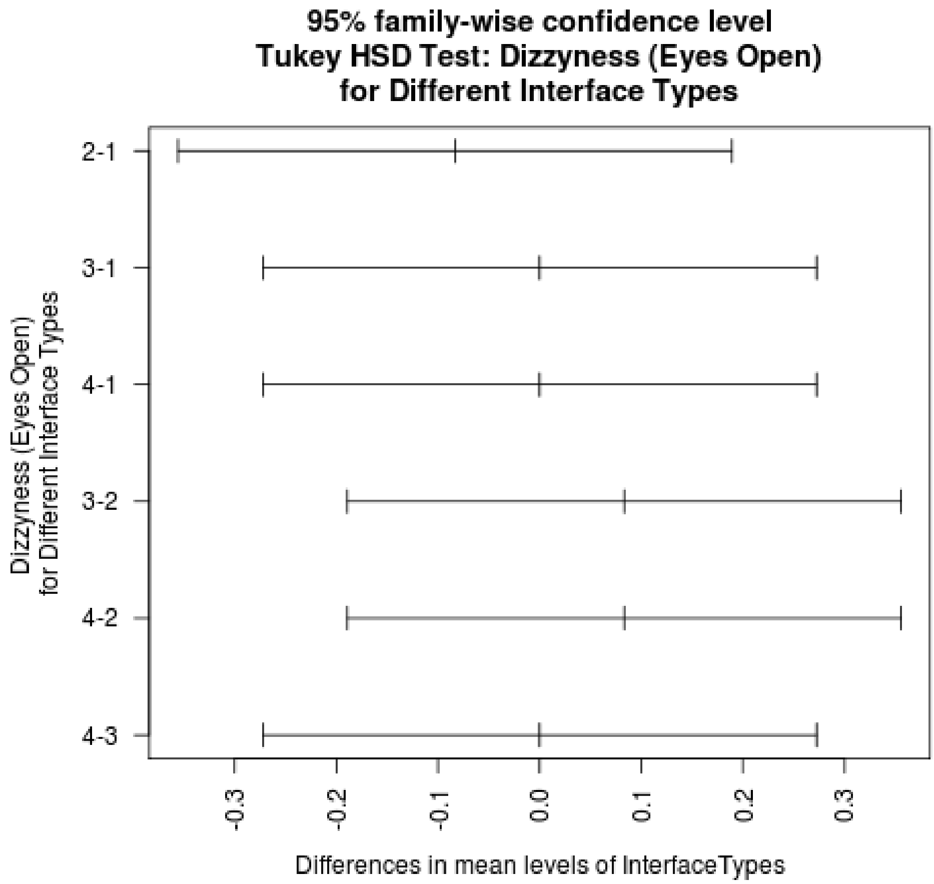
Blurred Vision Histogram for Interface Type 4



D.2.9.14 Dizzy (Eyes Open)



Subject Count	UI1	UI2	UI3	UI4
1	0	0	0	0
2	0	0	0	0
3	0	0	1	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	1	0	0	0
11	0	0	0	0
12	0	0	0	1



One-way ANOVA: Dizzy (Eyes Open) vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.063	0.021	0.333	0.801
Residuals	44	2.750	0.063		

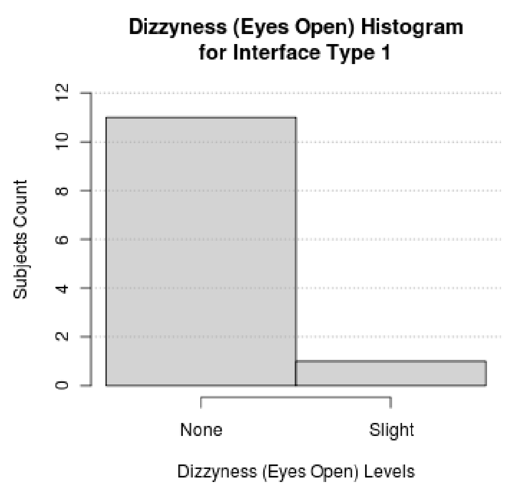
Dizzy (Eyes Open) vs. Interface Used Friedman test:	
X^2	1.000
p	0.801
DoF	3

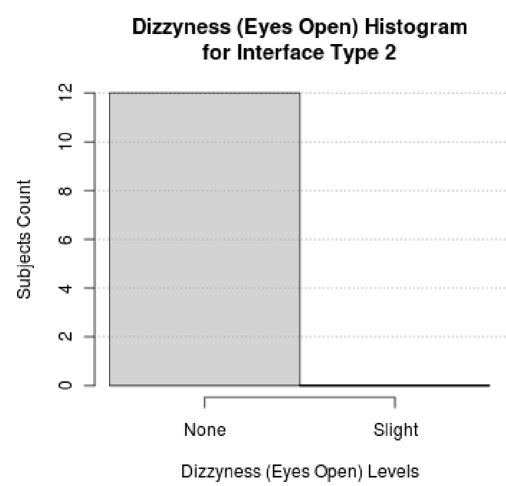
Dizzy (Eyes Open) vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	1.000	1.500	0.000	0.000	0.000	1.500
Z	1.000	0.000	-1.000	-1.000	-1.000	0.000
p	1.000	1.000	1.000	1.000	1.000	1.000
R	0.102	0.000	-0.102	-0.102	-0.102	0.000

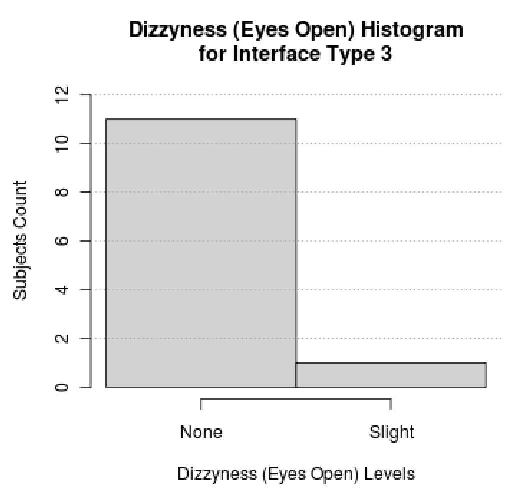
Dizzy (Eyes Open) vs. Interface Used Kurskal-Wallis test:	
X^2	1.044
DoF	3
p	0.790

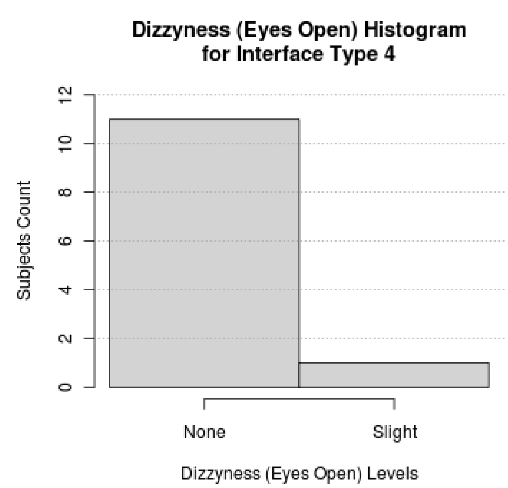
Dizzy (Eyes Open) vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	1.000	0.000	0.000	1.000	1.000	0.000
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	0.317	1.000	1.000	0.317	0.317	1.000

Dizzy (Eyes Open) vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.083	0.289	0.000
2	0.000	0.000	0.000
3	0.083	0.289	0.000
4	0.083	0.289	0.000

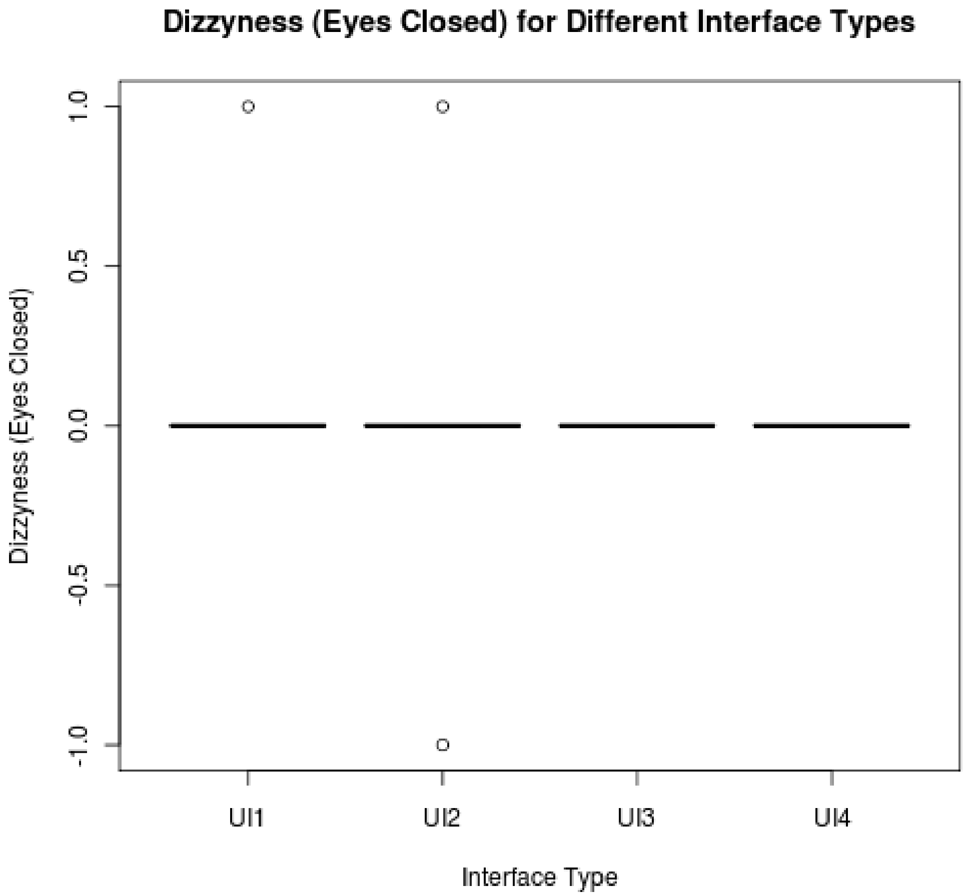




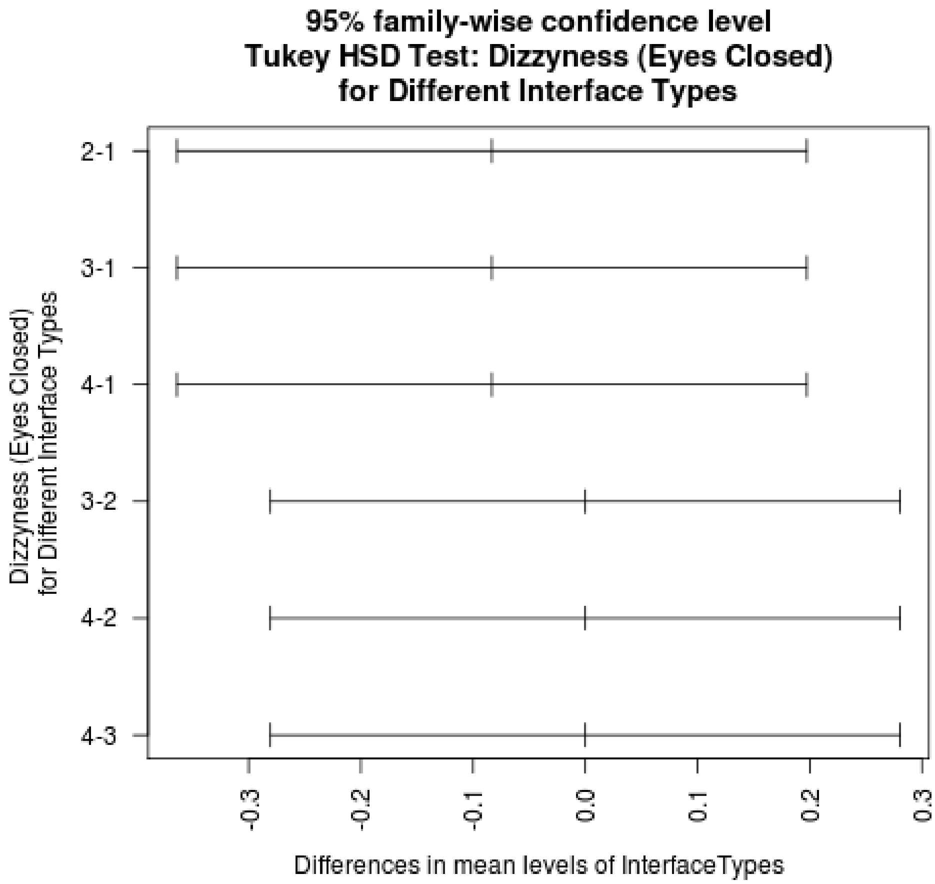




D.2.9.15 Dizzy (Eyes Closed)



Subject Count	UI1	UI2	UI3	UI4
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	-1	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	1	1	0	0
11	0	0	0	0
12	0	0	0	0



One-way ANOVA: Dizzy (Eyes Closed) vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.063	0.021	0.314	0.815
Residuals	44	2.917	0.066		

Dizzy (Eyes Closed) vs. Interface Used Friedman test:	
X^2	1.286
p	0.733
DoF	3

Dizzy (Eyes Closed) vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	1.000	1.000	1.000	1.500	1.500	eq.
Z	1.000	1.000	1.000	0.000	0.000	eq.
p	1.000	1.000	1.000	1.000	1.000	eq.
R	0.102	0.102	0.102	0.000	0.000	eq.

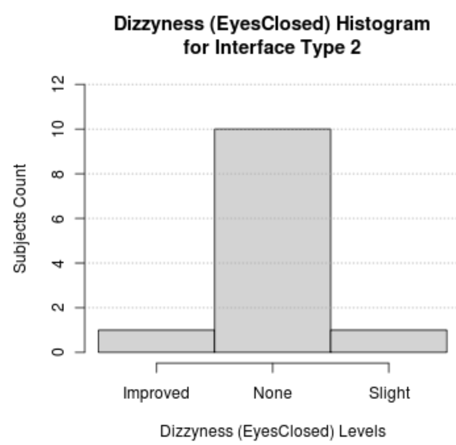
Dizzy (Eyes Closed) vs. Interface Used Kurskal-Wallis test:	
X^2	0.987
DoF	3
p	0.804

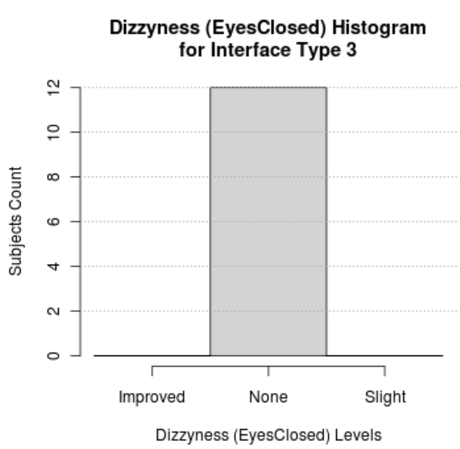
Dizzy (Eyes Closed) vs. Interface Used
Kruskal-Wallis test:

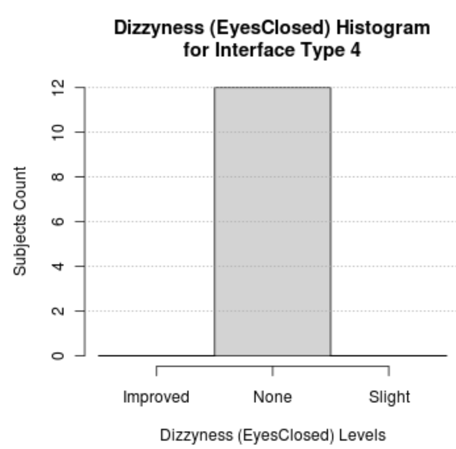
	UI1 – UI2	UI1 – UI3	UI1 – UI4	UI2 – UI3	UI2 – UI4	UI3 – UI4
X^2	0.306	1.000	1.000	0.000	0.000	na
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	0.580	0.317	0.317	1.000	1.000	na

Dizzy (Eyes Closed) vs. Interface Used Summary:

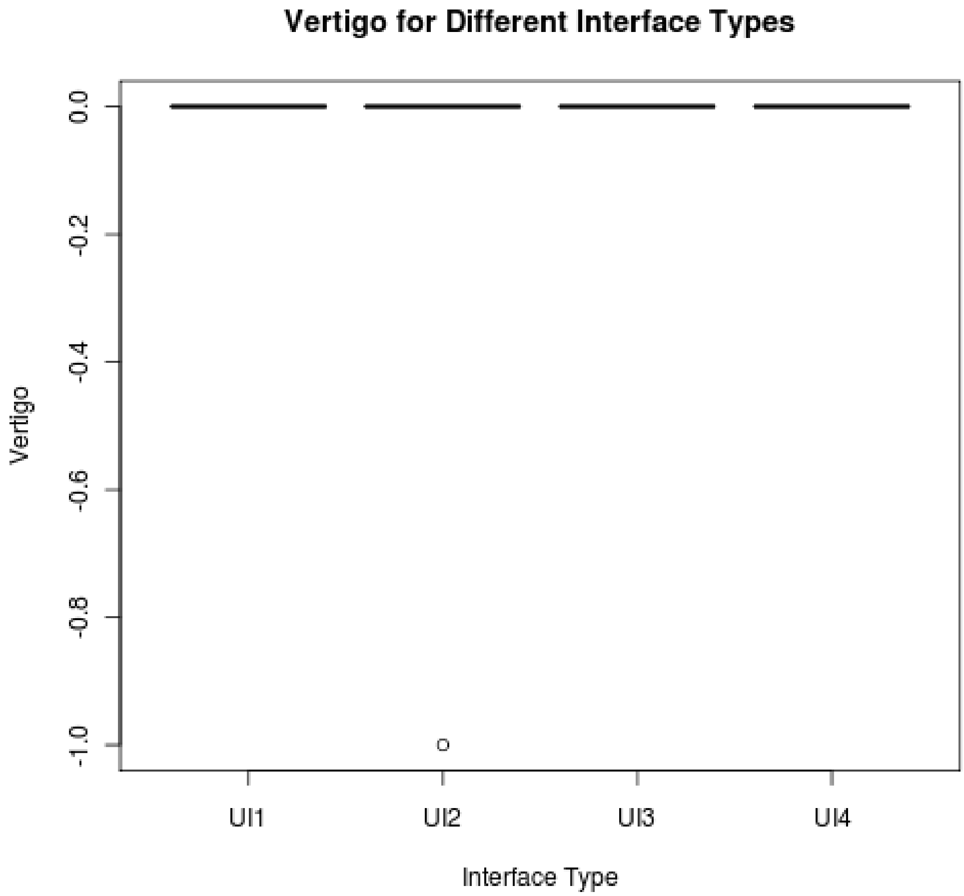
Interface	Mean	Std. Dev.	Median
1	0.083	0.289	0.000
2	0.000	0.426	0.000
3	0.000	0.000	0.000
4	0.000	0.000	0.000



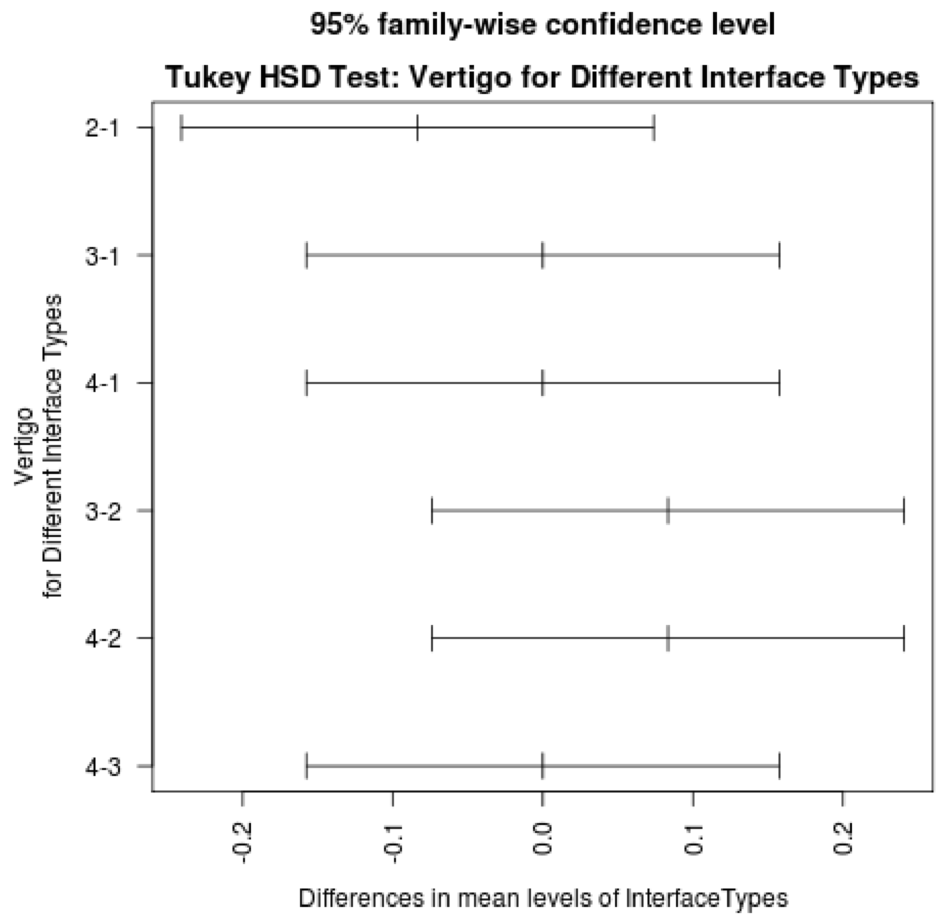




D.2.9.16 Vertigo



Subject Count	UI1	UI2	UI3	UI4
1	0	0	0	0
2	0	-1	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0



One-way ANOVA: Vertigo vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.063	0.021	1.000	0.402
Residuals	44	0.917	0.021		

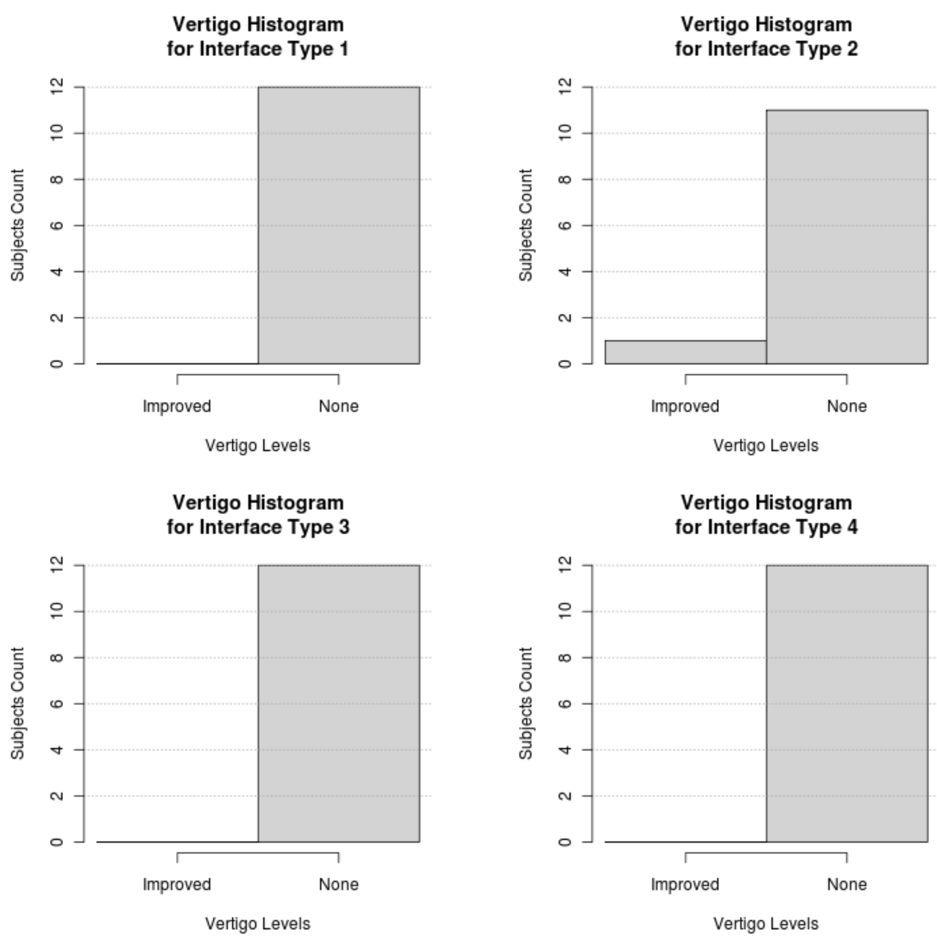
Vertigo vs. Interface Used Friedman test:	
X^2	3.000
p	0.392
DoF	3

Vertigo vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	1.000	eq.	eq.	0.000	0.000	eq.
Z	1.000	eq.	eq.	-1.000	-1.000	eq.
p	1.000	eq.	eq.	1.000	1.000	eq.
R	0.102	eq.	eq.	-0.102	-0.102	eq.

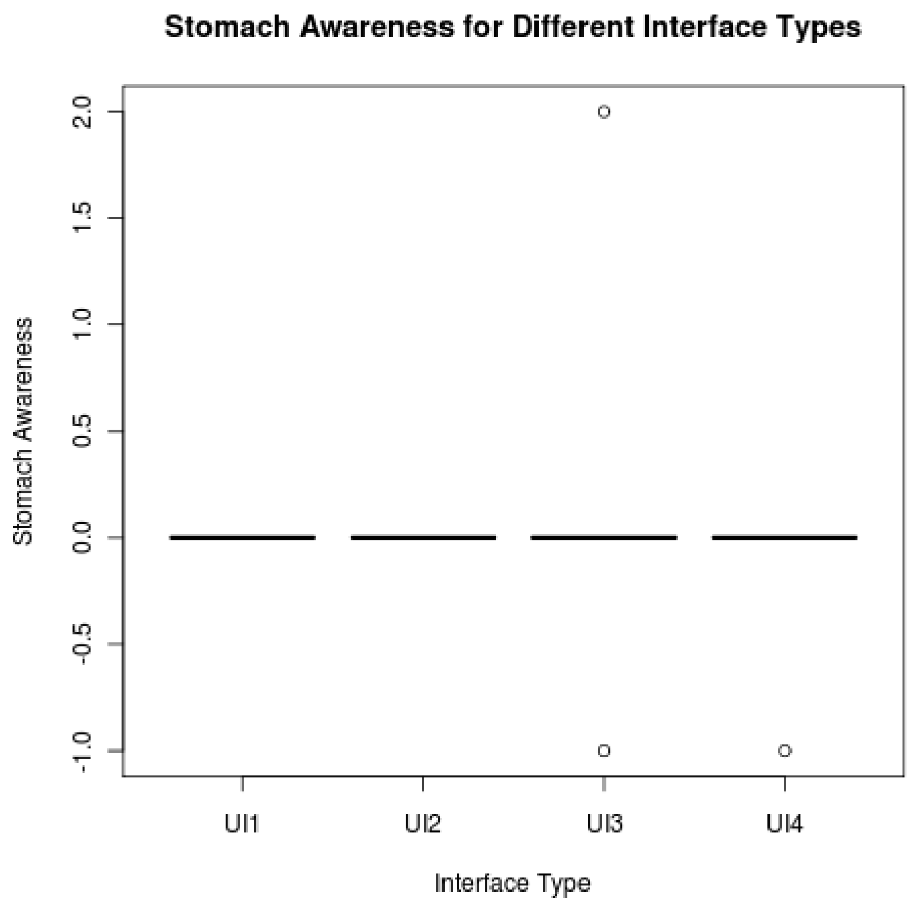
Vertigo vs. Interface Used Kurskal-Wallis test:	
X^2	3.000
DoF	3
p	0.392

Vertigo vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	1.000	na	na	1.000	1.000	na
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	0.317	na	na	0.317	0.317	na

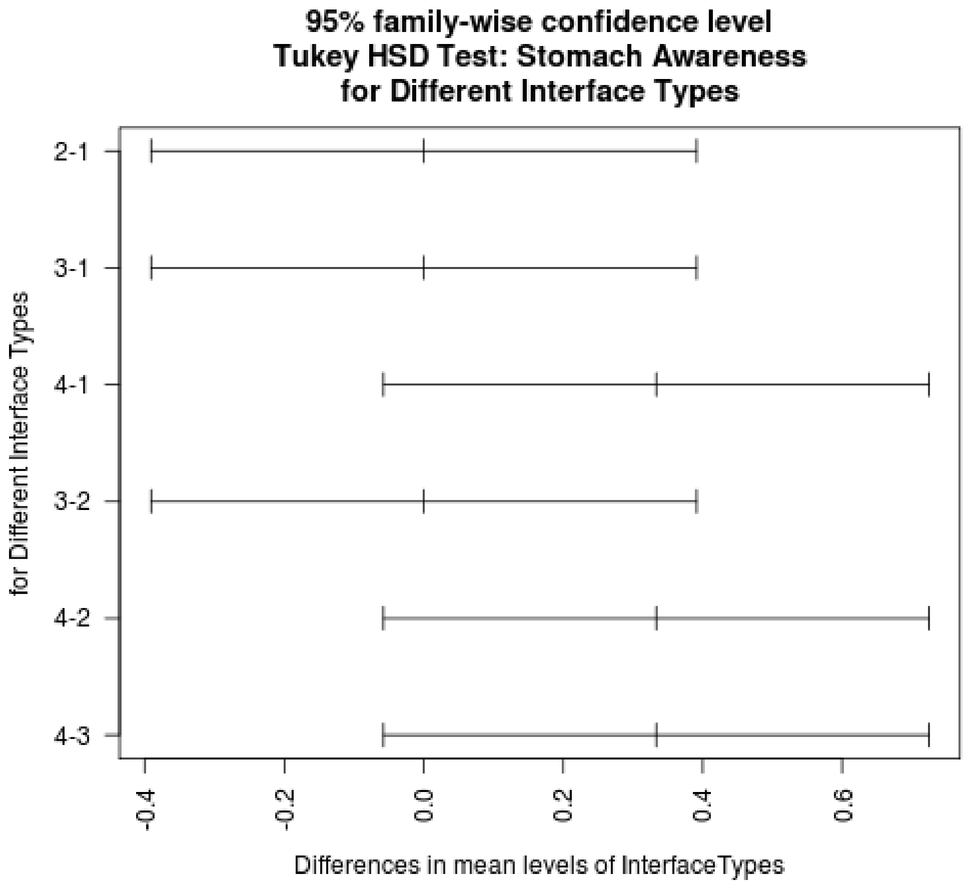
Vertigo vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.000	0.000	0.000
2	-0.083	0.289	0.000
3	0.000	0.000	0.000
4	0.000	0.000	0.000



D.2.9.17 Stomach Awareness



Subject Count	UI1	UI2	UI3	UI4
1	0	0	0	0
2	0	0	0	0
3	0	0	2	0
4	0	0	0	0
5	0	0	0	-1
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	-1	0
12	0	0	0	0



One-way ANOVA: Stomach Awareness vs. Interface Used					
	DoF	***Sum Sq.***	***Mean Sq.***	***F-value***	***Pr(>F)***
interface type	3	0.167	0.056	0.419	0.740
Residuals	44	5.833	0.133		

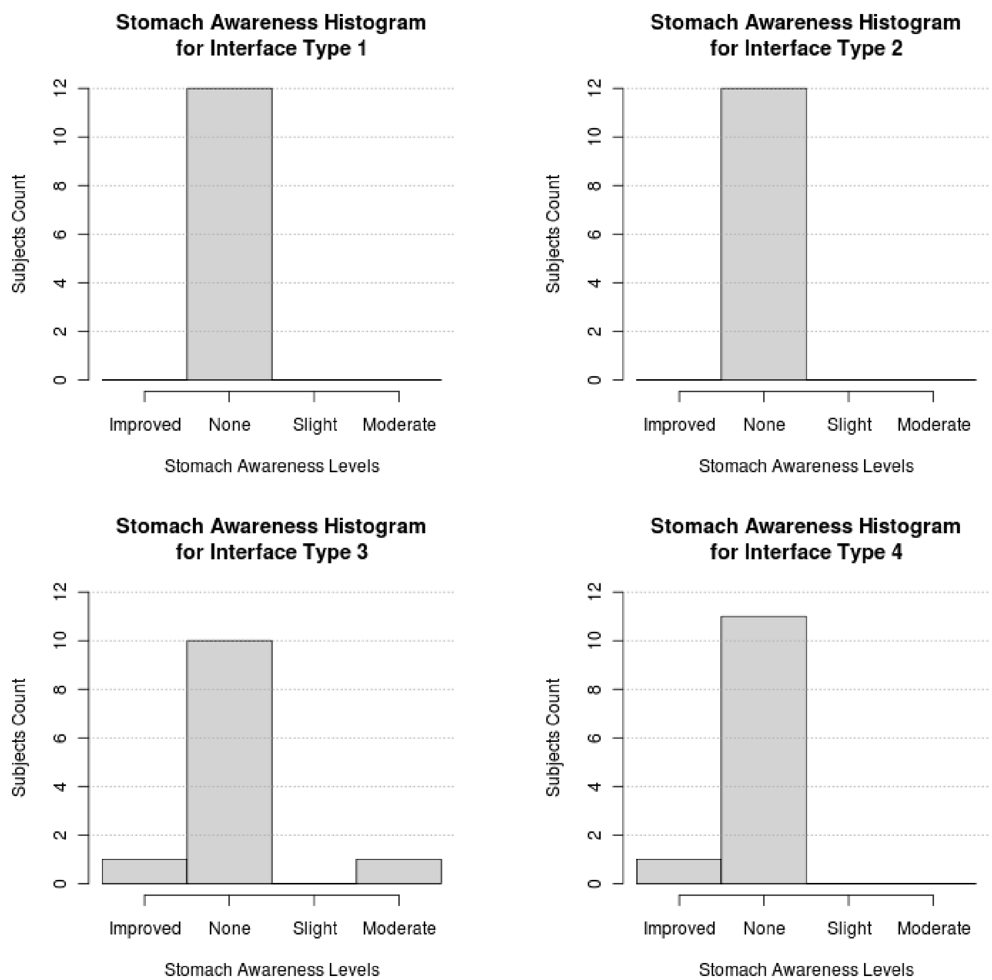
Stomach Awareness vs. Interface Used Friedman test:	
X^2	1.000
p	0.801
DoF	3

Stomach Awareness vs. Interface Used Wilcoxon test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
W	eq.	1.000	1.000	1.000	1.000	4.500
Z	eq.	-0.061	1.000	-0.061	1.000	0.629
p	eq.	1.000	1.000	1.000	1.000	0.750
R	eq.	-0.006	0.102	-0.006	0.102	0.064

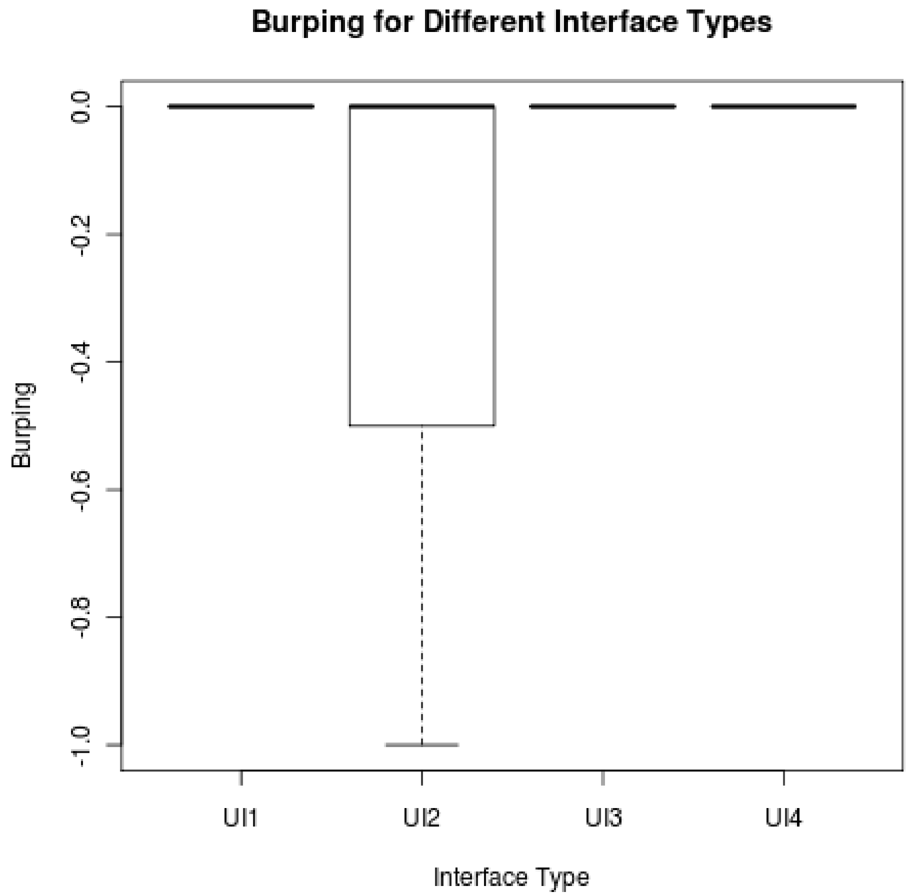
Stomach Awareness vs. Interface Used Kurskal-Wallis test:	
X^2	0.987
DoF	3
p	0.804

Stomach Awareness vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	na	0.000	1.000	0.000	1.000	0.306
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	na	1.000	0.317	1.000	0.317	0.580

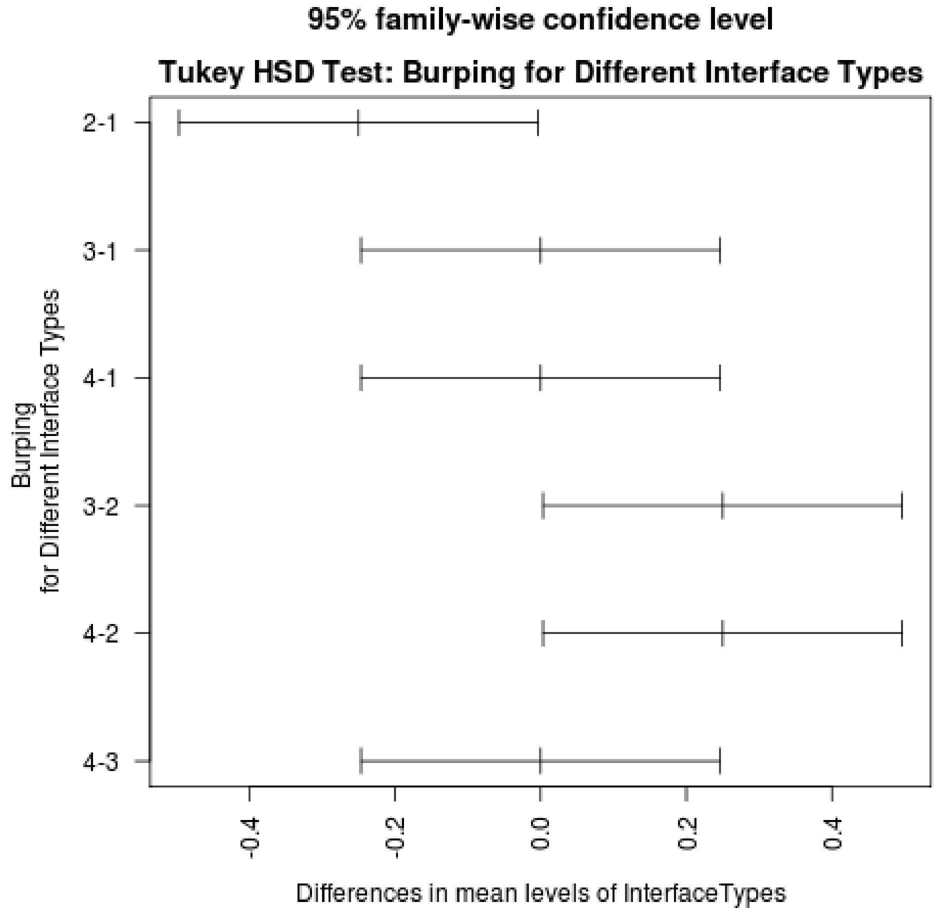
Stomach Awareness vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.000	0.000	0.000
2	0.000	0.000	0.000
3	0.083	0.669	0.000
4	-0.083	0.289	0.000



D.2.9.18 Burping



Subject Count	UI1	UI2	UI3	UI4
1	0	0	0	0
2	0	-1	0	0
3	0	-1	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	-1	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0



One-way ANOVA: Burping vs. Interface Used					
	DoF	*Sum Sq.*	*Mean Sq.*	*F-value*	*Pr(>F)*
interface type	3	0.563	0.188	3.667	0.019
Residuals	44	2.250	0.051		

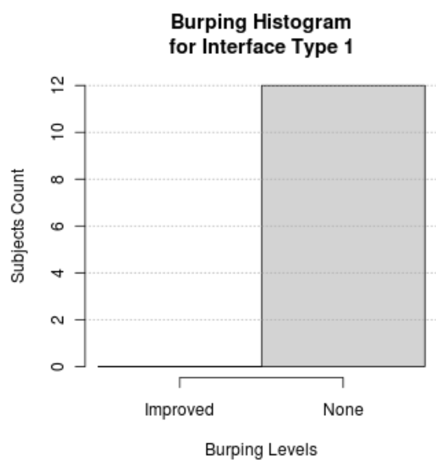
Burping vs. Interface Used Friedman test:	
X^2	9.000
p	0.029
DoF	3

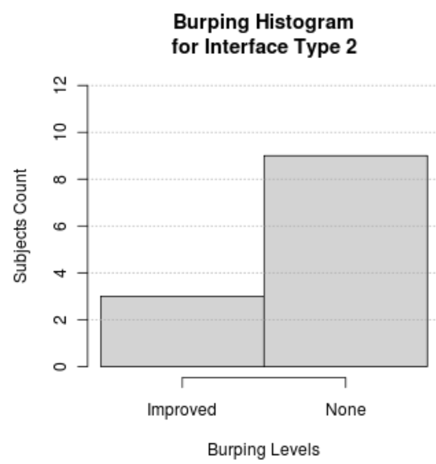
Burping vs. Interface Used Wilcoxon test:						
	UI1 – UI2	UI1 – UI3	UI1 – UI4	UI2 – UI3	UI2 – UI4	UI3 – UI4
W	6.000	eq.	eq.	0.000	0.000	eq.
Z	1.732	eq.	eq.	-1.732	-1.732	eq.
p	0.250	eq.	eq.	0.250	0.250	eq.
R	0.177	eq.	eq.	-0.177	-0.177	eq.

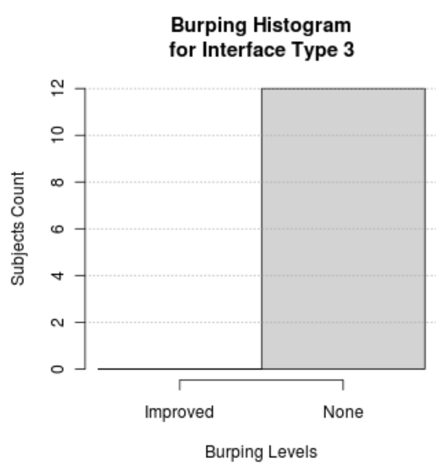
Burping vs. Interface Used Kurskal-Wallis test:	
X^2	9.075
DoF	3
p	0.028

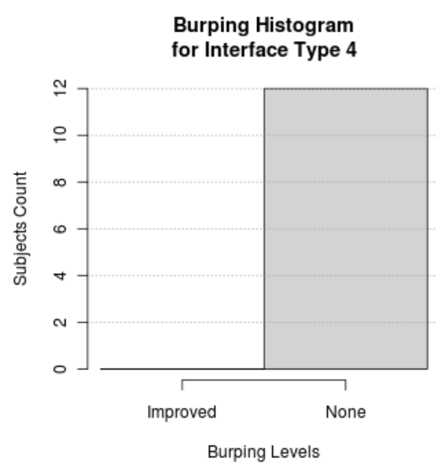
Burping vs. Interface Used Kruskal-Wallis test:						
	UI1 – UI2	**UI1 – UI3**	**UI1 – UI4**	**UI2 – UI3**	**UI2 – UI4**	**UI3 – UI4**
X^2	3.286	1.000	na	4.018	3.286	1.000
DoF	1.000	1.000	1.000	1.000	1.000	1.000
p	0.070	0.317	na	0.045	0.070	0.317

Burping vs. Interface Used Summary:			
Interface	**Mean**	**Std. Dev.**	**Median**
1	0.000	0.000	0.000
2	-0.250	0.452	0.000
3	0.000	0.000	0.000
4	0.000	0.000	0.000

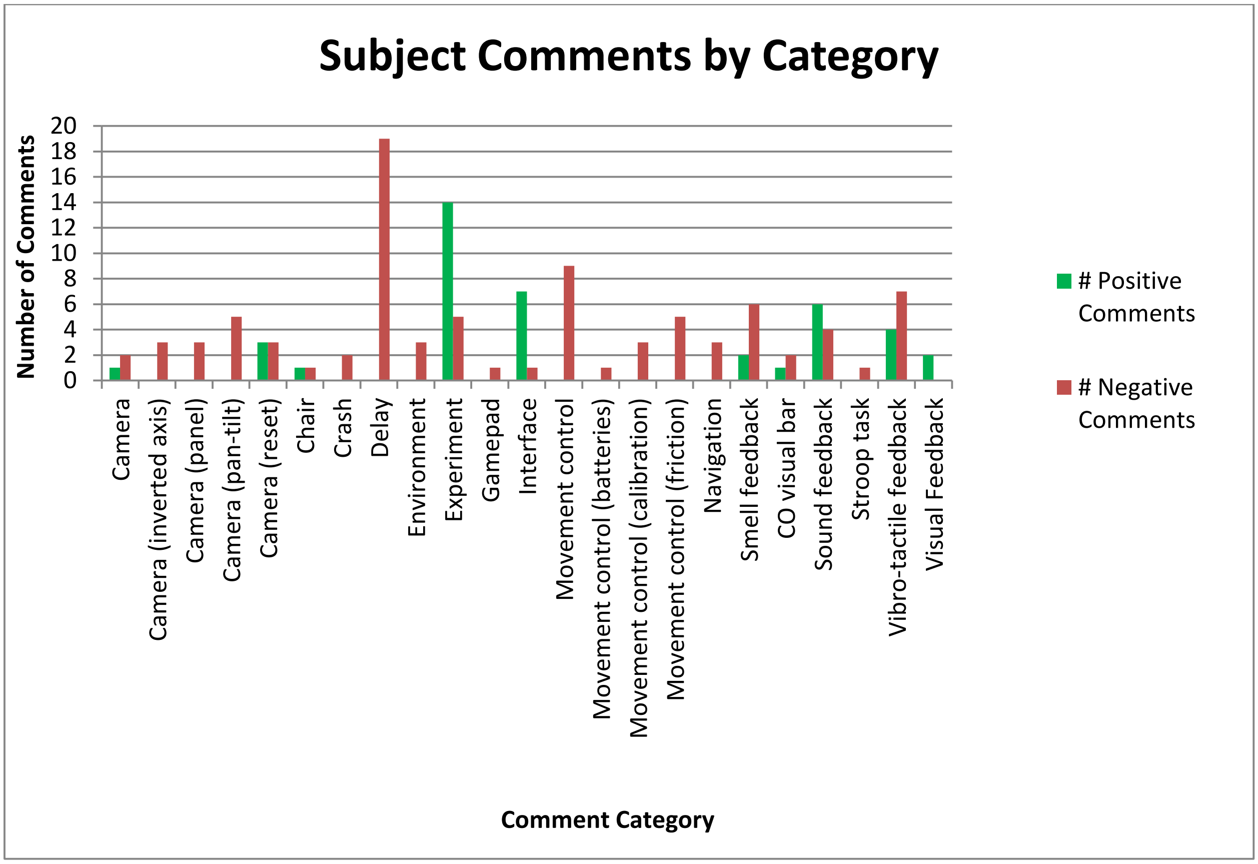








D.2.10 Comments



Comment	Category
The robot was the only problem I had, not the interface or the controls.	N/A
It was a little harder than I thought learning how the robot worked but once I picked it up, I was able to use it successfully.	N/A
I feel like having the tactile and smell feedback would actually be quite useful. I only had visual feedback and I found myself so engrossed with trying to drive the vehicle I was ignoring the visual cues such as the bump detection. If I had been zapped by the vibrating thing it would have made me much more aware of where the problem was.	N/A

camera was very annoying though, made me want to end experiment early.	camera
Camera somewhat difficult.	camera
The camera is very helpful.	camera
I would have reversed the camera vertical axis control, but that might just be personal preference.	camera (inverted axis)
I never did get used to the y-axis being reversed as I don't play games that way and ended up barely ever looking up or down as a result	camera (inverted axis)
Î would like to have the vertical camera inverted just like the option to do this in flight simulation games.	camera (inverted axis)
The camera only provided a small area of vision, so grasping a sense of the whole room at once was nearly impossible.	camera (panel)
View is tiny and very low resolution.	camera (panel)
View finder was too small; I would have liked the screen to be as big as it was when I was taking the picture.	camera (panel)
It would have helped me a lot more if the video on my screen were made larger or would cover the entire screen (even more so than showing me the positioning of the camera). I think that would have greatly increased the feeling of telepresence and aided greatly during the test.	camera (panel)
but my greatest concern remained my field of vision	camera (panel)
The camera panning was helpful, but the angle when looking to the extreme left or right was sometimes disorienting or distracting.	camera (pan-tilt)
Tilting the camera was not as difficult, making it highly useful for examining the immediate area.	camera (pan-tilt)
The skew on the view, when the camera pans, is awkward.	camera (pan-tilt)
The mechanic to look around and know where I was looking was clever	camera (pan-tilt)
The camera plane rotating with respect to the direction the robots front was facing is a good idea. It helps to remain oriented.	camera (pan-tilt)

Also, the sensitivity of how fast the camera turned around was very high. Numerous times I found that I turn much further than I hoped to.	camera (pan-tilt)
Sometimes, when I centered the camera I felt it was kind of disorientating and I would be confused where the robot was in the room. Since, I got confused about where I was in the room it was also hard to determine which of the red dots I had already taken a picture of and which were new ones(This could also be because the debris looked very similar in all areas- like a lot of white poster board used).	camera (reset)
The camera reset feature was very useful however.	camera (reset)
Chair was not as comfortable as it looks and having long legs made it difficult to focus.	chair
I want a chair like the one I sat in.	chair
the robot kept crashing in a software sense. This seemed to happen only during full collisions.	crash
the robot crushed a lot.	crash
I also noticed sometimes that the camera was unable to keep up with the robot in real time. Sometime I would notice the screen appeared frozen, so I didn't move anything, and then the robot would be in a new location. This confused me a few times.	delay
but I think it would be more appropriate as an optional view for when you want to specifically ~look around~ (the camera was pretty laggy too).	delay
The lag was incredibly annoying. More than anything else, the delay between my action's and the robot's made this difficult.	delay
The delay between using the controller and the effect of the controls was the main obstacle that made the task difficult.	delay
The time-lag also made it difficult to maneuver around the room quickly.	delay
Lag.	delay

The lag in the video made it difficult sometimes to tell how much I was actually moving the robot at any given time.	delay
The delay and carpet friction were my greatest difficulties and slowed me down significantly. I feel as though I could have done the test in a more timely matter if the response time was more instantaneous like I am used to with other simulated-reality games.	delay
Laggy.	delay
The delay between input on the controller and robot movement took 5 or 6 minutes to get used to.	delay
Lag time made it hard to control the robot.	delay
But then again, it had some delay to it and sometimes I would not know if I was close to an object or not, that's why the vibrations helped a lot.	delay
it seemed to lag quite a bit, difficult for me to use	delay
Besides the delay in feedback	delay
The only observation I would say is that there should be more synchrony in time between the camera and the robot movement.	delay
The lag on the camera made the task nearly impossible to perform.	delay
While driving the robot, I had to be aware of its particular mechanics. Delays in control and feedback were the most distracting factors.	delay
Navigating the robot was not easy mainly due to the delay from the input to the movement of the robot.	delay
There is a delay on showing the real time image, makes the controlling difficult.	delay
It was sometimes hard to know if I was supposed to go somewhere or if it was not part of the experiment.	environment
Also, things in the room that are red or similar to red in color made it confusing to tell if it was one of the circles or not.	environment
Also, kind of gave up on third entry point because could not get robot back there.	environment

I found using the robot very frustrating, possibly because I never play video games (which I find to be frustrating too)	experiment
Overall, it's a good project to start with and has an excellent scope.	experiment
Certain factors may confound the data, for example, people who visited the lab before and hence can navigate easily.	experiment
Also, cultural background may also affect the experiment results.	experiment
If it is ever possible to improve the response time of the robot, I could certainly imagine this being a method of examining unsafe areas without much danger to the user. That is assuming the technology becomes affordable enough that losing robots is not too disastrous.	experiment
The experiment was difficult only because it was frustrating to move around the room and get a sense of where everything was.	experiment
I was very focused during the experiment because I felt as if the red dots were actual human lives. This drove me to try and execute all my movements without mistakes because I my mind, people were in danger and I could help save them.	experiment
I had fun. It was hard. Part of that is probably due to how the robot responds.	experiment
It is entertaining.	experiment
I enjoyed the sense of exploration and trying to carry out a search operation,	experiment
But it was hard to get immersed for much of the experience due to the lag of the controls and the inverted y-axis on the camera.	experiment
However, I definitely enjoyed it and will be recommended the lab to my friends.	experiment
a bit buggy	experiment
But really cool anyway.	experiment
I really enjoyed the experiment; the largest distraction was the cookies, candy and chips! Well done	experiment

I thought that it was an interesting experiment and I enjoyed participating	experiment
cool robot	experiment
It was certainly interesting, difficult adjusting to the sensitivity of the controller to get the robot to move, but other than that went fine.	experiment
Very interesting	experiment
Really interesting! I would like to drive the robot again!	experiment
Very interesting and well-designed study. But it is hard to make sure it always works like many robotic experiments. I think the purpose of the study is meaningful. At least for me having more sensory feedback is more helpful than only having visual feedback.	experiment
Nice application, pretty fun.	experiment
The controller does not work quite well.	gamepad
Very cool concept, controls were very simple, considering I owned a PlayStation 2.	interface
The interface was designed pretty well;	interface
Controlling the robot was intuitive and interesting.	interface
It was easy to learn how to use the robot.	interface
I think once I got used to the controls though, it became fairly natural to move around in the space.	interface
In general, the robot control is easy to learn but a little difficult to be skilled.	interface
In general, the robot control is easy to learn but a little difficult to be skilled.	interface
it is not too hard to get accustomed to the interface (after a while),	interface
The difficulty was in navigating around objects that the robot hit, given the turning radius of the wheels.	movement control

Used too much time just trying to steer the robot in the right direction.	movement control
Moving side to side was much more unpredictable than using forwards and backwards.	movement control
Controls weren't as sensitive as I thought. However, enjoyable all the same	movement control
I never felt that I had a consistent idea of how much the robot was likely to move when I tilted the left analog stick.	movement control
The main difficulty that I had was with the sensitivity of the robots motion control stick. At times I found I was moving or turning it too much or too little and this made it harder to move faster in the environment.	movement control
Sensitivity and delay made control difficult, otherwise straight-forward.	movement control
Controller to motor feedback was a bit slow turning left or going backwards, but forward and right turning was fine	movement control
And the precision in movement.	movement control
Trying to turn robot was tough at first but once batteries were changed, navigation was much easier.	movement control (batteries)
The robot did not want to turn left easily.	movement control (calibration)
Feel that the control of the robot could in general be improved. I had a lot of difficulty in physically getting the robot to go where I wanted it to. I found that the robot would not move without moving the thumbstick fully in one direction, and then the robot would spin around or go too far.	movement controls (calibration)
Turning Left was much harder than turning right, similarly, Forward was harder than moving back.	movement controls (calibration)
The delay and carpet friction were my greatest difficulties and slowed me down significantly.	movement control (friction)

Also I felt like it was very unresponsive when trying to move carefully forward or back, as if I either could go full speed or barely at any speed all with almost nothing in-between.	movement control (friction)
Friction seemed to be the most difficult aspect. Turning the robot was easier once it was moving, I think, but still not very easy and it took a while to figure this out.	movement control (friction)
In my opinion, turning the robot required a too precise amount of force, that is, if given too little, it wouldn't turn, if given too much, it would rotate too much. However, I felt that moving forward or backwards was smoother and easier to handle.	movement controls (friction)
The robot behaved differently depending on the surface it was on. Very challenging!	movement controls (friction)
Sorry I hit so many things with the robot.	navigation
I bumped into something.	navigation
Also it seemed like the controls wouldn't allow me to both look and move which is something I would normally do a lot in games.	navigation
Felt that the scent feedback was super helpful in finding red circles.	smell feedback
I really enjoyed the course but, would suggest making the sound and smell a little more exorbitant so that it enhances the experience.	smell feedback
I found that the smell didn't have much of an effect on the difficulty of finding the circles.	smell feedback
I think I smelled something faint from the fan in the beginning but this may not be true. Maybe the perfume ran out.	smell feedback
The smell sense wasn't there or I just have a bad sense of smell.	smell feedback
I haven't felt the smell during the search phase, only during the test phase	smell feedback
The smell is not as useful when there is already visual odometer, but it does provide a strong indication for the corresponding location.	smell feedback
The smelling was a little helpful in the beginning	smell feedback
But later I completely forgot the differences on smelling.	smell feedback

The CO2 sensor isn't very accurate.	CO visual bar
I feel like the CO2 gauge helped me minimally compared to actual feedback from the camera. I did not know how close I had to be to the red dot for the gauge to go up.	CO visual bar
The CO2 scale was a good addition, but if scent and tactile were also added, it could prove overwhelming.	CO visual bar
Headphones were good though, I thought they were the sweaty kind. Good luck though	sound feedback
Misleading audio feedback - although sound indicated torque it did not correlate with vehicle motion. It worked for the torque dial but audio torque feedback was misleading. It made me feel like I should be moving or turning, even though I wasn't. I was more ready to believe that the visuals were severely lagging, rather than believe I wasn't actually moving. this caused frustration.	sound feedback
The sound was helpful for getting a sense of the space,	sound feedback
The non-visual sensors were very helpful.	sound feedback
The sound feedback was at least as, maybe even more, useful than the visual feedback for setting the robot in motion. This is because the throttle was very sensitive and it was harder to gauge visually.	sound feedback
I found the sound feedback very helpful because it shows me that my motion command has been accepted by the computer. This is important especially when there is delay. So that I know it the delay that is causing the robot not moving but not because the joystick is not controlled well.	sound feedback
Sound is very good for collision. The combination of the two seems very good.	sound feedback
But I did not feel like the motor revving noise was always that accurate because of the delay in the controls. Maybe the sound being delayed a bit as well would have made it feel more natural.	sound feedback
The sound for motor and collision is really helpful. I felt like it was the real sound from the robot.	sound feedback

I really enjoyed the course but, would suggest making the sound and smell a little more exorbitant so that it enhances the experience.	sound feedback
I really cannot do the main task and the color matching task at the same time. Too distracting for me.	stroop task
Vibration belt was a good addition to just traditional visual feedback	vibro-tactile feedback
The belt tickles! :)	vibro-tactile feedback
The tactile feedback felt excessive at times- It gives better warning feedback that you are near something but once I knew I was near something I used the visual sensors to determine what I was near. The belt then became a distraction.	vibro-tactile feedback
The vibration can made me feel uncomfortable towards the end and may have caused me to hurry through the search.	vibro-tactile feedback
The vibration did not add much to my experience and in fact was overall very distracting and made getting stuck even more annoying than it would already be.	vibro-tactile feedback
The collision sensor is very sensitive, the belt vibrating almost all the time, which makes me feel uncomfortable	vibro-tactile feedback
I liked the vibrations because it gave me a sense of what was around me. The increasing intensities of the vibrations helped me understand how close I was to a collision and to avoid it.	vibro-tactile feedback
The vibrations were nice, but after a while, it started to get itchy in those areas, but it was all in all helpful.	vibro-tactile feedback
The vibration is always on. I think it's only necessary if collision happens. It's not necessary for proximity detection. Otherwise, I will ignore it.	vibro-tactile feedback
Vibration feedback was not annoying at all this time for me.	vibro-tactile feedback
Vibration is very useful to indicate proximity	vibro-tactile feedback
I would prefer having a 3D visual feedback (panoramic) but, the camera footage was not that bad either.	video
The visual was nice because it gave me vision.	visual feedback

My major problem was with the visual feedback.	visual feedback
Two recommendations -I suggest that the operator be given a chance to drive the robot while observing it (i.e. 3rd person point of view if the robot is the subject). This will give the user a better “feel” for how the robot operates.	N/A
Secondly, I suggest implementing a function whereby the vehicle aligns itself with the direction the camera is pointing (kind of like the reverse of the -align camera forward- function button).	N/A
I wonder, though, whether additional stimuli would help or hinder a rescue effort.	N/A