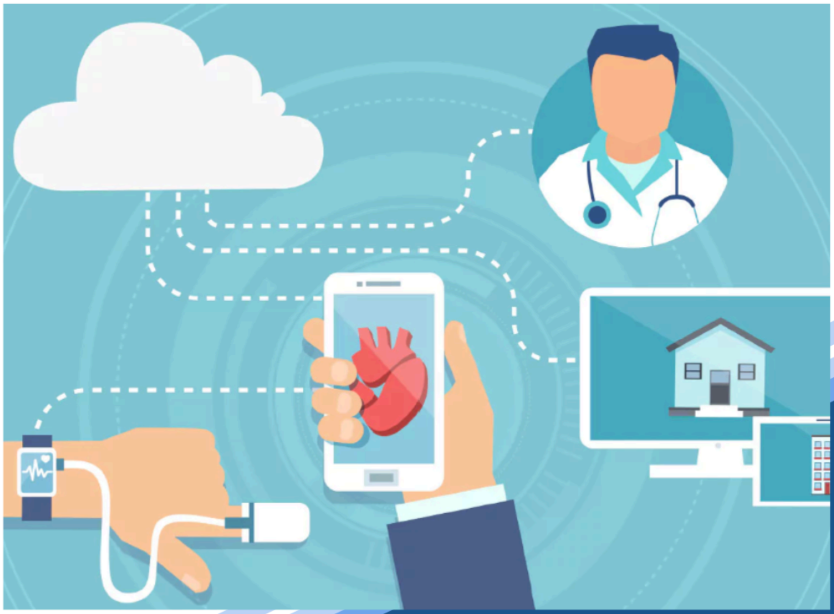
ENHANCING RESPIRATORY CARE: THE POWER OF TELEMONITORING

By: Alejandro Clermont-Delgado, Lori Ganjian, Brynne MacWilliams, Matthew McLellan, and Alyssa Ogi



Enhancing Respiratory Care:
The Power of Telemonitoring

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WORCESTER POLYTECHNIC INSTITUTE

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Degree of Bachelor of Science

By

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Abstract

This project focuses on improving patient care in the context of the Spanish healthcare system through creating an app unifying respiratory health data through telemonitoring technologies. It aimed to devise secure data collection and transmission methods for communicating respiratory data between healthcare providers and patients while fostering user engagement through intuitive interfaces. The app offers symptom assessment, weight tracking, wristband data, and air quality monitoring. Recommendations include expanding dashboard modules, integrating indoor air quality sensing, oximetry, AI, and enhancing usability.

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First, we would like to thank the University of Cádiz for sponsoring our project and providing us with the necessary resources needed for the completion of the project. We extend our deepest appreciation and gratitude to our direct sponsor, Dr. Daniel Sanchez Morillo and his team for their support and guidance throughout the duration of this project. Their expertise and constructive feedback have been invaluable in helping us to work towards our goals and overcome challenges along the way.

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1. Introduction: Addressing the Need for Unified IoT Systems in Respiratory Illness Monitoring

In an age defined by technological advancements and a growing emphasis on remote healthcare solutions, the global adoption of telemonitoring stands as a focal point in reshaping the foundations of patient care. “Telemonitoring” is defined as the remote intake of patient health data through the use of Internet of Things devices (IoT). IoT devices are sensors which are capable of sharing data with other devices and systems over the internet. From remote patient tracking to real-time data analysis, telemonitoring systems and related eHealth technologies offer personalized and accessible healthcare on an unprecedented scale. However, the integration of telemonitoring technologies on both a global and national level requires a favorable political and social context. Sufficient government funding, resource allocation, and firm support from patients and healthcare providers are critical to facilitate the establishment of these systems (Ramos et al., 2020).

Telemonitoring in the realm of Spanish healthcare presents a spectrum of challenges and advantages. While telemedicine experienced a worldwide boom with the Covid-19 pandemic, the use of teleconsultations and virtual applications in Spain has become widespread and the foundations are being laid for remote monitoring of chronic patients, while the first steps are being taken in surgery thanks to the deployment of 5G networks. With the advance of sensorization, robotics, the Internet of Things and Artificial Intelligence, the future of this process looks bright, but it must overcome some obstacles. These barriers include the cost of implementing these technologies, such as the cost of the devices themselves, and the training for healthcare professionals and patients that is necessary in order to utilize the devices (Mahou et al., 2021). Health institutions require additional financial assistance to provide all patients access to telemonitoring systems. Policy advocates and researchers argue that telemonitoring systems accompanied by the integration of supplemental respiratory devices to allow for remote patient monitoring would enhance the efficacy of patient care, reduce hospital visits, and thus, reduce hospitalization costs as well. (Lyth, 2019). Likewise, minimizing hospitalization rates serves to alleviate the burden and stress often endured by healthcare workers (Spain, 2024).

Our sponsor, Professor Daniel Sanchez Morillo, head of Bioengineering, Automation and Robotics (ATARI) Research Group at the University of Cadiz, has emphasized the potential of remote telemonitoring of patients with chronic respiratory conditions. Telemonitoring for respiratory care has great promise as a solution to foster the self-management of the disease, enhance quality of life of patients', and enable doctors to perform thorough health assessments and recommend lifestyle changes. Telemonitoring would also allow for intervention when data indicates an oncoming worsening of respiratory symptoms, again, with the potential of reducing hospitalizations, and consequently, costs. Telemonitoring can enable patients to have access to their data and understand their own health trends, allowing for better self-care in lifestyle management, and for patients to predict an exacerbation of their condition ahead of time (Angelucci, 2020). Our sponsor has tasked our group with devising methods for effectively communicating data derived from respiratory telemonitoring to the patient in a way that is understandable and significant.

Patient engagement is key to successful respiratory telemonitoring. To foster user engagement and the adoption of remote telemonitoring altogether, patients must be able to correctly set up sensors and be willing to collect and check their data every day (Kodali, 2015). The initial implementation of these technologies requires providers to work closely with patients. Patient engagement and consistency in using the system is essential, and often the use of apps is integral to encouraging patients to keep up with their health. Many apps incorporate dashboards displaying the highlights of patient health and other features in an aesthetic and intuitive manner, and send alerts and reminders to patient mobile devices. Apps which incorporate opportunities for patient feedback allow dashboards to be tailored to patient needs and desires. The use of an app would engage patients and allow them to easily understand their data on their mobile device anywhere, anytime.

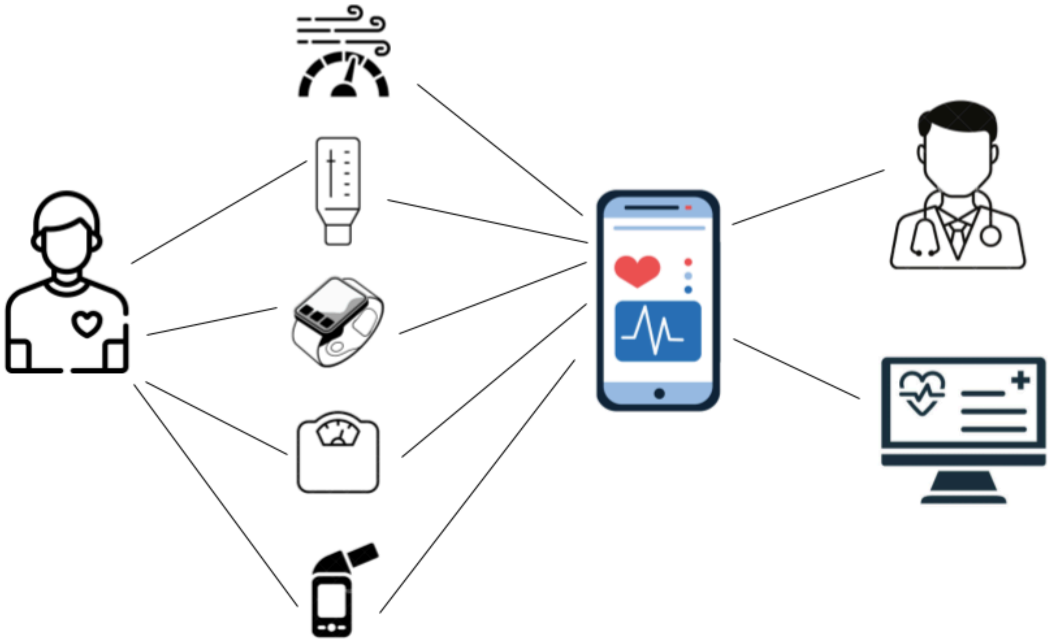


Figure 1. Flow of patient data from devices to healthcare providers via android app.

Our goal is to develop an engaging Android application that integrates commercially available IoT respiratory health sensors to provide a full picture of respiratory health. The app will integrate and visualize patient data while also securely transmitting information to a central server and healthcare providers. Meeting objectives around app development, secure data sharing, and improving patient engagement will allow us to decrease hospitalizations and costs by increasing accessibility and efficacy of respiratory healthcare. Our prototype app will connect to sensors that fully assess respiratory health. We will store data securely within a central server and share with medical professionals to enable better treatment. Through an engaging interface, the app experience itself will educate patients about their health to further positive outcomes. By accomplishing these technical and user experience objectives, we aim to meaningfully improve respiratory patient care through this telehealth system.

2. Background: Investigating the Field of Telemonitoring

2.1 Existing Challenges in the Infrastructure of Health Information Technologies (HIT)

The Spanish healthcare system is characterized by its commitment to universal healthcare for all residents and ensuring equal access to healthcare irrespective of social demographics (Mahou et al., 2021). The decentralized system holds each of the 17 autonomous communities of Spain responsible for managing and organizing healthcare services in their respective territory. Within Andalusia, The Andalusian Public Health System (SSPA), oversees the entirety of the primary care network and functions to govern healthcare services and initiatives within the region (Ramos et al., 2020).

In recent years, the use of new information and communication technologies (ICTs) within public administration, including healthcare services, has steadily advanced across Spain, motivated by the potential to reduce costs, improve the quality of services, and increase accessibility of basic systems via the internet (Mahou et al., 2021). Health Information Technology (HIT), also referred to as eHealth, consists of the implementation of ICTs to allow for the processing, storage, retrieval, and sharing of healthcare-related information, data, and knowledge for medical and lifestyle purposes (Villalba-Mora et al., 2015). eHealth technologies prove to be valuable given their potential to enhance the quality and efficiency of medical processes, mediate communication between patients and providers, and improve access to healthcare altogether.

Currently in Andalusia, the healthcare information and management system, Diraya, has been widely adopted throughout the region. With support from the SSPA, as of 2010, Diraya covered 94% of the Andalusian population (Andalusian Health Service, 2010). The system operates based on three principles: (1) Integrate all information for a given user into a single health record, regardless of the data source or their healthcare provider, so it is accessible wherever and whenever needed (2) Facilitate access to all services and provisions of the health care system (3) Ensure relevant information is structured using common tables, codes, and catalogs (Andalusian Health Service, 2010). Diraya provides digital access to services including a centralized appointment system, electronic prescriptions, lab tests and results, and most importantly, a Single Health Record. The User Database component of the platform supplies citizens with a Single Andalusian Health Record Number (NUHSA), linking them to their medical information (Andalusian Health Service, 2010).

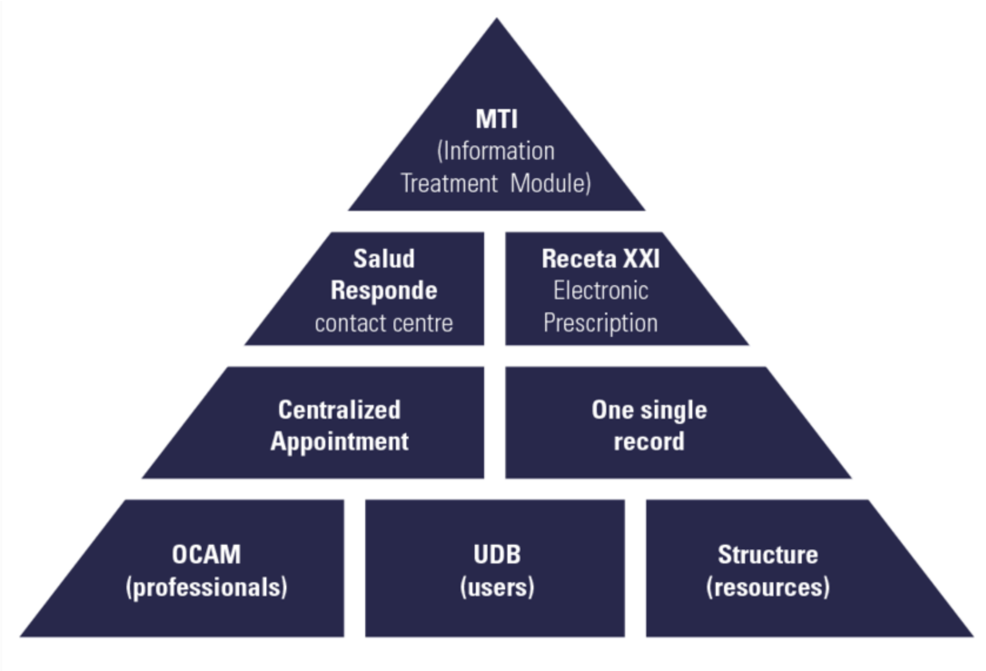


Figure 2. Hierarchy of modules that comprise DIRAYA and relay information (PubMed).

While many of the described eHealth services are well-established, other services such as telemedicine require further development to attain widespread adoption and user satisfaction on both a national and regional level (Ramos et al., 2020). Studies examining the perspectives of both patients and healthcare providers consistently identify several systemic barriers hindering the unanimous adoption of eHealth technologies across Spain. First, greater economic investment is required to cover expenses associated with the implementation of HIT systems (Villalba-Mora et al., 2015). Insufficient funding restrains both the establishment of new technologies as well as restricts physicians from attaining the necessary training and skills required to utilize these systems (Mahou et al., 2021). Due to the decentralized structure of the Spanish healthcare system, financing for HIT is derived from both public and private sources and is dependent on the healthcare agenda of a given community. Thus, without the allocation of funds from the central government, HIT financing relies on fluctuating regional initiatives to pursue the implementation of eHealth (Ramos et al., 2020).

The deployment of new systems necessitates standardized operating processes and regulations to facilitate the fusion of the new technology with existing systems (Villalba-Mora et al., 2015). In many hospitals, physicians use applications adapted specifically to their organization, diminishing the appeal of introducing new systems which may prompt significant structural changes (Villalba-Mora et al., 2015). In order to promote the consistent integration of HIT within hospitals across the varying regions of Spain, standardized guidelines and procedures must be established (Villalba-Mora et al., 2015). Likewise, with the implementation of new technologies comes uncertainty regarding data security and confidentiality. Particularly in the case of telemedicine, both patients and physicians voice concerns regarding the way in which their personal medical data would be stored, shared, and accessed (Ramos et al., 2020). Such apprehension makes both parties hesitant to utilize platforms like those of electronic medical records and telemedicine systems that collect and share individuals' personal information. Ultimately, to facilitate the widespread adoption of HIT technologies on both the national and regional levels, a favorable political and social context must be established (Ramos et al., 2020). Ample financial backing from the government, allocation of resources, and firm support from both patients and healthcare providers are essential for fostering the development of these systems.

2.2 Interoperability of Telehealth Systems

Telehealth systems in Spain currently consist of a fragmented landscape of localized programs and initiatives. While there have been numerous pilots and small-scale deployments of telehealth platforms across different regions, there is a lack of coordination and interoperability between these systems (Toledo et al. 2006). Many of these platforms have been developed independently by hospitals, research institutes, and technology vendors using proprietary protocols and data formats. For example, the MATRICE project by the Polytechnic University of Madrid focuses on home telecare for elderly patients, the NEXES project by La Fe Hospital uses telemonitoring for patients with heart failure, and other systems exist for diabetes management, COPD, and more (Bousquet et al., 2022). However, there is a small capacity for data and system integration between these initiatives. This fragmentation results in technological silos and closed ecosystems that cannot effectively share patient health information and analytics for providing continuous and coordinated care. Patients receiving telecare from one program cannot seamlessly transition that monitoring and data history if they begin receiving services from another program. This lack of interoperability limits the potential benefits of telehealth in enabling more connected patient-centered care. Additionally, many existing telehealth deployments rely on proprietary medical devices and custom hardware for in-home patient monitoring. These monitoring devices often embed proprietary communication protocols rather than adopting standards-based approaches for interfacing with other systems (Li et al., 2018). There is a need for device manufacturers to shift towards open APIs and standard data schemas to better support integration with a variety of telehealth platforms.

Ongoing adoption of standard protocols for medical device connectivity and health data exchange will be crucial to unlocking the potential of telehealth in Spain. National initiatives to coordinate the rollout of telehealth systems across autonomous communities with shared platforms and interfaces would also catalyze further integration. Overcoming these infrastructure and interoperability challenges through methods such as telehealth systems remains a key priority to improving equal access to care.

2.3 Integrating IoT for Efficient, Convenient, and Reliable Healthcare Monitoring

Improving and emerging treatment methods for diseases and injuries, the wide-scale use of computers and electronic health records, and telehealth have advanced the Andalusian healthcare system. Telehealth capabilities include video chatting or messaging between patients and doctors, and monitoring patient conditions remotely using Internet of Things (IoT) devices. Internet of Things refers to anything that can exchange data with another device or human, or device to human, over communication networks (Madakam et al., 2015). Within the healthcare system, IoT includes different types of devices like fitness trackers, smartwatches, smart clothing, ECG monitors, blood pressure monitors, and many more. Sensors in these devices transmit recorded data to the cloud for secure storage, then forward the data to doctors for analysis. With the incorporation of artificial intelligence, some devices can monitor and interpret data readings independently. This form of healthcare, specifically the continued integration of IoT, can lead to more efficient and convenient health monitoring (Li et al., 2024).

The technology of IoT devices is designed to give patients with chronic health problems effective health-tracking abilities. Chronic respiratory diseases have a significant need for telemonitoring technologies due to the common diagnosis of respiratory conditions and the unrelenting nature of respiratory diseases (Metting et al. 2021). The installation of these telemonitoring technologies signifies a shift towards a more patient-centered, efficient healthcare system (Pare, Jaana, and Sicotte, 2007). Designs which incorporate multiple sensors track a variety of important patient data like heart rate, respiratory rate, body temperature, environment temperature, and humidity. Doctors and patients would be able to view and interpret data that signal steady or worsening conditions, like the onset of a fever or asthma attack. This not only helps to intensify management of chronic conditions, but also assists in reducing the pressure and costs on healthcare facilities by minimizing unnecessary hospital visits and admissions.

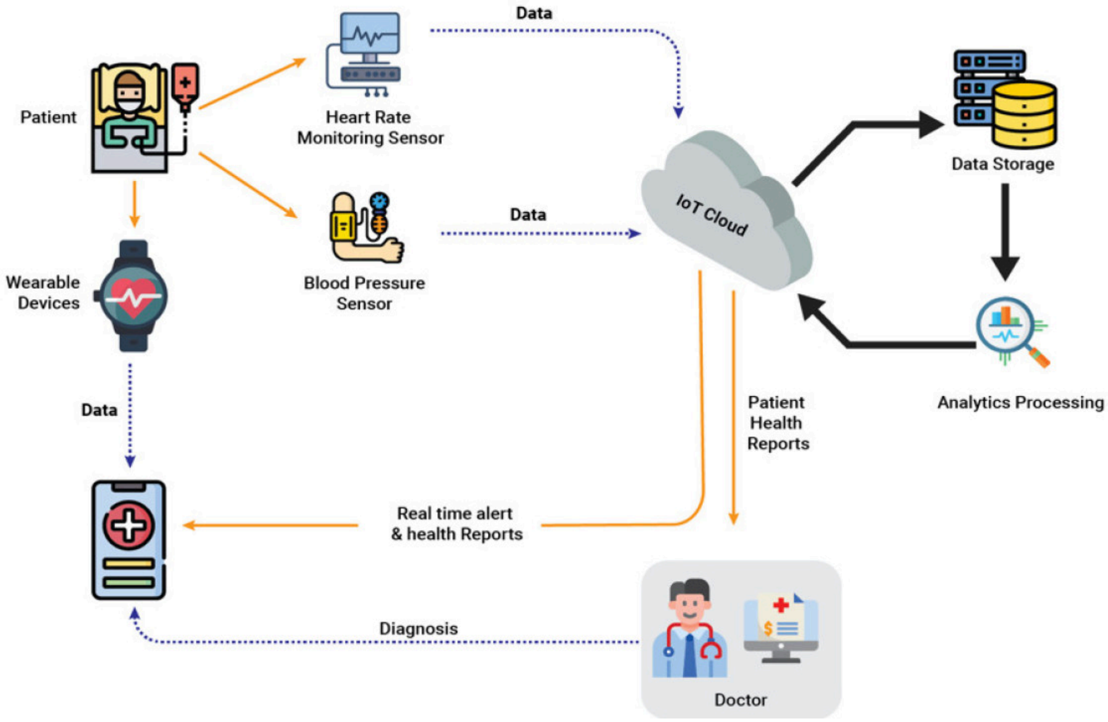


Figure 3. Transmission of patient data between IoT devices and healthcare providers.

Therefore, combining data from multiple sensors and alerting patients when their readings are abnormal is a key feature of IoT. Modern telemonitoring systems employ high-tech sensors and structured algorithms to ensure the standard of the data received is reasonable and balanced. Furthermore, these systems incorporate calibration and error-checking mechanisms to ensure the accuracy of the data. (Angelucci, 2021). A prototype developed by Bhowmik et al. detected when body measures like pulse, body temperature, and SpO2 levels, or environmental conditions like smoke level and environment temperature exceeded a “safe” range hardcoded into the system and alerted the user with SMS messages and a buzzer within the device (Bhowmik et al., 2021). Not only could the IoT device alert the user, but it could also contact healthcare providers, and family members in case of an emergency. Martin-Lesende et al. (2013) used a telemonitoring approach to decrease the number and length of hospitalizations of patients with heart failure or chronic lung disease. Their device measured heart rate, respiratory rate, blood pressure, oxygen saturation, weight, and body temperature and alerted patients and healthcare professionals of abnormal measures. The device helped to decrease the number of hospitalizations by catching symptoms early on but did not decrease the length of hospital stays (Martin-Lesende et al., 2013). Telemonitoring also plays an important role in post-operative care and rehabilitation, where monitoring lung function and respiratory health is essential. IoT devices on their own are valuable to patient health and treatment, but improving them could save lives.

The emergence of Artificial Intelligence (AI) and machine learning have enormous potential to improve telemonitoring. Using AI can improve the accuracy of patient health status prognoses by interpreting the data from IoT sensors and detecting patterns (Fouad et al., 2020; Fernandez-Granero et al., 2018). In a study by Fouad et al., researchers evaluated accuracy metrics such as error rate, precision, and accuracy, for five machine learning methods predicting a patient's health. The Iterative Gold Section Optimized Deep Belief Neural Network (IGDBN) achieved a 99.86% accuracy rate in predicting a patient’s health (Fouad et al., 2020). In a 2018 study Fernandez-Granero, Sanchez-Morillo, and Leon-Jimenez utilized AI to predict acute exacerbations of COPD. While this study had a small sample size, the authors achieved 78.0% and 75.8% accuracy in predicting reported episodes and 87.5% accuracy in predicting unreported events, with an average of 4.4 days before the onset of symptoms (Fernandez-Granero, 2018). Fouad et al. used IGDBN, and Fernandez-Granero et al. used AI to analyze patient data to anticipate exacerbations, alert them when their health might deteriorate, and seek medical attention. These methods would give doctors more time to treat the patient to prevent their condition from worsening. Combining AI techniques like the above, data aggregation, and alerts could benefit the well-being of patients and improve healthcare outcomes.

Integrating telemonitoring into healthcare is not only beneficial for the patients, but it is advantageous for healthcare providers as well. For in-hospital use of IoT devices, the sensors on devices can take vital readings, creating more time for healthcare workers to spend on urgent duties (Kodali et al., 2015). This enables doctors and nurses to focus on patients without expending unnecessary time manually recording vitals. In addition, since COVID-19 is still prevalent and life-threatening in some cases, IoT devices can enable patients to be monitored with very limited contact with healthcare professionals to help limit the spread (Fagroud et al., 2021). IoT devices can help healthcare professionals rapidly identify symptoms and contribute to workload reduction for doctors and nurses (Fagroud et al., 2021).

IoT devices can also enable patients to manage their own health. The devices can transmit data to the patient's phone or computer, so the patient can then keep track of their health metrics. Once alerted to abnormalities like elevated or decreased heart rate, feverish body temperature, or low oxygen saturation, the user can seek medical attention. Lyth et al. (2019) studied 94 elderly patients with lung or heart diseases and found that, although overall healthcare costs stayed the same, the use of telemonitoring reduced the number of hospital visits and the cost of hospitalization decreased. Using a telemonitoring device can indicate when treatment is needed, essentially eliminating unnecessary trips to the hospital. However, lowering hospitalization costs or the easy use of devices is not guaranteed by using IoT. One research project that aimed to combine three telehealth systems into a single platform exemplifies some difficulties. They noted that the initiative was motivated by the difficulty of integrating telemonitoring into routine patient management workflow, high costs of technology implementation, and low flexibility of the systems regarding interoperability between devices and hospitals (Toledo et al., 2006). It should be noted this paper is dated; technology has progressed significantly since this paper was written and telemonitoring devices are more common today.

Patients' reluctance to embrace telemonitoring may come from concerns regarding privacy, trust in technology, and the perceived replacement of personal doctor visits. This doubt highlights the importance of ensuring patient confidentiality in integrating these technologies, placing an emphasis on the complementary nature of telemonitoring to traditional care and its potential benefits such as convenience, timely intervention, and improved health outcomes. Clear communication between patients and providers as well as involving patients in decision-making processes can facilitate trust in these systems and greater acceptance of telemonitoring technologies altogether. Future advancements in respiratory telemonitoring are likely to focus on these challenges, creating improved interfaces, and expanding the development of more advanced algorithms for data analysis (Dieffenderfer et al 2015). With the goal of creating more intuitive, unified systems that provide comprehensive monitoring with user-friendly interfaces for patients and healthcare providers, our project aims to fuse these elements in developing an application capable of aggregating, sharing, and representing data from various sensors. Patients suffering from COPD and their care team are in great need of such a system for improved care and convenience.

2.4 Telemonitoring in the Post-Covid Era

The COVID-19 pandemic has acted as a significant catalyst for the advancement of telemedicine and eHealth services. Teleconsultations experienced a remarkable surge midst and past pandemic, effectively alleviating strain on healthcare facilities and systems by enabling remote detection, diagnosis, and monitoring of COVID-19 cases (Cernadas Ramos et al., 2023). Various national health services worldwide embraced telemonitoring solutions as an alternative to traditional in-person consultations. Yet, rather than introducing new services, there has been a notable uptick in the utilization of existing eHealth offerings, indicating a consolidation of already available resources(Cernadas Ramos et al., 2023). The pandemic has played a pivotal role in diminishing apprehensions toward technology adoption in healthcare delivery. Despite expectations for an expansion in services, recent literature suggests a trend of intensified usage of existing services rather than the introduction of novel ones in both Spain and neighboring countries amidst the pandemic (Cernadas Ramos et al., 2023). Ultimately, the heightened demand for telemonitoring highlights the importance of advancing these technologies to effectively meet evolving healthcare needs on an unprecedented scale.

2.5 Patient Engagement with Respiratory Telemonitoring

A key component of all types of telemonitoring is patient participation. Placing care responsibilities into patient hands is an increasingly relevant and complex debate. The primary concern with providing patients with respiratory sensors is the validity of the collected data. Many of these devices depend upon correct placement and setup for accurate data collection, and therefore patients collecting their own data have a higher risk of collecting false negative or positive diagnoses than a clinical expert. Therefore, extensive training is required before sending a patient home with a multiple-sensor system. However, many sources that consider these potential downfalls ultimately determine that the data collected from telemonitoring is viable and valuable for informing patient health (Angelucci, 2020)(Dieffenderfer, 2014).

One of the major benefits of telemedicine is fostering patient knowledge and participation in their own healthcare. Cegarra-Navarro et al. (2012) examined the relationship between telemedicine technologies, and the enhancement of patient electronic knowledge, providing insights into learning through telemedicine. Fairbrother et al. (2013) found that using telemonitoring for patients with COPD greatly enhanced their understanding of their diagnosis, and they felt more informed when making healthcare decisions. This engagement is crucial to ensuring patients are invested and active in their treatment, and points towards improved outcomes and quality of life. However, Fairbrother et al. (2013) also note that telemonitoring can promote increased dependence on professionals. Transitioning patients from occasional physician appointments to frequent virtual updates leads to an increase in patient communication, which is beneficial to their health and understanding, but could overburden physicians. This issue could call for further staffing to reduce the burden on individual professionals.

The core goal of respiratory telemonitoring is to improve patient quality of life. Mobile sensors are a major motivating factor for patients to commit to respiratory telemonitoring, as they are essential to patient comfort and independence, and allow for further observation of patient lifestyle in terms of activity and location. Through 24/7 monitoring, a far more detailed picture of a patient’s lifestyle and respiratory condition can be achieved, leading to improved diagnosis and treatment recommendations (Kodali, 2015).

A full profile of a patient’s respiratory health can be built through the combination of multiple sensor techniques. Encouraging patients to use traditional sensors used with respiratory illnesses, such as spirometers, pulse oximeters, and heart rate monitors represent an individual's respiratory health condition. By aligning this data with that of sensors measuring patient lifestyle habits, potential risks can be identified from trends (Angelucci, 2020). Activity sensors allow patients to better understand how factors such as climbing stairs, exercising, and changing altitude might exacerbate their respiratory condition. Environmental sensors incorporated into urban areas and even inside patient homes can identify temperature and air quality issues, which may indicate their living conditions are worsening their symptoms. Stevenson (2017) took a public health approach and found that incorporating these environmental sensors into public neighborhoods can be a huge help in identifying residential areas whose population is at a high-risk for respiratory illnesses, while also providing a better perspective of areas to avoid for individuals already suffering from a respiratory illness.

Telemonitoring with multiple sensor types (respiratory, heart rate, activity, environmental) must be represented in a user-friendly manner to ensure easy and accurate data collection. Muhammad-Waleed (2023) proposes a cloud-based patient monitoring model divided into modules for sensing, network, and application. The sensor data is sent to a smart device app to allow patients and physicians to interact with the data. This proposed system can handle significant data, and was found to enable the observation of four times more patients than traditional clinical methods. Users found the application simple to use and gained an improved understanding of their health through the convenience of the app and the daily use of relevant sensors. Jiménez-Fernández et al. (2013) focus on the usability and interoperability of wireless sensor networks for patient telemonitoring, addressing challenges related to technology usability and sensor device interoperability. This study specifically provides insights into user interfaces and the importance of meeting the specific needs of elderly patients, who may not be technologically-savvy. Ultimately, to collect viable data from various sensors in respiratory monitoring, it is important to create an app that is easy to use for both the physician and the patient.

2.6 Epidemiology of COPD

Chronic Obstructive Pulmonary Disease (COPD) is a prevalent and debilitating chronic lung condition characterized by the obstruction of airflow from the lungs and additional respiratory symptoms including coughing, sputum production, and dyspnea. COPD typically develops over years of exposure to noxious particles or gasses, most commonly from cigarette smoke, although other environmental and genetic factors can also contribute. The disease is progressive in nature and presents with periodic exacerbations of symptoms, leading to irreversible damage to the airways and lung tissue, ultimately impairing respiratory function and quality of life.

COPD represents a significant public health burden globally, with millions of individuals affected and substantial associated morbidity, mortality, and healthcare costs. According to findings from The World Health Organization (WHO), approximately 210 million individuals suffer from COPD across the globe, with the disease being the fourth most common cause of death worldwide. In Europe, approximately 10% of the population is affected by COPD, with a higher occurrence in men compared to women, particularly in the elderly population, and is collectively responsible for 80% of deaths within the region (Workgroup of the Clinical Practice Guideline for the Treatment of Patients with Chronic Obstructive Pulmonary Disease [COPD], 2012). In 2011, COPD imposed a direct total cost of €23.3 billion, and an indirect total cost of €141.4 billion within Europe (Nielsen et al., 2009). The primary cost-driving factors linked to COPD include hospitalizations, accounting for 40-45% of expenses, and medication costs, comprising 25-35% (Nielsen et al., 2009). These expenditures are primarily incurred by patients experiencing respiratory failure, necessitating home oxygen therapy. A distinct correlation between disease severity and associated costs has been established, wherein the most severe cases of COPD inflict notably higher expenses often up to fourfold (Nielsen et al., 2009).

Within Spain, the estimated prevalence of COPD among adults aged 40-80 years stands at 10.2%, notably differing between genders with rates reported at 15.1% in men and 5.7% in women (Epidemiologic Study of COPD in Spain, 2007). While variations are observed across different geographic regions, COPD is the most common cause of chronic respiratory failure in Spain and is the fifth cause of death among men, and the seventh for women (Epidemiologic Study of COPD in Spain, 2007).

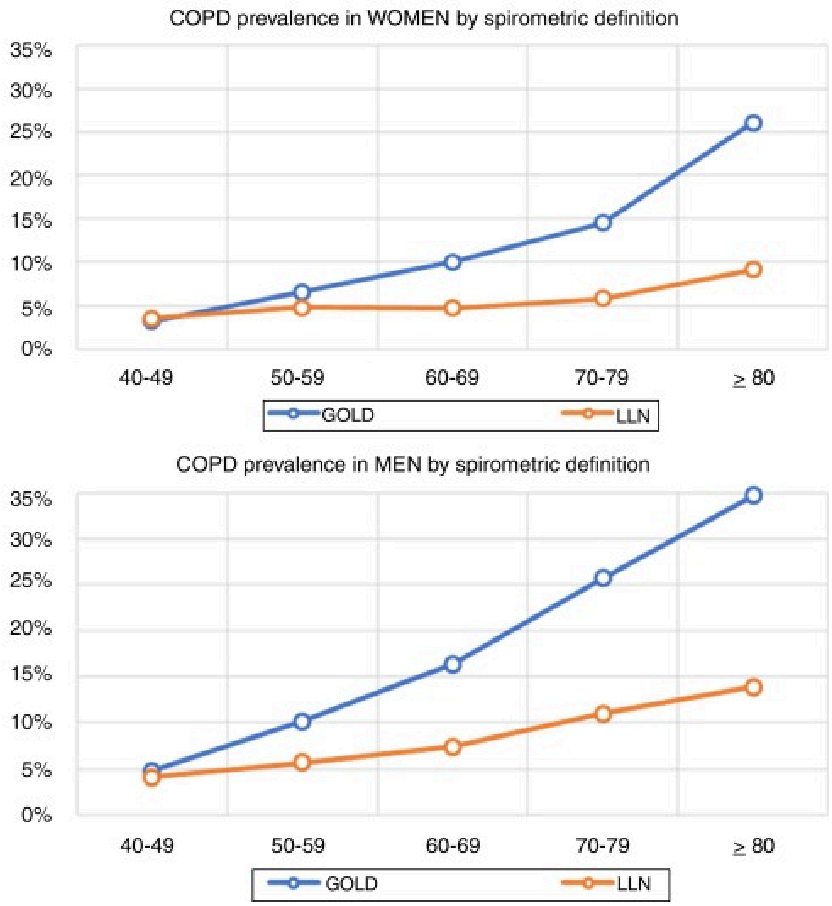
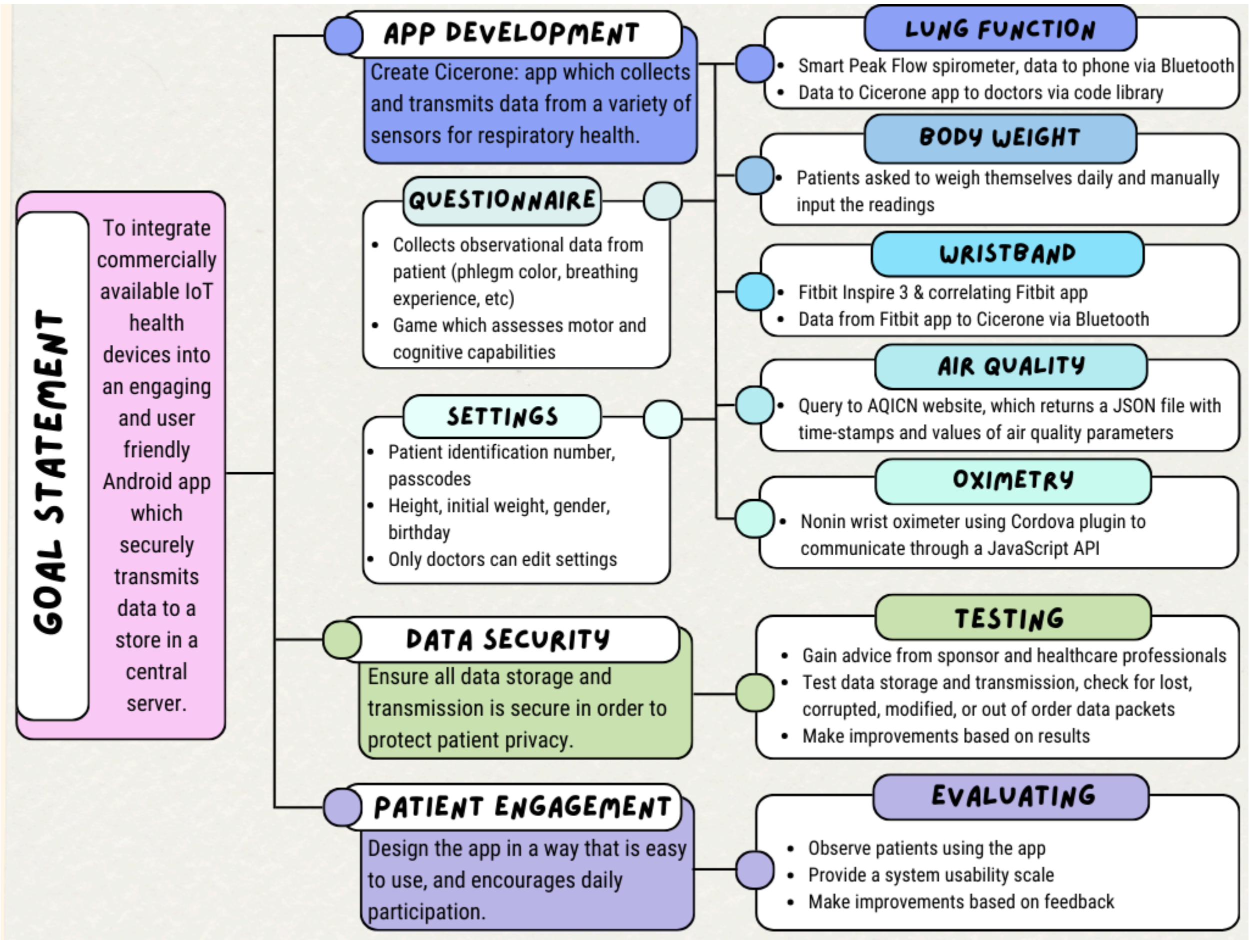


Figure 4. Prevalence of COPD by age and sex in Spain (2020).

According to data obtained from the 1987 National and Andalusian Health Surveys, the province of Cádiz exhibited a smoking prevalence of 42.9%, surpassing the Andalusian average by four points, which stood at 38.9% during that period. Particularly among men, tobacco consumption reached 67% in 1987, marking an 8-point difference from the male Andalusian average of 59% (Sistema Sanitario Público de Andalucía, 2005). Increased tobacco usage by males within the province is reflected by the mortality rate of 36.2%, which is notably higher than that of Andalusia and the rest of Spain (Epidemiologic Study of COPD in Spain, 2007). The 1980s marked a period of intense industrial activity for Cadiz, resulting in increased exposure to vapors, gasses, fumes, dust, and other toxins. Considering that it may take more than 30 or 40 years for the effects of risk factors to manifest as COPD, modern day Cádiz is evidently facing the repercussions of elevated levels of smoking and industrialization in the 80s (Epidemiologic Study of COPD in Spain, 2007).

3. Methodology: Creating an Application for Aggregating Data from Respiratory IoT Devices



GOAL STATEMENT

To integrate commercially available IoT health devices into an engaging and user friendly Android app which securely transmits data to a store in a central server.

APP DEVELOPMENT

Create Cicerone: app which collects and transmits data from a variety of sensors for respiratory health.

QUESTIONNAIRE

- Collects observational data from patient (phlegm color, breathing experience, etc)
- Game which assesses motor and cognitive capabilities

SETTINGS

- Patient identification number, passcodes
- Height, initial weight, gender, birthday
- Only doctors can edit settings

LUNG FUNCTION

- Smart Peak Flow spirometer, data to phone via Bluetooth
- Data to Cicerone app to doctors via code library

BODY WEIGHT

- Patients asked to weigh themselves daily and manually input the readings

WRISTBAND

- Fitbit Inspire 3 & correlating Fitbit app
- Data from Fitbit app to Cicerone via Bluetooth

AIR QUALITY

- Query to AQICN website, which returns a JSON file with time-stamps and values of air quality parameters

OXIMETRY

- Nonin wrist oximeter using Cordova plugin to communicate through a JavaScript API

DATA SECURITY

Ensure all data storage and transmission is secure in order to protect patient privacy.

TESTING

- Gain advice from sponsor and healthcare professionals
- Test data storage and transmission, check for lost, corrupted, modified, or out of order data packets
- Make improvements based on results

PATIENT ENGAGEMENT

Design the app in a way that is easy to use, and encourages daily participation.

EVALUATING

- Observe patients using the app
- Provide a system usability scale
- Make improvements based on feedback

Figure 5. Visual outline of methodology

Goal Statement

Our project aimed to integrate commercially available IoT health devices into an engaging Android app, which displayed data in a comprehensible manner for the patient, and securely transmitted it to a store in a central server. This data would then be accessible to researchers and medical professionals for the development of AI based models for assessing respiratory health. Respiratory telehealth systems have the potential to reduce hospitalizations and costs of treatment, increasing the accessibility and efficacy of healthcare. We aimed to accomplish this goal by addressing the following objectives:

1. Developed a prototype of an app containing modules relating to sensors for gathering biomedical data to characterize patient respiratory health.
2. Stored patient data within a central server, and securely shared with authorized researchers and healthcare professionals.
3. Performed system usability testing and generated recommendations for improvements.

3.1 App Development

To analyze the patient's respiratory health, the application utilized six differing modules of assessment: health questionnaire, lung function, weight, wristband data, and outdoor air quality. Each of these modules provided valuable information regarding patient treatment, and allowed for the training and validation of personalized AI-based models for prediction of respiratory exacerbations (Sànchez-Morillo, 2015). Patients in the later clinical trial will be given an informed consent form regarding the app to ensure they understood the purpose of the app and potential risks involved in sharing data (see Appendix D).

Questionnaire

The patients will be asked to complete a daily questionnaire (Appendix A), which provided information not gathered by the sensors. The sponsor for the project wrote these questions which were designed and validated as a part of a previous research project on both chronic obstructive pulmonary disease (COPD) and asthma. The questionnaire was complemented with some simple games, aimed to assess the cognitive status of the patient.

Spirometry

Lung function was assessed through the Smart Peak Flow device. The peak flow meter transmitted data to the patient's phone wirelessly through Bluetooth. The data acquired from the peak flow meter was analyzed by the app, allowing lung functioning to be assessed. A "library" supplied by our sponsor provided the necessary communication mechanisms that were implemented between the sensor and app to calibrate the instrument and record data. In HIT, a code library consists of pre-built software components, modules, or scripts that developers can utilize to implement specific functionalities related to data collection, sharing, or storage. These libraries contained code for interoperability standards, data exchange protocols, security mechanisms, data processing algorithms, and more. A non-disclosure agreement (NDA) was signed in order to access the library, given the SmartPeakFlow company has provided a time limited license to the sponsor.

Figure 6. Courtesy of SmartPeakFLow (https://smartpeakflow.com/).

Scale

Patient body weight provided important information in analyzing respiratory health. Obesity is a large contributing factor to breathing problems, and rapid fluctuations in weight could be indicative of a drastic health change. Our app contained a module for the patient to manually enter their weight from a personal scale daily.

Wristband

Respiratory monitoring in our app is supplemented with data regarding a patient's pulse and activity habits, each of which could be measured in smartwatches. Our sponsor selected the Fitbit Inspire 3 as the first watch model to be compatible with our app. Data from the watch could not be directly integrated into the app as initially planned, however we kept the functionality offered in the app provided by our sponsor. That is, the wristband module activated Bluetooth in the mobile device and launched the Fitbit app in the background. The data could then be continuously sent from the Fitbit app to the app. For the initial testing of the app, our sponsor set up a temporary system for his watch data, in which his data was sent to a server, which our app then pulled data from.

Figure 7. The Fitbit Inspire 3 wristband. Courtesy of Fitbit.

Oximetry

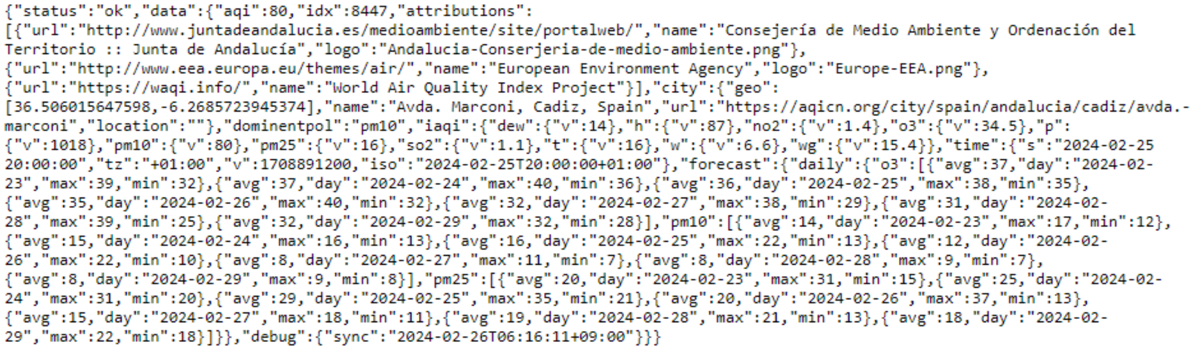
Pulse oximetry was a method used to monitor a patient's blood oxygen saturation, revealing an important method of evaluating patient lung efficacy. Our sponsor had asked us to add this component of the app only if we had time, but we unfortunately were unable to carry out our proposal, which had been included in the recommendations section.

Air Quality

Air quality was another key element of respiratory telemonitoring. Areas with poor air quality could greatly increase the risk to patients with chronic respiratory conditions. The website aqicn.org was used to access outdoor air quality information data for Cadiz, Spain (https://aqicn.org/city/spain/andalucia/cadiz/avda.-marconi/) which presented the following air quality parameters:

- AQI (air quality index)
- PM2.5 (fine particulate matter)
- PM10 (respirable particulate matter)
- O3 (ozone)
- NO2 (nitrogen dioxide)
- SO2 (sulfur dioxide)
- Pressure
- Humidity
- Wind

The air quality data was extracted from the website using regular expressions. A daily query with a specific token to the AQICN website returned a JSON file with timestamps and values of the parameters mentioned above. Figure 3 shows an example of a returned JSON.



```
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{"url":"https://waqi.info/","name":"World Air Quality Index Project"}],"city":{"geo":
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marconi","location":""},"dominentpol":"pm10","iaqi":{"dew":{"v":14},"h":{"v":87},"no2":{"v":1.4},"o3":{"v":34.5},"p":
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29","max":22,"min":18}]}},"debug":{"sync":"2024-02-26T06:16:11+09:00"}}}
```

Figure 8. JSON file with information about the air quality measured by the station located at Cadiz, Spain.

The air quality data would be transmitted to the central server when the app connected, using a specific HTTP POST request provided by our sponsor. The message format contained a timestamp, location, and the measured values for each parameter. This data allowed for the analysis of correlations between air quality and the patient's condition over time. This feature provided users and healthcare providers with easily accessible outdoor air quality data that could influence respiratory health. Likewise, clear visualizations and historical trend data increased patient engagement and understanding.

Settings

The settings screen allowed privileged users to configure several app parameters. The app connected to a central server to transmit health data. During the app customization for each patient, the IP address and port of the remote server were set. In addition, upon first opening the app, doctors or caregivers entered patient gender, height, initial weight, and date of birth. Healthcare providers were able to reset these parameters if needed, but patients could not alter them in order to maintain data integrity. These user parameters allowed the app to accurately interpret health data from IoT devices. Several app settings were configurable only by healthcare professionals due to privacy and security considerations. These included the user ID, healthcare provider assignments, and data-sharing permissions. Clinicians and researchers logged in with secure credentials to modify these sensitive settings. Restricting access prevented patients from tampering with settings that determined how their health information is managed.

3.2 Securely Storing and Sharing Respiratory Data

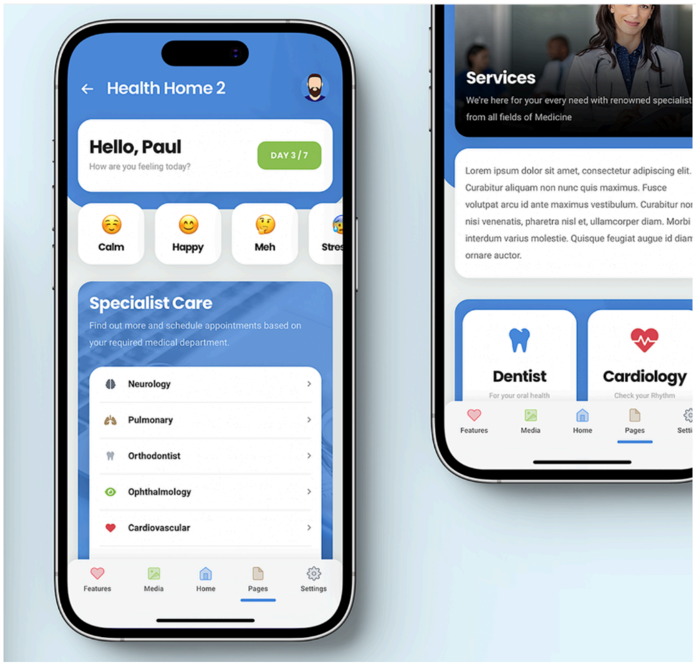
The sensors used to measure patient data had to securely transmit the data to a centralized server before being transmitted to the mobile device and app. We had a basic understanding of secure data transmission, utilizing Transmission Control Protocol (TCP), HTTPS, and other general security protocols. However, we did not use any specific procedures for secure transmission. Accordingly, the team first researched techniques to securely transmit data between sensors and a centralized server and between a centralized server and an Android app. This research provided us with a basic understanding of the means to transmit data securely. Our project group looked at our sponsor’s existing code for guidance, as he had been working with IoT devices and data being sent to a centralized server for many years, he had prior knowledge of effective transmission security measures.

Our group focused our research on the specific requirements for data transmission or began implementing the HTTP POST services for secure data transmission immediately.

Using Professor Sanchez's answers to the interview questions and through research of our own we put our transmission protocol through a series of tests. Some of these tests we administered are checking that the data packets arrived at the centralized server through queries, ensuring no packets were lost, corrupted, modified, or out of order. Then we checked for the same requirements for the data arriving at the app. Based on those test results, we either fixed our bugs and tested again or continued implementing the rest of our project. In any case, specific security mechanisms for the HTTP APIs are necessary. Their development is outside our objectives due to the limited time available.

3.3 Assessment of System Usability

For the initial phase of this project, the app provided by our sponsor operated without allowing patients to view their results on the dashboard. This mode was useful for observational studies, where the patient could not receive feedback while using the application and sensors to maintain control of the experiment. Data was loaded via transmission from the IoT sensors to the app and manually (in the case of the scale and questionnaire) by the user. Elements of the dashboard included buttons related to the correlating apps for lung functioning (Smart Peakflow), the wristband (FitBit), air quality (AQICN website), and oximetry (NoninConnect), where patients could then view their data. The app prototype therefore functioned to allow patients to remotely access and understand their health data in the absence of a trained medical professional. This would allow for the adaptation of therapies according to the output of the AI models that would be developed in the future.



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Lorem ipsum dolor sit amet, consectetur adipiscing elit. Curabitur aliquam non nunc quis maximus. Fusce volutpat arcu id ante maximus vestibulum. Curabitur no nisi venenatis, pharetra nisl et, ullamcorper diam. Morbi interdum varius molestie. Quisque feugiat augue id diar ornare auctor.

Figure 9. Inspiration for app user interface.

To evaluate the usability and efficiency of the app as well as overall user satisfaction, a sample population was surveyed using The System Usability Scale (SUS) questionnaire (Appendix C). SUS is a question-based method that consists of a standardized ten-item scale to provide a global view of the usability of a system. Unfortunately, the clinical trial was to take place months after the conclusion of our part of the project, so we were unable to interact with the target population: patients with COPD living in Cadiz. However, app usability could still be evaluated to some degree from anyone's perspective, and so the sample population for the survey was college-aged students from 20-21 years of age from our cohort. Prior to interacting with the app, participants were given an overview of the context of the app's purpose as a platform for daily use, uniting data from various sensors and components of respiratory care for chronic obstructive pulmonary disease. A brief explanation of each of the modules and their functioning was given, mimicking how a doctor might explain the app to their patient for the first time. All participants interacted with the prototype for an equal amount of time before completing the questionnaire. Following the completion of the questionnaire, we posed additional follow up questions regarding specific features of the prototype to gain insight into how users felt about specific features of the app. Scores from each questionnaire were determined and evaluated per the SUS scoring procedure. In analyzing this data, we were able to gain a general understanding of the serviceability of the prototype as well as areas that may require further improvement or development. In the future clinical trial, the same system usability scale could be utilized to make additional adjustments to the app.

Additional Follow-Up Questions:

1. What specific features of the prototype did you find easy to use (and/or intuitive)?
2. What specific features of the prototype did you find difficult to use?
3. Do you feel the dashboard page provides a succinct summary of your relevant health information?

3.4 Stakeholder Summary

There were several stakeholders involved in this project, the main one being the patients with respiratory illnesses. The other stakeholders consisted of hospitals, doctors, nurses, caregivers, and the public administration. To build on our work, there will be a cohort of 25-30 patients in the field trial that will be conducted for nine months in September. We unfortunately were unable to interact with these patients and their doctors and nurses, but later this year, our sponsor will be involving them in the design of the app dashboard through interviews and user testing to get a better understanding of what is working and what areas need improvement in each iteration of the cycle of design. The main goal of our project was to develop tools to collect and aggregate data efficiently to help with the clinical trial. The trial will allow the gathering of data for AI models capable of personalizing to individual patients. These models will be evaluated in a second phase to assess their ability to contribute to the self-management of COPD or asthma, reduce the number of hospitalizations, and increase the quality of life, which will save money for both the patients and healthcare providers/hospitals. By the end of the project, our working prototype would have facilitated secure data transmission with the central server, potentially benefiting communities in Spain by enhancing healthcare accessibility and efficiency through circumventing the decentralized healthcare system.

4. Results and Discussion

The initial goal of our project was to integrate commercially available IoT health devices into an engaging and user-friendly Android app. We aimed to display data in a comprehensible manner for the patient, and securely transmit it to a store in a central server, accessible to researchers and medical professionals for the development of AI models for assessing and predicting respiratory health.

This section will discuss the progress made towards each of these objectives in coding the app. The starting point was the existing CICERONE app, whose source code was provided by our sponsor. In this app, the questionnaire module, the customization and configuration module, the weight reading module, and the FITBIT application management module were implemented. Our goal was to implement further developments to finalize the app, which will be reviewed in our project recommendations.

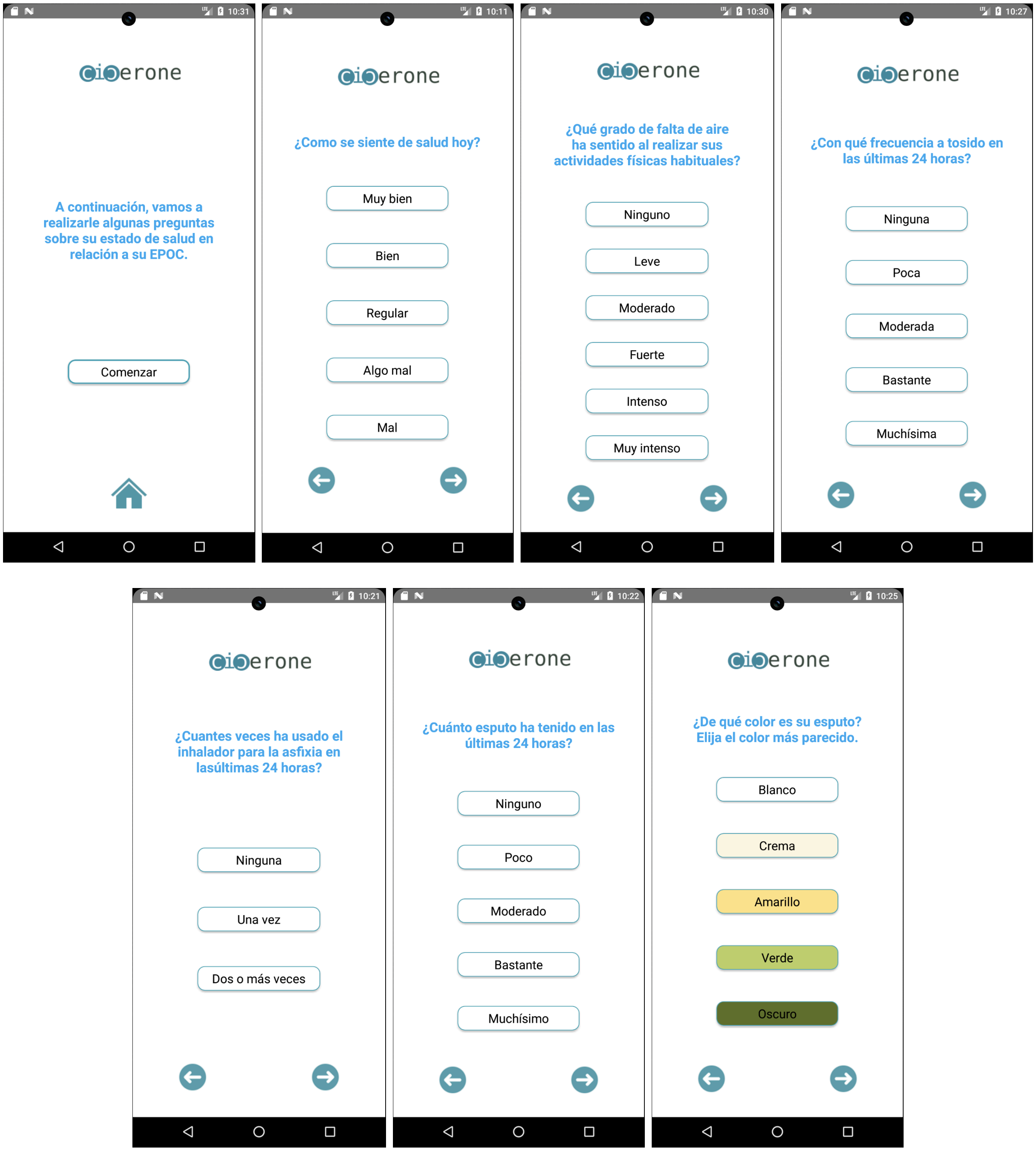
4.1 App Development

We worked on modifying the CICERONE application to provide patient information. The evolved Cicerone app contains six modules to assess respiratory health: the health questionnaire, lung function, weight, wristband data, oximetry, and outdoor air quality. An informed consent form was written to provide to patients in the future clinical trial so as to ensure their understanding of the purpose of the app, and inform them of potential risks involved in sharing data (see Appendix D).

Figure 10: Home page

Questionnaire

A daily questionnaire was integrated into the app (Appendix A), which provides information not gathered by the sensors. The sponsor for the project created and tested this questionnaire for a previous research project on both chronic obstructive pulmonary disease (COPD) and asthma (Sanchez-Morillo et al, 2015). The questionnaire asks basic questions regarding health observations the patient can easily make on their own, such as the color of their phlegm, or the number of times they have used their inhaler. These qualitative data observations are stored in the app and sent to the centralized server created by our sponsor to be viewed by the appropriate caregivers, as this data is essential to inform both doctors and patients of respiratory health. Typically, such qualitative observations are collected in conversation in a clinical setting, and so daily data provides a far more detailed view of each patient's respiratory status. Additionally, this qualitative data can be used to train AI models to better predict oncoming respiratory exacerbations.



A continuación, vamos a realizarle algunas preguntas sobre su estado de salud en relación a su EPOC.

¿Como se siente de salud hoy?

¿Qué grado de falta de aire ha sentido al realizar sus actividades físicas habituales?

¿Con qué frecuencia a tosido en las últimas 24 horas?

¿Cuantes veces ha usado el inhalador para la asfixia en lasúltimas 24 horas?

¿Cuánto esputo ha tenido en las últimas 24 horas?

¿De qué color es su esputo? Elija el color más parecido.

Figure 11: Questionnaire page

The questionnaire was followed by some simple games, aimed to assess the cognitive and tactile status of the patient. The first two games, designed by our sponsor, ask the patient to tap squares which appear on the screen, and to draw a circle in the center of the screen with an offset touch. The final game was designed by our team, and asks the patient to trace a maze with their finger as quickly as possible. The app keeps track of how long it takes patients to complete the maze, as well as how many times their finger leaves the boundaries of the maze. The code for this game was developed, but it has yet to be integrated into the app.

Assessing the cognitive and tactile capabilities of each patient through this game is important to provide a full perspective on patient health. Often, patients may not notice worsening slowness or shakiness in their movements, which can be indicative of a downturn in respiratory health. The game indirectly assesses patient tactile capability, allowing data to be collected and compared on a daily basis to better inform doctors, researchers, and to enhance predictive and analytic capabilities of AI technologies.

Spirometry

We aimed to assess lung function through the Smart PeakFlow spirometry device, which transmitted blood oxygen saturation data to the patient's phone wirelessly through bluetooth. Typically, the PeakFlow spirometer connects to an app created by the Smart PeakFlow company. However, to simplify respiratory care for both the patient and their healthcare providers, we aimed to directly incorporate the sensor readings directly into the Cicerone app so as to aggregate peak flow data with the other aforementioned sensors. This data is then securely transmitted from the app to the server to be viewed by researchers and clinicians. In order to carry out the data transfer process, we worked to incorporate the software components of the provided library into the Cicerone app, including code for interoperability standards, methods of data exchange and secure transfer, data processing algorithms, and sensor calibration mechanisms. Though more work must be done to ensure full functioning of this module, progress was made in implementing the PeakFlow sensor and debugging the code. Therefore, for the future clinical trial, patients will be able to use the peak flow device at any time. Data will automatically upload into the Cicerone app for the user to view and to the central server for their doctors and researchers to utilize. This data can also be used in strengthening AI predictions of worsening respiratory health status.

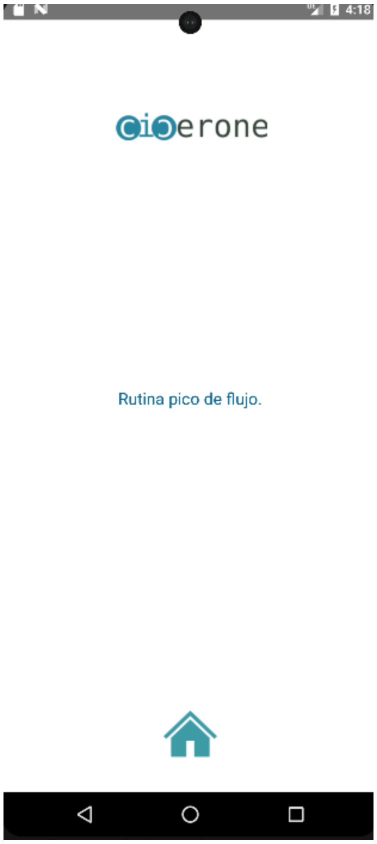

Rutina pico de flujo.

Figure 12: Peak flow page

Scale

The Cicerone app contains a module for the patient to manually enter their weight from their personal scale on a daily basis. The patient simply selects the button titled “Peso,” meaning “Weight,” and inputs the reading from their scale. These readings are sent on a daily basis to the central server to be accessed by the designated clinicians and researchers. This enhances AI predictive capabilities and allows for doctors to track weight fluctuations in their patients, which could be indicative of worsening respiratory health.

Acepte la activación de Bluetooth que aparecerá a continuación. Suba al peso sin ropa y pulse aceptar.

La aplicación Fitbit no está instalada

Figure 13: Scale page

Wristband

Fitbit was selected as the first device brand to connect to the Cicerone app. The app allows the wristband module to activate Bluetooth, which launches the Fitbit app in the background upon opening the Cicerone app. The data will then be sent continuously from the Fitbit app to the central server to be viewed by doctors and researchers, then from the server to the Cicerone app to be viewed by patients. This mechanism still needs to be fully debugged for the clinical trial to ensure complete functioning, though the server created by our sponsor provides a temporary solution. The button for the wristband module takes the patients directly to the Fitbit app, similar to the lung functioning module. Data from smart watches allows for doctors, researchers, and AI platforms to analyze connections between patient respiratory health and their heart rate and activity habits, allowing for better predictive foresight, preventative treatment, and detailed lifestyle recommendations.

Coloque su móvil cerca de la pulsera. A continuación, acepte la activación de Bluetooth para enviar los datos. Se abrirá la aplicación para el envío de los datos. Pasado 1 minuto, puede cerrar la aplicación FITBIT o regresar a CICERONE pulsando el botón ATRAS.

Figure 14: Fitbit Page

Oximetry

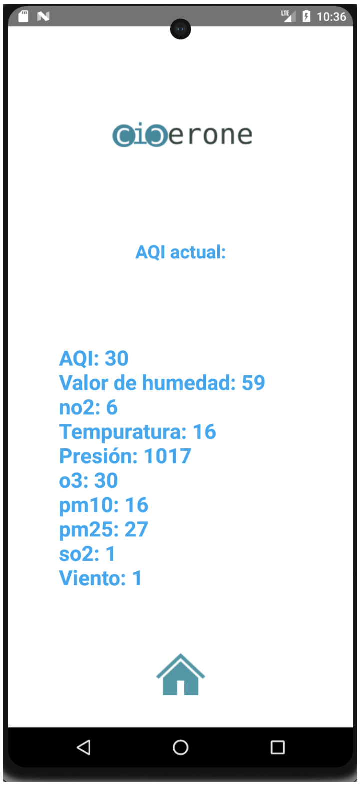
Due to time constraints in our project, we were unable to make significant progress on implementing the Nonin WristOx pulse oximeter. However, our initial plans for incorporation will be included in the later recommendations section, as our sponsor will continue to follow a similar plan to complete the oximetry module in time for his clinical trial in September.

Air Quality

Outdoor air quality data for Cadiz, Spain was accessed on the website aqicn.org (https://aqicn.org/city/spain/andalucia/cadiz/avda.-marconi/) which presents the following air quality parameters:

- AQI (air quality index)
- PM2.5 (fine particulate matter)
- PM10 (respirable particulate matter)
- O_3 (ozone)
- NO_2 (nitrogen dioxide)
- SO_2 (sulfur dioxide)
- Pressure
- Humidity
- Wind

Daily air quality data was extracted from the aforementioned website using regular expressions. With the help of our sponsor, we created a daily query with a specific token to the AQICN website when the air quality module is opened. This returns a JSON file with time-stamps, locations, and values of the parameters mentioned above. This data is parsed to a simple format and transmitted to the central server, using an specific HTTP POST request provided by our sponsor. Once the data is in the server, it can be viewed by the appropriate researchers and healthcare providers. The data is also made viewable on the air quality page so that patients can also check their local air quality. If patients are informed of air quality in their area, they can make more informed decisions about their daily habits in terms of exertive activity and time spent outside. Collection of air quality data also allows for the analysis of correlations between air quality and the patient's condition over time and further informs AI platforms, enhancing their predictive capabilities.



AQI actual:

AQI: 30
Valor de humedad: 59
no2: 6
Tempuratura: 16
Presión: 1017
o3: 30
pm10: 16
pm25: 27
so2: 1
Viento: 1

Figure 15: Air Quality Page

Settings

The settings for the Cicerone app allow the app to be individualized to each patient. For testing, we use the infrastructure created by the sponsor's research group to store and transmit patient health data to healthcare professionals. During the initial app customization for each patient, the IP address and port of the remote server is set. These user parameters allow the app to accurately interpret health data from IoT devices. Several other app settings are configurable only by healthcare professionals due to privacy and security considerations. These include the user ID, healthcare provider assignments, and data-sharing permissions. Clinicians and researchers will log in with secure credentials to modify these sensitive settings. Restricting access prevents patients from accidentally altering settings that determine how their health information is managed.

4.2 Securely Storing and Sharing Respiratory Data

The overall goal of our project was to aggregate data from a variety of sensors into one application and server to be viewed and used by patients and their healthcare providers, but an essential element to this process was data security. The first step in collecting this data was to securely transmit the data collected in the app (the questionnaire, tactility games, and weight) and from the sensors (air quality, Fitbit, and peak flow) into a protected central server. The specific methods in collecting and sending each piece of data are outlined in the previous section. Additionally, the centralized server was created by our sponsor, acting as a secure platform which stores and protects patient data. The server ensured that only healthcare providers and researchers with the proper permissions can access the appropriate patient data through protective passkeys.

4.3 Enhancing Patient Engagement

One of our primary objectives was to create an app that is both easy to use and provides an engaging user experience. These qualities are integral to health apps, as they must cater to a wide range of patients with varying levels of experience with technology. Additionally, users should feel encouraged to use the app on a daily basis so their health can be completely and accurately evaluated by their healthcare providers. After completing user testing, during which we provided our participants with a system usability scale (Appendix C), we concluded that we were successful in creating a user-friendly and engaging app. It should be noted that our participants are college students in our cohort. They were asked to answer from the perspective of using the Cicerone app on a daily basis as advised by their doctor, but ultimately, the sample population remains younger than the target population, and does not have COPD. Considering this, the results of our user testing are summarized and discussed below:

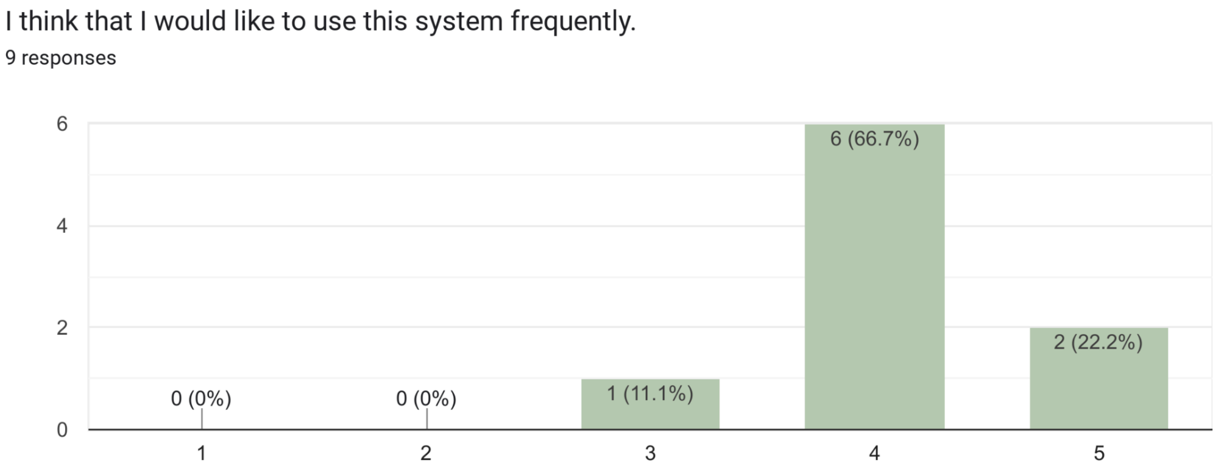


Figure 16: Responses of question 1 from survey

The responses in Figure 19 reflect a positive attitude towards using the Cicerone app frequently, with 66.7% of users rating a 4 and 22.2% rating a 5. This indicates that the current app prototype is engaging and appealing enough for use on a daily basis. 11.1% of users responded with a 3, indicating that there are still changes to be made on the interface to improve user experience. Considering our population is younger than the typical COPD patient, they may be more comfortable with technology and therefore more willing to use an app for health monitoring. However, as our population does not have experience monitoring a chronic respiratory illness, our subjects may be less understanding of the potential benefits of the app.

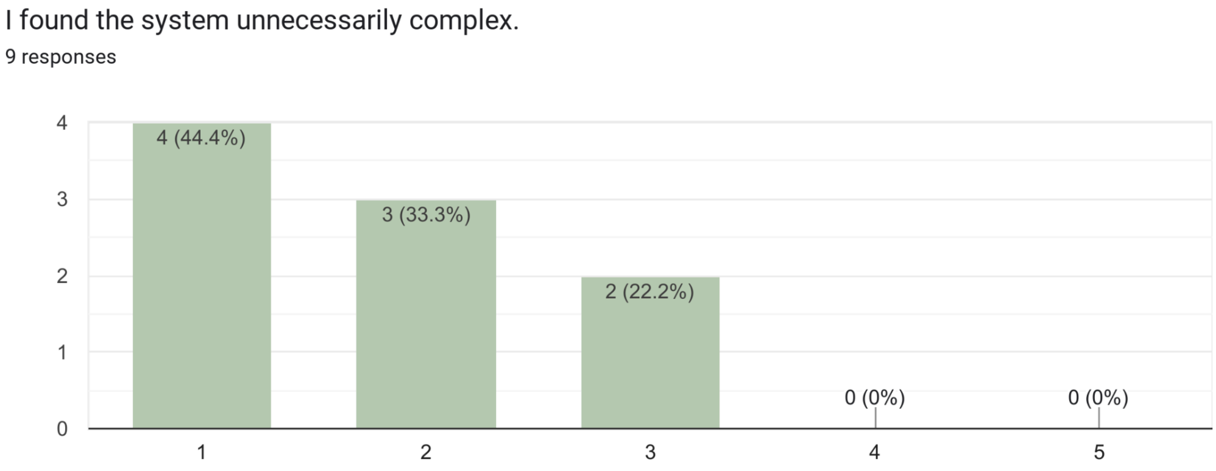


Figure 17: Responses of question 2 from survey

Based on the responses displayed in Figure 20, most users did not find the Cicerone app very complex, with 44.4% rating complexity at a 1, 33.3% rating a 2, and 22.2% rating a 3. These results do, however, indicate there are further simplifications that could be made to the app. The sample population is younger and more attune to using technologies such as the app and related sensors, so their indication of complexity may have an even higher impact on the target population of users.

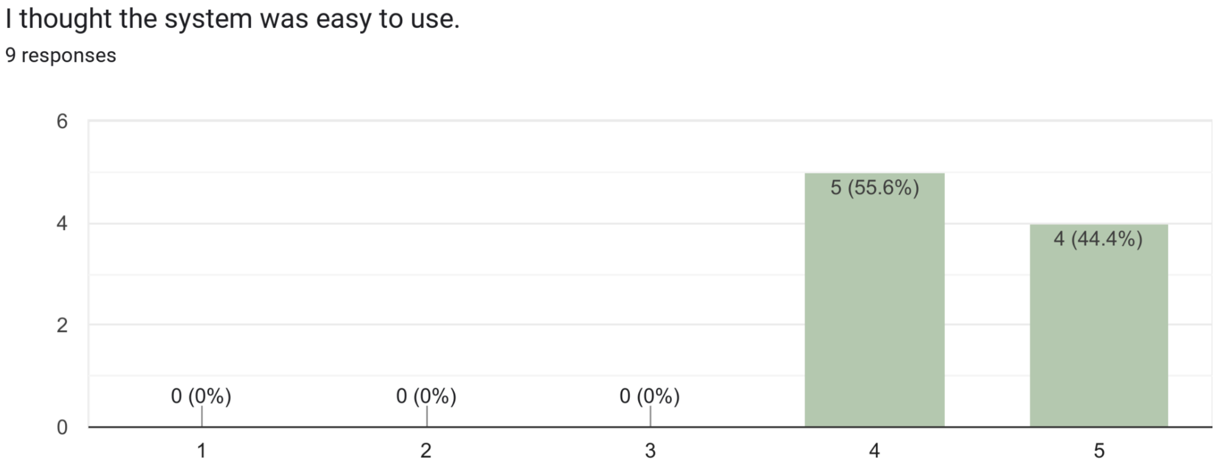


Figure 18: Responses of question 3 from survey

The responses in Figure 21 reflect that users mostly find the Cicerone app to be easy to use, with 55.6% of users ranking the app at a 4, and 44.4% at a 5. Again, it should be noted that the sample population is of a younger, more technologically savvy generation, so they may find the app to be more intuitive than the target population. Therefore, it is ideal that the app be made as easy as possible, so further renditions should search for avenues of improvement in user-friendliness.

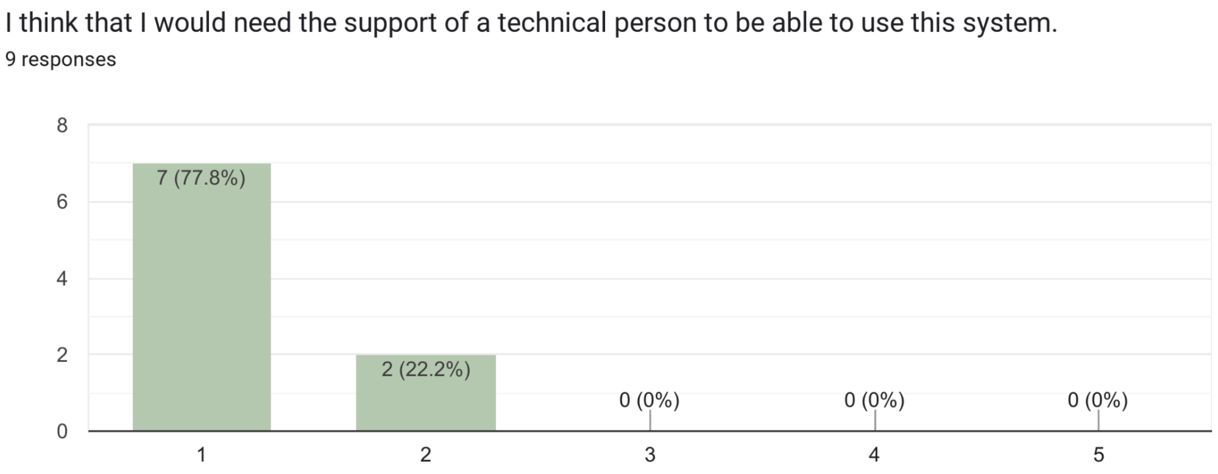


Figure 19: Responses from question 4 of survey

As shown in Figure 22, when our sample population was asked if they might need the support of a technical person to be able to use the Cicerone app, 77.8 % rated a 1, meaning they did not feel they would need any support. However, 22.2% rated a 2, showing that some users may need some technical support. One should note that for participants in the future clinical trial, setting up the app will take place in person, with a clinician with experience with the app. Therefore, with preliminary explanations, it is hopeful that users may not require much further assistance with the app. Again, our survey sample may be a more technologically comfortable population than the target, and so further simplifications should be made to ensure ease of use.

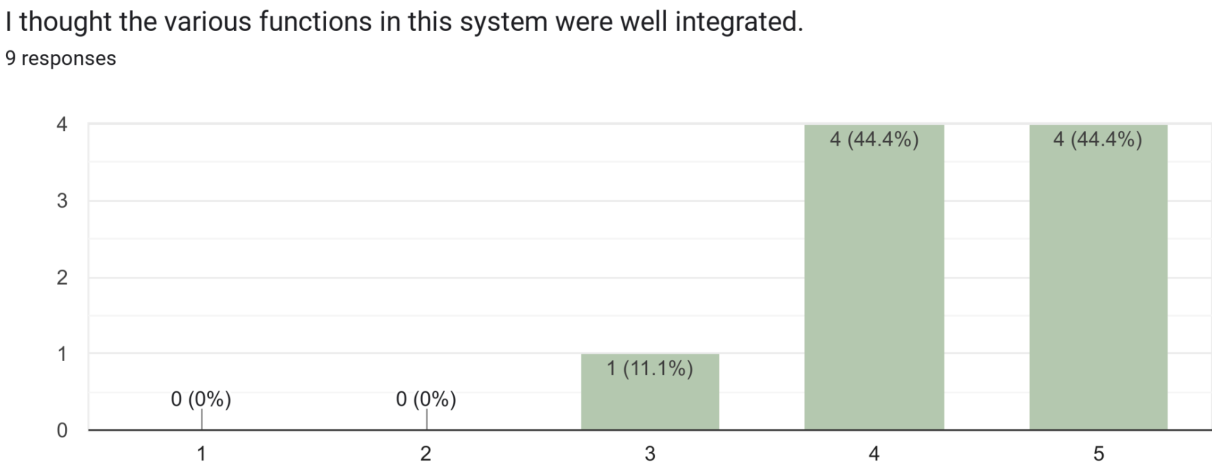


Figure 20: Responses from question 5 of survey

Figure 23 shows that participants mostly found the Cicerone app to be well-integrated, with 44.4% rating it a 4 and 5 respectively, and 11.1% rating a 3. This points to some users struggling with aspects of the Cicerone application. Occasionally during user testing, some inconsistencies in the app were observed, such as random crashes. Therefore, some users may have had a less ideal app experience, showing that there are errors to be ironed out in the code. App debugging should be completed prior to the clinical trial in September so as to ensure users do not encounter any difficulties with the app functioning.

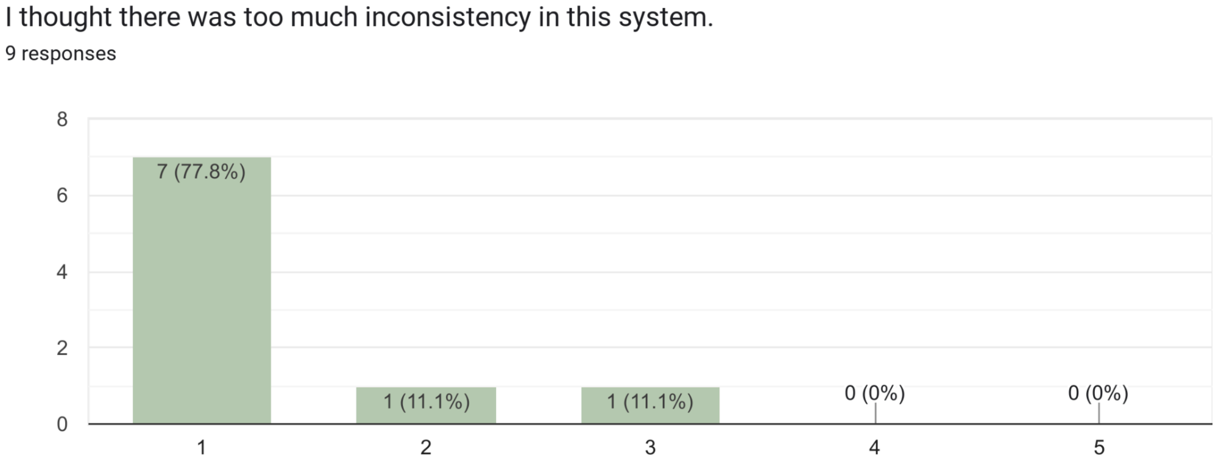
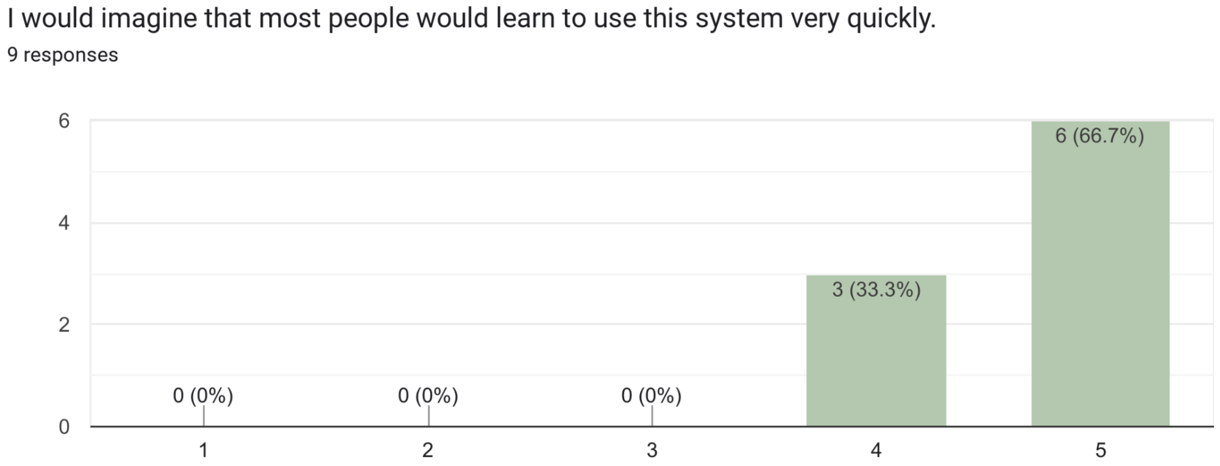


Figure 21: Responses from question 6 of survey

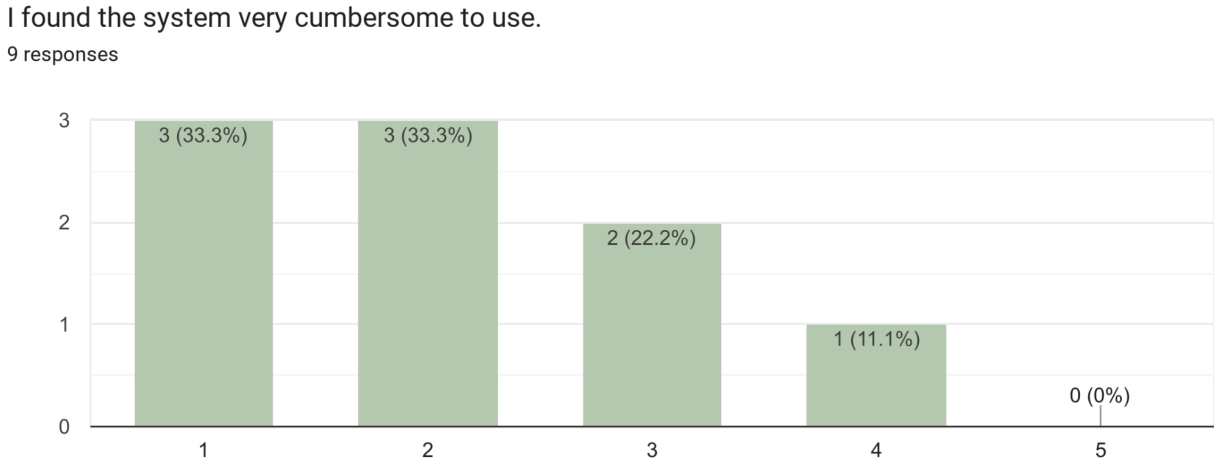
Figure 24 reflects results which point to some users experiencing inconsistencies in the system, with 11.1% ranking a 2 and 3 respectively, though most did not experience any inconsistencies, with 77.8% rating a 1. As was previously mentioned, a few system crashes were observed during user testing, which could explain some of the rankings which indicate participants did experience some inconsistencies. Before the clinical trial in September, it will be essential to ensure that all aspects of the Cicerone app work consistently without errors.


I would imagine that most people would learn to use this system very quickly.

9 responses

Figure 22: Responses of question 7 from survey

The responses shown in Figure 25 signify that the sample population feels confident that future users would be able to learn to use the Cicerone app quickly, with 66.7% ranking a 5 and 33.3% ranking 4. Of course, there are still parts of the app that could be simplified or further explained to ensure maximized ease of use, especially considering our older target population; suggestions for such adaptations will be discussed in the recommendations section of this paper.


I found the system very cumbersome to use.

9 responses

Figure 23: Responses of question 8 from survey

Figure 26 reflects a variety of responses when users were asked if they found the system “cumbersome” to use, with 33.3% ranking a 1 and 2 respectively, 22.2% a 3, and 11.1% a 4. These results imply that while some users did not feel inconvenienced by the app, others did feel that the app was somewhat of a hassle. With the Cicerone app in its current state, some users may find daily use to be a bother. Therefore, recommendations to evolve the app will be provided, ensuring that the system is as streamlined as possible, and ideally more enjoyable to interact with.

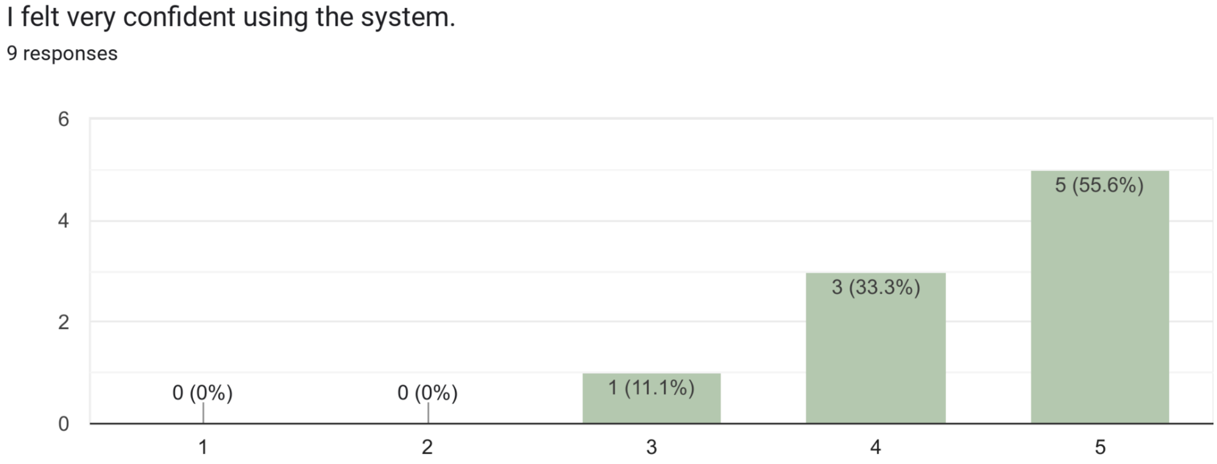


Figure 24: Responses of question 9 from survey

When the sample population was asked if they felt confident using the system, 55.6% rated a 5, 33.3% rated a 4, and 11.1% rated a 3, as can be seen in Figure 27. These responses convey fairly high user confidence, though it should once again be considered that our sample population is far younger and potentially more comfortable with app technologies as compared to the target user base. With this in mind, recommendations for simplification and user support will follow.

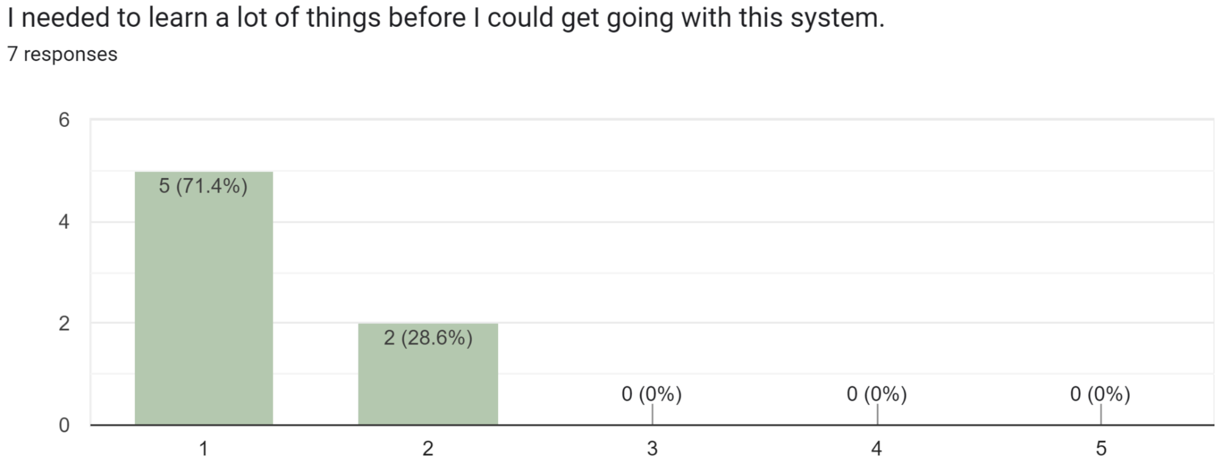


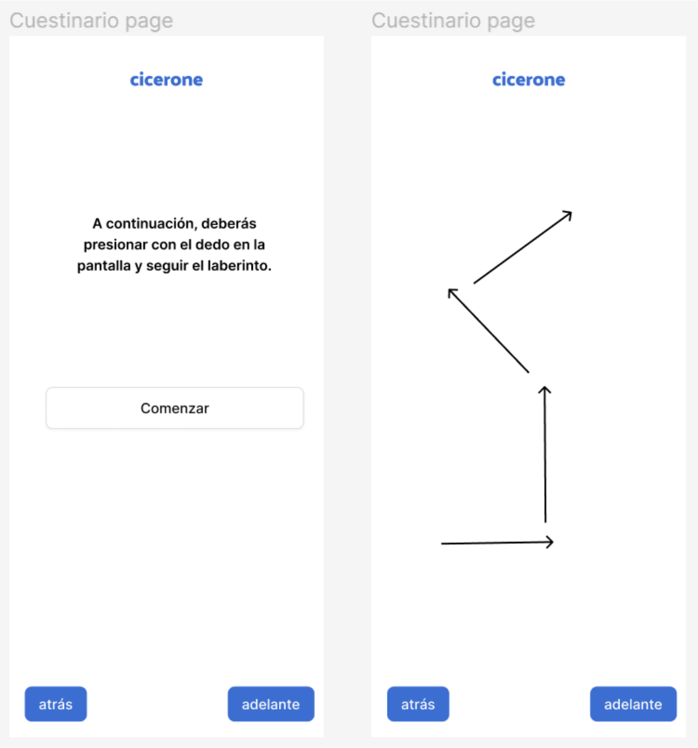
Figure 25: Responses from question 10 of survey

The results displayed in Figure 28 reflect that the sample population felt comfortable with the amount of instruction they were provided prior to interacting with the app. Preceding each test, users were given a brief explanation of the functioning of each module of the Cicerone app, mimicking how a clinician might walk a patient through their first use of the system. Though the results from the sample population indicate users needed minimal assistance to start interacting with the system, the final rendition of the app should be as simplified as possible, and should contain resources for resolving lingering uncertainties.

5. Recommendations

App Functioning

While progress was made in most modules of the app, which include the daily questionnaire and tactile game, daily weight tracking, peak flow, air quality, and wristband data, there are still improvements to be made. The weight collection module, air quality module, and questionnaire are fully functioning. However, the last and most difficult tactile game, in which the user quickly traces a maze with their finger, still needs to be fully implemented into the final application. Though we wrote the code for the game, we were unable to overcome the errors in the final steps of adding the game to the end of the questionnaire. These errors should be eliminated prior to the clinical trial in order to ensure a full perspective of patient tactile capabilities is collected.



A continuación, deberás presionar con el dedo en la pantalla y seguir el laberinto.

Figure 26: Game portion of questionnaire cont.

The peak flow module was partially completed by our group. The various components of the library provided to us by our sponsor included interoperability standards, methods of data exchange and secure transfer, data processing algorithms, and sensor calibration mechanisms. We worked to integrate these components into the code for the Cicerone app, but there are still steps that need to be taken to ensure full functioning of each of these aspects.

The wristband module was also partially completed by our group, but due to time limitations, we were unable to create a visualization of the watch data in the app. In the future, the wristband module would be far more beneficial to patients if data from the watch could be summarized in a visual manner. Additionally, the module would have a greater impact on improving patient health if the app was to provide recommendations based on the readings of the wristband. For example, if pulse or blood pressure are high following strenuous activity, the app should notify the user that they may be in danger of an exacerbation of their respiratory illness and should rest.

The air quality module successfully queries the selected air quality website (aqicn.org), receives a JSON file, and visualizes the numerical data. Later on, the app could be programmed to recommend actions based on the air quality values. For example, during days with poor air quality, the app could notify the user to avoid spending long amounts of time outside, or to refrain from exercise until quality improves.

Oximetry

Unfortunately, due to time constraints, our group was unable to incorporate the oximetry module, but we were able to research the oximetry device- the Nonin WristOx 3150 wrist pulse oximeter. There are three major components related to oximetry in the Cicerone app: device integration, data collection and display, and error handling.

The oximeter would integrate with the mobile application using the Cordova plugin for Bluetooth Low Energy (BLE) peripherals. This would allow connection and communication with the device using a cross-platform JavaScript API. The Cicerone app would initiate a connection request to detect this bluetooth signal from the WristOx. Authentication would be handled using services and characteristics outlined in the device protocol provided. Once connected, the WristOx continuously streams oxygen saturation (SpO2) and pulse rate data through notification characteristics.

SpO2 and pulse rate values could be extracted from the raw data stream and displayed in the Oximetry module user interface in real-time updated graphs and info boxes. Accompanying explanatory text and visualizations would be included to aid patient understanding. The streamed data would be time-stamped on receipt and temporarily cached before transmission to the central server. Both raw data packets and processed SpO2/pulse readings would be stored to enable re-processing and verification if needed, allowing the app to handle connection losses and data transmission errors. Reconnection attempts would be made automatically before notifying the user, and any data gaps could be indicated in the graphs. Oximetry is an essential statistic in evaluating respiratory health, as a low oxygen saturation in the blood is a direct result of reduced breathing efficacy; therefore, the future inclusion of the oximetry module is necessary.

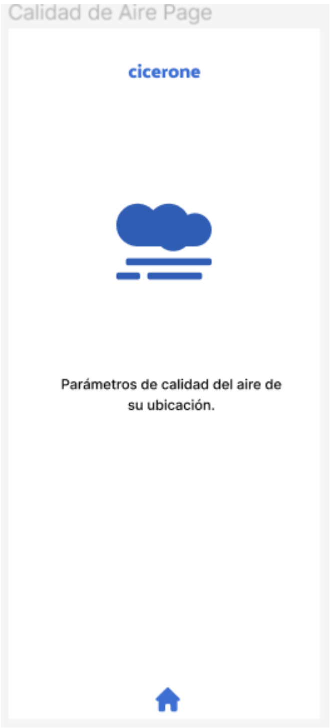
Usando el enchufe Cordova para periféricos bluetooth de baja energía, el oxímetro de pulso de muñeca Nonin Bluetooth WristOx 3150 se conectará a la aplicación móvil. Esto le permitirá ver datos de SpO2 y frecuencia del pulso en tiempo real.

Figure 27: Oximetry page

Indoor Air Quality

The quality of air in an individual's living environment greatly impacts one's respiratory health, especially those suffering from respiratory illnesses like COPD. While the current version of the Cicerone app has successfully included outdoor air quality parameters, indoor air quality measurements could provide monumental insight into patient living conditions. Fortunately, the sponsor's team has developed an IoT air-quality node for in-home use to be incorporated into future versions of the Cicerone app.

Modern developments in technology for air quality tracking in the home offer the opportunity for doctors to provide far more detailed lifestyle recommendations for those living with a respiratory illness. Patients with COPD are highly sensitive to conditions which healthy individuals may be unaffected by- for example, car exhaust may infiltrate rooms near a road, cooking could create fumes in and around the kitchen, or an older section of the house could have high particulate matter. Indoor air quality sensors could alert patients of these and other dangerous scenarios, as well as identify areas of the home where patients could go to avoid irritation of their condition. Healthcare providers could use indoor air quality data to recommend changes in daily lifestyle habits within the home, and AI could be trained to use this data to predict when a patient may experience an exacerbation of their respiratory illness. Therefore, it would be very beneficial to incorporate indoor air quality sensors as an additional module of the Cicerone application in future development.



Parámetros de calidad del aire de su ubicación.

Figure 28: Air Quality recommended page

App Engagement and Usability

Based on the results obtained from the system usability survey, the app in its current state could use improvements to ensure a positive user experience. The app should be as simple as possible, so it may be best to have data displayed on one screen, rather than having separate platforms to interact with each module (questionnaire, weight, wristband, spirometer, and air quality). We recommend adding the main statistics for each of these parameters to this central page, and then allowing an expansion of the module to show further data analysis and recommendations. Currently, when an activity is performed, the module turns a darker shade of gray. After user testing, it seemed most did not notice this feature, so we suggest having a checkbox on each module to show users when they have added a measurement or checked on their daily data. This would allow users and their caretakers to ensure they have collected all of the necessary statistics which allo w their doctor to gain a full perspective on their current health status. Considering the results of our system usability survey, there should also be avenues for assistance if the patient has any difficulty navigating the app. Currently, the help section of the app encourages users to reach out to their clinician with questions, but it would be more convenient for both parties to find an alternative solution. We recommend including an automated chat, where users can select common questions and be provided with instructions for use based on their needs.

Interoperability of Health Systems in Spain

Currently, each province in Spain runs their own independent health system, which results in a fractured network where doctors cannot access data from patients who live in different provinces. This was not part of the scope of our project, as we focused specifically on creating a workable prototype, but telemonitoring apps such as Cicerone would benefit greatly from a change in the structure of the Spanish health system. Telemonitoring apps provide a partial solution to this problem, as they are able to store important data on the patient's phone, and in secure servers operating outside of the health systems. However, it is still important for this issue to be addressed so telemonitoring data can be integrated into the Spanish health system to be accessed by all authorized doctors and researchers. It is essential for health data to be shared so that progress can be made in research, and so that patient history can be accessed and individuals can be properly cared for anywhere in Spain. The solution to this problem would come from the Spanish government introducing legislation that would make all the provinces into one centralized health system. Though this would be a complicated process, a systemic change would allow information to be shared more seamlessly and would help advance the field of healthcare as a whole.

Artificial Intelligence

Our work is in the context of a project led by our sponsor and aimed at the final training and validation of AI models to early detect deterioration episodes. The use of artificial intelligence in the analysis of respiratory data could provide innumerable benefits to doctors and patients alike. It is possible to train AI models to analyze correlations between patient symptoms and the measurements collected within each of the modules, which include blood-oxygen saturation from the spirometer, daily weight measurements, air quality specs, and pulse, heart rate, and movement data from the wristband. As AI learns from these relationships, it can predict what data patterns may cause an individual’s symptoms to worsen, as well as when an individual may be near experiencing an extreme exacerbation of their condition. With these predictive capabilities, AI could alarm patients, allowing them to make changes to their environment or activity levels to avoid worsened symptoms. Additionally, in cases where readings indicate imminent danger to the patient, AI could be used to identify when a patient should go to the hospital, allowing them to avoid emergency hospital transportations.

Avenues for Future Research Developments

Moving forward, the project's future directions entail a comprehensive approach aimed at enhancing stakeholder engagement, improving data collection, and maximizing the involvement of patients in the design of the application. This involves expanding collaboration with caregivers and public administration to develop a complete understanding of the needs of all stakeholders involved. Additionally, the project will focus on evaluating the long-term capability of self-management strategies through extended field trials and accurate assessment of their impact on reducing hospitalizations, improving quality of life, and minimizing healthcare costs. Furthermore, efforts will be directed towards ensuring scalability, interoperability, and data security of the developed prototype. By adhering to these future directions, the project aims to advance the field of respiratory illness management, ultimately leading to improved patient outcomes and reduced healthcare burdens.

6. Conclusions

In the context of advancing healthcare through technological innovation, the development and usage of telemonitoring applications for respiratory conditions emerge as a transformative solution. Our project emphasizes the important role of telemonitoring in reshaping patient care and their health management. Through the integration of Internet of Things (IoT) devices and innovative eHealth technologies, telemonitoring offers personalized and accessible healthcare, overcoming limitations of location and enabling real time monitoring analysis.

However, as highlighted by challenges observed in the Spanish healthcare system, the fostering of telemonitoring methods requires support in both the social and political environments. Dealing with restrictions such as limited awareness, financial constraints, and the necessity for thorough training shows why it is significant of collective efforts among policymakers, healthcare providers, and researchers. By utilizing telemonitoring technologies along with additional respiratory devices, we not only enhance the effectiveness of patient care but also lessen the burden on healthcare systems and workers.

Looking forward, our focus on patient engagement and the development of intuitive telemonitoring mobile applications represents a crucial step towards realizing the full potential of telemonitoring in respiratory care in a context of enormous socio-health relevance. By providing patients with access to their health data and helping people take action in the early phase, home telemonitoring has potential to promote a culture of self-care and allow individuals to manage their respiratory conditions efficiently. Through ongoing collaboration and technological innovation, we foresee a future where telemonitoring emerges as a foundation of respiratory healthcare, delivering benefits in terms of reduced hospitalizations, improved outcomes, and better quality of life for patients.

Appendix

A. Health Questionnaire

Bienvenido al proceso de consentimiento informado para Cicerone. Este documento está diseñado para brindarle información detallada sobre el propósito, los procedimientos, los riesgos, los beneficios y sus derechos relacionados con su participación en este programa. Léalo atentamente y no dude en hacer cualquier pregunta antes de continuar.

1. Propósito:

La aplicación de telemonitorización de salud respiratoria está diseñada para monitorear de forma remota su salud respiratoria, incluidos síntomas, signos vitales y otros datos de salud relevantes, para ayudar a controlar y mejorar su condición. Al utilizar esta aplicación, puede realizar un seguimiento de su estado de salud de manera más efectiva y comunicarse con sus proveedores de atención médica para un mejor manejo de su afección respiratoria.

2. Trámites:

Para participar en este programa, se le pedirá que descargue e instale la aplicación de telemonitoreo de salud respiratoria en su teléfono inteligente o tableta. Luego, se le guiará a través del proceso de configuración de su perfil e ingresará información de salud relevante, incluidos síntomas, uso de medicamentos y signos vitales como saturación de oxígeno y lecturas de flujo máximo.

Una vez configurada, se le pedirá que utilice periódicamente los módulos de salud de la aplicación, según las instrucciones de su proveedor de atención médica. Esto incluye controles diarios de síntomas y mediciones de signos vitales utilizando dispositivos compatibles conectados a su teléfono inteligente o tableta.

3. Intercambio de datos:

Sus datos de salud recopilados a través de la aplicación de telemonitoreo se transmitirán de forma segura a sus proveedores de atención médica designados, incluidos médicos, enfermeras y otros miembros de su equipo de atención médica. Este intercambio de datos es esencial para que puedan monitorizar su condición de forma remota, brindar intervenciones oportunas cuando sea necesario y tomar decisiones informadas sobre su atención.

4. Riesgos:

Si bien se hacen todos los esfuerzos posibles para garantizar la seguridad y privacidad de sus datos de salud, existen riesgos inherentes asociados con la transmisión de información confidencial a través de Internet. A pesar de emplear cifrado y otras medidas de seguridad, existe la posibilidad de acceso no autorizado o violaciones que podrían comprometer la confidencialidad de su información de salud. Además, problemas técnicos como problemas de conectividad o mal funcionamiento del software pueden interrumpir el proceso de telemonitorización. Sin embargo, todos los datos del paciente son anónimos, su identidad siempre será privada.

5. Beneficios:

Participar en el programa de telemonitorización ofrece varios beneficios potenciales, que incluyen:

Comodidad mejorada: puede controlar su salud respiratoria desde la comodidad de su hogar, lo que reduce la necesidad de visitas frecuentes a la clínica.

Intervención oportuna: sus proveedores de atención médica pueden identificar rápidamente cambios en su condición e intervenir según sea necesario, previniendo potencialmente exacerbaciones o complicaciones.

Comunicación mejorada: la aplicación facilita la comunicación entre usted y su equipo de atención médica, lo que permite una gestión más proactiva de su salud respiratoria.

Empoderamiento: al participar activamente en el seguimiento y la gestión de su salud, puede sentirse más en control de su afección y tomar decisiones informadas sobre su atención.

6. Derechos:

Como participante del programa de telemonitoreo, tienes los siguientes derechos:

El derecho a retirar el consentimiento en cualquier momento sin repercusiones para su atención continua.

El derecho a acceder y revisar sus datos de salud recopilados a través de la aplicación.

El derecho a solicitar correcciones a cualquier inexactitud en su información de salud.

El derecho a recibir explicaciones claras sobre cómo se utilizarán y compartirán sus datos.

7. Confidencialidad:

Su privacidad y confidencialidad son de suma importancia para nosotros. Todos los datos de salud recopilados a través de la aplicación se manejarán de acuerdo con las leyes y regulaciones de privacidad aplicables. Solo los proveedores de atención médica autorizados involucrados en su atención tendrán acceso a su información de salud y se tomarán medidas estrictas para proteger contra el acceso o la divulgación no autorizados.

8. Consentimiento:

Al aceptar participar con esta aplicación, usted reconoce que ha leído y comprendido la información proporcionada en este formulario de consentimiento. Usted comprende el propósito, los procedimientos, los riesgos y los beneficios de participar en el programa, así como sus derechos con respecto al uso y el intercambio de sus datos de salud. Usted acepta voluntariamente la recopilación, el uso y el intercambio de su información de salud para los fines descritos anteriormente.

9. Información de contacto:

Si tiene alguna pregunta, inquietud o desea retirar su consentimiento, comuníquese con gr-cadiz_24_telemonitoring@wpi.edu y/o daniel.morillo@uca.es.

Gracias por tomarse el tiempo de revisar este documento de consentimiento informado. Apreciamos mucho su participación en la aplicación de telemonitoreo de salud respiratoria y esperamos poder ayudarlo a controlar su condición respiratoria de manera efectiva.

Firme aquí para aceptar estos términos: ______________________

- How is your health today?
    - ¿Cómo se siente de salud hoy?
- How short of breath have you felt while performing your usual physical activities?

    - ¿Qué grado de falta de aire ha sentido al realizar sus actividades físicas habituales?

- How often have you coughed in the last 24 hours?

    - ¿Con qué frecuencia ha tosido en las últimas 24 horas?

- How much sputum have you had in the last 24 hours?

    - ¿Qué cantidad de esputos ha tenido en las últimas 24 horas?

- What color is your sputum or phlegm?

    - ¿De qué color es su esputo o flema?

- How many times have you used the inhaler for choking in the last 24 hours?

    - ¿Cuántas veces ha usado el inhalador para la asfixia en las últimas 24 horas?

B. Interview Questions for Secure Data Transmission for Sponsor

Your participation in this interview is voluntary, and if you wish to stop at any time, you are free to do so. By participating in this interview, you are agreeing to these conditions. We will be using the responses from this interview to aid our team in developing secure data transmission for the project. If there is any information you would like to remain confidential, we will respect your preferences and take measures to do so. We will send you a copy of our interview notes so you can review your responses. This interview should be between 10-30 minutes.

Sign here to consent to these terms: ______________________________

1. Are you ok with us using your name when describing this interview in our project report?
2. Is there any information you would like to be left out of our project report?
3. Can you describe your past projects' implementation of secure data transmission to a centralized server?
4. Can you give more detail about the current HTTP POST services already existing to store user data in a server?
5. What are your specific recommendations for implementing secure data transmission for this project?
6. What challenges have you faced with secure data transmission to and from a centralized server?
7. Can we see your past projects' implementations of secure data transmissions as examples for our project?
8. What are your standards for transmission security?
9. How have you tested the security of data transmission?
10. Do you have any recommendations to test the security of our data transmission?

C. The System Usability Scale (SUS)

We are a group of students from an American university collaborating with the University of Cadiz to develop an app prototype for remote telemonitoring for chronic respiratory illnesses. Your participation in this study will help to provide guidance for improving the prototype in order to enhance user experience.

In this study, we will ask you to interact with the prototype independently for [X] minutes before completing the System Usability Scale questionnaire which functions to evaluate the serviceability and learnability of the application. In this study, "system" refers to the prototype application. Following completion of the questionnaire, we may ask additional follow up questions regarding specific features of the prototype.

Your participation in this study is completely voluntary and you may withdraw at any time. Please remember that your answers will remain anonymous. No names or identifying information will appear in any of our project reports or publications.

Sign here to consent to these terms: ________________________

1. I think that I would like to use this system frequently.

   1 2 3 4 5

   Strongly Disagree Strongly Agree

2. I found the system unnecessarily complex.

   1 2 3 4 5

   Strongly Disagree Strongly Agree

3. I thought the system was easy to use.

   1 2 3 4 5

   Strongly Disagree Strongly Agree

4. I think that I would need the support of a technical person to be able to use this system.

   1 2 3 4 5

   Strongly Disagree Strongly Agree

5. I thought the various functions in this system were well integrated.

1 2 3 4 5

Strongly Disagree Strongly Agree

6. I thought there was too much inconsistency in this system.

1 2 3 4 5

Strongly Disagree Strongly Agree

7. I would imagine that most people would learn to use this system very quickly.

1 2 3 4 5

Strongly Disagree Strongly Agree

8. I found the system very cumbersome to use.

1 2 3 4 5

Strongly Disagree Strongly Agree

9. I felt very confident using the system.

1 2 3 4 5

Strongly Disagree Strongly Agree

10. I needed to learn a lot of things before I could get going with this system.

1 2 3 4 5

Strongly Disagree Strongly Agree

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