

To investigate the feasibility of utilising mobile phones, in conjunction with wearable devices, to aid the detection of respiratory conditions, through the capture and analysis of audio and biometric data, culminating in a proof-of-concept cross platform mobile application

Justin Hendy
Student Number: 0250941
University of Wales Trinity Saint David

September 2025

Contents

1	Introduction	3
2	Literature Review	3
2.1	Background on Respiratory Diseases and Their Global Impact	3
2.2	Mobile and Wearable Technology in Healthcare Monitoring	4
2.3	Existing Mobile Applications	6
3	Rationale and Context	7
4	Aims and Objectives	7
5	Expected Outcomes and Deliverables	7
6	Project Plan and Timeline	8
7	Requirements for Implementation	8

1 Introduction

This project proposal outlines a research study to investigate the feasibility of utilising mobile phones, in conjunction with wearable devices, to aid in the detection of respiratory conditions through the capture and analysis of audio and biometric data, culminating in a proof-of-concept cross-platform mobile application. The proposal begins with a literature review that provides background information on respiratory diseases and their global impact, as well as mobile and wearable technology in healthcare monitoring and existing mobile health applications. Following this, the proposal will provide a rationale and context for the study, which leads to a clearly defined hypothesis and a series of objectives. To conclude, the proposal provides details regarding expected outcomes, project timeline and implementation requirements.

2 Literature Review

2.1 Background on Respiratory Diseases and Their Global Impact

To provide context for this study, it is essential to clarify the range of diseases and conditions classified as respiratory, outline their prevalence and impact both globally and within the UK, highlight the challenges related to early detection and ongoing management, and explore current diagnostic and monitoring approaches.

Many different types of respiratory diseases fall into the following two categories: chronic respiratory diseases (CRD) and acute respiratory infectious diseases. Shakula et al. highlight a range of CRD conditions such as asthma, chronic obstructive pulmonary disease (COPD), interstitial lung disease (ILD), cystic fibrosis (CF), lung cancer and tuberculosis (TB). ILD is a broad subset of CRD, encompassing a diverse range of conditions. Althobiani et al. estimate the number of linked diseases to be approximately 200 [1], grouped into six subcategories: idiopathic, autoimmune-related, sarcoidosis, exposure-related, ILDs with cysts or airspace filling, and a category of others. Idiopathic pulmonary fibrosis is highlighted as being the most aggressive of all ILDs. Finally, acute respiratory infectious diseases are categorised as those caused by viruses/bacteria affecting the nasal cavity, throat, trachea and bronchus [2] and include influenza (flu), the common cold, COVID-19, sinusitis, pneumonia and bronchitis.

In 2017, global estimations put the number of people suffering from a CRD at roughly 550 million, representing a 40% increase when compared with figures from 1990, with CRD-related deaths totalling roughly 4 million, making it the third leading cause of death worldwide [3]. More specifically, Hang et al. reported 41,555,628 new cases of asthma in 2021, of which Western Europe reported 1.6 million. These figures represent a slight decrease between 1990 and 2021. Although asthma-related deaths during the same time period have increased, the mortality rate has decreased from 9.64% to 5.2% per 100,000 [4]. Hang et al. conclude that asthma remains highly prevalent, especially in countries with higher Social-demographic Index and among individuals under the age of 9. Global figures relating to COPD cases tend to vary due to differing definitions employed over the years, with estimates ranging from 212 to 400 million worldwide [5] [6]. Boers et al. estimate that respiratory disease direct costs for the European Union represent 6% of the total annual healthcare expenditure, with 56% (€38.6 billion) allocated to COPD. Similarly, it is estimated that the United States' annual COPD costs will increase to \$40 billion over the next 20 years. Within the UK, predictions place the number of those affected by COPD at around 3 million; however, as previously mentioned, COPD estimations are notoriously varied [7][8]. Rayner et al. also highlight the estimated cost to the NHS of around £800 million per year, with annual deaths of 30,000. Scully et al. sought to standardise a variety of datasets relating to the number of new cases of asthma, COPD and ILD across England, Scotland and Wales per 1,000 people per year. For 2019, England, Scotland, and Wales, respectively, saw an estimated 50,000, 3,700, and 2,000 new

asthma cases; 46,000, 5,800, and 2,100 new COPD cases; and 183,000, 9,000, and 4,300 new ILD cases [9].

There are many methods employed in the diagnosis and monitoring of respiratory conditions/diseases. Spirometry is often cited as the most widely employed test, providing measurements on how much air a person can inhale or exhale, and the speed at which they exhale [10]. Spirometry testing is carried out using a spirometer and is considered a relatively simple test to complete, albeit with training required to ensure accurate results [11]. Robert Crapo, in his paper Pulmonary-Function Testing, also lists several other tests such as "measurement of lung volumes, airway resistance, carbon monoxide diffusing capacity, and arterial-blood gases" [10]. Although this paper is now over 30 years old, spirometry remains one of the key assessments for measuring respiratory function [12]. Georgakopolou et al. highlight a significant number of advancements in modern respiratory condition diagnosis; however, many are beyond the scope of this paper. Georgakopolou et al. do, however, detail the greater importance that telemedicine, remote monitoring and AI will have on this field and that the ever-increasing global prevalence of respiratory diseases will result in greater demand for early detection and accurate monitoring via "sensitive and non-invasive" means [12].

There are several challenges in the early detection and ongoing management of respiratory conditions. It is believed that somewhere between 70 to 80% of adults suffering from COPD are undiagnosed, with studies showing that late diagnosis leads to worsening conditions and the development of simultaneous conditions such as depression, diabetes and cardiovascular disease[13]. Lin et al. highlight that low spirometry testing is one of the key factors in the underdiagnosis of COPD, where, although the test itself is relatively simple to administer, there is a lack of expertise related to the interpretation of the results [14] [13]. Suggested improvements to COPD early detection involve the use of handheld spirometers, questionnaires, or a combination method that incorporates a questionnaire with a peak expiratory flow device. One of the key issues related to asthma management is poor inhaler technique, where the incorrect use of recommended guidance in adults and children is found to be anywhere between 35 and 75%, depending on the method of measurement, population, and setting [15] [16]. Both Poplicean et al. and Boven et al. draw attention to recent developments in mHealth (Mobile Health) and electronic monitoring devices as solutions to this issue, many of which provide mobile phone integration.

2.2 Mobile and Wearable Technology in Healthcare Monitoring

An MIT professor in the 1960s first suggested the notion of wearable technology [17], and now, over 60 years later, this technology is not only a reality but also has a ubiquitous presence in everyday modern life. The term mobile health (mHealth) has been around since 2003 and is seen as a subset of ICT Health Domains; however, its definition has become vague since the introduction of the smartphone in 2007 [18]. An overview of mHealth and its various definitions will now be provided, along with a discussion of its evolution alongside wearable devices in clinical settings, a summary of modern devices and sensors, and an examination of its advantages and limitations when employed in the field of respiratory health.

Istepanian notes that the fundamental building blocks or technologies of mHealth are medical sensors, mobile computing and communication systems, and their application within the domain of healthcare services [18] [19]. Following 2007 and the introduction of the smartphone, Istepanian highlights the introduction of new meaning centred on the market forces of smartphone technology and its related ecosystems. Safavi et al. estimated in 2019 that by 2020, consumers would spend approximately \$49 billion on digital health products; however, they found that the majority of top-funded US-based digital health companies did not measure the "clinical effectiveness" of their products or assess their use within populations considered "high-cost, high-burden" such as the elderly, disabled and those suffering with chronic illnesses. The most significant number of studies evaluated healthy patients, with 34 studies; however, only 5 of these studies sought to evaluate clinical effectiveness. By comparison, the four

respiratory-related areas of asthma, COPD, ILD, and influenza garnered a total of 8 studies, of which only three studies related to asthma focused on high-burden populations, with only two evaluating clinical effectiveness [20]. Despite these concerns, wearable devices have become increasingly prevalent in clinical settings due to their ability to connect doctors with patients and other parties, provide insight into changes in condition, facilitate real-time data collection, enable remote monitoring, and improve patient outcomes and preventive medicine [17] [21]. Chowdhury et al. provide a general definition for a wearable device as any device that can be worn on the body, is flexible, and uses sensors to measure medically related biometric data [21]. Lu et al. list health and safety monitoring, chronic disease management, disease diagnosis and treatment, and rehabilitation as key areas of the medical field that employ wearable technology [17]. Health and safety monitoring provides data on a wide range of medical concerns, including the detection of falls, tracking daily activities, posture, respiratory rate, and mood. The use of wearables in the field of chronic disease management has provided a range of benefits and solutions for managing conditions such as diabetes, pulmonary diseases, cardiovascular disease, and hypertension. The evolution of wearables, from invasive and implantable devices used with a limited scope to the multi-sensor, flexible, non-invasive devices of modern medicine, has been vast [22]. With the plethora of options available in both the consumer-grade and medical-grade wearables and mHealth device markets, the following section provides an overview.

The types of devices available within the domain of mHealth include smartphones, wearables such as smartwatches and fitness trackers, as well as medical-grade wearables. Escobar-Linero et al. found that wearables are often marketed as either commercial or research products. Commercial wearables come in various forms, including watches, wristbands, patches, earrings, garments, rings, and in-ear devices. In contrast, research wearables also include wristbands, patches, t-shirts, and rings, as well as slightly more restrictive designs such as chestbands, waistbands, insoles, anklebands, helmets, and motes (small, low-powered sensors often part of a wider network) [22]. It is important to note that the EU has guidelines that set out to define the difference between commercial wearables and medical wearables specifically, devices "intended for medical purposes such as disease diagnosis, monitoring, treatment, injury management and physiological process modification" are classed as medical wearables and devices that are mobile-phone based such as smartwatches and smart bands are considered commercial [23]. To measure key biometric data, all wearable devices must utilise some form of sensor, such as heart rate monitors (ECG), accelerometers, temperature sensors, photoplethysmographs (PPGs), GPS, and galvanic skin response (GSR) sensors [24] [22]. Modern medical sensors measure several key health indicators, including heart rate, blood oxygen saturation, blood pressure, respiratory rate, body temperature, and electrodermal activity (changes in the skin's ability to conduct electrical current) [25]. Away from wearable technology, the smartphone is a key component of mHealth, not only as a means of connecting devices and providing the means for data storage and transfer, but also because the phone itself contains sensors and other hardware that can be utilised, such as a gyroscope and accelerometer [26]. Within the field of respiratory disease detection, sound features such as wheezing, reduced breath sounds, crackles, cough patterns, and chest sounds are key to detection and diagnosis; therefore, a mobile phone's built-in microphone is a low-cost and readily available solution for capturing such sounds. Where more sophisticated audio solutions are required, such as the use of high-quality external microphones or acoustic sensors, smartphones offer several physical and wireless connection methods [27].

Wearable and mobile technologies offer numerous advantages when applied to the field of respiratory health in the medical sector. Zhuang et al. highlight the importance of patient engagement and how mobile health encourages self-management through real-time data and vital sign monitoring [28]. Althobiani et al. also emphasise the importance of patient empowerment, noting that this can lead to a reduction in face-to-face contact requirements [29]. Further benefits include the ability to detect the onset of acute exacerbations of chronic obstructive pulmonary disease through continuous monitoring of

respiratory rate, heart rate, and oxygen saturation [29]. Kamble and Ragha list several opportunities, including personalised health monitoring, disease management and prevention, enhanced wellness and lifestyle management, data analytics and artificial intelligence, predictive analytics and early warning systems, and a connected healthcare ecosystem [24]. In terms of limitations, there is a current lack of evaluation regarding the impact of mHealth within the context of respiratory diseases [28] [26]. Althobiani et al. note several challenges or limitations, including usability, which is a key concern, especially given the prevalence of respiratory conditions among older adults. Other key issues relate to data privacy and security, a reduction in engagement over a prolonged period, the high cost of purchasing and maintenance, access to robust internet infrastructure, and, finally, a lack of trust within the clinical professions towards consumer-grade wearable data [29]. Kamble and Ragha provide a comprehensive overview of the challenges relating to the use of wearable sensors in healthcare. They are grouped into four categories - technical challenges, regulatory and ethical challenges, use acceptance and engagement challenges, and data management and analysis challenges [24]. Technical challenges arise due to the accuracy and reliability of sensor readings, battery life when considering long-term monitoring, and finally, the ability to export data from wearable devices to existing healthcare systems. The key regulatory and ethical challenges concern data privacy and security; however, they also address the ethical issues surrounding informed consent and data ownership. User acceptance and engagement challenges relate to user experience and usability, as well as the ability to bring about any required behavioural change. Finally, the amount of data produced through wearable and other mHealth devices will be substantial and will require relevant analysis to facilitate accurate clinical appraisal. The integration of data between various data points will also need to be considered.

2.3 Existing Mobile Applications

The Hyfe Cough Tracker is a smartphone-based AI cough monitoring app that can detect, record, and count coughs from cough-like sounds when used in acoustically controlled environments [30]. The app can continuously track audio and extract cough data from the audio stream. While the app displayed a high level of correlation when compared to human detection, the study highlights the need for further analysis within community and clinical settings. Hyfe applications are available on both the Android and Apple app ecosystems.

The iMedic application is presented as a smartphone-based self-auscultation tool for AI-Powered pediatric respiratory assessment [31]. Auscultation is a diagnostic method typically performed by a healthcare professional with the aid of a stethoscope to assess the current health of the circulatory, respiratory, and gastrointestinal systems. The iMedic application requires completion of three steps to carry out an assessment. Step one involves the user inputting symptoms that the child is currently exhibiting. Step two guides the user through the process of capturing a range of lung sound recordings via a series of visual instructions. Step three involves an AI assessment with provided audio recording categorisation. The iMedic application is available on both the Android and Apple app ecosystems.

Both the applications listed here utilise audio recording for their analysis and therefore do not use any other biomarkers such as heart rate or blood oxygen levels. Other applications in this field include Eupnoos, a breath analysis tool described as "Shazam for diagnosing respiratory diseases" [32]. Welch et al. concluded that the Eupnoos application has "promising" accuracy for diagnosing asthma or COPD, but accuracy was limited by the small number of disease cases [33]. In terms of mobile applications and connected devices, there are several commercial systems, such as StethoMe and Felix. StethoMe is a smartphone application that connects to a smart wireless stethoscope and utilises AI to provide in-home examinations. It appears that StethoMe is scheduled for clinical trials, but at the time of writing, these have yet to commence [34]. Similarly, Felix by Sonavi Labs is a digital stethoscope connected to a mobile application.

3 Rationale and Context

Given the continued global burden of respiratory diseases due to their high prevalence, mortality rates, and economic impact, new and innovative approaches to early detection and monitoring must be developed to improve patient outcomes and reduce healthcare costs. Consumer-grade wearable technology, smartphones and mobile health applications are ubiquitous in modern life and already provide a great deal of insight into our health and wellbeing. However, medical diagnosis of respiratory diseases in this field is limited to either audio-only solutions, such as Hyfe or Eupnoos, or applications with additional pieces of related hardware, such as the StethoMe or Feelix systems. With the range of modern fitness trackers and smartwatches available on the market, and their ability to track a range of health biomarkers, there is a gap for a service that allows for the combination of audio and wearable technology within the field of respiratory disease diagnosis. Before any assessment can be made regarding the accuracy or improvements such a system would provide, it is vital to develop and test a platform that can capture and provide feedback on audio and other biometric data in a real-time setting. This study aims to provide that platform as a first step towards clinical assessments of respiratory diseases using consumer-grade mobile health devices.

4 Aims and Objectives

This research aims to determine whether the use of audio analysis via built-in smartphone microphones, combined with a user health-related questionnaire and other physiological biomarkers measured using consumer-grade mobile wearable technology, can be successfully developed and deployed on the Apple iOS and Android platforms with acceptable performance metrics for real-time data processing.

Here are the four objectives for this study:

- To develop a mobile application for the Apple and Android mobile platforms that integrates audio capture with wearable sensor data and a user questionnaire
- To assess performance in real-time conditions by measuring the latency between data capture and output
- To monitor resource usage associated with real-time data processing
- To determine the reliability and stability of the application when placed under various operational conditions

5 Expected Outcomes and Deliverables

Upon completion of this study, a fully functional cross-platform application will be submitted, along with a technical report that measures a range of predetermined performance criteria to evaluate the effectiveness of employing the app in collecting and processing real-time data for the mobile health consumer market in relation to respiratory disease diagnosis.

6 Project Plan and Timeline

To complete this study, there are four key stages: completion of a comprehensive literature review, application development, application performance testing and the review and summarisation of the process and completed application.

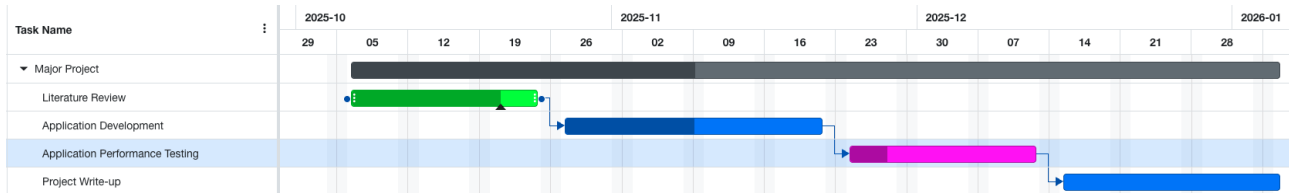


Figure 1: Project Gantt Chart

7 Requirements for Implementation

To complete this study, a range of hardware devices, including various mobile phones with different specifications and platforms (Apple/Android), as well as several wearable devices equipped with multiple sensors for collecting diverse biometric data, is required. Access to a range of software development kits is essential, including, but not limited to, the Apple Health SDK and Samsung Health SDK. To work with the Apple Health SDK, access to Xcode is also required, as well as some form of application performance management tool, such as Dynatrace, Instana, or Apple's own MetricKit.

References

- [1] M. A. Althobiani, A.-M. Russell, J. Jacob, Y. Ranjan, A. A. Folarin, J. R. Hurst, and J. C. Porter, “Interstitial lung disease: a review of classification, etiology, epidemiology, clinical diagnosis, pharmacological and non-pharmacological treatment,” *Frontiers in Medicine*, vol. 11, Apr. 2024.
- [2] Z. Qin and G. Su, “Pathogen distribution and laboratory diagnosis of acute respiratory infectious diseases,” *Advances in Infectious Diseases*, vol. 11, no. 01, pp. 21–28, 2021.
- [3] J. B. Soriano, P. J. Kendrick, K. R. Paulson, V. Gupta, E. M. Abrams, R. A. Adedoyin, T. B. Adhikari, S. M. Advani, A. Agrawal, E. Ahmadian, F. Alahdab, S. M. Aljunid, K. A. Altirkawi, N. Alvis-Guzman, N. H. Anber, C. L. Andrei, M. Anjomshoa, F. Ansari, J. M. Antó, J. Arabloo, S. M. Athari, S. S. Athari, N. Awoke, A. Badawi, J. A. M. Banoub, D. A. Bennett, I. M. Bensenor, K. S. S. Berfield, R. S. Bernstein, K. Bhattacharyya, A. Bijani, M. Brauer, G. Bukhman, Z. A. Butt, L. A. Cámara, J. Car, J. J. Carrero, F. Carvalho, C. A. Castañeda-Orjuela, J.-Y. J. Choi, D. J. Christopher, A. J. Cohen, L. Dandona, R. Dandona, A. K. Dang, A. Daryani, B. de Courten, F. M. Demeke, G. T. Demoz, J.-W. De Neve, R. Desai, S. D. Dharmaratne, D. Diaz, A. Douiri, T. R. Driscoll, E. E. Duken, A. Eftekhari, H. Elkout, A. Y. Endries, I. Fadhil, A. Faro, F. Farzadfar, E. Fernandes, I. Filip, F. Fischer, M. Foroutan, M. Garcia-Gordillo, A. K. Gebre, K. B. Gebremedhin, G. G. Gebremeskel, K. E. Gezae, A. G. Ghoshal, P. S. Gill, R. F. Gillum, H. Goudarzi, Y. Guo, R. Gupta, G. B. Hailu, A. Hasanzadeh, H. Y. Hassen, S. I. Hay, C. L. Hoang, M. K. Hole, N. Horita, H. D. Hosgood, M. Hostiuc, M. Househ, O. S. Ilesanmi, M. D. Ilic, S. S. N. Irvani, S. M. S. Islam, M. Jakovljevic, A. A. Jamal, R. P. Jha, J. B. Jonas, Z. Kabir, A. Kasaeian, G. G. Kasahun, G. M. Kassa, A. T. Kefale, A. P. Kengne, Y. S. Khader, M. A. Khafaie, E. A. Khan, J. Khan, J. Khubchandani, Y.-E. Kim, Y. J. Kim, S. Kisa, A. Kisa, L. D. Knibbs, H. Komaki, P. A. Koul, A. Koyanagi, G. A. Kumar, Q. Lan, S. Lasrado, P. Lauriola, C. La Vecchia, T. T. Le, J. Leigh, M. Levi, S. Li, A. D. Lopez, P. A. Lotufo, F. Madotto, N. B. Mahotra, M. Majdan, A. Majeed, R. Malekzadeh, A. A. Mamun, N. Manafi, F. Manafi, L. G. Mantovani, B. G. Meharie, H. G. Meles, G. G. Meles, R. G. Menezes, T. Mestrovic, T. R. Miller, G. Mini, E. M. Mirrakhimov, B. Moazen, K. A. Mohammad, S. Mohammed, F. Mohebi, A. H. Mokdad, M. Molokhia, L. Monasta, M. Moradi, G. Moradi, L. Morawska, S. M. Mousavi, K. I. Musa, G. Mustafa, M. Naderi, M. Naghavi, G. Naik, S. Nair, V. Nangia, J. R. Nansseu, J. Nazari, D. E. Ndwandwe, R. I. Negoï, T. H. Nguyen, C. T. Nguyen, H. L. T. Nguyen, M. R. Nixon, R. Ofori-Asenso, F. A. Ogbo, A. T. Olagunju, T. O. Olagunju, E. Oren, J. R. Ortiz, M. O. Owolabi, M. P. A, S. Pakhale, A. Pana, S. Panda-Jonas, E.-K. Park, H. Q. Pham, M. J. Postma, H. Pourjafar, H. Poustchi, A. Radfar, A. Rafiei, F. Rahim, M. H. U. Rahman, M. A. Rahman, S. Rawaf, D. L. Rawaf, L. Rawal, R. C. Reiner Jr., M. B. Reitsma, L. Roever, L. Ronfani, E. M. Roro, G. Roshandel, K. E. Rudd, Y. D. Sabde, S. Sabour, B. Saddik, S. Safari, K. Saleem, A. M. Samy, M. M. Santric-Milicevic, B. P. Sao Jose, B. Sartorius, M. Satpathy, M. Savic, M. Sawhney, S. G. Sepanlou, M. A. Shaikh, A. Sheikh, M. Shigematsu, R. Shirkoohi, S. Si, S. Siabani, V. Singh, J. A. Singh, M. Soljak, R. Somayaji, M. Soofi, I. N. Soyiri, Y. M. Tefera, M.-H. Temsah, B. E. Tesfay, J. S. Thakur, A. T. Toma, M. Tortajada-Girbés, K. B. Tran, B. X. Tran, L. Tudor Car, I. Ullah, M. Vacante, P. R. Valdez, J. F. M. van Boven, T. J. Vasankari, Y. Veisani, F. S. Violante, G. R. Wagner, R. Westerman, C. D. A. Wolfe, D. Z. Wondafrash, A. B. Wondmieneh, N. Yonemoto, S.-J. Yoon, Z. Zaidi, M. Zamani, H. J. Zar, Y. Zhang, and T. Vos, “Prevalence and attributable health burden of chronic respiratory diseases, 1990–2017: a systematic analysis for the global burden of disease study 2017,” *The Lancet Respiratory Medicine*, vol. 8, no. 6, pp. 585–596, Jun. 2020.
- [4] Y.-q. Hang, X. Piao, J. Wu, Q.-w. Jiang, and Y. Han, “The epidemiology of asthma and its

- attributable risk factors from 1990 to 2021: A systematic analysis based on the global burden of disease study 2021 and mendelian randomization studies,” *Public Health*, vol. 243, p. 105731, Jun. 2025.
- [5] D. Adeloye, P. Song, Y. Zhu, H. Campbell, A. Sheikh, and I. Rudan, “Global, regional, and national prevalence of, and risk factors for, chronic obstructive pulmonary disease (copd) in 2019: a systematic review and modelling analysis,” *The Lancet Respiratory Medicine*, vol. 10, no. 5, pp. 447–458, May 2022.
 - [6] E. Boers, M. Barrett, J. G. Su, A. V. Benjafield, S. Sinha, L. Kaye, H. J. Zar, V. Vuong, D. Tellez, R. Gondalia, M. B. Rice, C. M. Nunez, J. A. Wedzicha, and A. Malhotra, “Global burden of chronic obstructive pulmonary disease through 2050,” *JAMA Network Open*, vol. 6, no. 12, p. e2346598, Dec. 2023.
 - [7] L. Rayner, J. Sherlock, B. Creagh-Brown, J. Williams, and S. deLusignan, “The prevalence of copd in england: An ontological approach to case detection in primary care,” *Respiratory Medicine*, vol. 132, pp. 217–225, Nov. 2017.
 - [8] R. Halbert, S. Isonaka, D. George, and A. Iqbal, “Interpreting copd prevalence estimates,” *Chest*, vol. 123, no. 5, pp. 1684–1692, May 2003.
 - [9] S. Scully, H. Evans, S. Hatam, S. Cook, H. Whittaker, C. Kallis, I. Farr, C. Orton, A. Sheikh, and J. Quint, “Incidence and prevalence of asthma, copd, and ild across england, wales, and south-east scotland – a harmonised approach to data analysis,” *International Journal of Population Data Science*, vol. 9, no. 5, Sep. 2024.
 - [10] R. O. Crapo, “Pulmonary-function testing,” *New England Journal of Medicine*, vol. 331, no. 1, pp. 25–30, Jul. 1994.
 - [11] V. Moore, “Spirometry: step by step,” *Breathe*, vol. 8, no. 3, pp. 232–240, Jan. 2012.
 - [12] V. Georgakopoulou, D. Spandidos, and A. Corlateanu, “Diagnostic tools in respiratory medicine (review),” *Biomedical Reports*, vol. 23, no. 1, pp. 1–13, May 2025.
 - [13] C.-H. Lin, S.-L. Cheng, C.-Z. Chen, C.-H. Chen, S.-H. Lin, and H.-C. Wang, “Current progress of copd early detection: Key points and novel strategies,” *International Journal of Chronic Obstructive Pulmonary Disease*, vol. Volume 18, pp. 1511–1524, Jul. 2023.
 - [14] S. Hangaard, T. Helle, C. Nielsen, and O. K. Hejlesen, “Causes of misdiagnosis of chronic obstructive pulmonary disease: A systematic scoping review,” *Respiratory Medicine*, vol. 129, pp. 63–84, Aug. 2017.
 - [15] E. Poplicean, A. F. Crişan, E. Tudorache, P. Hogeia, R. Mladin, and C. Oancea, “Unlocking better asthma control: A narrative review of adherence to asthma therapy and innovative monitoring solutions,” *Journal of Clinical Medicine*, vol. 13, no. 22, p. 6699, Nov. 2024.
 - [16] J. F. van Boven, J. C. Trappenburg, T. van der Molen, and N. H. Chavannes, “Towards tailored and targeted adherence assessment to optimise asthma management,” *npj Primary Care Respiratory Medicine*, vol. 25, no. 1, Jul. 2015.
 - [17] L. Lu, J. Zhang, Y. Xie, F. Gao, S. Xu, X. Wu, and Z. Ye, “Wearable health devices in health care: Narrative systematic review,” *JMIR mHealth and uHealth*, vol. 8, no. 11, p. e18907, Nov. 2020.

- [18] R. S. H. Istepanian, “Mobile health (m-health) in retrospect: The known unknowns,” *International Journal of Environmental Research and Public Health*, vol. 19, no. 7, p. 3747, Mar. 2022.
- [19] R. Istepanian, E. Jovanov, and Y. Zhang, “Guest editorial introduction to the special section on m-health: Beyond seamless mobility and global wireless health-care connectivity,” *IEEE Transactions on Information Technology in Biomedicine*, vol. 8, no. 4, pp. 405–414, Dec. 2004.
- [20] K. Safavi, S. C. Mathews, D. W. Bates, E. R. Dorsey, and A. B. Cohen, “Top-funded digital health companies and their impact on high-burden, high-cost conditions,” *Health Affairs*, vol. 38, no. 1, pp. 115–123, Jan. 2019.
- [21] S. Chowdhury, A. Kaur, S. B. P. G. Kanmani Prince, T. Agarwal, and N. Vashisht, “Advancements in iot and sensor-enabled wearable devices for healthcare applications,” in *2025 International Conference on Automation and Computation (AUTOCOM)*. IEEE, Mar. 2025, pp. 500–505.
- [22] E. Escobar-Linero, L. Muñoz-Saavedra, F. Luna-Perejón, J. L. Sevillano, and M. Domínguez-Morales, “Wearable health devices for diagnosis support: Evolution and future tendencies,” *Sensors*, vol. 23, no. 3, p. 1678, Feb. 2023.
- [23] P. Moorthy, L. Weinert, C. Schüttler, L. Svensson, B. Sedlmayr, J. Müller, and T. Nagel, “Attributes, methods, and frameworks used to evaluate wearables and their companion mhealth apps: Scoping review,” *JMIR mHealth and uHealth*, vol. 12, p. e52179, Apr. 2024.
- [24] P. C. Kamble and L. K. Ragha, “Sensing health: Exploring issues, scope, and future of smart wearable sensors in healthcare,” in *2024 11th International Conference on Computing for Sustainable Global Development (INDIACom)*. IEEE, Feb. 2024, pp. 223–228.
- [25] S. Guarducci, S. Jayousi, S. Caputo, and L. Mucchi, “Key fundamentals and examples of sensors for human health: Wearable, non-continuous, and non-contact monitoring devices,” *Sensors*, vol. 25, no. 2, p. 556, Jan. 2025.
- [26] B. E. Dicianno, B. Parmanto, A. D. Fairman, T. M. Crytzer, D. X. Yu, G. Pramana, D. Coughenour, and A. A. Petrazzi, “Perspectives on the evolution of mobile (mhealth) technologies and application to rehabilitation,” *Physical Therapy*, vol. 95, no. 3, pp. 397–405, Mar. 2015.
- [27] Troncoso, Ángela and Ortega, Juan A. and Seepold, Ralf and Madrid, Natividad Martínez, “Non-invasive devices for respiratory sound monitoring,” *Procedia Computer Science*, vol. 192, pp. 3040–3048, 2021.
- [28] M. Zhuang, I. I. Hassan, W. M. A. W Ahmad, A. Abdul Kadir, X. Liu, F. Li, Y. Gao, Y. Guan, and S. Song, “Effectiveness of digital health interventions for chronic obstructive pulmonary disease: Systematic review and meta-analysis,” *Journal of Medical Internet Research*, vol. 27, p. e76323, May 2025.
- [29] M. A. Althobiani, A.-M. Russell, J. Jacob, Y. Ranjan, R. Ahmad, A. A. Folarin, J. R. Hurst, and J. C. Porter, “The role of digital health in respiratory diseases management: a narrative review of recent literature,” *Frontiers in Medicine*, vol. 12, Feb. 2025.
- [30] M. Galvosas, J. C. Gabaldón-Figueira, E. M. Keen, V. Orrillo, I. Blavia, J. Chaccour, P. M. Small, G. Giménez, M. Rudd, S. Grandjean Lapierre, and C. Chaccour, “Performance evaluation of the smartphone-based ai cough monitoring app - hyfe cough tracker against solicited respiratory sounds,” *F1000Research*, vol. 11, p. 730, Jun. 2023.

- [31] S. G. Jeong and S. E. Kim, “Patient domain supervised contrastive learning for lung sound classification using mobile phone,” 2025.
- [32] A. Systems, “Eupnoos respiratory app for lung function tests,” Website, Oct. 2025. [Online]. Available: <https://www.atta.systems/case-studies/eupnoos#:~:text=Eupnoosisaninnovativerespiratory,tests,anduserexperiencedesign>.
- [33] L. Welch, M. Shaban, C. Sheppard, A. Gratiot, D. Kodak, and S. Siddiqui, “S134 eupnoos: advancing early diagnosis of respiratory diseases with smartphone-based audio phenotyping,” *Thorax*, vol. 78, no. Suppl 4, pp. A97–A98, 2023. [Online]. Available: <https://thorax.bmj.com/content/78/Suppl.4/A97.2>
- [34] Y. Kim, Y. Hyon, S. Lee, S.-D. Woo, T. Ha, and C. Chung, “The coming era of a new auscultation system for analyzing respiratory sounds,” *BMC Pulmonary Medicine*, vol. 22, no. 1, Mar. 2022.