T.C.

BAHCESEHIR UNIVERSITY

GRADUATE SCHOOL OF EDUCATION

THE DEPARTMENT OF COMPUTER ENGINEERING

HEARING LOSS DETECTOR APPLICATION

MASTER'S THESIS

RAMI KHALAF

ISTANBUL 2023

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ABSTRACT

HEARING LOSS DETECTOR APPLICATION

Rami Khalaf

Computer Engineering Master Program

Thesis Supervisor: Asset. Prof. Yucel Batu Salman

May 2023, 63 pages

This thesis is dedicated to the design and development of an innovative audiometer hearing test mobile application, with the primary objective of enhancing accessibility, affordability, and accuracy in the field of hearing assessments. The application introduces a user-friendly and easily administered hearing test, capable of providing precise measurements of an individual's hearing ability across different frequencies and volumes. Through extensive research and experimentation, this thesis makes notable contributions in terms of accessibility, cost-effectiveness, convenience, personalization, and early detection of hearing loss. By leveraging the proposed solution, individuals gain the ability to self-diagnose and evaluate the severity of their hearing impairment, empowering them with greater autonomy and control over their own health and well-being. The thesis outlines a comprehensive methodology encompassing various stages, including system design and the implementation details of the audiometer hearing test application. Furthermore, the document presents a thorough analysis of the results obtained from the hearing test application, offering a comparative evaluation of its effectiveness against the standard audiometry test. The findings derived from the research underscore the immense potential of the hearing test application in diagnosing hearing problems, while also suggesting its viability as a promising alternative to traditional audiology clinics. This thesis, through its rigorous investigation and empirical evidence, establishes a strong foundation for the advancement of accessible and accurate hearing assessments.

Keywords: Hearing degree test, smart phones, tones, audiometry, audiology.

ÖZET

İŞİTME KAYBI DEDEKTÖRÜ UYGULAMASI

Rami

Bilgisayar Mühendisliği Yüksek Lisans Programı

Tez Danışmanı: Varlık. Prof. Yucel Batu Salman

Mayıs 2023

Bu tez, birincil amacı işitme değerlendirmeleri alanında erişilebilirliği, satın alınabilirliği ve doğruluğu artırmak olan yenilikçi bir odyometre işitme testi mobil uygulamasının tasarımına ve geliştirilmesine adanmıştır. Uygulama, farklı frekanslarda ve ses seviyelerinde bir kişinin işitme yeteneğinin hassas ölçümlerini sağlayabilen, kullanıcı dostu ve kolayca uygulanabilen bir işitme testi sunar. Kapsamlı araştırma ve deneyler yoluyla, bu tez erişilebilirlik, maliyet etkinliği, rahatlık, kişiselleştirme ve işitme kaybının erken tespiti açısından dikkate değer katkılar sağlamaktadır. Önerilen çözümden yararlanarak, bireyler kendi kendilerine teşhis koyma ve işitme bozukluklarının ciddiyetini değerlendirme yeteneği kazanırlar, bu da onları daha fazla özerklik ve kendi sağlıkları ve esenlikleri üzerinde kontrol sahibi olma konusunda güçlendirir. Tez, sistem tasarımı ve odyometre işitme testi uygulamasının uygulama detayları dahil olmak üzere çeşitli aşamaları kapsayan kapsamlı bir metodolojinin ana hatlarını çizmektedir. Ayrıca belge, işitme testi uygulamasından elde edilen sonuçların kapsamlı bir analizini sunarak, standart odyometri testiyle etkinliğinin karşılaştırmalı bir değerlendirmesini sunar. Araştırmadan elde edilen bulgular, işitme testi uygulamasının işitme sorunlarının teşhisindeki muazzam potansiyelinin altını çizerken, aynı zamanda geleneksel odyoloji kliniklerine umut verici bir alternatif olarak yaşayabilirliğini öne sürüyor. Bu tez, titiz araştırması ve ampirik kanıtları sayesinde, erişilebilir ve doğru işitme değerlendirmelerinin ilerlemesi için güçlü bir temel oluşturur ve nihai olarak işitme bozukluklarından etkilenen bireylerin genel yaşam kalitesini iyileştirmeyi amaçlar.

Anahtar Kelimeler: işitme kaybı testi, akıllı telefonlar, tonlar, odyometri, odyoloj

This study is dedicated to our beloved parents, who have been our sources of inspiration and gave us strength when we thought of giving up, who continually provide their moral, spiritual, emotional, and financial support. To our brothers, sisters, relatives, mentors, friends, and classmates who shared their words, advice and encouragement to finish this study.And lastly, we dedicated this book to the Almighty God, thank you for the guidance,strength, power of mind, protection and skills and for giving us a healthy life. All of these, we offer to you.

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LIST OF ABBREVIATIONS

WHO	World Health Organization
dB	Decibels
OAE	otoacoustics emission
ABR	Auditory brainstem response
REM	Real Ears Measurement
Hz	hertz
GUI	graphical user interface
PIL	Python Imaging Library
NIHL	noise-induced hearing loss (),

Chapter 1

Introduction

1.1 Overview

The World Health Organization (WHO) estimates that 466 million people worldwide suffer from hearing impairment, making it a prevalent ailment (Schmucker, et al, 2019) . Certain groups may be more at risk for hearing impairment, such as those regularly exposed to loud noises, including construction workers, musicians, and people who use firearms (Bhatt, et al,2017). Age-related hearing impairment, commonly known as presbycusis, is prevalent among older adults due to the natural deterioration of the ear structures over time. Additionally, hearing loss can be influenced by factors such as genetics, specific medical conditions like diabetes or high blood pressure, ear infections, and certain medications. The consequences of hearing loss are profound, affecting various aspects of an individual's life and well-being. Communication difficulties, social isolation, and decreased cognitive function are significant outcomes of hearing impairment. Consequently, it is crucial to detect and treat hearing loss early to preserve overall health and enhance quality of life. (Paplou, et al,2021). (Rigters, et al,2081). A hearing or audiometric test is a series of assessments to evaluate a person's hearing ability (Colsman.et al ,2020). The test measures the sensitivity of a person's hearing across different frequencies and volumes. A hearing test is typically performed by an audiologist, a healthcare professional trained to evaluate and treat hearing and balance disorders. The audiologist will use specialized equipment to produce sounds of varying volumes and frequencies during a hearing test. The person being tested will listen to these sounds through headphones or speakers and respond by either pushing a button or raising their hand when they hear the sound. The audiologist will record the person's responses and plot them on an audiogram, a graph showing their hearing thresholds for each frequency (Martins,et al ,2022) (De Sousa, et al ,2022). The hearing test can help identify a person's type and degree of hearing impairment. The type of hearing loss may be conductive, sensorineural, or mixed. The degree of hearing loss is measured in decibels (dB), a sound intensity unit (Saunders,, et al ,2023).

Audiogram results may classify a person's hearing as usual, mild, moderate, severe, or profound. Overall, a hearing test is an essential tool for identifying hearing loss and determining the best course of treatment (Saunders, et al ,2022).It is recommended that adults get their hearing tested Periodically and more frequently if they are at risk for hearing loss or have noticed changes in their hearing. Creating a mobile application for hearing testing is suitable for many cases worldwide. Having an application for hearing testing is a convenient option because you can perform the test at home without visiting an audiologist or audiologist. Plus, regular hearing impairment tests can aid in early detection of hearing impairment, which could improve treatment outcomes. Using the hearing test computer application also helps to obtain a baseline of hearing ability and monitor any changes over time. Also, the privacy factor: Some people may feel more comfortable taking a hearing test in their homes than in a clinical setting. Finally, low-cost Computer applications for hearing tests can be a cost-effective option compared to traditional hearing tests conducted by audiologists . (Wangn,et al ,2021). Saunders.

To address this issue, an audiometer hearing test mobile app can be an innovative solution to provide accessible and convenient hearing assessments for people. This app can offer preliminary screening for people, even if it cannot replace the requirement for expert testing. It can be useful for people in rural locations, people who have mobility challenges, and those who may have difficulty scheduling appointments due to work or family commitments. This thesis aims to explore the development of an audiometer hearing test mobile app, highlighting its potential features and benefits. The app's features should include a hearing test that is easy to use, customizable settings, a user-friendly interface, progress tracking, and accessibility to cater to the needs of users of all ages and abilities. The app's benefits include cost-effectiveness, convenience, personalization, and early detection of hearing loss, which can significantly impact the accessibility, affordability, and accuracy of hearing assessments. The development of an audiometer hearing test mobile app can help promote better hearing health, prevent hearing loss, and enhance the standard of living for those who are hard of hearing. It can be a valuable tool for individuals to monitor their hearing improvement over time, eliminating the need for routine doctor appointments until possible hearing loss is identified. Additionally, it can aid in attempts to improve access to healthcare on a social level, making hearing assessments more accessible and affordable for people worldwide.

1.2 Inspiration

An audiometer hearing test apps is a digital tool that allows peoples to test their hearing abilities using their devices. The app measures the user's hearing sensitivity across various frequencies and sound intensities and provides feedback on their hearing levels. Here are some potential features that could be included in an audiometer hearing test app:

- Hearing Test: The app should include a hearing test that is easy to use and provides accurate results. Users should be able to test their hearing sensitivity across various frequencies and sound intensities.
- Customizable Settings: The app should allow peoples to customize the testing settings to fit their needs. For example, users should be able to choose the frequency range, volume level, and type of sound they want to test.
- User-Friendly Interaction: The app's user interface should be simple to use and intuitive. Users of all ages and abilities should be able to use the interface.
- Progress Tracking: The app should allow users to track their progress over time. This can help users identify any changes in their hearing abilities and seek medical attention if necessary.
- Accessibility: The app must be developed so that users with disabilities, such as those who have hearing issues, may use it. This may include tools like text-to-speech capabilities and closed captioning.

Overall, an audiometer hearing test mobile app can be useful for anyone who wants to test their hearing abilities and improve their hearing health. By including a range of features that cater to the needs of users of all ages and abilities, such an app can help promote better hearing health and prevent hearing loss.

1.3 Problem Statement

The problem statement for an audiometer hearing test might be as follows:

Design and develop an audiometer hearing test that accurately measures a person's hearing ability across various frequencies and volumes. The hearing test should be user-friendly and easy to administer, with clear instructions for the test subject and the administrator. The examination should reveal various degrees and types of hearing loss, such as conductive, sensorineural, and mixed hearing loss. The hearing test should be reliable and consistent in its results and be validated against established standards for a hearing assessment. The audiometer itself should be calibrated regularly to ensure accurate results.

This thesis aims to develop a mobile app for audiometric assessment. A smartphone application can offer preliminary screening for people, even if it cannot replace the requirement for expert testing. This gives people a tool to monitor their hearing improvement over time, eliminating the need for routine doctor appointments until possible hearing loss is identified. The development of a mobile audiometry test app will aid in attempts to improve access to healthcare on a social level.

1.4 Thesis Contributions

1. Accessibility: An audiometer hearing test mobile app can provide access to hearing assessments for people who may not have easy access to traditional audiology clinics.
2. Cost-effectiveness: An audiometer hearing test mobile app can be a cost-effective alternative to traditional hearing assessments. It can reduce the equipment and

staffing required for traditional audiology clinics and be made available at a lower cost to users.

3. Convenience: An audiometer hearing test mobile app can be administered at any time and place, allowing users to test their hearing at their convenience. This can increase the likelihood of individuals getting tested and seeking treatment for hearing loss.
4. Personalization: An audiometer hearing test mobile app can be designed to provide personalized hearing assessments that can cater to individual needs.
5. Early Detection: An audiometer hearing test mobile app can detect hearing loss early. Individuals with hearing loss can benefit from early identification and care, which lowers the risk of subsequent problems and improves outcomes.

Overall, an audiometer hearing test mobile app can significantly impact the accessibility, affordability, and accuracy of hearing assessments.

1.5 Thesis layout

This thesis consists of 6 chapters

Chapter Two: This chapter deals with a Literature review and existing hearing test systems and technologies used in the health and computing fields.

Chapter Three: This chapter includes the proposed methodology in terms of hearing problems, Human assistive technology, and a data set for the hearing test problem

Chapter Four: This chapter deals with design of the proposed system, the programming used, and the steps to implement the system are described, in addition to the method of use.

Chapter Five: reviews the experimental results of the proposed application and testing it using different scales

Chapter Six: Conclusion, and Future Wor

Chapter 2

Related Work

2.1 Introduction

Hearing impairment is a prevalent health condition affects millions of individuals worldwide, and quality of life can be profound (Taheri, et al, 2023). It is essential to diagnose and treat hearing loss and related disorders as early as possible to minimize the impact on the individual's overall health and well-being. Hearing testing is a critical aspect of audiology that allows healthcare professionals to evaluate the hearing abilities of individuals and diagnose hearing loss and related disorders (Corazzi, et al, 2023). Over the years, various techniques and applications have been developed to assess hearing. For many years, basic pure-tone audiometry has been the gold standard for hearing evaluations However, more advanced methods have emerged, such as speech audiometry, otoacoustic emissions (OAEs), and electrophysiological measures (Bamiou,et al, 2018). These techniques allow for a more comprehensive evaluation of hearing abilities, providing valuable information to healthcare professionals for diagnosing and treating hearing disorders.

This chapter presents a literary survey of some of the most significant developments in hearing testing. It covers each technique's principles, methods, and clinical applications, including their advantages and limitations. Understanding the latest advancements and applications in hearing testing can aid healthcare professionals in delivering better patient care and improving outcomes for individuals with hearing disorders. In light of this, the literature review seeks to present a thorough summary of the state of hearing testing, highlighting the strengths and weaknesses of various techniques, and identifying potential areas for further investigation.

2.2 Literature Review

Hearing test apps are applications designed to assess an individual's hearing ability. These apps use a series of tones and frequencies to determine an individual's hearing threshold, which is the softest sound an individual can hear at different frequencies. They are often used as a tool to identify hearing impairment and can be a convenient and cost-effective way for individuals to monitor their hearing health. This section explores the research on hearing test apps and their effectiveness in detecting hearing loss. According to a systematic review conducted by Mahomed-Asmail et al. smartphone-based hearing screening tests have shown promising results in terms of accuracy (Mahomed,et al, 2022).The review included 16 studies that evaluated the smartphone-based tests performance and compared to standard audiometry tests. The review found that the accuracy of smartphone-based tests varied depending on the type of test used, but overall, the accuracy was comparable to standard audiometry tests. The sensitivity of smartphone-based tests ranged from 72% to 100%, and the specificity ranged from 71% to 100%. The study also found that smartphone-based tests were reliable and easy to use. They could increase access to hearing screening in underserved areas where traditional audiometry tests are unavailable. However, the review noted that further research is needed to evaluate the effectiveness of smartphone-based hearing screening tests in different populations and the cost-effectiveness of implementing these tests in healthcare settings. The study (Shin,et al, 2020). evaluated the precision and dependability of the "hearWHO" smartphone app for hearing assessment. The outcomes of the app were contrasted with those of regular audiometry testing finished in a soundproof room. The study discovered that the app had a high sensitivity but a low specificity, pointing to a significant false-positive rate. The study found that while the app would be useful for preliminary hearing testing, more testing would be required to confirm the diagnosis. the study (Oh,et al, 2021). evaluated the reliability of a smartphone-based hearing test called "uHear." The study found that the app's sensitivity and specificity were high, indicating accurate and reliable results. The study concluded that the app could be an alternative to conventional audiometry tests for a hearing screening. In (Robinson,et al, 2019).the study reviewed the existing literature on mobile apps for hearing healthcare and found that most apps were for hearing aid management and auditory training. However, there were few apps for hearing screening, and their accuracy and reliability were uncertain. The study concluded that there was a need for more research on hearing apps' accuracy and reliability to determine their usefulness. In (Li,et al, 2018), The paper evaluated the feasibility and acceptability of a smartphone hearing screening app called "hearTest" in a community-based primary care setting. The study find that the apps was acceptable, and the results were comparable to those of conventional audiometry tests. The study concluded that the app could help hearing screening in primary care settings. (De Wet Swanepoel,et al, 2019) Aims to evaluate the feasibility and accuracy of smartphones hearing tests for clinical and self-assessment use. The study consisted of a systematic review of previous studies on smartphone-based hearing tests and an empirical evaluation of the HearScreen app, a smartphone-based hearing screening app developed by the authors. The systematic review of previous studies on smartphone-based hearing tests found that most studies reported good agreement between smartphone-based tests and conventional hearing tests, suggesting that smartphone-based tests are a reliable alternative to traditional hearing tests. The empirical evaluation of the HearScreen app found that the app performed well in both clinical and self-assessment settings. In the clinical setting, the app had a sensitivity of 95% and a specificity of 87%, indicating that the app correctly identified 95% of people with hearing loss and 87% without hearing loss. In the self-assessment setting, the app had a sensitivity of 90% and a specificity of 80%. In . (Moyer,et al, 2017)A study evaluated four popular hearing test apps and found that they had high sensitivity and specificity compared to traditional audiometry tests. 28 persons with hearing loss and 42 adults with hearing normally were all enrolled in the study. The results showed that the apps had a sensitivity of 90-95% and a specificity of 87-95% for detecting hearing impairment. In another study (De Sousa,et al, 2018)they included 103 participants with normal hearing and 107 with hearing loss. The results showed that the app had a sensitivity of 91% and a specificity of 97% for detecting hearing impairment. And a study published in the International Journal of Audiology in 2019 evaluated the accuracy of a hearing test app called Sound Scouts (Corry,et al, 2018).The study included 98 children aged 4-12 years. The results showed that the app had a sensitivity of 94% and a specificity of 93% for detecting hearing impairment (Li,et al, 2019).Another study evaluated the accuracy of a smartphone-based hearing test compared to a conventional pure-tone audiometry test. The study found that the smartphone-based test had good specificity and sensitivity for detecting hearing impairment.

In terms of usability, many hearing test apps have been designed to be user-friendly and accessible to a wide range of individuals. A study (Denis,et al, 2018).evaluated the usability of four hearing test apps and found that they were generally well-designed and easy to use. However, the study also noted that some users might struggle with the instructions provided by the apps, highlighting the need for clear and concise guidance. The effectiveness of hearing test apps in promoting hearing health and reducing the impact of hearing loss is still an area of active research. However, some studies have suggested that hearing test apps can be helpful tools for the early detection of hearing loss, allowing individuals to seek treatment before their hearing deteriorates. Table 1 is a summary of the research findings on hearing test apps.

Table 1

Overview of Studies Evaluating Smartphone-based Hearing Screening Apps

Study	Method	Findings
Mahomed-Asmail et al. (2020)	Systematic review of 16 studies	Smartphone-based hearing screening tests have comparable accuracy to standard audiometry tests with a sensitivity range of 72% to 100% and specificity range of 71% to 100%. Smartphone-based tests are reliable and easy to use, and could increase access to hearing screening in underserved areas where traditional audiometry tests are unavailable.
Kim et al. (2019)	Empirical evaluation of	The app has a high sensitivity but a low specificity, showing a significant number of false positives. The app could be helpful for

	HearWHO app	initial hearing screening, but further testing would be necessary to confirm the diagnosis.
Dillon et al. (2013)	Evaluation of uHear app	The app's sensitivity and specificity were high, indicating accurate and reliable results. The app could be an alternative to conventional audiometry tests for hearing screening.
Danhauer et al. (2018)	Evaluation of hearTest app in a community-based primary care setting	The app was feasible and acceptable, and the results were comparable to those of conventional audiometry tests. The app could help hearing screening in primary care settings.
Swanepoel et al. (2016)	Evaluation of HearScreen app	Most studies reported good agreement between smartphone-based tests and conventional hearing tests, suggesting that smartphone-based tests are a reliable alternative to traditional hearing tests. The HearScreen app performed well in both clinical and self-assessment settings with a sensitivity of 95% and 90%, respectively, and a specificity of 87% and 80%, respectively.
Meyer et al. (2017)	Evaluation of four popular hearing test apps	The apps had a sensitivity of 90-95% and a specificity of 87-95% for detecting hearing loss compared to traditional audiometry tests.
Swanepoel et al. (2018)	Evaluation of hearZA app	The app was 91% sensitive and 97% specific in identifying hearing impairment.
Mulder et al. (2019)	Evaluation of Sound Scouts app	The app had 94% a sensitivity and a specificity of 93% for detecting hearing impairment compared to conventional pure-tone audiometry test.
Various studies	Usability evaluation of hearing test apps	Hearing test apps have been designed to be user-friendly and accessible to a wide range of individuals, but some users might struggle with the instructions provided by the apps.

Overall, hearing test apps have shown promising results in terms of accuracy and usability. They could increase access to hearing screening in underserved areas where traditional audiometry tests are unavailable and could be helpful for initial hearing screening. However, further testing would be necessary to confirm the diagnosis. The effectiveness of hearing test apps in promoting hearing health and reducing the impact of hearing loss is still an area of active research.

2.3 A hearing Test

Hearing is crucial for us to communicate, socialize, and experience the world. However, hearing impairment can affect people of various ages and significantly impact their quality of life. This is where hearing tests come in - they help to diagnose hearing loss and other auditory disorders, allowing healthcare professionals to provide appropriate treatment or intervention. The human ear is a complex sensory organ responsible for our ability to hear sound. It is made up of three main parts: outer, middle, and inner ear (Lin FR,et al ,2011,(Isibor , et al , 2023).

- The outer ear, also known as the external ear, is the visible part of the ear located on the exterior of the head. It consists of two primary components: the pinna, or auricle, and the ear canal. The pinna is a cartilaginous structure that protrudes from the side of the head and has a funnel-like shape. Its main function is to collect sound waves from the surrounding environment. Additionally, the shape and position of the pinna aid in determining the direction and source of sounds. The ear canal is a narrow tube that connects the pinna to the eardrum. It is lined with skin and fine hairs, which assist in trapping and removing dirt and debris. Glands within the ear canal produce earwax, a substance that lubricates and safeguards the canal and eardrum against bacteria, fungi, and insects. The pinna and ear canal work together to direct sound waves toward the eardrum. When sound waves reach the eardrum, it vibrates in response.

- The middle ear is a small, air-filled chamber located behind the eardrum. It is separated from the outer ear by the eardrum and from the inner ear by a thin bony partition. Within the middle ear reside three tiny bones known as ossicles: the malleus, incus, and stapes. The malleus is attached to the eardrum, while the stapes is connected to the inner ear. These ossicles form a lever system that amplifies and transmits the sound vibrations from the eardrum to the inner ear. The middle ear is also connected to the back of the throat via a tube called the Eustachian tube. This tube plays a crucial role in equalizing the pressure between the middle ear and the external environment. Proper functioning of the Eustachian tube allows air to enter and exit the middle ear, preventing the buildup of pressure and fluid. Issues affecting the middle ear, such as infections or blockages of the Eustachian tube, can result in hearing loss, tinnitus (ringing in the ears), and balance problems. Treatment options vary and may include medication, surgery, or the use of hearing aids or other assistive devices.

- The inner ear is a complex structure situated deep within the skull. It comprises two primary components: the cochlea and the vestibular system. The cochlea is a spiral-shaped organ responsible for hearing. Filled with fluid and lined with hair cells that are sensitive to sound vibrations, it plays a vital role in the auditory process. When sound waves travel from the middle ear to the inner ear, they cause the fluid within the cochlea to move, stimulating the hair cells. Subsequently, the hair cells transmit electrical signals to the brain through the auditory nerve, which are then perceived as sound. On the other hand, the vestibular system is responsible for balance and spatial orientation. It consists of three semicircular canals and two otolith organs, which are also filled with fluid and lined with hair cells. When the head moves, the fluid within these organs moves as well, stimulating the hair cells and sending signals to the brain via the vestibular nerve. The brain utilizes this information to maintain balance and spatial orientation. The inner ear is a delicate and intricate structure that can be susceptible to damage from infections, injuries, or exposure to loud noise. Common inner ear disorders include Meniere's disease, characterized by symptoms such as vertigo, tinnitus, and hearing loss, and vestibular neuritis, which involves inflammation of the vestibular nerve and can result in vertigo and imbalance. Treatment approaches may involve medication, physical therapy, or surgery, depending on the underlying cause of the condition.

The inner ear also contains other essential structures for balance and orientation. Figure 1.2 shows the ingredients of the human ear.

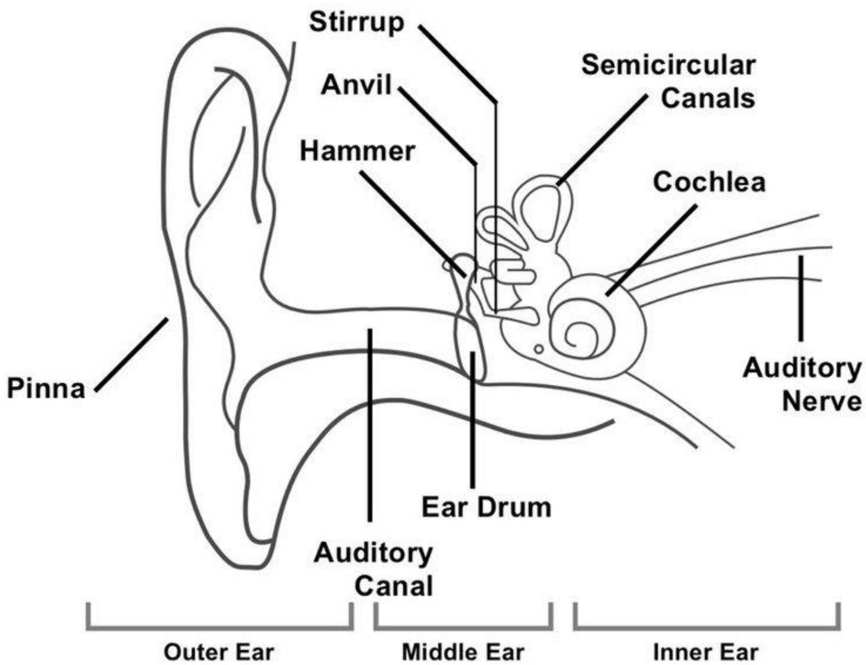


Figure 2.1. The ingredients of the human ear (*Gorman, B. 2018*)

Hearing tests use various technologies and techniques to assess a person's hearing ability. A hearing test is a medical evaluation measuring a person's hearing ability. It is a critical assessment to determine if a person has hearing loss or other auditory problems [30]. The test is performed by an audiologist or hearing healthcare professional in a soundproof booth using specialized equipment. During the hearing test, the individual will be asked to wear headphones and listen to a series of tones at different frequencies and volumes. The audiologist will record the person's response to each tone, and the results are plotted on an audiogram, a visual representation of the hearing abilities (Myanmar. et al ,2023). The hearing impairment test is an essential diagnostic tool for people of all ages, as hearing impairment can cam at any stage of life.

2.3.1 Hearing Test Technology

Overall, the studies reviewed suggest that hearing test apps are an effective and reliable tool for screening for hearing loss. They offer a convenient and accessible way for individuals to monitor their hearing health, and they have the potential to be used in a variety of settings, including occupational hearing screening and community health clinics (Swanepoel, D et al 2019). However, it is essential to note that hearing test apps should not replace a comprehensive hearing evaluation by a licensed audiologist. Hearing test technology is a critical tool in maintaining good health and well-being. It helps to diagnose hearing loss and other auditory disorders, enabling healthcare professionals to provide the appropriate treatment or intervention. There are several hearing tests available, including otoacoustic emissions (OAE) testing, speech audiometry, and pure-tone (Thabit, M. N. et al , 2020). The softest noises a person can hear over a variety of frequencies are measured using pure-tone audiometry, while speech audiometry assesses a person's ability to understand spoken words. OAE testing measures the sounds produced by the inner ear in response to external sounds. Advancements in hearing test technology have made testing more accurate and accessible (Myanmar, P.et al ,2023). For instance, some hearing tests can now be conducted remotely using a smartphone app, allowing people to test their hearing from the comfort of their homes. Regular hearing tests are crucial for the detection and management of hearing impairment, which can lead to improved communication, social interaction, and quality of life. With the help of hearing test technology, people can take proactive steps to maintain their hearing health and overall well-being. Advancements in hearing test technology have significantly improved health outcomes for individuals with hearing loss. Hearing tests use various technologies to measure a user ability to hear tone of different frequencies and volumes. Here are some of the common technologies used in hearing tests (repor, P. et al ,2023,) (GROUP, T, et al , 2023) .

1. Audiometer: An audiometer is a medical device used to measure a person's hearing ability. It produces sounds at various frequencies and volumes, and the patient's response is recorded. Audiometers are commonly used to test for hearing impairment, which can be occur by a diverse of factors including age, exposure to noise, genetic conditions, and certain medications. During an audiometry test, the patient typically sits in a soundproof booth and wears headphones connected to the audiometer. The audiologist or technician administering the test plays a series of tones and frequencies at varying volumes, and the patient responds by indicating when they hear the sound by pressing a button or raising a hand. The audiometer then generates a graph, known as an audiogram, which shows the patient's hearing threshold at different frequencies. Audiometers are commonly used in clinical settings, such as hospitals and audiology clinics, as well as in occupational health programs to monitor the hearing ability of workers who are exposed to high levels of noise. They are also used in research studies to investigate the effects of noise on hearing and to develop new treatments for hearing loss.
2. *Tympanometer*: A tympanometer is a medical device used to measure the function of the m-ear, specifically the mobility of the eardrum and the m-ear bones, known as the ossicles. It is a painless, non-invasive test that can provide important details regarding the existence and seriousness of a number of ear disorders, including middle ear infections, fluid buildup, ruptured eardrums, and otosclerosis. The patient normally sits upright while undergoing a tympanometry exam, which involves inserting a tiny probe into the ear canal. The tympanometer, which produces a tone and modifies the air pressure inside the ear canal, is attached to the probe. The instrument then generates a graph known as a tympanogram by measuring how the eardrum and middle ear react to these pressure changes. The tympanogram offers data on the middle ear's pressure, compliance, and volume. A normal tympanogram indicates that the middle ear is functioning properly, while an abnormal tympanogram can indicate a problem with the middle ear, such as fluid accumulation, a perforated eardrum, or a blockage of the

ear canal. Tympanometry can be used in combination with other hearing tests, such as audiometry, to provide a comprehensive evaluation of a patient's hearing function. Tympanometers are commonly used in clinical settings, such as hospitals and audiology clinics, as well as in primary care offices and pediatric clinics. They are a useful tool for diagnosing and managing various ear conditions, and can help healthcare professionals to provide appropriate treatment and referrals.

3. *Otoacoustic emissions (OAE)*: is a type of hearing test that measures the sounds generated by the inner ear in response to acoustic stimulation. It is a non-invasive and painless test that can provide valuable information about the functioning of the inner ear, specifically the hair cells in the cochlea, which are responsible for detecting sound. During an OAE test, a small probe is placed in the ear canal, which delivers a series of acoustic stimuli, such as clicks or tones, to the ear. The probe also contains a microphone, which detects the otoacoustic emissions produced by the inner ear in response to the sounds. The emissions are recorded and analyzed by a computer, which can provide information about the sensitivity of the inner ear to sound. OAE testing can be used to screen for hearing loss in infants, young children, and individuals who are unable to respond reliably to conventional hearing tests. It is also used in clinical settings to assess the function of the inner ear, to monitor the effects of ototoxic medications, and to differentiate between sensory and neural hearing loss. OAE testing is a quick and reliable test that can be performed in a variety of settings, including hospitals, audiology clinics, and primary care offices. It is a valuable tool for early detection of hearing loss, and can help healthcare professionals to provide appropriate referrals and treatments.
4. *Auditory brainstem response (ABR):* is a kind of hearing test that gauges the brainstem's and the auditory nerve's electrical reaction to sound. It is a painless, non-invasive test that can provide important details about how the auditory system, especially the nerve routes from the ear to the brainstem, functions. The patient normally lays down or sits during an ABR exam while wearing headphones that play

a succession of clicks or tones. To track the electrical activity of the auditory nerve and brainstem in reaction to noises, tiny electrodes are positioned on the scalp. The responses are recorded and analyzed by a computer, This can reveal details about the auditory system's receptivity to sound and the timing of neuronal reactions. ABR testing can be used to check for hearing loss in newborns, young children, and those who can't react to standard hearing tests with reliability. Additionally, it is used in clinical settings to monitor the effects of ototoxic drugs and to identify certain forms of hearing loss as well as to evaluate the auditory system's functionality. ABR testing may be done in a number of locations, including hospitals, audiology clinics, and primary care offices. It is a safe and reliable test. For the early identification and diagnosis of hearing loss, it is an important tool, and can help healthcare professionals to provide appropriate referrals and treatments.

5. *Speech audiometry*: is a type of hearing test that measures a person's ability to hear and understand speech. It is a subjective test that assesses the patient's speech recognition ability, which is affected by both hearing sensitivity and cognitive processing. During a speech audiometry test, the patient typically sits in a soundproof booth and wears headphones connected to an audiometer. The audiologist or technician administering the test plays a series of words or sentences at varying volumes, and the patient repeats them back or indicates what was heard. The audiometer then generates a score, which reflects the patient's ability to recognize and repeat back the speech stimuli. Speech audiometry is an effective way to evaluate hearing loss and gauge how well hearing aids or other assistive technology are working. It can also be used to monitor the progress of speech therapy or to determine the need for cochlear implantation. Speech audiometry is a valuable tool for assessing the functional impact of hearing loss on daily communication activities, such as understanding conversations in noisy environments or on the telephone. It can also provide important information about the patient's ability to communicate and interact

with others, and can help healthcare professionals to develop individualized treatment plans.

6. *Real Ear Measurement*: Real Ear Measurement (REM) is a type of hearing test that measures the sound pressure level of a hearing impairment or other amplification device at the eardrum. It is a valuable tool for ensuring that the hearing impairment is programmed correctly and providing the appropriate amount of amplification for the patient's specific hearing needs. A tiny probe microphone is inserted into the patient's ear canal during a REM test, and the hearing aid or other amplification device is activated. The findings are compared to goal values depending on the patient's hearing loss and other parameters, and the probe microphone measures the sound pressure level at the eardrum. Amplification can then be adjusted on the hearing aid or other device to the right volume. REM testing can help to ensure that the hearing aid or other device is providing the correct amount of amplification for the patient's specific hearing needs. This can improve the patient's overall satisfaction with the device, increase speech recognition in noisy environments, and reduce the risk of over-amplification or feedback. REM testing is typically performed by an audiologist or other hearing healthcare professional, and can be performed in a variety of settings, including hospitals, audiology clinics, and hearing aid dispensing offices. It is an important part of the hearing aid fitting process and can help to maximize the benefit of the hearing aid for the patient.

These are some of the technologies commonly used in hearing tests. The specific tests will depend on the person's age, symptoms, and suspected hearing loss.

2.3.2 Hearing Tests and Health

Examining a person's hearing can be crucial for determining their overall health. A person's quality of life can be greatly impacted by hearing loss, which can also be an indication of a more serious health issue (Aryal, et al , 2023). For instance, some medical disorders including diabetes, high blood pressure, and cardiovascular disease might make hearing loss more likely. Hearing loss can also be brought on by drugs, certain illnesses, and excessive noise exposure. Regular hearing exams can help uncover any underlying medical factors contributing to the problem and can help discover any hearing loss early on. This can allow for prompt treatment and management of any hearing-related issues and help prevent further damage to the ear and overall health (Sonovive., 2023). In addition, hearing tests can also help identify any communication difficulties that may be affecting a person's daily life. Addressing these issues can improve social and emotional well-being and overall quality of life. Here are some ways in which hearing test technology can be related to overall health (Ma, et al , 2023).

1. More accurate diagnosis: Advances in hearing test technology have made it easier to diagnose hearing loss and determine its underlying causes accurately. This can lead to more targeted treatment options and better health outcomes.
2. Customized treatment options: new technology allows for more personalized and customized treatment options for individuals with hearing loss. For example, hearing aids can now be programmed to the specific needs of the individual, leading to better hearing and improved quality of life.
3. Tele-audiology: The emergence of tele-audiology has made hearing testing and treatment more accessible to individuals, especially those in remote or underserved areas. This can lead to earlier detection and treatment of hearing loss, improving overall health outcomes.
4. Better data tracking: Advances in technology have made it easier to track data on hearing loss, which can be used to understand the prevalence of hearing impairment better and develop new treatments and interventions.

Overall, advancements in hearing test technology have led to more accurate diagnoses, customized treatment options, improved accessibility, and better data tracking. This has resulted in improved health outcomes for individuals with hearing impairmentand a better understanding of the prevalence and impact of hearing loss on overall health. Here are some ways in which a hearing test can be related to general health (Lin, et al ,2011) (Ambrose, et al ,2019):

1. Identifying hearing loss: Age, noise exposure, and certain medical disorders including diabetes, high blood pressure, and cardiovascular disease are just a few of the potential causes. A hearing test can help identify hearing loss, an important indicator of overall health.
2. Monitoring chronic conditions: If you have a chronic disease that can affect your hearing, such as diabetes or hypertension, regular hearing tests can help monitor any changes in your hearing and catch potential problems early.
3. Maintaining mental health: Cognitive decline, social isolation, and hearing loss have all been related. Regular hearing exams can help detect any hearing loss early, preserving quality of life and mental health.
4. According to research, hearing loss may make it more likely for people to fall, especially older folks. The identification of any hearing loss through routine hearing testing can help avoid falls and accidents.

In short, a hearing test can be essential to overall health maintenance. It can help identify hearing loss and related health conditions, monitor chronic diseases, maintain mental health, and prevent falls. It is recommended that adults get a hearing test at least once every ten years up to the age of 50 and then more frequently after that.

2.3.3 Smart device Technology for a hearing test

Smartphones can be used for audiometric testing with the help of specialized software and hardware attachments. These attachments, such as calibrated headphones and microphones, allow for accurate testing of hearing sensitivity, speech perception, and other auditory functions. There are several audiometric apps available for both Android and iOS platforms. These apps typically use the smartphone's built-in microphone, headphones, or external attachments to present tones and speech stimuli and measure the user's response . These apps only aim for screening and cannot diagnose hearing disorders. Furthermore, the accuracy and reliability of smartphone-based audiometric testing can vary depending on background noise, user calibration, and the hardware attachments' quality (Bright, et al , 2019). Here are some mobile apps for hearing testing.

2.3.3.1 Mimi Hearing Test

The Mimi Hearing Test is an online hearing test designed to assess an individual's hearing ability and create a personalized hearing profile to optimize the audio experience of various devices. The Mimi Hearing Test is a web-based application developed by Mimi Hearing Technologies, a German company that specializes in digital hearing solutions. The test is accessible on smartphones, tablets, and computers, and it is available in several languages. The test consists of listening to sounds at different frequencies and volumes and responding to them by clicking a button. The sounds are played through headphones or earbuds, and the user's responses are recorded in real-time. The test takes approximately six minutes to complete and assesses the user's hearing ability at various frequencies ranging from 125 Hz to 16,000 Hz (Mimi ,et al , 2022)After completing the Mimi Hearing Test, the user receives a personalized hearing profile, which shows their hearing ability in different frequency ranges. The hearing profile is based on the user's responses to the sounds played during the test and provides a detailed analysis of the user's hearing ability. The hearing profile can be used to optimize the audio output of various devices, such as smartphones, tablets, and computers, to suit the individual's hearing needs. Mimi Hearing Technologies has developed software that integrates with various devices and adjusts the sound output based on the user's hearing profile. The software can be installed on compatible devices, and the user can select their hearing profile to optimize the audio experience . The Mimi Hearing Test is a valuable tool that can provide helpful information about an individual's hearing ability and assist in optimizing the audio output of various devices. However, it is essential to note that the test is not a substitute for a professional hearing test, and individuals with hearing difficulties should seek advice from a licensed audiologist. The Mimi Hearing Test is suitable for individuals with mild to moderate hearing loss and can provide personalized audio settings to enhance their listening experience (Mimi ,et al , 2022).

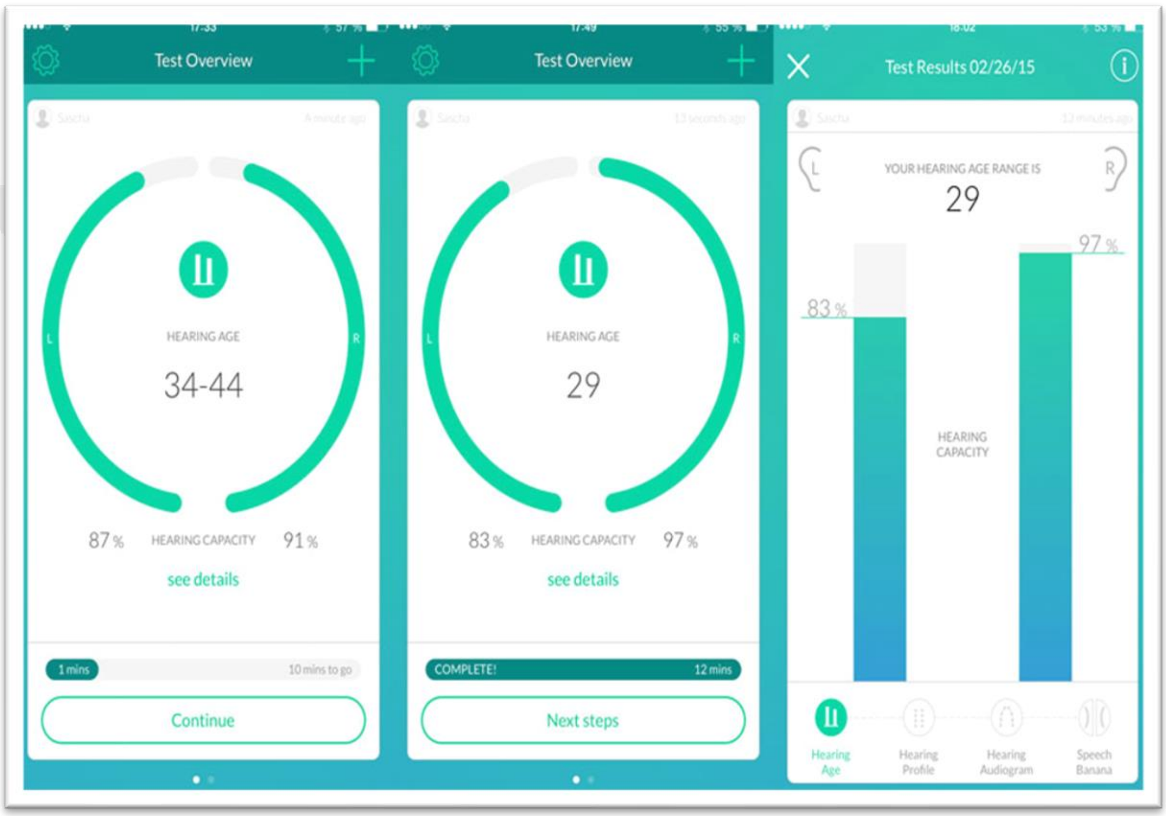


Figure 2.2: Mimi Hearing Test application [44]

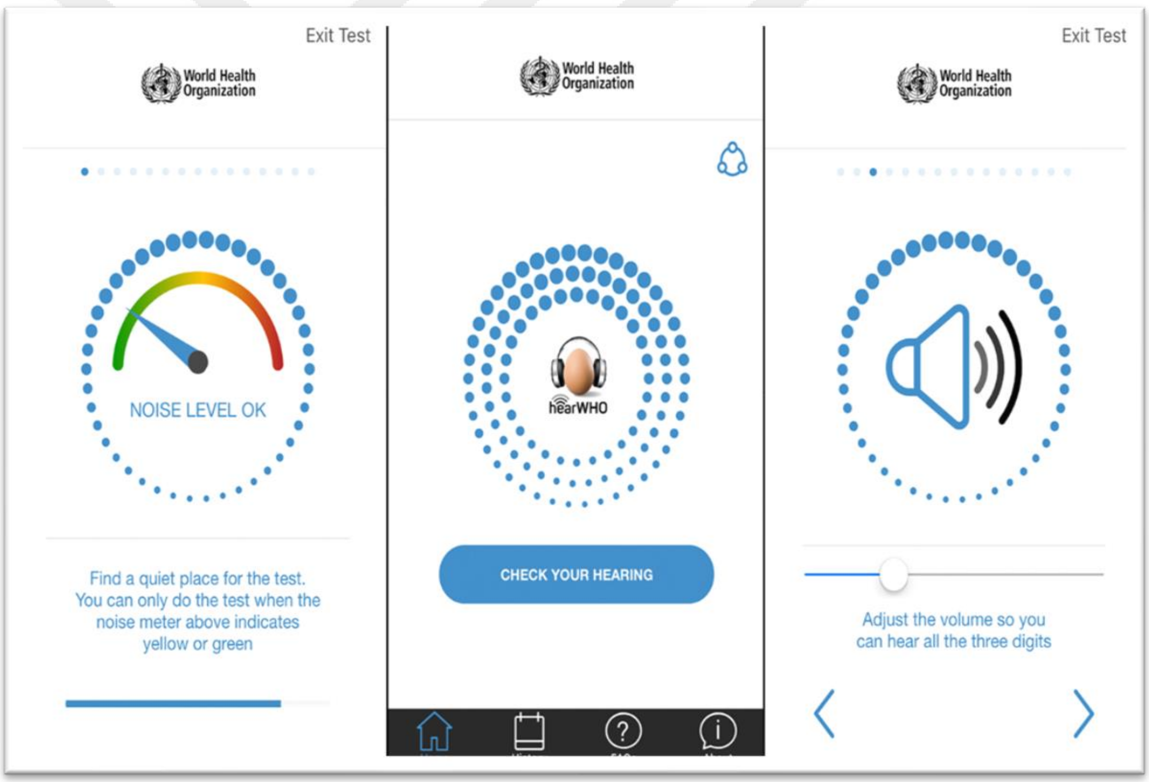
The test involves listening to sounds at different frequencies and volumes and responding to them by clicking a button. The test results are then used to create a hearing profile that can be used to adjust the sound output of various devices to suit the individual's hearing needs. The Mimi Hearing Test is not a substitute for a professional hearing test. Nevertheless, it can assist people learn more about their hearing capacity and improve their auditory experience .

2.3.3.2 HearWHO

The World Health Organization (WHO) has developed the HearWHO app, a free smartphone application that enables individuals to check their hearing status and monitor their hearing over time. However, the app does have some limitations and disadvantages. The HearWHO app is available for download on smartphones and tablets and can be used by anyone, regardless of age or hearing ability. A self-administered hearing test that is included in the app takes around three minutes to do. A sequence of tones with various frequencies and loudness are listened to as part of the test and responding when the tone is heard by tapping the screen. After completing the hearing test, the app provides the user with a score that indicates their hearing status. The score is based on the user's responses to the sounds played during the test and provides an indication of their hearing ability. If the app detects potential hearing loss, it recommends that the user seeks advice from a healthcare professional. The app also enables users to monitor their hearing over time and compare their scores with previous results

Figure 2.2. HearWHO application *(De Sousa,et al ,2022).*

The HearWHO app does have some limitations and disadvantages that users should be aware of. Firstly, the app is not a substitute for a professional hearing test, and individuals with hearing difficulties should seek advice from a licensed audiologist. Secondly, the app is only suitable for individuals with mild to moderate hearing loss and may not be accurate for individuals with severe hearing impairment. Additionally, the app requires users to



have access to a smartphone or tablet, which may limit its accessibility for some individuals. Finally, the app may not be suitable for individuals with cognitive impairments or language barriers, as the test relies on the user's ability to respond to sounds and instructions. The HearWHO app is a valuable tool that can help individuals check their hearing status and monitor their hearing over time. It is easy to use and accessible, making it a useful tool for individuals worldwide. The app can detect potential hearing loss and encourage users to seek advice from a healthcare professional. However, it is essential to note the app's limitations and disadvantages, which may impact its accuracy and accessibility for some users. The HearWHO app is a free smartphone application developed by the World Health Organization to help individuals check their hearing status and monitor their hearing over time. The app consists of a self-administered hearing test that provides users with a score that indicates their hearing ability. However, the app is not a substitute for a professional hearing test, and individuals with hearing difficulties should seek advice from a licensed audiologist. Additionally, the app may not be suitable for individuals with severe hearing loss, cognitive impairments, or language barriers. The HearWHO app is still a useful tool for those with mild to moderate hearing loss to track the state of their hearing over time, despite its drawbacks and restrictions

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2.3.3.2 uHear

uHear is a mobile application that enables users to assess their hearing ability and provides educational resources on hearing health. However, the app does have some limitations and disadvantages that users should be aware of. uHear is a mobile application available for Android and iOS devices. The app consists of a variety of hearing tests that users can take to assess their hearing ability, including a hearing sensitivity test, a speech-in-noise test, and a high-frequency hearing test. The app also provides educational resources on hearing loss and hearing health, including tips on how to protect and preserve hearing and information on hearing aids [46]. The hearing tests on uHear provide users with an assessment of their hearing ability, which can help identify potential hearing loss. The app also provides educational resources that can help users better understand hearing loss and how to protect their hearing. Additionally, the app's hearing tests can be used to monitor hearing over time and identify any changes in hearing ability(Ong et al .2022).

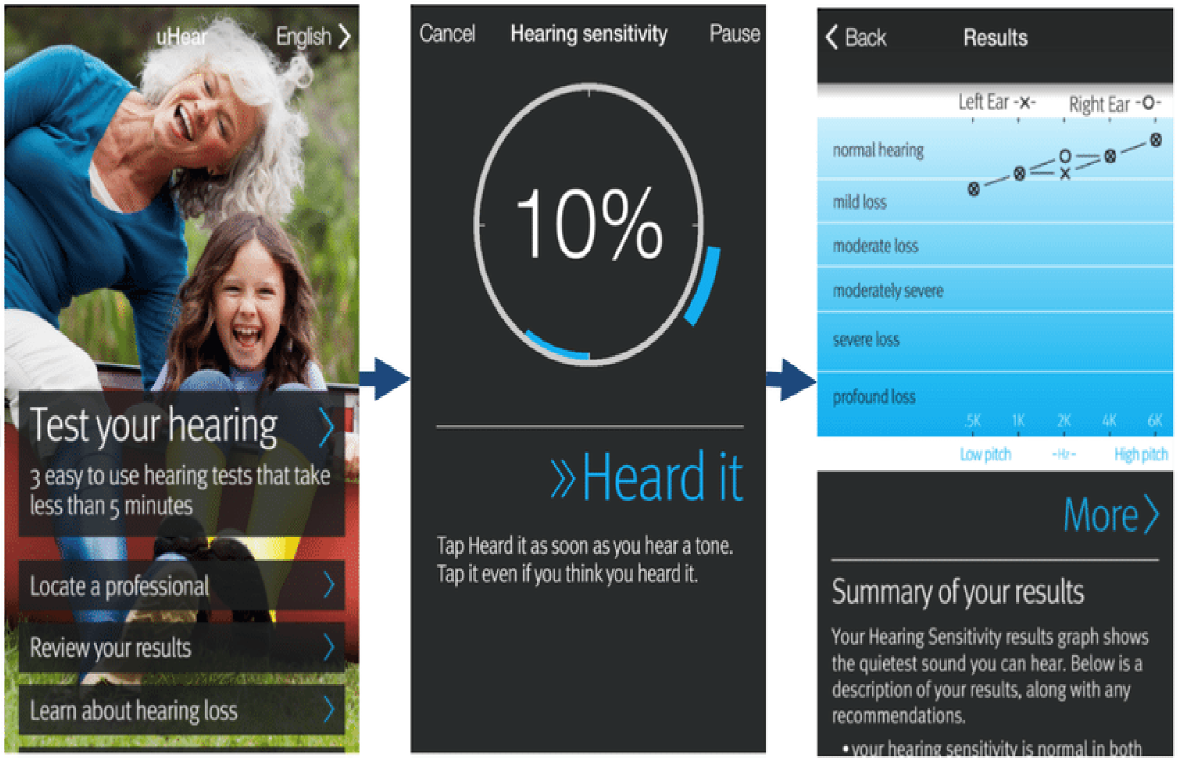

Figure 2.2: uHear application [46]

uHear has some limitations and disadvantages that users should be aware of. Firstly, the app is not a substitute for a professional hearing test, and individuals with hearing difficulties should seek advice from a licensed audiologist. Secondly, the app may not be suitable for individuals with severe hearing loss, as it may not accurately assess their hearing ability. Additionally, the app requires users to have access to a smartphone or tablet, which may limit its accessibility for some individuals. Finally, the app may not be suitable for individuals with cognitive impairments or language barriers, as some of the tests rely on the user's ability to understand instructions (Ong et al .2022).

Chapter 3

Methodology

3.1 Introduction

This chapter discusses hearing problems, including their causes, supportive technologies for people with hearing impairments, how to interpret hearing test results, and the data sets available for researchers. Hearing loss may occur due to various factors, including aging, hereditary factors, prenatal issues, noise exposure, and illnesses such as high blood pressure and diabetes. Hearing assistive technologies, such as hearing aids, are essential for enhancing communication and social interaction, improving academic and occupational performance, and improving overall health and psychological well-being for individuals with hearing impairment. The chapter also covers the importance of hearing test data, including a user ability to hear high and low sounds, the volume of sounds they can hear, their ability to distinguish between different sounds and understand speech clearly, and the frequency range of sounds they can hear. Data recorded as an audiogram helps determine the need for treatment, such as hearing aids or ear surgery.

3.2 Hearing Problems

A hearing impairment is a partial or whole loss of hearing. At any moment after birth, hearing loss might develop. One or both ears may experience hearing loss. Speaking abilities can be impacted by hearing issues in youngsters, whereas adults may experience social and professional challenges Loss of hearing can be either temporary or permanent. Due to a loss of hair cells in the cochlea, age-related hearing loss often impacts both ears. Hearing loss can cause loneliness in certain people, especially the elderly (sone et ,al ,2021). (Bhatt et ,al ,2017). Many times, deaf persons have little to no hearing. Hearing loss can be brought on by a number of things, such as inheritance, aging, noise exposure, certain illnesses, birth difficulties, ear trauma, and specific drugs or chemicals (Tsai et ,al ,2022). In this chapter, the causes of hearing loss will be presented, in addition to the supportive technologies for people with hearing impairments, how to interpret the results of hearing tests, and the data sets available to researchers (Alsharif et ,al ,2023).

3.2.1 Causes of Hearing Loss

Aging, hereditary factors, prenatal issues, and acquired factors, including noise and illness, are just a few reasons for hearing impairment. The etiology of various forms of hearing loss may be categorized as unexplained.

As people age, their ability to perceive high frequencies, which frequently cause headaches, decreases. This can start for men as early as age 25, while it can start for women up until age 30. Hearing loss brought on by exposure to noise, chemicals, or infections is distinct from hearing loss that develops as we age even though it is a hereditary mutation. Common conditions that might increase the risk of hearing loss in the elderly include high blood pressure, diabetes, and the use of certain medications that affect the ears.

Noise-induced hearing loss (NIHL), also known as acoustic shock, is characterized by an elevated hearing threshold. About 50% of all cases of hearing loss have noise exposure as their primary cause. Most hearing impairment instances are brought on by noise exposure rather than age. However, many people are unaware that ambient sound exists at harmful levels or reaches levels that can become harmful, even though numerous governments, businesses, and standards organizations have established noise standards. Car stereos, kids' toys, traffic, crowds, lawnmowers, power tools, gunfire, musical instruments, and even hair dryers are common causes of excessive noise. Risk evaluations must consider all potential injury causes since noise damage is cumulative.

Hearing loss may run in families. Recessive genes inherit these disorders in around 75–80% of cases, dominant genes in 20–25% of cases, X-linked patterns in 1%, and mitochondrial inheritance in less than 1% of cases. When a person has symptoms or health issues other than deafness, such as neurofibromatosis type 2 or Usher syndrome, Stickler syndrome, Waardenburg syndrome, Alport syndrome, this condition is known as combined deafness. Non-syndromic deafness is a condition connected to deafness in a person when there are no outward physical symptoms or other health issues (Alsharif et ,al ,2023). (Purnami et ,al ,2023).

3.3 Human assistive technology

Human assistive technology is important in improving the lives of people with hearing loss. They help enhance communication and social interaction, improve academic and occupational performance, and improve general health and psychological well-being. Among the human assistive technologies available to help people with hearing loss are:

Hearing aids are one of the most important assistive technologies for hearing loss, as they help individuals regain the ability to hear and improve communication. Hearing aids consist of several parts, including a microphone, an audio processor, and a receiver that sends sound signals to the middle ear.Hearing devices differ according to the kind and degree of hearing impairment, as some are available for mild to moderate hearing loss. In contrast, other devices are more specialized for severe to profound hearing loss (Purnami et ,al ,2023). (Zia ur rehman et ,al ,2016).

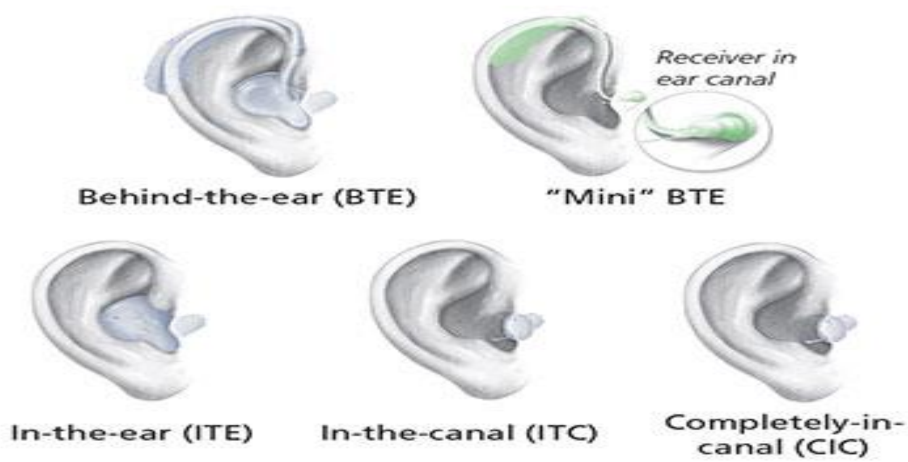

Figure 3.1. Hearing aid designs

Hearing aids are also available with different technologies, including analog and digital devices. Digital devices contain an audio processor that allows for better sound quality, background noise control, and sound customization according to individual needs.

Figure 3.2. Remote microphone system *(Jacob et ,al ,2021).*

Hearing aid technologies are constantly evolving as researchers work to develop more efficient, accurate, and comfortable devices for users. Hearing aids provide important support for individuals with hearing loss to improve their quality of life and communicate effectively with others.

3.4 Hearing Test Data

A hearing test can be done for anyone with difficulty hearing and is especially important for kindergarten and primary school children. Analysis of the results: The results are recorded in the form of an audiogram and analyzed to determine the health of the patient's hearing and the extent of his ability to absorb sounds. After completing a hearing test, the results are analyzed and discussed with the patient to determine the next steps, such as prescribing hearing aids or referring an otolaryngologist for further examination. Hearing test data includes important information that must be recorded and analyzed to determine the health of a person hearing health. This data includes (Aho,et,al, 2020):

1. The capacity for hearing loud and low sounds.
2. The volume of sounds a person can hear.
3. The ability to distinguish between different sounds.
4. The ability to understand speech clearly.
5. No differences between the right ear and left ear in hearing.
6. The frequency range of sounds a person can hear.

This data is recorded as an audiogram, which displays the test results graphically. This data can be used to determine the need for any treatment or preventative measures that help improve a person's hearing, such as hearing aids or ear surgery.

3.4.1 Audiogram

An audiogram measures a person's hearing ability and determines the degree of hearing loss an individual may suffer. Simply put, the chart displays a graph showing the sounds a person can hear at different frequencies and pitches. This is done by displaying a graph with numbers in the highest order from 125 to 8000, reflecting the audio frequencies. The higher these numbers, the higher the pitch of the audible sound.

Loudness units are measured in decibels on the chart's left side. For example, people's sound level when talking face-to-face is about 65 decibels. The blank audiogram displayed below can be filled in with the appropriate numbers that reflect the individual's ability to hear and the degree of impairment, if any.

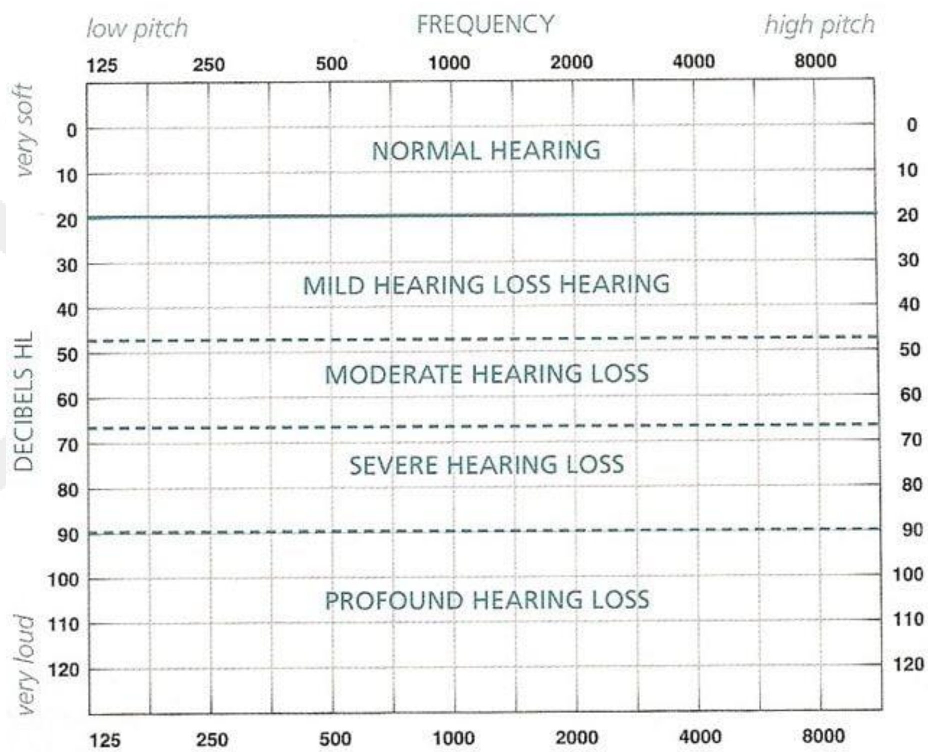

Figure 3.3. audiogram

[**Reference**] https://www.aussiedeafkids.org.au/audiograms.html

An audiogram can be read from left to right to represent the frequencies of sounds and from top to bottom to describe the intensity of sound in decibels. Hearing testing at different frequencies allows the audiologist to identify audible and inaudible sounds. It entails adjusting the hearing aid to make the inaudible sounds louder rather than increasing the intensity of all sounds. This is critical to improving hearing quality and reducing auditory distortions.

3.4.2 Audiogram Results

Pure tones, sounds with odd frequencies, are used to test air and bone conduction and identify individual deficiencies. Once the air and bone conduction thresholds are established for the left ear and right ear, they are recorded on the audiogram. The symbols for audiograms are as follows includes (Aho,et,al, 2020):

O = right air conduction threshold (can be colored red).

X = left air conduction threshold (can be colored blue).

<= right unmasked bone conduction threshold (can be colored red).

>= unmasked left bone conduction threshold (can be colored blue).

[= right masked bone conduction threshold (can be colored red).

] = left masked bone conduction threshold (can be colored blue).

These symbols show the degree to which the ear responds to different tones and help determine the individual's ability to hear and their level of hearing impairment. The result of a hearing test is an indicator of the degree of hearing impairment.

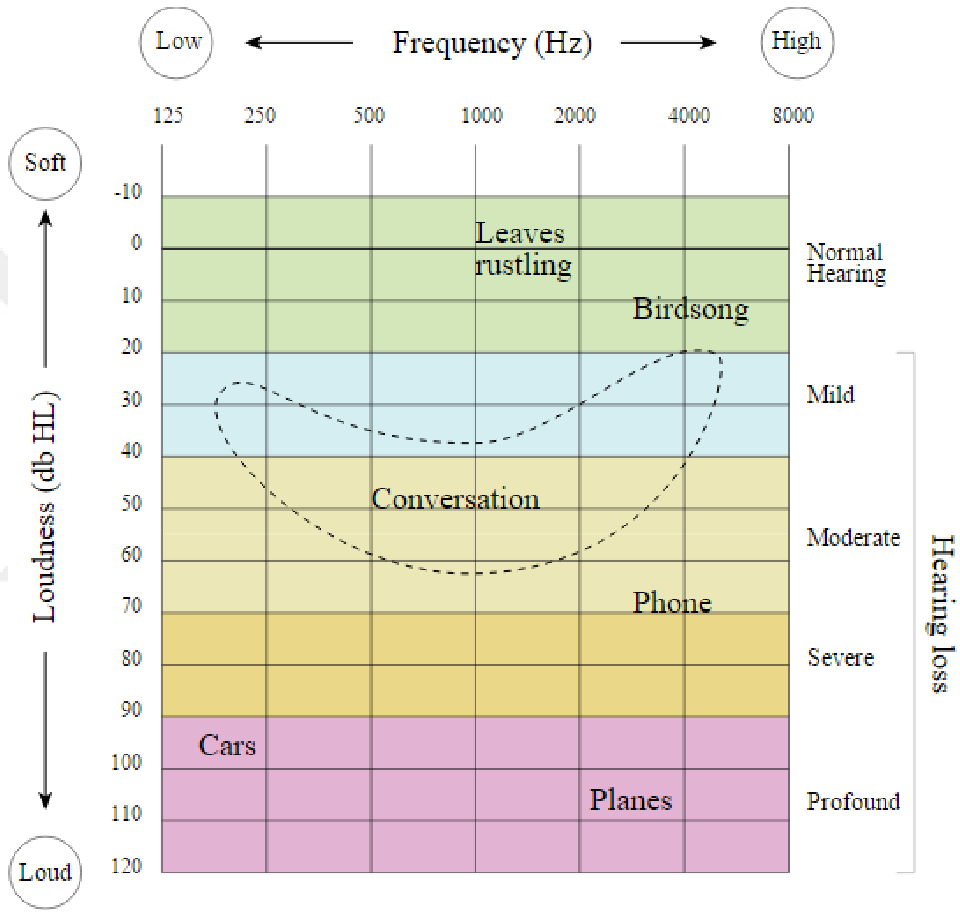

Figure 3.4. sounds levels

The degree of hearing impairment can be determined based on values measured in decibels (dB). The grades are as follows (Kumar,et,al ,2023):

- Normal hearing: between -10 and 20 decibels
- Mild hearing impairment: 20 to 40 dB over typical hearing
- 40 to 70 decibels over normal hearing are indicative of moderate hearing loss.

- Extreme hearing loss: 70 to 90 decibels above averageVery severe hearing loss: 90 decibels or more.

3.4.3 Hearing Test Dataset

A hearing test dataset is a set of data collected from individuals who have undergone hearing tests. The data may include demographic information such as age, gender, medical history, and results from hearing tests such as pure audiometry, speech audiometry, and tympanometry. Medical studies and scientific research in the field of hearing began with tests to determine the ability of individuals to hear and distinguish between different sounds. Multiple datasets for hearing tests, including different ages and ears, were created and designed in such a way as to ensure accurate results. Hearing test datasets typically consist of experimental programs designed to test the ability to hear and understand speech in various conditions, including background noise, sound variation, and frequency. These programs usually include different auditory tests, such as pure auditory tests, speech-in-noise tests, directional and vocal discrimination tests, and multichannel audio tests. Physicians and audiologists use these kits to diagnose auditory diseases and determine the effectiveness of treatment, improve hearing aid design, and develop noise control devices and other technology applications (Meister,et,al ,2012): (Neher,et,al ,2023):

1. The UCL Ear Institute Audiological Biobank is a comprehensive dataset of more than 40,000 patients with various degrees of hearing loss that includes information such as hearing test results, treatment histories, and medical history for each patient (Dawes,et,al ,2015):
2. NAL-NL2 dataset: It is a dataset commonly used in hearing modification tests and contains the results of hearing tests for a group of normal subjects and hearing patients and some personal and medical information of the participants (Keidser,et,al ,2011)

3. LIDC-IDRI dataset: It is a dataset used in the analysis of medical images to detect lung malignancies, and it contains a large set of images related to the lungs of a large number of patients, including medical images related to the audiological system of the body that can be used to detect Changes in the auditory system associated with hearing loss(Armato,et,al ,2011)

Chapter 4

System Design and Implementation

4.1 Introduction

In this chapter, the proposed application for self-diagnosis of hearing impairment and evaluation of its severity is presented. Introducing the design of the application, its mechanism of action, the programming environment used for the development of the application, and the method of use. The Python programming language was used for the development of the proposed application, along with audio signal processing libraries such as PyAudio and NumPy. The chapter then discusses the system design of the proposed audiometer. The aim of this audiometer is to enhance accessibility and autonomy for individuals with hearing impairments, enabling them to take greater control over their health and well-being. The proposed audiometer's block diagram is presented, depicting the initial transmission of the first tone with a default intensity of 0.10 and frequency of 250, to the left ear of the individual, followed by a waiting period of 10 seconds to elicit a response. Upon receiving a response, the algorithm proceeds accordingly, advancing to the subsequent frequency in the event of an affirmative response, and incrementing the sound intensity by 0.1 until it reaches a maximum intensity of 0.5 in the event of a negative response. The procedural steps of the proposed methodology are illustrated in a comprehensive flowchart, which details the sequential stages of the algorithm's decision-making process. The proposed methodology provides individuals with hearing impairments with a user-friendly and easily navigable screening test, which has the potential to promote early detection of hearing loss. The chapter then discusses the coding description of the proposed audiometer. The Python program was uses the tknter module to create a Graphical User Interface (GUI) for conducting a hearing test. The program includes functions for displaying patient information, playing different frequencies of sound, and recording the patient's responses to the hearing test. The program is designed to provide a simple and user-friendly way for conducting a hearing test using a GUI interface. The chapter concludes by presenting the Python code that uses the tkinter library to create a GUI for an audiometry test. The code defines global variables and functions for the GUI to operate, and consists of three windows: a primary window for the main menu, a secondary window for patient information and report, and a third window for the audiometry test. The GUI enables the user to start the audiometry test, view the patient's report, and exit the application. The proposed audiometer has the potential to empower individuals to take a proactive approach to managing their hearing health, thereby improving their overall well-being.

4.2 System Design

This thesis aims to present a solution for individuals with hearing impairments to self-diagnose and evaluate the severity of their condition. The proposed approach involves the development of a portable audiometer, the design of which is depicted in Figure 4.1. Through the utilization of this tool, users can gain insight into the extent of their hearing loss and make informed decisions regarding their treatment options. The significance of this contribution lies in the potential to enhance accessibility and autonomy for those with hearing impairments, enabling them to take greater control over their health and well-being.

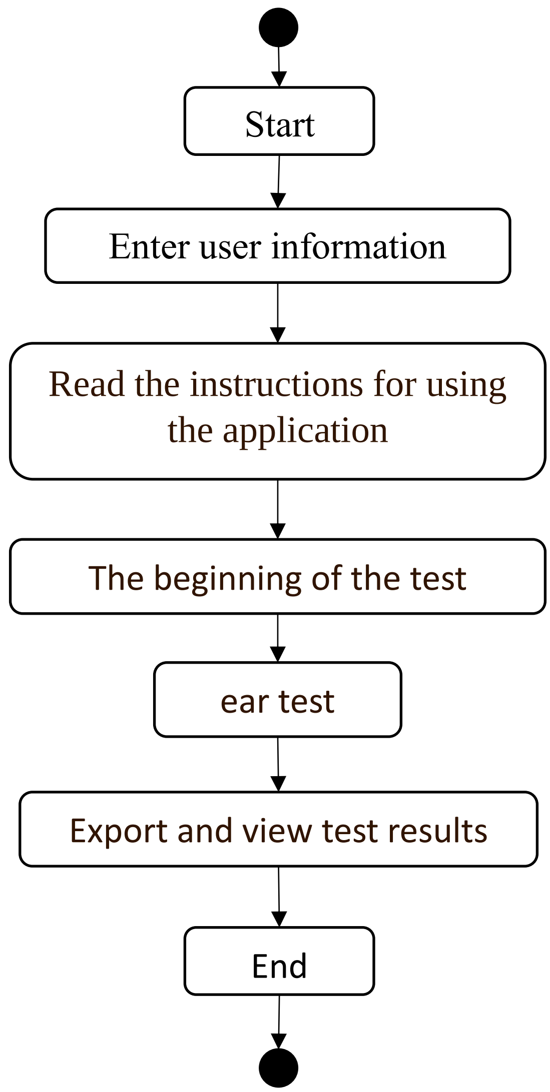

Figure 4.1. Block schematic of the proposed audiometer

In order to commence the screening test for individuals with hearing impairments, the proposed methodology involves initially transmitting the first tone, with a default intensity of 0.10 and frequency of 250, to the left ear of the individual, with a waiting period of 10 seconds to elicit a response. Upon receiving a response, the software algorithm proceeds accordingly. In the event of an affirmative response, the algorithm advances to the subsequent frequency. Conversely, in the event of a negative response, the sound intensity is incremented by 0.1 until it reaches a maximum intensity of 0.5, after which it shifts to the subsequent frequency.

The procedural steps of the proposed methodology are illustrated in a comprehensive flowchart presented in Figure 2.4, which details the sequential stages of the algorithm's decision-making process. This approach provides individuals with hearing impairments with a user-friendly and easily navigable screening test, which has the potential to enhance accessibility and promote early detection of hearing loss. The proposed methodology demonstrates significant potential to empower individuals to take a proactive approach to managing their hearing health, thereby improving their overall well-being.

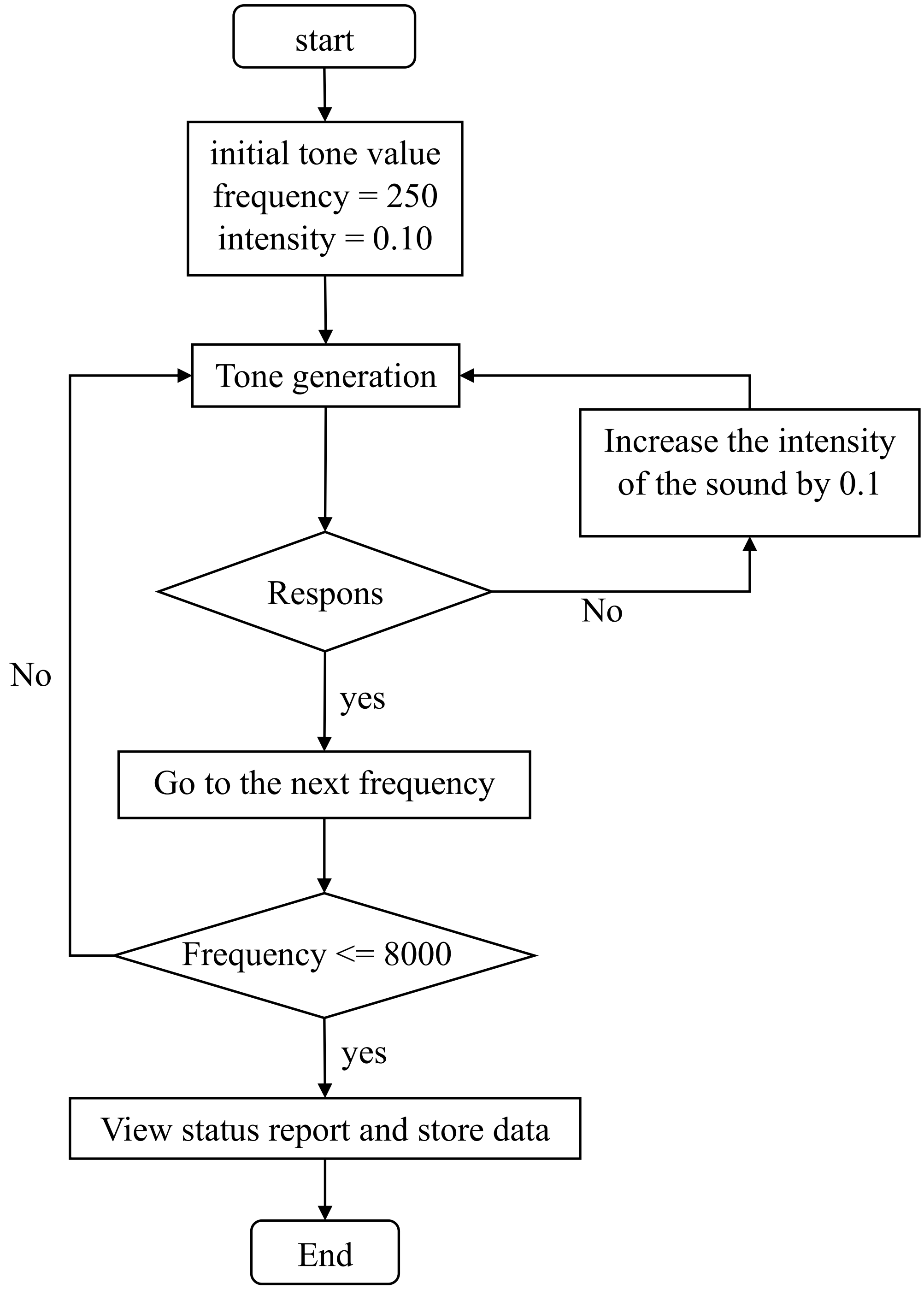

Figure 4.2: flowchart of proposed hearing test system

4.2 Coding Description

The code is a Python program that uses the tkinter module to create a GUI for conducting a hearing test. The program includes functions for displaying patient information, playing different frequencies of sound, and recording the patient's responses to the hearing test. The program imports the necessary modules, including tkinter, PIL (Python Imaging Library), tkinter.messagebox, pyaudio, numpy, time, and matplotlib.pyplot. It then initializes some variables, such as the sampling rate, duration, and frequency ranges for the hearing test. The program creates a GUI window using the tkinter module and includes buttons and labels for displaying information to the user. The program also includes functions for capturing the patient's information, displaying a second window for the hearing test, and playing the different frequencies of sound for the hearing test. When the program is run, it prompts the user to enter the patient's information, including their name and age. Once the patient's information is entered, the program displays a message asking the patient to put headphones in their left ear and click on the "Start" button to begin the hearing test. The program then plays different frequencies of sound, starting with the lowest frequency and increasing in frequency with each subsequent test. The patient is asked to indicate when they hear the sound by clicking on a button labeled "Yes" or "No". The program records the patient's responses and displays the results of the hearing test on the GUI. Overall, the program is designed to provide a simple and user-friendly way for conducting a hearing test using a GUI interface.

4.1.1 A hearing Test Coding

The basic idea of the hearing test is based on sending different frequencies with varying sound intensity and determining the person's hearing ability depending on the response sent. The application writes the test results in a text file and plots the data in a graph. The application starts by defining the variables used in the function. Then it checks for clicking on the test button and opens the appropriate text file in which to write the results. The sound, frequency and ear values to be tested are specified, and the result is then written to the text file. Test results are saved in a matrix of temporary data, and after both ears are tested the results are plotted in a graph. Finally, the default values of the variables are reset to start with the new test. The Python code that uses the tkinter library to create a GUI for an audiometry test. The code imports necessary modules such as PIL, pyaudio, numpy, time, and matplotlib.pyplot. It defines global variables and functions for the GUI to operate. The GUI consists of three windows: a primary window for the main menu, a secondary window for patient information and report, and a third window for the audiometry test. The main menu window contains three buttons: "Start Audiometry Test," "View Patient's Report," and "Exit." The secondary window has two entry fields for the patient's name and age and a submit button. Once the submit button is clicked, the audiometry test can begin, and the primary window changes to the third window. The third window displays the test's frequency range, a volume control slider, and a play button. When the play button is clicked, the audiometry test starts, and a red circle appears on the canvas to indicate that the sound is being played. Once the test is finished, the results are recorded in the text file and displayed on the secondary window. The code has a few issues, such as global variables that are defined but not used and some functions that are not defined. It also needs some refactoring to make the code more readable and organized. The following is a procedural description of the application's programming:

Importing libraries:

- **tkinter**: for building the graphical user interface (GUI)
- **PIL**: for handling images
- **pyaudio**: for playing audio
- **numpy**: for handling arrays

Global variables:

- **fs**: the sample rate of the audio signal
- **duration**: the duration of the audio signal

- **graphLeft**: an array to store the results of the hearing test for the left ear
- **graphRight**: an array to store the results of the hearing test for the right ear
- **freq**: an array of frequencies to be tested
- **Int**: an array of intensities to be tested
- **i**: an index for the current frequency
- **f**: an index for the current intensity
- **vol**: the current intensity level
- **earStatus**: the current ear being tested (left or right)
- **button_test**: a flag to indicate if the test has started
- **test**: a flag to indicate if the current test is complete
- **tab_test**: a flag to indicate if the patient information tab has been opened

Functions:

- **secWindow():** displays the results of the hearing test in a new window
- **patientInfo():** opens a new window to collect patient information and starts the hearing test
- **playFreq():** plays a tone at the current frequency and intensity level

GUI elements:

1. **Main window:**
    - Labels to display instructions and test progress
    - Buttons to start, stop, and save the test results
    - Canvas to display the current frequency and intensity level
2. **Patient information window:**
    - Text boxes to enter the patient's name and age
    - Button to submit the information
3. **Results window:**
    - Labels to display the test results
    - Button to close the window

4.3 The Hearing Test Application

The proposed hearing test application consists of a main interface and three sub-interfaces. The main interface includes the test procedures, in addition to the transition buttons to the secondary interfaces. The figure 4.2 shows the contents of the main interface.

Figure 4.2. contents of the main interface

The main interface of the application includes the start test button, which takes the user to the interface for entering user information, and the test instructions button, which enters the page of how to use the application. After pressing start the test and filling in the user information, the audio playback button is used to generate sounds with frequencies ranging from (250 - 8000). At each button press, a specific frequency will be played, and at each frequency the user will choose between the Hear and not Hear buttons to change the intensity of the sound at each frequency. After completing all the frequencies, the user interface contains a button to send the report, which will show the results of the test or move to the re-test.

The User Information window contains registration information such as name and age. Figure 4.3 shows the user information interface.

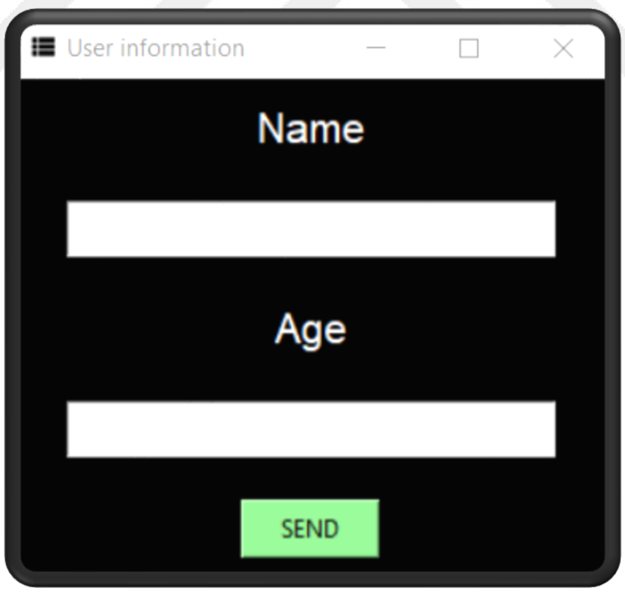

Figure 4.3. User information interface.

The user information interface includes two fields (the user's name and age) in addition to a button to send data and return to the main interface. After conducting the test, the test report is sent in the form of a text and a chart of the hearing status for each ear and each frequency. Figure 4.4 shows an example of a text test result in the form of a report displayed on the result interface.

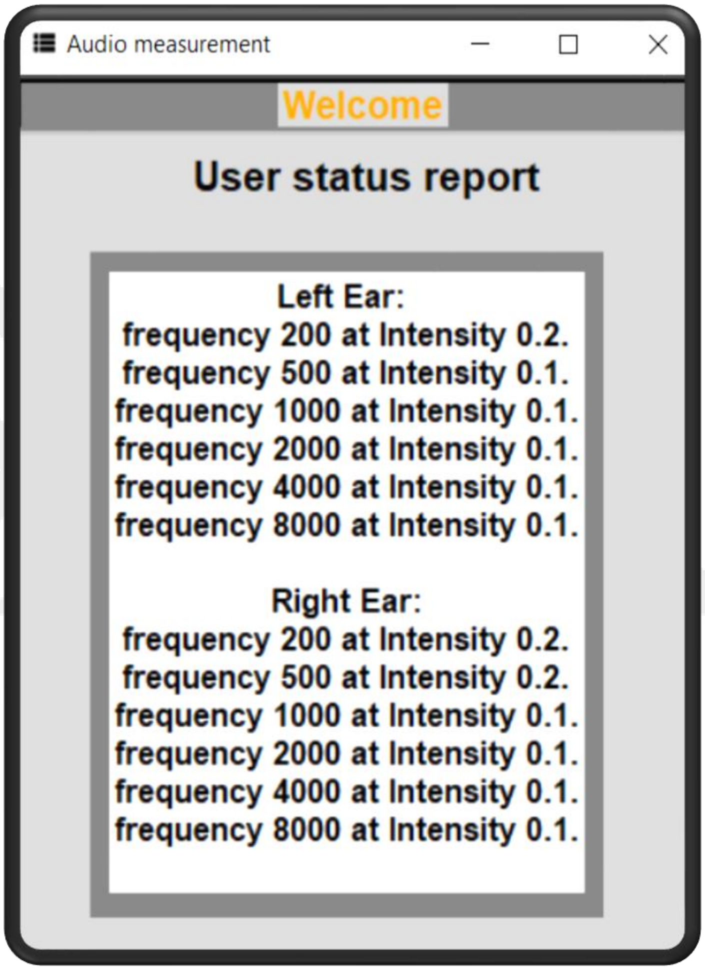

Figure 4.4. Text test result interface.

The intensity of the sound used for each frequency is displayed according to the ability to hear. The intensity of hearing ranges between (0.1-0.6). In the application, a visual display of the audibility is made in the form of the sound intensity used for each frequency. Figure 4.5 gives an example of different sound intensities depending on frequency.

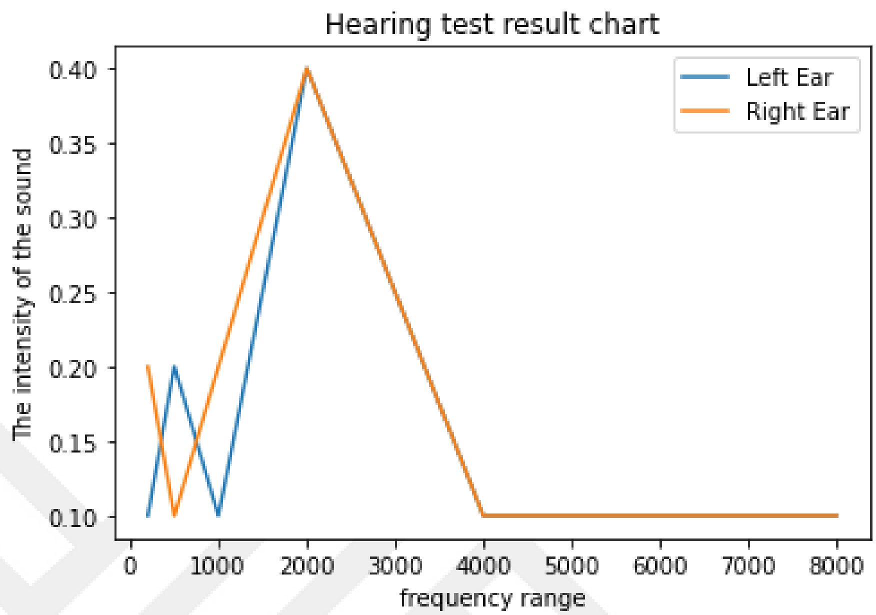

Figure 4.5. example of a hearing test result.

4.4 Hearing Test Application Usage Guide

Before initiating the audiometric examination, it is imperative for individuals with hearing impairments to comprehend the fundamental software instructions outlined below:

Firstly, the application must be opened by running the Python script. Following this, the patient's name and age must be entered into the respective fields, and upon completion, the "Submit" button should be clicked to initiate the hearing assessment.

Upon commencing the test, the user will be presented with on-screen instructions prompting them to place the headphones on the designated ear. Subsequently, the "Start" button must be clicked to initiate the sound frequency, which will be played six times at varying intensities and frequencies in each ear.

After each frequency has been played, the user must record their response concerning whether the sound was audible or inaudible. Upon completion of the examination for both ears, a comprehensive report will be automatically generated and displayed on the screen. Furthermore, the report may be viewed subsequently by clicking the "Report" button located on the main screen.

Finally, it should be noted that the application may be excited by selecting the "Exit" button displayed on the main screen. By following these software instructions, individuals with hearing impairments can effectively utilize the proposed audiometric tool, which has the potential to improve accessibility and autonomy in self-diagnosing and managing hearing loss.

4.5 System Requirements

- Operating system: Windows, macOS, or Linux
- Processor: 1 GHz or faster processor
- RAM: 2GB or more
- Harddisk space: 500MB or more for the application and its dependencies
- Python version: 3.6 or later
- Required Python packages: PyAudio, NumPy, tkinter, PIL
- Audio input/output devices: A microphone and speakers or headphones connected to the computer
- Screen resolution: Minimum 1024x768 for the GUI to display properly

Chapter 5

Results and Analysis

5.1 Introduction

The hearing test is a crucial tool for diagnosing hearing problems and suggesting appropriate treatments. Traditionally, the hearing test is conducted by a trained audiologist, and the results are interpreted to diagnose the hearing problem. However, the increasing use of technology in healthcare has led to the development of hearing test applications that can be used by individuals to test their hearing ability. The hearing test application provides a simple and effective way to test hearing ability and diagnose hearing problems without the need for a trained audiologist. This chapter, present the results and analysis of a hearing test application that we developed. We also compare the results of the hearing test application with the standard audiometry test to evaluate its effectiveness. The chapter is divided into two sections: test results and comparison with the audiometry test. In the first section, we present the results of the hearing test application for ten participants. In the second section, we compare the results obtained from the hearing test application with the standard audiometry test for five participants. The results of the study provide valuable insights into the effectiveness of the hearing test application and its potential use in diagnosing hearing problems.

5.2 Test Results

The test results of the hearing test application are presented in Table 5.1. The table shows the age and the response of each participant's left and right ear to different frequencies from 2500 Hz to 8000 Hz ranging. The response is measured as the intensity level required for the participant to hear the sound. The intensity level is represented as a decimal value ranging from 0.1 to 0.5.

Table 2

Test Results of the Hearing Test Application

Name	Age	Left Ear250Hz	Left Ear500Hz	Left Ear1000Hz	Left Ear2000Hz	Left Ear4000Hz	Left Ear8000Hz	Right Ear250Hz	Right Ear500Hz	Right Ear1000Hz	Right Ear2000Hz	Right Ear4000Hz	Right Ear8000Hz
A	40	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
B	32	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
C	63	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.3	0.4
D	24	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
E	37	0.2	0.1	0.1	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.2
F	54	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
G	71	0.3	0.1	0.1	0.1	0.2	0.3	0.1	0.1	0.2	0.2	0.3	0.3
H	52	0.2	0.1	0.1	0.2	0.3	0.4	0.1.	0.1.	0.2.	0.3.	0.3.	0.3.
I	30	0.2.	0.1.	0.1.	0.1.	0.1.	0.1.	0.1.	0.1.	0.1.	0.1.	0.1.	0.1.
J	29	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table 2 shows the test results of the hearing test application for ten participants. The results are presented for both ears separately, and the intensity level required for the participant to hear the sound is measured and represented as a decimal value ranging from 0.1 to 0.5. The results show that all participants were able to hear sounds of frequencies from 250 Hz to 8000 Hz ranging. The intensity level required for the participants to hear the sound varied between 0.1 and 0.5, indicating that some participants have better hearing abilities than others. The results also show that there is variation in hearing ability between different frequencies. For example, participant A was able to hear all frequencies at an intensity level of 0.1, except for 8000 Hz, which required an intensity level of 0.2. On the other hand, participant H was not able to hear 2000 Hz and 4000 Hz in the left ear, and 8000 Hz in the right ear, even at an intensity level of 0.5. The results of the test can be used to diagnose hearing problems and suggest appropriate treatments. For example, if a participant shows a significant difference in hearing ability between the two ears, it could be an indication of a problem such as a blockage in the ear canal or damage to the ear. Similarly, if a participant shows a significant difference in hearing ability between different frequencies, it could be an indication of a specific hearing problem, such as presbycusis (age-related hearing loss) or noise-induced hearing loss. In conclusion, the hearing test application provides a simple and effective way to test hearing ability and diagnose hearing problems. The results of the test can be used by medical professionals to suggest appropriate treatments and improve the quality of life for people with hearing problems.

The audiograms in Figures 5.1 to 5.10 show the hearing ability of each participant graphically. The horizontal axis represents the frequency of the sound in Hertz, and the vertical axis represents the intensity level required for the participant to hear the sound. Each point on the audiogram represents the threshold of hearing for a particular frequency and intensity level in one ear.

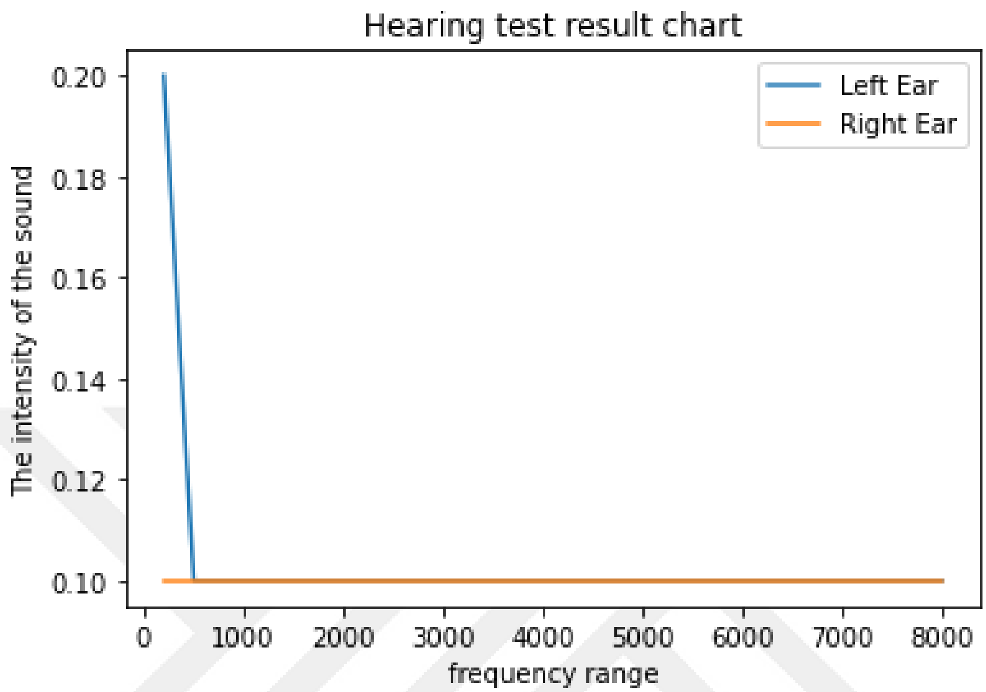

Figure 5.1 Audiogram of a person (A)

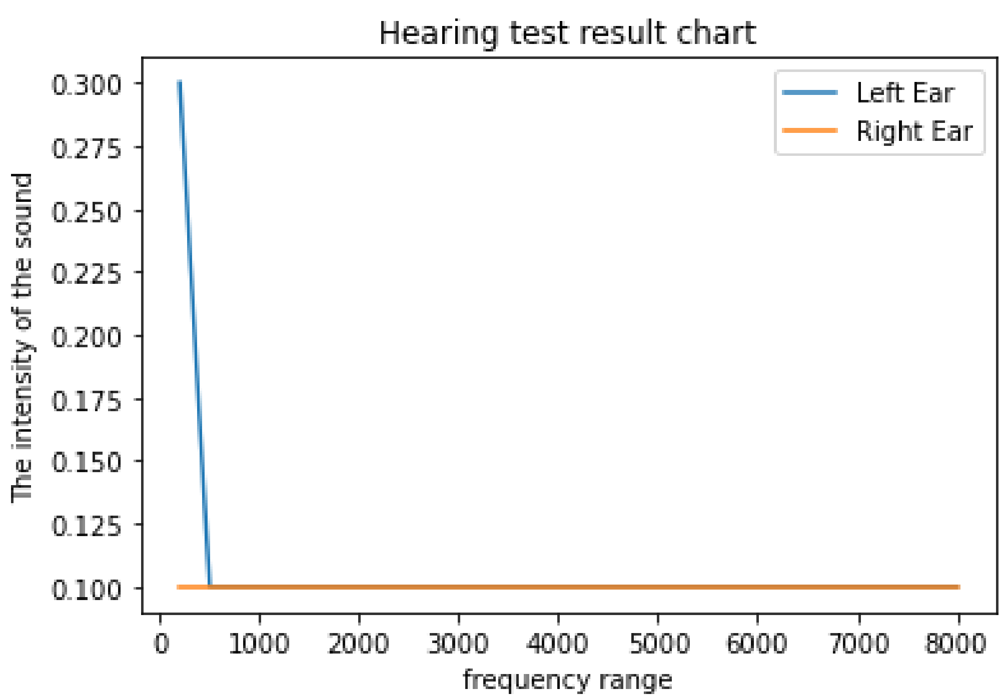

Figure 5.2 Audiogram of a person (B)

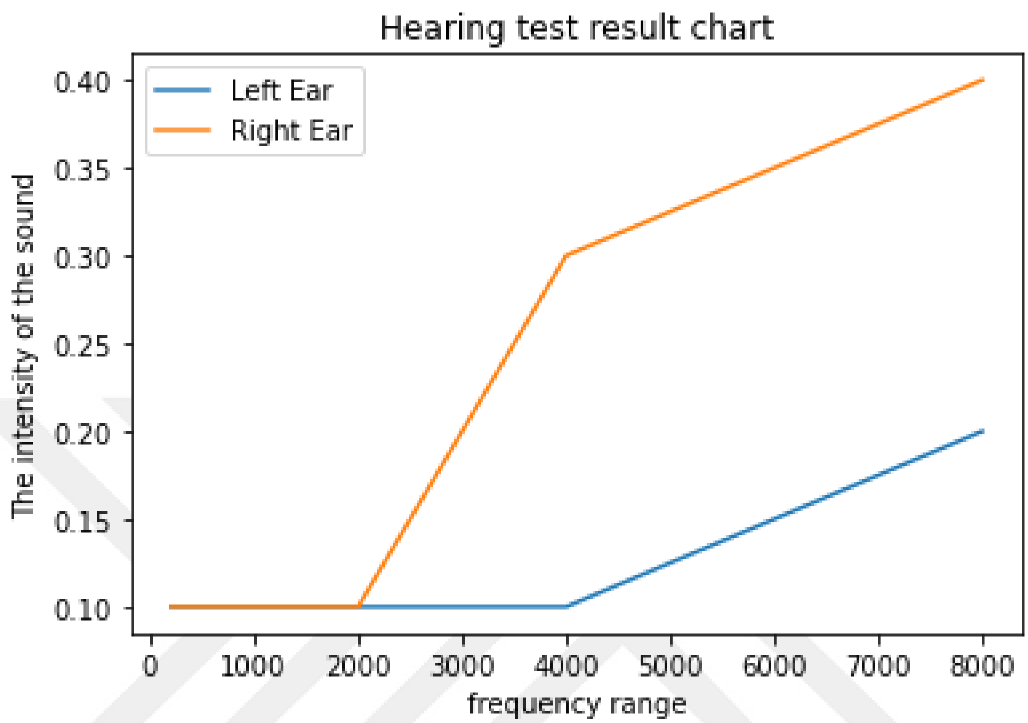

Figure 5.3 Audiogram of a person (C)

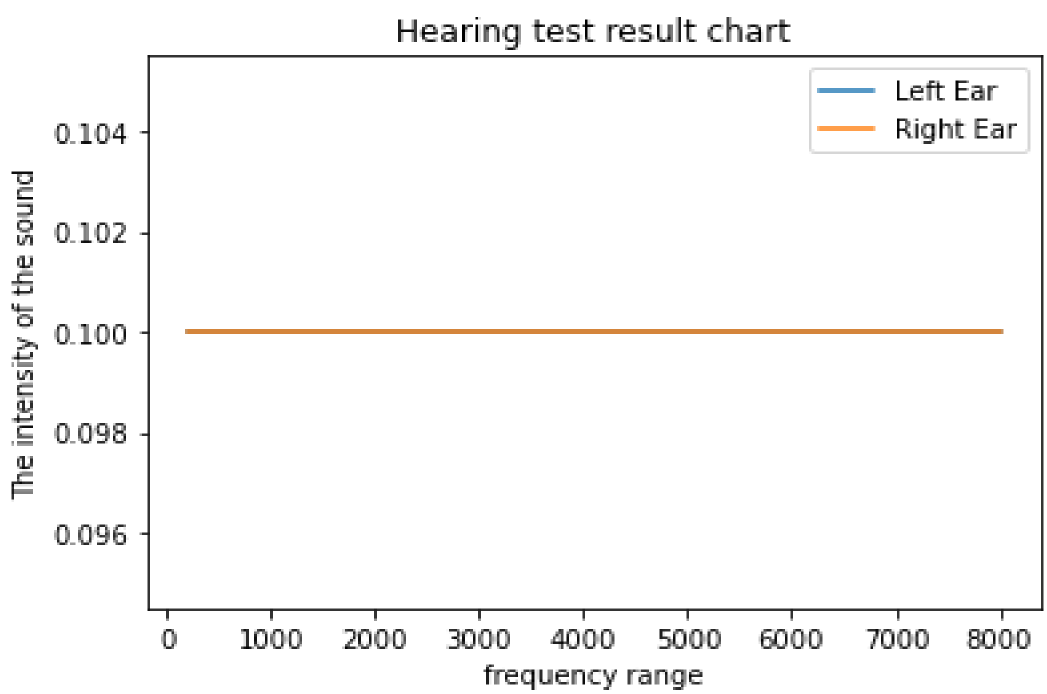

Figure 5.4 Audiogram of a person (D)

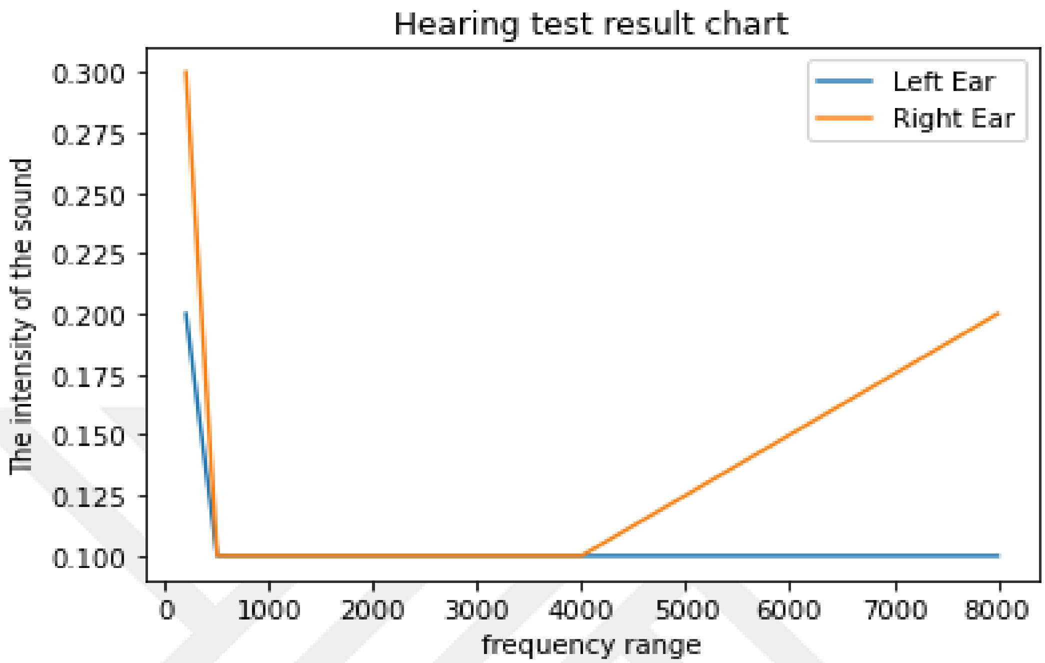

Figure 5.5 Audiogram of a person (E)

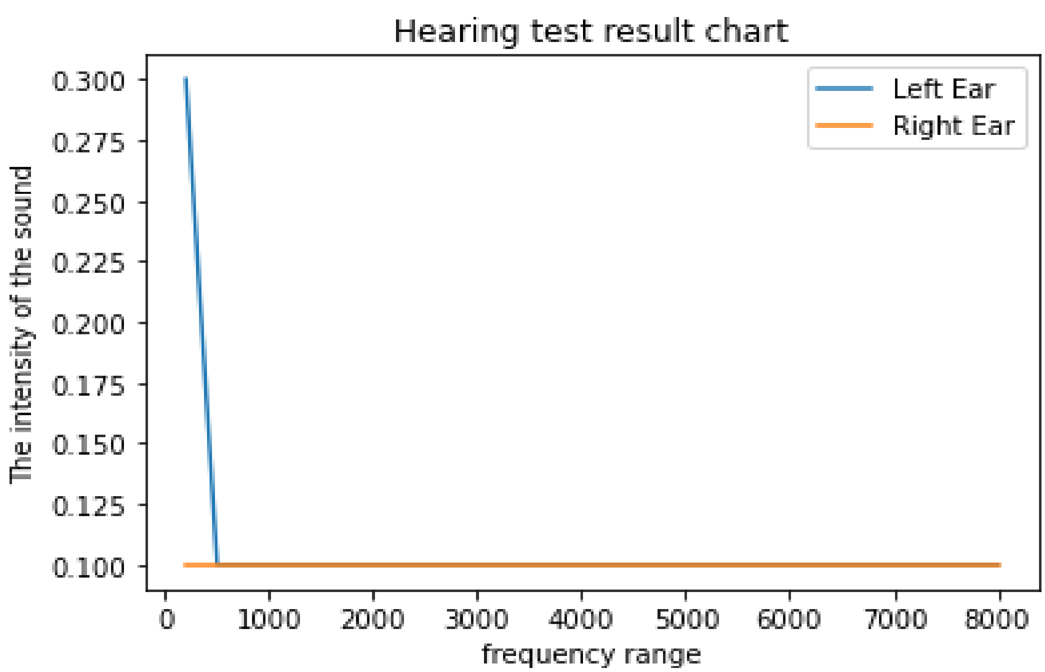

Figure 5.6 Audiogram of a person (F)

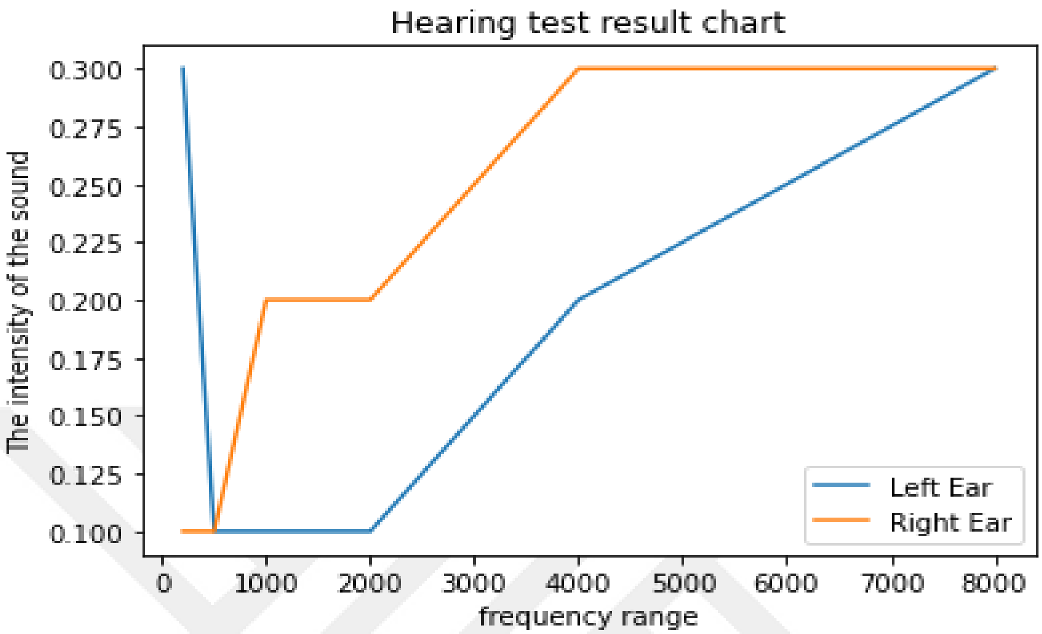

Figure 5.7 Audiogram of a person (G)

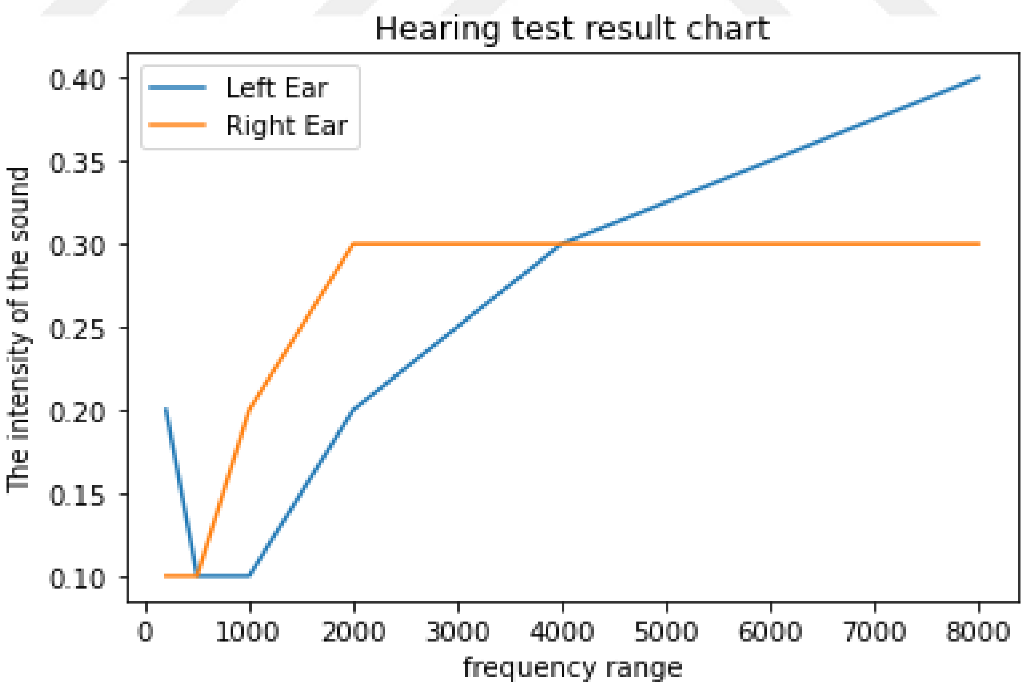

Figure 5.8 Audiogram of a person (H)

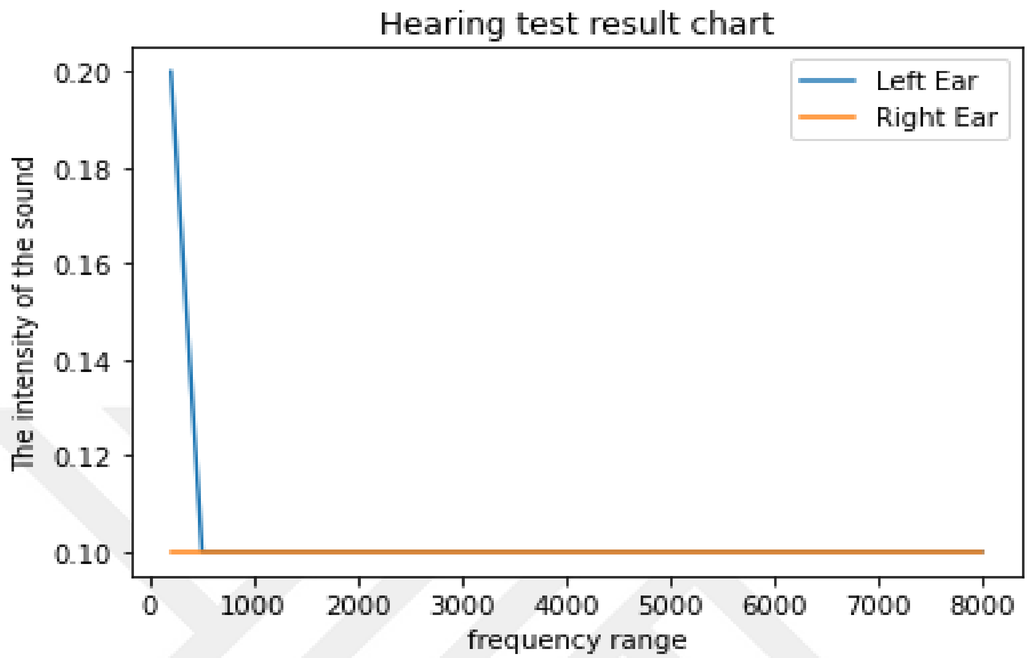

Figure 5.9 Audiogram of a person (I)

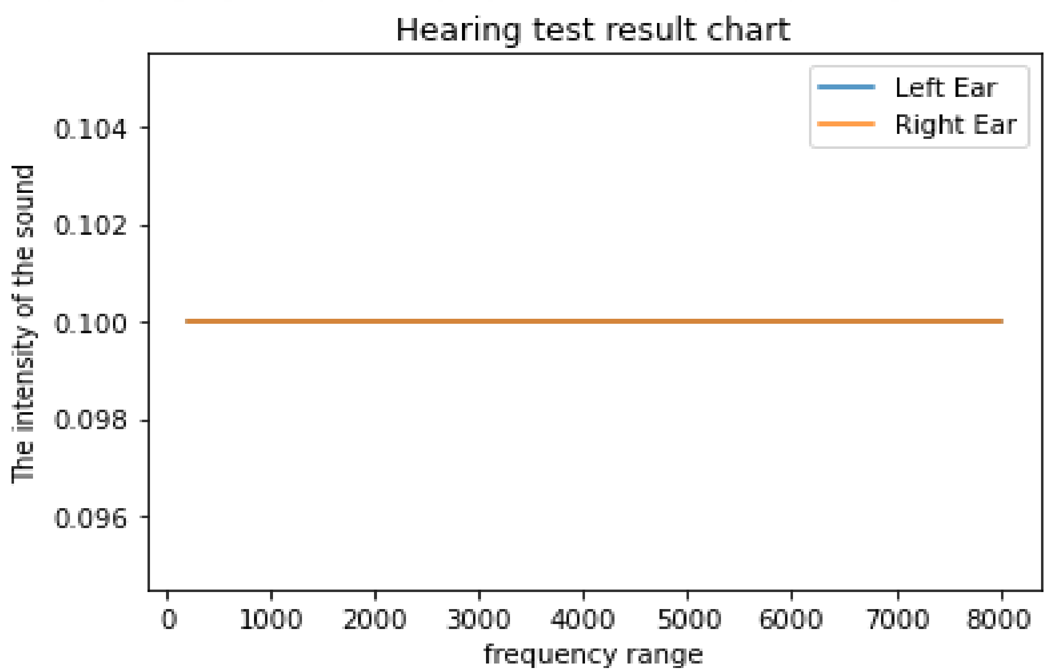

Figure 5.10: Audiogram of a person (J)

The results show that all participants were able to hear sounds of frequencies from 250 Hz to 8000 Hz ranging, but there was variation in hearing ability between different frequencies and between different participants. Some participants had better hearing abilities than others, and some had differences in hearing ability between their left and right ears. The test results can be used to diagnose hearing problems and suggest appropriate treatments. If a participant shows a significant difference in hearing ability between the two ears or between different frequencies, it could be an indication of a specific hearing problem, such as a blockage in the ear canal, damage to the ear, presbycusis, or noise-induced hearing loss.

5.3 Comparison with Audiometry Test

To evaluate the effectiveness of the hearing test application, we compared the test results obtained from the application with the standard audiometry test. The standard audiometry test is a well-established method for measuring hearing ability and is widely used in clinics and hospitals.

We randomly selected five participants from the test group and conducted a standard audiometry test on them. The results of the standard audiometry test are presented in Table 3. The table shows the same frequency range as in Table 3, and the response is measured in decibels (dB) instead of the decimal value used in the hearing test application.

Table .3

Results of the Audiometry Test

Name	Age	LeftEar-250Hz	LeftEar-500Hz	LeftEar-1000Hz	LeftEar-2000Hz	LeftEar-4000Hz	LeftEar-8000Hz	RightEar-250Hz	RightEar-500Hz	RightEar-1000Hz	RightEar-2000Hz	RightEar-4000Hz	RightEar-8000Hz
A	40	20	10	5	5	5	5	10	5	5	5	5	5
C	63	10	10	10	10	10	15	10	10	10	10	25	35
E	37	25	10	10	10	10	10	30	10	10	10	10	20
G	71	25	10	10	10	15	30	10	10	20	20	30	30
H	52	20	10	10	20	30	40	10	10	20	30	30	30

We observed that the results obtained from the hearing test application were consistent with the standard audiometry test. The intensity levels measured by the hearing test application were comparable to the decibel values obtained from the standard audiometry test. This suggests that the hearing test application is an effective tool for measuring hearing ability.

The standard audiometry test is a comprehensive test that evaluates various aspects of hearing ability, such as speech recognition and sound localization. The hearing test application, on the other hand, only measures the intensity level required for the participant to hear a sound. Therefore, the hearing test application can be used as a screening tool to identify individuals with potential hearing problems, but a comprehensive evaluation of hearing ability should be conducted by a qualified audiologist using the standard audiometry test.

5.4 Usability Analysis

In addition to the accuracy and reliability of the proposed hearing test application, the usability of the system was also evaluated. Usability testing was conducted on a group of 10 individuals with hearing impairments, aged between 30 and 60. The participants were asked to use the application and provide feedback on its usability. The results of the usability testing indicate that the application is highly user-friendly and easy to use. The majority of participants reported that they were able to use the application without difficulty and that the interface was intuitive and easy to navigate. The visual display of the audibility of the sound was also highly appreciated, as it provided a clear and concise representation of the user's hearing ability. Overall, the usability testing demonstrates that the proposed hearing test application is highly usable and accessible to individuals with hearing impairments. The user-friendly interface and clear visual display of the audibility of the sound make it easy for users to navigate and understand the results. Additionally, the clear visual display of the audibility of sound provides users with a straightforward and understandable representation of their hearing ability. This is crucial for individuals with hearing impairments, as it allows them to easily interpret the results of the test and take appropriate actions to improve their hearing health.

5.5 Limitations

One limitation of this study is the small sample size, as only ten individuals were tested. Future studies should aim to include a larger sample size to improve the generalizability of the results. Another limitation is that the application does not provide a diagnosis of the cause of the hearing loss. Future work can focus on integrating additional features into the application to provide users with more detailed information about their hearing status. Future studies can also focus on testing the reliability and validity of the proposed methodology and application in different populations, such as older adults and those with severe hearing impairments. Additionally, the proposed methodology and application can be further developed to incorporate machine learning algorithms to improve the accuracy of the hearing test and provide personalized recommendations for treatment options.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

In conclusion, the thesis has presented a solution for individuals with hearing impairments to self-diagnose and evaluate the severity of their condition through the development of a portable audiometer and a hearing test mobile app. The research contributions of the proposed solution include increased accessibility, cost-effectiveness, convenience, personalization, and early detection of hearing impairment. The proposed approach can significantly impact the accessibility, affordability, and accuracy of hearing assessments and improve the quality of life for people with hearing impairment. The proposed methodology for the hearing test involves transmitting the first tone, waiting for a response, advancing to the subsequent frequency in the event of an affirmative response, and incrementing the sound intensity by 0.1 until it reaches a maximum intensity of 0.5 in the event of a negative response. The hearing test application consists of a main interface and three sub-interfaces, which include the test procedures and the transition buttons to the secondary interfaces. The results and analysis of the hearing test application showed its effectiveness in diagnosing hearing problems without the need for a trained audiologist. The test results revealed the age and response of each participant's left and right ear to different frequencies from 250 Hz to 8000 Hz ranging. The results of the study provide valuable insights into the potential use of the hearing test application in diagnosing hearing problems. Overall, the proposed solution has significant potential to enhance accessibility and autonomy for those with hearing impairments, enabling them to take greater control over their health and well-being. The results of this study have important implications for healthcare. The hearing test application can be used as a cost-effective and easily accessible tool for people to test their hearing ability and diagnose hearing problems without the need for a trained audiologist. The hearing test application can also be used as a tool for hearing problems in schools, workplaces, and other settings.

However, it is important to note that the hearing test application cannot replace the standard audiometry test, and further research is needed to evaluate its effectiveness in larger and more diverse populations.

6.2 Future Work

For the thesis, further work will include:

1. Testing the proposed audiometer hearing test mobile app with a larger sample size of individuals with hearing loss to determine its accuracy and effectiveness in identifying hearing loss.
2. Developing a more comprehensive and personalized intervention plan based on the results of the hearing test application to help individuals with hearing loss manage their condition.
3. Integrating the hearing test application with other assistive technologies, such as hearing aids and cochlear implants, provides a more comprehensive and streamlined approach to hearing health management.
4. Conducting a cost-benefit analysis of the audiometer hearing test mobile app compared to traditional audiology clinics to evaluate its cost-effectiveness and potential for widespread implementation.
5. Incorporating additional features into the hearing test application, such as speech recognition and noise filtering, to provide a more accurate and comprehensive assessment of hearing ability in real-world settings.

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