Sensitivity and Specificity of Smartphones Based Hearing Testing Applications

17AUD006

This Dissertation is submitted as a part of fulfilment

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CERTIFICATE

This is to certify that this dissertation entitled **'Sensitivity and Specificity of Smartphones Based Hearing Testing Applications'** is the bonafide work submitted in part fulfilment for the Degree of Master of Science (Audiology) of the student with Registration No: **17AUD006**. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this Master's dissertation entitled **'Sensitivity and Specificity of Smartphones Based Hearing Testing Applications'** is the result of my own study under the guidance of Dr. Ganpathy M.K, Lecturer of Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Diploma or Degree.

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DEDICATED TO MY PARENTS

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ABSTRACT

Aim: The aim of the study was to determine the sensitivity and specificity of smartphone hearing screening technology.

Objectives: Objective of the study were, **(**a) To determine the hearing threshold by using Diagnostic Audiometer. (b) To determine the hearing threshold by using Android and iOSbased mobile/iPad applications. (c)To compare the hearing threshold obtained by a diagnostic audiometer and smartphone applications.

Participants: A total of 70 subjects participated in this study, in which 50 were normal hearing, Ten participants with mild hearing loss and 10 subject with moderate hearing loss.

Methods: Hearing thresholds were measured by using conventional audiometry and with three mobile based hearing screening application. Applications were "Indian Hearing Screening Test", "Hearing Test" and uHear application, first two applications were Androidbased and uHear was iOS-based application. Threshold obtained by Audiometer and applications were compared.

Results: There were no significant difference between conventional audiometric thresholds and thresholds obtained using mobile based hearing application. These application has a good sensitivity and specificity. Participants with the moderate hearing loss had shown higher degree of hearing loss such as moderately-severe and severe hearing loss. Thus these applications may not be useful for hearing loss above mild hearing loss.

Conclusion: These smartphones based applications showed an accurate score in quite situations. These are able to differentiate between normal hearing and hearing loss. So these application can be used by the person to screen their hearing and it can be used for early detection. If there will a presence of hearing loss they can go for detailed diagnostic evaluation.

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Chapter 1

INTRODUCTION

The sense of hearing is perhaps the most important of all the five senses of the human body. The hearing ability of humans has made it possible for them to communicate through verbal language. The acquisition and monitoring of speech, detection of potential danger, the elementary feeling of existing in a living universe, all depends upon the auditory modality (Sah, & Barman, 2002)

The incidence and prevalence of hearing loss is very high globally and it is largely preventable and avoidable. According to the WHO in 2005, 278 million individuals were heaving hearing impairment. In Southeast Asia prevalence of hearing loss ranges from 4.6% to 8.8%. Nationwide disability surveys have estimated the hearing loss to be the second most common cause of disability (WHO, 2005). 63 million people (6.3%) suffer from significant hearing loss In India.

There is a higher prevalence of hearing loss and lack of adequate awareness of hearing loss. Also there is a lack of skilled manpower, limited access to hearing care services in the suburban/rural area, high cost of services makes this a huge challenge.

The WHO reports that, 360 million individuals have a disabling hearing loss (WHO, 2013) in worldwide. The majority if hearing loss is high in low and middle-income countries (WHO, 2014). Availability of hearing health-care professionals in developing countries is limited (Goulios, & Patuzzi, 2008; Windmill, & Freeman, 2013) and due to the shortage of qualified professionals the detection and rehabilitation are not met (Fagan, & Jacobs, 2009).

To increase the availability of diagnostic audiological services, more professional audiologists need to be trained, which is a slow and costly process. Other alternative strategies would be to develop tools or applications for easy ways detection of hearing loss at the earliest.

The studies shows that hearing loss become 4th leading disability in 2015, in 2010 it wa the 11th leading disability (Wilson et al., 2017). More specifically, the prevalence of a hearing loss is more in some countries such as the Asia-Pacific area, southern Asia, and sub-Saharan Africa in both children and adults (Mulwafu et al, 2017; Olusanya et al, 2014; Stevens et al., 2011).

Indian audiological services are very less in both private and government organization. By the Parliament of India in 1983, The National Health Policy was established and updated in 2002. Now hearing professionals are there in both government and private sectors of India. Audiological services, including hearing assessment and, fitting of hearing aids and aural rehabilitation are present in both the sectors. Some of the centers also have successful cochlear implant programs. However, there are few professionals working in specialized areas of audiology, such as vestibular assessment and rehabilitation, tinnitus rehabilitation, assessment and management of auditory processing disorders. National Programme for Prevention and Control of Deafness (NPPCD) was initiated by the government of India in 2006. It was initially started as a pilot project and was implemented in 25 districts in 10 states and 1 union territory. It will be upscale to include 203 districts in all states and union territories by the end of the eleventh 5-year plan. Public sectors are also working to extend audiological services in rural as well as urban areas by conducting campus and appointing public workers to identify and refer those in need of services.

The following tables demonstrate the various ear and hearing health care professionals in India (Manchaiah, Shivprasad, Chundu, & Dutt, 2010):

Table 1.1:

Ear and hearing care professionals in India (Manchaiah, Shivprasad, Chundu, & Dutt, 2010)

Professionals	Approximate Number	Ratio to the Population
Audiologists	1,200	1:950,000
Otolaryngologists	8,000	1:142,500
Micro-ear surgeons	4,000	1:285,000
Teachers of the deaf	4,039	1:282,248
Physicians	500,000	1:2,280

Note: These are approximate numbers and the population ratio was calculated using a population of 1.14 billion (2008) and data on professionals was based on a report published in 2007.

Table 1.2:

The approximate number of ear and hearing health care centers in India (Manchaiah, Shivprasad, Chundu, & Dutt, 2010)

Centers	Level	Approximate number
Primary healthcare centers	Primary	22,974
District healthcare centers	Secondary	600
Specialist centers	Tertiary	350/120*

* denotes facilities that have equipment for early diagnosis and rehabilitation

Screening is the process of assessing a large number of individuals in a limited period. It is a simple measure that identifies individuals with a high probability of a disorder. Screening, of course, is not intended as a diagnostic procedure, it merely surveys a large population of asymptomatic individuals to identify those who are suspected of having a disorder and referred for elaborate diagnostic procedures (Anna,& Shiam, K. 2001).

The most basic screening measure in audiology is to find out the degree of hearing loss. This, however, requires a pure tone audiometer, which is an instrument for the assessment of the hearing. This is the first choice for a hearing screening. Further, audiological testing requires a soundproof booth that is highly expensive. These audiological types of equipment and infrastructure are expensive and there are limited trained professionals to carry out the evaluation and rehabilitation. Studies report that there is lack of infrastructure and resources which inhibits the provision of adequate hearing health-care services (Clark & Swanepoel, 2014; Fagan & Jacobs, 2009; Peer & Fagan, 2015; Swanepoel, & Olusanya, et al., 2010).

There are numerous factors those contribute to the increasing global prevalence of hearing loss; the most common is age-related hearing loss with increased average life expectancies globally (Olusanya et al, 2014). Apart from age-related hearing loss, other factors are exposure to noise, ototoxic medications and others (Arslan et al, 1999; Basneret al, 2014; Fuente & Hickson, 2011; Olusanya. et al, 2014). Establishing a timely and accurate diagnosis of hearing loss is very important in the prevention of disabling consequences such as social communication, psychological health, and quality of life.

Many people are smartphones user, people listen to music, and mostly older people are not aware of the hearing loss in the early phase, and they need to monitor their hearing. Hearing test in clinics is called "Pure Tone Audiometry" (PTA), and this is performed in a sound-treated room with an audiometer and more manpower is needed for doing pure tone audiometry. So there is a need to develop and use alternative screening/diagnostic equipment for an elderly population which can be easily accessible to test their hearing in developing and developed countries. The smartphone-based applications with good sensitivity and specificity can be an alternative for identifying hearing loss in young and older populations.

In many developing countries to get ear and hearing evaluation is a big challenge. Telehealth approach is usual for assessment and rehabilitation in recent years (Swanepoel, & Hall, 2010). Because of their accessibility, many mobile applications related to u-healthcare have been developed to monitor people's health. The use of u-healthcare applications may help guess health conditions such as blood pressure and heart rate. Several studied have done in hearing testing using a smartphone. The hearing-test applications could be conveniently and alternatively used to check the hearing level instead of audiometry by a healthcare clinician.

Smartphones applications provide easy accessibility and people can perform a self- test anytime time in their daily life. Even though a test could be performed in a quiet place, it is very difficult to find out a sound-treated room in daily condition and in some private's clinics also because of its cost. The smartphone's user can administer these tests in any place and if the noise level will be high in those places the applications terminate the test or it will give the warning regarding the high noise level.

More freshly mobile health is seen a subset of eHealth has emerged as a possible mean of hearing evaluation (Clark & Swanepoel, 2014). In hearing health care, there are already many smartphones-based hearing screening applications are existing for pure tone audiometry and speech audiometry, etc. There is a need for more accessible audiometry. However, the ubiquity of portable device has encouraged the development of a variety of mobile-based applications for evaluating hearing sensitivity. The technology of automatic audiometry is improving day by day. Some devices have a very user-friendly interface to perform air conduction testing.

In hearing health care, there are many smartphone applications available to evaluate basic hearing assessment such as pure tone audiometry and speech audiometry. Few such application developed for Apple's iOS devices (iPhone &iPad) called "uHear" (Unitron 2009), and some are android based such as, "Hearing test" (Marcin Masalski 2014) and "Indian Hearing Screening Test" (AIIMS Bhubaneswar). These provide a self-assessment of air conduction hearing thresholds. These new applications are widely accessible and can be used by an individual without formal training. However, there is no available literature on their sensitivity and specificity. A promising opportunity for automatic audiometry is the development of technology on commonly available portable electronic devices. Mobile phone technology has been used in several health screening instances. Many researchers have studied the use of smartphones to screen hearing loss. However, further investigation is required to assess the reliability of the thresholds obtained by smartphone-based applications and also to validate its sensitivity and specificity.

1.1 Need of the study

Monitoring the hearing sensitivity will be helpful for the diagnosis and management of the hearing loss. And for it, pure tone audiometry is needed, which determines the threshold in the wide frequency range. However, pure tone audiometry requires proper equipment and professionals. And in most of the countries, the professionals and the proper equipment that is needed for the evaluation of the hearing loss are not efficient. Automated audiometry is an optional in these situations. Automated audiometry requires selfdetermination of the threshold, following which they can refer an Audiologist for complete diagnostic evaluation.

As a screening tool if an individual feels they are having reduced hearing sensitivity, the hearing evaluation applications can be used. The availability of professionals to test population in need are less, thus use of smartphone based applications will be an easily available tool that can be assessed by everyone to test their hearing sensitivity. However, there are very few studies to validate the use of mobile applications as a screening tool. So this brings to the need of the study to measure the sensitivity and specificity of these applications.

1.2 Aim of the study

The aim of the study is to determine the sensitivity and specificity of smartphone hearing screening technology.

1.3 Objectives

a. To determine the hearing threshold by using Diagnostic Audiometer.

b. To determine the hearing threshold by using Android and iOS-based mobile/iPad applications.

c. To compare the hearing threshold obtained by a diagnostic audiometer and smartphone applications.

1.4 Hypothesis of the study:

The null hypothesis is assumed for the present study is:

There will be no difference between audiometric threshold and threshold obtained by mobiles apps.

Chapter 2

REVIEW OF LITERATURE

2.1. Hearing threshold:

We often conclude that someone has a hearing loss because they listen louder than normal level for that person to hear. Even though we cannot directly experience the degree of that person's hearing loss, we can appreciate its magnitude in term of how loudly we must speak to be heard. We can quantify the degree of persons hearing the loss in terms of the magnitude of the stimulates needed for him to respond to it.

The lowest intensity of the sound that can be detected by the person is called threshold for the sound. For the clinical purposes, we defined the threshold as the lowest intensity at which the patient responds to the sound at least 50% of the time.

The sound used to test a person's hearing must be clearly specified so that his thresholds are both accurate and repeatable. The sound used to determine the degree of hearing losses are usually pure tones of various frequencies. The normal threshold at each frequency is said to be 0 dB hearing level (HL) {American National Standard Specifications for Audiometers (ASNSI S3.6-2004)} hearing threshold are thus given in decibels of hearing level or dB HL re: ANSI 2004 or "dB HL re; ANSI/ISO" or "dB HL re: ANSI 1969 (because original version was published in 1969).

2.2 Different methods for pure tone audiometry

2.2.1 Modified Hughson Westlake method (ASHA 1978) {given by Harrell, 2002,

Handbook of clinical audiology 5th edition}

This method is modified by Carhart and Jerger (1959). The original H-W method, as well as Carhart and Jerger, modified involve an ascending technique. The testing begins at an intensity level which is not audible. Then the tone is increased until a response is obtained.

Thereafter the 10 down 5 p procedure is used.

Procedure

The tone of 1-2 second duration is used. the interrupter which is presented each time a toll has to be presented. begin at 30dBHL if the participants are expected to the normal hearing based on informal interview. begin at 70dBHL, if hearing loss is suspected. if a response is obtained at the starting level reduce the intensity in 10dB step sizes.

The criterion for the threshold

According to ANSI S- 3.2 1 episode is determined as the lowest hearing level at which responses occur in at least one half of a series of ascending tile with a minimum of two responses out of 3 require at a single level.

2.2.2 Bracketing method (Hughson Westlake, 1959)

Procedure

a. The stimulus is increased from the low intensity in 10 to 15 dB steps until the first level at which response is obtained. Alternative leave the modified Hughson Westlake procedure of starting at 30 or 70-dB HL can be used until the first response is obtained.

   Next, reduce the intensity in 10dB step till the level of no response is reached then use 5dB Up Steps to get to a level of response. This level is called “X”.

b. Now increase the intensity by 5db and present tone i.e. X + 5 dB. we expect the participants to response if x was a real threshold.

c. If the participant's response at X + 5 reduces the intensity by 10db (X-5) we expect no response at this level.

d. Increase intensity again to “X” check for response increased to x + 5 check for a response in the manner bracket the threshold between x, x + 5 x and x-5.

e. Repeat steps 2,3 and 4 three times if the participants do not respond at X + 5 in step 2 then increase Again by 5db step until the participants respond this would be the new "X".

f. This method is based on the premise that once the threshold found, increase in intensity should definitely result in a response and decrease in the intensity below the threshold should reduce or eliminate the chance of the response.

2.2.3 ANSI S3. 21.1978,1986 SWEEP UP PROCEDURE

Procedure

a. It is called Swift up procedure. The examiners start from the lowest intensity level available on audiometer. The reverse button is pressed to keep the tone continuously on.

b. The intensity is gradually increased until the participants indicate having heard the tone. At this point, a tone is stopped (reverse button is deactivated). Then present the tone once again at the same intensity if the participant hears the tone than start reducing the intensity in 10dB step.

c. From this point, the procedure is similar to the modified H-W procedure.

The threshold is determined as the lowest hearing level at which responses occur in at least one half of a series of ascending trials, with the minimum of two responses out of three required at the single level.

Pure tone testing is first completed for AC before testing BC. The conventional is to begin testing the better ear first in order to give the participants a chance to understand the task well. The unmasked ac thresholds are obtained by placing the vibrator on the side (right or left) which shows the batter AC thresholds. If the gap between these unmasked "common BC threshold" and the AC thresholds is more than 10 dB at any frequency, then masking is required.

Pure tone testing usually begins at 1000Hz following which shows that 2000, 4000, 8000Hz are determined. Next, the threshold at 1000Hz is traced again to check for reliability. After confirming the reliability (thresholds should be within ± 5 degrees that obtain in the first trial), the threshold at 500 and then 250 Hz are determined. Mid octave frequencies frequency (750 1500 300 3000 and 6000 Hz) are tested if threshold at two consecutive octave frequencies differs by 20 dB or more.

In case of severe to profound hearing loss, it may be necessary to test the low frequency first (250 to 500 Hz) before testing the higher frequency hence the normal sequence of testing 1000 Hz first, may need to be changed for such individuals.

2.3 Incidence and prevalence

a. According to the study done by Garg et al in 2018. They have found that the prevalence of conductive hearing loss was present among 61 (10.3%) participants; the mixed hearing loss was found among 5 (0.8%) participants and sensorineural hearing loss among 94 (15.8%) participants. The overall prevalence of hearing loss was 25.1%. On OAE, 62 (89.9%) children passed the test, and 7 (10.1%) were referred. Increasing age, female gender, and low education were significantly associated with hearing loss. (An Epidemiological Study on Burden of Hearing Loss and Its Associated Factors in Delhi, India).

b. According to Occupational safety measures and morbidity among welders in Vellore, Southern India. Ear symptoms between welders and non-welders in the earlier 12 months in Vellore, India. Hearing loss was found in 3(2%) in welders and 0 (0%) in non –welders (Occupational safety measures and morbidity among welders in Vellore, Southern India).

c. The prevalence of hearing the loss in US in 2003-2004 (Agrawal et al., 2008), 16.1% of US adults (29 million Americans) had hearing loss in speech frequencies. In the youngest age group (20-29years) 8.5% showed hearing loss, and the prevalence seems to be increasing between this age group. Odds of hearing loss were 5.5-fold higher in men vs women and 70% lower in black participant's vs white participants. In participants, habits such as drinking and smoking can increases the prevalence of hearing loss.

d. A study was done on to see the Health impact and noise exposure assessment in the cricket bat industry of Kashmir, India On average (Manzoor et al., 2016), 62.5% of the employees reported that they have difficulty in hearing and 24.1% of the employees have become patients for hypertension.

e. A study was done on the genetic hearing loss by Subathra et al in 2016. By analysis, the family history those revealed the incidence of minimal sensorineural hearing loss was sporadic in 75% (543/729) of the probands. Prenatal consanguinity was present in 28% of the cases (150/543), whereas in 162 familial cases parental consanguinity accounts for about 50% (80/162). Only three pathogenic mitochondrial variants were observed in 1.1% of the probands (8/729). One variant was observed in the MTRNR1 gene and two were observed in the MT-TS1 gene. The chromatogram of the most frequently (0.7%) observed variant m.1555A>G. It showed thet chromatograms of the m.7472insC variant (0.274%) and the m.7444G>A variant (0.137%), respectively.

f. The study was done on 63,042 infants (Shaheen et al., 2014), 966 (1.5%) were confirmed to have significant hearing loss. We identified additional risk factors that were associated with hearing the loss in infants. According to the disability data published in the report (2002) of the National Sample Survey Organization. A broad idea about the magnitude of disability can be known if we compare the prevalence of disability as found in National Sample Surveys conducted at different points of time. Tables 2.1 and 2.2 show that there is a significant decline in the prevalence and incidence of disability including hearing disability. This can be attributed to the general growth in health, education and infrastructure sector. The incidence of hearing loss is nearly similar in both rural and urban area. The incidence is also detected to be higher between males than females as is the prevalence rate.

Table 2.1:

Prevalence Rate of Disabled Persons Per 100,000 Persons (NSSO,2002)

NSS	*36th Round 1981*	*47th Round 1991*	*58th Round 2002*
Rural	1844 (573)	1995 (467)	1846 (310)
Urban	1420 (390)	1579 (339)	1499 (236)

Table 2.2:

Incidence Rate of Hearing Disabled Persons Per 100,000 Persons(NSSO,2002)

NSS	*36th Round 1981*	*47th Round 1991*	*58th Round 2002*

Rural	19	15	8
Urban	15	12	7

2.4 Screening

An estimated 360 million (WHO, 2012) individuals have a hearing impairment worldwide, the majority of hearing loss was in low- and middle-income countries (LMICs). Early identification through screening is important to reduce the negative effects of hearing impairment. Large number of barriers exist in screening for hearing impairment in LMICs, such as the skilled hearing health care professionals and too expensive equipment of hearing assessment. These challenges may be overcome through the utilization of available smartphone app technologies for ear and hearing assessments that are easy to use by unskilled professionals.

In 2012, WHO estimated that disabling hearing impairment (DHI) affects approximately 360 million people (5.3%) of the global population. The definition of DHI is a pure tone average (PTA) of thresholds at 500, 1000, 2000 and 4000 hertz (Hz) in the better hearing ear of greater than 30 decibels (dB) in children, and greater than 40 dB in adults.

2.4.1 Universal neonatal hearing screening:

It is recommended that a policy of universal neonatal screening is adopted in all countries and communities with available rehabilitation services and that the policy be extended to other countries and communities as rehabilitation services are established. The USPSTF (US

Preventive service task force) (Whitlock et al., 2010) found that newborn hearing screening leads to earlier identification and treatment of infants with hearing loss.

An ideal hearing screening test should be easy to done, reliable and valid. Its reliability is dependent on providing reliable results while validity involves the correct detection of the majority of children with hearing loss (high sensitivity) without designating most children without hearing loss as failing the test (high specificity).

The process of screening should identify infants with PCEHL (permanent congenital or early-onset hearing loss) for whom further action is taken (test-positives) and infants without PCEHL for whom no further action is needed (test-negatives).

It is highly doubt that any hearing screening test can precisely distinguish all infants with PCEHL from those without, due to the intrinsic differences in biomedical investigation and test algorithms.

2.4.1.1 The performance of an infant hearing screening test based on these four outcomes can be further evaluated on the basis of the following parameters:

Sensitivity: Probability of a positive test in children with hearing loss or the percentage of children with hearing loss correctly detected.

Specificity: Probability of a negative test in children without hearing loss or the percentage of children without hearing loss correctly detected as having normal hearing.

False Positive Rate (FPR): Probability of a child without hearing loss testing positive or the percentage of children without hearing loss who had positive test results.

Positive Predictive Value (PPV): Probability of a child having hearing loss when the test is positive or the percentage of those with positive test results who actually have hearing loss.

2.5 Hearing screening applications

Pure tone audiometry (PTA) is important hearing test used to identify hearing threshold levels of an individual, enabling determination of the degree, type and configuration of a hearing loss.

Monitoring of the hearing sensitivity is important for the diagnosis and management of the hearing loss. And for it, pure tone audiometry is needed, which determines the threshold in the wide frequency range. However, pure tone audiometry requires proper equipment and professionals. And in most of the countries, the professionals and the proper equipment that is needed for the evaluation of the hearing loss are not efficient. Automated audiometry is optional in these situations. Automated audiometry requires self-determination of the threshold, following which they can refer an Audiologist for complete diagnostic evaluation.

As a screening tool, if an individual feels they are having reduced hearing sensitivity, the hearing evaluation applications can be used. The availability of professionals to test population in need are less, thus use of smartphone-based applications will be an easily available tool that can be assessed by everyone to test their hearing sensitivity.

Hearing screening application used in this study are the following:

2.5.1 Indian Hearing Screening test (IHST)

2.5.2 Hearing test
2.5.3 uHear

2.5.1 Indian Hearing Screening Test

Indian Hearing Screening Test application is developed by AIIMS Bhubaneswar by a team of professionals for the hearing screening of children, adult and the geriatric population who are at risk of hearing loss.

2.5.1.1 Indian Hearing Screening Test features:

The test can be done on pediatric as well as the older population. The hearing thresholds of Children less than 5 years also can be determined by using this application. Screening of children from o to 5 years' age group can also be done with it. The test result is Self-explanatory. Test results can be saved and emailed, after the testing cause of hearing loss can be determined and the probable treatment reviewed.

2.5.2 Hearing test

Pure-tone audiometry is the basic hearing test which determines the degree and type of hearing the loss.

2.5.2.1 Hearing Test features:

Initially, it does the calibration of the device (in the case of lack of predefined coefficients or for headphones other than bundled). If there will be any correction factor it will automatically adjust the calibration factor. Pure tone audiometry using bundled headphones and predefined calibration factors from the record. There is also an option of masking noise for the purpose of free field audiometry. Local database (offline access to tests results, without connecting to the server). Tests results can be stored on a remote account, created for a given email address; data are easy to recover, transfer to/from any other mobile or simultaneously synchronize on different devices. **2.5.3 uHear** uHear was designed by Donald Hayes, Ph.D. Director of Clinical Research for Unitron. This simple self-administered hearing test helps people with hearing loss take that first step to better hearing. This is an IOS-based application.

uHear allows to test hearing in less than 5 minutes, on any one or all three of these easy tests:

a. Hearing Sensitivity test permits to evaluate the hearing sensitivity.

b. Speech in Noise test is to evaluate ability to understand speech in noisy environments.

c. The questionnaire is for to know hearing ability in common listening situations.

There have been studies using uHear and Hearing test applications. However these have not been tested in Indian population. Further these applications are being compared with Indian Hearing Screening Test application. This will give an understanding about the sensitivity and specificity of these applications with reference to the conventional audiometry.

Chapter 3

METHODS

The aim of this study is to find out the sensitivity and specificity of smartphone-based hearing screening application and for which the following procedure was followed:

3.1 Participant

This study included 2 groups:

Group 1- This group consists of 50 individuals with hearing sensitivity within normal limits, in the age range of 20-40 years (Mean age 24years).

Subject selection criteria

The participants of Group 1 were selected based on the following test results:

a. Pure tone audiometry was carried out to determine normal hearing sensitivity. All the participants had both AC and BC thresholds less than 15dBHL for frequencies between 250Hz–8000 Hz.
b. Normal middle ear functioning was ensured based on tympanometry. All the participants had A-type of tympanometry with reflexes present at 1 kHz.
c. Only participants with present otoacoustic emissions and ABR responses present at 30 dBnHL were included in the study.
d. A detailed case history was administered to exclude individuals with history or complaint of the middle ear and neurological disorders.

Group 2- This group consists of fourteen ears with mild and fourteen ears wih moderate hearing loss individuals.

Subject selection criteria:

The clients with mild and moderate hearing loss were taken for the study after they were diagnosed at the hearing clinic. Patients were excluded from the study if they were not able to follow simple commands and who were not able to press the button on the touch screen device. Total of 20 participants with mild and moderate hearing loss was included in the study.

3.2 Instrumentation

- Otoscope was used for examination of the ear canal and find out any contraindication for audiological evaluations.
- Calibrated double channel clinical audiometer (GSI-61, USA) with Sennheiser supraaural headphones were used for estimating the air conduction thresholds. Radio ear B-71 bone vibrator was used for bone conduction thresholds.
- A calibrated middle ear analyzer, GSI tympster (GSI-USA) were used for tympanometry and reflectometry.
- ILO 292 DPEcho port system (Otodynamics Inc., UK) will be used to assess the transient evoked otoacoustic potential.
- Bio-logic Navigator ® Pro (Optometrics) will be used to assess the Auditory Brainstem responses.
- Android Smartphone loaded with “Hearing Test”, “Indian Hearing Screening Test” and iPad loaded with “uHear” application was used to find the hearing threshold.

3.3 Test Environment

Conventional air conduction audiometry was carried out in the sound treated room by using calibrated double channel clinical audiometer (GSI-61, USA) with Sennheiser supra-aural headphones and bone conduction audiometry was carried by Radio Ear B-71 bone vibrator in both the groups.

Smartphone-based audiometry was done in quite a room by using Indian Hearing Screening Test, Hearing Test and uHear application in normal as well as in mild and moderate hearing loss population. Sennheiser supra-aural headphones were used for the testing.

3.4 Test Procedures

Testing was done in the following steps:

3.4.1 Case history

3.4.2 Otoscopy

3.4.3 Immittance evaluation

3.4.4 Conventional Audiometry

3.4.5 Smartphone-Based Audiometry

3.4.1 Case history:

A detailed case was taken to gather information about demographic details and to find out the client’s complaints and the onset of the problem in both the groups.

3.4.2 Otoscopic Examination:

The otoscopic examination was carried out in both the groups by using video otoscope to find out any abnormality in the ear canal in all the participants.

3.4.3 Immittance evaluation

Immittance evaluation was carried out to see the middle ear status, Tympanometry, and the acoustic reflex test was administered in all the participants.

3.4.4 Conventional Audiometry

Before starting conventional audiometry, Sennheiser supra-aural headphone was calibrated with double channel clinical audiometer (GSI-61, USA) by using the sound level meter (Larson, & Davis System 824). Conventional audiometry was done in all the participants by using modified Hughson-Westlake method as recommended by the British Society of Audiology. Each participant was tested by using conventional audiometry before testing with smartphones based applications. Instructions were given to the client before administration of the pure tone and application based audiometry. Instructions were that participants have to raise his/her hand or finger when he/she will hear the tone.

Testing was started from 60dBHL and if the client was able to hear the stimulation then intensity was decreased by 10dB steps till the level of no response and intensity was increased in 5dB step in the frequencies 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz and 8000Hz. 50% of the correct responses at the lowest level was taken as the threshold of the client in conventional audiometry. Pure tone average was taken of the frequencies 500Hz, 1000Hz,2000Hz and 4000Hz.

After air conduction audiometry, bone conduction audiometry was administered in the frequencies range of 250Hz to 4000Hz by using a bone vibrator.

3.4.5 Smartphone-Based Audiometry

Android Redmi 6 Smartphone was loaded with "Hearing Test", "Indian Hearing

Screening Test" applications and iPad was loaded with "uHear" to find the hearing thresholds. Before starting the hearing evaluation by using these applications, participants were instructed about the instructions given in the smartphone hearing screening applications.

3.4.5.1 Indian Hearing Screening Test

Indian Hearing Screening Test application is developed by AIIMS Bhubaneswar by a team of professionals for the hearing screening of children adult and a geriatric population who are in risk or hearing loss.

Procedure

The aim of this application is to evaluate the hearing threshold. The test was done in a quiet room, first of all when the client opened this application, He/She had filled all the demographic detailed showed in the screen. This application was in four Indian languages (Hindi, Odia, Tamil, Telugu) and in the English language also. For this study, the English language was used for instruction. Volume was kept in a maximum level before testing. First hearing threshold was checked in the right ear after that in the left ear in frequencies ranging from 250Hz to 8kHz. Initial presentation level to find the threshold was 40dB in both the ear and if tone was audible to the client then tone was reduced by 10dB and if the tone was not audible then it was increased by 5dB after pressing Audible and not Audible respectively. The procedure is similar to the modified H-W method of pure tone audiometry.

3.4.5.2 Hearing test

Pure-tone audiometry is the basic hearing examination which determines the degree of hearing the loss in relation to the sound frequency.

Procedure

When participants opened this application, first he/she had to select a new test, further, they had to select the headphones. There were two types of headphones Bundled headphones and Other headphones. The bundled headphone was calibration headphones, basically, that type of headphones is used in pure tone audiometry for checking the hearing threshold or for speech audiometry. The second type of headphone was Other headphones, these headphones needed calibration before administering the test, and calibration was performed in a normal hearing person. A calibration procedure was automatically done by the application in frequencies range of 125Hz to 10kHz. In which person was pressing the button when sound is being heard and release the button when there was no sound.

After calibration, the threshold was estimation from frequencies 250Hz to 8KHz, and for that instruction was shown in the screen those instructions were followed by the participants. The instruction was like use the buttons "I can Hear" And "I cannot Hear" to determine the quietest audible sound and conform with the button "Barely audible". And hearing threshold was checked in the all frequencies from 250Hz to 8kHz, and after the test, all thresholds were showed in a screen in a single audiogram.

3.4.5.3 uHear uHear was designed by Donald Hayes, Ph.D. Director of Clinical Research for Unitron. This simple self-administered hearing test helps people with hearing loss take that first step to better hearing. This is an iOS-based application. This application basically used for 3 test i.e.

Hearing Sensitivity, Speech in Noise and Questionnaire is a series of questions regarding your hearing ability. In the current study, we are focusing on hearing sensitivity.

Procedure

When participants opened this application in I pad, they had chosen the test "Hearing Sensitivity" to check their threshold and the next step was to select the headphone. After that, they were able to check their threshold by keeping the volume at full level. They had to press the button "Heard" when the tone was audible or if they felt like they can hear the tone. After finishing the test result for both the ears were shown in the screen in the range of 500Hz to the 8kHz range of frequencies.

3.5 Statistical Analyses

The data obtained from the study were tabulated to statistical analyse and analyzed using the IBM Statistical package for social science (SPPS version 20) software. Descriptive statistics were carried out. The Shapiro-Wilk test was used to check the normality. Result reveals it does not follow a normal distribution ($p<0.05$). Non- Parametric test Cohen's Kappa test was done to analyses quantitative data of "Hearing Test" and "Indian hearing screening test" applications. Spearman's rank-order correlation is carried out to analyze quantitative data of "uHear" application.

Chapter 4

Results

The present study aimed to study the sensitivity and specificity of smartphone-based hearing screening applications. This study included a total of 70 subjects or 127 ears consisting of both males and females, age range from 20 to 40 years. Fifty subjects (99 ears) had normal hearing and 10 subjects (14 ears) had mild and 10 subjects (14 ears) had moderate hearing loss. Hearing loss was divided according to the Classification of Severity of Hearing Impairment (Goodman's, 1965).

The result of the study is provided under the following heading:

4.1 To determine the hearing threshold by using Diagnostic Audiometer.

4.2 To determine the hearing threshold by using Android and iOS-based mobile/iPad applications.

4.3 To compare the hearing threshold obtained by a diagnostic audiometer and smartphone applications.

Data collected from normal hearing participants and hearing impaired individuals were tabulated. The data obtained were subjected to statically analysis using statistical package for social sciences (SPSS version 20) software. Descriptive statistics was carried out to estimate the mean and standard deviation. Prior to the analyses of the data, the ShapiroWilk test was used to check the normality of the data. The results indicate that they were not normally distributed. Hence, the data were subjected to non-parametric analyses. Non- Parametric test Cohen's Kappa test was done to analyses quantitative data of "Hearing Test" and "Indian hearing screening test" applications. and non-parametric Spearman's rank-order correlation is carried out to analyze quantitative data of “uHear” application, “Indian Hearing Screening Test” and “Hearing test”.

4.1 To determine the hearing threshold by using Diagnostic Audiometer

Hearing threshold were estimated using GSI-61 diagnostic calibrated audiometer in the sound-treated room in the frequency range of 250Hz to 8000Hz in normal hearing individuals as well as in mild and moderate hearing impaired individuals by using the same audiometer. Results of diagnostic audiometry were compared with thresholds obtained by the three different Android as well as iOS-based application. The Table 4.1 shows the mean thresholds of normal hearing individuals and in individuals with mild and moderate hearing loss.

Table 4.1:

Mean threshold of Conventional Audiometry in normal, mild and moderate hearing loss.

Sl. No.	Hearing level	Number of ears	Mean Threshold
1.	Normal Hearing	99	10
2.	Mild Hearing loss	14	30
3.	Moderate Hearing loss	14	45

4.2 To determine the hearing threshold by using Android and iOS-based mobile/iPad applications.

Hearing thresholds were examined by using the two Android apps and one iOS-based application after the conventional audiometry in two different groups of subjects i.e. normal hearing, mild and moderate hearing impaired individuals. Results obtained by these three applications were compared with the conventional audiometric thresholds. The iOS based application uHear does not give the thresholds in each frequency, it shows degree of loss at each frequency. Hence it is discussed later in this chapter. The table 4.2 shows the mean thresholds of Indian Hearing Screening test and Hearing Test in normal hearing individuals and in individuals with mild and moderate hearing loss.

Table 4.2:

Mean threshold of Indian Hearing Screening Test and Hearing Test applications in normal, mild and moderate hearing loss.

Sl. No.	Hearing level	Number of ears	Mean Threshold of IHST	Mean Threshold of Hearing Test
1	Normal Hearing	99	15	7
2	Mild Hearing loss	14	35	33
3	Moderate hearing loss	14	71	65

`

Here the mean threshold of Indian Hearing Screening Test application was 15dB, 35db and 71dB in normal, mild hearing and moderate hearing loss respectively. Mean threshold of Hearing Test are 7dB, 33db and 65dB in normal, mild hearing loss and moderate hearing loss respectively. The mean thresholds for moderate hearing loss were higher in both the Android applications.

4.3 To compare the hearing threshold obtained by a diagnostic audiometer and smartphone applications:

Initially, hearing thresholds were examined by using convention audiometry in the sound-treated room and thereafter hearing threshold were calculated by using the android based smartphone with "Indian Hearing Screening test" and "Hearing test" applications and also with iPad iOS based application "uHear" in quite a room.

4.3.1 Comparison between conventional audiometry and "Indian hearing screening test" application.

To assess the agreement between the threshold obtained by diagnostic audiometer and Indian hearing screening test application, qualitative analysis was carried out. Kappa coefficient was calculated for comparison between thresholds obtained by Audiometer and application. Kappa coefficient value ranged between 0.61-0.80 i.e. k = 0.666 which is indicative of substantial agreement (Landis, & Koch, 1977) between the conventional audiometry and Hearing Test application.

In normal hearing

The threshold obtained by conventional audiometry in normal hearing subjects was compared with Indian hearing screening test application in ninety-nine ears. The results of normal hearing subjects in Indian hearing screening test application showed, ninety-seven ears with normal two normal ears showed as mild hearing loss out of ninety-nine ears. In terms of percentage in normal hearing subjects, Indian hearing screening test application showed 98% normal and 2% mild hearing loss.

In mild hearing loss

The threshold obtained by conventional audiometry in mild hearing loss subjects was compared with Indian hearing screening test application in fourteen ears. Results had shown that two ears with mild hearing loss showed normal hearing, eleven ears with mild hearing loss were showed as mild hearing loss and one ear was showed a moderate hearing loss. In terms of percentage, Indian hearing screening test application showed 14.3% normal, 78.6% mild hearing loss and 7.1% moderate hearing loss for mild hearing loss.

In moderate hearing loss

The threshold obtained by conventional audiometry in the moderate hearing was compared with Indian hearing screening test application in fourteen ears. Results had shown that four ears with moderate hearing loss showed moderate hearing loss, seven ears with moderate hearing loss were showed as moderately-severe hearing loss and three ears were showen a severe hearing loss. In terms of percentage, Indian hearing screening test application showed 28.6% moderate, 50.0% moderately-severe hearing loss and 21.4% severe hearing loss for moderate hearing loss.

4.3.2 Comparison between conventional audiometry and “Hearing Test” application.

To assess the agreement between the threshold obtained by diagnostic audiometer and Hearing test application, qualitative analysis was carried out. Kappa coefficient was calculated for comparison between thresholds obtained by Audiometer and application. Kappa coefficient value ranged between 0.61-0.80 i.e. k = 0.686 that was indicative of substantial agreement (Landis, & Koch, 1977) between the conventional audiometry and Hearing Test application.

In normal hearing

The threshold obtained by conventional audiometry in normal hearing subjects was compared with Hearing Test application in ninety-nine ears. The results of normal subjects in Hearing Test application showed, ninety-seven ears with normal two normal ears showed as mild hearing loss out of ninety-nine ears. In terms of percentage in normal hearing subjects, Hearing Test application showed 98% normal and 2% mild hearing loss.

In mild hearing

The threshold obtained by conventional audiometry in mild hearing loss subjects was compared with Hearing Test application in fourteen ears. Results had shown that two ears with mild hearing loss showed normal hearing, eleven ears with mild hearing loss were showed as mild hearing loss and one ear was showed a moderate hearing loss. In terms of percentage, Indian hearing screening test application showed 14.3% normal, 78.6% mild hearing loss and 7.1% moderate hearing loss for mild hearing loss.

In moderate hearing

The threshold obtained by conventional audiometry in the moderate hearing was compared with Hearing Test application in fourteen ears. Results had shown that four ears with moderate hearing loss showed moderate hearing loss, seven ears with moderate hearing loss were showed as moderately-severe hearing loss and three ears was showed a severe hearing loss. In terms of percentage, Indian hearing screening test application showed 28.6% moderate, 50.0% moderately-severe hearing loss and 21.4% severe hearing loss for moderate hearing loss.

4.3.3 Comparison between "India Hearing Screening test" application and "Hearing test" application.

To assess the agreement between the threshold obtained by Hearing test and Indian hearing screening test application, qualitative analysis was carried out. Kappa coefficient was calculated for comparison between thresholds obtained by Audiometer and application. Kappa coefficient value ranged between 0.61-0.80 i.e. k = 0.708 that was indicative of substantial agreement (Landis, & Koch, 1977) between the conventional audiometry and Hearing Test application.

In normal hearing

The threshold obtained by Indian hearing screening test application in normal hearing subjects was compared with Hearing Test application in ninety-nine ears. The results of normal subjects in Hearing Test application showed, ninety-seven ears with normal two normal ears showed as mild hearing loss out of ninety-nine ears. In terms of percentage in normal hearing subjects, Hearing Test application showed 98% normal and 2% mild hearing loss in normal hearing individuals.

In mild hearing loss

The threshold obtained by Indian Hearing Screening Test application in mild hearing loss subjects was compared with Hearing Test application in thirteen ears Results of Hearing test application had shown that two ears with mild hearing loss showed normal hearing, eleven ears with mild hearing loss were showed an as mild hearing loss. In terms of percentage, Hearing Test screening application showed 15.4% normal, 84.6% mild hearing loss comparison to Indian hearing screening application.

In moderate hearing loss

The threshold obtained by Indian Hearing Screening Test application in the moderate hearing was compared with Hearing Test application in twelve ears. Results of Hearing test application had shown that five ears with moderate hearing loss showed moderate hearing loss, seen ears with moderate hearing loss were showed as moderately-severe hearing loss. In terms of percentage, Indian hearing screening test application showed 45.0% moderate, 55.0% moderately-severe hearing loss as compare to Indian hearing screening test application.

4.4 Analyses of qualitative data done by using non- Parametric Spearman's rank-order correlation test.

Non-parametric Spearman's rank-order correlation test was done to correlate the test results of "uHear", "Indian Hearing Screening Test" and "Hearing test" applications with conventional audiometry.

Table 4.3:

Comparison between conventional audiometry to Indian Hearing Screening Test, Hearing Test and uHear in two Android apps and in iOS-Based app by using Spearman's rank-order

Sl. No.	Apps	Spearman's rank-order correlation test
1.	Indian Hearing Screening Test	p>0.05
2.	Hearing Test	p>0.05
3.	uHear	p>0.05

Table 4.3 The Spearman's rank-order correlation test shows that there is good correlation ($p>0.05$). Results showed that there is a good correlation between the Indian Hearing Screening Test, Hearing Test and uHear application with the threshold obtained in the frequency range of 250 to 8000Hz.

4.4.1 Comparison between Indian Hearing Screening Test and Hearing Test and uHear application based on frequencies.

According to the Spearman's rank-order correlation test, if $p>0.05$ there is a good correlation. Comparison between Indian Haring Screening Test, Hearing Test and uHear application was seen, that was showed in following table:

Table 4.4

Comparison between Indian Haring Screening Test, Hearing Test and uHear application

Sl. No.	Comparison between application	Spearman's rank-order correlation test
1.	Indian Haring Screening test and Hearing Test	p>0.05
2.	Indian Haring Screening test and uHear	p>0.05
3.	uHear and Hearing Test	p>0.05

The Table 4.4 shows that, there is good correlation between Indian Hearing Screening Test and hearing test application (p>0.005) in frequencies between 250 to 8000Hz. There is a good correlation between Indian Hearing Screening Test and uHear application in frequencies between 500 to 8000Hz. There is also good correlation between Hearing Test and uHear application in frequencies between 500 to 8000Hz.

4.5 Sensitivity and specificity of Indian Hearing Screening Test hearing screening application and hearing test application.

Sensitivity and specificity of Indian Hearing screening test and Hearing test was evaluated by using these formulas.

Sensitivity and specificity was calculated by using following formulas:

Sensitivity = True positive/true positive + false negative x 100

Specificity = True negative/ false positive + false negative x100

True positive = normal is identified as normal

False positive = Abnormal is identified as normal

False negative = normal is identified as abnormal

True negative = abnormal is identified as abnormal

In these apps for hearing threshold were lower in normal and in few individuals with mild hearing loss. Out of ninety-nine ears with normal hearing sensitivity two had shown mild hearing loss, and in Individuals with mild hearing loss also showed normal hearing in two ears. In moderate hearing loss individual's threshold were poor in all the frequencies. Further, Sensitivity of Indian Hearing Screening Test application and Hearing Test application is 97.98%. This range is between 92.89% to 99.89% and confidence interval is 95%. Specificity of Indian Hearing Screening Test application and Hearing Test application is 92.86%. The range is between 76.50% to 99.12% with confidence interval of 95%.

Because of good sensitivity and specificity these apps can be used for early identification and regular hearing screening. However, for greater degree of hearing loss these apps may not be very sensitive.

4.6. Difference in thresholds obtained in applications in comparison with conventional audiometry

The uHear application mentions the degree at each frequency whereas the other two applications gives the dB levels. uHear application had a dip in 2 kHz. Further, uHear4 and Hearing Test application a threshold shift was seen at 4 and 8 kHz. In normal hearing, mild and moderate hearing loss individuals mean threshold difference between audiomentry and Indian Hearing Screening test were 5 dB, 5 dB and 26 dB respectively. In Hearing test application the mean difference for normal hearing, mild and moderate hearing loss were -3 dB, 3 dB and 20 dB respectively.

Chapter 5

Discussion

The aim of the present study is to compare the hearing threshold obtained by a diagnostic audiometer and smartphone applications. Hearing test was administered in individuals with normal hearing and individuals with mild and moderate hearing loss.

5.1 To determine the hearing threshold by using diagnostic audiometer.

Mean thresholds in ninety-nine normal hearing ears were 10dB. Mean Thresholds in fourteen mild hearing loss ears were 30dB and in fourteen moderate hearing loss ears mean thresholds were 45dB. The main idea behind was to measure the thresholds with diagnostic audiometer was, and compare with the mobile applications.

5.2 To determine the hearing threshold by using Android and iOS-based mobile/iPad applications.

The mean threshold in ninety-nine normal hearing ears were 15dB in Indian Hearing Screening Test application and 7dB in Hearing Test application. In fourteen ears with mild hearing loss, mean threshold were showed by Indian Hearing Screening Test application and Hearing Test is 35dB and 33dB respectively. And in fourteen ears with moderate hearing loss mean threshold were 71dB and 65dB in Indian Hearing Screening Test application and Hearing test application respectively. In case of moderate hearing loss, these application were showing higher degree of PTA as compare to conventional audiometry. Reason for that could be, subject related factor, or mobile phone was not able to give sufficient output.

5.3.Comparison between conventional audiometry and "Indian hearing screening test" application.

In normal

In comparing the thresholds of Indian Hearing Screening Test application with conventional audiometry. It showed a substantial agreement for frequencies from 250Hz to 8000Hz. Mean thresholds were also in the severity range of hearing impairment classified by Goodman in 1965. However, out of ninety-nine ears two ears were showing mild hearing loss.

In Mild hearing loss

In case of mild hearing loss there is a substantial agreement between the thresholds obtained by this application and conventional audiometry. Scores obtained by this application was in the severity range of hearing impairment range given by Goodman,1965 for conventional audiometry. But it had been seen that thresholds in higher frequencies 2000Hz and above, threshold were more elevated compared to the conventional audiometry. It had assumed that, it can be because of subjects related factors or due to mobile phones sensitivity at higher frequencies.

In moderate hearing loss

As results had shown that in moderate hearing loss there is 45% agreement between this app and the conventional audiometry. 55% of the time this app was showing moderatelysevere to severe hearing loss. It could be due to the limitations of the mobile phones. The output of the mobile phone could be limited restricting the intensity levels. The other possibility could also be subject factor as 45% have reported were correctly diagnosed. These results indicate that this application may not be suitable for higher degree of hearing loss.

5.3.2 Comparison between conventional audiometry and "Hearing Test" application.

In normal

In comparing the thresholds of Hearing Test application with conventional audiometry. It showed a substantial agreement between 250Hz to 8000Hz.and mean thresholds were also in the severity range of hearing impairment classified by Goodman in 1965. Earlier studies of this app is done in the iPhones/iOS-based software, and study has shown that difference was within 4dB (Foulad, A., Bui, P., & Djalilian, H., 2013) between this app and conventional audiometry. However, the current study results show that thresholds of 4000 Hz and 8000 Hz were higher by an average of 6 dB. This could be due to difference in the equipment and mobile application used in the current study.

In mild hearing loss

In case of mild hearing loss there is a substantial agreement between the thresholds obtained by this application and conventional audiometry. Scores obtained by this application was in the severity range of hearing impairment given by Goodman,1965 for conventional audiometry. But it had been seen that thresholds in higher frequencies 4000Hz to 8000Hz, threshold were more elevated by 6 to 10 dB. The reason for substantial agreement could be because the thresholds compared were average of 500, 1000 and 2000 Hz.

In moderate hearing loss

In case of moderate hearing loss there is a substantial agreement between the thresholds obtained by this application and conventional audiometry. Hearing Test application showed

28.6% moderate, 50.0% moderately-severe hearing loss and 21.4% severe hearing loss for moderate hearing loss. By looking these results, it may be because of mobile phones were not able to produce sufficient output for moderate level of intensity. Maybe because of that these thresholds are shifted to moderately- severe to severe hearing loss. In many individuals in this application there was a no response in higher frequencies 4000Hz and 8000Hz after 65dB.

5.3.3 Comparison between conventional audiometry and "uHear" application.

In normal

It showed a substantial agreement between 500Hz to 8000Hz and mean thresholds were also in the severity range of hearing impairment classified by Goodman in 1965. According to the study done by Peer and Fagan in 2015, it showed that this app has a 100% of sensitivity. During evaluation of hearing threshold, it had observed that there was a notch in the 2000Hz in all the individuals. That was showing mild hearing loss at 2000 Hz and rest of the frequencies were showing normal results. This is one of the pitfall of this application.

In mild hearing loss

In case of mild hearing loss there is a substantial agreement between the thresholds obtained by uHear application and conventional audiometry. Threshold obtained in 500Hz, 1000Hz and 2000Hz were in the mild range in the app but higher frequencies 4000Hz to 8000Hz threshold were elevated till moderate hearing loss.

As we had discussed earlier, reason could be low output in higher frequencies. Study done by Peer & Fagan in 2015 showed threshold getting from iPhone is sensitive for higher frequencies such as 4000Hz, 6000Hz and 8000Hz. However this study points out that it is less sensitive at higher frequencies. This reduced sensitivity is seen only while evaluating individuals with hearing loss. This difference could also be due to the difference in transducers used. Study by Peer and Fagan (2015) "earbud' earphones" and in current study we had used Sennheiser supra-aural headphone.

In moderate hearing loss

In case of moderate hearing loss there it had seen that all the frequencies were elevated in 500Hz to 8000Hz. However, this study points out that it is less sensitive at higher frequencies. This could be due to; instrument was not able to give sufficient output, or due to subject related factor.

5.4 Sensitivity and specificity of smartphone based application.

All the applications had shown good Sensitivity and specificity in normal as well as in affected population. It was observed that Indian Hearing Screening test application is slightly better than uHear and Hearing test application. In uHear a dip in 2 kHz was seen and in Hearin Test application threshold shift was seen at 4 and 8 kHz. However Indian Hearing Screening Test the responses were in normal limits.

Hence, based on our observation we can hierarchically classify Indian Hearing Screening Test is better than uHear and uHear is better than Heaing Test. That indicates that it will be the effective screening tool for hearing screening.

As seen in the results there was consensus with results from the applications and conventional audiometry hence the null hypothesis that there will be no difference between audiometric threshold and threshold obtained by mobiles apps is accepted.

5.5 Advantages and Disadvantages of the applications Advantages:

1. It is available free of cost and portable as it can be loaded in mobile phones.
2. These results indicate that these application can be efficient tool in early identification and prevention of handicap.
3. It can be self-administered or can be done by any health care professional for screening when audiometer is not available.
4. It will be a very helpful screening tool for remote area/rural and in low socioeconomic countries.
5. It will be helpful for the places with electricity.
6. In the uHear application, the person will not get visual cues of varying threshold levels. This avoids the bias to tap better thresholds and this can give more reliable responses than others.
7. These applications take 4-5 minute for hearing screening of both the ears.

Disadvantages:

1. Differential diagnosis of the type of hearing loss is not possible.
2. Mobile phones testing can be affected by notifications by other applications.
3. In the uHear application (iPad) testing response reaction time is fast. This could be difficult for older population and in individuals with dexterity problems.
4. Background noise can affect test results.
5. In Indian hearing screening Test application, the results can be affected by subject's mistake, such as omitting the frequencies by accidental button pressing or pressing the button for threshold conformation. But in Hearing Test application, the client can re-edit his threshold.

6. The factor limiting the accessibility of the test in relation to the number of Android-based and iOS mobile devices are bundled headphones and calibration coefficient. Not all the devices offered with bundles headphones.

5.6 Implication

More than 360 million in the world suffering from hearing loss, and many persons are exposed to noisy environments each day. Many persons may not have access to a clinic. Thus, these hearing screening applications are useful in the understanding of hearing loss. The results clearly point out that these applications have good sensitivity and specificity. These applications can be used for early detection and treatment of hearing loss thus reducing the negative consequences of hearing loss. We expect that a ubiquitous hearing test using a smart device can provide early identification of hearing loss.

Chapter 6

SUMMERY AND CONCLUSION

The aim of the study is to determine the sensitivity and specificity of smartphone hearing screening technology.

A Total of 70 individuals participated in the study, in which 50 individuals had normal hearing. Ten individual with mild hearing loss and 10 subject with moderate hearing loss were taken for study. Hearing thresholds were measured by using conventional audiometry and with three mobile based hearing screening application. Applications were “Indian Hearing Screening Test”, “Hearing Test” and uHear application, first two applications were Android-based and uHear was iOS-based application.

There was no significant difference between conventional audiometric thresholds and thresholds were obtained by using mobile based hearing application. These applications have a good sensitivity and specificity. These applications can be used as a screening tool for hearing screening.

Based on the comparison of the results obtained by the applications it was seen that Indian Hearing Screening test application is slightly better than uHear and Hearing test application. In uHear a dip in 2 kHz was seen and in Hearing Test application threshold shift was seen at 4 and 8 kHz. However Indian Hearing Screening Test the responses were in normal limits. Hence, based on our observation we can hierarchically classify Indian Hearing Screening Test is better than uHear and uHear is better than Heaing Test.

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