

**HEARING LOSS IN THE DEVELOPING WORLD:
EVALUATING THE iPhone MOBILE DEVICE AS A
SCREENING TOOL**

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Dissertation presented for the degree

MASTER OF MEDICINE (MMED) IN OTORHINOLARYNGOLOGY

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DECLARATION

I, *SHAZIA PEER*, hereby declare that the work on which this dissertation is based, is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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STRUCTURE OF THE DISSERTATION

An abstract of the study is first presented. Thereafter there are 3 parts to the dissertation.

Part A is the protocol that outlines the justification for the study, the methods and analyses as well as the potential implications.

Part B presents the findings of the literature review that was conducted.

Part C concludes the dissertation in the format of a submission to the *South African Medical Journal*. The format of the journal author instructions require that Vancouver referencing be used. To maintain consistency between the Parts, the Vancouver referencing convention – and not Harvard - has been used.

Part D includes the appended documents

Appendix A – Consent / Assent Form

Appendix B – Ethics Approval

Appendix C – “Instructions to authors” as provided by the *South African Medical Journal*

ABSTRACT

Background: Hearing loss is a global health burden affecting 360 million people. The highest prevalence is in the Developing World where hearing screening programmes are scarce, and failure to address growing high-risk populations will result in new deaf communities. In resource stretched communities such as these, new strategies to alleviate this burden are necessary. Advances in technology have led to innovative mobile digital devices like smartphones and tablets with the potential to test hearing through audiometric applications. Given the recent upsurge of mobile technology in Africa, it is befitting to determine whether the implementation of science can translate to health service delivery.

Objectives: To validate the Apple iPhone mobile device using the uHear™ application “app” as a possible hearing screening tool in the Developing World.

Methods: This was a quasi-experimental study design. Participants were recruited from the ENT Clinic at Groote Schuur Hospital in Cape Town. All participants had a formal audiogram, and then completed the iPhone uHear™ test in 3 different settings – the waiting room, a quiet room and a soundproof room. “Earbud” headphones supplied with the device were used.

Results: 25 patients were tested (50 ears in total). Pure tone thresholds recorded with the iPhone in all 3 rooms were compared to a formal audiogram. Data collected were analysed using kappa statistical analysis. The iPhone was found to be a highly sensitive test for high frequency hearing loss (2000Hz, 4000Hz, 6000Hz) in quiet and soundproof rooms. Kappa values showed “good” and “very good” correlation of the iPhone thresholds when compared to the formal audiogram in the above environments, and was statistically significant with p values <0.05. The iPhone was moderately sensitive for low frequency hearing loss (250Hz, 500Hz, 1000Hz) in a soundproof room, but poor in quiet and waiting room settings.

Conclusion: The iPhone uHear™ test is highly sensitive for detecting high frequency hearing loss, making it well suited as a screening tool to detect presbycusis, and ototoxic hearing loss caused by HIV & TB therapy and chemotherapy. Its portability and ease of use makes it opportune to use in Developing World communities that lack screening programmes.

Key Words: hearing loss, Developing World, screening programmes, ototoxicity, presbycusis, mobile technology, portable audiology, HIV, TB, chemotherapy, ARVs, Ant-TB therapy, global health

Part A: PROTOCOL

PROJECT TITLE

Hearing loss in the Developing World: Evaluating the iPhone mobile device as a Screening Tool

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INTRODUCTION

Epidemiology

The global burden of hearing loss continues to affect millions of people around the world, with new estimates reaching 360 million people ⁽¹⁾, and an increased prevalence in Developing World nations ⁽²⁾. Furthermore, it is projected to be among the top ten causes of the global burden of disease in 2015 ^(3, 4, 5). Estimates of the percentage of Americans suffering from hearing loss are likely to increase to between 20 and 25% by the year 2015 ⁽³⁾, a country with vast resources and established hearing screening programmes. One can only imagine the projected decline in health and economic development of developing nations with little to no resources for screening programmes unless dramatic measures are taken to address this problem.

The impact of hearing loss includes the inability to communicate, a delay in language development, economic and educational disadvantage, stigmatisation and social isolation. While the value of early detection of hearing loss in infants is well established, the awareness of hearing loss in the elderly and other high-risk groups is much lower ^(3, 4, 5).

In a survey of ENT services in Sub-Saharan Africa, *Fagan et al reported* a paucity of audiology services in all 18 countries surveyed. South Africa had approximately 1 audiologist per 100 000 people, with the remaining countries having less than 1 audiologist per 100 000 people ⁽⁶⁾. In addition, Sub-Saharan Africa has one of the highest prevalence rates of hearing loss at 15.7%, with poor access to hearing screening programmes ⁽²⁾.

Hearing Screening Programmes

Screening programmes are the most effective way to detect hearing loss, but do not replace formal pure tone audiometry - the gold standard of diagnostic hearing assessment. They involve testing a community for hearing loss by trained audiologists or other health professionals, and then referring patients with suspected hearing loss for more sophisticated audiological testing, and for a medical opinion. Screening tests can identify hearing loss in the young population at an early age where early intervention by way of grommets or hearing-aids can be administered, thereby facilitating rehabilitation as early as possible. In the elderly population, hearing loss is often undertreated and under-diagnosed, due to lack of awareness by the patient and health care professionals. Screening tests available in the Developed World for the elderly permit earlier recognition of hearing loss and implementation of rehabilitative measures, and maintains their independent lifestyle ^(4, 5).

Many methods of hearing screening have been developed over the years, like questionnaires and telephone-based programmes ⁽⁵⁾. In addition, other methods like interactive internet-based screening programmes have brought hearing screening programmes into the digital world ^(7, 8). A valid concern with many of these testing tools is the interference of background (environmental) noise, which affects the reliability of results obtained in non-conventional testing environments. Two drawbacks of questionnaires are poor respondents, and subjectively, no quantifiable degree of detected hearing loss, i.e. the outcome depends on perceived disability ⁽⁵⁾. Telephone audiometry is widely used in the United Kingdom and in the Netherlands, and has been established as “The National Hearing Test”. This system too, has a number of recognized problems, the 2 main limiting factors being: 1) the wide range of telephones available on the

market and 2) the fact that signals are presented to one ear, rather than to both ears (diotic) as listening with two ears has an additional benefit of 1.4 dB. It does, however, have a sensitivity and specificity of 0.91 and 0.93 respectively ⁽⁵⁾.

Internet-based programmes are devised through collaborative efforts involving medical professionals and IT specialists. In what was one of the earliest publications of this kind, *Seren et al* did not find a significant difference between a web-based hearing test and conventional audiometry; both provided the same audiometric results and mean thresholds varied by no more than 1.78dB. However further audiometric investigation is necessary if hearing loss is suspected ⁽⁷⁾. Problems with internet-based programmes are often device or environment related. Device issues include variable earphones, calibration of device and software to be used, and quality and speed of internet connectivity. Background noise is almost always an issue often necessitating calibration of noise levels ^(7, 9, 10).

Tele-audiometry is also a web-based screening programme ^(11, 12). Through a website, an audiologist remotely operates a portable audiometer to generate pure tone stimuli at various frequencies and volumes to a patient at a distant location. If or when the patient hears a sound stimulus, he/she responds by pressing a button on the audiometer. This response is captured by the server and relayed back to the audiologist. The audiologist then analyses the data, and then relays the results back to the patient, often at a later stage. The system is reported to work in flexible configurations and to support hearing tests anytime and anywhere, as long as internet access is available ^(9, 10). The main drawback is that tele-audiometry requires internet access ^(11, 12).

Apple uHear™ Test (Figures 1 & 2)

With the advancement of technology and the accessibility and availability of mobile devices, especially smartphones, mp3 players and tablets, it is not unexpected that a hearing screening program has been developed for such devices. One such software program (application), entitled uHear™, was developed by Unitron, a Canadian hearing aid company in 2009. It was released by Apple, and is available as a free download on iTunes, and can be installed as an application onto any Apple touch interface device, including the iPhone, iPad and iPod Touch. Once downloaded, the uHear™ application does not require internet connectivity to operate. Using an iPhone, the uHear™ application is basic in design and user-friendly. It is a self-assessment test, with easy-to-perform commands that can be followed by any audiotically challenged individual. The uHear™ application generates results immediately after testing. With no waiting period, patients do not have to be recalled for test results. Africa has experienced an exponential growth in mobile technology related sales, especially cellular phones, with 1 in 5 users owning a smartphone⁽¹³⁾. Making use of hearing screening tools that utilize already available technology would be ideal in resource-stricken communities and would be an excellent way to merge science with health benefits at a predictably low cost.

However, despite being so freely accessible, there are no published studies that report the accuracy of the uHear™ application as a hearing screening tool.

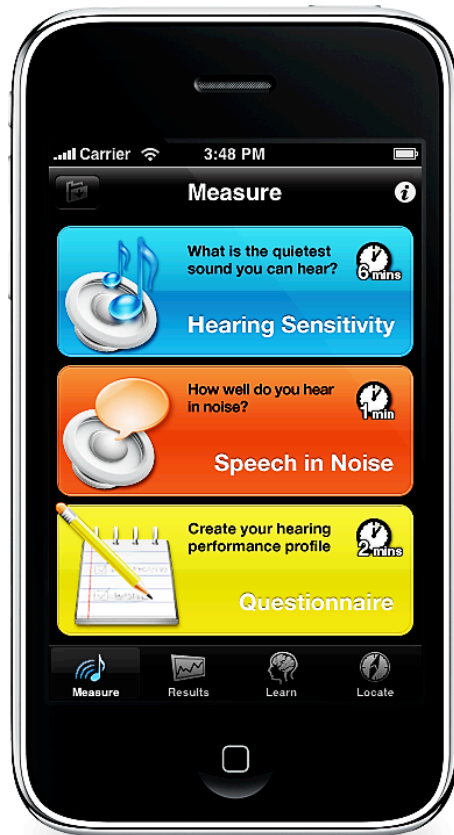


Figure 1: Initial screen view



Figure 2: Audiogram

AIMS

1. To determine the accuracy of audiometric screening with the uHear™ software application using an iPhone mobile device
2. To ascertain the technical feasibility and clinical utility of using the device
3. To test whether it is an effective and efficient screening tool for patients in centres where no access to audiological trained personnel and equipment is available
4. To assess whether it is applicable in a Developing World setting with stretched resources and financial constraints

OBJECTIVES

Validation as a hearing screening tool will be done by assessing the accuracy of the iPhone (using the uHear™ application) to detect pure tone thresholds at low frequencies: 250Hz, 500Hz, 1000Hz, and high frequencies: 2000Hz, 4000Hz and 6000Hz, when compared to pure tone thresholds from a formal audiogram at the same frequencies. In addition, the usability of the device and the “application” will be assessed with regards to ease of use, speed, and applicability as a self-assessment device.

METHODOLOGY

- **Study design:** A prospective study
- **Study population**
 - Patients with or without hearing loss will be recruited in the ENT Outpatients Department at Groote Schuur Hospital

- Otoloscopic examination will be performed before pure tone testing to exclude active otorrhoea and wax impaction. Infection control will be maintained during testing
- Inclusion Criteria - Participants between the ages of 15 – 80 years
- Exclusion Criteria
 - Patients with visual impairment, developmental or cognitive problems, otorrhoea or impacted wax
 - Patients who do not speak English but understand the process and steps to complete the program will not be excluded
- Demographic information (age and gender) will be collected
- All patients will have an audiogram done by a trained audiologist within 2 weeks of the iPhone testing
- **Test Instrument**
 - A single iPhone device will be used. The uHear™ software application will be downloaded from the iTunes website (for free). Apple “ear bud” earphones supplied with the device will be used
 - The device emits pure tone sounds at the following decibel levels and frequencies:
 - 10-25 dB, 25-30dB, 40-55dB and 70-100dB
 - At 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz, 6000Hz
 - Each patient will be tested in 3 settings - the waiting room, a quiet room and a soundproof room
 - Instructions to participants: Once the application is opened and the ear buds are inserted, connectivity is confirmed. The participant will simply follow the only command. “When the slightest of sound is heard, please tap the screen”.

- The test takes 6 minutes to complete
- **Conduct of iPhone test**
 - The test will be supervised by an audiologist or the Primary Investigator
 - The test must be conducted in all 3 different settings: 1. Waiting room (where we anticipate background noise); 2. Quiet room and 3. Soundproof room (soundproof booth)
 - A OMD G45 71-6229 Psio™ sound level meter will be used at regular intervals to measure background noise (all 3 environments will be tested daily, and levels need to adhere to the South African Bureau of Standards (SABS) requirements for each environment
 - The Apple “earbud” earphones that are supplied with the device are inserted into the patient’s ear and the position of the ear bud is confirmed by the supervisor
 - The device is turned on, the uHear™ program is initiated, and the volume of speaker is calibrated before each test
 - The right ear is tested first, then the left ear in the waiting room, quiet room and the soundproof room
 - The iPhone device captures the responses and plots the results as an audiogram

STATISTICAL ANALYSIS

The primary outcome measures will be pure tone thresholds obtained by the iPhone device in all 3 locations, and the formal audiogram pure tone thresholds. Data collected from the iPhone and uHear™ application will be analysed using Kappa statistical analysis. This will describe how well the thresholds (hearing level in decibels) at a particular frequency correlate with the

thresholds (hearing level in decibels) at the same frequency as the gold standard – the formal audiogram. Kappa values with good and very good correlation will be assessed if statistically significant.

ETHICS APPROVAL

The study will be approved by the Research Ethics Committee, Faculty of Health Science, University of Cape Town. All participants will give informed consent, assent if underage.

PILOT STUDY

A small pilot study was first conducted in the Division of Otolaryngology at the University of Cape Town to determine whether the study was at all feasible. The accuracy of an audiometric test (uHear™) using the iPod Touch was assessed and correlated with a formal audiogram. Of 40 patients recruited at the ENT clinic, 15 were tested in the waiting room, 25 were tested in the quiet room, and 10 (of the 25) were further tested in the soundproof room. The data captured were then automatically plotted onto an audiogram, and results from the 3 different settings were correlated with the formal audiogram performed by a trained audiologist. Accuracy of results was measured by the decibel discrepancy between formal audiogram and the iPod Touch audiograms. Results showed that in the soundproof room, the decibel discrepancy was within 0-7.5dB of the formal audiogram at both low and high frequencies with a sensitivity of 100 percent. In the quiet and waiting rooms, the decibel discrepancy increased to more than 10dB, and in 6 patients, to more than 20dB (12 percent). However, at the high frequencies, the decibel discrepancy was much improved with a specificity approaching 70 percent. The comparative results of the decibel discrepancy between the waiting room and the soundproof room

audiograms, were found to be statistically significant ($p=0.0001$). We concluded that the study was feasible.

RISKS TO PATIENTS

There are no additional risks or expenses to the patients.

POSSIBLE CONCLUSIONS

An ideal screening program for the Developing World is one that is portable, quick and easy to use, safe and cost-effective and can be used in areas that otherwise would have no access to audiology testing without the expertise of a skilled audiologist.

Should the Apple iPhone and uHear™ program prove to be technically feasible and clinically credible as a screening tool in our clinical setting of an ENT outpatients' department, it might be concluded that it is suited for non-audiologically trained skilled health care workers as a community-based project to screen for hearing loss in high-risk populations that reside within the Developing World setting.

DISCLAIMER

The Division of Otorhinolaryngology and Groote Schuur Hospital do not have any affiliation to the Apple or Unitron companies.

BUDGET

The purchase of an iPhone mobile device is valued at R9500.00

The OMD G45 71-6229 Psio™ sound level meter belongs to Groote Schuur Hospital.

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Part B: LITERATURE REVIEW

OBJECTIVES

The first objective was to identify the burden of disease for hearing loss globally, and to highlight its impact on individuals and their communities. Specific emphasis was placed on the Developing World and Sub-Saharan Africa. In addition, specific adult population groups were identified to be high risk – the elderly, who are prone to adult onset hearing loss (presbycusis) and patients receiving potentially ototoxic drugs - like chemotherapy; anti-TB therapy; HIV therapy).

The second objective was to identify a way forward to address disabling hearing loss within resource-poor communities – reviewing screening programmes in general, and monitoring for any above-mentioned high-risk groups, as well as the effectiveness of different screening procedures that could work in low-budget settings. Included in this was to highlight available technological advancements in audiometric applications (hearing assessment tools), and those that can be effectively utilised in Developing World communities.

CONTEXT

There is presently a global increase in the number of people with disabling hearing loss. Estimates have risen to 5.3% of the world's population. Notwithstanding the fact that hearing loss is multifactorial, affects all age groups, and extends beyond all geopolitical and socioeconomic barriers, the recent World Health Organisation (WHO) report on the Global Burden of Hearing Loss, highlights the overwhelming majority of sufferers as having a distinct population profile: adults with low incomes living in the Developing World including Sub-Saharan Africa ⁽¹⁾. Recognising high-risk groups within this larger population can help to identify

what is failing in existing services, and identify potential sustainable avenues to address this global problem.

LITERATURE SEARCH STRATEGY AND QUALITY CRITERIA

The information presented in this paper is supported by a Pubmed Medline search using the key words: hearing loss, deafness, hearing screening, mobile devices, developing world, ototoxicity, tuberculosis, TB, HIV, ARVs, presbycusis, age related hearing loss, technology, global health. Clinical studies and systematic reviews that directly address the above-mentioned population-specific hearing loss, hearing screening tools and mobile device audiometry, were included. Four global statistics online sources were used - The World Health Organisation (WHO), the Health Professions Council of South Africa (HPCSA), the United Nations (UN) and up-to-date statistical factsheets from verifiable sources of industry.

INCLUSION CRITERIA FOR ARTICLES WERE STUDIES RELATING TO:

- The global burden of Hearing Loss in the Developing world – including prevalence and its impact on society and the individual
- Adult populations at high risk of hearing loss, in particular high frequency hearing loss – specifically the elderly and drug-related hearing loss (ototoxicity). Examples of these include chemotherapy (anti-neoplastic drugs), second line anti-TB therapy and some anti-retroviral regimens
- Available audiology services and hearing screening programmes in the Developing World
- Non-conventional screening techniques

SUMMARY AND INTERPRETATION OF THE LITERATURE

GLOBAL BURDEN OF DISEASE - EPIDEMIOLOGY

The World Health Organisation (WHO) in 2012 estimated that 360 million people worldwide were living with disabling hearing loss* ⁽¹⁾, an increase from their previous report in 2000 with an estimate of 278 million people ⁽²⁾. The prevalence is greatest in South Asia, Asia Pacific and Sub-Saharan Africa, regions that fall within the Developing World. With more than 50 percent of the world's population residing here ⁽³⁾, addressing this challenge is an ethical one for human welfare, and a moral one for social justice.

Funding for prevention, early detection, and rehabilitative programmes for hearing loss is severely limited in developing countries ^(3,4). Despite the reality of these needs being highlighted lately, advocates need to compete against “centre-stage” priorities like life-threatening, pandemic communicable diseases such as Human Immunodeficiency Virus (HIV), Malaria, and Tuberculosis ^(5,6).

In addition, access to formal audiological testing is limited. Africa has a paucity of audiologists in practice and training, with only a handful of screening programmes available ⁽⁴⁾. *Fagan et al*, conducted a survey of ENT services in 18 African countries, and found that when compared to the UK service ratios, for the 18 countries as a whole, there was a deficiency of 20 406 audiologists. Also, South Africa's access to audiology services, hearing aids and ENT care was

* Disabling hearing loss refers to hearing loss greater than 40 dB in the better hearing ear in adults (15 years or older) and greater than 30 dB in the better hearing ear in children (0 to 14 years).

the most advantaged of the 18 African countries surveyed. Currently there are 3457[#] registered health professionals in South Africa capable of screening for hearing loss - 3457 audiologists to service 50 million South Africans⁽⁷⁾. Not surprisingly then, South Africa still only fulfilled less than half of the required service ratios when compared to UK service ratios⁽⁴⁾.

THE IMPACT OF HEARING LOSS

Adult hearing loss constitutes 91 percent of the 378 million sufferers⁽¹⁾. One third of this group is over 65 years of age, indicating that the remaining two-thirds fall within the prime of economic life. Hearing disability has far reaching effects, manifesting as lack of social and economic development as a community and a nation. As an individual, consequences lead to social isolation, stigmatisation, and economic disadvantage^(8,9). These adults tend to have much higher unemployment rates. Those employed, are in lower grades of employment when compared to the general workforce^(2,5). Additionally, an increase in prevalence of hearing loss is directly linked to a decrease in GNI (gross national income, per capita).

HIGH-RISK POPULATION GROUPS IN THE DEVELOPING WORLD

These are identified patients with the possibility of developing high frequency hearing loss, from certain aetiological factors.

[#] This figure is the total sum of 436 audiologists; 2940 speech therapists and audiologists and 81 community speech and hearing workers.

Human-Immunodeficiency Virus (HIV), Tuberculosis (TB) and related drug therapies

As mentioned, in developing countries health provisions are dominated by communicable diseases like HIV and TB. Non-communicable diseases like hearing impairment receive less attention, despite being a major public health concern. In South Africa however, these diseases are linked, owing to the high prevalence of HIV and the increasing problem of multi-drug resistant (MDR) TB (within the pandemic of TB), together with existing socio-economic challenges⁽¹⁰⁻¹²⁾.

Sub-Saharan Africa houses 70.1% of all HIV positive individuals globally, a total of 25 million people^(13,14) - the highest prevalence among people between 15 and 49 years of age⁽¹²⁾.

According to UNAIDS, there are approximately 15 million people receiving ARVs⁽¹⁴⁾. Hearing loss related to HIV is varied (*Figure 3*). Sensorineural hearing loss (HFSNHL) can be caused by the virus itself neurotropically, or from ototoxic damage by ARVs^(12, 15, 16, 17). Nucleoside analogue reverse transcriptase inhibitors (NRTIs), one of the 3 classes of ARVs, is reported as most likely to cause SNHL⁽¹⁵⁾. Opportunistic infections can also target the auditory system, including many medications to treat them, and can have a synergistic effect on patients receiving ARVs⁽¹⁸⁾.

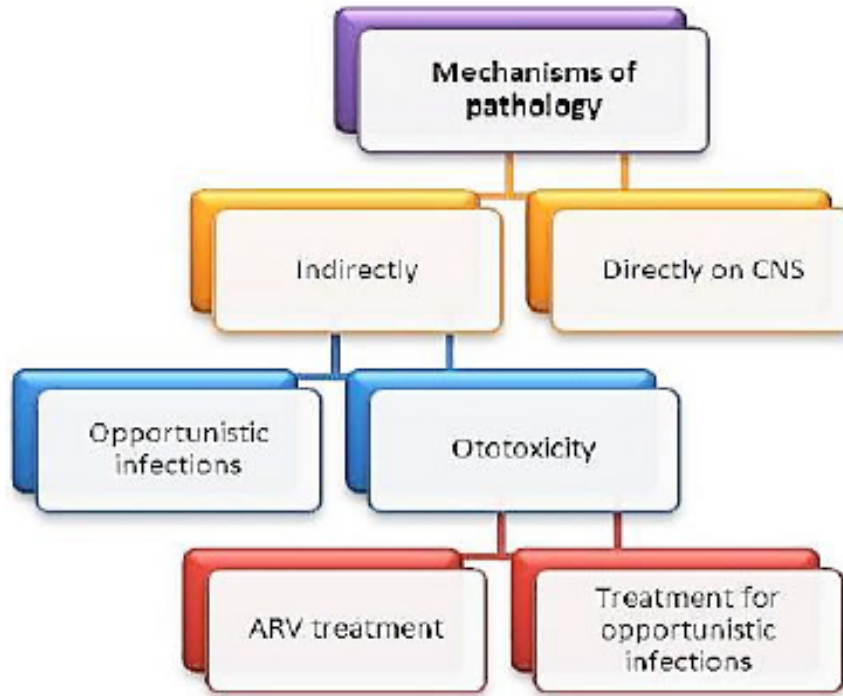


Figure 3: Mechanisms of HIV-Related auditory disease ⁽¹⁶⁾

South Africa, like many sub-Saharan and South Asian countries, witnessed a dramatic upsurge of TB cases over the last decade ⁽¹⁹⁾. This still continues, due to HIV co-infection, and increased reports of multidrug-resistant TB (MDR-TB) nationally ⁽²⁰⁾. The prevalence of MDR-TB is five to six times higher than that in China and India ^(21, 22).

Injectable aminoglycosides, the commonest drug by far to cause hearing impairment ⁽²³⁾ are used to treat MDR-TB. Treatment is guided by resistance to Isoniazid and Rifampicin (first-line therapy) ⁽²¹⁾. Injectable aminoglycosides like Kanamycin and Amikacin are administered for prolonged periods of 18-24 months ⁽²²⁾. *Harris & Fagan* reported that SNHL occurred in 57 percent of patients with MDR-TB after three months of aminoglycoside therapy and SNHL occurred in 70 percent of those who were also being treated for HIV ⁽¹¹⁾. The effect of the above

anti-TB regimen with ARVs had a synergistic ototoxic effect on the outer hair cells of the cochlea ^(12, 24).

Anti-Neoplastic Therapy

Cisplatin, a platinum compound, is a commonly used anti-neoplastic drug. Its ototoxic potential was first described by *Piel et al* almost 40 years ago ⁽²⁵⁾. Despite this, Cisplatin is widely used in standard treatment protocols for many cancers including soft tissue neoplasms, lymphomas, lung and head and neck squamous cell cancers ^(11, 26, 27). Ototoxicity is a permanent, dose-related side-effect, ⁽²⁵⁾ with escalation of the dose causing almost every patient to develop some hearing loss ⁽²⁶⁾. Furthermore, noise exposure may result in a threefold increase risk of hearing loss ⁽²⁵⁾ by acting synergistically with drugs that are not fully cleared from the cochlea ⁽²⁸⁾.

Cancer in the Developing World, referred to as ‘the cancer Tsunami’, is on the increase ⁽²⁹⁾.

According to *Farmer et al*, 70 percent of newly diagnosed cancers will be found in the Developing World by 2030. Consequently, projected prevalence of ototoxicity-related hearing loss from chemotherapy protocols using platinum compound agents, like Cisplatin and Carboplatin, will increase immensely.

The Elderly

Presbycusis or age-related hearing loss, prevalent in the ageing population of the Developed World ^(30, 31), is also prevalent in the Developing World accounting for one third of adult hearing loss ⁽¹⁾. Patients and health care staff often don’t recognize hearing loss, particularly early on, making presbycusis under-diagnosed and undertreated ⁽³⁰⁻³²⁾.

Until recently, hearing loss in older adults was seen as an unfortunate and negligible part of ageing. Presentation is classically gradual, leading to poor communication and inevitable social isolation. Presbycusis is strongly associated with depression and cognitive decline^(9, 30). Recent studies show hearing loss to be independently associated with poor cognitive function and incident dementia when compared to same age individuals with normal hearing⁽³³⁾.

SCREENING PROGRAMMES

In general screening programmes are strategies intended to reduce morbidity and mortality of the disease process being tested. They are designed to identify disease in their earliest stages when treatment is more successful. Patients usually have no clinical symptoms.

In order for screening programmes to be effective, the burden of disease must be significant enough to justify the effort of screening and an accurate, practical, and convenient screening test must exist - ideally one that has a good sensitivity (indicating few cases of the disease is missed) and an acceptable specificity (so that there are not too many false positives). Since screening interventions are not designed to be diagnostic, appropriate follow-up is necessary for those with positive screening results to ensure effective treatment for the detected condition.

SCREENING PROGRAMMES FOR HIGH-RISK GROUPS

In the abovementioned high-risk groups, even without reported epidemiological data, the burden of disease is evident and hearing screening for these specific groups is suitable. The concerns lie in 1) identifying a screening tool that is practical and highly sensitive, and 2) effective treatment

protocols for detected hearing loss, which as outlined above, is a resource-driven challenge. As yet there are few programmes for any of the abovementioned high-risk groups in Sub-Saharan Africa. Hearing screening if available, is done at the discretion of individual institutions and health care practitioners. Failure to address these high-risk groups will lead to the creation of new deaf communities ⁽³⁾.

The need to prioritize hearing screening for all HIV positive patients before commencement and during ARV therapy, is paramount. Moreover, with improved health on ARVs, hearing loss may become a concerning symptom in quality of life assessments. Baseline screening and follow-up hearing tests for chemotherapeutic drugs are deficient in South Africa and many developed nations, fundamentally hindering effective and comprehensive management of hearing difficulties for cancer patients ^(12, 24, 34). There are still few screening programmes for presbycusis in the Developed World ⁽³¹⁾. Screening should be part of routine check-ups for the elderly, given individual lack of awareness, and gradual nature of progressive hearing loss ⁽⁹⁾.

Ototoxicity monitoring

Ototoxic monitoring encompasses 2 principles:

- Firstly to screen, identify and monitor changes in the auditory system attributed to a drug therapy. These changes can be detected before they are even noticeable to the patient.
- Secondly, this is followed by prompt audiologic intervention, in addition to the consideration of modifying the drug regimen.

These monitoring programmes are generally guided by audiologists, who decide on testing protocols; supervision of monitoring by personnel; and follow-up when clinically significant

hearing loss is detected. All patients must have a baseline hearing test, used as the patient's control, allowing for adequate interpretation of prospective tests ^(23, 35).

Three main strategies for monitoring have emerged: A) the basic audiologic assessment; B) high frequency audiometry (HFA); and C) otoacoustic emissions (OAE), each with their own considerations of utility ⁽¹¹⁾. Ideal practices should include all, yet this may not be always be possible. According to the American Speech-Language-Hearing Association (ASHA) guidelines HFA has significant change criteria, and is well established with excellent specificity and sensitivity ^(11, 35). Furthermore, HFA usually detects ototoxic changes prior to distorted product otoacoustic emissions (DPOAEs).

In order to shorten test time while maintaining a high sensitivity for ototoxic damage, a *shortened test protocol* is recommended. This targets monitoring a range of frequencies near each patient's upper frequency limit of hearing called the sensitive range of ototoxicity (SRO) and is identified on the baseline test prior to any drug therapy. The reported success rate for this protocol is approximately 90% in large groups of adult patients with ototoxic hearing changes observed using full-frequency. The *shortened test protocol* therefore demonstrated a high degree of sensitivity to early decrements in hearing as a consequence of drug therapy, whether the SRO occurred within conventional audiometric frequencies (<8 kHz) or within the ultra-high frequency range (>8 kHz) ⁽³⁵⁾.

Prospective assessments of hearing function therefore remain the only reliable method to detect ototoxic damage prior to symptomatic hearing loss, relying solely on dosage or serum concentrations of ototoxic drugs is insufficient to predict the risk of ototoxicity ⁽²³⁾.

Monitoring hearing in patients receiving ototoxic drugs therefore provides audiologists opportunities to counsel patients about the effects of ototoxicity-induced hearing loss, tinnitus,

and vertigo, the synergistic effects of noise and ototoxic damage, and lastly communication strategies.

Advances in Screening Tools

Questionnaire and telephone-based hearing screening programmes are well utilised in first-world settings, but are unsuitable for developing world environments. With the introduction of the digital age, through collaborative efforts between information technology and medicine, internet-based programmes were born. Audiologists could now test patients in remote locations. Drawbacks of early inventions related to hardware integration, software compatibility, environment interference, and specifically internet connectivity. Recently tele-audiometry has shown promise in healthcare provision and professional education. Testing is performed through application sharing software, allowing audiologists to remotely operate equipment on-site^(36,37). Tele-audiometry is performed synchronously (real-time testing with audiologist present remotely via videoconferencing), or asynchronously (automated testing with no audiologist present remotely). It requires high-speed internet connectivity however, and if done synchronously, needs the availability of a local facilitator and an audiologist working remotely. Tele-audiometry also makes use of different audiometers; one such novel South African invention is the KUDUwave 500TM. This portable audiometer comes with compatible software, testing for air and bone conduction. It can also record environmental noise - vital information for pure tone testing outside soundproof booths. A recent collaborative study done on older adults shows valid diagnostic pure tone thresholds and good test re-test reliability⁽³⁸⁾.

With ever evolving technology available, and the accessibility of mobile devices like smartphones and tablets that use touchscreen interfaces, it is not unexpected to find hearing

screening applications - “apps” available for download and use on these devices. Many are quick and easy to use. One such app is uHear™, a software application devised for use on any Apple touch interface device. Marketed as a simple and easy tool, it doesn’t require specialised skills or internet access to perform once downloaded. As this is a new field of interest that incorporates technology and medicine, there is very little in the literature, and only four published reports using Apple touch interface technology. One study from Eastern Ontario Children’s hospital has tested a novel play audiometric “app”, designed in-house for addressing the shortcomings in play-audiometry testing⁽³⁹⁾. Testing is in the first phase, with high sensitivity and specificity ratios reported. In young children compliance for test completion is often a challenge, and threshold detection can be difficult and even lead to multiple visits for testing. As this “app” for testing hearing is designed like a video game, showing promising results in improved compliance for test completion. Further testing is underway.

Sudzek et al was the first study to report hearing screening using the uHear™ “app” with an iPodTouch, and tested participants in a soundproof room and a clinic room⁽⁴⁰⁾. *Handel et al* compared accuracy of threshold changes in patients with unilateral sudden sensorineural hearing loss⁽⁴¹⁾, and *Khosa-Shangase* tested 100 South African school children in a school environment⁽⁴²⁾. Outcome measures from all three studies involved comparing pure tone averages (PTAs) from the iPodTouch uHear™ test (from all test environments) to PTAs from a formal audiogram. *Khosa-Shangase* reported large deviations in the lower frequencies, standard deviations of >10dB at individual thresholds and a 34% higher pick-up rate of hearing loss⁽⁴²⁾. The remaining two studies however, highlighted that it is possible to rule out moderate or worse (disabling) hearing loss^(40, 41). In all three, even though low frequencies appeared inaccurately elevated⁽⁴⁰⁻⁴²⁾, one can possibly predict the degree of hearing loss in the abnormal hearing participant in the

high frequencies ^(40, 41). Further, large multi-centre studies are still needed to challenge or corroborate these findings.

THE WAY FORWARD

1. Make more noise

Current global health care efforts by the *World Health Organisation (WHO)* and the Prevention of Blindness and Deafness (PBD) campaign have created some awareness, but this is still not reaching the vast majority of people in need. Addressing the global burden of hearing loss lies in addressing the inequities facing the distinct profiled population that is most affected, as much as it lies in addressing the sensory disability. Global health policies and practices need to change and invest in sustainable solutions to address the global inequity between the developing and developed worlds.

2. Devise adaptive hearing screening programmes suitable for Developing World systems that translate modern technology to health benefit

Institution-based programmes are useful in communities with existing infrastructure and access to healthcare, but won't work in developing communities ⁽³⁷⁾.

Universal adult screening for hearing loss is not sustainable. Prioritising high-risk groups is optimal. A proposal to target community-related projects already in existence, like medical units that cater for high-risk groups, is the best way to start screening programmes. Within these medical units, one needs to prioritise hearing loss with patients and healthcare workers, and facilitate regular hearing screening during visits. Oncology centres, ARV rollout centres, TB

centres with inpatients receiving long-term therapies including “isolated MDR / X-MDR TB” sufferers, as well as community centres that are involved with directly observed therapy (DOTS). Ototoxic monitoring principles can be incorporated into regular visits. Older adults who regularly receive chronic medication from satellite (community) clinics can also be recruited to have hearing screening tests performed while waiting for medication or during routine medical assessment of blood pressure, glucose etc.

Community projects outside of medical visits but still within existing frameworks can also be a step-up for health-directed causes and can be targeted. Introducing hearing screening in social spaces like schools, pension centres, places of worship, post-offices to name a few, are ideal places to identify undetected sufferers. Testing is encouraged, but entirely voluntary.

Community-based programmes are therefore ideal, as they can integrate into already existing services ^(36, 37).

Screening techniques that reduce the need for skilled professionals, but at the same time are effective and safe, are needed because, as is already mentioned by *Fagan et al*, it would be impossible to upgrade service delivery by only increasing the number of trained audiologists to meet the demand across Africa ⁽⁴⁾.

There has been an exponential rise in the availability and usage of mobile phones and internet-based technology in developing countries. In addition, there are 5,98 billion mobile subscriptions globally ^(43, 44). This includes South-East Asia, West Africa and Sub-Saharan Africa, with major controversy erupting on World Water Day 2013, when the United Nations highlighted that more people have access to mobile phones than working toilets ⁽⁴³⁾. Canadian marketing and social media consultant, Mike Kujawski reported that 1 in 5 people with mobile

phones in Africa owned a smartphone, and at least 8 African countries have mobile penetration rates of more than 100%⁽⁴⁴⁾. Hence, advancement in technology fed the need to communicate. Herein lies an opportunity to leverage a technology that's already in use.

With this in mind, a new age of hearing screening techniques can emerge - involving portable devices that require no expert audiologist (thereby reducing the demand on skilled audiologists), is quick, efficient, easy to perform, and uses already available tools to serve the needs of the people. In this way, minimal resources are utilised, and *screening is taken to the patient*.

IDENTIFICATION OF GAPS OR NEEDS FOR FURTHER RESEARCH

- Large-scale epidemiological studies in the Developing World are needed, with emphasis on demographics including socioeconomic status, aetiology, risk factors.
- Developing sustainable hearing screening programmes for high-risk population groups, including audiologist guided ototoxicity monitoring.
- More collaborative studies are required to evaluate the feasibility of screening protocols using portable technology in low-budget countries, providing a great opportunity for “science implementation”.
- More initiative is needed by governments and global health groups to improve health and social systems of disease as it relates to poverty.

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Part C: ARTICLE

HEARING LOSS IN THE DEVELOPING WORLD: EVALUATING THE iPHONE MOBILE DEVICE AS A SCREENING TOOL

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ABSTRACT

Background

Hearing loss affects 360 million people globally. The highest prevalence is in the Developing World where hearing screening programmes are scarce. Failure to address high-risk populations will result in new deaf communities. In resource-stretched communities, new strategies are needed. Mobile devices like smartphones have the potential to test hearing through audiometric applications. Given the upsurge of mobile technology in Africa, it is befitting to determine whether implementation of mobile applications can translate to this health problem.

Objectives

To evaluate the uHear™ “app” using an Apple iPhone mobile device as a possible hearing screening tool in the Developing World. To also determine accuracy of certain hearing thresholds that could prove useful in early detection of hearing loss for high-risk populations in resource-poor communities.

Methods

This was a quasi-experimental study design. Participants were recruited from the Otolaryngology Clinic at Groote Schuur Hospital in Cape Town, South Africa. All participants had a formal audiogram and completed the iPhone uHear™ test in 3 different settings – the waiting room, a quiet room and a soundproof room. “Earbud” headphones supplied with the device were used. iPhone uHear™ pure tone thresholds recorded in all 3 rooms were compared to formal audiograms.

Results

Twenty-five patients were tested (50 ears). The iPhone uHear™ test was able to accurately detect moderate or worse hearing loss (PTA>40dB) with a sensitivity of 100% in all 3 environments. Specificity varied with 88% in the soundproof room, 73% in the quiet room and 68% in the waiting room. Using Kappa statistical analysis the iPhone was also found to be highly accurate in detecting high frequency hearing loss (2000Hz, 4000Hz, 6000Hz) in quiet and soundproof rooms. Kappa values were “good” and “very good” at these frequencies, which were statistically significant ($p < 0.05$). The iPhone was moderately accurate for low frequency hearing loss (250Hz, 500Hz, 1000Hz) in a soundproof room, but poor in quiet or waiting rooms.

Conclusion

Using the iPhone, the uHear™ “app” is a feasible screening test to rule out significant hearing loss (PTA>40dB). It is also highly sensitive for detecting threshold changes at high frequencies, making it reasonably well suited to detect presbycusis, and ototoxic hearing loss caused by HIV & TB therapy and chemotherapy. Its portability and ease of use makes it opportune to use in Developing World communities that lack screening programmes.

Key Words - hearing loss, developing world, screening tools, ototoxicity, presbycusis, mobile technology, portable audiology, HIV, TB, chemotherapy, ARVs, anti-TB therapy, global health

DISCLAIMER

The Division of Otorhinolaryngology, Groote Schuur Hospital and the authors do not have any affiliation to the Apple or Unitron companies.

INTRODUCTION

Hearing disability is one of the major health problems affecting the world ⁽¹⁾. An estimated 360 million people currently live with disabling hearing loss* ⁽²⁾. Prevalence is greatest in the Developing World, where the majority of deaf people reside ⁽¹⁾. Hearing loss is more common in adults, constituting 91% of all cases ⁽²⁾. The highest prevalence rates are found in Sub-Saharan Africa (15.7 %) and South Asia (17%) ⁽¹⁾. Not dealing with this health challenge perpetuates economic and health decline, as is seen with the inverse relationship between the prevalence of hearing loss and GNI ⁽²⁾. For the individual, hearing loss leads to poor communication and social isolation ⁽³⁾. One is less likely to obtain employment, and for those who are employed, their income is in the lowest bracket ^(1,3).

Screening programmes directed at high-risk groups are necessary. If effective, they can reduce morbidity from hearing loss through early detection and rehabilitation ⁽⁴⁾. Highly sensitive tools that yield lower false positives and higher true negatives are ideal for screening and monitoring hearing. Currently few screening programmes exist in the Developing World for high-risk groups. Failure to do so, commits them to new deaf communities ⁽⁵⁾. High-risk groups include the elderly, and patients who are receiving potentially ototoxic medication like chemotherapeutic agents ⁽⁶⁾, second line anti-tuberculosis (TB) regimens, and anti-retroviral therapy (ARVs) ^(1,7,8). These groups are at risk of developing high frequency hearing loss as explained below.

* Disabling hearing loss refers to hearing loss greater than 40 dB in the better hearing ear in adults (15 years or older) and greater than 30 dB in the better hearing ear in children (0 to 14 years).

High-Risk Groups

Presbycusis

Presbycusis (adult-onset hearing loss) is generally under-diagnosed and undertreated. This leads to late detection, disease progression, and poor rehabilitation^(9, 10). Hearing loss is predominantly high frequency and sensorineural. *Lin et al* reported that older adults with hearing loss are more likely to develop cognitive impairment and dementia than their contemporaries without hearing loss^(11, 12). Regular monitoring and early detection and treatment of presbycusis could maintain an existing quality of life.

HIV and TB therapy

Currently 25 million people are HIV positive in South Africa⁽¹³⁾. Hearing loss can be caused by the HIV and / or the treatment thereof; both are implicated in sensorineural hearing loss⁽⁷⁾. Treatment of opportunistic infections and anti-neoplastic therapy can have synergistic effects on patients receiving ARVs^(7, 8). TB therapy is one such treatment. TB still continues to be an increasing problem in Sub-Saharan Africa due to the co-infection with HIV, with reports of increased cases of multidrug-resistant TB (MDR-TB) in South Africa^(8, 14). The treatment of which involves injectable aminoglycosides known to cause ototoxicity^(8, 15). This TB regimen has a synergistic ototoxic effect together with ARVs on the outer hair cells of the cochlea, leading to high frequency sensorineural hearing loss (HFSNHL)⁽¹⁵⁾.

Chemotherapy

Cancer rates are rapidly increasing in the Developing World ⁽¹⁶⁾. Cisplatin, a commonly used anti-neoplastic drug, is known to cause irreversible dose-dependant ototoxicity ^(6,17) leading to HFSNHL. Noise exposure may result in a three-fold increased risk of hearing loss with Cisplatin ^(17, 18).

Ototoxicity monitoring is aimed at preventing or minimizing the progression of hearing loss through prospective hearing assessments. It is the most reliable method for detecting ototoxicity prior to development of symptomatic hearing loss ⁽¹⁹⁾. It allows on to counsel patients, possibly modify treatment regimens, and rehabilitate hearing. Three different methods of testing can be utilized namely: conventional audiology, high frequency audiometry (HFA) and otoacoustic emissions (OAEs). HFA has significant change criteria and has excellent specificity and sensitivity ^(8, 19) but is generally not available in developing countries.

Advances in Screening Techniques

Screening programmes traditionally involve audiologists testing patients in soundproof booths. There has been an evolution of alternative screening programmes in recent years. Telehealth projects allow patients in remote areas to be tested using high speed internet ⁽²⁰⁾. Portable audiometers are also advancing to provide good quality diagnostic audiometry in any environmental setting ⁽²¹⁾.

Global mobile phone penetration is at 85% of the world's population ⁽²²⁾ and 1 in 5 Africans own smartphones. Automated hearing screening “apps” using commercially available technology present an opportunity to address the global problem of hearing loss. *Yeung et al* from the Children's Hospital of Eastern Ontario reported on the first portable clinical “conditioned play” iPad-based audiometer for the paediatric population ⁽²³⁾. Their study shows promise in focusing on the shortcomings of existing play audiometry. The remaining papers have reported on the Apple uHear™ “app” using an iPodTouch device, with varying results. uHear™ is a hearing program devised by Unitron and Apple for use on any touch-interface Apple device, and is freely available for download from the iTunes Apple store. *Sudzek et al* was the first of three groups to evaluate this “app” as a potential hearing screening tool ⁽²⁴⁾. Using an iPodTouch, participants were tested in different noise level environments. Pure tone averages (PTAs) calculated as a mean at thresholds of 500Hz, 1000Hz, 2000Hz & 4000Hz, from the uHear™ application were compared to the formal audiogram. uHear™ was able to correctly diagnose the presence of moderate or worse hearing loss (PTA>40dB) in 100 participants, with a sensitivity of 98% and a specificity of 82% in the clinic. In the soundproof room, sensitivity improved to 100%, and specificity improved to 90%. *Khoza-Shangase et al* sampled a group of children using an iPodTouch in a school environment; PTAs (mean at thresholds of 500Hz, 1000Hz & 2000Hz) with compared to formal audiograms ⁽²⁵⁾. They reported large deviations in the lower frequencies, standard deviations of >10dB at individual thresholds and a 34% higher pick-up rate of hearing loss. The third study by *Handzel et al* tested participants with unilateral sudden sensorineural hearing loss using the uHear™ on an iPodTouch, and reported a sensitivity of 76% and a specificity of 91% when compared to a formal audiogram ⁽²⁶⁾. Inaccurately elevated thresholds at low frequencies using uHear™ were also detected, thereby corroborating the

findings of the previous study⁽²⁵⁾. Interestingly, uHear™ reflected hearing thresholds more accurately in mid- to high frequencies compared to low ones, and deviations in low frequencies were less pronounced in the abnormal hearing (diseased) ear. These two observations were also reported by Sudzek⁽²⁴⁾. These studies have highlighted two important points. Firstly it is possible to rule out moderate or worse (disabling) hearing loss^(24,26). Secondly, even though low frequencies may be inaccurately elevated^(24,25,26), one can possibly predict the degree of hearing loss in the abnormal hearing participant in the high frequencies^(24,26).

AIM

To determine the accuracy of

A) The iPhone using the uHear™ app as a screening tool for moderate or worse hearing loss (PTA >40dB), where PTA is the mean at thresholds of 500Hz, 1000Hz, 2000Hz & 4000Hz.

B) Individual thresholds at certain frequencies, especially the high frequencies (may have use in high-risk population groups)

METHOD

The study was approved by the Research Ethics Committee, Faculty of Health Sciences, University of Cape Town. The design was quasi-experimental. Study participants were consecutively recruited from patients attending the Otolaryngology Clinic at Groote Schuur Hospital, Cape Town. The inclusion criteria were patients from 15 to 80 years of age having had a formal audiogram by a trained audiologist at Groote Schuur Hospital in the previous 2 weeks.

Exclusion criteria included otorrhoea; visual impairment; learning disability; and poor gross

motor skills rendering them incapable of tapping the screen. Non-English speaking patients were not excluded if they understood the instructions after being explained the task. All participants gave informed consent - assent if underage. The results obtained from the iPhone testing did not affect the treatment plans of participants.

Test Instruments

An *iPhone 4* mobile device (iOS 4.2) was used. The *uHear*TM “app” was downloaded from *iTunes* onto the device at no cost. The application allows users to test their pure tone air-conduction hearing sensitivity as well as speech in noise. For this study, participants only completed the hearing sensitivity test which employs a 267ms pulse duration, with a “10 dB down and 5 dB up” approach. The time delay between tone presentations is randomized to prevent anticipation and the lowest threshold with two positive responses of three excursions is recorded as the hearing sensitivity.

“Earbud” earphones that come standard with the device were used. With reference to calibration, a single iPhone was used to test all participants. The same *uHear*TM application (version 1.0) was used for all participants tested. Ambient noise levels in all 3 test environments were measured at regular intervals with the OMD G45 71-6229 *Psio*TM sound level meter, providing an adequate measure of quality control. Sound levels for the respective environment complied with the *South African Bureau of Standards (SABS)* requirements for all 3 environments.

Technique

Otosopic examination was performed to exclude otorrhoea and wax impaction. Infection control was maintained during testing. All participants had formal audiograms done, and were tested in 3 different settings with the iPhone, *i.e.* the waiting room (WR); a quiet room (QR) and the soundproof room (SR).

Instructions to participants

Participants were given the device and the earphones to insert. The uHearTM “app” was selected, earphone connectivity confirmed and the participant was advised to “tap the screen when a sound is heard”. The program plays a series of pure tones of varying levels so that a threshold can be determined. On hearing a sound, the participant was expected to follow the commands. The duration of the test is 6 minutes. No audiologist is normally required as this is a self-assessment program. However, as this was a formal study, an investigator was present to ensure the test was completed.

Data Analysis

For hearing screening, the presence or absence of moderate or worse hearing loss (PTA>40dB) in each ear was determined by formal audiometry, as 40dB is considered the critical hearing threshold for disabling hearing loss according to the WHO, and warrants further investigation.

The iPhone uHearTM PTAs in all 3 settings were compared to the formal audiogram PTAs, where the PTA is calculated as a mean of thresholds (hearing in decibels) at 500Hz, 1000Hz, 2000Hz &

4000Hz. This data was captured into 2x2 tables to calculate sensitivity, specificity and accuracy ratios.

Additionally, in view of the possibility for agreement by ‘chance’, kappa analysis was performed on iPhone thresholds from all 3 settings when compared to the formal audiogram to detect *agreement at all 6 frequencies*. Kappa values range from less than 0.2 to 1.0 depending on how well two thresholds correlate with each other, at a particular frequency. The best correlation kappa value *i.e.* “very good” is one that is closest to 1. This describes how well the thresholds at a particular frequency correlated with the thresholds at the same frequency of the gold standard – the formal audiogram, and values this correlation according to the range, described in *Table 1*.

Kappa Values	‘Agreement’ / comparison
< 0.2	POOR
0.21 – 0.4	FAIR
0.41 – 0.6	MODERATE
0.61 – 0.8	GOOD
0.81 – 1.0	VERY GOOD

Table 1: Kappa range of values and their correlation

RESULTS

Thirty patients met the inclusion criteria and were recruited, of which 5 were excluded for incomplete testing (unrelated to device or software). Twenty-five patients were therefore fully tested (50 ears in total). Participants’ demographics are described in *Table 2*.

Total number of participants		25
Age (in years)		
Mean		43
Range		15 – 86
Number according to age (in years)		
15-20		4
21-40		7
41-60		6
61-80		8
Gender		
Female		13
Male		12
Number of ears with PTA (dB)		
Normal	≤ 25	24
Mild loss	26-40	18
Moderate loss	41-55	5
Moderate-Severe loss	56-70	2
Severe loss	71-90	1
Profound loss	≥ 91	0

Table 2: Participants’ Demographics and Hearing Loss (as graded by the American Speech Language & Hearing Association’s (ASHA) Degree of severity of hearing loss)

Accuracy of the iPhone uHear™ as a screening test: All ears with moderate or worse hearing loss (PTA >40dB) were detected in all 3 settings. This translated to a sensitivity of 100%. Of the 42 ears without moderate or worse hearing loss (PTA ≤ 40dB), 15 had moderate or worse hearing in the waiting room (specificity of 64%); 11 had moderate or worse hearing in the quiet room (specificity of 74%); and 5 had moderate or worse hearing loss in the soundproof room (specificity of 88%) (Table 3). Accuracy in the waiting room was calculated as 70%; the quiet room as 78% and the soundproof room as 90%.

Accuracy of the iPhone uHear™ thresholds at all 6 frequencies: Kappa analysis compared the “agreement” of the iPhone thresholds in all 3 rooms to the formal audiogram thresholds as reflected in *Table 4*. The iPhone was highly accurate at the high frequencies (2000Hz, 4000Hz, 6000Hz), where there was “good” and “very good” correlation in the soundproof and quiet rooms (*Table 4*). This was found to be statistically significant (p values <0.05). The iPhone did not correlate well at low frequencies in all 3 rooms, being “fair to moderate” in the soundproof room, and “poor to moderate” in the quiet room. The waiting room showed “poor to fair” correlation at low frequencies, and “moderate” correlation at high frequencies.

		(Formal Audiogram)	
		PTA ≤ 40dB	PTA > 40dB
iPhone			
Waiting Room (iPWR)	PTA ≤ 40dB	27	0
	PTA > 40dB	15	8
Quiet Room (iPQR)	PTA ≤ 40dB	31	0
	PTA > 40dB	11	8
Soundproof Room (iPSR)	PTA ≤ 40dB	37	0
	PTA > 40dB	5	8

Table 3: Accuracy of the iPhone in all 3 settings as a screening test compared to the formal audiogram

The iPhone uHear™ therefore reflected thresholds more accurately in the mid to high frequencies than the low frequencies. Furthermore, the soundproof room did not eliminate this low frequency inaccuracy. These two salient findings correlate with all 3 reviewed studies (24,25,26).

		LOW FREQUENCIES		Formal Audiogram
iPWR		250	500	1000
250		- 0.0516	0.2217	0.4123
500		0.0044	0.2399	0.4997
1000		- 0.0693	0.2526	0.5126

		250	500	1000
iPQR				
250		- 0.0101	0.2751	0.5677
500		0.0134	0.3102	0.5113
1000		- 0.0239	0.212	0.5207

		250	500	1000
iPSR				
250		0.097	0.5309	0.4386
500		0.1309	0.5283	0.5316
1000		0.0113	0.481	0.66 (p=0.000)

		HIGH FREQUENCIES		Formal Audiogram
iPWR		2000	4000	6000
2000		0.496	0.663	0.4261
4000		0.4667	0.339	0.5529
6000		0.484	0.187	0.517

		2000	4000	6000
iPQR				
2000		0.73 (p=0.001)	0.5122	0.5535
4000		0.4471	0.74(p=0.0000)	0.69 (p=0.0051)
6000		0.4339	0.69 (p=0.0092)	0.79 (p=0.0026)

		2000	4000	6000
iPSR				
2000		0.75 (p=0.000)	0.72 (p=0.0039)	0.69 (p=0.005)
4000		0.73 (p=0.000)	0.85 (p=0.000)	0.89 (p=0.000)
6000		0.77(p=0.0007)	0.92 (p=0.0010)	0.94 (p=0.000)

Table 4: Kappa values seen with iPhone thresholds all 3 rooms (waiting iPWR; quiet iPQR; soundproof iPSR) down the columns & formal audiogram thresholds across the rows. The first table shows the low frequencies, and the second table shows the high frequencies. In the “good” and “very good” correlation values, p values of <0.05 imply good statistical significance (figures in brackets).

DISCUSSION

This study is one of the first to evaluate smartphone-assisted audiometry as a hearing screening tool for populations that currently have no access to formal audiometry. Results indicate that the iPhone uHear™ application is reasonably accurate at screening for moderate or worse (disabling) hearing loss. We found a sensitivity of 100%, with a very high negative predictive value, implying an ideal test for screening. The highest test accuracy (90%) was found in a soundproof room with a specificity of 88%, rendering the least false positives. This highlights caution when testing in a waiting room setting.

The iPhone uHear™ application was found to be highly accurate for detecting high frequency hearing loss in quiet and soundproof rooms in patients with different levels of hearing. The iPhone uHear™ application could therefore be used to screen those at high risk of developing high frequency hearing loss through early detection of abnormal or worsening thresholds.

The iPhone uHear™ application therefore makes for an appropriate screening tool for disabling hearing loss, and to detect high frequency hearing loss that is seen with the abovementioned high-risk groups within poorly-resourced communities that have no access to health care. In particular, it can be used to screen and monitor hearing in drug-related ototoxicity where high frequency assessments of both conventional audiometry and HFA have a high degree of sensitivity to detect early change in hearing ⁽¹⁹⁾.

In addition, uHear™ is a self-assessment application that is freely available from iTunes for all Apple users and is downloadable to any Apple device with a touchscreen interface and speakers (includes iPhone, iPad and iPodTouch). The test is quick and easy to perform, designed for use by people of any language, socio-economic status and intellectual capacity. Patients who are

bed-bound, isolated, or too weak to ambulate to an audiology centre could benefit from a mobile, freely available self-assessment hearing screening test as this.

POSSIBLE LIMITATIONS OF THE STUDY AND TECHNIQUE

More participants with varying degrees of hearing loss would possibly yield more accurate positive and negative predictive values thereby rendering the testing more accurate.

Environmental noise may have been a cause for poor results at the lower frequencies. Testing can possibly be improved by using background noise eliminators. Inset earphones are theoretically recommended as a more effective way to reduce ambient noise. By being placed within the external ear canal, they can provide 30 to 40dB attenuation of ambient noise⁽²⁷⁾. In our study inaccuracy can be related to insertion depth, since “earbud” earphones sit just beyond the concha at the entrance to the external ear canal, which could explain the poor low frequency outcomes. In the future, testing that incorporates inset earphones cupped by circumaural ear covers with integrated ambient noise level monitoring that eliminates or adjusts testing to accommodate background noise, can be done. Although this would be ideal it does counter the intention to screen using a device with its standard hardware. A single iPhone device was used for this study; to avoid problems relating to inter-device reliability, every iPhone may have to be calibrated.

CONCLUSIONS

The sensitivity of the uHear™ “app” used with the iPhone is adequate to screen for disabling hearing loss, and has good accuracy to high frequency hearing loss in soundproof and quiet

rooms. Early detection of hearing loss with hearing screening programmes is thus possible using mobile digital technology. A mobile, non-operator dependent method used to screen for disabling hearing loss and detect early high frequency threshold changes such as an Apple iPhone, can help overcome the lack of trained audiologists or available infrastructure in developing countries⁽⁵⁾. Because of its portability, hearing screening with the iPhone uHear™ test is taken directly to the patient and is an opportune way to utilise existing community health and educational facilities. Oncology units, ARV rollout centres and TB hospitals with MDR / X-MDR TB sufferers are ideal centres to use this technology. In addition, satellite clinics that regularly administer chronic medication for older adults can also be considered.

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Part D: APPENDICES

APPENDIX A: CONSENT FORM TO ACT AS A SUBJECT IN A CLINICAL STUDY

TITLE: Hearing Loss: Devising a screening tool using the iPhone mobile device

INVESTIGATORS:

Dr S Peer, Ms S Pithey, Prof JJ Fagan

ADDRESS FOR ALL INVESTIGATORS:

Division of Otorhinolaryngology, H53, OMB, Groote Schuur Hospital, Observatory, Cape Town, 7925

DESCRIPTION:

You are being asked to participate in this study to see whether the hearing test on the iPhone is accurate.

We ask that you have the following tests done:

1. Hearing test (audiogram) by a trained audiologist
2. Hearing screening tests using the iPhone in 3 different settings namely; a soundproof room, a quiet room and a waiting room.

RISKS AND BENEFITS:

There are no risks or benefits to you, and the information collected from the iPhone will not be utilised in your hospital management plan. It is for research purposes.

COSTS AND PAYMENTS:

There will be no additional costs to you or your family.

CONFIDENTIALITY:

The information obtained from this study will be published in the future such that your identity will remain anonymous. Medical records related to this study are confidential, but may be examined by researchers from this institution.

RIGHT TO WITHDRAW:

You have the right to refuse to participate in this study at any time, and your decision will not adversely affect your care at this institution.

VOLUNTARY CONSENT:

I understand what is stated above and agree to participate in this clinical study.

Participant Signature.....Guardian’s Signature.....

I certify that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with participating in this research study, have answered any questions that have been raised and have witnessed the above signature.

Researcher: Name.....Signature.....

Witness: Name.....Signature.....

APPENDIX B; ETHICS APPROVAL (from Research Ethics Committee, UCT)

UNIVERSITY OF CAPE TOWN



**Health Sciences Faculty
Human Research Ethics Committee
Room E52-24 Groote Schuur Hospital Old Main Building
Observatory 7925
Telephone [021] 406 6338 • Facsimile [021] 406 6411
e-mail: shuretta.thomas@uct.ac.za**

07 March 2012

HREC REF: 185/2010

Dr S Peer
Otolaryngology (ENT)

Dear Dr Peer

PROJECT TITLE: HEARING LOSS IN THE DEVELOPING WORLD: EVALUATING THE IPHONE MOBILE DEVICE AS A SCREENING TOOL

Thank you for responding to the issues raised by the Faculty of Health Sciences Human Research Ethics Committee in your e-mail dated 29th February 2012.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year till the 30th March 2013.

Please submit a progress form, using the standardised Annual Report Form (FHS016), if the study continues beyond the approval period. Please submit a Standard Closure form (FHS010) if the study is completed within the approval period.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please quote the HREC. REF in all your correspondence.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, HSF HUMAN ETHICS

Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938

This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Convention on Harmonisation Good Clinical Practice (ICH GCP) and Declaration of Helsinki guidelines.

The Human Research Ethics Committee granting this approval is in compliance with the ICH Harmonised Tripartite Guidelines E6: Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95) and FDA Code Federal Regulation Part 50, 56 and 312.

APPENDIX C: SAMJ AUTHOR GUIDELINES

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Research articles should have a structured abstract not exceeding 250 words comprising: Objectives, Methods, Outcome measures, Results and Conclusions. For scientific letters/short reports an abstract (summary) up to 100 words in length should be provided.

Refer to articles in recent issues for guidance on the presentation of headings and subheadings.

Abbreviations should be spelt out when first used in the text and thereafter used consistently.

Scientific measurements should be expressed in SI units except: blood pressure should be given in mmHg and haemoglobin values in g/dl.

If in doubt, refer to 'uniform requirements' above.

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Figures consist of all material that cannot be set in type, such as photographs and line drawings. If any tables or illustrations submitted have been published elsewhere, the author should obtain written consent to republication from the copyright holder and the author(s). All illustrations,

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References should be inserted in the text as superior numbers and should be listed at the end of the article in numerical and not in alphabetical order.

Authors are responsible for verifying references from the original sources.

References should be set out in the Vancouver style and approved abbreviations of journal titles used; consult the List of Journals in Index Medicus for these details.

Names and initials of all authors should be given unless there are more than six, in which case the first three names should be given followed by et al. First and last page numbers should be given.

Journal references should appear thus:

Price NC . Importance of asking about glaucoma. *BMJ* 1983; 286: 349-350.

Book references should be set out as follows:

Jeffcoate N. Principles of Gynaecology. 4th ed. London: Butterworth, 1975: 96-101.

Weinstein L, Swartz MN. Pathogenic properties of invading microorganisms. In: Sodeman WA jun, Sodeman WA, eds. Pathologic Physiology: Mechanisms of Disease. Philadelphia: WB Saunders, 1974: 457-472.

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