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AUTOMATED SCREENING AUDIOMETRY IN THE DIGITAL AGE: EXPLORING UHEAR™ AND ITS USE IN A RESOURCE-STRICKEN DEVELOPING COUNTRY

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Background: The current study aimed to determine the accuracy of UHear™, a downloadable audiometer on to an iPod Touch©, when compared with conventional audiometry.
Methods: Participants were enrolled primary school scholars. A total number of eighty-six participants (172 ears) were included. Of these eighty-six participants, forty-four were female and forty-two were male; with the age ranging from 8 years to 10 years (mean age, 9.0 years). Each participant underwent two audiological screening evaluations; one by means of conventional audiometry and the other by means of UHear™. Otoscopy and tympanometry was performed on each participant to determine status of their outer and middle ear before each participant undergoing pure tone air conduction screening by means of conventional audiometer and UHear™. The lowest audible hearing thresholds from each participant were obtained at conventional frequencies.
Results: Using the Paired *t*-test, it was determined that there was a significant statistical difference between hearing screening thresholds obtained from conventional audiometry and UHear™. The screening thresholds obtained from UHear™ were significantly elevated (worse) in comparison to conventional audiometry. The difference in thresholds may be attributed to differences in transducers used, ambient noise levels and lack of calibration of UHear™.
Conclusion: The UHear™ is not as accurate as conventional audiometry in determining hearing thresholds during screening of school-aged children. Caution needs to be exercised when using such measures and research evidence needs to be established before they can be endorsed and used with the general public.

Keywords: Conventional audiometry, UHear™, Accuracy, Screening, Developing country, Resources, iPod Touch©

Audiometers have increasingly become smaller, with greater applications available on each machine. Although the audiometer has substantially advanced, visually it still looks rather intimidating (particularly under screening environments); and remains costly. This raises the question: how can one test an individual's hearing with a machine that is smaller, more aesthetically pleasing and cost effective than the conventional audiometer? The answer may lie in the usage of the ever growing popular iPod™. One such device is the iPod Touch© or iPhone™, which has a downloadable application for UHear™, a self-administered hearing screening test. Why then could this be an important device for hearing screening, especially in the developing world?

The World Health Organization (WHO) estimates that over 278 million people around the world present with a moderate to serious (>40 dB) hearing impairment n both ears, making hearing impairment the greatest sensory deficit experienced by humans (1). This figure increases to approximately 642 million when individuals with mild or unilateral hearing losses of any severity are included (2).

Undetected mild or unilateral hearing impairment in children may result in developmental delays with serious hearing impairment having adverse effects on speech, receptive language, expressive language; as well as academic, social, and cognitive development (3). Early identification of hearing impairment and intervention has been shown to significantly reduce known adverse effects by improving speech, language, educational, and social outcomes (4); hence, the importance of exploring every possible avenue of identifying hearing impairment early.

Hearing screening has been designed specifically for early identification of hearing impairment. Although hearing screening has been linked to increased early identification, disadvantages are still evident. In countries where infant hearing screening programs are implemented, there is great concern for the high false-positive rates, which range between 3 percent and 8 percent (5). In South Africa, several individuals may proceed to school with an unidentified hearing impairment. In developed countries such as the United Kingdom, it is estimated that just fewer than 20 percent of children aged 6 years and older with a permanent moderate or greater hearing impairment remained unidentified at time of entry to school (6).

It is estimated that 80 percent of individuals with a hearing impairment live in low- and middle-income countries (1). Approximately 80 percent of the 278 million people estimated to have a hearing loss, who live in the developing world, may not be identified as having a hearing loss (1). Although hearing screening provides a solution to the increased number of hearing tests needed around the world, there is still a huge gap in terms of demand and capacity. Demand, in terms of this study refers to the number of individuals in need of audiological services in a given population, and capacity refers to the number of providers available to conduct relevant services for that population.

South Africa is a prime example of a country where the demand of hearing tests outweighs the available capacity, where a prevalence of 10 percent inner ear hearing loss (7;8) has to be serviced by approximately 1,374 speech-language therapists and audiologists registered with the health professional Council of South Africa (9). The capacity is currently 1,374 hearing professionals for a population (demand) of approximately 4.9 million individuals with a sensorineural hearing loss, therefore, each professional needs to evaluate approximately 3,566 individuals. Many of these professionals work in the private health sector, whereas approximately 85 percent of the population relies on the public health sector, creating an even wider gap between capacity and demand (10).

Two possible solutions have been proposed to narrow the gap between demands and capacities throughout the world; and these are use of tele-health audiology, and the use of automated audiology. Tele-health involves delivery of healthcare by means of telecommunications technology such as dial-up, high-speed computer networks, and the Internet (11;12). A recent study of thirty-two participants in Grade 3, conducted by Lancaster et al. (12) revealed that there were no statistically significant differences between thresholds obtained from tele-audiology and on-site school screening procedures.

Automated audiology involves the use of automating certain audiological procedures involved in a basic hearing test battery, such as tones presented at predetermined levels (13). This is ideal for pure-tone threshold searches as a sequence of steps need to be used to obtain a threshold which can be implemented using a software-based testing system (13). The use of this technology may help by increasing the number of individuals assessed for a hearing disorder, by reducing the amount of time spent on each individual and ultimately reducing the cost of basic tests (13). An example of automated audiometry, is the Octogram™, a computer-assisted audiometer (14). Ho et al. (10) highlighted in their study of forty-eight participants that the Octogram was a reliable audiometer with thresholds falling within 10 dB of the thresholds obtained from an audiologist. Therefore, both solutions provide an alternative to conventional audiometry, in both the developed and developing world.

Automated technology in the form of the UHear™, designed by Unitron (15) can allow self-administered screening audiometry to reduce the unidentified numbers of hearing impairments in resource-stricken environments. UHear™ is a self-administered hearing screening test, which is downloaded to an iPod Touch© or iPhone™ (15). This program uses the principles of automated audiology in a cellular phone sized device, making it more user friendly than typical screening audiometers. Approximately 8.7 million iPhones™ were sold in Apple's® fiscal 2010 first quarter ending December 26, 2009, with over 30 million sold by September 2009, making it a largely obtainable device (16;17). Due to the fact that this tool can be self-administered, it has the potential to allow for the increase of capacity and thereby closing the gap between demands and capacities within the hearing impaired population. Due to the dearth of research regarding this form of hearing screening tool, it is imperative that the UHear™ be thoroughly evaluated in terms of accuracy, hence the current study which aimed at determining the accuracy of UHear™ compared with conventional audiometry.

RESEARCH METHODOLOGY

Aim

To determine the accuracy of the downloadable automated screening audiometer, UHear™ when compared with conventional audiometry.

Design

This study used a within-subject design to compare the same participants across different situations (18). For this study, a two condition (A and B) design was set up to compare audiometric thresholds obtained from a typical audiometer (AD299e) and those obtained from UHear™ for each participant.

Description of participants

Sample and Sampling. Quota sampling was used where school-aged children from a public Primary School in Gauteng (South Africa) between the ages of 8 and 10 years old were invited to participate in the study.

Participation was reliant on informed consent provided by each child's parent or legal guardian following verbal and written invitations for voluntary participation through the school teachers.

A total number of eighty-six participants (172 ears) were included of approximately 120 invited, based on consent forms having been signed and returned by data collection day. Of these eighty-six participants, forty-four were female and forty-two were male. Participants included in the study ranged from 8 to 10 years old with a mean age of 9.0 years. Due to the fact that the current research aimed at determining the accuracy of UHear™, participants with middle ear diseases were included to determine sensitivity and specificity. As far as middle ear disease was concerned, of the 172 ears, 13 presented with type As tympanograms, 7 with type B tympanograms, 5 with Ad tympanograms, and 1 with a type C tympanogram. It should be noted though that all of the participants with middle ear pathologies presented with hearing within normal limits as determined by conventional audiometry.

Testing Procedures

Infection control was maintained during data collection.

Otoscopic examination was conducted on each participant before pure tone testing, where observations regarding active ear disease, the appearance of the tympanic membrane, and whether impacted cerumen or foreign bodies are present were made. This was followed by tympanometry for each participant, and this gives information about the patient's middle ear status,

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such as the condition of the middle ear structures, Eustachian tube dysfunction, and the presence of fluid within the middle ear (19). When recording results, pressure, static compliance and ear canal volume were noted (19). Normative data by Margolis and Hunter (20) were used while interpreting the results.

Typical pure-tone audiometry was used as it is the gold-standard for describing hearing sensitivity, and provides information about frequency and ear specific information. Auditory stimuli were presented to the patient by means of headphones to each ear separately at frequencies between 250 Hz and 8,000 Hz; using the modified Hughson-Westlake procedure of bracketing (21). Hearing level below 15 dBHL are considered normal, and this was adopted in the current study. The UHear™ screening was conducted using the same procedure as for the typical audiometer except that the tones were automatically altered using the same bracketing method. Ambient noise levels were measured through the use of a sound level meter before and throughout data collection to determine if levels were appropriate for screening to ensure reliability of results. Each child was subjected to both screening methods to allow for within-subject comparisons. Station A tested participants with the typical audiometer and station B tested them with the iPod Touch© UHear™.

Data Analysis and Statistical Procedures

Data analysis was conducted on IBM® SSPS® Statistics Base software package using both descriptive and inferential statistics. The paired *t*-test was calculated to compare the means of both groups (18).

Pure-tone air-conduction thresholds obtained from audiometers should be within 5 dB of one another in order for reliability to be accepted. Previous studies researching similar variables have indicated that thresholds within 10 dB of conventional audiometry are not considered a significant shift in thresholds. Therefore, any difference greater than 10 dB was considered a significant shift in hearing thresholds and was, therefore, deemed inaccurate. Research on the Octogram™, a computer-assisted audiometer revealed that of the forty-eight participants studied, 94 percent of the air conduction thresholds were within 10 dB of thresholds obtained from manual audiometry carried out by audiologists (14). As a result, the Octogram™ was considered just as reliable as audiologists manually obtaining thresholds (14). As a result, the current study considers hearing threshold differences of between 0 and 10 dB as being accurate.

Ethical Considerations

Following ethical clearance (protocol number: M10361), all ethical considerations for research on human subjects were observed, with strict adherence to the ethical principles advocated in research (22;23).

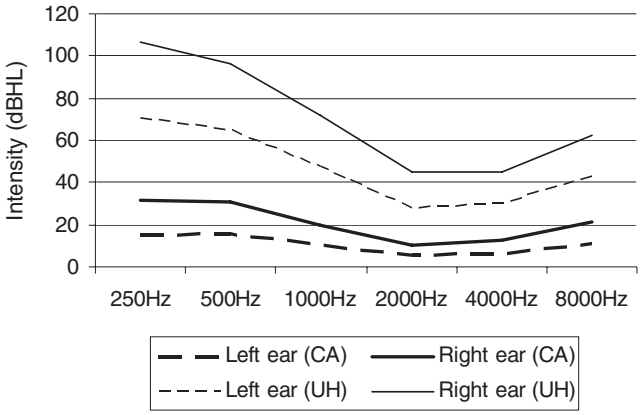

Figure 1. Mean screening thresholds obtained from conventional audiometry (CA) and UHear™ (UH).

RESULTS

Hearing Screening Results Obtained

Figure 1 and Supplementary Table 1, which can be viewed online at www.journals.cambridge.org/thc2013072, give results for conventional audiometry thresholds across ears and frequencies, varying from 5.1 dB to 16.2 dB. The difference between ears was less than 1.05 dB across all frequencies. The mean pure-tone average (PTA) (average of thresholds at 500, 1,000, and 2,000 Hz) obtained from conventional audiometry was 9.94 + 6.02 dB for the right ear and 10.44 + 7.71 dB for the left.

For the UHear™ in the same participants, the thresholds varied from 15.41 to 38.60 dB; while the difference between ears was less than 3 dB across all frequencies. The mean PTA values of 24.63 dB + 10.84 dB for the right and 26.16 dB + 13.37 dB for the left ear were elevated in comparison to conventional audiometry.

Comparing the UHear™ Findings to Those of the Conventional Audiometer

The means of two paired scores obtained from the same scholars using different ways of measuring were calculated to determine if the difference between the two measures was significant. The mean differences varied from 9.2 to 23.4 dB. The standard deviation scores ranged from 9.4 to 21.9 dB, indicating a large difference in obtained thresholds (Table 1). Large deviations were especially evident in lower frequencies.

The difference between the two assessment tools was statistically significant at all frequencies. Thus, the null hypothesis that UHear™ will not cause a change in hearing screening thresholds when compared with conventional audiometry thresholds was rejected.

Plotting the mean difference obtained for each ear (Figure 1), a pattern emerges. The mean thresholds measured using UHear™ presents worse hearing function than conventional audiometry in both ears across all frequencies. None of the school children would have been referred for further examinations after conventional audiometry; when compared with

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Table 1. Mean Difference and Standard Deviation (SD) Values between Thresholds (dB) for Conventional Audiometry and the iPod Touch©, UHear™ Screening Audiometer ($n = 172$ Ears)

Frequency	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Right Ear	20.2 ± 18.5	16.3 ± 16.1	15.1 ± 13.0	12.7 ± 9.4	9.2 ± 10.9	9.9 ± 12.2
Left Ear	23.4 ± 21.9	18.2 ± 17.3	17.6 ± 14.5	11.4 ± 11.8	11.4 ± 14.1	9.8 ± 14.1

twenty-nine who would have been after UHear™. This indicates a 34 percent rate of children who would have been diagnosed as having hearing difficulties when they actually did not.

DISCUSSION

Determining the accuracy of pure-tone audiometry is vitally important as pure-tone testing is the foundation for diagnostic audiometry. Therefore, determining the accuracy of UHear™ is important for accurately identifying a possible hearing impairment. Conventional audiometry is currently the gold standard for obtaining accurate and reliable hearing thresholds in the frequency range 0.5 to 8 kHz, therefore, thresholds obtained from UHear™ should be similar to those obtained from conventional audiometry of the same participants to be considered accurate.

In the current study, the mean differences obtained from comparing hearing thresholds obtained from conventional audiometry and UHear™ indicated that the accuracy of UHear™ is questionable. The mean thresholds obtained from the use of conventional audiometry revealed overall, that hearing was within normal limits (ranging from 5.06 dB to 16.16 dB). In comparison hearing thresholds obtained from UHear™ ranged from 15.41 dB (hearing within normal limits) to 38.60 dB, which is classified as a mild hearing loss (24). As a result of these elevated thresholds obtained from UHear™, the mean difference in thresholds ranged from 9,244 dB to 23,430 dB, resulting in threshold differences generally greater than 10 dB. These differences of greater than 10dB are considered significant, and raise an index of suspicion for test reliability.

In addition to determining individual thresholds at certain frequencies, calculating the pure-tone average (PTA) allows a clinician to summarize the degree of hearing impairment an individual may present with. The PTA is the mean of air-conduction thresholds at 500, 1,000, and 2,000 Hz (24). The PTA for conventional audiometry of both the right (9.94 dB) and left ear (10.44 dB) can be categorized as normal hearing, whereas the PTA for UHear™ of both the right (24.63 dB) and the left ear (26.16 dB) indicated a mild hearing loss (4). This further highlights the overall mean elevation of the hearing thresholds (right ear = 14.69 dB; left ear = 15.72 dB) obtained when comparing conventional audiometry to UHear™. This highlights the danger of UHear™ leading to false positive findings which will have a negative influence on the already stressed resource system when those who would have failed the UHear™ test seeking diagnostic testing from audiologists.

The three frequencies taken into consideration when calculating the PTA, with the inclusion of 4,000 Hz are especially important during pediatric hearing screening. If children undergoing a hearing screening fail to respond to any one of these frequencies in any ear; they fail the hearing screening and are referred for diagnostic audiology. The importance of these four frequencies in the pediatric population is that they constitute frequencies important for speech; and if these speech sounds are not normally perceived it could ultimately affect speech and language development. The mean PTA thresholds from conventional audiometry indicate higher sensitivity and specificity of this measure over UHear™; which in the current study lead to numerous false-positives and referrals for diagnostic audiology.

It should be taken into account that when the means of each device for each ear were plotted on a graph, it illustrated an increased reliability of individual thresholds obtained. The graph illustrated a similar configuration for both measures, therefore, it can be deduced that responses obtained from each participant in n each test measure were consistent and, therefore, reliable. Both tracings follow the same pattern although the mean thresholds obtained for UHear™ were elevated.

Taking this observed consistency in responses into account one is left with a query as to what factors, external to the participants, could contribute to the significant shift in obtained thresholds. One such factor could be the usage of different transducers in the current study. Earphones such as supra-aural and insert earphones are both used in audiological testing environments to test the sensitivity of an ear. The current study made use of supra-aural earphones for conventional audiometry; and commercially available insert earphones were used for UHear™ to match the commercial availability of the iPod Touch©.

The advantages of using insert earphones over supra-aural headphones include the fact that they reduce environmental noise with greater precision, they provide increased inter-aural attenuation and greater comfort (24). When considering these advantages one must take into account that the advantages are only advantageous if the earphones have been correctly and recently calibrated. Typically, insert earphones have receivers that are attached to the tube that is coupled with the tip that is placed into the ear canal. The commercially available insert earphones that were used in the current study did not include an attached receiver nor was it calibrated as they were purchased from a commercial store as expected of what the general iPod Touch© user would do. Therefore, the use of commercially available,

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noncalibrated insert earphones could have contributed to the large variance in means obtained from the different machines. Nonetheless, the size of this difference in thresholds seems too large to be explained only by this factor.

The fact that the current research took place at a school, where there were at times increased but not excessive ambient noise levels could have also had an effect on the current findings. Research carried out by Wong et al. (25) highlighted that low frequency ambient noise levels result in the increased variance of hearing thresholds for the lower frequencies with higher frequencies being less affected, findings consistent with current findings. Ambient noise could, therefore, have had an influence in the current study. Nonetheless, it is assumed that this environmental variable would have had a similar effect on both measures; however, in the current study; this factor seems to have significantly affected only the UHear™ results. The combination of noise and noncalibrated insert earphones may have resulted in sound leakage and, therefore, account for the increased effect on the UHear™ screening thresholds.

A third possible reason for the discrepancy between mean thresholds obtained from the different equipment could be calibration issues. Calibration is reported to be important to ensure that an audiometer produces a pure tone at a specified intensity and frequency, that the signal is present only in the transducer to which it is directed, and that the signal is without distortion or unwanted noise interference. UHear™ is a downloadable application from iTunes. Every application is downloaded to a different iPod Touch© or iPhone™ and each device uses different earphones as per user preferences. Therefore, ensuring that the level and frequency of the auditory stimulus is the same as those produced by a conventional audiometer can be challenging. This particular point may explain why the same pattern/configuration of responses with significantly different intensities was found in the current study.

Earphones, ambient noise levels, and calibration may all have contributed individually or in combination with one another to the variance in thresholds obtained from the conventional audiometer and from UHear™ in the current study. These results indicate the poor accuracy of UHear™ under the current study's parameters. The current findings raise implications for portable audiometry; as well as for the use of UHear™ under screening conditions.

CONCLUSIONS

The current study aimed to determine whether or not UHear™, a downloadable screening audiometer on an iPod Touch© or iPhone© was accurate in terms of hearing thresholds when compared with the gold standard of conventional audiometry. Determining that UHear™ correctly and accurately establishes hearing thresholds could be valuable in the clinical and humanitarian settings of audiology. Using the popular iPod™ as a screening instrument could help in decreasing the ever growing demand of hearing tests worldwide due to their reduced costs in comparison to conventional audiometers, and the fact that they are automatic, therefore, reduce the need for audiologists or hearing care providers to run tests individually.

Previous research in automatic audiometry and tele-health audiometry have highlighted the need for both portable and automated audiometry especially in developing countries with both measures proving to be a reliable and accurate alternative to conventional audiometry. In the same sense, UHear™ has the potential to increase the identification of hearing impairment worldwide if their hearing thresholds are accurately determined. Current findings, however, highlight the need for caution when such procedures and devices are endorsed and introduced to the general public. Current findings also raise the need for more rigorous research into portable and tele-health audiometry as risks of these measures may outweigh the benefits if not closely monitored.

SUPPLEMENTARY MATERIAL

Supplementary Table 1:
www.journals.cambridge.org/thc2013072

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CONFLICTS OF INTEREST

The authors report they have no potential conflicts of interest.

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