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Validation of an iPod-Based Hearing Screening for a Pediatric Population

by

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Abstract

Objective: This study we explore the validity of using the uHear™ application on an Apple Incorporated's, iOS product to test hearing thresholds in a pediatric population.

Methods: 52 participants, ages 5 to12 had their hearing tested in 3 ways. A portable screening audiometer was used as the gold standard for hearing. Hearing was also tested using the uHear™ app from Unitron and again with a set of noise reducing earmuffs. Additionally, a parent questionnaire was administered that explored behavioral factors that may have influenced performance.

Results: Results indicated the uHear currently does not measure hearing thresholds as accurately as the audiometer, resulting in many false positives results. The parent questionnaire showed no strong correlations between the measures and the uHear results.

Discussion: The uHear is not currently accurate in its hearing threshold measurement. However, it has some promising aspects that may make it a valuable tool in the future.

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Introduction

Problem Statement

Statistics Canada estimates that 13% of children under the age of 14 have a hearing disability (Statistics Canada, 2001). Hearing loss can have far reaching consequences as it may result in compromised perceptual and linguistic abilities because of the reduced auditory environment (Holtby, Forster, & Kumar, 1997; Flexer & Madell, 2008). Even a mild loss can lead to difficulties in the educational system that are greater than might be predicted based on the degree of hearing loss (Bess, Dodd-Murphy, & Parker, 1998). This in turn may result in significant language and communication delay and a decrease in educational attainment and social development (Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998). Language is necessary not only for creating personal relationships but also for learning appropriate social behaviour and discipline (Barker et al., 2009). Consequently, language deficits have been linked to internalizing and externalizing behavioural difficulties that impact the child's behaviour (Barker et al., 2009). To help mitigate the language, academic and behavioural deficits associated with hearing loss, early intervention is recommended (Bess & Humes, 2008). For school-aged children, the American Speech-Language Association recommends that children have their hearing screened upon entry to school, annually in kindergarten to grade three, in grade seven and in grade eleven (American Speech-Language-Hearing Association [ASHA], 1997). Additionally, children should be screened as needed, when no screening documentation exists, or upon entrance to special education or grade repetition (ASHA, 1997). To accommodate this increased demand for audiological testing, a more available screening system that allows for both flexibility and accuracy is needed for effective coordination and cooperation between health professionals, families, and the education system (Doyle & Ristevski, 2010).

Importance of screening at the school-age

The current model of hearing screening within Alberta does not include universal newborn hearing screening and this service is only available in select communities (Alberta Health Services, 2012b). In addition, hearing screenings are completed for students at the school-age only at the request of their parent and teacher (Alberta Health Services, 2012b). There is currently no standard program in Alberta to ensure that all school-age children have their hearing assessed.

Hearing loss can occur after infancy therefore it's important to consider ways to identify children that may have been missed with neonatal screening, have a progressive hearing loss because of a genetic factor, have had persistent otitis media with effusion, or have hearing loss from a change in medical status or exposure to harmful environments (Baltussen, et al., 2009; Crowley, Bains, & Pellico, 2005; Kemper, Fant, Bruckman, & Clark, 2004; Meinke, & Dice, 2007). In particular, a structured screening program would help identify children with mild or moderate or unilateral hearing loss who otherwise may remain undetected (Fonseca, Forsyth, & Neary, 2005; Meinke & Dice, 2007). A school screening program would help identify these children when intervention is critical for education and language development (Bristow, Fortnum, Fonseca, & Bamford, 2008; Skarżyński & Piotrowska, 2012). The school setting is ideal for a screening program as it provides a structured setting within which to conduct the hearing assessments and possibly the opportunity to include an ear health program (Doyle & Ristevski, 2010; Lancaster, Krumm, Ribera, & Klich, 2008). However, an effective screening program would first and foremost be both cost-effective and reliable with a consistent protocol (Skarżyński & Piotrowska, 2012; Śliwa, Hatzopoulos, Kochanek, Piłka, Senderski, & Skarżyński, 2011). One possible approach to a screening program is automated audiology.

Automated Audiology

Automated audiology has been proposed to help efficiently meet the demand for hearing testing by using computer-based systems, PDA-based systems, and computer-assisted audiometers (Śliwa et al., 2011; McPherson, Law, & Wong, 2010; Ho, Hildreth, & Lindsey, 2009; Margolis & Morgan, 2008). It allows the patient to self-administer their audiometry test without the direct involvement of the audiologist. Because of the independence in testing, automated screening devices have the potential to reduce demand on the profession while still maintaining accurate results if the automated hearing system is validated (Swanepoel, Mngemane, Molemong, Mkwanazi, & Tutshini, 2010). This will allow patients to fast track their hearing assessment while freeing audiologists to work with difficult to test patients and those with more specialized challenges. Automated audiometry is not intended to replace audiologists but provides them another tool to use in their clinical practice (Ho et al., 2009; Lancaster et al., 2008). As an extension of automated hearing testing, automated hearing screening has been proposed to compliment the process and increase the availability of hearing screening.

Ho and colleagues (2010) found that the Otogram^{TM} by Ototronix Diagnostics, an automated hearing assessment system, had reliable results, which were consistent with audiograms obtained by audiologists. Other researchers have also determined automated audiology to have good threshold correspondence with the thresholds determined by the audiologist using conventional manual audiometry (Swanepoel et al., 2010; Margolis, Glasberg, Creeke, & Moore, 2010). The consistency in results provides confidence in using automated audiometry to complete a hearing test, which may allow health personnel other than audiologists to carry out the test and determine if a referral is necessary or to send the results to the audiologist for review (Bristow et al., 2007; Gloria-Cruz, Chiong, Chan, Llanes, Reyes-Quintos,

& Abes, 2007; McPherson et al., 2010; Margolis & Morgan, 2008; Swanepoel & Biagio, 2011). The ability for other professionals to complete the test opens up new opportunities to obtain hearing tests for rural populations who do not have access to audiologists and for expanding audiological services in developing countries (McPherson et al., 2010; Honeth, Bexelius, Eriksson, Sandin, Litton, Rosenhall, Nyrén, & Bagger-Sjöbäck, 2010). Automated audiology facilitates accuracy because a computer will administer the test in the same way every time which provides consistency and reliability (Margolis & Saly, n.d.). However, with automatization comes less flexibility and fewer opportunities to stop or adapt the test and reinstruct if the clinician feels that the patient does not understand the task (McPherson et al., 2010). The accuracy of the test also hinges upon the setting in which it is performed. For example, the integrity of the room, the calibration and maintenance of the equipment, and the instructions given to the patient can all influence the results (Donahue, Dubno, & Beck, 2010). A further consideration for automated audiometry is the test battery chosen to be included in the test administration. A more complex battery provides more information but the time required to complete the test cannot be longer than manual conventional audiometry or the efficiency of using automated audiometry is partially lost (Śliwa, et al., 2011). Determining which tests to include in an automated test battery has been a primary consideration since the start of automated audiology. Śliwa and colleagues (2011) suggest that the most economical and simplest test protocol would be an automated multi-tone audiometric test. They found that a four tone automated audiometric assessment, using a Fujitsu-Siemens PDA-based screening device with additional hardware and software components, combined with tympanometry provided the best detection of hearing loss in school age children while maintaining a short assessment time of approximately three minutes (Śliwa et al., 2011). To maintain the benefit of using automated

audiometry, an automated hearing screening protocol may be ideal as it allows the efficiency of a shorter test protocol while still providing information as to the degree of hearing loss and the necessity of a referral.

While automated audiometric assessment has been introduced for full hearing testing, less focus has been placed on hearing screening (Lancaster et al., 2008). However the validation of automated hearing testing suggests that the protocols can be simplified and used as an effective hearing screening tool to identify persons with hearing loss. Screening programs for preschool and school-aged populations are often unorganized and incomprehensive (Taha et al., 2010); an automated screening protocol may address this difficulty by providing a standardized protocol that can be run by a trained professional. This allows for ASHA's screening recommendations to be followed rather than leaving the identification of the possibility of hearing problems to parents and teachers (Laing & Rossor, 1999). It also provides a low-cost hearing screening option that can be consistently implemented in a variety of settings around the world for a range of populations (Taha et al., 2010). Automated audiology may increase the efficiency of hearing testing resulting in reduced demands on audiologists and increased availability of accurate audiograms (Swanepoel et al., 2010). By the same reasoning, automated audiology for screening purposes may help create a streamlined, efficient screening program that allows for more children to have an accurate audiogram completed. However, most of the proposed automated systems are large and bulky resulting in logistical and financial barriers to completing the hearing screening (Szudek et al., 2012).

uHear™ Application

The uHear™ (herein referred to as uHear) application for iOS devices, designed and developed by Don Hayes, PhD, director of audiology for Unitron, is available for free download

from iTunes (Unitron, 2009). It allows users to test their hearing through air conduction with a pure-tone threshold test at 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz, and 6000Hz for both ears as well as incorporating a speech in noise component. The user presses a button on the screen to indicate when they hear the beep. The user must complete the test at all six frequencies for both ears to complete the screening and cannot choose which frequencies they would like to test. The application uses the modified Hughson-Westlake method of 5dB up when the participant does not respond and 10dB down when they do respond. An audiogram is produced at the end of the hearing evaluation for the pure-tone air conduction test. Szudek and colleagues (2012) found the uHear to be 98 to 100% sensitive and have a specificity of 82% in the clinic and 90% in the sound booth, as well as a clinically relevant likelihood ratio of 9 in a clinical setting with an adult population, which describes the likelihood of a person with hearing loss testing positive over the likelihood of someone without the diagnosis testing positive in this situation. They determined that the uHear is a reasonable screening test to rule out moderate hearing loss, that is a pure tone average greater than 40dB and that the uHear was more accurate in measuring pure-tone threshold levels in ears with established hearing loss than in ears with hearing within normal limits. (Szudek, et al., 2012). This suggests that the uHear may be a viable solution for screening and monitoring patients' hearing, particularly in situations where there is a known hearing loss, as the uHear has a dynamic range of 15 to 100dB and may overestimate pure-tone thresholds in ears with normal hearing (Szudek et al., 2012). The uHear application's promising hearing screening potential, as well as the ubiquitous presence of Apple products with over 350 million iPods and 400 million iOS devices, including the iPad, iPhone, and iPod Touch, sold (Apple, 2012) combine to position the uHear application as a viable solution for increasing the availability of a convenient, accurate hearing screening tool.

Current Standards of Hearing Screening

A standard hearing evaluation centers on the pure-tone audiometry test where the hearing thresholds for a set amount of frequencies are determined. The hearing threshold is the lowest decibel level at which a person can detect the sound stimuli 50 percent of the time. It is obtained with both air and bone conduction (Bess & Humes, 2008). Air conduction thresholds help identify the total integrity of the hearing mechanism but cannot determine where the breakdown in the system may occur (Bessie & Humes, 2008). To accurately assess the hearing thresholds and integrity of the hearing system, pure-tone air conduction audiometry relies on a set of steps that are well established, which makes it ideal for automatization using computers (Margolis & Morgan, 2008). However there are some drawbacks to conventional pure-tone audiometry including the length of time required to complete the test, the necessity of proper equipment calibration, the influence of clinical judgment on testing procedures, and the behavioural requirements for the child being tested (Halloran, Hardin, & Wall, 2009). To obtain a representative audiogram for the child, it is imperative that the child be able to understand the task and understand the language used (Halloran et al., 2009). Conventional manual pure-tone audiometry is the gold standard for hearing assessments (Swanepoel et al., 2010). Pure tone audiometry has well-established test-retest reliability for difficult-to-test young patients (Stuart, Stenstrom, Tompkins, & Vandenhoff, 1991), which is why it remains as the primary procedure for hearing testing for both adults and children (Swanepoel et al., 2010). The simplicity of the test and its reputation as the gold standard makes it an ideal starting point for developing a hearing screening program for school age children (Śliwa et al., 2011).

Screening protocols incorporate the principals of conventional manual pure-tone audiometry to create an efficient, simplified measure of hearing. ASHA recommends that a

hearing screening test screen for the typical speech frequencies of 1000Hz, 2000Hz and 4000Hz at 20dB, which is the threshold of normal hearing (ASHA, 1997; Nadol, 1993). Testing at 6000Hz is generally not recommended because of the likelihood of a high failure rate (Holmes et al., 1997). The tones are presented to both ears, while the participant sits at right angle to the examiner so that they are unable to see the audiometer (Reilley, Troiani, Grossman, & Wingfield, 2007). Screening programs often vary from this formula and can be inconsistent (Taha et al., 2010). They may also have poor specificity and sensitivity in primary care and school settings as Halloran and colleagues (2009) found that a pure-tone audiometer screening program that lead to referrals to an audiologist had a specificity of 78% and a sensitivity of 50%, although there was a high rate of noncompliance with follow-up appointments. This may be because of poor environmental control, high ambient noise levels, patient behaviour, and poor tester competence (Halloran et al., 2009). These concerns are important to note and automated screening procedures may help address some of these concerns as they rely less upon the skills of the examiner and they provide a consistent protocol for screening. For the purposes of this study, a screening program using the modified Hughson-Westlake method will be used to provide a more comprehensive understanding of the participant's threshold levels.

Hearing Screening with Children

When testing children, all possible variables must be considered as possible influences on test performance. To ensure that the assessment being completed has face validity, which means that it is testing what it purports to be testing, variables that could have a biasing effect need to be considered. This includes methodological variables that present during the course of the assessment such as the familiarity of the presentation format, the required response, and environmental distractions (Mendel, 2008). If a child has difficulties understanding how they

should respond or has motoric difficulties, this difficulty could negatively bias their score and lead to incorrect conclusions about both their hearing ability and the validity of the machine. To circumvent these variables, it is essential that the test administer train the children on the task so that they understand what their role is in the hearing assessment (Newton, Chiat, & Hald, 2008; Mac Ardel, Hazan, & Prasher, 1999). This will help the test maintain face validity as well as help decrease the gap between the child's performance and their actual competence (Mendel, 2008).

In addition to the task requirements and linguistic competencies of the child, the age, cognitive abilities, ability to guess, and behaviour must also be taken into account (Mendel, 2008; Mac Ardel et al., 1999). These factors will influence how well a child completes the test and the potential outcome of the assessment, particularly motivation as the task relies on intrinsic motivation and has little extrinsic motivation to encourage the children to continue on with the task. For children with higher cognitive abilities and greater guessing skills, their audiograms may show lower thresholds. However this will be consistent across both the uHear application and conventional audiometry and should not bias the results. To take into account the extra variables and difficulties that are associated with pediatric testing, Kosky and Boothroyd (2003) suggested the following considerations when developing assessments: 1) the test should have age-appropriate cognitive, attentional and motoric demands, 2) the task should be motivating for the child to help maintain their interest, and 3) the child's performance and results should not be influenced by their speech and language skills. By respecting these guidelines, the validity of the pediatric hearing assessment will be better preserved.

Parent Questionnaires

A parent questionnaire is a useful pre-screening tool to help identify which children may have more difficulty with the uHear hearing assessment and potential reasons for the difficulty.

Parents are often first to notice a possible hearing loss and seek further investigation of the child's hearing abilities (Hovind & Parving, 1987). Thus, parent reports show advantages in augmenting the assessment process because they access parents' extensive knowledge about their own children including the behavioural skills of the child across different situations and times (Boudreau, 2005). Parents are the experts on their own children and questionnaires seek to tap that resource while still respecting the boundaries of knowledge that the parents may have. Hammond, Gold, Wigg, and Volkmer (1997) did not find a hearing loss questionnaire to be a sensitive screening measure for hearing loss in children who were 4-5 years old and concluded that this could be a result of the questions asked but also may be because parental concern alone is not enough to detect hearing loss (Hammond et al., 1997). This suggests that a questionnaire alone is not enough to determine who should participate in a hearing assessment but it still provides valuable information that may guide the assessment. Parents were found to be sensitive to developmental problems including language, motor, cognitive, and global development (Glascoe, 1997). This sensitivity combined with their extensive knowledge of their children makes parents an ideal resource for information when completing a hearing assessment.

Research Purpose

The primary focus of this study was to determine if the uHear application is a valid and appropriate tool for screening the hearing of children between the ages of 5 and 12. The uHear application has already been partially-validated for administering hearing screening tests to adults to rule out moderate hearing loss and it would be beneficial for health and educational service delivery to find a similar option for children (Szudek et al., 2012). Typically children in this age group participate in a manual conventional audiometry screening test using a portable audiometer with the screening procedure of testing both ears at 20dB with the three frequencies

of 1000, 2000, and 4000Hz (Bess & Humes, 2008). The uHear application currently does not allow the examiner to customize the hearing test. Therefore, this study will test hearing thresholds at 6 frequencies for both ears. The whole test will be completed, however only the screening frequencies of 1000, 2000, and 4000Hz will be used in the analysis. Thus, the uHear application is the focus of this study to determine if it is accurate and reliable when used with the more variable pediatric population. Further, noise reducing earmuffs were used to create a more auditory controlled environment to determine if reducing background noise would increase the accuracy of the application. Thus, the participants will complete three audiograms: the audiometer, uHear with standard earbuds, and uHear with standard earbuds and noise reducing earmuffs. This study will seek to determine if children can complete the test when they are independent with limited support, rather than with the guidance of a speech language pathologist or audiologist.

The secondary focus of the study is to explore measures that may predict if a child has the ability to complete an accurate hearing screening test using the uHear application, where an accurate uHear assessment would be one that does not yield a significantly different hearing threshold result compared to the audiometer. A parent report that focused on the behavioral skills required to complete the test was used to explore these variables. Parent impressions of their child's strengths and weaknesses regarding behaviour such as attention and motivation may help determine the relationship between the abilities of the child has and the accuracy of the hearing assessment using the uHear application.

Thus, the study addressed three research questions:

1. Is the uHear an accurate screening tool compared to the standard audiometer?

2. Is the uHear with extra noise reduction an accurate screening tool compared to the audiometer?
3. Can the accuracy of the uHear screening be predicted using a parent questionnaire asking about the behavior and skills of the participant?

Research Design

This study uses a 3x3 repeated measures ANOVA design with two independent variables with three levels each. The first independent variable is frequency with the three levels being the three different frequencies included in the analysis that are tested in a standard screening (i.e., 1000, 2000, and 4000Hz). The second independent variable is the delivery of the hearing test with the three levels being the test with the standard audiometer, the test with the uHear alone, and the test with the uHear with the extra noise reducing earmuffs. The dependent variable is the measured threshold in decibels at each frequency for each device. For research question three, correlations will be completed with the individual questions and the difference in the pure tone threshold averages obtained between each the three testing conditions.

Methods

Participants

The study was approved by the University of Alberta Ethics Research Board Health Board. For this study, fifty-two children were recruited through local music schools and teachers, local homeschooling associations, and through personal contacts. Appendix A contains the recruitment poster that was placed in the various recruitment locations. All children were between the ages of five and twelve years old (5 years, 0 months to 12 years, 6 months). This age range corresponds to the age when children are in school as well as when conventional manual audiometry is used to conduct a hearing test. The participants were English speakers with no known cognitive delays. Please see Table 1 for demographic information. Information regarding the participants' experience with hearing screenings and their parents' perspective of their hearing ability is addressed in the results section for the parent questionnaire. Two children were identified by their parents as having hearing loss and were currently being followed by an audiologist, however neither participant wore hearing aids.

Table 1. *Study Demographics*

Age (years)	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total**
Male	6	3	6	4	3	5	2	4	33
Female	8	3	3	2	0	1	2	0	19
Total	14	6	9	6	3	6	4	4	52

All participants gave assent to be part of the study as well the parents or guardians of the children gave consent. All participants completed a hearing test with the audiometer, uHear, and uHear with noise reducing earmuffs during the study and no children withdrew at any time.

Materials

The materials needed for the study included a portable audiometer, an iPod Touch, earbuds, and noise reducing earmuffs. The two portable audiometers used in the study were both produced by MAICO and were model MA-25. The iPod Touch (iOS 4.1, model number A1367) was used to run all the uHear hearing tests with the standard issue Apple earbuds that were sold with the iPod Touch. The same noise reducing earmuffs, the Oris Sabres, were also used with all participants. The earbuds were chosen because they are what most people using an iOS device (e.g., iPod Touch) would have access to. In the previous study out of this lab (Szudek et al., 2011), the earbuds were calibrated in a 2-cc coupler to ensure that we had a good understanding of the relationship to the device output settings and the actual level produced by the earbuds (Hodgetts, 2012; personal communication).

The sensitivity test portion of the uHear application involves four steps. The user is first directed to go to a quiet environment and put the earmuffs or earbuds in the correct ear. The next step is the calibration where the user moves a slider to 50% and when it was in the correct position, the examiner chooses which listening device they are using (i.e., earmuffs or earbuds) and the test begins. The test screens both the left and right ears at six different frequencies (250, 500, 1000, 2000, 4000, 6000Hz), starting with the right ear and moving to the left once all six frequencies have been presented to the right ear. The tone is a presentation of three short pulses at the frequency currently being tested. The participant presses a large button when they hear the tone. The uHear uses a modified Hughson-Westlake method where the tone decreases by 10dB and increases by 5dB depending on the participants response. The lowest threshold is determined by a positive response two out of three times at the lowest decibel level. The time between presentations is randomized to reduce anticipation and guessing. The uHear test continues with

the same frequency until it has determined a consistent threshold. The completion bar at the bottom of the app allowed both the user and others overseeing the test to see the progress made and the number of frequencies yet to be tested. At the end of the assessment, a standard audiogram displays the hearing threshold results. The test is designed to take approximately six minutes to complete (Smaka, 2009). Because the uHear uses a threshold testing procedure to test the user's hearing, this study also uses threshold testing. The ideal test format for a screening would be the ASHA protocol outlined above, however for the purposes of this study to maintain consistency between the three conditions, the threshold testing was used with all three deliveries of the hearing test, although only the results from the 1000Hz, 2000Hz, and 4000Hz frequencies were used.

Procedure

Each child came for one session where the three audiograms were collected. The sessions were primarily held in one of three small treatment rooms which were in quiet areas of the same building (Table 2). Two sessions were completed in different rooms because of limited room availability at the time. None of the rooms were soundproof and all had some ambient noise. The treatment rooms were used to act as a comparable stand-in to rooms at a school where hearing screenings typically are completed. Prior to every session, the audiometer and uHear app were tested to ensure that all the tones were distinguishable in the room and that there were no equipment malfunctions. All sessions were run by the same speech language pathology student and a portion of the sessions were observed by an audiologist to monitor accuracy and proper procedure with the audiometer screening.

Table 2. *Locations of Testing Sessions*

Room	1	2	3	4	5	Total
Number of Sessions	37	6	7	1	1	52

When the child and their parent or guardian came to Corbett Hall, they were taken to the treatment room where the study was explained to them. The entire procedure was explained and an information letter given to them before each child and parent completed an assent and consent form, respectively (Appendix B, C, and D). The parents and child chose if the parent stayed in the room during testing or if they watched the testing from the adjacent observation room. In situations where there were multiple children, the children were tested one at a time in the treatment room while the others waited in the observation room to avoid excess distractions and noise while testing.

There were three testing conditions in this study, 1) pure-tone threshold testing with the modified Hughson Westlake method and a portable audiometer, 2) uHear testing with earbuds, 3) uHear testing with earbuds and noise reducing earmuffs. The order the audiograms were completed was randomized (Table 3) with some exceptions. The portable audiometer was used for the first set of instructions presented during the testing session to provide an example to the participant of what the sound would be like that they were to listen for. This was done to ensure that the results were accurate and that the child completed the task appropriately. If the child had difficulty identifying the sound they were to listen for or if they were unsure of what their response was to be with the uHear when practicing making responses, the condition without the extra earmuffs was completed first as it was easier to reinstruct when you did not have to remove the earmuffs first. Each of the testing conditions is described below. Following the screenings,

all audiograms were reviewed by an audiologist and when a concern was noted, the child and parent was asked to return to Corbett Hall for a full screening by an audiologist in a sound booth.

Table 3. *Number of Participants Who Completed the Screenings in Each Order*

Order	A-I-O	A-O-I	I-A-O	I-O-A	O-A-I	O-I-A
Number of Participants	13	6	9	9	8	7

Note: A- Portable Audiometer; I- uHear application; O- uHear application with earmuffs

Portable Audiometer

The threshold hearing testing with the audiometer used the same threshold testing procedure as the uHear where the left and right ears were tested at 250, 500, 1000, 2000, 4000, and 6000Hz using the modified Hughson Westlake method. During testing, the frequency would first be presented at 30dB, if the participant responded, the decibel level would be decreased by 10dB and the tone presented again. If the participant did not respond the decibel level would be increased by 5dB until the participant did respond. The testing would continue with the 10dB down, 5dB up style until a threshold was established by a positive response two times at the lowest decibel level. The tone was a single presentation of the frequency for approximately 1.5 seconds and the time between presentations was randomized to reduce anticipation and guessing. When the participant heard the tone, they raised their hand to indicate that they heard it. All participants used one of the two audiometers used in the study that were both calibrated.

Participants received the instructions as follows: “I am going to use this machine to play some beeps, like this (example tone played for child) or like this (another example tone at a different frequency played). When you hear the beep, I want you to raise your hand high. Put your hand down when the beep goes away. Raise your hand even if the beep sounds really soft or like it is far away.” With the portable audiometer, the child first listened to a 1000Hz tone at a

high decibel level without the earphones on. They then practiced raising their hand when they heard the tone. For the younger children, they practiced longer and when they consistently raised their hand as soon as the beep started and put it down quickly, the hearing test started. The older children and calmer younger children were seated with their backs to the administrator and raised their hand when they heard a tone. Some of the younger children felt more comfortable sitting at 90 degrees such that they could not see the administrator pushing the buttons on the portable audiometer but they were able to see the administrator, which reduced their distraction and kept them on task. To compare the efficiency of each condition, the time to complete the assessment was calculated. With the portable audiometer, the time was measured from the presentation of the first stimulus tone to the child's final response to the last stimulus tone.

uHear Application

When completing the uHear screening, the instructions were the same for both the uHear alone condition as well as for the uHear with noise reducing earmuffs condition. The children were shown a screen capture of the app, printed out on paper, as they would see it when listening to the tones (Appendix E). The location where they would press was shown as well as clarification given that they only needed to press once even though the tone played as a series of three beeps. To help the children understand the required response, a sample tone was presented at a high decibel level using the portable audiometer without the earmuffs on the child. The child was shown that as soon as the tone was heard, they pushed the screen. The directions given to the participant were as follows: "We are going to use the iPod Touch to test your hearing. You will hear some beeps like this (audiometer used to demonstrate tones). Press the screen whenever you hear a beep, even if it sounds really soft or far away. The button looks like this where you touch. The bottom part of the screen shows how much of the test you have done. When it is all blue,

you are all done." When the child showed a consistent response of pointing to the button on the screen capture when they heard a tone, the testing procedure began. The earbuds were placed in the ear and then taped with medical tape to ensure that the placement stayed the same. For the second uHear condition, the instructions remained the same. The child was shown the extra earmuffs and given the opportunity to try them before the earbuds were put in their ears. They were then given the same instructions as above and the earbuds placed and taped in the ears. The noise reducing earmuffs were then placed over top of the earbuds. Some children further adjusted the earmuffs, which may have affected the placement of the earbuds. During the screening, the app was paused when the child asked a question or if re-instruction was needed. Re-instruction was given when the child was taking more than a few minutes to complete one tone, as determined by the completion bar, such that the test appeared paused or if the child started pressing the screen in a way that impacted the test results (i.e., holding the button down or pressing multiple times for one tone). If the child struggled to move past a tone, a reminder to press the button only when they were sure they heard the tone was given to help them continue with the test. All audiograms were saved immediately however results were not reviewed until testing had been completed (Appendix F). The timing for both conditions with the uHear application was measured from the time when play was pressed to when the keyboard appeared, which showed that the test was finished. Some children completed the three screenings consecutively while others took short breaks between each screening as per their own comfort level.

Parent Questionnaire

While the child was completing the hearing assessments, the parent or guardian filled out a short questionnaire of 10 questions (Appendix G). A task analysis with the uHear was

completed to identify skills and behaviors necessary to complete the task. These were then adapted into the parent questionnaire. The instructions for the questionnaire were as follows: "For each question, make a mark on the line that best answers the question, like a rating scale. If you would like to add a comment, you can. But it is optional. There is a front and back side to the questionnaire, please answer all ten questions. Fill one out for each child (relevant when siblings were being tested) and you can return them to me at the end of the session." The parents put a mark on the line where they felt it best represented their child. The distance along the line of the mark was measured and recorded for analysis to determine if any of the questions correlated with the hearing thresholds or had predictive power for success with the uHear testing. The questionnaire probed areas related to the child's experience with hearing screenings and touch screens, their ability to work independently, and other behaviors that might benefit them during the assessment.

Results

Research Question 1 and 2

The pure tone average (PTA) was calculated as the mean of hearing thresholds for both ears at each of the frequencies of 1000, 2000, and 4000 Hz. A 3x3 repeated measures ANOVA where the variables were the frequency tested (1000, 2000, 4000 Hz) and the method of testing (audiometer, uHear, uHear with earmuffs) were compared. In addition, paired t-tests with a Bonferroni correction were used to compare the results between devices.

The results of the 3x3 ANOVA show a significant main effect of device ($F_{(1.758, 89.677)}$ = 117.124, $p<0.001$), a significant main effect of frequency ($F_{(1.000, 51.000)}$ = 54.978, $p<0.001$), and a significant interaction between device and frequency ($F_{(1.746, 89.057)}$ = 29.562, $p<0.001$). For each analysis, sphericity cannot be assumed as Mauchly's Test of Sphericity was significant. Figure 1 shows the means for each effect.

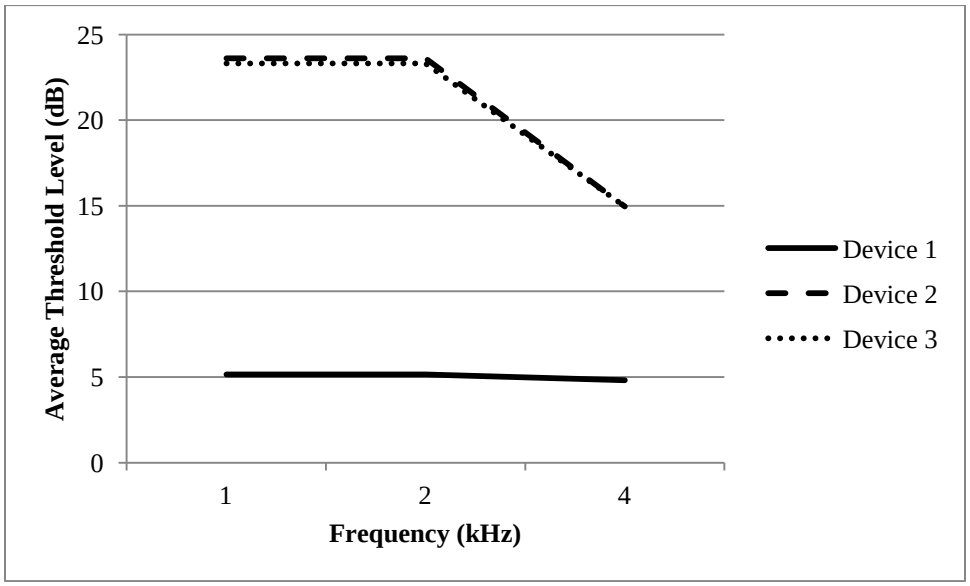

Figure 1*:* Estimated Marginal Means for Each Device at Each Frequency. Where Device 1 is the Audiometer, Device 2 is the uHear, Device 3 is the uHear with extra earmuffs

With the maximum number of means being 9, there are 36 possible comparison which leads to a Bonferroni correction of $p = 0.00139$ ($p = 9/36$). T-tests were run to compare between devices at each frequency. The pure tone average for the audiometer was significantly lower than the pure tone average of the uHear at 1000Hz ($t = -14.982$, $df = 51$, $p<0.001$), at 2000Hz ($t = -14.982$, $df = 51$, $p<0.001$), and at 4000Hz ($t = -10.284$, $df = 51$, $p<0.001$). The pure tone average for the audiometer was also significantly lower than the pure tone average of the uHear with earmuffs at 1000Hz ($t = -13.722$, $df = 51$, $p<0.001$), at 2000Hz ($t = -13.722$, $df = 51$, $p<0.001$), and at 4000Hz ($t = -10.765$, $df = 51$, $p<0.001$). There was not a significant difference between the pure tone averages of the uHear and the uHear with earmuffs condition at 1000Hz ($t = -0.170$, $df = 51$, $p = 0.866$), at 2000Hz ($t = -0.170$, $df = 51$, $p = 0.866$), or at 4000Hz ($t = 0.000$, $df = 51$, $p = 1.000$).

Table 4 compares the pass or fail results of the uHear with the results obtained through pure tone testing with the portable audiometer. A cut-off score of 20dB was used as the standard criterion for "passing" a hearing screening. Three participants had a PTA greater than 20dB as measured by the audiometer condition, indicating a "failed test" and suggesting possible hearing loss. All three of these participants were also identified by the uHear as having thresholds higher than 20 dB. This corresponds to a sensitivity of 100.0% (95% CI = 31.0–100.0%) suggesting that the uHear app identified all the participants who required follow-up. However, for the 49 participants that had hearing thresholds below 20 dB as measured by the audiometer condition (a "passed test"), 30 were identified by the uHear as having hearing thresholds above 20 dB (a "failed test"). This translates to a specificity of 38.8% (95% CI = 25.5-53.8%) which suggests that the uHear app produces a high number of false positive results, only correctly identifying 38.8% of the population who do not have hearing loss. For any test result with the uHear, the

probability that it will be positive is 0.63 (95% CI = 0.49-0.76) and the probability it will be negative is 0.37 (95% CI = 0.24-0.51). For any particular positive test result with the uHear, the probability that it is a true positive is 0.09 (95% CI = 0.02-0.25) and the probability that it is a false positive is 0.91 (95% CI = 0.75-0.98). For any particular negative test result, the probability that it is a true negative is 1 (95% CI = 0.79-1) and the probability that it is a false negative is 0 (95% CI = 0-0.21). This suggests a high probability of receiving a false positive when using the uHear to test hearing.

Table 4. *Number of Participants who Passed or Failed Each Hearing Test where Pure Tone Averages (PTA) for the Audiometer and the uHear App were Collapsed across Frequencies of 1000, 2000, 4000Hz and Across Ears*

	Audiometer	
uHear	PTA <20	PTA>20
PTA <20	19	0
PTA >20	30	3
Total	49	3

The results of the uHear with the noise reducing earmuffs compared with the standard audiogram are shown in Table 5. The results parallel those from the uHear app with only earbuds, with a sensitivity of 100% (95% CI = 31.0-100.0%). Of the 49 participants with hearing thresholds below 20dB, 21 were identified by the uHear app with the earmuffs as having thresholds above 20dB, which leads to a specificity of 57.1% (95% CI = 42.3-70.9%). For any test result with the uHear app with the noise reducing earmuffs, the probability that it will be positive is 0.46 (95% CI = 0.32-0.60) and the probability it will be negative is 0.54 (95% CI = 0.40-0.68). For any particular positive test result, the probability that it is a true positive is 0.13 (95% CI = 0.03-0.33) and the probability that it is a false positive is 0.88 (95% CI = 0.67-0.98). For any particular negative test result, the probability that it is a true negative is 1 (95% CI = 0.85-1) and the probability that it is a false negative is 0 (95% CI = 0-0.15). This again parallels

the results of the uHear app with earbuds only, as there is the greatest likelihood of having a false positive when using the uHear app with the noise reducing earmuffs.

Table 5. *Number of Participants who Passed or Failed Each Hearing Test where PTA for the Audiometer and the uHear App with the Earmuffs were Collapsed across Frequencies of 1000, 2000, 4000Hz and Across Ears*

	Audiometer	
uHear	PTA<20	PTA>20
PTA<20	28	0
PTA>20	21	3
Total	49	3

When using the ASHA screening guidelines (ASHA, 1997) of having a threshold greater than 20 dB in either ear at any frequency leading to a failed screening, the screenings lead to different sensitivity and specificity ratings. All 8 of the participants who failed the audiometer screening based on the ASHA guidelines, also failed the uHear screening for a sensitivity of 100% (95% CI = 59.8-100%). Of the 44 participants who passed the audiometer screening, 5 also passed the uHear screening, while 39 failed the uHear screening for a specificity of 11.4% (95% CI = 4.3-25.4%). Table 6 shows these results.

Table 6. *Number of Participants Who Qualified for Each Category Where a Fail is a Threshold Higher Than 20 dB for at Least One Frequency in at Least One Ear.*

	Audiometer	
uHear	Passed Audiometer	Failed Audiometer
Passed uHear	5	0
Failed uHear	39	8
Total	44	8

The uHear with earmuffs condition also showed changes in the sensitivity and specificity levels when examined with the ASHA guidelines. The 8 participants who failed the audiometer also failed the uHear with earmuffs condition resulting in a sensitivity of 100% (95% CI = 59.8-100%). Forty-four participants passed the audiometer and 27 of those also failed the uHear with

earmuffs screening which results in a specificity of 38.6% (95% CI = 24.7-54.5%). Table 7 shows these results.

Table 7. *Number of Participants Who Qualified for Each Category Where a Fail is a Threshold Higher Than 20 dB for at Least One Frequency in at Least One Ear.*

	Audiometer	
uHear + earmuffs	Passed Audiometer	Failed Audiometer
Passed uHear + earmuffs	17	0
Failed uHear + earmuffs	27	8
Total	44	8

Taken together, these results show that across frequencies, there is a difference in the testing results between the audiometer and both conditions of the uHear. Figure 2 summarizes the results of all three conditions. Testing with the audiometer results in significantly lower hearing thresholds than the uHear and the number of participants who failed the screening or had a pure tone average of greater than 20dB increased when screening with the uHear, in both conditions. There was no statistical difference between the thresholds obtained in the two conditions of the uHear, and both conditions had a sensitivity level of 100%. However, the specificity differed between the conditions for both analyses as the uHear with the earmuffs had a higher level of specificity each time. This suggests that the uHear with earmuffs is more likely to correctly identify the children without hearing loss than the uHear app alone but will still produce a large number of false positive findings.

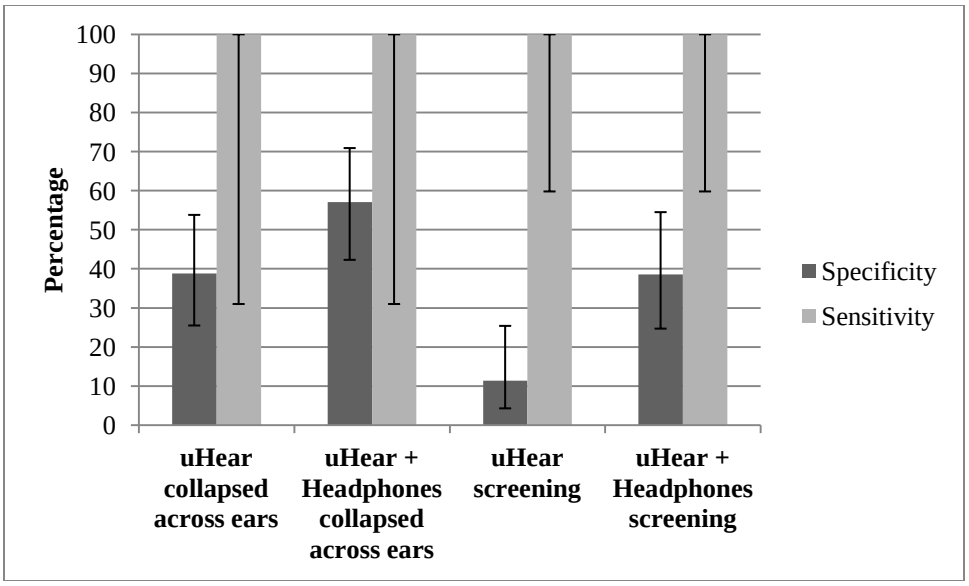

Figure 2. Summary of Specificity and Sensitivity for Each Analysis. The collapsed across ears represents Tables 4 and 5, and the screening represents Tables 6 and 7.

In addition to the differences in hearing thresholds measured, the testing also showed differences between the three conditions in the time taken by participants to complete the testing. The time it took for all the thresholds to be determined was measured, and this did not include instruction time. The uHear app was cited as taking six minutes to complete by Don Hayes (Smaka, 2009). In this study, the audiometer took the least amount of time to complete at 394.7 seconds (394.7 ± 89.9 seconds) or 6 minutes and 35 seconds. The uHear alone took an average of 515.2 seconds (515.2 ± 226.5 seconds) or 8 minutes and 35 seconds, significantly greater than the time taken to complete the audiometer testing ($p<0.01$). The uHear with the earmuffs took an average of 476.2 seconds (476.2 ± 161.1 seconds) or 7 minutes and 56 seconds, also significantly greater than the audiometer testing time ($p<0.01$). These are both greater than the six minutes cited by the creators of the application, however there was not a significant difference between the time taken to complete the screenings with either condition of the uHear ($p=0.14$). The uHear with the earmuffs had the lowest time overall where one participant completed the test in 266

seconds, while the minimum time for uHear alone took a different participant 292 seconds and the audiometer took a minimum of 294 seconds. The audiometer screening took a maximum of 687 seconds, while the uHear had a maximum of 1199 seconds and the uHear with the earmuffs took a maximum of 1036 seconds. The median length of time taken to complete the audiometer assessment was 367.5 seconds, 446 seconds for the uHear, and 433 seconds for the uHear with the earmuffs. These results are shown in Figure 3. Of note is the great degree of variability on the time taken to complete the uHear only condition.

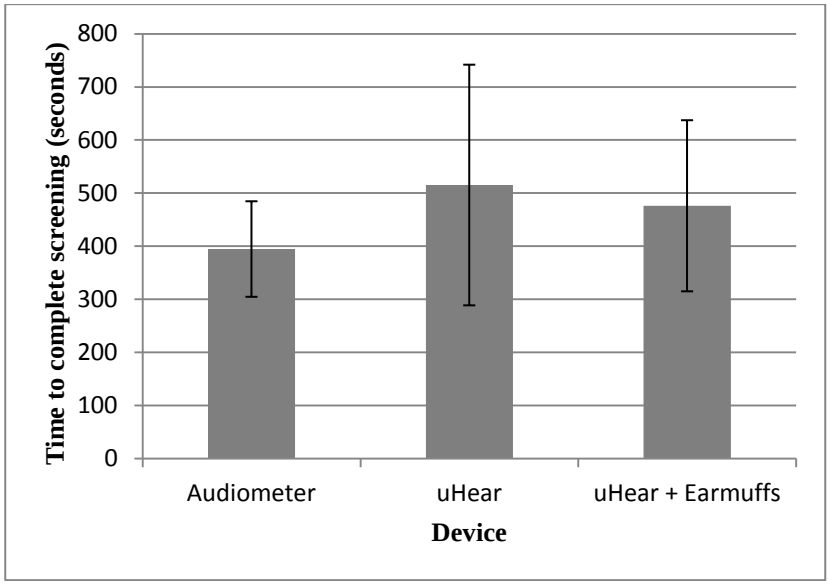

Figure 3. Average Time to Complete the Screening in Seconds for Each Device Plus the Standard Deviation

After testing, the participants were asked which test they preferred. Preferences were closely balanced with 18 participants preferring the uHear with the earmuffs, 16 preferred the audiometer, and 12 preferred the uHear with earbuds only, as shown in Figure 4. This seems to indicate that for a large portion of participants in the study, the touch screen technology was an acceptable method to provide responses.

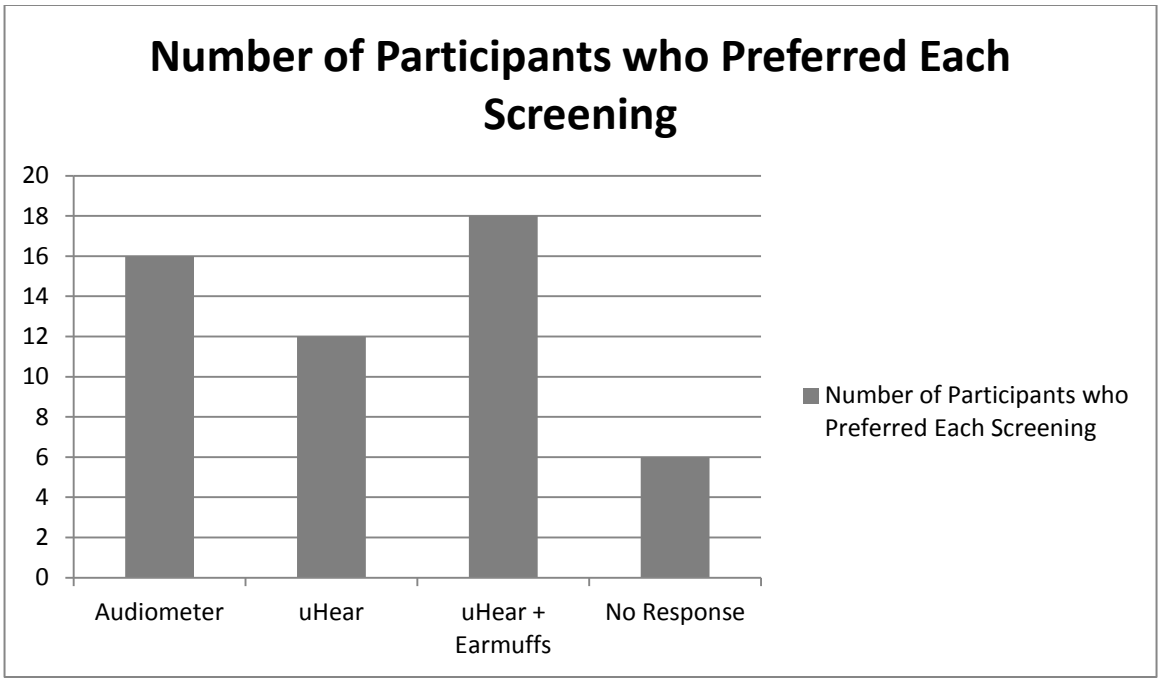

Figure 4. Number of Participants Who Preferred Each Screening Method

A final variable considered with performance on the uHear screening was the age of the participant. The PTA for each participant for each device was calculated by collapsing both ears and the three tested frequencies together to determine one PTA for each device. The difference between the PTA for the audiometer and the uHear PTA and the difference between the audiometer PTA and uHear with noise reducing earmuffs PTA were each calculated. These were each correlated with the age of the participant. As Table 8 shows, there were no significant correlations between age and the differences in PTA suggesting that age is not a predictive factor of success with the uHear alone or with the uHear with noise reducing earmuffs. Figures 5 and 6 show the relationship between age with the PTA differences and confirms the lack of a correlation.

Table 8. *Results of Correlations Between Age and the uHear, and Between Age and the uHear with Noise Reducing Earmuffs*

		Age	uHear – Audiometer	uHearNR - Audiometer
Age	Pearson Correlation	1	-0.141	-0.220
	Significance (2-tailed)		-0.319	0.118
	Age	52	52	52
uHear - Audiometer	Pearson Correlation	-0.141	1	0.238
	Significance (2-tailed)	0.319		0.090
	Age	52	52	52
uHearNR - Audiometer	Pearson Correlation	-0.220	0.238	1
	Significance (2-tailed)	-0.118	0.090	
	Age	52	52	52

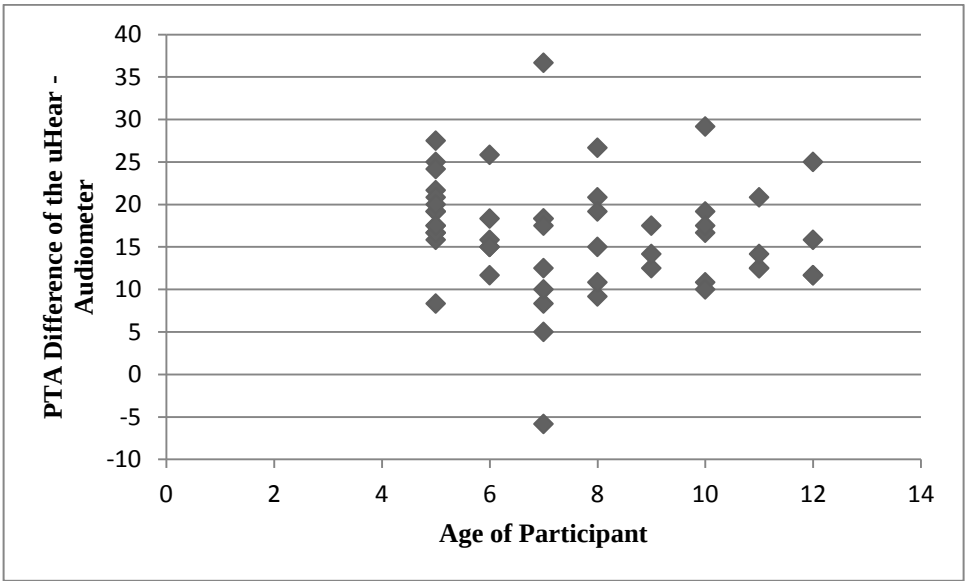

Figure 5. Correlation Between Age and the PTA Difference Between the uHear and the Audiometer

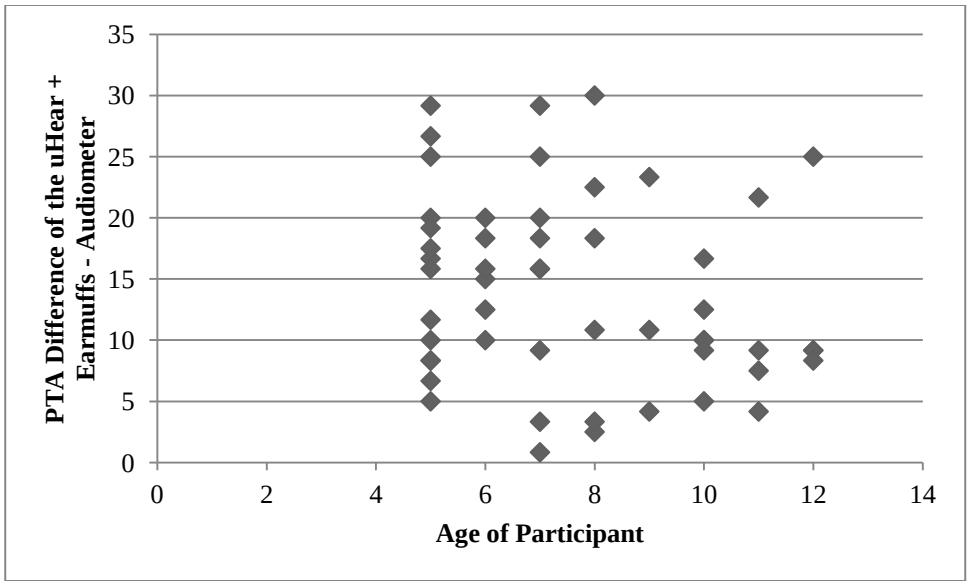

Figure 6. Correlation Between Age and the PTA Difference Between the uHear with Noise Reducing Earmuffs and the Audiometer

Research Question 3

The parent questionnaire showed a general skew towards the higher end of the scale for all questions except for question two, which skewed lower. However, there was also a large standard deviation and range of answers for each question, as seen in Table 9. To determine the possible relationship between areas the parent questionnaire addressed and the results of the hearing tests, correlations were calculated with the rating scale value and the difference in PTA between the uHear and the audiometer. Additionally, correlations were calculated with the rating scale value and the difference in PTA between the uHear with noise reducing earmuffs and the audiometer. PTA for each device was collapsed across the three test frequencies for both ears, resulting in one PTA for each device. As seen in Table 10, the only significant correlation was between question seven and the PTA difference for the uHear with the audiometer ($r = 0.287$, $N = 49$, $p = 0.046$, two-tailed). Question seven addresses a child's ability to hear sounds in their environment and as seen in Figure 7, the correlation is weak. The lack of a relationship between question seven and the PTA difference between the audiometer and uHear with noise reducing

earmuffs suggests that the predictive power lies more with a parent's ability to identify when their child is not hearing everything within their environment and not as a prediction on the child's ability to complete an accurate hearing test with the uHear. The correlation results also show a weak relationship between age and question six ($r = 0.310$, $N = 49$, $p = 0.030$, two-tailed). This suggests that age can weakly predict a child's understanding of louder and softer, however because neither factor predicts performance on the uHear hearing test, these results cannot be extrapolated and used to predict a relationship with the accuracy of the uHear app.

Table 9. *Summary of Results from the Parent Questionnaire*

Question Topic	Average	Standard Deviation	Median	Range
Touch screen use ability	7.74	2.41	8.75	0.15-9.6
Hearing screening experience	2.36	3.13	0.45	0-9.6
Attention to a repetitive task	7.04	1.99	7.6	1.35-9.6
Independent working ability	7.55	1.90	8.1	2.65-9.6
Following directions ability	7.52	1.54	7.9	3.1-9.6
Softer vs. louder knowledge	8.36	1.39	8.8	4.6-9.6
Hearing ability in usual environment	8.47	1.44	8.9	1.75-9.6
Willingness to guess	6.22	2.32	6.25	1.5-9.6
Appropriate response times	8.57	1.12	8.8	4.7-9.6
Typical day	7.15	3.07	8.65	0-9.6

Table 10. *Results of Correlations Between Each Question From the Parent Questionnaire and the uHear, and Between Each Question and the uHear with Noise Reducing Earmuffs*

		Age	uHear - Audiometer	(uHear + Earmuffs) - Audiometer
Question 1	Pearson Correlation	0.188	0.087	-0.058
	Significance (2-tailed)	0.183	0.541	0.682
	Age	52	52	52
Question 2	Pearson Correlation	-0.167	-0.084	0.178
	Significance (2-tailed)	0.235	0.554	0.206
	Age	52	52	52

Question 3	Pearson Correlation	0.210	-0.188	0.050
	Significance (2-tailed)	0.140	0.186	0.725
	Age	52	52	51
Question 4	Pearson Correlation	0.120	-0.230	0.085
	Significance (2-tailed)	0.396	0.101	0.547
	Age	52	52	52
Question 5	Pearson Correlation	0.013	-0.055	0.009
	Significance (2-tailed)	0.928	0.696	0.947
	Age	52	52	52
Question 6	Pearson Correlation	0.310	-0.142	-0.117
	Significance (2-tailed)	0.030	0.330	0.424
	Age	49	49	49
Question 7	Pearson Correlation	0.205	0.287	0.055
	Significance (2-tailed)	0.157	0.046	0.708
	Age	49	49	49
Question 8	Pearson Correlation	0.254	0.065	0.137
	Significance (2-tailed)	0.082	0.663	0.353
	Age	48	48	48
Question 9	Pearson Correlation	0.144	-0.231	-0.253
	Significance (2-tailed)	0.322	0.110	0.080
	Age	49	49	49
Question 10	Pearson Correlation	0.093	-0.216	-0.059
	Significance (2-tailed)	0.528	0.141	0.690
	Age	48	48	48

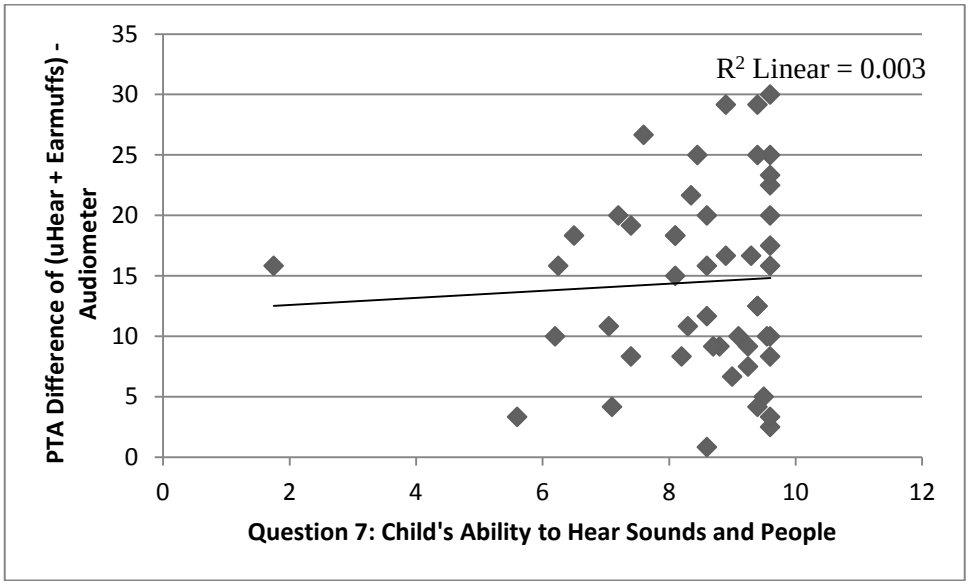

Figure 7. Correlation Between Question 7 and the PTA Difference Between the uHear with Earmuffs and the Audiometer

Discussion

Research Question 1 and 2

The statistical analysis of the audiograms showed the uHear application with and without earmuffs is not currently as accurate as the audiometer at obtaining hearing thresholds for pediatric participants. The uHear testing resulted in significantly higher pure-tone threshold levels and thus would lead to an over-referral of patients if employed as a screening tool for this population. This is preferable to having false negatives and there are some suggestions that over-referral may be a factor of all hearing screening with the school age population (Halloran et al., 2009). The uHear was, however, able to correctly identify all participants who would have been referred to an audiologist based on the results of the audiometer screening. This is consistent with previous studies involving the uHear (Szudek et al., 2012) where the uHear had a high level of sensitivity.

The uHear showed some test-retest reliability as there were no statistical differences between the two conditions of the uHear. This highlights the promise in using the uHear as a screening tool in the clinic as the results are already reliable and there is promise that the validity can be increased (Szudek et al., 2012). This was seen in this study as there were children who did have thresholds below 20dB as measured by the uHear, suggesting that it is possible to measure lower thresholds. The sensitivity is higher in the uHear with the extra noise reduction earmuffs compared to the uHear alone as well a larger number of children preferred the uHear with noise reducing earmuffs. However there was no difference in the time taken to complete the hearing assessment between the two uHear condition and this is not enough information to suggest that the earmuffs impacted children's performance with the uHear application or increased their confidence in their answers.

The limitations of the uHear can be considered within five factors including the device, task, examiner, subject, and environment. These factors relate as to why the uHear was not as sensitive as the audiometer when measuring hearing thresholds. The environment and examiner were held constant during the testing session so it`s not likely that these factor contributed significantly to the differences in accuracy between the uHear and the audiometer. The subject may be a possibility as to why the uHear assessment was failed, however considering the large number of false positives and failed assessments, this may not be the fundamental reason for the differences in accuracy. Therefore, it is more likely that device and task played a part in the different results. The device includes the earbuds and calibration of the iPod while the task may involve the length of the assessment, the frequencies involved, and the nature of the task. There are ways that these can be improved upon, which is addressed in the recommendations section.

In its current state, the uHear application is not an accurate hearing screening tool with children. The results found in this study are similar to those found by Szudek and colleagues (2012), where the uHear application over-estimates the pure-tone threshold in normal-hearing ears. However, the uHear appears to be consistent and more children preferred completing the assessment with the app over the audiometer. The application had features that worked well for the testing and some areas where improvements could be made to increase the accuracy of the assessment and reduce the number of false positives.

Research Question 3

The parent questionnaire results showed that the there were no major correlations between the result differences between the conditions and the parent ratings of the task parameters of the uHear test. As well, with the overall low pass rate, it is likely that the issues with passing the screening are a factor of the app and not a factor of individual characteristics.

The areas addressed in the parent questionnaire do not have predictive power with the uHear results as the only significant correlation can equally be explained as the ability of the parents to notice when their child may not be hearing correctly rather than an ability of the app to identify the children as having hearing loss. In its current form, the parent questionnaire does not allow for a predictive measure to be used to determine if a child has the skills necessary to obtain reliable and valid results.

However, an important trend to consider from the parent questionnaire is the participant's lack of experience with hearing screenings as it was the only question from the parent questionnaire to skew lower on the rating scale. This suggests that the pediatric population is not being properly exposed to hearing testing such that not all children with hearing loss may be identified and receive intervention. This highlights the importance of implementing a hearing screening program with the school-age population as they are currently underexposed to hearing evaluations.

Strengths of the uHear

The participants showed an overall preference for using the app to complete the hearing screening. It allowed the children to have a greater feeling of control over the test as the role of the examiner was minimal. The test was simple for them to complete as the response was limited to touching the screen. Some participants looked for a greater role in completing the test by starting the test themselves and navigating the instructional screens with minimal prompts from the examiner. Other participants had some difficulty with the responses required as they tapped the screen multiple times for each tone; however re-instruction helped them limit their responses to one tap per set of tones. The large size of the button ensured that performance was not impacted by limited fine motor ability or an inability to accurately touch the screen. The touch

screen technology was simple and intuitive for the participants to use to complete the screening and the majority of the participants had previous experience using touch screens. For those whom it was a more novel experience, the touch screen was simple for them to understand and did not impede their performance.

The use of the iPod Touch was also an advantage for the uHear. As the prevalence of Apple iOS products grows, so does their reputation for being a source of entertainment and games. This may have contributed to the participant's interest in using the iPod Touch as children are more interested in completing tasks and learning when games are used as a context for the task (Blumberg, 1998; Sedig, 2008).

The completion bar showing how the percentage of the test completed and the illustrating how many tones were yet to come is another aspect of the app that may have aided the success of the screening as it provided the user a way to mark progress. The creator of the app highlighted the status bar as a way to allow the user to feel as though they are in control of the assessment (Smaka, 2009). The time between tone presentations can test the user's patience and the status bar allows the user a way to mark the passage of time and show that the test is continuing. The completion bar has advantages for both the user and the examiner to help ensure a smooth testing session.

Recommendations for the uHear

While the basic protocols of the uHear app are simple and intuitive, there are some areas which can be improved in a bid to increase the accuracy of the testing with children. The test could improve the accurateness of its measurement of the hearing thresholds, the level of engagement of the participant, and the length of time taken to complete the test. Adjustments to

the protocols and presentation of the test may help to address these issues and transform the app into a valid and reliable screening tool to be used by multiple health professionals.

The accuracy of the test relies on the participant maintaining a constant level of attention and attendance to the tone stimuli for the duration of the assessment which can be anywhere from approximately 4.5 minutes to 20 minutes. It requires participants to actively attend to the stimulus while ignoring other available stimuli for a long period of time (Green & McKewon, 2001). Older children are more successful with these tasks as they are better able to focus on one particular task while ignoring peripheral stimuli than younger children who are not able to disregard irrelevant stimuli which then impacts their performance on the primary task (Vasta, Younger, Adler, Miller, & Ellis, 2009). It has been established that older children are able to sustain attention for longer lengths of time, and in general, all children pay more attention to meaningful activities (Bjorklund, 2005). When children are engaged with the activity, their attention and focus increases which allows for them to complete the task to the best of their ability. To take advantage of this, the uHear app would benefit from being a more motivating task as well more explicitly goal directed. The task is long; therefore subdividing the test visually for the participants would allow for the participants to mark when they have accomplished one goal and their progress through the test, making the assessment more interactive (Sedig, 2008). The completion bar attempts to address this need, however with this population, it may not provide enough motivation or marking of goals. Introducing elements of a game would possibly allow for children to have a more vested interest in paying attention if the goals were clear and they were motivated to achieve them (Blumberg, 1998; Sedig, 2008). Meinke and Dice (2007) posit that it is possible to test hearing within the context of a computer game.

The length of time required to complete the uHear's testing portion also relates to the attention required to complete the test as the longer the test is, the longer the participants must attend to the screening. When looking for ways to improve engagement of the participants, the length of testing must also be considered. The app cites a test length of 6 minutes (Smaka, 2009) however in this study the test took an average of 7 minutes and 56 seconds to 8 minutes and 35 seconds, depending on the condition. This is much longer than the assessment time of three minutes that the assessment recommended by Śliwa and colleagues (2011) took the children to complete. In consideration of the testing length, this study introduced a training portion separate from the uHear to attempt to have participants complete the screening as quickly as they were able. Participants were given a preview of what the tones sounded like using the audiometer. This helped train them to press the button when they heard a similar type of sound and helped focus attention on the sounds that they needed to attend to. However, there were still participants who required more training while completing the screening as they were not progressing through the assessment. These participants were able to complete the screening in a time more comparable to their peers after the extra instruction. The extra training portion of the study made the app dependent on having the audiometer there to complete the testing. If the app was being used alone without the audiometer, a training option built into the app would be beneficial to use with the population involved in this study. Training beforehand ensures that misunderstanding the task does not confound responses and lead to false responses on the actual assessment as the participants may not understand when to indicate that they heard the tone or what the tone that they should be listening for sounds like. When participants are unsure about the task, this can lead to an increased test duration which would then increase fatigue as the longer you persist with a task, the more demands you are making upon yourself and the more resources you are

depleting (Bjorklund, 2005; Śliwa et al., 2011). This can then limit performance on the screening as well, increased screening times lead to fewer screenings being completed (Śliwa et al., 2011).

Related to the lengthy test time and participants spending increased lengths of time on one tone, is the issue of some participants commenting that they could not remember what sound to listen for. While testing, a number of participants forgot the tone and commented to the examiner that they were unsure what to listen for. In this situation, the examiner was unable to assist the participants and the only option was to continue to listen and wait for the decibel level of the tone to increase to a volume that the participant was sure that that was the tone that they were to listen for. The lack of flexibility in the testing protocol of the uHear may have resulted in an increased testing time and it increased the frustration of the participants as they waited to hear the tone again. An option for a reminder tone which have addressed this issue.

In addition to the reminder tone, more flexibility in the testing procedure would allow for the app to be used across a greater number of situations. The app currently tests across six frequencies in both ears using a modified Hughson-Westlake method. This provides a complete assessment of the hearing thresholds, however in some situations, not all the frequencies need to be tested. For example, if the app was to be used as a screener using ASHA's hearing screening guidelines, only three out of the six frequencies would need to be tested and they would not need to be tested below 20dB. This would help shorten the testing time and decrease the demands on the participant, as they would be listening for more audible tones for a shorter length of time. Another instance where screening flexibility would be preferable would be if the concern was noise-induced hearing loss. The addition of being able to screen around the frequency of 3000Hz would be beneficial to specifically address the possible notch of hearing loss (Meinke & Dice, 2007). In addition to the standard hearing testing condition, allowing examiners to use the app to

build their own screener including allowing the choice of which ear, which frequencies, and the decibel range to test would increase the apps relevancy to a broader range of situations. It would also allow for decreased testing time and a more customizable experience for each participant based on their age and skill level.

Limitations of the Study

Although the study aimed to be consistent with screening procedures and create a similar environment to a school, there are some limitations to the study. In particular, there were some problems with the earbuds and the earmuffs. Insert earphones do have an advantage in the environments where there is a higher level of ambient noise, however inserts are not readily available to those outside of the audiological profession (Meinke & Dice, 2007). For this study, we used the standard earbuds that came with the iPod touch. For some of the children, the earbuds were slightly larger than their ears which was an issue when it came time to put on the earmuffs as occasionally the earmuffs would tug on the earbuds, particularly when the children readjusted the earmuffs. In some instances when the earmuffs were readjusted repeatedly, the earbuds were more likely to slip partially out of place. If the earbud was out of place, it would make it more difficult for the participant to hear the tones at their softest level, artificially increasing their hearing thresholds.

The study did not measure the overall time to complete the assessment including the instructional time which would have provided clinically relevant information. The overall length of assessment would have shed light on whether the uHear has the possibility to decrease the time of assessment compared to the audiometer or if it stays the same. There were some difficulties with measuring the overall assessment time as some participants were able to watch others do the assessment first which meant that when it was their turn, they had already been

partially trained and their training portion would be shorter. Future studies should consider the impact of training time on the performance with the uHear application.

The testing environment was also a limitation in the study as the treatment rooms were quiet but not sound dampening. There were some background mechanical noises and occasional noise from people in the hallways or the other family members of the child being tested which would increase the noise levels of the testing environment, however this was consistent for all the testing conditions. The majority of the noises were transient in nature (e.g., a door of another room closing) and were not present for the entirety of testing. Because the aim of the study was to consider screening methods appropriate for schools, the imperfect environment is representative of schools. The difficulty of the testing environment is that it may mask the lower frequencies when there is mechanical noise and all frequencies may be masked at the lower decibel levels, which may lead to artificially raised threshold levels (Meinke & Dice, 2007). This is a trade-off that must be considered when looking at hearing screening within the school setting as few schools have access to a sound dampening room. In these situations, a quiet room may be the best location available for the hearing screening.

The study was designed to reduce the number of times that a participant had to return to complete this study. In our study design, participants only had to come in for one session to participate in the study and they completed all three hearing screenings at this session. This may have lead to some fatigue as the tasks were repetitive and similar, which may have lead to decreasing focus and attention on the task as the study continued. To address this potential issue, the participants' order of completion of screenings was randomized. No adverse effects on the results were noted during the session or in the analysis that would suggest that the length of the

session negatively impacted the results, however it is important to consider that this may have implications for the study results.

A final limitation for the study was the population. The children involved in the study were typically developing with no known neurological delays and had English as their first language. When looking to expand the screening with the uHear, there may be difficulty with populations who have less attention than the typically developing population or less understanding of responding appropriately in an appropriate length of time. Before the uHear could be used with a broader range of populations, there should be further study on the success of the uHear (or more likely a similar, but more child-friendly app) with a variety of specific populations.

Conclusion

Currently there is a lack of standardized, consistent screening programs for hearing within the health system. This can be seen in the results of the parent questionnaire where the majority of the participants had limited experience with hearing screenings as rated by their parents. When informally asked during testing if the participant had ever had their hearing tested, the majority of children responded in the negative. Because school age is a time of increasing educational and auditory demands, a standardized program would be beneficial (Sekhar et al., 2011). The use of automated audiology may help meet this need as it reduces the demand on audiologists while allowing for a standardized protocol (Swanepoel et al., 2010).

The uHear offers a low-cost option for an automated audiological tool as the app is free and requires only an iPod or other similar Apple^{TM} product to run. The results of the parent questionnaire show that there is interest in using the touch screen technology that the iPod Touch uses from the children which complements the idea of using a software application as a way to

screen the hearing of more children more efficiently. The participants were positive about their experiences with the uHear and the majority showed a preference for using the iPod Touch for the screening, however in its current form, the uHear is not accurate enough for use as a screening tool. There were some areas of the app that could be improved upon to help increase the reliability and accuracy of the thresholds detected. If the app's accuracy was increased with this population, it could serve as a way to implement a structured hearing screening program within the schools, which could then provide a platform to increase awareness about hearing loss and hearing health. At this point, an application-based automated screening device shows potential for inclusion in a school-aged screening protocol; however, in its current form, the uHear does not yet have the accuracy to be used. Future work should focus on the development of a more child-focused hearing-screening app with accuracy that matches the screening audiometer of today.

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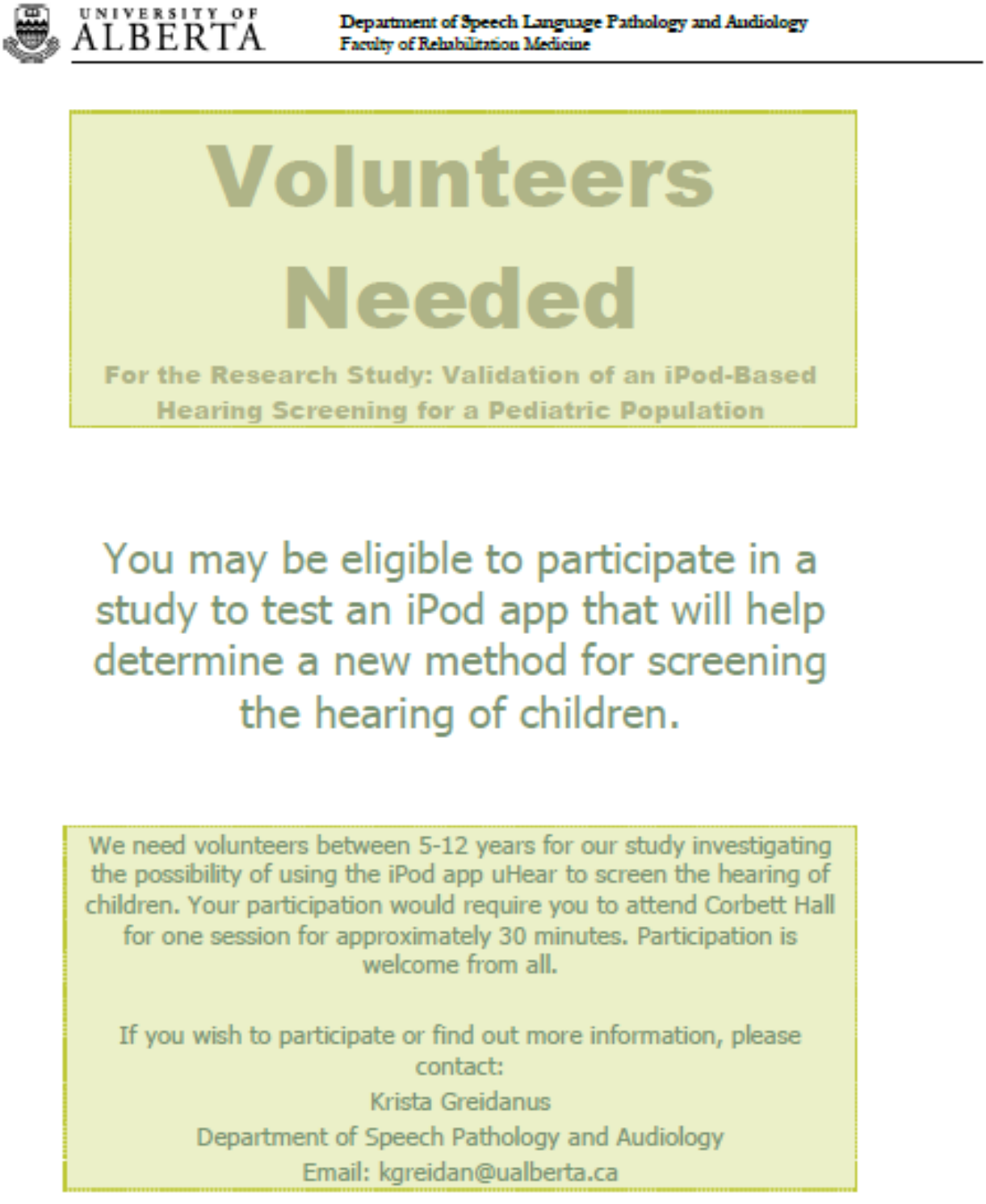
Appendices

Appendix A: Recruitment Poster



Appendix B: Information Letter

Information for Participants

Title: *Validation of an iPod-based Hearing Screening for a Pediatric Population*

Name of Principal Investigators:	Krista Greidanus
Co-Investigator:	William Hodgetts
Location:	University of Alberta

Overview
You and your child are invited to take part in a study that will help see if there is new method for screening the hearing of children.

Background
At times in the school setting is may be helpful to screen a child's hearing. This is often done by a Speech Language Pathologist using a portable audiometer. It would be helpful to find new ways to complete this hearing screening that are more available and less costly.

Apple® products including the iPod, iPhone, and iPad, have become widely available over the last 5 years. Many applications have been created for these products. One of these apps is uHear, which allows for hearing to be screened using the iDevice and standard earphones. This app is the one involved in this study. During the session, the child will use an iDevice and earmuffs to follow the instructions given by the app. To make responses, the child touches the screen. The test is similar to the screening by the speech language pathologist.

Objective
The goal of this study is to determine whether or not the uHear app can be used to accurately screen a child's hearing.

As part of this study, one session lasting approximately 30 minutes is required. If you and your child agree to participate, this session will include:

1) One hearing screening done using a portable audiometer. The researcher will administer this test. The child will be required to respond to a tone sound. They will raise their hand when they hear the tone.
2) Two hearing screenings will be done using an iDevice and the uHear app. One screening with standard earbud earmuffs and one with noise cancelling earmuffs. The child will follow the prompts of the app and touch the screen when they hear the tone.
3) You will be asked to complete a short questionnaire during the testing. This will ask questions related to the child's experiences and behavior and take less than 10 minutes.

Associated Risks
There are no known associated risks with the portable audiometer or with the uHear application. It may be that we discover a potential hearing loss that was unknown. If that is the case the researchers will contact you promptly to discuss the findings and work with you to find further diagnostic testing options. If no unusual findings occur, you will not be contacted.

Your Participation
Participation in this study is voluntary. You or your child may choose not to participate, refuse to answer any questions, or withdraw at any time. You do not have to explain your decision.

Confidentiality
All information will be held confidential or private. The information you give will be kept for five years following the end of the study. The information will be kept in a secure area (i.e. locked filing cabinet). Your name or any other identifying information will not be attached to the information you give. Your name will not be used in any presentations or reports related to the study results.

Additional Information
If you have any questions before, during or after this study, please contact Krista Greidanus at the address below.

Thank You.

Contact

Krista Greidanus
University of Alberta
Phone: (780) 934-7151
Email: kgreidan@ualberta.ca

Bill Hodgetts, PhD, R(Aud).
Assistant Professor, U of A, iRSM
2-16 Corbett Hall,
Edmonton AB T6G 1G1
Phone: (780) 492-0834
Fax: (780) 492-9333
Email: bill.hodgetts@ualberta.ca

Additional Contacts

If you have any concerns about any aspect of this study, you may contact the Health Research Ethics Office at the University of Alberta at (780) 492-2615. This office has no affiliation with this study or its investigator(s).

Appendix C: Assent Form

UNIVERSITY OF ALBERTA

CONSENT FORM

Title of Project: *Validation of an iPod-Based Hearing Screening for a Pediatric Population*

Investigator: *Krista Greidanus* **Phone Number:** ***780-934-7151***
Supervisor: *Bill Hodgetts, PhD*

We are doing a study to look at testing hearing. We would like to do three listening activities. One activity will be with the audiometer. The other two activities will use an iDevice.

Your parents know that I am asking you to do these activities. They have said that you can be in the study.

You don't have to be in this study. It is up to you. You can say no if you don't want to do this. If you say yes and then change your mind that is ok. You can stop at any time. You just need to tell us.

Would you like to be in this research study?

☐ **Yes I will be in this research study**

☐ **No I do not want to be in this research study**

Signature _____ Date _____

(Printed Name) _____

Signature of Investigator or Designee _____ Date _____

(Printed Name) _____

Who explained this study to you? _____

Appendix D: Consent Form

U N I V E R S I T Y O F A L B E R T A

CONSENT FORM

Title of Project: *Validation of an iPod-Based Hearing Screening for a Pediatric Population*

Investigator: *Krista Greidanus* **Phone Number:** ***780-934-7151***
Supervisor: *Bill Hodgetts, PhD*

	Yes	**No**
Do you understand that you have been asked to participate in a research study?	□	□
Have you read and received a copy of the attached Information Letter?	□	□
Do you understand the benefits and risks involved in taking part in this research study?	□	□
Have you had an opportunity to ask questions and discuss this study?	□	□
Do you understand that you are free to withdraw from the study at any time, without having to give a reason?	□	□
Do you understand that your participation in this study is confidential and your data will not be linked to your name in any way?	□	□
Do you understand who will have access to your records/information?	□	□

Who explained this study to you? _____

I agree to take part in this study: YES □ NO □

I give permission for my child to participate: YES □ NO □

Signature _____ Date _____

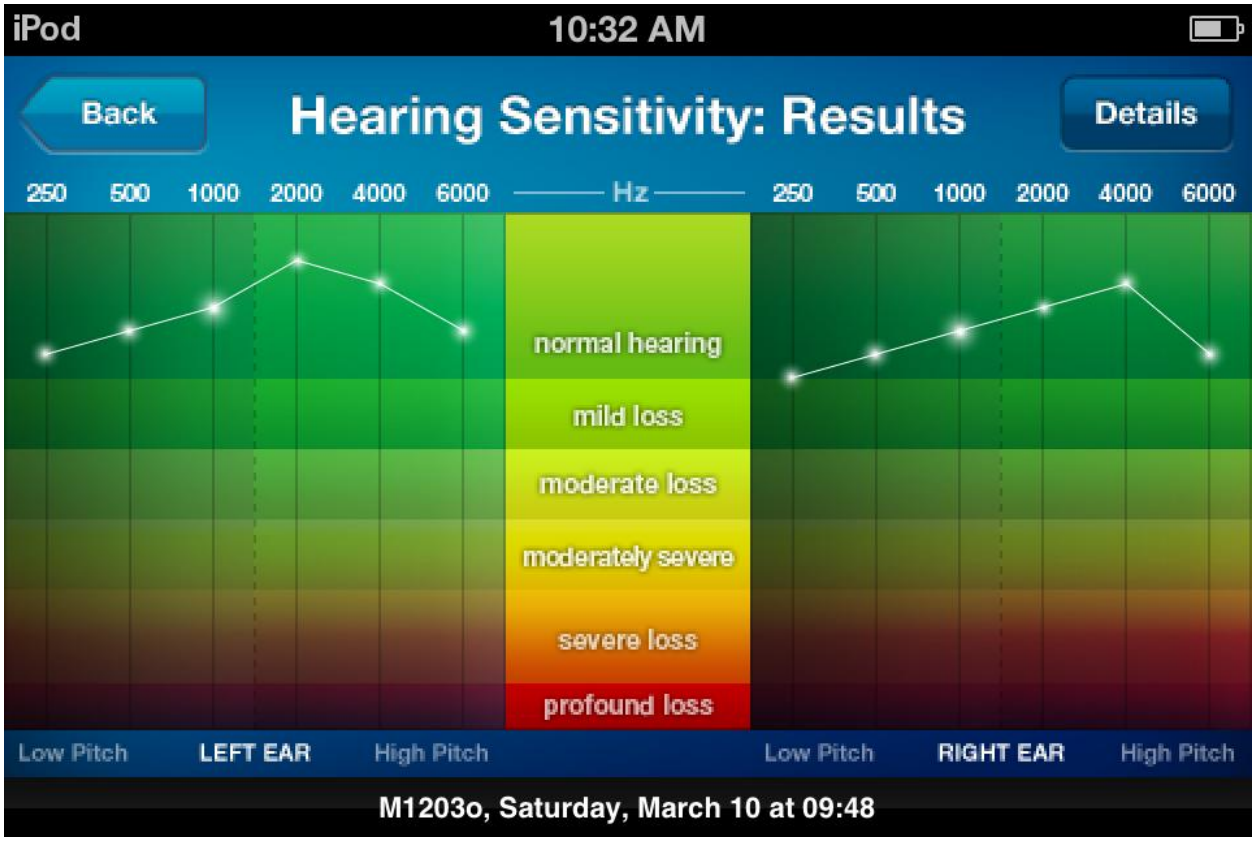
(Printed Name) _____ Phone Number: _____

Signature of Investigator or Designee _____ Date _____

(Printed Name) _____

Appendix E: Screen Capture of uHear

Appendix F: Sample Audiogram from the uHear



Appendix G: Parent Questionnaire

Hearing Screening Questionnaire for Parents

Please read the following questions and make a mark on the scale where you feel best answers the questions.

1. Rate your child's ability to use touch screen ability.

No previous experience — Very skilled

Comments:

2. Rate your child's experience with hearing screenings.

No previous experience — Very skilled

Comments:

3. Rate your child's ability to pay attention to a repetitive task compared to others their age.

Less skilled — Very skilled

Comments:

4. Rate your child's ability to work independently.

Less skilled — Very skilled

Comments:

5. Rate your child's ability to follow directions that are spoken out loud.

Comments:

_____

_____

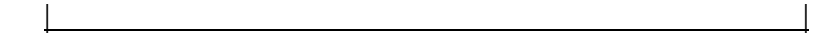
6. Rate your child's understanding of the difference between softer and louder.

Comments:

_____

_____

7. Rate your child's ability to hear the sounds and people around them.

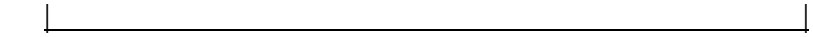


Comments:

_____

_____

8. Rate your child's willingness to guess what the answer may be even if they are unsure.



Comments:

_____

_____

9. Rate your child's ability to make a response (i.e. push a button) in an appropriate length of time.

Less skilled — Very skilled

Comments:

10. Rate how typical this day is for your child regarding amount of sleep, energy, attention, etc.

Less typical — Very typical

Comments: