Tablet Audiometry in Canada’s North: A Portable and Efficient Method for Hearing Screening

Ryan Rourke, MD, FRCSC1, David Chan Chun Kong2, and Matthew Bromwich, MD, FRCSC1

Abstract

Background. Access to hearing health care is limited in many parts of the world, creating a lack of prompt diagnosis, which further complicates treatment. The use of portable audiometry for hearing loss testing can improve access to diagnostics in marginalized populations. Our study objectives were twofold: (1) to determine the prevalence of hearing loss in children aged 4 to 11 years in Iqaluit, Nunavut, and (2) to test and demonstrate the use of our tablet audiometer as a portable hearing-testing device in a remote location.

Study Design. Prospective cross-sectional observational.

Setting. Remote elementary schools in 3 Canadian Northern communities.

Subjects and Methods. Tablet audiometers were used to test hearing in 218 children. Air conduction pure tones thresholds were obtained at 500, 1000, 2000, and 4000 Hz. Children with hearing loss ≥30 dB in either ear were referred for audiology services.

Results. Tablet audiology screening testing revealed abnormal results in 14.8% of the study participants. No significant difference in the rate of hearing loss was seen by sex; however, the rate of hearing loss decreased significantly with increasing age. The median duration of the hearing test was 5 minutes 30 seconds.

Conclusions. Of the study population, 14.8% tested positive for hearing loss based on our interactive tablet audiometer. In this setting, the tablet audiometer was both time efficient and largely language independent. This type of testing is valuable for providing much-needed hearing health care for high-risk populations in rural and remote areas where audiology services are often unavailable.

Keywords

hearing loss, screening audiometry, prevalence, population based, tablet audiometry, ShoeBOX audiometry, portable audiometer, mHealth, digital health, rural, remote, hearing test, hearing testing

Received March 3, 2016; revised March 18, 2016; accepted March 23, 2016.

Hearing plays a critical role in the development of receptive and expressive communication skills in children. Undiagnosed hearing impairment interferes with normal social, emotional, and cognitive maturation, which can lead to poor academic achievement, low self-esteem, and behavioral issues. The World Health Organization estimates that 32 million children live with disabling hearing loss. In addition, early detection and intervention may provide profound benefits, including better scholastic performance and higher earning potential. Canadian Aboriginal children are at particularly high risk of developing hearing loss due to factors such as lifestyle, genetic predisposition, and geographic remoteness from large medical facilities.

Conditioned play audiometry (CPA) is the recognized standard approach to test the hearing of children aged 2 to 5 years. Although the hearing-testing technique for children >5 years old is usually the same as for adults, CPA can also be used and is better suited for an automated screening, as it helps maintain engagement. Developing countries, as well as regions in rural and Northern Canada, have limited access to the audiologists and facilities required for traditional CPA; thus, accurate, cost-effective, and user-friendly alternatives are desirable.

Tablet computers present an inexpensive portable medium to perform interactive tests such as CPA. Our team recently developed a tablet application, the Pediatric Automated Mobile Play Audiometer, which enables children to perform

1Children’s Hospital of Eastern Ontario, Ottawa, Canada
2Faculty of Medicine, University of Ottawa, Ottawa, Canada

Corresponding Author:
Matthew Bromwich, Division of Otolaryngology – Head and Neck Surgery, Children’s Hospital of Eastern Ontario, 401 Smyth Road, Ottawa, ON K1H 8L1, Canada.
Email: mbromwich@cheo.on.ca
their own hearing test by engaging in an interactive “forced-choice paradigm” game on a tablet (iPad; Apple Inc, Cupertino, California). In a previously published study validating the technique, the tablet audiometer demonstrated high sensitivity (93.3%), specificity (94.5%), and negative predictive value (98.1%) when conducted in a controlled soundproof booth environment. The device has subsequently become commercially available (ShoeBOX Audiometer; Clearwater Clinical Limited, Ottawa, Canada). A group at the Mayo Clinic recently externally validated the ShoeBOX Audiometer as a pure tone air conduction hearing test by comparing automated thresholds outside a sound booth against conventional audiometry thresholds measured inside a sound booth. In this clinical population, sensitivity and specificity were reported to be 90.0% and 88.9%, respectively. The ShoeBOX Audiometer is an interactive testing method calibrated with standard audiometric equipment to meet American National Standards Institute S3.1 and S3.6 standards and is both Health Canada and Food and Drug Administration listed. Tablet audiometry is especially well suited to remote and rural areas as in Canada’s Northern communities, where hearing health care is not easily accessible.

Our study objectives were twofold: (1) to determine the prevalence of hearing loss in children aged 4 to 11 years in Iqaluit, Nunavut, and (2) to test and demonstrate the use of our tablet audiometer as a portable hearing-screening device in a remote location.

Materials and Methods

Setting and Population

Hearing testing was performed with the interactive tablet audiometer on 218 children, aged 4 to 11 years, attending elementary school in Iqaluit, Nunavut. The testing was performed over a 4-day period during the winter months of 2014 in the libraries of Nakasuk School, Joamie Ilinniaruik School, and Nanook School. This community was chosen for its known high rate of middle ear disease and conductive hearing loss in children as well as its remote location. Children were excluded from the study if they had a cognitive or physical delay that rendered them unable to understand or physically use the tablet audiometer. Informed consent was obtained from the parents or guardians of eligible children, and the children themselves signed assent forms in their language of choice.

Tablet-Based Audiometry

Our automated play audiometer application is a tablet computer game where the user is tasked with sorting different icon objects according to whether they produce a sound or are silent (Figure 1). The game is largely language independent, as there are no verbal or written descriptions inherent to it; rather, feedback is represented visually during the game. We have observed the game to be simple yet engaging. Each object produces a unique tone at 500, 1000, 2000, or 4000 Hz. The child performs several iterations where the intensity of sound is decreased until it is inaudible and the child sorts the objects as silent. The intensity is then increased via the modified Hughson-Westlake method in an up-down fashion until the true threshold can be correctly determined. Outside a sound booth, the lowest test level is set at 15 dB to avoid excess false positives, but it can be set as high as 20, 25, or 30 dB, depending on the background noise. As a control, several silent objects are randomly included to ensure that the child is not sorting the objects incorrectly. During the testing, there is continuous frequency-specific background noise monitoring in place. Background noise is monitored in a 1/8-octave frequency-specific manner at the moment of sound administration. The tablet’s microphone is calibrated against a standard field sound-level meter. The American National Standards Institute–published maximum permissible ambient noise levels and the attenuation characteristics of the headphones are used to calculate the apparent background noise level at the ear. If the frequency-specific background level exceeds that of the test frequency during sound administration, then an exception is generated. However, if the patient’s response is within a normal screening threshold despite the background noise, the test continues. If the patient’s response is outside a normal threshold at a certain frequency during an exception, that test frequency is marked as being confounded by background noise. Once all frequencies are tested, a standard audiogram is generated and stored on the application, which can later be forwarded to an expert as a PDF.

Study Design

A cross-sectional study design was used. After a brief otoscopic examination, an otolaryngology resident from the University of Ottawa and a school official instructed the students on how to complete the activities for the hearing testing. Tympanometry was not available at the remote loca-
tions and was not conducted as part of screening. The hearing testing was performed with our tablet audiometer application through a tablet computer and TDH-39 audiometry headphones in the school library. The tablets were later transported to the Children’s Hospital of Eastern Ontario (Ottawa, Canada), where the audiograms were reviewed by both the otolaryngology resident and a pediatric otolaryngologist. The children who were determined to have hearing loss based on the tablet hearing test were referred for traditional audiometry and, in some cases, to an otolaryngologist for further medical follow-up.

The study was financially supported by a grant from the Grand Challenges Canada–Stars in Global Health competition. A Nunavut medical research license was issued (license 01 003 14N-M), and this study was approved in full by the Children’s Hospital of Eastern Ontario Research Ethics board (protocol 12/165x).

Outcome Measures

Pure tone air conduction audiometry was conducted on all children through our application on a calibrated device. The children were defined to have hearing loss if any of the hearing thresholds—obtained at 500, 1000, 2000, and 4000 Hz—was ≥30 dB in any frequency in one or both ears. The differences in hearing loss between ages and sex were compared. The time until hearing test completion was also measured, and differences by age were examined. Middle ear fluid was not treated as an outcome measure, as no tympanometry was available and otoscopy was conducted by trainees.

Statistical Analysis

Sample size was based on a desired margin of error in the estimate of prevalence of ±5%. The assumed prevalence of hearing loss was 20% based on previous studies with similar populations. Since the target population was children aged 4 to 11 years in Nunavut (5213 children, per census data), a finite population correction was also used (though it was almost negligible). With these assumptions, the targeted sample size was 235. All statistical analyses were independently conducted with IBM SPSS 22.0, based on \( P < .05 \), to determine statistical significance.

Results

Although a large proportion of the participants did not speak English, all eligible children were able to understand and perform the testing, regardless of their primary language, although not all completed the testing. A total of 218 children were tested, ranging in age from 4 to 11 years old. Nine children were excluded from the analysis; 6 had developmental delay; and 3 were not able to complete the test due to behavioral issues. Therefore, 209 reliable tests were included in the analysis. Of the 209 reliable tests, 15.3% (n = 32) identified a hearing loss (≥30 dB) via the tablet audiometer. The majority of hearing loss was found to be mild in severity and to present at a low frequency, namely 500 Hz (Table 1). Background noise was identified by the tablet application as a confounding factor in 3 of these 32 abnormal tests, although in 2 cases hearing loss was still present even when eventual booth testing was performed.

Prevalence of Hearing Loss by Age and Sex

Overall, there was a significant decrease in positive identification of hearing loss (≥30 dB) with increasing age until 10 years (\( P = .018; \) Table 2). The general trend showed a decrease in apparent hearing loss from children 5 years (33.3%) to 9 years of age (9.4%), with the prevalence then slightly increasing to 15.1% in children 10 years of age.
in 10 children, 2 of whom had background noise as a factor during initial screening, but it did not affect the eventual diagnosis. Twelve were subsequently now found to have normal hearing.

**Discussion**

This study took place in Iqaluit, Nunavut, where 60% of the population is of Inuit origin. It was previously demonstrated that Inuit children have a higher prevalence of hearing loss than that of the general Canadian population. Baxter found that >30% of Inuit students of Baffin Island, Nunavut, suffered from chronic otitis media with conductive hearing loss. In sharp contrast, the prevalence of unilateral or bilateral conductive hearing loss (>25 dB) in American children and adolescents from the general population is only 3.1%. Although no large population studies exist and no current studies have been conducted in this field, a similar prevalence among Canadian children is expected.

The etiology for hearing loss in Canada’s Northern population is likely to be multifactorial. Poor access to health care, social crowding, lower socioeconomic status, poor nutrition, increased indoor air pollution, and higher rates of household smoking all predispose children to middle ear disease. Another consideration is that Aboriginal populations have craniofacial differences that are associated with eustachian tube dysfunction and chronic middle ear disease.

In this study, the tablet audiometer was able to test the participants in as few as 193 seconds (3 minutes 13 seconds). This longer average duration as compared with our previously published work may be due to the higher incidence of hearing loss, which takes longer to test. Since the tablet audiometer test is self-directed, it allows for multiple children, each with one’s own tablet, to be tested simultaneously. In 4 days, our 2-person study team was able to test 218 children with 3 tablets. Tablet audiometry has the potential to decrease the workload of audiologists working in this Northern community and to allow them to direct their efforts toward children who have abnormal test results.

**Limitations**

Several study limitations should be considered in the interpretation of our results. High levels of background noise can cause false-positive hearing test results. In particular, the majority of the apparent false positives were at mild presentation levels and were found at 500 Hz. Excluding this frequency in a screening setting may further mitigate the risk of false positives. Furthermore, setting the “abnormal” threshold for 500 Hz at a higher level, such as 25 or 30 dB, would further eliminate background noise–related false positives, but doing so runs the risk of missing mild low-frequency hearing loss. Clearly, background noise is less important in actual cases of hearing loss, as it becomes a smaller fraction of the test signal as the test volume increases. The current background noise–monitoring system is calibrated but not yet independently validated for clinical purposes; nevertheless, it is useful in screening situations. In our study, background noise had an effect on 6 cases when

**Table 2.** Duration of test by age.

(Duration of Test)

Overall, the median time to completion was 332 seconds. This duration was partially used as a measure of reliability (range: 193-1101 seconds)—approximately 5 minutes 30 seconds (**Figure 2**). There was a statistically significant inverse relationship between the duration of the test and the age of the participant for ages 5 to 10 years \(P = .008\). Ironically, the fastest time recorded in this study was 193 seconds (3 minutes 13 seconds), by a child 10 years of age, as was the slowest time of 1101 seconds (18 minutes 21 seconds). For each additional year of age, the average duration to complete the test was 15 seconds less, as older children appear to be faster at performing the hearing test (**Figure 2**).

**Follow-up**

Most participants found to have hearing loss followed up with an audiologist for formal retesting in a sound booth. Of the 32 participants found to have hearing loss, 22 participants were assessed by standard sound booth audiometry testing within 4 weeks after the initial test. The remaining 10 participants were lost to follow-up, as they failed to attend clinic testing and did not return phone calls; however, we are continuing to attempt to contact them to determine reasons for lack of follow-up. One subject who was lost to follow-up may have been a false positive due to background noise that was reported on the tablet during his initial testing. When we accounted for this possible false positive, the corrected prevalence was 14.8% \((n = 31)\). Of the 22 who did attend follow-up, conductive hearing loss was confirmed
standard audiometric supra-aural headphones were used, despite the library setting. Three of these cases were in the group of 9 students who were excluded because of failure to complete the test, owing to attention difficulty, and as a result did not influence the prevalence calculation. Two others in the group who tested positive for hearing loss and who did attend follow-up later had hearing loss confirmed. This leaves only 1 reported case where background noise may have created a false positive. This case was excluded from the reported number of children who screened positive for hearing loss, to avoid falsely exaggerating the apparent prevalence.

There is debate in the literature regarding what cutoff hearing level should be used in a hearing-screening setting. After careful consideration, we chose ≥30 dB in any 1 frequency to be indicative of significant hearing loss and thus accepted 25 dB to be a normal result. Future studies could consider using different cutoff values or noise-excluding headphones. We also recognize that our testing was not always conducted in a suitably quiet room, and without noise attenuation headphones, our results may not represent a true prevalence of hearing loss in this population. However, other studies of clinical populations conducted outside a sound booth have been demonstrated to be reliable.6

The somewhat delayed timing of the follow-up test proved to be a major limitation of our study. A variety of factors contributed to the loss of patients, including long travel times in the North, availability of audiology, and a possible lack of parental willingness to follow up. We were pleased from a medical care standpoint that the follow-up hearing testing for participants with hearing loss occurred within 4 weeks of the screening test. It is important to note that the most common etiology of hearing loss in children is middle ear fluid, which fluctuates over time. Furthermore, it was not logistically feasible to follow up with these participants on the same day of hearing screening. Hence, although we were able to calculate a positive predictive value (45.5%), this is likely affected in turn by the lack of complete follow-up, by the delay in diagnostic testing (which provided time for a change in hearing status), and partially by background noise at 500 Hz. In previous studies, when standard audiometry was conducted immediately after tablet audiometry, the sensitivity was calculated to be as high as 90.0% to 93.3%, with a positive predictive value of 82.3% with and without a sound booth.3,6 Given the nature of hearing testing, one could expect the same result across populations, but we have not yet verified this assumption. However, the value of testing devices outside clinical settings should not be underestimated. It should be noted that the newborn hearing-screening test has a positive predictive value generally accepted to be around 6.7%.10,11 A closer comparison would be that from McPherson et al, who found a similar positive predictive value of 5.6% (95% confidence interval: 4.5%-6.7%) when using automated computer systems for screening children outside the sound booth.12 Technology and techniques to mitigate the impact of background noise are the subject of active investigation.

Through our sample size calculation, we determined a target study population of 235 participants. Due to time constraints, we tested 218 children with the tablet audiometer and fell just short of this goal.

Although this type of testing can be used for the majority of children, it is important to keep in mind that certain patients may not be suitable for tablet hearing screening, such as those with physical and/or cognitive delays, as these children and other children at high risk of hearing loss (children with craniofacial syndromes, cleft palate, etc) should be seen directly by an audiologist for assessment.

Conclusion

After an accounting for possible false positives due to noise, 14.8% of our study population in Iqaluit, Nunavut, tested positive for hearing loss. In this study, we have demonstrated the practical and efficient use of this device in a remote community where children are at high risk of hearing loss. We believe that this device can benefit the hearing health care of children in rural and remote communities through early detection and implementation of medical and surgical management strategies, enabling these children to continue to develop normally and better achieve their potential. Broader use of such a hearing-testing device could have a meaningful impact on the economic burden of hearing loss on the Canadian health care system. Formal cost-benefit analysis is currently in progress, as is comparison with other testing devices. Further validation and evaluation of the tablet audiometer are also underway in various rural and remote settings in Canada and Uganda as well as in larger school boards in Canadian and American cities.

Acknowledgments

We thank and acknowledge the following individuals for their contribution to this study: Kimberly Hurley—audiologist, Iqaluit, Nunavut; Deepi Reddy and Nick Barrowman—CHEO Research Institute; Nancy Singoorie—translation services; principals, teaching assistants, and teachers at Nakasuk, Joamie, and Nanook schools.

Author Contributions

Ryan Rourke, data analysis, drafting, final approval, accountability for all aspects of the work; David Chan Chun Kong, data analysis, drafting, final approval, accountability for all aspects of the work; Matthew Bromwich, design, data analysis, drafting, final approval, accountability for all aspects of the work.

Disclosures

Competing interests: Matthew Bromwich, Clearwater Clinical Limited—inventor of the audiometer device under study, patent holder, shareholder.

Sponsorships: None.

Funding source: Grand Challenges Canada, no role in study other than grant funding.
References


