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Is there a clinical application for tablet-based automated audiometry in children?☆

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ABSTRACT

Introduction: Recent research supports the clinical use of automated audiometry for pediatric hearing screenings. However, very few studies have tested whether tablet-based automated audiometry can offer a valid alternative to traditional manual audiometry for estimation of hearing thresholds in children. This study examined the validity and efficiency of automated audiometry in school-aged children.
Methods: Hearing thresholds for 0.5, 1, 2, 4, 6, and 8 kHz were collected in 32 children ages 6–12 years using standard audiometry and tablet-based automated audiometry in a soundproof booth. Test administration time, test preference, and medical history were also collected.
Results: Results exhibited that the majority (67%) of threshold differences between automated and standard were within the clinically acceptable range (10 dB). The threshold difference between the two tests showed that automated audiometry thresholds were higher by 12 dB in 6-year-olds, 7 dB in 7- to 9-year-olds, and 3 dB in 10- to 12-year-olds. In addition, test administration times were similar, such that standard audiometry took an average of 12.3 min and automated audiometry took 11.9 min.
Conclusions: These results support the use of tablet-based automated audiometry in children from ages 7–12 years. However, the results suggest that the clinical use of at least some types of tablet-based automated audiometry may not be feasible in children 6 years of age.

1. Introduction

Approximately 15% of school-aged children in the United States have some form of hearing loss [1]. Hearing loss can negatively impact a child's speech and language development [2], social-emotional well-being, and academic and vocational success. Early identification of hearing loss through hearing tests is crucial to a child's development [1]. Typically, behavioral hearing tests are performed in a soundproof booth by an audiologist using standard manual audiometry.

Audiologic care is limited in small clinics, educational settings, rural environments, and low socioeconomic communities, which restricts access to hearing tests for some populations. However, within the last few years, tablet-based automated audiometry options have been released in an attempt to facilitate hearing testing outside of common soundproof audiology booths to reach out to various populations and allow individuals to test their hearing on a portable tablet device without the need of hearing health care professionals for the screening phase. The tablet-based automated audiometry apps automatically administer pure tones of different frequencies and intensities to identify hearing thresholds. Unlike conventional audiometry, the tablet apps do not require individuals to test in a professional audiometry booth with a trained audiologist as long as the guidelines in terms of environment and protocols are respected. Because it ideally does not require a soundproof audiology booth, tablet-based automated audiometry is less expensive than conventional audiometry, which could increase access to hearing tests in areas with fewer resources. In addition to the apps'

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mobility and flexibility, the tablet-based tests often resemble a game, potentially helping children who have difficulty attending to conventional hearing tests. Currently, there are multiple automated audiometry apps available, but only a few apps such as SHOEBOX (Clearwater Clinical Ltd., Ottawa, ON, CA), [3–5], hearScreen, (hearX, Pretoria, South Africa) [6], uHear, (unitron, Kitchenen, ON, CA) [7,8], and EarTrumpet (GitHub, San Francisco, CA) [9] have reported their test validity in scientific journals. Not all of these tests are available on the same platform or approved by the U. S. Food and Drug Administration (FDA). For example, SHOEBOX, EarTrumpet and uHear run under Apple devices, whereas hearScreen is an Android based app. Not all employ a game-like interface for children.

Previous research suggests that tablet-based automated audiometry can be used clinically in adult populations [3,9]. Agreement between the thresholds obtained by conventional and automated audiometry is very high. For example, the percentage of automated audiometry thresholds falling within the clinically acceptable range (10 dB) of conventional audiometry results ranged between 94% [9] and 97% [3] in these two recent studies. Sensitivity and specificity of tablet-automated audiometry were also high in adults. For example, Thompson et al. [3] reported 0.89 and 0.9 for sensitivity and specificity.

Thus far, the majority of tablet-based automated audiometry research in children focuses on its applicability as a screening tool [4–6,10,11]. Previous studies suggest that tablet-automated audiometry can be effective for hearing screenings in children as young as 5 years of age [10]. However, sensitivity and specificity values reported for the tablet hearing screening tests among children were not as high as in adult populations. Yet, the reported values indicated that the table-based screening is a good test to identify hearing loss with high percentages of thresholds within 10 dB of each other, between the two techniques.

However, because hearing screening does not require testing for all frequencies that are examined in a diagnostic test, previous tablet automated audiometry studies in children have not reported results at 500 Hz [10,11] and/or high frequencies such as 6 and 8 kHz [4–6,10]. Moreover, several of these studies have compared both methods in the same subjects but not necessarily on the same day [4,10] or in the same controlled environment [4,5,10,11]. Hence, their results are subject to caution because temporal hearing threshold shifts may happen due to conductive hearing loss or loud noise exposure following various music or sporting events. Furthermore, while Thompson et al. [3] compared both methods in the same environment on the same date, the majority of their samples were adults and the results in children were not reported separately. Because of these various limitations, the clinical use of tablet-based automated audiometry beyond the screening phase in children remains to be demonstrated. Recently, Mahomed-Asmail et al. [12] examined the validity and efficacy of automated audiometry in children for diagnostic hearing assessment. Their findings are extremely promising and suggest a potential clinical use of automation to help diagnose hearing loss in children. The automated technique they use, however, was not conducted on the same tablet device but was based on a response button connected to a laptop computer that the children had to push. It would be ideal to conduct both screening and diagnostic hearing tests on the same tablet device.

The aim of this study was to evaluate the validity and efficiency of tablet-based automated audiometry in school-aged children, 6–12 years old, for diagnostic purposes. Automated and conventional audiometry were conducted on the same day in a soundproof booth to determine if automated audiometry thresholds were similar to those obtained through conventional audiometry. In addition, test administration time was measured for both audiometry tests to determine if they were similar to each other. Finally, test preference was examined to determine whether children actually preferred tablet-based automated audiometry to conventional audiometry.

Table 1
Means and standard deviations (SD) of age in three age groups of participants.

Age group	Mean	N (boys:girls)	SD	Range
6 yo	6.00	10 (6:4)	0.00	6
7-9 yo	8.64	11 (8:3)	0.65	7–9
10-12 yo	10.64	11 (4:7)	0.89	10–12

yo: years old.

2. Methods

This study has been approved by the Nemours Institutional Review Board (Local IRB number 992614). Participants and their parents/guardians provided signed assent or parental permission to participate in the study prior to the experimental session.

2.1. Participants

Thirty-two children (18 boys) ages 6–12 years participated in this study. Participants were recruited using flyers and digital signage in Wilmington, Delaware. We included all children who did not have any existing hearing loss greater than 70 dB in both ears and who were able to follow English instruction and perform the hearing tests without physical disabilities or cognitive limitations. Participants were divided into three groups based on age: 6 years old (yo), 7–9 yo, and 10–12 yo. The mean and standard deviation of age of the participants are summarized by each age group in Table 1.

2.2. Procedure

Data were recorded at Nemours/Alfred I. duPont Hospital for Children, Wilmington, Delaware. Research electronic data capture (REDCap) [13] was used for data management. Hearing thresholds for 0.5, 1, 2, 4, 6, and 8 kHz were collected using both conventional manual air conduction audiometry (conventional audiometry) and tablet-based automated air conduction audiometry (automated audiometry) in a soundproof booth that meets the American National Standards Institute (ANSI) standards [14,15]. A counterbalanced design was used to assign the order of conventional and automated audiometry for each participant. To ensure consistency between the two tests, testing was started at 1 kHz at an intensity level of 40 dB hearing level (HL) in either the left or right ear in both testing conditions. The side of ear tested first was selected randomly. The intensity levels we tested were between −10 and 70 dB HL in both tests.

Conventional audiometry was conducted with an audiometer (Equinox, Interacoustics, Eden Prairie, MN) with EAR-3A insert earphones in a soundproof audio booth. Earphones and the audiometer are annually calibrated with the Larson Davis System 824 sound level meter, RA0113 insert earphone adapter, and AEC100 coupler (Larson Davis, PCB Piezotronics, Provo, UT). Equipment met ANSI standards [14,15]. The modified Hughson-Westlake method [16] was implemented for determining hearing threshold in conventional audiometry. Pulsed tones were presented and the child responded to each tone by raising his/her hand. Speech reception threshold was also obtained using a list of six spondees (Equinox, Interacoustics) with EAR-3A insert earphones. The child responded to the recorded stimuli by pointing to one of the six corresponding pictures or saying aloud the word.

Automated audiometry was conducted using the SHOEBOX iPad app version 4.4 to 4.9 (Clearwater Clinical Ltd.) with circumaural headphones (Sennheiser HDA-280, Wedemark, Germany). Headphones were calibrated to the SHOEBOX iPad app by Clearwater Clinical Ltd. using the Larson Davis system 824 sound level meter (Larson Davis, PCB Piezotronics, Provo, UT) and the Brüel & Kjær type 4152 artificial ear, type 4144 microphone, and type 4200 pistonphone (Brüel & Kjær,