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Automated Audiometry in Quiet and Simulated Exam Room Noise for Listeners with Normal Hearing and Impaired Hearing

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Abstract

Background Up to 80% of audiograms could be automated which would allow more time for provision of specialty services. Ideally, automated audiometers would provide accurate results for listeners with impaired hearing as well as normal hearing. Additionally, accurate results should be provided both in controlled environments like a sound-attenuating room but also in test environments that may support greater application when sound-attenuating rooms are unavailable. Otokiosk is an iOS-based system that has been available for clinical use, but there are not yet any published validation studies using this product.

Purpose The purpose of this project was to complete a validation study on the OtoKiosk automated audiometry system in quiet and in low-level noise, for listeners with normal hearing and for listeners with impaired hearing.

Research Design Pure tone air conduction thresholds were obtained for each participant for three randomized conditions: standard audiometry, automated testing in quiet, and automated testing in noise. Noise, when present, was 35 dBA overall and was designed to emulate an empty medical exam room.

Study Sample Participants consisted of 11 adults with hearing loss and 15 adults with normal hearing recruited from the local area.

Data Collection and Analysis Thresholds were measured at 500, 1,000, 2,000, and 4,000 Hz using the Otokiosk system that incorporates a modified Hughson-Westlake method. Results were analyzed using descriptive statistics and also by a linear mixed-effects model to compare thresholds obtained in each condition.

Results Across condition and participant group 73.6% of thresholds measured with OtoKiosk were within $\pm$ 5 dB of the conventionally measured thresholds; 92.8% were within $\pm$ 10 dB. On average, differences between tests were small. Pairwise comparisons revealed thresholds were $\sim$3.5–4 dB better with conventional audiometry than with the mobile application in quiet and in noise. Noise did not affect thresholds measured with OtoKiosk.

Conclusions The OtoKiosk automated hearing test measured pure tone air conduction thresholds from 500 to 4,000 Hz at slightly higher thresholds than conventional audiometry, but less than the smallest typical 5 dB clinical step-size. Our results suggest OtoKiosk is a reasonable solution for sound booths and exam rooms with low-level background noise.

Keywords
- audiology
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- automated
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- hearing loss
- noise

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According to the World Health Organization (WHO), there are ~466 million people worldwide that have a disabling degree of hearing loss, defined as a loss greater than 35-dB HL in the better hearing ear.[1] According to the 2012 National Health Survey, there were ~37.5 million adults in the U.S. who reported some degree of hearing loss.[2] Together, these data indicate more than 10% of the U.S. population has some amount of hearing loss. While this relatively large group of people with hearing loss might or might not choose to pursue hearing evaluation and management, the capacity of services that can be provided by audiologists is insufficient to meet the needs of the population with impaired hearing.

One way to provide improved access in the U.S. and around the world is to make clinical services more efficient, for example through automation. Margolis and Morgan (2008)[3] estimated that up to 80% of audiograms could be automated which would allow for more time dedicated to specialty services. The "gold standard" for audiometric testing is behavioral threshold testing in response to pure tone stimuli presented at a variety of frequencies primarily used for understanding speech. Typically, this test is completed by an audiologist using an audiometer, in a sound-attenuating room.[4] The provider then interprets the results and an appropriate management plan is discussed with each patient. This scenario requires specialty equipment, including a sound-attenuating room, which limits the masking potential of external background noise. The sound-attenuating room is stationary, and there can be a cost for patients in terms of traveling to a clinic for treatment.

An automated product that does not require an audiologist can be used to increase access to hearing care and reduce costs (Shojaeemend and Ayatollahi, 2018),[5] especially in areas with no direct access to an audiologist or a sound-attenuating room. Even in areas with robust audiologic availability, there could be additional applications of an automated audiometry product, including hearing testing in a physician's exam room, pharmacy, community center, etc. Another potential application for automated audiometry in the U.S. is as part of an over-the-counter (OTC) hearing aid delivery model in an existing audiology clinic.

Before an automated audiometry product can be used clinically, it must first be validated to demonstrate it can provide results similar to gold standard pure tone audiometry in a clinical setting with the desired population. To that end, there are published investigations describing the development and validation of automated methods, in a variety of formats.

Although there is work on many systems, three different systems with automated audiometry capability have emerged and are backed by rigorous scientific investigation. These systems include KUDUwave (Geoaxon Holdings, South Africa), the Automated Method for Testing Auditory Sensitivity (AMTAS®),[6] and ShoeBOX (Clearwater Clinical, Canada). Each of these systems have at least some scientific data collected from participants with normal hearing and also with impaired hearing. This is important because the presence of hearing loss should not change the accuracy of thresholds. Each of these systems has also been tested in some form of background noise. This is important because a potential application would be for testing outside of traditional sound-attenuating rooms.

Swanepoel and Biagio (2011)[7] completed a validation study of the KUDUwave audiometer in adults by comparing results to thresholds obtained with an industry-standard diagnostic audiometer. Air conduction thresholds measured with the KUDUwave were found to be within ± 5 dB of the thresholds measured by the industry-standard audiometer in 90% of the cases. Storey et al[8] found similar results when they compared performance with the KUDUwave automated test completed in quiet and in noise to performance with standard audiometry in quiet. For the noise condition, a calibrated 16-talker babble was presented via sound field speakers at a level of 40 dBA to approximate a quiet room with the door closed as in a physician's office. The investigators reported 89% of pure tone air conduction thresholds were within ± 5 dB in quiet and 92% were within ± 5 dB in background noise. Storey et al also studied effects of hearing loss on pure tone threshold with the KUDUwave. With all participants included, their results for the listeners with impaired hearing indicate 76.5% and 85% of thresholds were within ± 5 dB for quiet and noise, respectively. This is compared with 94.3% in quiet and 95% in noise for the listeners with normal hearing. Although results suggested poorer accuracy for listeners with impaired hearing, there was no statistical difference in system performance between these groups. The authors did observe a difference between groups when statistical outliers were removed from the analysis for the noise condition only.

Other investigators have included listeners with normal and impaired hearing but did not attempt to compare their results for group differences in system performance. Margolis et al[9] included 56 participants in their AMTAS Home Hearing Test™ study. Two participants had normal hearing and the rest had varying degrees of hearing loss. During the AMTAS condition, participants were instructed to complete the test in their home in a quiet, distraction-free space. The authors noted that 71% of AMTAS thresholds were within ± 5 dB of conventionally obtained thresholds while 91% were within ± 10 dB. Margolis et al[9] also report that pure tone thresholds measured with AMTAS had a mean difference of 2.8 dB (5.7 dB mean absolute difference) compared with thresholds obtained with standard audiometry results in a sound-attenuating room. These values are similar to previous work with AMTAS, where the mean difference was 5 dB (6.6 dB mean absolute difference.[10] However, these mean differences are somewhat higher than other differences reported for AMTAS. For example, Margolis et al[6] reported a mean difference of −0.1 dB (3.6 dB mean absolute difference) and Margolis et al[11] reported a mean absolute difference of 3.9 dB. The authors attributed the slightly higher results for the AMTAS Home Hearing Test™ to time interval between test in sound-treated room and in-home version (mean = 53 days), the possibility of ambient noise, and variation related to different participants.[9]

Saliba et al[12] also measured pure tone thresholds for listeners with normal and impaired hearing using an

automated system, ShoeBOX. Similar to Margolis et al,[9] they did not compare these groups but considered all data together. The investigators obtained pure tone thresholds both in quiet and in the presence of 50 dB SPL white noise. Saliba et al[12] found 95.8% of ShoeBOX automated thresholds in quiet were within ± 10-dB of standard audiometric thresholds. 91.3% of automated thresholds in noise were within ± 10-dB of standard audiometric thresholds.

As described, Storey et al[8] and Saliba et al[12] used noise conditions in an attempt to measure how automated audiometry systems may perform in environments that are closer to real-world environments than a quiet, sound-attenuating room. Measured noise levels in empty patient rooms have been shown to fluctuate between 37 and 50 dBA.[13] This is in agreement with Swanepoel et al[14] who measured maximum ambient noise levels between 33.7 and 46.3 dB SPL in the "natural environment" they used for testing outside a sound booth. The 50 dB SPL white noise used by Saliba et al[12] is also similar to those measured in real environments.

In summary, there is support in the literature that automated audiometry systems provide accurate results when compared with results obtained with standard audiometric procedures and equipment.[8,9,12] Investigations have included both listeners with normal hearing and impaired hearing, though the results are not always compared for between-groups performance of automated audiometry systems.[9,12] Storey et al[8] did not find an effect of hearing loss when all participants were included in the analysis. Additionally, there is evidence that the presence of various types of low-level noise does not significantly affect pure tone thresholds using these systems.[8,12] There is no published work regarding validation of the OtoKiosk automated audiometry system. The purpose of the current study was to determine accuracy of the iOS-based automated hearing test (OtoKiosk) by comparing results from this test to results obtained using standard audiometric procedures. Specifically, pure tone thresholds were obtained for listeners with normal hearing and for listeners with impaired hearing both in quiet and in noise shaped to simulate a medical exam room.

Methods

Participants

Potential participants were identified through clinical chart review and through a list of members of the community who had expressed interest in participating in hearing research. The inclusion criteria included adults who were native English speakers with no reported history of neurologic or cognitive disorder. Informed consent was obtained from all participants. A few participants had hearing loss documented by audiogram prior to this investigation but this was not considered among criteria for inclusion. Participants were 26 adults with normal hearing or some degree of hearing loss. A total of 15 (30 ears) participants were recruited and included in the group with normal hearing. Eleven (22 ears) participants were recruited and included in the group with impaired hearing. For the group with normal hearing, the mean age was 58.7 years (range: 47–71 years) with three males. For the group with impaired hearing, the mean age was 65.5 years (range: 55–76 years) with six males. Participants were paid a flat rate of $15 (gift card) for their time, and all testing was completed in a single visit with duration of ~45 minutes. This investigation was approved by the Vanderbilt University Medical Center Institutional Review Board (# 191433).

Equipment

Automated audiometry was completed using the iOS-based OtoKiosk, a Type 2 audiometer implemented on an iPad (iOS 11.2.6; Apple). The OtoKiosk includes a set of circumaural Peltor H7A earmuffs with RadioEar DD45 transducers that attach to the iPad via Apple's 1/8" audio jack. According to the manufacturer (Otohub), a secondary resource calibrates their systems according to the specifications for a Type 2 audiometer prior to distribution. The Otokiosk system used in the current investigation was used "out of the box" just like might happen in a setting with limited audiologic resources. The OtoKiosk creates test stimuli (pure tones in the current study) in real time. Conventional audiometry was completed using a calibrated (ANSI S3.6) GSI-61 audiometer with ER-3C insert earphones. All testing was completed within a double-walled sound-attenuating booth. Background noise, when present, was delivered from four Definitive loudspeakers (model BP-2X). The loudspeakers were positioned within the sound booth around the participant at 45°, 135°, 225°, and 315° at a distance of 1.25 m.

Background Noise

To simulate testing conditions in a physician exam room, a background noise sample was created. To create this sample, four measurements were taken of baseline noise levels in an empty exam room during normal daily otolaryngology clinic at Vanderbilt University Medical Center using a Larson Davis sound level meter (model 824). The levels for each ⅓ octave band from 100 to 10,000 Hz were averaged together (►**Fig. 1**). The overall level of these recordings was 38.5 dBA. Using Adobe Audition, a white noise sample was shaped to match the average spectrum of the recordings for use during the noise condition of this investigation.

Procedures

All participants completed three audiometric threshold conditions: conventional audiometry, automated audiometry in quiet, and automated audiometry in noise. Conditions were randomized to reduce order effects. Air conduction thresholds were measured for each ear at four frequencies: 500, 1000, 2000, and 4000 Hz. For conventional testing, the examiner used her typical threshold measurement technique used in standard clinical practice most similar to the guideline published by the American Speech-Language-Hearing Association.[15] During each automated audiometry

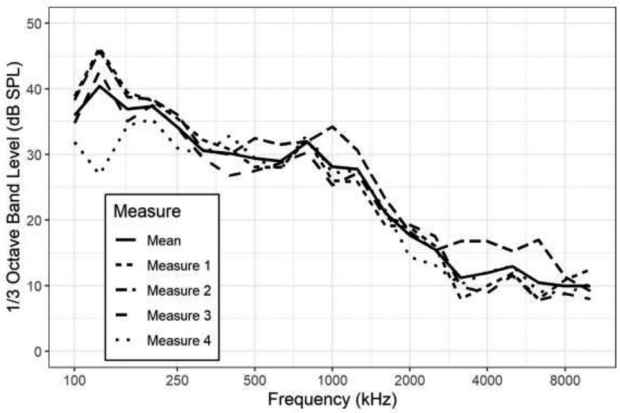

Fig. 1 Spectrum of noise sampled within an actual exam room during clinic hours. The heavy line indicates the averaged spectrum that was used to shape a white noise for presentation as a simulated exam room background noise during the automated audiometry in noise condition.

condition, the pure tone stimuli had a starting level of 35 dB HL, with a stimulus duration of 3.5 seconds and an interstimulus interval of one second. Participants were instructed to press a button on the iPad touchscreen any time they heard a tone. Testing was started at 500 Hz and ended at 4000 Hz. Automated testing always began in the left ear. Stimulus presentation levels were adaptively varied using the proprietary OtoKiosk automated application until threshold was determined. After all automated thresholds were measured, the participants indicated they were complete by notifying the examiner. The difference between the two quiet conditions and the noise condition was that the shaped white noise was delivered at 38 dBA from the four loudspeakers. This noise was turned on prior to the participant beginning testing and was turned off once they verbally indicated they were finished with testing. Peltor H7A circumaural earmuffs are designed to provide 40 dB of attenuation at 1000 Hz which would suggest our background noise would be inaudible. We felt it was important to complete confirmatory analysis there was no difference between results in quiet and noise, which seemed important given the custom coupling of the DD45 transducers to the earmuff by Otohub.

Data Analysis

All threshold data were first analyzed descriptively. The mean difference and mean absolute difference between threshold values were obtained for conventional audiometry compared with OtoKisok in quiet, conventional audiometry compared with OtoKiosk in noise, and between OtoKiosk in quiet and OtoKiosk in noise. The percentage of thresholds that fell within ± 5 and ± 10 dB difference ranges was determined to compare with other reports.

Thresholds (in dB HL) were then statistically analyzed using linear mixed-effects models. The full model included a between-participant factor (Hearing Status) and two within-participant factors, Test Type (conventional, OtoKiosk quiet, OtoKiosk in noise) and Frequency (500, 1000, 2000, 4000 Hz). The effects of fixed factors on the model fit were systematically evaluated by comparing the change in log-likelihood ratio with an effect or interaction removed. Effects or interactions were maintained in the final model if the change in log-likelihood ratio was significant. Based on the analysis of variance results, the most parsimonious model was maintained, following the recommendations by Matuschek et al (2017) and Bates et al (2015).[16,17] Significant main effects or interactions in the parsimonious models were explored with pairwise comparisons with Satterthwaite degrees of freedom and Benjamini-Hochberg corrections for family-wise error rate. Linear mixed-effects model analyses were conducted in R (v 3.6.1; R Core Team, 2019)[18] using the lme4 package and the lmer function,[16] whereas model comparisons were conducted using the anova function in base R. Pairwise comparison testing was accomplished using the emmeans package in R.[19]

Results

Descriptive Statistics

►**Fig. 2** shows the median hearing thresholds for all ears tested in each condition. On average, the participants in the normal hearing group had thresholds within the normal hearing range from 500 to 4000 Hz. On average, the participants in the group with impaired hearing had a mild sloping to moderate hearing loss from 500 to 4000 Hz.

►**Table 1** provides data when thresholds obtained with Otokiosk in quiet and noise were compared with thresholds obtained with conventional audiometry. Data are presented by group (normal hearing or impaired hearing) and also by condition (quiet or noise) for each test frequency. Percentage of thresholds within ± 5 and ± 10 dB is provided as well as mean difference and mean absolute difference data. For mean difference data, the automated thresholds were subtracted from the conventional thresholds. Negative values indicate conventional audiometry provided lower (better) thresholds. Data are also provided collapsed on group and condition.

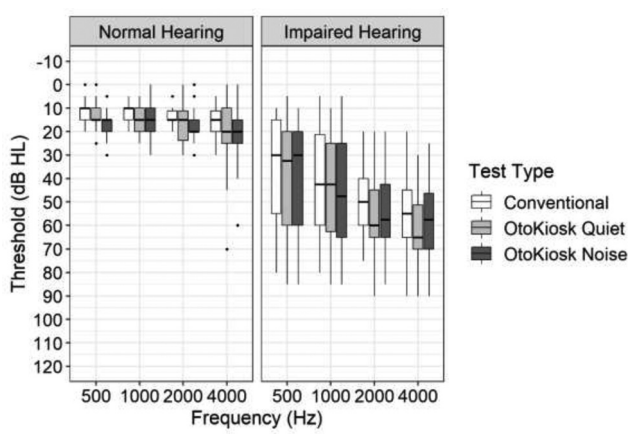

Fig. 2 Pure tone threshold data are shown for each group and all three conditions. The heavy line indicates the median, the boxes represent the interquartile range, and the whiskers represent the 95% confidence interval for the mean thresholds.

Table 1 Pure tone threshold data collected using conventional audiometry was compared with data collected using automated audiometry. Percent within +5 and +10 dB was determined as well as mean difference (dB) and mean absolute difference (dB) data for each group and condition across frequency. To determine mean difference, the automated threshold values were subtracted from the conventional threshold values. Overall data collapsed on group and condition is also provided

Group and Condition		500 Hz	1000 Hz	2000 Hz	4000 Hz	Average
Normal Hearing Quiet	Thresholds ± 5 dB (%)	80	86.7	73.3	70	77.5
	Thresholds ± 10 dB (%)	100	100	96.7	86.7	95.8
	Mean Difference in dB (SD)	−2.5 (5)	−3.17 (3.82)	−3.17 (5.65)	−4.7 (11.52)	−3.38 (7.11)
	Mean Absolute Difference in dB (SD)	4.17 (3.73)	3.5 (3.5)	4.83 (4.25)	7.33 (9.98)	4.96 (6.1)
Normal Hearing Noise	Thresholds ± 5 dB (%)	66.7	80	70	63.3	70
	Thresholds ± 10 dB (%)	93.3	93.3	96.7	90	93.3
	Mean Difference in dB (SD)	−6 (4.43)	−2.83 (5.83)	−3.5 (5.75)	−4.17 (9.57)	−4.13 (6.69)
	Mean Absolute Difference in dB (SD)	6.33 (3.92)	4.83 (4.25)	5.17 (4.25)	7.17 (7.51)	5.88 (5.21)
Impaired Hearing Quiet	Thresholds ± 5 dB (%)	95.5	72.7	59.1	77.3	76.1
	Thresholds ± 10 dB (%)	100	90.9	90.9	90.9	93.2
	Mean Difference in dB (SD)	−2.5 (4.01)	−2.05 (12.41)	−5.91 (5.03)	−4.09 (5.49)	−3.66 (7.51)
	Mean Absolute Difference in dB (SD)	3.86 (2.64)	6.59 (10.62)	5.91 (5.03)	5 (4.63)	5.32 (6.43)
Impaired Hearing Noise	Thresholds ± 5 dB (%)	81.8	72.7	63.6	63.6	70.5
	Thresholds ± 10 dB (%)	95.5	90.9	90.9	72.7	87.5
	Mean Difference in dB (SD)	−3.64 (4.92)	−5 (5.12)	−5.68 (4.95)	−1.14 (12.72)	−3.86 (7.76)
	Mean Absolute Difference in dB (SD)	4.55 (4.06)	5.45 (4.61)	5.68 (4.95)	8.41 (9.43)	6.02 (6.21)
Overall	Thresholds ± 5 dB (%)	79.8	78.8	67.3	68.3	73.6
	Thresholds ± 10 dB (%)	97.1	94.2	94.2	85.6	92.8
	Mean Difference in dB (SD)	−3.75 (4.81)	−3.22 (7.17)	−4.38 (5.47)	−3.65 (10.2)	−3.75 (7.21)
	Mean Absolute Difference in dB (SD)	4.81 (3.75)	4.95 (6.09)	5.34 (4.53)	7.02 (8.23)	5.53 (5.95)

Table 2 Results of model comparison testing. Significant effects were maintained in the final, parsimonious linear mixed effects model

	χ^2	df	*p*
Test Type	23.7	2	<0.0001
Hearing Status x Test Type	0.086	2	0.958
Hearing Status x Frequency	62.5	3	<0.0001
Test Type x Frequency	2.93	6	0.817
Hearing Status x Frequency x Test Type	2.52	6	0.866

Overall results do not vary considerably by group or condition. When all threshold data are considered, 73.6% of automated thresholds were within ± 5 dB of conventional thresholds. 92.8% of automated thresholds were within ± 10 dB of conventional thresholds. Mean difference between automated and conventional thresholds was -3.75 dB and mean absolute difference was 5.53 dB.

Statistical Analyses

Results of the statistical analysis, displayed in ►**Table 2**, revealed all interactions with Test Type were non-significant. The Frequency x Hearing Status interaction was significant ($p < 0.0001$), as was the main effect of Test Type ($p < 0.0001$). Pairwise comparisons of the effects of Hearing Status at each frequency, displayed in ►**Table 3**, indicate hearing thresholds were higher for participants with hearing loss and the difference was greater at higher frequencies.

Pairwise comparisons of the effect of Test Type, displayed in ►**Table 4**, revealed thresholds were better with standard audiometry than with the automated application in quiet (~3.5 dB) and in noise (~4 dB). The non-significant interaction between other factors of interest indicate the difference between thresholds obtained with automated applications are stable across hearing status, ambient noise level, and frequency.

Discussion

The purpose of this project was to complete a validation study on the iOS-based OtoKiosk automated audiometry system by comparing pure tone thresholds obtained with automated audiometry to thresholds obtained with gold-standard audiometric measures. Additionally, this study included listeners with impaired hearing as well as listeners with normal hearing. Results were also obtained in a noise condition that simulated the environment of testing in a physician exam room. The findings indicate thresholds were better with conventional audiometry than with the automated application in quiet (~3.5 dB) and in noise (~4 dB), and that this difference in threshold was statistically significant. It is important to note this difference is smaller than the standard clinical step-size of 5 dB and overall results are similar to results for other automated audiometry systems. Further, the finding that there was no effect of noise on thresholds confirms the Peltor H7A earmuffs maintain their attenuation properties even with the custom Otohub coupling of the DD45 transducers.

In the current study, 73.6% of all automated audiometry thresholds were within ± 5 dB of conventional audiometry thresholds. This increased to 92.8% within ± 10 dB. These results are nearly identical to those reported previously in the literature. For example, Margolis et al[9] reported that, with the AMTAS Home Hearing Test™, 71% of thresholds were within ± 5 dB and 91% were within ± 10 dB for their participants that included primarily listeners with impaired hearing. Similarly, Saliba et al[12] reported that 95.8% of their automated ShoeBOX system were within ± 10 dB measured in quiet and 91.3% within ± 10 dB measured in noise. Again, their data were combined across listeners with normal and impaired hearing. The current data with the OtoKiosk system

Table 3 Results of pairwise comparison testing for the effect of test type

Contrast		Estimate (dB HL)	SE	df	*t* ratio	*p*	Sig
Conventional	Otohub Quiet	−3.52	0.9	606.11	−3.9	<0.001	***
Conventional	Otohub Noise	−4.05	0.9	606.11	−4.49	<0.0001	***
Otohub Quiet	Otohub Noise	−0.53	0.9	606.11	−0.59	0.56	n.s.

Table 4 Results of pairwise comparison testing for the frequency x Hearing Status interaction

Contrast		Frequency (Hz)	Estimate (dB HL)	SE	df	*t* ratio	*p*	Sig.
Normal Hearing	Impaired Hearing	500	−23.86	4.74	33.2	−5.04	<0.0001	***
Normal Hearing	Impaired Hearing	1000	−28.53	4.74	33.2	−6.02	<0.00001	***
Normal Hearing	Impaired Hearing	2000	−36.05	4.74	33.27	−7.61	<0.00001	***
Normal Hearing	Impaired Hearing	4000	−39.07	4.74	33.14	−8.25	<0.00001	***

are nearly identical to these when results in quiet and noise are considered; 94.7% of automated thresholds within ± 10 dB in quiet and 90.9% within ± 10 dB in noise.

Interestingly, the current results are consistent with the ShoeBox[12] and AMTAS Home Hearing Test™.[9] However, all of these systems appear to have lower accuracy than the KUDUwave; Storey et al[8] reported that 89% of automated thresholds were within ± 5 dB for quiet and 92% were within ± 5 dB for noise when compared with standard audiometric thresholds. There are certainly differences in equipment and underlying derivation of threshold data which could influence results. Another apparent difference is in participant age. The mean ages of our participants were 58.7 for the group with normal hearing and 65.5 for the group with impaired hearing. For Margolis et al,[9] the mean age was 65 and the mean age for Saliba et al[12] was 49.7. Storey et al[8] reported mean ages of 23 for the group with normal hearing and 35 for the group with impaired hearing. They did complete correlation analysis on mean absolute difference and age which was not significant. Thus, although there are age differences across studies, it is unclear if age differences contributed to the system accuracy differences.

Another parameter reported by some investigators in their work on automated audiometry is the mean threshold difference and the mean absolute threshold difference. We observed a mean threshold difference of -3.75 dB. This is larger than the -1.08 dB and −2.2 dB reported by Storey et al[8] in quiet and noise, respectively. However, this is within 1 dB of the 2.8 dB mean threshold difference reported by Margolis et al.[9] We observed a mean absolute threshold difference of 5.53 dB. Storey et al[8] report 4.39 dB mean absolute threshold difference in quiet and 3.47 dB in noise. Our results are again most similar to Margolis et al[9] who report mean absolute threshold difference of 5.7 dB.

Combined, these data demonstrate thresholds obtained with OtoKiosk are similar to those obtained via conventional audiometry. Importantly, the pattern of results is the same for participants with normal hearing and hearing loss. This finding is consistent with Storey et al,[8] who also found similar accuracy results for listeners with normal and impaired hearing. These results are important because they demonstrate the automated audiometry system has the potential to be a useful clinical tool for identifying hearing loss via air conduction and for separating patients with normal and impaired hearing.

Despite the evidence from this study that OtoKiosk could be a potentially viable tool for evaluating air conduction thresholds for listeners with normal and impaired hearing, future work is warranted to fully establish the benefits and limitations of this system. For example, in the current study, only four frequencies were tested. Future work is warranted to establish the accuracy of the automated system in higher (e.g., 8000 Hz) and lower (e.g., 250 Hz) test frequencies, where variability would be expected to be greater based on the work of others.[8,12] These test frequencies were not included in the current investigation given the demonstrated variability, although they could be clinically useful. In addition, future work is warranted to determine the extent to which the findings generalize to age groups beyond 47–76 years. It is likely that accuracy might decline for pediatric or geriatric patients. The primary purpose of this investigation was to compare pure tone thresholds obtained using the automated system to pure tone thresholds obtained using manual techniques. Future work to better understand the ~3.5 dB difference may include obtaining thresholds using the different methods with the same transducers. Finally, all testing in the current study was accomplished in a sound-attenuating booth, with limited distractions. It is possible thresholds acquired by automated or other methods would be susceptible to distractions that might be in other environments, such as exam rooms with open doors or busy clinic waiting areas.

Conclusions

The iOS-based OtoKiosk automated audiometry system can measure pure tone air conduction thresholds at 500, 1,000, 2,000, and 4,000 Hz in a quiet sound booth and in the presence of 38 dBA shaped white noise within ~3.5 - 4 dB of conventionally measured pure tone thresholds. Although there was a statistically significant difference when comparing automated audiometry thresholds to conventional thresholds there was no difference between automated threshold in quiet or noise. This finding indicates the transducer configuration used by OtoKiosk helps block out any influence of low-level noise on these thresholds. Additional measures of accuracy including percentage that thresholds were within ± 10 dB and mean absolute threshold difference values were quite similar to other available automated audiometry systems. These results indicate the OtoKiosk is a reasonable solution for certain test applications and environments including potential use in test environments like exam rooms. Further investigations of additional clinical application are warranted.

Note

Portions of this work were completed by Brianna N. Bean as a part of her capstone project at Vanderbilt University School of Medicine.

Source of Funding

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Conflict of Interest

Equipment and funding that supported this research project was provided by Otohub, SRL.

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