EVOLUTION OF AUDIOMETRY: CLINICAL TESTING OF A NEW TABLET AUDIOMETER

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1. INTRODUCTION

Early detection of hearing loss in young children is critically important as hearing plays an essential role in the development of speech and communication skills [1]. Typical hearing tests, whereby sound is administered and the patient presses a button upon hearing it, pose a particular challenge for the paediatric population: getting children to cooperate and retaining their attention for the duration of the test is difficult. Conditioned play audiometry (or CPA) is a standard testing technique designed to address this problem. In a CPA test a child is conditioned to respond to hearing sounds at different frequencies with specific play behaviour: for example, when the sound is heard, the child is allowed to drive a car down a race track. However, CPA is resource intensive and only available in select locations. It is more time consuming than conventional audiometry, and requires special training and the availability of two audiologists to administer the listening test.

The development of tablet technology and the widespread popularity of the touch interface, especially among children, have made possible a new iOS-based application designed to measure hearing thresholds in this population [2]. The iPad® (Apple® Inc., Cupertino, CA) application helps overcome some challenges associated with CPA by introducing a novel paradigm to automate certain tasks. The benefits of automating audiometric tests using computer-based systems have been documented in recent studies [3]–[8]. Moreover, owing to the portability of the tablet environment, the application opens the door to low-cost, automated hearing diagnosis for children in new locations, such as developing countries where hearing loss is prevalent [9].

In this work, we present a clinical study to determine the accuracy of audiometric thresholds measured using tablet audiometry. The results are compared to those obtained with accepted conventional CPA.

2. METHODS

2.1. Tablet audiometry: application overview

Under the new paradigm, control over the presentation and pace of the sound stimuli is driven by the patient rather than the audiologist. The 'game' consists of presenting the subject with a series of objects (*e.g.* eggs) to be sorted in two containers: 'sound-producing' objects in one container (*e.g.* a chicken coop), and 'silent' objects in another (*e.g.* an egg carton). Thus, using a simple dragging motion, the child is able to navigate his/her own way through the test by responding in a yes/no fashion to each stimulus. The sound intensity decreases with each presentation until the child is not able to sort the object reliably, at which point the sound intensity is increased. This process allows the hearing thresholds to be determined using an up/down bracketing procedure [10]. Several "silent objects" are also presented randomly to provide a measure of internal consistency (reliability). The application interface provides different test stimuli (pure-tones, warble tones, and narrowband noise) for testing at the standard audiometric frequencies from 125 to 8000 Hz. Finally, once all selected frequencies are tested, a standard audiogram is obtained.

2.2. Test subjects

The present study was conducted on a population of 85 patients with normal or abnormal hearing, aged 3–16, at the Audiology Clinic at the Children's Hospital of Eastern Ontario. Patients were identified by a staff otolaryngologist (MB) after a review of their patient record. Informed consent was obtained from the parent/guardian at the time of enrollment. Of these patients, 15 were discarded after the assessment due to technical/game-play issues, behavioural issues or questionable reliability defined as incorrectly assigning silent objects more than 50% of the time. The demographics for the 70 subjects retained for this study are summarized in Table 1.

2.3 Study design

All participants completed two audiometric evaluations, one with the tablet audiometer and one with conventional CPA. The order of the test was determined at random. In both cases, measurements of warble-tone thresholds were performed inside a double-walled sound booth. For simplicity and speed, unmasked air-conduction thresholds at 4 test frequencies (500, 1000, 2000, and 4000 Hz) were measured for this study. Sound stimuli were presented using TDH-39 headphones for both assessments, testing the left and right ears separately. Children who were not amenable to wearing headphones (14 subjects) were tested in a sound-field using the sound booth speaker system or the tablet speaker. All equipments (tablets, headphones and speakers)

Table 1. Population demographics and reliability statistics.

	Abnormal hearing	Normal hearing
Number of subjects	15	55
Mean age	5.81 (range 3–13)	5.06 (range 3–9)
Reliability (%)	92.0 (SD: ±10.8)	90.4 (SD: ±22.4)
SD denotes standard deviation.		

Table 2. Comparison of tablet audiometry and conventional CPA

Play audiometry / Tablet audiometry	Abnormal hearing (15)	Normal hearing (55)
Abnormal hearing (17)	14	3
Normal hearing (53)	1	52

Sensitivity: 93.3% (95%CI = 71.7–99.6%)
Specificity: 94.5% (95%CI = 88.6–96.3%)
Positive Predictive Value: 82.3% (95%CI = 63.3–87.9%)
Negative Predictive Value: 98.1% (95%CI = 92.0–99.9%)
Positive Likelihood Ratio: 17.1 (95%CI = 6.31–26.7)

used in this study were calibrated according to ANSI S3.6-1996 (R2010) [11]. A trained audiologist accompanied the participants in both assessments to provide motivation.

3. RESULTS

Table 2 summarizes the results of the analysis based on 70 patients. In this study, a patient with abnormal hearing is defined as one who scored a threshold of 30 dB or more for at least one of the audiometric frequencies tested. Overall, 55 subjects were identified by the conventional CPA test to have normal hearing. Of these, 52 were correctly identified with tablet audiometry, the remaining 3 children scoring slightly outside the parameters defined for normal hearing. This appeared to be the results of the child moving too quickly through the game, or the presentation timing out before the child could make a decision. Moreover, a total of 53 patients were identified by tablet audiometry to have normal hearing, of which one child was found to have a true mild hearing loss. This child appeared to understand the game, but scored a low reliability of 75%, which, however, is still above the criteria for exclusion (<50%).

Preliminary statistical measures to evaluate the performance of tablet audiometry are also shown in Table 2. The data, especially the narrow confidence intervals which suggest sufficient statistical power, reveal that the tablet audiometer produces warble-tone thresholds that are in agreement with conventional CPA. Moreover, for patients who had separate left-right ear assessments (54 patients), a repeated measures model for the threshold in each ear at each frequency was fitted using linear mixed effects modelling. The model showed no significant effect of the assessment modality (tablet versus conventional CPA) for all patients, as well as for each group (normal versus abnormal hearing).

4. DISCUSSION AND CONCLUSION

This work summarizes the results of the first trial study of a new tablet audiometer. It is, to our knowledge, the first tablet-based semi-automated play audiometer to be used in a paediatric setting. The study is aimed at testing the novel interactive play algorithm used in the tablet audiometer: the user-directed paradigm requires more action (and decision) from the user than in standard audiometry, where no action is required when the user does not hear a sound. Despite this challenge, this work shows the tablet audiometer to be a child-friendly application, as the majority (82%) of children aged 3 and up were able to understand the concept of the game and complete the hearing assessment. Moreover, the 82% represents a conservative estimate since 4 out of the 15 patients excluded from the study failed to complete the assessment due to technical issues related to the audiologist. It is also worth noting that, of the remaining 11 patients excluded, 10 had abnormal hearing.

The data in this study demonstrate that air-conduction thresholds measured using the tablet audiometer were not significantly different from those obtained by standard CPA. With a strong predictive value for normal hearing, and high sensitivity for hearing loss, the portable tablet audiometer is shown to be an efficient and clinically accurate instrument for hearing assessment in children.

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