EFFECTIVENESS OF A NEW TABLET-BASED HEARING SCREENING SYSTEM, AMONG A COHORT OF INDIVIDUALS WITH A HIGH INCIDENCE OF HEARING LOSS

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1 INTRODUCTION

Hearing loss presents a significant global cost impact, including the costs to productivity as well as the cost of long term healthcare. Occupational hearing loss also presents a considerable cost to employers, with the average total case number of NIHL caused or made worse by work from 2009/10 - 2011/12 being 19 000 cases [1]. With an ageing population and legislative requirements to screen and protect workers from occupational hearing damage, the traditional method of audiometric screening in which tests are run on a 1:1 basis with a qualified audiometrist is expensive. However, an Australian study concluded that the average overall economic cost of hearing loss is $3,314 AUS per person with hearing loss per annum, and the overall economic benefits of widespread screening significantly outweigh the costs [2,3].

Audiometry in various forms is the core approach used to screen for hearing loss in patients. Audiometric methods include air or bone conduction [4], with manually controlled pure-tone air conduction testing being most common [5]. An increased legislative requirement to monitor and screen workers, and a corresponding increase in litigation relating to hearing loss is putting greater reliance on this as a tool. This in turn is increasing the cost burden for health service providers and employers who need to provide sufficient screening to identify hearing issues at an early stage.

Improvements to the current hearing impairment intervention structure are being examined which aim to lead to overall better patient care. One way in which this can be achieved is by increasing the frequency and availability of hearing testing, so that more people can be accurately diagnosed. This raises issues of resources and cost, as there is an insufficient number of audiologists to cope with the extra demands of a greatly increased regime of testing, especially in developing countries [6]. The cost of referral to an audiologist is also significant, and reducing the number of unnecessary referrals and directing referrals more quickly and appropriately would provide potential significant cost savings for the health service.

In order to offer much more widespread access to high quality screening, the use of mobile devices offers significant potential, being low cost and widely available. This study examined the efficacy of a new low-cost touch-screen automated screening system, developed by Audiology-Online Ltd, and assessed its performance in relation to manual audiometry.

The premise of the system is to provide a preliminary test to inform patients and medical practitioners of potential hearing issues before they commit to booking a full audiological test. This would increase the availability of effective screening, not only leading to an increased number of patients with access to treatment, but would also categorise patients so that audiologists could concentrate time and resources on individuals with real otological problems. This would help make the intervention system more efficient, combining a higher level of patient care with reduced costs.

1.1 Background

Pure tone audiometry was originally developed from “tuning fork” tests of the early 20th century, and has now been in use for over 90 years [7]. The first audiometers were designed by Carl E

Seashore, to measure the “keenness of hearing”, a concept which was then commercialised by Otaudion (1919) and Western Electric (1922) [8,9] who designed and marketed the 1-A and 2-A range. More advanced features such as bone conduction audiometry and masking noise [9] were already available on audiometers from Sonotone as early as 1928 [8].

The basic structure of an air conduction audiometric test involves an audiometrist, an audiometer and a patient response system. The audiometrist manipulates the audiometer to deliver pure (sine wave) tones to the patient at known amplitudes. The patient then responds to which sounds are heard through the patient response system [10]. The audiometrist uses the pattern of patient responses to determine the threshold of hearing for that patient at the various audiometric frequencies. If a person is hard of hearing in a single ear, masking noise may be used – a broad frequency spectrum sound that masks one ear from hearing loud tone presentations from a very insensitive ear.

Bone conduction audiometry works in a similar way to air conduction audiometry, but with the sound waves resonating through the structure of the skull instead, usually through a bone conduction transducer mounted via a headband to the “mastoid prominence” below and behind the ear pinnae [10] . This has the advantage of allowing an audiologist to bypass the middle ear function, as bone conduction stimulates the cochlea directly, enabling them to diagnose the performance of the cochlea itself. This allows the audiologist to classify the hearing loss as either conductive (indicative of a problem of the middle ear) or sensorineural (indicative of a problem with the cochlear or nerves) [11].

Despite this rapid early rise in development, there has been relatively little progress since. In current practice it is recommended [12] and extremely common to use a calibrated test system that uses Telephonics TDH-39 headphones, a design that was conceived for use by the Air Force in World War 2 [13]. There is very little written evidence of the first use of these headphones in audiometry, however they are shown to be commonly used (84% in a study involving 100 audiometers, randomly selected) by 1969 [14].

Since this time, there have been a number of improvements in headphone design that could be relevant and useful to the audiometry industry, such as improved sensitivity (TDH-39 measure at 108 dB at 1 mW), better external noise attenuation (insert earphones have shown better attenuation, for instance [15]), and improved frequency response (TDH-39 are quoted at just 100-8000 Hz [16] compared to human hearing, around 20 Hz-20 kHz [10]). As an example of the progress that has been made in the last 60 years; although attenuation data is unavailable at this time, the commonly used Sennheiser CX300 headphones (costing approximately £30), perform better than TDH-39 in both frequency response and sensitivity (10-21 kHz, and 113 dB respectively [17]) despite their non-specialized design and general use.

For a patient visiting an audiology department, a greater headphone sensitivity would allow louder signal levels to be delivered to patients who were more seriously hearing impaired, and allow for the audiometer to be designed using a smaller, less powerful headphone amplifier. Better external noise attenuation would allow their test to be undisturbed by external noise, and allow the test to take place in a potentially more noisy environment.

Computer controlled audiometry has been around for several years [18], with a range of products currently on the market. These audiometers are structurally the same as a conventional audiometer, using the same headphone type. The testing procedure follows that laid out in ISO 8253-1:2010, in which testing is done in the presence of a trained audiometrist, who will fit the headphones, but the test itself is controlled automatically by a computer connected to the audiometer. While this allows for screening of multiple people at one time, these systems are still expensive and have limitations in the number of people who can be screened at a given time, as well as still suffering from the issues described above. This suggests that there is significant potential for fully automated audiometry, using the advantages of mobile computing and contemporary headphones.

2 METHODS

2.1 Equipment

The tablet system consisted of an Acer W700 Tablet computer, running the Windows 8 operating system, and Beyerdynamic DT770 circumaural headphones. The tablet computer was running customised software developed by Audiology-Online Ltd, which allows tone presentation through a web browser at different frequencies in the audiometric bands (250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, and 6 kHz). The system is designed so that it can run on any computer or tablet, and allows the calibration of any complete system (the combination of headphones and computer system) in order to meet the standards defined by BS EN ISO 389-8:2004.

The tablet system was calibrated by the use of an IEC artificial ear manufactured by Larson Davis (model number AEC201, with a type 2 adaptor), connected to a Bruel and Kjaer type 2250 Sound Level Meter. The system was calibrated in accordance with methods defined in IEC 60645-1:2001. Levels were calibrated in accordance with headphone output levels specified in BS EN ISO 389-8:2004 for Sennheiser HDA200 audiometric headphones [19]. This is due to the lack of a generic profile in the ISO standard for circumaural headphone designs other than the HDA200.

2.2 System Operation

In order to start the test the user presses a virtual 'start button' on the screen. They are then prompted to enter personal details (name, date of birth, doctor or medical practice). The test then presents a series of diagnostic questions to ascertain if the subject has symptoms which could affect the test or would prevent entry into the Direct Access Adult Hearing Service, (such as ear pain, ear discharge, sudden loss of hearing, fluctuation in hearing, and tinnitus)

The system has a simple check procedure to ascertain if headphones are placed the correct way round. A tone is played in one ear only, and a screen prompt states which ear the tone should be playing in. At this stage the headphones can be reversed if they have been placed incorrectly.

The system then plays a test tone at 60 dBHL, to determine if the individual's loss is such to prevent them hearing the standard tone presentations. This acts as a "safety tone" so that users with good hearing are not exposed to loud sound unnecessarily.

The system then runs the full audiometric test. If the user responded that they could not hear the 60 dBHL test tone, the test starts with presentation level at the highest level of 80 dBHL, while if they responded that they could hear the initial tone, presentation starts at 60 dBHL. Subjects failing to respond to the 80 dB HL tone at any frequency would be automatically classified as having hearing loss.

The system presents a random number of tones at each presentation, and the individual is asked to count the number of tones that can be heard and enter the result. For each frequency, the system then reduces the level of the tone presentation in 10 dB steps from 60 dBHL down to 20 dBHL, or from 80 dBHL to 45 dBHL where the user could not hear the initial test tone. As this is a screening tool, rather than a full audiometer, 20 dBHL is the lowest presentation level used. This is considered sufficient to assess for measured threshold shift, as the system is designed to screen to assess whether subjects need referral to an audiologist. A subject who correctly identifies all frequencies at a 20 dBHL presentation level would not be categorized as having hearing loss under the standard classification scheme [20].

The system presents tones at 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz and 6 kHz. Once all tones have been presented, the user is informed that the test is finished, and the system automatically sends

the results to the medical practitioner, along with the results from the initial diagnostic questions, and the system resets ready for the next individual.

2.3 Cohort

The study aimed to include a cohort of individuals with a higher than average occurrence of hearing loss, in order to provide data that would be relevant to a hearing screening system with operating amplitude levels of 20 dB HL to 80 dB HL. Subjects in the study were 3 male and 6 female volunteers from a residential care home for individuals aged 60+, all of whom had registered hearing difficulties.

The subjects were as follows:

Subject	Gender	Age
1	F	63
2	M	92
3	F	71
4	F	83
5	F	90
6	M	89
7	F	90
8	M	93
9	F	91

Table 1: Cohort of test subjects, 3 male, 6 female.

2.4 Ethical Approval

This study achieved ethical approval from the ethics committee at Southampton Solent University on 25/6/2013. All participants read and understood an information form detailing the aims of the study, and signed a consent form to participate.

2.5 Procedure

The study aimed to ascertain if the tablet based system provided reliable screening within an acceptable level of variance compared to traditional audiometry. Traditional pure tone air conduction audiometric testing was conducted on all subjects in the morning of the test day. The audiometer used for comparison was a Maico MA51, which was within current calibration from a UKAS certified laboratory.

The audiometry section of the test was performed to BSA (British Society of Audiology) standard procedure, based on that specified by BS EN ISO 8253-1 [21]. Otoscopic examination was undertaken before testing for all subjects in order to ascertain that there were no occlusions of the audiometric canal or other issues which may cause errors with the audiogram [22].

Audiometric testing was carried out by two audiometrists certified to British Society of Audiology standards. Audiograms and otoscopy notes were recorded and filed for each individual.

The Tablet test was administered in the afternoon session, and due to the nature of the intuitive touch interface was minimally supervised. The subjects were then invited to make comment on the test procedure, and how they found it, compared to traditional audiometry.

In order to accurately compare the outcome of this trial with the typical level of variability experienced in traditional audiometry, data from a previous experiment can be considered [23]. In this study, the hearing of a similar group of eleven people was tested with three different calibrated manual audiometers, including the Maico MA51 that was used as the comparison in this study.

Tests were run at the same time of the day and week, over a period of 3 weeks. For the purposes of this study, this data for the other two audiometers was then compared to the output of the Maico MA51 and to the output of the tablet system (Figure 1)*. The mean differences (Delta) between the Tablet and the MA51, and other audiometers and the MA51 are shown in figure 2*.

This comparison shows that the mean differences in any given band between the Tablet system and MA51 are within one standard deviation of the differences one can expect from comparing normal audiometers, and there is even a lower mean difference in the 6 kHz band which traditionally provides a wider range of error.

3 RESULTS

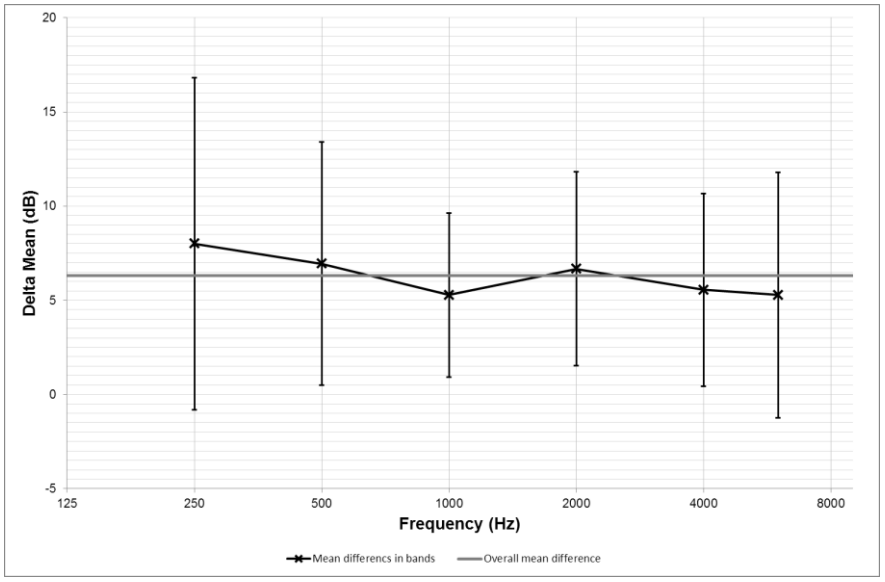

Figure 1: Mean and standard deviation of difference (dB) Tablet and Maico MA51 in each frequency band, with overall mean difference.

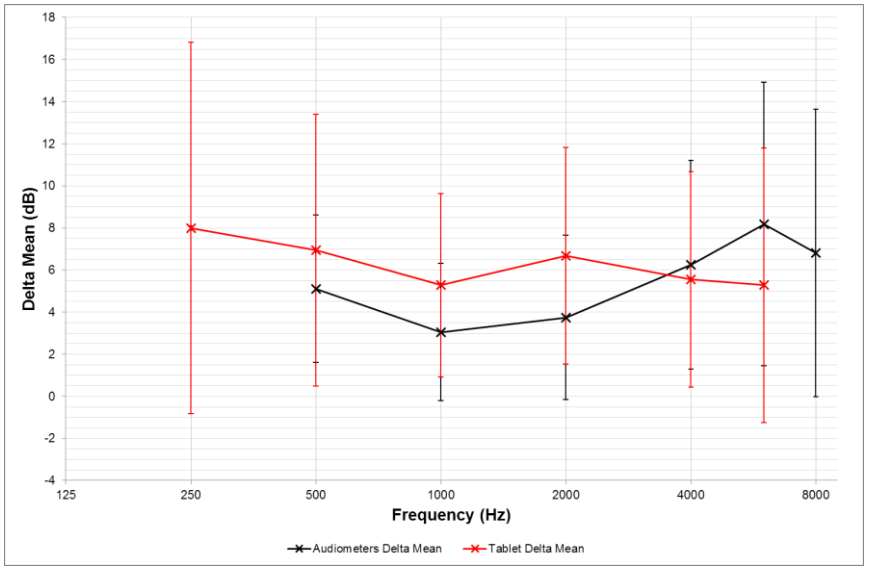

Figure 2: Comparison of mean differences between Tablet and Maico MA51, and between two other manual audiometers and Maico MA51.

Frequency	250	500	1000	2000	4000	6000	Overall Mean Difference
Mean Difference (dB)	8.0	6.9	5.3	6.7	5.6	5.3	6.3

Table 2: Mean differences between the tablet system and traditional audiometry in the audiometric bands

4 DISCUSSION

As can be seen from figure 2, the Tablet system shows an overall mean variance of 6.3 dB across the spectrum, while the manual audiometers exhibit an overall mean variance of 5.7 dB. This result, while very slightly higher, fits within the general level of variance attributable to audiometers, and a paired t-test shows no significant difference between the results of the two groups ($p>0.05$).

The shape of the curve on figure 1 shows that there is more likely to be a larger difference in the low and high frequency ranges. This is to be expected, and is likely due to headphone placement variability, causing a resonance at low frequency, and suffering from directivity effects at high frequency.

One issue that arose while testing is a misunderstanding of the Tablet test procedure. When the test prompts the user to count the number of tones, two of the test subjects read the instruction incorrectly, and were counting the 60 dB “safety tone” As the first presentation of the test to count. This issue has since been corrected in the test software, however the audiograms for test subjects 1 and 7 have been corrected for this error, and the revised versions used in the calculations of differences (revised scores are shown as subjects 1a and 2a in the full results table).

Probably the largest source of error in this study was the effect of potential cognitive impairment issues. Some subjects found both the traditional audiometry test and the Tablet System difficult to understand, and therefore introduced a variable to the test. This may account for the high levels of congruence seen between the two different system tests on some individuals, and the slightly more erratic traces seen on others. Further testing would be advisable to establish if there is a higher

success rate among younger candidates with hearing impairment. There is also a large variable in the form of physical differences between individuals, such as head size and shape, seating position, presence of a high backed chair (wheelchair), etc., all of which could impact the headphone placement and concentration level of the subjects, leading to test variance.

Subject	Frequency (Hz)	Tablet						Audiometer					
		250	500	1000	2000	4000	6000	250	500	1000	2000	4000	6000
	Ear												
1	L	70	50	55	30	40	35	60	55	65	30	40	55
	R	45	45	50	30	30	40	75	70	65	45	50	65
2	L	>80	>80	>80	>80	>80	>80	80	80	85	80	100	100
	R	60	70	75	50	75	>80	65	75	75	65	70	85
3	L	55	60	55	70	>80	80	#N/A	60	55	55	65	80
	R	55	50	65	70	60	80	55	55	60	70	70	80
4	L	60	>80	75	75	70	>80	75	75	75	65	60	85
	R	>80	>80	>80	>80	>80	>80	110	105	110	105	105	120
5	L	50	60	60	70	75	70	#N/A	65	50	65	65	80
	R	30	40	40	60	75	75	#N/A	35	35	60	80	80
6	L	50	60	60	60	65	65	50	45	60	50	55	75
	R	50	60	60	50	65	65	50	45	50	45	70	70
7	L	30	25	25	25	35	55	30	25	25	25	45	60
	R	30	40	25	30	45	40	30	30	25	20	50	60
8	L	30	30	30	55	>80	>80	15	15	20	45	100	105
	R	40	35	40	80	>80	>80	15	25	30	75	95	80
9	L	50	50	60	50	60	65	45	45	50	45	60	75
	R	60	60	65	65	70	80	65	60	55	60	75	75
1a	L	75	55	60	35	45	40	60	55	65	30	40	55
	R	50	50	55	35	35	45	75	70	65	45	50	65
2a	L	35	30	30	30	40	60	30	25	25	25	45	60
	R	35	45	30	35	50	45	30	30	25	20	50	60

Table 3: Registered values in dB HL for each subject. (#N/A shows missing data)

Test subjects were all hearing aid equipped when entering the experiment, which indicates that they had been administered traditional audiometry in the past, which would have made it more familiar to them. Despite this, although there was a slightly higher rate of difference between the Tablet system and the MA51, this difference was not significant, and may be reduced further if the system was used with younger patients more familiar with touch screen and tablet type systems.

The worst level of congruence between the two systems seen on any single audiogram is that of subject 1. In the amended form, the mean difference between the two systems is 12.1 dB, a difference of 3.8 dB above the next highest, subject 8, at 8.3 dB. Omitting this outlier from the test brings the average down to 5.3 dB.

5 CONCLUSION

These results suggest that the tablet system is as effective a method of audiometric screening as conventional manual audiometry. There is no evidence at the 5% level of significance that there is a difference in variability between the tablet system used without supervision and pure tone manual audiometry undertaken by a qualified practitioner. Taking into consideration that equipment cost is significantly lower than that of traditional audiometers, the test takes around half the time to conduct of the traditional audiometric test, and takes minimal or no supervision to conduct, this would appear to offer significant benefits for basic screening in occupational health and general practice, both in terms of ease and speed of access and reduced cost of provision, while maintaining a level of accuracy in diagnosis which is equivalent to that of traditional audiometry.

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