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<th><strong>Title</strong></th>
<th>Hearing screening of school children</th>
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<tr>
<td><strong>Other</strong></td>
<td>Contributor(s)</td>
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<td><strong>Author(s)</strong></td>
<td>Wong, Sze-man, Mandy; 黃思敏</td>
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<td><strong>Citation</strong></td>
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</table>
Hearing screening of school children:

Comparison of computer-based and conventional audiometers

Wong Sze Man, Mandy

A dissertation submitted in partial fulfillment of the requirements for the Bachelor of Science (Speech and Hearing Sciences), The University of Hong Kong, June 30, 2008
Abstract

In most developing countries, routine hearing screening programmes are often not available due to unaffordable resources. There is an urgent need to develop a cost-effective but reliable audiometer for use in such regions. The purpose of this study was to investigate the screening accuracy of a low cost, computer-based audiometer compared with a conventional audiometer. An additional purpose was to find out whether there were frequency effects in the accuracy of the computer-based audiometer. A total of 80 children were screened using both conventional and computer-based audiometers. There was no significant difference between the two different audiometers for screening referral rates in the mid and high frequencies at the passing criterion of 40 dBHL (p>0.05). This suggested that computer-based audiometers may be a promising, low-cost alternative for developing country use.
Introduction

Hearing impairment is often undetected in developing countries as routine hearing screening is uncommon. According to a 2005 estimate by the World Health Organization (WHO), 278 million people worldwide have moderate to profound hearing loss in both ears. One quarter of hearing impairment cases begin during childhood, and 80% of all deaf and hearing-impaired people live in low- and middle-income countries (WHO, 2005). Despite the high prevalence rates of ear pathology and hearing impairment in developing countries, routine hearing screening programs are often unavailable because of adverse environmental test conditions and shortages of qualified testers and screening equipment. Audiometers in developing countries tend to be expensive and non-portable diagnostic instruments which are rarely recalibrated. They are often second-hand instruments donated by agencies in developed countries as a ‘useful’ way to dispose of out-of-date equipment (Gell et al., 1992). Therefore, there is an urgent need to develop reliable, cost-effective and affordable hearing screening procedures for use in developing countries.

Impact of childhood hearing loss and possible solutions

Childhood hearing impairment, even when mild, may have a detrimental effect upon linguistic and educational development, which can result in psychosocial problems for
affected children and their families (Downs, 2004). Children with hearing impairment often experience delay in development of speech, language and cognitive skills, which may result in learning difficulties in school. The cost of special education and lost employment due to hearing impairment can also impose a substantial economic burden on societies (Downs, 2004). However, 50% of deafness and hearing impairment can be avoidable through prevention, early detection and management (Smith, 2003). WHO has suggested that children in developing countries should be screened using an audiometer at school entry (Rao et al., 2002). Timely detection and management of hearing impairment are essential for optimal speech and language development.

Present screening programs in developing countries

Although pure tone screening audiometry was found to accurately assess hearing status in children six years and older in a rural Bangladeshi village (Berg et al., 2006), this screening was often unaffordable in most developing countries. Low cost, hand-held screening audiometers have been designed, such as the Liverpool Field Audiometer (McPherson & Knox, 1992), the Welch-Allyn Audioscope™ (Frank & Peterson, 1987) and the Otoscreener™ (Alvord & Davenport, 1992). Nevertheless, the Liverpool Field Audiometer was found to have low test-retest reliability at 500 Hz, when a 30 dB HL screening intensity was used (McPherson & Knox, 1992). Unacceptably high false
positive rates were also found in other hand held devices at low intensity levels (Bess et al., 1998). Therefore, a more reliable and cost effective means of hearing screening is needed.

Questionnaire-based screening by teachers and parents has been used for children in developing countries. Despite the low cost of this screening procedure, identification of hearing loss by questionnaire was often ineffective. A recent Brazilian project (Gomes & Lichtig, 2005) used a parental report questionnaire to detect hearing impairment in children aged 3 to 6 years. Results were disappointing as the 33 item questionnaire failed to differentiate between children with normal hearing and those with slight to mild hearing loss. With teachers’ evaluation, Nodar (1978) revealed over 50% of the children who failed audiometer hearing screening were missed by educators. Teachers’ failure to identify children with hearing loss may be possibly due to large class sizes and language differences. For example, there are class sizes of 60 students or more in African urban areas and 100 students in some classes in Guatemala (ILO, 1996). Therefore, teachers may have little opportunity for close observation of each individual student. At the same time, children may come to school with a variety of first language backgrounds. Hearing loss may be misperceived as the cause of communication difficulties (Chambers & Anderson, 1997).
With advances in computer technology, computer-based instruments and telehealth services in clinical audiology have been developed. Software can be easily downloaded from the Internet for self-check of hearing status or for audiologist use. These programs include computer-based tinnitus tests and computer-based audiometers. However, few research studies have been done to evaluate the accuracy of these new techniques.

Givens et al. (2003) proposed the application of real-time assessment of hearing thresholds through the Internet. 45 adults were evaluated by conventional and Internet-based audiometers in a double-blind study in a soundtreated room. Results from the conventional audiometer were treated as the gold standard. Results showed that the mean thresholds obtained with the two audiometers varied no more than 1.3 dBHL. However, this Internet-based audiometer still required an audiologist to control the device through the Internet in the real time, thus not reducing the cost of services in developing countries. Choi et al. (2007) also demonstrated comparable results between a PC-based audiometer and a conventional audiometer. 37 subjects received face-to-face conventional audiometry and PC-based audiometry in a remote site. The PC-based audiometer estimated the mean hearing thresholds with an error of less than 2.3 dBSPL. Only 10.7% of the threshold results exhibited an error greater than 5 dBSPL at a remote site. Besides audiometers, computer-based tinnitus tests were found to be reliable in clinical
application. Henry et al. (2000) found high test-retest reliability for a computer-controlled psychoacoustical system for tinnitus measures. Tinnitus loudness and pitch were quantified using a tone-matching technique and hearing thresholds were obtained as part of the procedure. In conclusion, previous studies have demonstrated the feasibility of Internet-based and computer-based hearing instruments for adults under a soundtreated environment.

Principles of hearing screening

The purpose of hearing screening is to detect individuals who have significant or potentially significant hearing problems, so they may be referred for further diagnostic evaluation. Whatever screening test is selected, a cutoff value (criterion) must be chosen. The outcome of the screening is one of two possibilities: pass or refer. Test criteria recommendations reflect a desire to find a test value that maximizes the performance of the test in identifying those with the disease (sensitivity) while maintaining an acceptable rate of correctly identifying those without the disease (specificity).

ASHA (1990) recommended hearing screening tests at 25 dBHL for frequencies 500, 1000, 2000 and 4000 Hz. Lack of response to 25 dBHL at any frequency in any ear is regarded as failure. However, in developing countries, WHO guidelines suggest provision of hearing aids for those with hearing thresholds greater than 40 dBHL in the better ear
(WHO, 1999). Those with mild hearing loss (25 to 40 dBHL) are often not given treatment. Thus, in this study, the passing criterion is set at a higher intensity level (40 dBHL) across test frequencies of 500, 1000, 2000 and 4000 Hz. Furthermore, a higher intensity level of screening is often needed due to ambient noise and poor noise attenuation of the audio headset in the computer-based audiometer. This headset was designed for listening to audio files and using communication software like Skype. Moreover, soundtreated rooms are often unavailable in developing countries. Even background noise levels in isolated village or rainforest locations may exceed 40 dBA (Counter, 1986). Moreover, it is likely that background noise in educational settings can be greater, probably closer to the 60.7 dBA level found in Hong Kong classrooms when in active use (Choi & McPherson, 2005). Therefore, a passing criterion at 40 dBHL was chosen in order to minimize the chance of getting a high over-referral rate (false positive referrals).

*Frequency effects in screening accuracy*

Due to the ambient noise, hearing thresholds obtained are raised especially at lower frequencies, i.e. 500 Hz. Computer-based audiometers are more susceptible to noise masking effect because of the poor noise attenuation properties of the audio-headset, which was developed mainly for leisure use. Conversely, the headphone (Madsen) of the
conventional screening audiometer is specially made for hearing testing and about 18.3 dBHL noise level can be attenuated at 500 Hz (Frank, Creer & Magistro, 1997). Therefore, it is hypothesized that the referral rates of computer-based audiometers will be higher at 500 Hz than those resulting from the use of conventional screening audiometers.

**Rationale for the Present Study**

The World Health Organization (WHO) and World Wide Hearing Care for Developing Countries (WWHearing) are now initiating programmes to improve hearing health care for adults and children in developing countries (WHO, 2008). These include developing low-cost, affordable hearing aids for use in developing countries and low-cost equipment that can be used in under-resourced audiology clinics. The present study will be part of this global effort.

Although previous studies have demonstrated the reliability of computer-based audiometric instruments, most of them investigated adult subjects within a sound treated room. In contrast, hearing screening in developing countries may be provided at school entry and a sound treated room for hearing tests is often unavailable. The present study will focus on hearing screening of school-age children under a quiet but non-sound treated environment.
Comparisons between computer-based and conventional audiometers

Computer-based audiometers using downloadable software could be a low-cost option for hearing screening. Laptop computers increase the portability of services from school to school. A second-hand notebook computer (e.g. IBM T22 laptop computer) can be purchased for US$300 at minimum in Hong Kong. If a computer is already available, the cost of one conventional pure-tone audiometer (HK $8000) is about 12-13 times the cost of a computer-based audiometer system (see Table 1). This can effectively lower the equipment cost of hearing screening in developing countries.

Table 1.  
Comparison of costs between computer-based and conventional audiometers

<table>
<thead>
<tr>
<th>Computer-based audiometer</th>
<th>Conventional screening audiometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>IBM T22 laptop computer</td>
<td>HK $2400</td>
</tr>
<tr>
<td>Software ‘Home Audiometer’</td>
<td>HK $210</td>
</tr>
<tr>
<td>a USB hub</td>
<td>HK $80</td>
</tr>
<tr>
<td>a USB joystick</td>
<td>HK $30</td>
</tr>
<tr>
<td>an Audio headset</td>
<td>HK $330</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>HK $3050</strong></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>HK $8000</strong></td>
</tr>
</tbody>
</table>
Table 2.  *Comparisons between computer-based and conventional audiometers*

<table>
<thead>
<tr>
<th></th>
<th>Computer-based audiometer</th>
<th>Conventional audiometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of equipment</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Noise attenuation</td>
<td>Poor</td>
<td>Better</td>
</tr>
<tr>
<td>Tracking of data</td>
<td>Allowed</td>
<td>Not allowed</td>
</tr>
<tr>
<td>Time required</td>
<td>Longer</td>
<td>Shorter</td>
</tr>
</tbody>
</table>

*Training of personnel as testers*

Since computer-based audiometers can automatically determine thresholds of pre-selected frequencies at both ears, professionals like audiologists and speech and language pathologists are rarely required to perform the screening (Hong & Csazar, 2005). Basic health workers can be trained to become testers. Thus, it can lower the cost of hearing screening. At the same time, it may ease the problem of the limited availability of professional personnel in developing countries.

*Purpose of Present Study*

By comparing the referral rates of the conventional and computer-based audiometers, we aim at answering these research questions:

1. Is there any significant difference in referral rates between computer-based and
conventional audiometers at different frequencies?

It is hypothesized that the two referral rates will be comparable at mid to high frequencies. The referral rates of the computer-based audiometer at 500 Hz will be significantly greater than that of the conventional audiometer due to poor noise attenuation of the headset in the computer-based audiometer.

2. Is there any age effect on the referral rates in different audiometers?

It is hypothesized that younger children will have higher referral rates as they have a shorter attention span and are less developmentally able to response accurately and in a timely manner to each tone presentation.

Method

Subjects

80 subjects, aged 6:00 to 9:00, were recruited from a normal Hong Kong Government primary school which had volunteered to participate in this study. Most of children in this school were in middle to low socioeconomic status. All subjects were Cantonese-speaking children with no known language or cognitive impairment. They were recruited on a voluntary basis with consent forms signed by parents and children prior to testing. Ethical approval was obtained from the University of Hong Kong prior to this study. Table 3 shows the demographic characteristics of the subjects.
Table 3. **Detail of subjects with respect to age, gender and grade**

<table>
<thead>
<tr>
<th>Age in years; months</th>
<th>No. of subjects (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6;00 - 6;11</td>
<td>20 (25%)</td>
</tr>
<tr>
<td>7;00 - 7;11</td>
<td>37 (46%)</td>
</tr>
<tr>
<td>8;00 - 8;11</td>
<td>23 (29%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gender</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>50 (62.5%)</td>
</tr>
<tr>
<td>Female</td>
<td>30 (37.5%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grade</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary 1</td>
<td>26 (32.5%)</td>
</tr>
<tr>
<td>Primary 2</td>
<td>37 (46.3%)</td>
</tr>
<tr>
<td>Primary 3</td>
<td>17 (21.2%)</td>
</tr>
</tbody>
</table>

**Testers**

Two testers who were speech and hearing sciences undergraduate students were randomly assigned to operate the conventional audiometer and the computer-based audiometer. They had received 12-hour training in audiological assessment procedures during their undergraduate program. They were double-blind to each other’s screening results.
Test Equipment

1. Computer-based audiometer

Figure 1 shows the computer-based audiometer. A headphone (Ovann OV880V circumaural headphones) and a joystick (Blazepro USB Joystick) were directly connected to a personal computer (IBM T22 laptop computer). The computer audiometer software (Home audiometer software – version 1.83) was installed into the PC. The program was developed for an audiological research in a British University in 2006. It can measure thresholds at 125, 250, 500, 750, 1k, 1.5k, 2k, 3k, 4k, 6k and 8k Hz. with a total range from -10 dBHL to 70 dBHL. The audiometer was calibrated by an audiologist before testing commenced.
2. **Conventional audimeter**

A portable pure-tone screening audiometer (Madsen Micromate) was used for hearing screening. The audiometer was calibrated according to ISO 389 series standards. Results from a conventional pure-tone audiometer are treated as the “gold standard” as the reliability of conventional pure-tone audiometry in hearing screening is high (Sideris & Glattke, 2006; Wang et al., 2002), and this screening method has been used extensively in past decades.

*Test Environment*

Hearing screening was conducted in an assigned room at the primary school over two non-school days. The room was not soundtreated. Ambient noise level was measured by a sound level meter on five occasions each day, randomly during testing. The average noise level measured over two days was summarized in Table 4.

![Table 4. Average Noise Level (dBA) in the testing room on two days](image)

<table>
<thead>
<tr>
<th>Date</th>
<th>Average Noise Level (dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>03/11/2007</td>
<td>36.4</td>
</tr>
<tr>
<td>17/11/2007</td>
<td>37.2</td>
</tr>
</tbody>
</table>
Test procedures

Each subject received two hearing screenings, one by conventional audiometer and one by computer-based audiometer. The two screenings were conducted on the same day in order to minimize any possible change in the subjects’ auditory status. The order of testing in respect to the two audiometers was random. The two testers were randomly assigned to each audiometer. They were double-blinded to each other’s screening results. The subjects were seated at right angles to the tester to avoid any visual cue during screening. They were fitted with headphones by the tester. They were instructed to press the instrument button when they heard a tone no matter how soft it was.

1. Screening in conventional audiometry

With the conventional audiometer, the subjects were screened with 500 Hz, then 1000, 2000 and 4000 Hz, at 40 dBHL starting from the left ear. The passing criterion was having reliable responses in 2 out of 3 trials at each frequency at 40 dBHL in both ears. Failure to respond at any frequency in either ear was regarded as ‘refer’. This procedure was chosen in order to match the test sequence of the computer-based audiometer.

2. Screening in computer-based audiometry

With the computer-based audiometer, hearing thresholds at each frequency (500,
1000, 2000 and 4000 Hz) were automatically determined using a Békésy protocol (Békésy, 1960). Testing started in the left ear at 500 Hz, then 1000, 2000 and 4000 Hz. The signal duration was preset to 1s and the gap duration was 1s. The initial intensity level was 40 dBHL. Intensity increased by 3 dBHL each time a tone was represented until the subject responded. After each response, the intensity level decreased by 3 dBHL. The audiometer drove an analog chart recorder in which a seesawed pattern representing intensity level against frequency was shown. Hearing threshold was determined after several series of responses were made by the subject. Hearing threshold results greater than 40 dBHL at any frequency in either ear was regarded as ‘refer’. A screen shot of the computer-based audiometer in operation is shown in Figure 2.

**Figure 2. Screen shot of a computer-based audiometer**
Follow-up procedures

The parents and the school principal received hearing screening reports of all tested children. The parents of referral case children were given recommendations regarding follow-up assessments.

Results

80 subjects received hearing screening with both computer-based and conventional audiometers. Subjects with one or more thresholds greater than 40 dBHL at any frequency at either ear were regarded as refer. Pass and referral rates obtained from two audiometers were represented in a 2x2 table for chi-square test analysis using SPSS (Kirkpatrick & Feeney, 2005).

Table 5. *Comparison of referral rates before and after excluding results at 500 dBHL*

<table>
<thead>
<tr>
<th>Referral rates</th>
<th>Before excluding 500 Hz</th>
<th>After excluding 500 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer-based audiometer</td>
<td>56% (45/80)</td>
<td>15% (12/80)</td>
</tr>
<tr>
<td>Conventional audiometer</td>
<td>13% (10/80)</td>
<td>11% (9/80)</td>
</tr>
<tr>
<td>Chi-square ($\chi^2$)</td>
<td>33.9</td>
<td>0.49</td>
</tr>
</tbody>
</table>
Table 5 compares the referral rates before and after excluding results of 500 Hz for both audiometers. Before excluding results at 500 Hz, the referral rates for the computer-based audiometer and the conventional audiometer were 56% and 13%, respectively. Results from a chi-square test showed a statistically significant difference in the referral rates ($\chi^2 = 33.9$, $p<0.05$, $df=1$). After excluding results at 500 Hz, the referral rates of the computer-based audiometer and the conventional audiometer were 15% and 11%, respectively. A chi-square test showed no statistically significant difference in the referral rates ($\chi^2 = 0.49$, $p>0.05$, $df=1$) between the results from the two audiometers, when 500 Hz results were excluded.

Table 6. *Comparison of referral rates at each frequency*

<table>
<thead>
<tr>
<th>Referral rates (no. of subjects)</th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>4000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Right*</td>
<td>Left*</td>
<td>Right*</td>
</tr>
<tr>
<td>Conventional audiometer</td>
<td>6.3%</td>
<td>3.8%</td>
<td>3.8%</td>
<td>2.5%</td>
</tr>
<tr>
<td></td>
<td>(5)</td>
<td>(3)</td>
<td>(3)</td>
<td>(2)</td>
</tr>
<tr>
<td>Computer based audiometer</td>
<td>55%</td>
<td>8.8%</td>
<td>12.5%</td>
<td>2.5%</td>
</tr>
<tr>
<td></td>
<td>(44)</td>
<td>(7)</td>
<td>(10)</td>
<td>(2)</td>
</tr>
</tbody>
</table>

*There is no statistically significant difference between two referral rates ($p>0.01$)
Comparison of referral rates across different frequencies

In order to determine whether the computer-based and conventional audiometers screen comparatively, referral rates at each frequency of 500, 1000, 2000 and 4000 Hz are compared using multiple chi-square tests. A more stringent significant level (p=0.01) was chosen. Table 6 showed that referral rates at the right ear were generally lower than the left ear. Using chi-square test analysis, there was no statistically significant difference in referral rates for both audiometers at all frequencies except at 500 Hz in the left ear ($\chi^2=45.1$, p<0.01, df=1).

![Diagram](image.png)

Figure 3. The median and interquartile range of thresholds obtained in computer-based audiometer
Figure 3 shows a graph of hearing thresholds obtained using the computer-based audiometer. Thresholds generally decreased as frequencies increased. Thresholds at the left ear were higher than that at the right ear, except at 4000 Hz.

Table 7. Comparison of referral rates with regards to age after exclusion of 500 Hz

<table>
<thead>
<tr>
<th>Age range</th>
<th>6;00 - 6;11</th>
<th>7;00 - 7;11</th>
<th>8;00 - 8;11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Referral rate</td>
<td>23% (6/26)</td>
<td>14% (5/37)</td>
<td>6% (1/17)</td>
</tr>
</tbody>
</table>

Table 7 shows referral rates with respect to age range. Referral rates generally decreased as age increased. However, an age effect was not statistically significant ($\chi^2=2.50, p>0.05, \text{df}=2$).

Discussion

Results showed that the computer-based and conventional audiometers worked similarly for mid and high frequencies ($p>0.05$), at the study’s 40 dBHL passing criterion. The referral rates between computer-based and conventional audiometers at mid to high-frequencies were comparable as results showed no significant difference between the two referral rates after excluding results at 500 Hz. After excluding results at 500 Hz, the referral rate of computer-based audiometer dropped from 56% to 15% while the
referral rate of conventional audiometer only dropped by 2%. This indicates that the computer-based audiometer is more susceptible to ambient noise. The headphone in the computer-based audiometer has poor noise attenuation properties while the headphone of conventional audiometer is specially made for hearing testing (Frank et al., 1997).

Interestingly, results revealed that referral rates between the two audiometers were significantly different at the first test frequency (500 Hz in the left ear) but not at other frequencies. Referral rates at 500 Hz in the right ear were not significantly different. This difference between two ears at 500 Hz cannot be simply explained by ambient noise since ambient noise should affect both ears equally. An alternative explanation may be the subject unfamiliarity with the computer-based audiometer screening procedures (Zhao et al., 2002). As the computer-based audiometer was an automatic device, the testers were unable to stop the test for reinstruction of the children. At the same time, there was a potential learning effect in which hearing thresholds of people with normal hearing were reduced across repeated tests (Henry et al., 2003).

In comparison of referral rates in different age ranges, Table 7 showed the referral rates increased as age decreased. Referral rate was the highest in the youngest age group (6;00-6;11). Younger children have a shorter attention span and less sophisticated cognitive abilities. They may not be able to understand the test procedures and the repetitive, button-pressing response mode. Since the signal gap duration was only 1s,
younger children may not be able to respond to each signal by pressing the response button on time. Hence, the referral rate for the youngest age range was the highest.

Results from this study were comparable to a similar study on hearing screening for children in Hong Kong under a non-soundtreated environment (Law, 2007). When 40 dBHL was used as the passing criterion for both studies, referral rates from conventional and computer-based computers were comparable (p>0.05) for mid and high frequencies. Law (2007) found a statistically significant difference in referral rates at 500 Hz for both ears. In contrast, the current study found statistically significant difference at 500 Hz only in the left ear, possibly due to subject unfamiliarity of test procedures. One possible explanation is that the average background noise in this study (36.8 dBA) was about 10 dBA lower than Law’s study (46.4 dBA). Therefore, the ambient noise effect on thresholds at low frequencies was reduced in the current study.

Besides working under a non-soundtreated environment, the computer-based audiometer has been shown to work reliably in soundtreated rooms as well. Pang (2007) demonstrated that a computer-based audiometer was able to obtain hearing thresholds with a mean difference, compared to a conventional diagnostic audiometer, of less than the clinically accepted error margin of ±5 dB at 250 Hz, 500 Hz, 1 kHz, 4 kHz and 8 kHz. Pang (2007) compared the difference between thresholds obtained from the two audiometers while the current study compared the referral rates at the 40 dBHL criterion
for both audiometers, regardless of the threshold values. In developing countries, it will often be more practical to analyze screening results at a predetermined intensity level rather than focusing on the threshold values obtained. This is because true threshold values can only be obtained under a sound-treated room which is often unavailable in developing countries.

Subjects who passed the conventional audiometer screening but failed with the computer-based audiometer may have failed the latter due to the following reasons. Firstly, the use of poor noise attenuating headphones with the computer-based audiometer may have raised the thresholds (Frank et al., 1997). Ambient noise affects all frequencies, particularly low frequencies, i.e. 500 Hz. The current headphone could be replaced by a headphone with better noise attenuation. However, this may increase the cost of the computer-based audiometer as noise-excluding headphones are more expensive to manufacture.

Secondly, hearing screening with a computer-based audiometer may cause fatigue as it took a longer duration (10-15 minutes) to complete. This may be challenging for school-aged children, especially those with a limited attention span. The children were required to press and hold down a button every time they heard a tone. This repeated Békésy procedure may be more difficult for children to comprehend and follow. Thus, fatigue and difficulty in comprehending instructions may hinder children from responding
accurately. Results indicated that the number of referrals with the computer-based audiometer were the greatest for the youngest age group (6:00-6:11 years). Therefore, it was particularly difficult for younger children to perform near hearing thresholds. It is suggested that some visual reinforcement or non-verbal praise by the tester (smiling, head nodding or gesture) can be provided when the child responds appropriately. This can reinforce the children and keep them responding throughout the screening. A pause function could also be added to the program in order to stop the test for reinstruction or allow rest for children at any time during screening.

Finally, despite ambient noise effects at low frequencies, the computer-based test commenced with a 500 Hz tone. This may result in unreliable responses as the subjects had difficulty in identifying the tone in the beginning of the test. In order to resolve this problem, the test needs to be modified according to guidelines in ANSI S3.21-1987 in which it should commence with 1000 Hz. Since 1000 Hz is perceptually identified as a pitch familiar to listeners, screening starting at 1000 Hz will give rise to a more reliable result (Katz, 2002).

Limitations of the present study

Only 80 children from one school were recruited as subjects and the number of girls participated exceeded that of the boys. Therefore, the sample may not be representative of
the school-aged population. At the same time, the sample of Hong Kong children may not be representative of the population of children in developing countries. There are possible differences between children in Hong Kong and those in developing countries. Children in developing countries have lower socioeconomic status, less education and less medical support. Therefore, they may be less likely to fully understand the screening procedures and the response mode. Moreover, hearing impairment is more prevalent in children in developing countries and the causes of hearing loss may be different from those in Hong Kong. Otitis media with effusion is a major cause of hearing loss in some developing countries (Smith & Mathers, 2006). As a result, it is predicted that referrals in developing countries will be much higher than this study.

Besides the limitation of sample representation, there also exists the difference in the nature of testers in developing countries and in this study. The two testers in this study did have some training in audiology. On the contrary, basic health workers in developing countries may lack background knowledge in audiology and clinical skills in carrying out hearing screening and discriminating responses. As a result, validity of hearing screening will decrease if basic health workers are the testers in developing countries, unless they have specific training prior to working in this area

Lastly, there may be differences between the noise level in the study school in Hong Kong and the test environment in many developing countries. Leung and McPherson
(2006) measured the mean noise level of unoccupied special school in Hong Kong to be 44 dBA. Greater ambient noise in developing countries will increase hearing threshold results at all frequencies, especially at lower frequencies. Ambient noise levels in quiet school rooms can still be very high - 43 dBSPL in Ghana (Amedofu et al., 2003) and up to 56 dBA in rural India (Rao et al., 2002). Thus, referral rates and false positive rates may increase. The diagnostic criteria at 40 dBHL may not be applicable under greater ambient noise effects.

**Conclusion and clinical application**

With advances in computer technology, low-cost computer-based audiometers may be a viable option to support hearing screening in developing countries. Results showed that the computer-based and conventional audiometers worked similarly for mid and high frequencies (p>0.05), at the study’s 40 dBHL passing criterion. This suggested that low-cost, computer-based audiometers can be a promising alternative for routine school-entry hearing screening after several modifications are made:

1. A headphone with better noise attenuation properties should used in order to reduce ambient noise effects on lower frequencies.

2. A pause function should be added. Screening can be stopped at any time when children need to be reinstructed or when they are fatigued.
3. There should be visual reinforcement or non-verbal praise during the screening test. This should be done to increase the attention span of the children in the screening.

4. The test should commence at 1000 Hz as it is more perceptually identified as a pitch familiar to listeners (Katz et al., 2002).

5. Pre-test practice should always be allowed before the actual test in order to let the children become familiar with the tone and the response mode.

6. Intervals for presenting tones should be irregular in order to minimize the chance of predicting the tone without real perception.

**Further research**

Further investigations of the feasibility of computer-based audiometers should be carried out in developing countries with basic health workers. Test-retest reliability and validity of computer-based audiometers at different frequencies can be evaluated. Other computer-based services such as tinnitus quantification tests, monitoring and programming of digital hearing aids, activation and mapping of cochlear implants, audiological diagnostic testing with otoacoustic emissions and middle ear immittance measures, and auditory training will need further evaluation for accuracy and feasibility in developing country environments.
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