<table>
<thead>
<tr>
<th><strong>Title</strong></th>
<th>Hearing screening for school-aged children: comparison of computer-based and conventional audiometry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Other Contributor(s)</strong></td>
<td>University of Hong Kong.</td>
</tr>
<tr>
<td><strong>Author(s)</strong></td>
<td>Law, Mei-shan</td>
</tr>
<tr>
<td><strong>Citation</strong></td>
<td>Law, M. [羅美珊]. (2007). Hearing screening for school-aged children: comparison of computer-based and conventional audiometry. (Thesis). University of Hong Kong, Pokfulam, Hong Kong SAR.</td>
</tr>
<tr>
<td><strong>Issued Date</strong></td>
<td>2007</td>
</tr>
<tr>
<td><strong>URL</strong></td>
<td><a href="http://hdl.handle.net/10722/55514">http://hdl.handle.net/10722/55514</a></td>
</tr>
<tr>
<td><strong>Rights</strong></td>
<td>This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.; The author retains all proprietary rights, such as patent rights and the right to use in future works.</td>
</tr>
</tbody>
</table>
Hearing Screening for School-aged Children: Comparison of
Computer-based and Conventional Audiometry

Law Mei Shan

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, 2007
Abstract

There is a need to develop a low cost but effective audiometer for developing countries. With advances in computer technology, low-cost computer-based audiometers have been developed. However, the application of computer-based audiometers in hearing screening is still in its infancy. The purpose of this study was to evaluate the accuracy of a low cost, computer-based audiometer in hearing screening. The second purpose was to find out whether there were frequency, age and/or gender effects in the accuracy of the computer-based audiometer. A total of 83 children were screened using the computer-based audiometer and also a conventional pure-tone audiometer. The results showed that there was a significant relationship between the computer-based audiometer and the conventional pure-tone audiometer when a 40-dBHL criterion was used in computer-based hearing screening. No significant relationship was found between two screening methods when a 30-dBHL criterion was used.
Introduction

The World Health Organization (WHO) has estimated that more than 4% of the world's population, i.e., 250 million people, suffer from hearing loss (McPherson & Brouillette, 2004). Among this population, approximately 165 million people live in developing countries. It was estimated that the prevalence rate of hearing loss is high among school aged-children. Although the prevalence rate in school-aged children is difficult to document as school screening is uncommon, some studies have noted prevalence data in developing countries. In Zimbabwe, a prevalence rate of 2.4% has been reported (Westerberg, Skowronski, Stewart, Bernauer, & Mudarikwa, 2005). In Kenya, it was reported that 5.6% of school children have hearing loss (Hatcher, et al., 1995). Studies in South India and Nigeria have reported even higher prevalence rates, of 11.9% and 13.9%, respectively (Rao, Subramanyam, Nair, & Rajashekhar, 2002). Though the prevalence rate varies considerably among developing countries due to differences in methodology, population, screening criteria or other factors, hearing loss is generally more prevalent in developing countries than in developed countries (Berg, Papri, Ferdous, Khan, & Durkin, 2006; Smith, 2001). For example, the prevalence rates in Finland and Denmark are 2.5% and 3.6%, respectively (North-Matthiassen & Singh, 2007).

Hearing loss is a significant health problem. Hearing loss, if undetected, can have a significant negative impact on the speech and language development, educational attainment and social-emotional development of children, even if it is a mild loss (Gomes & Lichtig, 2005; Berg et al., 2006). Since hearing loss is highly prevalent and detrimental to children's development, early identification is crucial. Early identification allows early intervention, which can reduce the impact of hearing loss on children (Downs, 2004; Olusanya, Okolo, & Adeosun, 2004). Hence, hearing screening for school-aged children in developing countries should be an essential part of public health services.

Hearing screening at school entry in developing countries seems justified in terms
of prevalence rates and the adverse consequences of undetected hearing loss. Unfortunately, while routine screening at school entry has been widely adopted in developed countries, children in developing countries are rarely screened for hearing loss (Madriz, 2001; McPherson & Olusanya, 2006). One major reason is that there are limited financial resources and trained personnel to provide routine hearing screening for school-aged children. For example, in Brazil, audiological services are often urban based, and are usually provided in hospitals and private clinics only. People who live in rural areas are not able to access theses services (Madriz, 2001; Jauhiainen, 2001; Gomes & Lichtig, 2005). As a majority of hearing impaired children have no access to audiological services in developing countries, early identification is not possible. As a consequence, many children who have hearing loss are not identified and thus no treatment is provided for them.

Because of the limited resources in developing countries, a low-cost but effective hearing screening method should be developed. Costs and effectiveness of hearing screening methods determine the success of hearing screening in developing countries. The costs of hearing screening may be attributed to the cost of equipment employed, the personnel required to carry out the screening and the time required to conduct the screening. In order to reduce the cost of screening, the method should be rapid, and low-cost equipment which can be easily operated by primary health care personnel should be used (Downs, 2004). The screening method should also be an effective method. The effectiveness of the method is determined by the sensitivity and specificity of hearing screening (Downs, 2004). Sensitivity refers to the number of people with hearing loss who are correctly identified as having hearing loss. Specificity refers to the accuracy of a test in identifying people who do not have hearing loss (Hind, Atkins, Haggard, Brady, & Grinham, 1999). A screening method is said to be effective only when it achieves both high sensitivity and specificity (Downs, 2004).

Generally, hearing screening methods nowadays are classified into three groups and the costs and effectiveness of each group has been evaluated. The three groups are:
1) Questionnaires;

2) Pure-tone screening methods and physiologic methods (e.g. otoacoustic immittance);

3) A combination of questionnaires and measurement tests (McPherson & Olusanya, 2006)

The feasibility of using questionnaires as a hearing screening method has been evaluated in different studies (Newton, Macharia, Mugwe, Ototo, & Kan, 2001; Gomes & Lichtig, 2005). The costs of using questionnaires are considered to be low and the implementation of a questionnaire approach does not require professionals—primary health assistants can be employed (Gomes & Lichtig, 2005; McPherson & Olusanya, 2006). However, the effectiveness of questionnaire-based hearing screening has been found to vary across different studies (McPherson & Olusanya, 2006; Newton et al., 2001). It has been reported that questionnaires that were used in screening in UK have achieved a certain degree of success. However, there are other studies showing that the sensitivity and specificity of questionnaires are low. Although the questionnaire approach is a low-cost method, the usefulness of employing it in hearing screening requires further research.

Physiologic methods such as otoacoustic emissions and immittance audiometry screening are often used in hearing screening programs (Downs, 2004; Roeser & Clark, 2004; Fisch, 1981). The costs of these physiologic methods have decreased in recent years. This increases the feasibility of using them for screening in developing countries. Nevertheless, the sensitivity and specificity of these methods is relatively low when compared with pure-tone audiometry. In addition, both of these methods do not aim to measure hearing per se, but they aim to investigate middle and inner ear functions (Berg et al., 2006; McPherson & Olusanya, 2006).

The WHO has suggested that children in developing countries should be screened using audiometers at school entry (Rao et al., 2002). If this recommendation is followed, a pure tone air conduction audiometer will be an essential component of the hearing screening.
The purpose of the audiometer is to determine whether a person can hear tones of different frequencies at a fixed level of intensity. It has been reported that a pure-tone audiometer is an accurate method of hearing screening (Berg et al. 2006). Though the effectiveness of pure-tone audiometry has been verified, the costs associated with it are considerable and the equipment may be unaffordable for many developing countries. In addition, pure-tone audiometric screening can only be reliably performed with a qualified tester (Roeser & Clark, 2004). This further increases the costs of carrying out audiometric screening.

In order to reduce the cost of hearing screening using pure-tone audiometers, various low-cost audiometers have been developed. One of the alternatives was the Liverpool Field Audiometer (LFA). The LFA was a hand-held audiometer which was operated manually. It was designed for hearing screening in developing countries. One study has shown that the LFA was a reliable device for hearing screening, except test-retest reliability was low at 500 Hz (McPherson & Knox, 1992). Another alternative is the Welch-Allyn Audioscope, which is also hand-held. Studies have revealed that the Audioscope, when used at 25 dBHL and 40 dBHL, is a reliable instrument, with high sensitivity and specificity in hearing screening (Frank & Pertsens, 1989). However, the use of these methods in hearing screening should be treated with caution as the false positive rate is quite high when intensity levels are low (Bess, Dodd-Murphy, & Parker, 1998).

In order to develop a low-cost audiometer for hearing screening in developing countries, the present study aims to investigate the effectiveness of a low-cost computer-based audiometer in hearing screening for school-aged children. There are several reasons supporting the use of a computer-based audiometer in hearing screening.

The application of computer technology in health care has been a new direction for hearing screening in recent years, especially in developing countries. With the advances in computer technology, the digital signal can now be stored in computer directly and the intensity and frequency can be accurately adjusted (Downs, 2004; Givens et al., 2003;
There are several advantages in the computerization of hearing screening programs. Personal computers are common nowadays so the accessibility of hearing screening equipment in developing countries, especially rural areas therein, can be improved. Even if personal computers are not currently available in developing countries, the cost of purchasing one is low when compared with that of purchasing a conventional pure-tone audiometer. This is mainly due to the fact that pure-tone audiometers are specialized devices that are manufactured in a small amount, which makes them uncommon and costly (Wootton, 2001; Givens, 2003; Henry, Flick, Gilbert, Ellingson, & Fausti, 2003). Some laptop computers that cost approximately US$100 are being developed for low-income countries now. The low-cost computers will further increase the feasibility of computer-based audiometers in developing countries.

Another advantage is that computer-based audiometers are usually automatic. Therefore, professionals are rarely required to perform this screening method (Hong & Caszar, 2005). This can solve the problem that trained personnel are often required in hearing screening programs. One additional benefit is that the use of computers can make the recording of data and tracking of the records easier (Hong & Caszar, 2005).

Since the application of computers in hearing screening is still in its infancy, only a few researchers have studied the feasibility of using computers in audiometric testing. Some studies have investigated the use of tele-audiometric systems and have demonstrated the feasibility of using this new technology (Givens, 2003; Henry et al., 2003). In one study, an internet-based audiometric system was compared with the conventional audiometer in determining auditory thresholds of 31 adult participants. By comparing the obtained hearing thresholds of participants, it was found that the hearing thresholds for air- and bone-conduction only varied by 1.3 dB and 1.2 dB, respectively (Givens, 2003). In addition, the effectiveness of another computerized testing system has also been studied. This computer-automated system achieved good reliability in obtaining thresholds in both normal and
hearing impaired people (Henry et al., 2003). In conclusion, though only few researchers have attempted to study the effectiveness of computer-based audiometers, the results of these researches have revealed good reliability of the computerized systems in hearing tests. The possibilities of integrating computers in audiometric testing should not be neglected.

The reliability of computer-based audiometers was usually evaluated on the basis of the accuracy in determining hearing thresholds (Givens, 2003; Henry et al., 2003). In this study, however, the feasibility of using a computer-based audiometer in hearing screening rather than in determining hearing thresholds was evaluated. The computer-based audiometer used is software-based, using the commercially available software named “Home Audiometer version 1.83”. This software was installed into a personal laptop computer to which a USB joystick and a supra-aural headphone were connected. Although this computer-based audiometer was used in hearing screening in this study, the computer-based audiometer was designed to obtain hearing thresholds.

In conclusion, the main aim of this study was to determine the accuracy of a computer-based audiometer in hearing screening. This was achieved by comparing results obtained with the computer-based audiometer and the conventional pure-tone audiometer. As mentioned previously, computerized audiometers have been found to reliably determine individual hearing thresholds. Therefore, it was hypothesized that a computer-based audiometer could also reliably be used in hearing screening. Results from the conventional pure-tone audiometer were treated as the “gold standard” in this study as the reliability of conventional pure-tone audiometry in hearing screening is high (Wang, Wang, Tai, Lin, & Shiao, 2002; Sideris & Glattke, 2006; Berg et al. 2006), and this screening method has been used extensively in past decades. Therefore, the new computer-based audiometer was compared with the conventional one to determine whether it was possible to replace the conventional audiometer in hearing screening in developing countries. Though the pure-tone audiometer was regarded as the “gold standard” in this study, it was not a “real” gold standard.
This was because the reliability of the audiometer may be low in low frequencies, e.g. 500 Hz, as the masking effect of ambient noise is high at these frequencies (McPherson & Olusanya, 2006).

Another aim of the study was to determine whether there is a frequency effect in hearing screening using the computer-based audiometer. In previous studies on the reliability of other low-cost audiometers, it was found that the reliability was low at low frequencies due to the abovementioned effect of background noise (McPherson & Knox, 1992). Hence, it was hypothesized that the computerized audiometer would also have lower reliability at low frequencies due to the presence of background noise.

In summary, the present study sought to answer the following two questions:

1. Is there any significant difference between the computer-based audiometer and conventional pure-tone audiometer in hearing screening?
2. Is there any significant difference between the pass/refer responses of the two audiometers at each frequency, or do both audiometers show a higher refer rate at low frequencies?

Method

Subjects

The subjects were 83 children (57 girls and 26 boys) aged between 6 and 11 years with a mean age of 6.9 years. They were primary 1 to 3 students who were recruited from two Hong Kong normal primary schools on a voluntary basis. Written consent forms were signed by the subjects' parents. A total of 83 out of the 105 children targeted responded positively and participated in the hearing screening program, amounting to a response rate of 79%. All of the subjects were native Cantonese speakers. Cantonese speakers were preferred as the instructions were given in Cantonese. The control of this factor eliminated the possibility that the subjects failed in the hearing screening due to an inability in understanding the
instructions. Table 1 summarizes the demographic characteristics of the 83 subjects.

Table 1

**Demographic Characteristics of the 83 Subjects**

<table>
<thead>
<tr>
<th></th>
<th>No. of subjects (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td></td>
</tr>
<tr>
<td>6; 00-6; 11</td>
<td>49 (59)</td>
</tr>
<tr>
<td>7; 00- 7;11</td>
<td>15 (18.1)</td>
</tr>
<tr>
<td>8;00 or above</td>
<td>19 (22.9)</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>26 (31.3)</td>
</tr>
<tr>
<td>Female</td>
<td>57 (68.7)</td>
</tr>
<tr>
<td><strong>Grade</strong></td>
<td></td>
</tr>
<tr>
<td>Primary 1</td>
<td>60 (72.3)</td>
</tr>
<tr>
<td>Primary 2</td>
<td>15 (18.1)</td>
</tr>
<tr>
<td>Primary 3</td>
<td>8 (9.6)</td>
</tr>
</tbody>
</table>

**Testers**

The two hearing screening tests were conducted by three testers. The three testers were undergraduate speech pathology students who had received 12-hour training in conducting conventional pure-tone air-conduction hearing screening. The testers had not received any training in conducting computer-based hearing screening. The testers were randomly selected to operate the two screening audiometers.

**Test Environment**
Hearing screening was conducted in two quiet, non-sound treated rooms at each school. Rooms were selected based on the ambient noise level as measured by a sound level meter. The ambient noise levels met ANSI standards (ANSI-1991). The noise level was measured on five occasions randomly during testing. The average noise level obtained in each room at the two schools was summarized in Table 2.

Table 2

*Average Noise Level (dB A) in Two Testing Rooms at Two Schools (School 1 and School 2)*

<table>
<thead>
<tr>
<th></th>
<th>Average Noise Level (dB A)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>School 1</strong></td>
<td></td>
</tr>
<tr>
<td>Room 1</td>
<td>48.7</td>
</tr>
<tr>
<td>Room 2</td>
<td>48.6</td>
</tr>
<tr>
<td><strong>School 2</strong></td>
<td></td>
</tr>
<tr>
<td>Room 1</td>
<td>45.3</td>
</tr>
<tr>
<td>Room 2</td>
<td>43.0</td>
</tr>
</tbody>
</table>

**Equipment**

**Conventional pure-tone audiometer**

A portable pure-tone audiometer (Madsen Micromate screening audiometer) was used in screening. The audiometer was calibrated according to 1989 American National Standard Institute (ANSI) standards before testing commenced.

**Computer-based audiometer**

i) System description

The computer-based audiometer is shown in Figure 1. It consisted of (1) a personal computer (IBM ThinkPad Laptop PC, model T22), (2) a headphone (Ovann OV88OV circumaural headphones) and (3) a joystick (Blazepro USB Joystick). The headphone and the joystick were connected directly to the PC.
The computer audiometer software, i.e., Home audiometer version 1.83, was installed into the PC. The program is automatic except the testers control the commencement of the test. The software was programmed to determine hearing thresholds by presenting tones at various levels of intensities and frequencies and recording responses from the subjects.

The ranges of frequencies tested were determined by the software and could be preset by the testers. Four frequencies—500, 1000, 2000 and 4000 Hz—were selected for the purpose of hearing screening according to the ANSI standard (ANSI-1991). The following parameters were preset by the software and could not be adjusted:

1. Stimulus: pulsed tone
2. Start side: Left ear
3. Sequence of frequency presentation: from 500, 1000, 2000 then 4000 Hz and retest 1000 Hz
4. Starting level
5. Rate of presentation of tones

The computer-based audiometer was biologically calibrated before testing commenced according to the accompanying instructions.
Procedures

All subjects were screened using the portable pure-tone audiometer and the computer-based audiometer. The test order was randomly assigned. The two screening tests were conducted on the same day to minimize any confounding effects of changes in the children's auditory status. In each session of hearing screening, two testers were assigned randomly to operate the two audiometers. The testers had no knowledge of the alternate test results, i.e., testers were blind to other screening outcomes.

i) Conventional pure-tone screening using the portable audiometer

Each subject was seated at a right angle to the tester. The subjects were fitted with ear phones and were screened bilaterally. The screening was conducted at 30 dBHL for frequencies 500, 1000, 2000 and 4000 Hz. The testers started testing at 30 dBHL at 1000 Hz in the right ear. Then, 2000 Hz, 4000 Hz and 500 Hz were tested. At each frequency, the tones were presented three times. The subjects were asked to respond by pressing a button as long as they heard a tone.

Pass/refer criterion: The subjects passed the screening if they were able to respond to two tones (out of 3 tones) at 30 dBHL for all frequencies. Inability to respond to two tones at any single frequency was regarded as fail. The responses were noted on a screening form.

ii) Hearing screening using the computer-based audiometer

Each subject was seated at a right angle to the tester. The subjects were fitted with ear phones and were screened bilaterally. The first test frequency was 500 Hz in the left ear, the tones started at a constant level (0 dBHL) which was predetermined by the software. The presentation of tones followed the following order:

1. The intensity level increased (step size 1 dBHL) until the subjects responded by pressing a joystick button.

2. If the subjects responded, the intensity level decreased (step side 1 dBHL) until the subjects failed to respond by pressing the joystick button.
3. Thereafter the intensity level increased until the subjects responded again. Depending on the subjects' responses, the intensity level increased and decreased several times to determine a hearing threshold. Based on the hearing threshold attained at the previous frequency, the starting level of the subsequent test frequency was calculated and procedures 1 to 3 were repeated. A screen shot of the computer-based audiometer in operation is shown in Figure 2. The hearing thresholds at each frequency and for each ear are shown.

![Screen shot of the computer-based audiometer.](image)

**Figure 2.** Screen shot of the computer-based audiometer.

**Pass/refer criterion:** Unlike the conventional screening audiometer, the computer-based audiometer automatically determines the hearing threshold of the subjects. Two criteria were selected in deciding the pass/refer responses. In criterion 1, the same criteria as in the conventional hearing screening was used, i.e., failure to respond at 30 dBHL or above at any frequency will be regarded as fail. In criterion 2, the screening level will be raised to 40 dBHL. This is done to compensate for the poor noise-excluding properties of the supra-aural headphone as it can raise overall thresholds by about 10 dBHL (Berger & Killion, 1989).
Follow-up Procedures

The parents and school representatives received hearing screening reports for all tested children. Recommendations were made regarding the appropriate follow-up procedures for referral cases.

Data Analysis

Data was analyzed using the Statistical Package for the Social Sciences (SPSS). To evaluate the accuracy of the computer-based audiometer, the overall referral rates (the proportion of subjects failed at any one frequency at either ear) between the computer-based audiometer and conventional pure-tone audiometer were compared using Chi-square test.

Additionally, the accuracy of the computer-based audiometer as a function of frequency was also analyzed using Chi-square test. However, the Fisher's exact test was used when one or more of the cells had an expected frequency of five or less.

Results

The effect of background noise at 500 Hz on the results of conventional hearing screening

Since the presence of background noise in hearing screening can raise hearing thresholds, especially at 500 Hz, the accuracy of the audiometers will be affected. In order to determine the extent of the effect of background noise in the study, the overall referral rates of conventional hearing screening before and after exclusion of the results obtained at 500 Hz in both ears were compared.

Before excluding the results obtained at 500 Hz, the percentage of children who failed the screening was 30%. When the results obtained at 500 Hz were excluded, the referral rate decreased by 15% in conventional pure-tone screening.

Comparison of the overall referral rates between two screening methods using two sets
The overall referral rates between two screening methods were calculated according to the referral criteria adopted for conventional hearing screening (> 30 dB HL) and compared the results with those according to two referral criteria used in computer-based hearing screening. The two criteria were

1) the hearing threshold is higher than 30 dB HL at any frequency and
2) the hearing threshold is higher than 40 dB HL at any frequency.

Table 3 summarizes the difference in the overall referral rates between two screening methods using 2 different sets of criteria.

When we used criterion 1 (> 30 dB HL) in both screening tests, the overall referral rate from the computer-based hearing screening test was higher than those from conventional hearing screening. The overall referral rates differed by 73%. Nevertheless, when the criteria in the computer-based audiometer was relaxed by 10 dB HL, the overall referral rate from the computer-based hearing screening test was similar to those from conventional hearing screening. The difference was only 3%.

To determine whether there was significant relationship between the results obtained from the conventional audiometer and the computer-based audiometer using two different sets of criteria, the Fisher’s exact test was employed. Using criterion 1, the result indicated that the data obtained was not significant at 0.05 level (Fisher's exact test, p=1.00). Therefore, it was concluded that there was no statistically significant relationship between the overall referral rates of the conventional pure-tone audiometer and the computer-based audiometer. In contrast, when criterion 2 was used, the result indicated that there was a significant relationship between two screening methods using chi-square analysis, $\chi^2 (1, N = 83) = 6.153$, $p \leq 0.05$.

of screening criteria
Table 3

**Difference in the overall referral rates between two screening methods (using 2 sets of criteria)**

<table>
<thead>
<tr>
<th>Conventional Audiometer</th>
<th>Computer-based Audiometer (Criterion 1)</th>
<th>Computer-based Audiometer (Criterion 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall referral rate (%)/ (No. of Subjects)</td>
<td>Overall Referral Rate (%)/ (No. of Subjects)</td>
<td>Overall Referral Rate (%)/ (No. of Subjects)</td>
</tr>
<tr>
<td>14%/(12)</td>
<td>87%/ (72)</td>
<td>17%/ (14)</td>
</tr>
</tbody>
</table>

Comparison between pass/refer rates as a function of frequency

Table 4 shows the referral rate at each frequency (500, 1000, 2000, 4000 Hz) and each ear (right and left ear) between the conventional pure-tone audiometer and the computer-based audiometer. Comparison of pass/ refer responses was made at different frequencies (500 Hz, 1000 Hz, 2000 Hz and 4000Hz) at each ear to determine whether there was a significant relationship between pure-tone audiometer and computer-based audiometer at each frequency at each ear. Chi-square/ Fisher's exact test was employed to compare the failure response at each frequency for each ear and the p-values are also shown in Table 4.

Table 4

**The Failure Fate (%) as a Function of Frequency at Each Ear between a Conventional Pure-tone Audiometer and a Computer-based Audiometer**

<table>
<thead>
<tr>
<th>Failure rate (%) / no. of subject failed</th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>4000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional pure-tone audiometer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right (18)</td>
<td>21.7</td>
<td>4.8</td>
<td>3.6</td>
<td>6.0</td>
</tr>
<tr>
<td>Left (14)</td>
<td>16.9</td>
<td>8.4</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Right (4)</td>
<td>4.8</td>
<td>8.4</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Left (7)</td>
<td>8.4</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>
Using criterion 1, there was a statistically significant relationship between the pass/refer responses at 2000 Hz in the right ear only (Fisher exact test, $p=0.037$). However, no significant relationship was found between the pass/refer responses at 2000 Hz in the left ear or at other frequencies (500 Hz, 1000 Hz and 4000 Hz) in either ear. In contrast, so far as criterion 2 is concerned, significant relationships were found at all frequencies except 500 Hz and 2000 Hz in the left ear.

**Mean difference between the hearing thresholds obtained from computer-based screening and the screening level (30 dBHL) for refer results**

The mean difference (in dBHL) in the hearing thresholds for each frequency tested obtained from the computer-based audiometer and the screening level (30 dBHL) of conventional audiometer was calculated for subjects who have passed the conventional hearing screening at a frequency but failed in computer-based screening at the same frequency. This is done to determine how different were the hearing thresholds obtained from the computer-based screening from the screening level, i.e., 30 dBHL. The means and standard deviations of the difference between the hearing thresholds obtained from the computer-based hearing audiometer and the screening level at each tested frequency were computed and compared. The results are presented in Table 5.

| Computer-based audiometer (criterion 1) | 65.1 (54) | 85.5 (71) | 51.8 (43) | 81.9 (68) | 12.0* (10) | 36.1 (30) | 37.3 (31) | 20.5 (17) |
| Computer-based audiometer (criterion 2) | 20.5 (17) | 31.3 (26) | 4.8* (4) | 13.3* (11) | 3.6* (3) | 3.6 (3) | 3.6* (3) | 7.2* (6) |

* $p \leq 0.05$

Table 5

*Mean and Standard Deviation of the Difference between the Hearing Thresholds Obtained*
from Computer-based Hearing Screening and the Screening Level (30 dBHL) for Subjects Who Have Passed Conventional Hearing Screening but Failed in Computer-based Screening at Each Frequency.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Ear</th>
<th>No. of subjects</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 Hz</td>
<td>Right</td>
<td>42</td>
<td>9.95</td>
<td>10.30</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>60</td>
<td>9.87</td>
<td>6.26</td>
</tr>
<tr>
<td>1000 Hz</td>
<td>Right</td>
<td>40</td>
<td>6.90</td>
<td>8.63</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>64</td>
<td>8.22</td>
<td>4.87</td>
</tr>
<tr>
<td>2000 Hz</td>
<td>Right</td>
<td>8</td>
<td>8.75</td>
<td>10.43</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>28</td>
<td>6.07</td>
<td>7.39</td>
</tr>
<tr>
<td>4000 Hz</td>
<td>Right</td>
<td>29</td>
<td>5.69</td>
<td>6.25</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>16</td>
<td>7.81</td>
<td>8.13</td>
</tr>
</tbody>
</table>

As indicated, the mean difference across difference frequencies in each ears ranged from 6.07 to 9.95 dBHL. In an overall trend, the mean difference between the hearing threshold and screening level generally decreased as the frequency increased. It can be clearly seen that the mean difference was the largest at 500 Hz.

**Discussion**

The computer-based audiometer is a low-cost audiometer that was designed to measure individual hearing thresholds automatically. This automated system was designed to determine the hearing thresholds at each tested frequency with 1 dBHL precision. The present study aimed to evaluate the possibility of applying the computer-based audiometer in hearing screening.
The accuracy of the computer-based audiometer was determined with reference to a conventional pure-tone audiometer. The conventional pure-tone audiometer was regarded as the “gold standard” in the study. Although the conventional pure-tone audiometer was regarded as the “gold standard”, its reliability in obtaining an accurate result at low frequencies in a non-sound treated environment is low.

It has been reported that there was high test-retest variability at 500 Hz due to the fact that background noise is usually at its greatest at 250 and 500 Hz (McPherson & Olusanya, 2006). In order to allow more accurate comparison, the results at 500 Hz might be excluded. In order to assess the effect of background noise on hearing screening in this study, the overall referral rates of pure-tone audiometer before and after excluding results obtained at 500 Hz in both ears were compared. The results indicated that the overall referral rates decreased by 15% when the results at 500 Hz were excluded. The overall referral rates, i.e., 14% after exclusion, were comparable to results of other researchers investigating the referral rates of hearing loss (Parving, 1999). This result suggested that excluding 500 Hz gives a more reliable result. As a result, results at 500 Hz in both ears were not included in comparing the overall referral rate between the computer-based and conventional pure-tone audiometer so as to reduce the effect of background noise on hearing screening.

**Comparison between a computer-based audiometer and a conventional pure-tone audiometer**

The overall referral rates of the computer-based audiometer and the conventional pure-tone audiometer were compared to investigate whether the computer-based audiometer can be an alternative to the conventional pure-tone audiometer. Nevertheless, no significant relationship was found in the overall referral rates when comparison was made between computer-based screening and conventional pure-tone screening using 30 dBHL as the screening level. In conventional pure-tone screening, only 12 out of 83 subjects failed and the
overall referral rate was 14.5%. However, 72 out of 83 subjects failed in computer-based hearing screening. The overall referral rate was 86.7%. The computer-based audiometer failed many subjects who passed the conventional hearing screening. This result indicated that the computer-based hearing screening failed to differentiate between children who failed in conventional pure-tone screening and who did not if 30 dBHL was selected as a screening level for the computer-based audiometer.

The present study failed to demonstrate the accuracy of computer-based audiometer in hearing screening when 30 dBHL was selected as the pass/refer criterion. The results were incompatible to previous studies that had demonstrated the good reliability of computer-based audiometers in obtaining hearing thresholds (Givens, 2003; Henry, et al., 2003; Hong & Caszar, 2005). Several explanations have been suggested to account for the discrepancy between the results of this study and the previous studies. The discrepancy might be accounted for by differences in the computer-based audiometers used. Although the computer-based audiometers employed in these studies were automatic in nature, some internal features such as the software installed and the headphones used were different between the present and the previous studies. Moreover, the calibration methods employed were also different. Another possible explanation is the difference in the conditions of conducting thresholds testing and screening tests. To obtain hearing thresholds, the tests must be conducted in a sound treated room, typically meeting ANSI S3.1-1991 standards (Givens, 2003; Henry et al., 2003). On the contrary, hearing screening is usually conducted in non-sound treated rooms like quiet classrooms or offices, which were used in this study. The background noise was considerably higher in non-sound treated rooms (Berger & Killion, 1989; Wong et al., 2007). Moreover, the subjects employed in the previous studies were adults, the difference in attention span between adults and children may affect the results of hearing testing. In summary, the differences in equipment employed, testing conditions and age of subjects may account for the variation in results between previous studies and the
present research project.

In this study, a significant relationship was found between the overall referral rates of computer-based audiometers and conventional pure-tone audiometers when the 40 dBHL criterion was used but the same could not be found when the 30 dBHL criterion was employed. This result suggested that when 40 dBHL was used as a pass/refer criterion for the computer-based audiometer, the computer-based audiometer showed results similar to that of the conventional pure-tone audiometer. In other words, for a subject who was screened as pass in conventional hearing screening, he was likely to be screened as pass in computer-based hearing screening. Nevertheless, if the 30 dBHL criterion was used, a subject who was screened as pass in the conventional hearing screening was more likely to be screened as fail in computer-based hearing screening. The poor performance of a computer-based audiometer when the 30 dBHL screening criterion was used might be accounted for by several factors.

First, it has been known that the use of poor noise attenuating headphones during computer-based screening can raise the subjects' thresholds (Frank, Greer, & Magistro, 1997; Berger & Killion, 1989). The headphones used in computer-based hearing screening were circumaural headphones but they were designed for leisure use, such as listening to music, and not specifically for hearing testing. It is known that earphones with poor noise attenuation properties can raise hearing thresholds (Henry et al., 2003). On the contrary, the noise attenuation properties of the headphones used in the conventional hearing screening were better as they were designed for hearing testing. The differences in the noise attenuation characteristics of the headphones might have adversely affected the consistency between the results of the two screening modalities.

Second, the computer-based audiometer is a type of automatic audiometer which the frequency and the intensity levels are preset by the software and controlled by the responses of subjects. The hearing results might be affected by the subjects' familiarity with the screening procedures (Zhao, Stephens, & Meyer-Bisch, 2002). As it is an automatic system,
the testers were not able to stop the test and reinstruct the children again. However, the testers were able to condition the children during conventional hearing screening if they found that the children were unfamiliar with the procedures. Research has shown that the hearing thresholds of normal-hearing people demonstrated a significant trend of improvement in repeated testing (Henry et al., 2003). This supports the belief that the hearing thresholds are affected by the subject’s familiarity with the procedures and that there is a potential learning effect.

Third, the subjects' concentration and alertness varied due to the longer duration of computer-based hearing screening (Zhao, Stephens, & Meyer-Bisch, 2002). As the hearing thresholds were obtained using 1 dB increments, the duration of the test was much longer than conventional hearing screening in which only 30 dBHL was tested. In addition, the screening required more concentration to listen to faint tones as the tones were presented at individual threshold levels. Therefore, it was possible that the children's concentration and alertness at the time of hearing screening affect the results of screening.

As it can be seen that 40 dBHL appeared to be a suitable criterion in hearing screening using computer-based audiometer in this study, it was possible that the 10 dBHL difference in screening criteria were able to compensate for the effect of different variables suggested above.

The increase in accuracy of the computer-based audiometer when the criteria were relaxed by 10 dBHL can be explained by calculating the mean difference between the hearing thresholds obtained from the computer-based screening and the screening level for those subjects who have passed the conventional hearing screening but failed in computer-based screening at that frequency. The results have indicated their hearing thresholds as measured by computer-based audiometer were only around 6-10 dBHL higher than the screening level despite the fact that the computer-based screening test has failed many subjects who have passed the conventional pure-tone screening. This 6 to 10 dBHL difference may be attributed
to the factors mentioned previously, such as the poor noise attenuation properties of the headphones used with the computer-based audiometer, subjects' familiarity with the procedures and the concentration and alertness of the subjects. Because there was a 6 to 10 dB difference only, the computer-based audiometer gave more reliable results when the criteria were relaxed by 10 dB.

**Comparison between computer-based audiometer and conventional pure-tone audiometer as a function of frequency**

In addition to comparing the overall referral rates between both screening methods, the accuracy of the computer-based screening was also investigated as a function of frequency in each ear. The pass/refer responses at each frequency in each ear for both screening modes were compared. The result has shown that if a 30 dBHL criterion was used, a significant relationship was found at 2000 Hz in the right ear only. No significant relationship between the pass/refer responses was found at other frequencies. On the contrary, when a 40 dBHL criterion was used, significant relationships were found at 1000 Hz, 2000 Hz and 4000 Hz. The result obtained from 40 dBHL was consistent with the results in the previous studies that the test-retest variability at low frequency was high due to the presence of background noise (McPherson & Knox, 1992).

The fact that a frequency effect was not observed when a 30 dBHL criterion was used might suggest that the background noise might not be the main factor affecting the accuracy of computer-based audiometers. Instead, variable(s) might be present and affect the accuracy of computer-based screening at all frequencies. It is possible that some variables such as subjects' familiarity with the screening procedures, concentration and alertness which have been suggested previously were the main contributing factors. Another possible explanation is that the due to the poor attenuation properties of the headphones used in the computer-based audiometer, the background noise affected to a large extent. Therefore, frequency effect was not observed.
Though a frequency effect was not observed when a 30 dBHL criterion was used, that a frequency effect existed was demonstrated by a significant relationship between the computer-based audiometer and conventional audiometer at higher frequencies (1000, 2000 and 4000 Hz) but not at 500 Hz. The results agreed with the previous studies that the reliability of screening at 500 Hz is low, attributed to the presence of background noise the masking effect of which is greatest at 500 Hz (Frank, Greer, Magistro, 1997; McPherson & Knox, 1992; Berger & Killion, 1989). Frequency effects can also be observed when calculating the mean difference between the hearing thresholds obtained from the computer-based hearing screening procedure and the screening level. As shown in Table 5, the mean difference between the hearing threshold and screening level generally decreased when the frequency increased. At 500 Hz, the mean differences were the largest which were 9.95 and 9.87 dBHL in right and left ears, respectively. The trend provides evidence that background noise was present and affected the accuracy of the computer-based audiometer.

**Limitations of the present study**

In this study, only 83 subjects were recruited. The sampling size was unlikely to be representative of the whole school population. The overall referral rate in this study was compared with the referral rate in previous studies. However, the sampling sizes in other studies were much larger than the present one. Therefore, the sampling size in the study may not be representative enough to make a truly representative comparison. In addition, the sample might be a biased one as the subjects were predominantly girls and 6 years old. It is possible that the females and students who were 6 years old were over-presented. The characteristics of the sample might be different from the target, i.e., school, population.

**Conclusion and clinical application**

In conclusion, the computer-based audiometer was an accurate method for hearing
screening if the screening criteria were adjusted. Moreover, several modifications should be made, based on the potential factors affecting the accuracy of the computer-based audiometer employed in this study:

1. The headphone should be replaced by another headphone with better noise attenuation properties. This should be done to reduce the raised threshold effect caused by the presence of background noise.

2. A pause function should be added so that the screening can be stopped manually at any time during the screening. This should be done so that the testers can stop the test any time when they find that the children are unfamiliar with the procedures or the children are tired.

3. There should be visual reinforcement during the screening test. This should be done to increase the attention span of the children on the screening.

Acknowledgements

I would like to express my sincere gratitude to Dr. Bradley McPherson for his guidance and support during the course of this dissertation. Thanks also go to Mr. Pang Sheung Ho and Ms. Leung Hei Man for their help during data collection. I would also like to thank the staff at St. Clare Primary School and the Catholic Mission School and all the students for their participation.
References


Olusanya, B. O., Swanepoel, D.W., Chapchap, M.J., Castillo, S., Habib, H., Mukari, S.Z., et
al. (2007). Progress towards early detection services for infants with hearing loss in developing countries. *BMC Health Services Research, 7*(14).


