Objective: To investigate the sensitivity and specificity in an automatic computer-controlled audiometric set-up, used for screening purposes.

Design: Comparison between standardized audiometry and automated audiometry performed in the same participants.

Study Sample: In total, 100 participants (51 females and 49 males) were recruited to take part of this study the same day they visited the hearing clinic for clinical audiometry. Ages varied between 18 and 84 years (mean 45.9 in females, 52.3 in males).

Results: The participants were divided into groups, dependent of type of hearing. A total of 23 had normal hearing, 40 had sensorineural hearing loss, 19 had conductive hearing loss and 18 showed asymmetric hearing loss. The sensitivity for the automated audiometry was 86%–100% and the specificity 56%–100%. The group with conductive hearing loss showed the poorest sensitivity (86 %) and specificity (56 %). The group with sensorineural hearing loss showed the smallest variation in difference between the two methods. Conclusions: The results show that automated audiometry is a method suitable to screen for hearing loss. Screening levels need to be selected with respect to cause of screening and environmental factors. For patients with asymmetric hearing thresholds it is necessary to consider the effect of transcranial routing of signals.

Keywords: Audiometry, computerized screening, hearing thresholds, hearing loss, TDH 39

INTRODUCTION

A large number of clinical audiograms are performed every year in Sweden. Besides clinical audiometry, even larger numbers of audiograms are performed yearly for screening purposes. According to this definition screening audiometry is used to establish unmasked pure tone thresholds above a certain screening level, with the purpose to establish if a hearing loss is present, and, if that is the case, the severity of it. Screening audiometry is performed in centers working with different aspects of health care. There are many reasons to perform screening audiometry. One important application is Hearing Conservation Programs (HCPs), to examine employees in working places were hazardous noise exposure and/or solvents could be present. Examples were HCPs are of fundamental importance are seen in military and occupational health care. The efficacy of such programs have been demonstrated.\[1,2]\ The hearing of pre-school and school children is investigated by screening audiometry at some occasions in order to identify those with hearing impairment not diagnosed by newborn hearing screening programs.\[3]\ Screening audiometry is also performed at the primary health care where people seek advice at the first signs of age-related hearing loss or other hearing problems.

Screening audiometry has been used in many countries for approximately 50 years. In the 1980s computerized audiometry was developed, but validation was executed only through laboratory experiments\[4,5]\ but not in clinical situations. Later comparisons between automated audiometry and pure tone audiometry have been done in smaller and
selected study groups.\cite{6,7} Mahomed-Asmail \textit{et al}.\cite{8} undertook investigation of automated audiometry in school children. Studies when investigating the validity of automated audiometry using internet or smartphone applications have been conducted.\cite{9,10,11} Automated audiometry has also been validated in a telehealth mode.\cite{12}

Screening audiometry, as well as clinically performed audiometry, can be conducted manually or automatically.

The purpose of the present study is to evaluate the clinical value of automated, computer-controlled audiometry by using manual pure tone audiometry, performed by a trained clinical audiologist, as gold standard.

**MATERIALS AND METHODS**

Automated audiometry was conducted at two hearing clinics belonging to the Dept. of Audiology and Neurotology, Karolinska University hospital, in the Stockholm County. The participants were invited to this study, which was performed at the same day each test person was visiting the clinic for a scheduled consultation regarding hearing problems, tinnitus, vestibular problems or combinations of these.

### Study groups

A consecutive selection of patients were invited to participate in the present study during a two week period in December 2011. Subjects below eighteen years of age were excluded, as well as persons with severe hearing loss/deafness, and persons with suspected cognitive impairment.

A total of 103 persons were invited to the study. Three out of the 103 were excluded from the study due to incomplete testing, or technical problems. Accordingly, 100 test persons, between 18 and 84 years of age (mean 49 years), were included in this study. Of these were 51 females and 49 were males. In the female group the age varied between 18 and 84 years (mean 45.9 years) and in the male group between 19 and 82 years (mean 52.3 years). All test-persons were given the same instructions as read by the test operators from a written paper. If the person was able to understand and follow instructions they were considered as suitable for participating in the study.

Information for each participant regarding age, sex, date, cause of consultation, the name of the audiologist who performed clinical audiometry and both audiograms (clinical and screening) was registered.

The numbers of test persons with normal hearing or different types of hearing loss is seen in Table 1.

### METHODS

The clinical audiograms (“gold standard”) included air conduction and bone conduction thresholds, performed monaurally according to ISO 8253-1 standard, using Telephonics TDH-39 ear phones, in soundproof booths. This is according to Swedish national clinical standards (modified Hughson-Westlake method). The audiograms were performed by several licensed audiologists.

Various clinical audiometers from the ordinary equipment at the clinic were used, all calibrated according to ISO 389-1. Air conduction hearing thresholds were manually established at 1 kHz, 1.5 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, 8 kHz, 1 kHz (re-test), 0.5 kHz, 0.25 and 0.125 kHz, for both ears separately. Bone conduction hearing thresholds were established at 1 kHz, 1.5 kHz, 2 kHz, 3 kHz, 4 kHz, 0.5 kHz and 0.25 kHz if the air conduction threshold was 15 dB HL or worse.

The automated, independently performed audiograms were supervised by the same person at each test site. Two automatic screening audiometers were used in this study (Entomed Scandinavian Audiometry 203 and 204) both together with TDH-39 ear phones equipped with Silenta noise reducing muffs. The audiometers were calibrated before the study was performed. At least five minutes before the first test-person of the day the audiometer was started up and the operator was listening to a test signal at

| Group | Type of hearing and criteria | Number of test persons | Males | Females |
|-------|-----------------------------|------------------------|-------|---------|
| 1     | Normal hearing (air conductive hearing thresholds ≤ 20 dB HL or max 25 dB HL at max two frequencies) | 23 | 6 | 17 |
| 2     | Sensorineural hearing loss (hearing thresholds ≥ 20 dB HL as well as the bone conductive thresholds close to the air conductive) | 40 | 24 | 16 |
| 3     | Asymmetric hearing loss (pronounced hearing loss at one ear or where the one ears air conduction thresholds was masked at two nearby frequencies or more) | 18 | 7 | 11 |
| 4     | Conductive hearing loss (a difference of 15 dB or more between the air – and bone conduction hearing thresholds at least two nearby frequencies) | 19 | 12 | 7 |
| Totally | | 100 | 49 | 51 |
1 kHz at a level of 40 dB HL in order to rule out any unexpected maladjustment i.e. hazardous sound levels.

The automated audiometry was performed in a silent, but not sound isolated, room, in order to mimic the normal situation for screening audiometry. The test persons were seated with their back against the audiometer with no possibility to observe the display of the audiometer while performing the test. The measurement took between 10 and 20 minutes. No threshold estimates were performed below 0 dB HL (“screening level”) and the setting of audiometers was that the hearing threshold defined as the lowest level where the test-person gave two positive responses out of three. Before the measurement was started an initially familiarization test at 1 kHz at a stating level of 40 dB HL was conducted. As soon as the familiarization test was approved, the automated audiometry started with hearing threshold determinations. The operator left the room during the test. The starting level for the subsequent test frequencies was at the same level as the threshold for the previous level. The duration of the stimuli was 1.3 seconds and the time between the stimuli was randomized between 3 and 5 seconds. The response from the test persons was registered during the presence of the test tone and up to 0.7 seconds three after. The frequencies were tested in the regular order (1 kHz, 1.5 kHz, 2 kHz, 3 kHz 4 kHz, 6 kHz, 8 kHz, 0.5 kHz, 0.25 and 0.125 kHz) with a re-test at 1 kHz, right ear, at the end of the test session. If the re-tested hearing threshold deviated 10 dB or more from the original registered threshold, the whole measurement was automatically stared all over again until the results were consistent. The test operators supervising the automated tests had no access to any information about the patient, such as medical journals, audiograms or the patients’ reason for visiting the clinic.

The order between the two measurements were varied and dependent on the schedule for the day.

Statistical analysis

The average of four frequencies (0.5, 1, 2 and 4 kHz) was calculated for both right and left ear, in both audiometric methods in each group and was used to summarize the outcome. Wilcoxon signed rank test was used to calculate significant differences between the hearing thresholds established using the two methods. The result was divided into the right and left ear when testing the sensitivity and specificity. In order to compare the results from automated audiometry with the clinical audiograms the hearing thresholds in the clinically performed audiograms were adjusted and set to 0 dB HL if the hearing threshold was established as better than 0 dB HL. In the case of not possible to establish any hearing threshold (screening or clinically performed audiogram) the non-response value was set to 129 for the opportunity not to totally exclude an observation at that specific frequency.

The participants were informed orally and writing and signed their informed consent.

The project was reviewed by and has received approval from the regional ethical review board in Stockholm, Sweden Ethical approval 2011/1961-31/2.

RESULTS

Out of the 100 participants 23 were considered as having normal hearing thresholds, 40 had a sensorineural hearing loss, 18 had asymmetric hearing thresholds (≤ 15 dB between the ears at two or more adjacent frequencies) and 19 had a conductive hearing loss [Table 1].

The four-tone averages (0.5, 1, 2 and 4 kHz) of the both ears, for the two measurements in all four groups and for all participants, are seen in Figure 1a and 1b.

It was no statistically significant difference between the results of the two measurements in either of the groups group 1 (n = 23), group 2 (n = 40), group 3 (n = 18), group 4 (n = 19) or in all participants (n = 100) (P > 0.05) in either right or left ear [Figure 1a and 1b].
The sensitivity in the present study is high, 87% or more in all groups, as well as in the whole population [Figure 1]. As expected, the variation is larger in the four groups of different types of hearing losses the use of clinical audiometer almost always gave lower four-tone average hearing thresholds compared to the screening audiometer [Figure 2a and 2b]. However, in the group of unilateral/asymmetrical hearing loss (group 3), and in the group with conductive hearing loss (group 4), lower hearing thresholds were more commonly seen in screening audiometry. This is most likely due to the effect of transcranial routing of signals from the better ear. The shadow curve that will occur in the audiogram in unmasked hearing thresholds could easily be misinterpreted and need to be aware of. The hearing thresholds established with the automated audiometer are unmasked, while the hearing thresholds with the clinical audiometer were masked if required due to methods. The levels of the masked thresholds were used in the present study.

As expected, the variation is larger in the four groups of hearing loss and in the whole population [Figure 1]. The definitions for group 1 permits only a variation between 0 and 20 dB HL.

The participants of this study probably mirror the patients that initially seek primary health care for evaluation of hearing acuity. The automated set-up in this study was selected in order to mimic the situations in different health care centers.

When calculating the four-tone average in all four groups of different types of hearing losses the use of clinical audiometry or the clinical “gold standard” audiometry.

The balance between the genders was as a result of coincidence and not a default requirement. However, the distribution between the genders was nearly 50% (51 females and 49 males). The test operators had no information of the subjects’ experience of screening audiometry or the clinical audiometry.

The participants of this study probably mirror the patients that initially meet patients with subjective hearing loss before they are referred to hearing clinics.

It is of great importance that patients that suffer from any kind of hearing loss is referred to the hearing rehabilitation in order to begin the rehabilitation process, however, it is also of importance that the patients are referred based upon the right criteria. If it is impossible to carry out an automated audiogram, a referral to the hearing clinic would be optional.

The aim of the present study was to evaluate automated audiometry, a method that can be used in occupational health care, in family doctor clinics and other non-specialized clinics that initially meet patients with subjective hearing loss before they are referred to hearing clinics.

The prevalence of any kind of hearing loss for the whole cohort in any ear was 77% (77/100). The sensitivity, specificity and positive and negative predictive values are shown in Table 2. The sensitivity for the automated measurements was 87% for the right ear and 98% for the left ear for the whole cohort (n = 100). When divided into the different groups of hearing losses it was between 86% and 100%. The specificity was 81% for the left ear and 93% for the right ear in the whole cohort (n = 100) and varied between 71% (group 4, left ear) and 100% (group 1, left ear). The negative predictive value was 89% for the right ear and 98% in the leaf ear for the entire study group (n = 100) and varied between 67% (group 4, right ear) and 100% (all groups left ear, and group 1 and 3, right ear) [Table 2].

**DISCUSSION**

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When calculating the four-tone average in all four groups of different types of hearing losses the use of clinical audiometer almost always gave lower four-tone average hearing thresholds compared to the screening audiometer [Figure 2a and 2b]. However, in the group of unilateral/asymmetrical hearing loss (group 3), and in the group with conductive hearing loss (group 4), lower hearing thresholds were more commonly seen in screening audiometry. This is most likely due to the effect of transcranial routing of signals from the better ear. The shadow curve that will occur in the audiogram in unmasked hearing thresholds could easily be misinterpreted and need to be aware of. The hearing thresholds established with the automated audiometer are unmasked, while the hearing thresholds with the clinical audiometer were masked if required due to methods. The levels of the masked thresholds were used in the present study.

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The sensitivity in the present study is high, 87% or more in all groups, as well as in the whole cohort. That indicates that the screening audiometry method used in this study is suitable to
In this study, the specificity in the present study is also high (56%–100%). The poorest result was seen in the group of conductive hearing loss, which could again be explained by the effect of transcranial routing of signals. The positive predictive value and the negative predictive value for the test is also high showing that the methods used here are suitable for identifying hearing losses i.e. the probability that a person with positive test result has normal hearing, as well as a person with a negative test result has a hearing loss [Table 2].

The concordance between the two types of audiometry was excellent for ears with normal hearing. The concordance was also fairly good for the subgroup of ears with sensorineural hearing loss, especially for the right ear. However, the variability of the PTAs was larger than for the normal subgroup, and there was a slight difference between the two methods.

The subgroup with asymmetrical hearing had rather similar median values for the two methods, but the variability of the results differed considerably. Most of the participants with asymmetrical hearing loss had mild to moderate PTA-differences between the ears. If ears with profound hearing loss had been included, the discrepancy between the audiological methods had probably been still more pronounced.

The subgroup with conductive hearing loss was similar to the asymmetrical subgroup, but even more pronounced differences between the methods could be observed. In all three subgroups including ears with hearing loss the outcome of the left ear was consistently poorer than that of the right ear. This was particularly valid for the variability, but also, to some extent, for the median values.

It can be concluded that automated audiometry has an excellent performance, comparable to manual audiometry, provided that the hearing is normal. The performance is also acceptable for ears affected with symmetrical sensorineural hearing loss. The situation is more complex for ears with asymmetrical or conductive hearing loss. The outcome of automated audiometry is fairly acceptable even for these subgroups, but the accuracy of the method is poorer than what is the case for manual audiometry. However, automated audiometry is a screening method, which can advantageously be combined with impedance screening. All patients who are diagnosed with abnormal screening results should be referred for a comprehensive clinical audiological evaluation.

The calibration of equipment is of great importance in both methods as has been showed before. The International organization of Standards (ISO) provides the international standards used for clinical and screening audiometers (www.iso.org).

In conclusion, the results from the present study show that the method for automated audiometry is very suitable to discriminate between ears with normal hearing from ears with hearing loss. A pronounced difference of the hearing thresholds between the ears can affect the outcome of the measurements. It is necessary that that calibration of the equipment is performed regularly.

In conclusion, the results from the present study show that the method for automated audiometry is very suitable to discriminate between ears with normal hearing from ears with hearing loss. A pronounced difference of the hearing thresholds between the ears, as well as conductive hearing loss, can affect the outcome of the measurements. Automated audiometry is a screening method with the purpose to select patients for referral to Audiological/ENT services. It is necessary that that calibration of the equipment is performed regularly.

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Nil.

**Conflicts of interest**

There are no conflicts of interest.

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