

Teleaudiometry as a screening method in school children

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OBJECTIVE: To compare the efficacy and feasibility of teleaudiometry with that of sweep audiometry in elementary school children, using pure-tone audiometry as the gold standard.

METHODS: A total of 243 students with a mean age of 8.3 years participated in the study. Of these, 118 were boys, and 125 were girls. The following procedures were performed: teleaudiometry screening with software that evaluates hearing at frequencies of 1,000, 2000 and 4000 Hz at 25 dBHL; sweep audiometry screening in an acoustic booth (20 dBHL at the same frequencies); pure-tone audiometry thresholds in an acoustic booth (frequencies of 500, 1000, 2000 and 4000 Hz); and acoustic immittance measurements.

RESULTS: The diagnostic capacities of the teleaudiometry/sweep audiometry screening methods were as follows: sensitivity = 58%/65%; specificity = 86%/99%; positive predictive value = 51%/91%; negative predictive value = 89%/92%; and accuracy = 81%/92%. Teleaudiometry and sweep audiometry showed moderate agreement. Furthermore, the use of these methods in series with immittance testing improved the specificity, whereas parallel testing improved the sensitivity.

CONCLUSION: Teleaudiometry was found to be reliable and feasible for screening hearing in school children. Moreover, teleaudiometry is the preferred method for remote areas where specialized personnel and specific equipment are not available, and its use may reduce the costs of hearing screening programs.

KEYWORDS: Hearing; Screening; Child; Audiometry; Telemedicine.

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■ INTRODUCTION

Hearing impairments are “invisible” problems and are often overlooked in less developed countries. Permanent hearing loss is a major global health problem. It is estimated that one in every 10 people is affected by some degree of hearing loss (1).

Although epidemiological data on the prevalence of hearing problems in developing countries are often incomplete, it is estimated that hearing loss is twice as common in these countries as in developed countries (2). Universal newborn hearing screening programs promote the early identification of and intervention in cases of permanent hearing loss. However, transient hearing loss, such as conductive hearing loss, may occur after the neonatal period and is often overlooked. Additionally, otitis media is one of the most common disorders in childhood; as a consequence

of otitis media, approximately 80% of school-age children suffer at least one form of temporary hearing loss within a given year (3). Thus, hearing screening programs in schools may help identify children with possible progressive and permanent hearing loss that occurs after birth and children at risk for conductive hearing loss.

Chronic otitis media is the leading cause of mild to moderate hearing loss in developing countries (1,4), and the *World Health Organization* (5) considers it one of the greatest public health problems for many people around the world, with substantial social and economic costs (1).

Hearing health actions in primary care should include the promotion, prevention and early identification of hearing problems in the community. However, primary care services and even secondary and tertiary care services in developing countries are not aware of or cannot meet the demand, as only a limited number of health professionals provide hearing care (1,6).

Therefore, it is necessary to adopt low-cost techniques or procedures that are accessible to areas that lack the funding to purchase technological or human resources to identify groups that are at risk of hearing impairment at the earliest possible stage, thereby helping to reduce inequalities in health (7).

Teleaudiometry has recently emerged as a component of teleaudiology. It uses audiometry tools and standards for

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hearing screening that can be automatically performed using software installed on a computer. Remote diagnosis has been shown to be feasible and safe despite the difficulties caused by the lack of personal contact (8).

This technology may permit assessments of the risk of hearing loss for patients in rural and remote areas who have no other access to a hearing-screening program. It may also reduce the costs for the patient and the health care system because teleaudiometry does not require specialized personnel or equipment (9–11). The creation and validation of teleaudiometry protocols are therefore essential to permit the routine implementation of this technology in health programs.

In this study, we evaluated the efficacy and feasibility of teleaudiometry compared to that of sweep audiometry in elementary school children, using pure-tone audiometry as the gold standard.

■ MATERIALS AND METHODS

The study was approved by the Research Ethics Committee of the institution (number 257/10). All of the elementary school children at a public school in Sao Paulo, Brazil were invited to participate in the study, and a total of 243 students accepted (118 boys and 125 girls; 6 to 15 years old; mean age: 8.3 years old; SD 1.6; median: 8).

We performed the procedures in the following order: otoscopy, immittance testing, teleaudiometry screening, sweep audiometry screening, and conventional pure-tone audiometry. All of the procedures were performed by an audiologist at the school. Noise was monitored throughout the data collection process (sound pressure level meter DEC-460) and remained below 50 dB (A) (12).

Immittance Testing

Immittance testing (typanometric curve and acoustic reflex testing at frequencies from 500 Hz to 4000 Hz) was performed using the Madsen Otoflex100 (GN Otometrics, Taastrup, Denmark).

Teleaudiometry

The teleaudiometry procedure was performed using specific software installed on a notebook computer (HP Pavilion® dv4000) with a 2.0 GHz Intel® Centrino, 1024 MB memory, 100 GB hard drive, SoundMAX Integrated Digital Audio® sound card processor and a 15.4" screen. TDH 39 headphones were used with a P10-P2 connector adapter.

This procedure was developed by Campelo and Bento (11) to be run on the ".Net" programming platform that interfaced with patient registration records, with remote communication between the interface and the central database via the Internet. The software runs on the Windows XP® operating system and requires a sound card for the automated simulation of audiometric screening. Thus, pure tones of 1000 Hz, 2000 Hz and 4000 Hz at an intensity of 25 dBHL are transmitted through the TDH 39 headphones separately for each ear. The execution algorithm and analysis are similar to the procedures recommended for audiometric screening (13). It should be emphasized that this procedure was not performed in a soundproof booth, and the equipment was calibrated to ensure that the intensity produced by the software and the earphones was correct.

Before beginning the test, each participant underwent a training session to ensure that he or she understood the task. After training, the sounds were presented to each ear, and

the children were instructed to press the space bar after they heard each stimulus. All of the children included in the study understood the instructions.

At the end of the teleaudiometry screening, a positive or negative result was automatically generated by the program. The data were automatically saved by the software and remained stored in the notebook until they were transmitted (via the Internet) to the central database for the evaluation and management of the results.

Pure-Tone Audiometry and Sweep Audiometry Screening

A Grason Stadler GSI-68 audiometer, TDH 39 headphones and a Redusom brand soundproof booth were used.

Pure-tone audiometry (air conduction) was performed at frequencies ranging from 500 Hz to 4000 Hz for the hearing threshold test. If the hearing threshold was ≥ 15 dB HL, bone conduction pure tone audiometry was also performed. The sweep audiometry screening (air conduction) was performed at an intensity of 20 dBHL and frequencies of 1000 Hz, 2000 Hz and 4000 Hz (13).

Analysis Criteria

For the teleaudiometry, a response to two of the three tones presented at 25 dBHL for each tested frequency in both ears was considered a negative screening (i.e., normal hearing).

Hearing thresholds higher than 15 dBHL in conventional pure tone audiometry were considered hearing loss (14). Notably, in cases of an air-bone gap or abnormal immittance, the result was considered abnormal even if the 15 dBHL thresholds were not exceeded.

The sweep audiometry screening classified children as "pass" or "fail". According to the criterion adopted, responses to two or three presentations of the stimuli at each of the frequencies tested (1,000, 2,000 and 4,000 Hz) were considered "pass" (13).

Immittance testing was considered abnormal in the presence of type B or C tympanometry in the case of elevated (above 100 dBHL) or absent acoustic reflexes (15,16).

Statistical Analysis

The McNemar chi-square and Kappa coefficient tests were used.

To evaluate the diagnostic accuracy of the tests and to compare the evaluations in parallel and in series (to improve the sensitivity or specificity of the screening program) using conventional pure-tone audiometry as the gold standard, the following measures were calculated: sensitivity, specificity, positive predictive value, negative predictive value and accuracy. Considering the results (pass or fail) for each screening test (immittance or teleaudiometry), we had specific hypotheses regarding what would happen if the test were applied using the serial or parallel approach. In this paper, we decided to first consider the teleaudiometry results (pass or fail); if there was a failure, we then considered the immittance test results (serial approach). In the parallel combination, both procedures' results were considered simultaneously.

A significance level of 0.05 was adopted for the hypothesis tests.

■ RESULTS

The frequency distribution and percentages for the conventional pure-tone audiometry results for the type of



Table 1 - Frequency distributions and percentages for conventional pure-tone audiometry by the type of hearing loss in the right and left ears.

Hearing loss	Right Ear		Left Ear	
	N	%	N	%
Conductive	43	17.7	46	18.9
Sensorineural	2	0.8	1	0.4
No hearing loss	198	81.5	196	80.7
Total	243	100	243	100

Table 2 - Frequency distributions and percentages for teleaudiometry and conventional audiometry.

Conventional audiometry	Teleaudiometry		Total
	Passed	Failed	
Normal	168 69.1%	27 11.1%	195 80.2%
Abnormal	20 8.2%	28 11.5%	48 19.8%
Total	188 77.4%	55 22.6%	243 100.0%

Table 3 - Frequency distributions and percentages for sweep audiometry and conventional audiometry.

Conventional audiometry	Sweep		Total
	Passed	Failed	
Normal	192 79.0%	3 1.2%	195 80.2%
Abnormal	17 7.0%	31 12.8%	48 19.8%
Total	209 86.0%	34 14.0%	243 100.0%

($p < 0.001$ McNemar test)

hearing loss in each ear are presented in Table 1. Notably, the highest prevalence was of normal hearing in both ears, followed by conductive hearing loss.

Table 2 shows the frequencies and percentages of the teleaudiometry results compared with the conventional pure-tone audiometry results. Notably, 69.1% of individuals passed both the conventional pure-tone audiometry and teleaudiometry screenings. When sweep audiometry was compared with conventional pure-tone audiometry (Table 3), 79% of individuals passed both tests.

When comparing teleaudiometry to sweep audiometry, we observed that 83.2% of individuals had the same hearing status for to both tests. We also observed that fewer children failed the sweep audiometry test than failed the teleaudiometry screening (Table 4). The observed Kappa coefficient value was 0.443 (standard error = 0.071), which indicates moderate agreement between the two tests.

To evaluate the diagnostic accuracy of the screening methods considering conventional pure-tone audiometry as the gold standard, the following measures were calculated: sensitivity, specificity, positive predictive value, negative predictive value and accuracy. In addition, the same measurements were obtained for teleaudiometry performed either in parallel or in series with immittance testing (Table 5).

Table 4 - Frequency distributions and percentages of results for sweep audiometry and teleaudiometry.

Teleaudiometry	Sweep audiometry		Total
	Passed	Failed	
Passed	178 73.3%	10 4.1%	188 77.4%
Failed	31 12.8%	24 9.9%	55 22.6%
Total	209 86.0%	34 14.0%	243 100.0%

($p = 0.001$ McNemar test)

DISCUSSION

In this study, we evaluated the efficacy and feasibility of using teleaudiometry to screen for hearing loss in children attending elementary school.

With improved technology, teleaudiometry has recently become a viable option for hearing tests. Teleaudiometry software can be used on portable computers, and data can be transmitted via the Internet (synchronously or asynchronously) and stored in a central database. Additionally, the results can be analyzed remotely by experts, and patients can be followed up from a distance (2,17,18).

This technology offers remote communities easier access to hearing health care by reducing costs and providing remote hearing screening services. However, the creation and validation of teleaudiometry protocols are essential to their implementation within routine health programs (19,20).

The hearing loss prevalence observed in this study is similar to the prevalence reported in other studies (19,21–24). In a previously conducted survey (25), the prevalence of hearing loss in children varied from 3.9 to 24.5%, and the prevalence of middle ear disorders ranged from 7.3 to 36.2%. This great variability in prevalence may be explained by the use of different evaluation protocols and by the characteristics (e.g., age and socioeconomic status) of the children who participated in the various studies cited above (25).

Regarding sweep audiometry, a review that analyzed a number of studies reported high values of sensitivity (86–100%) and specificity (70–99%) (26), confirming the validity of the test for identifying hearing loss in children. The sensitivity and specificity values for sweep audiometry that were found in this study corroborate the results of previous investigations.

Furthermore, this study obtained a sweep audiometry accuracy of 92%, suggesting that this method is highly reliable for identifying hearing impairment in school children older than 6 years and corroborating previous studies (26–28).

Notably, the sensitivity value obtained for sweep audiometry in this study (65%) may have been affected by possible conductive components, which often only reach a frequency of 500 Hz (29). This frequency was not measured with sweep audiometry but was verified with conventional pure-tone audiometry.

Fewer children passed the teleaudiometry test than the conventional pure-tone audiometry screening. This difference can be explained by both attentional factors and environmental noise (audiometry was performed in a soundproof booth, whereas teleaudiometry was performed in an environment without acoustic treatment). Although



Table 5 - Summary of the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and accuracy (confidence interval) for all procedures, using conventional pure-tone audiometry as the gold standard.

Procedures	Sensitivity	Specificity	PPV	NPV	Accuracy
Teleaudiometry	58% (44–72%)	86% (81–91%)	51% (38–64%)	89% (85–94%)	81% (76–86%)
Sweep	65% (51–78%)	99% (97–100%)	91% (82–100%)	92% (88–96%)	92% (88–95%)
Tests in parallel	98% (94–100%)	81% (75–87%)	56% (45–67%)	99% (98–100%)	84% (80–89%)
Tests in series	50% (36–64%)	97% (94–99%)	80% (66–94%)	89% (84–93%)	89% (85–93%)

these factors were controlled (either by confirming the child's understanding of the instructions for teleaudiometry or by monitoring the environmental noise), they may have affected the results and should therefore be considered in future studies.

Unlike the sweep audiometry and pure-tone audiometry tests, the teleaudiometry did not take place in a soundproof booth. Because some locations do not have a soundproof booth, we chose to use teleaudiometry as it would be used under those conditions. Via remote access, a better correlation may have been obtained among tests had we performed teleaudiometry in a soundproof booth; however, we still believe the tests can be compared with one another other.

McPherson et al. (23) evaluated a computer-based audiometry method used with school children and found a sensitivity of 78% and a specificity of 92%. Those values are better than the ones obtained in the present study. McPherson et al. also detected a failure rate of 15% for computer-based audiometry, whereas our study found a 19.34% failure rate for teleaudiometry. However, notably, McPherson et al. (23) and our study applied different analysis criteria for both conventional pure-tone and computer-based audiometry. For instance, in the McPherson et al. (23) study, hearing was considered abnormal only when thresholds were above 40 dBHL. This difference most likely contributed to the higher sensitivity and specificity values because this criterion facilitates the identification of hearing loss, especially when evaluations are not conducted in a soundproof booth and can suffer from interference from environmental noise.

In addition, we found a high degree of accuracy for teleaudiometry, which indicates that this method is reliable and valid. No other studies in the literature have evaluated teleaudiometry as a screening method; therefore, we were unable to compare our results for this method with those of other groups. Some studies (8,10,17,18,30) used teleaudiometry to determine tonal hearing thresholds and did not use the pass / fail criteria. The results of these studies are generally expressed in terms of the number of dB by which the teleaudiometry-determined thresholds differ from the thresholds determined by conventional pure-tone audiometry. Moreover, all of these studies examined adult populations. Nonetheless, all of these studies show that teleaudiometry provides reliable data that is similar to that obtained with conventional pure-tone audiometry.

When comparing the diagnostic ability of sweep audiometry to that of teleaudiometry, we found that the values obtained for sweep audiometry were slightly better. This difference may result from the fact that teleaudiometry was not conducted in the soundproof booth.

Although noise was monitored during data collection, the school environment is known to be a noisy place. Because of the characteristics of the sound pressure level meter, noise monitoring was conducted using instant readings. Noise peaks, though subjectively imperceptible to those performing

the test, may have occurred at certain times and may have influenced some measurements, especially in the case of teleaudiometry, which was performed outside the booth.

However, it should be emphasized that teleaudiometry will most likely be used in environments where there are no sound pressure level meters. Therefore, it is important to consider the results obtained in real environments. Obviously, basic precautions, such as choosing a quiet room and suspending the test during breaks from classes or other times when noise levels are higher, should be taken. Another possibility to consider is the use of shielded headphones or headphones with active noise cancellation, which can also reduce interference from environmental noise (31).

When evaluating the agreement between the teleaudiometry and sweep audiometry results, we obtained a Kappa coefficient that indicated moderate agreement, although teleaudiometry had lower sensitivity and specificity values compared with sweep audiometry.

Analyses of diagnostic methods in series and in parallel are used to improve the sensitivity or specificity of a screening program. In the series method, an initial test is performed, and if the result is positive, a second test is performed. This type of analysis improves the specificity of the results. In the parallel combination, both tests are performed at the same time, and any positive test is considered a positive result; this method improves the sensitivity of the program (32).

In this study, we decided to initially conduct teleaudiometry and then, if the screening was positive for a hearing problem, run the immittance test (serial approach). In the parallel combination, both procedures were simultaneously performed.

When analyzing the results of both tests in parallel, we observed that 80.2% of children passed the conventional pure-tone audiometry test, whereas 65.4% passed the teleaudiometry test associated with the immittance test. As an objective test, abnormal immittance measures are indicative of middle ear disorders and can reveal possible early and/or subclinical changes (33) that were not previously detected by pure-tone audiometry or teleaudiometry. This possibility may explain the higher number of failures in immittance testing (performed in parallel with teleaudiometry) was consistent with the number of pure-tone audiometry "fails".

The values obtained by evaluating the diagnostic accuracy of the parallel combination demonstrate that these procedures have high sensitivity, i.e., they show high reliability for detecting both true positives and true negatives.

A previous study of the diagnostic accuracy of parallel tests for hearing screening using different procedures (questionnaires and immittance testing) obtained values of 95–97% for sensitivity, 35–55% for specificity and 49–55% for accuracy (32). Our findings show similar sensitivity and better specificity and accuracy values compared with that study.



Notably, the parallel combination using immittance as one of the tests may better identify true-positive cases because of the objectivity of immittance measures. However, the parallel approach increases the cost of screening because it requires specialized equipment and professionals (32).

When analyzing the results of series testing, 87.7% of the children passed the screening (teleaudiometry followed by immittance testing for those who failed the first procedure). The values obtained with this combination yielded higher specificity.

Olusanya (25) found a sensitivity of 60% and a specificity of 58% in a series analysis that used two procedures (questionnaire/otoscopy and tympanometry) to screen school children, and Samelli et al. (32) observed between 60 and 95% sensitivity and between 62 and 88% specificity for a series combination (questionnaire and immittance testing). Both studies had slightly better sensitivity than the present study found for the series combination. However, the specificity and accuracy obtained in this study were higher than in those studies.

Furthermore, it is important to remember that performing procedures in series reduces the costs of screening compared with performing procedures in parallel because only the individuals who fail teleaudiometry and undergo immittance testing.

The calculation of screening program costs should consider not only the direct cost of screening procedures but also the costs of the evaluations performed as a result of screening. For this reason, higher specificity values are desirable to reduce the costs associated with false-positive results (e.g., parents missing work, transportation costs associated with test taking, and other unnecessary procedures) (34).

Thus, when considering both the direct and indirect costs of screening and accuracy, the most consistent approach appears to be conducting teleaudiometry in schools with the assistance of school professionals who are not specialists. Children who fail could then undergo immittance testing performed by an audiologist at the school. Only children who also fail the immittance test would be referred for a complete audiological evaluation outside of school.

However, this serial option may not be feasible for all locations because of a lack of either qualified professionals or specific equipment. In these cases, we suggest using teleaudiometry rather than sweep audiometry, although the sensitivity, specificity and accuracy values of the former are somewhat lower.

We must also consider that the accuracy of teleaudiometry was similar to the accuracy of parallel tests and that the specificity was higher. The sensitivity of teleaudiometry alone was superior to the sensitivity of the tests in series. Therefore, it is evident that teleaudiometry presents diagnostic reliability comparable to other procedures for hearing screening. Teleaudiometry also has certain advantages over other methods (10,23,35–37), as follows:

- It does not require specific equipment; the software can be installed on any compatible computer, which is available in most schools.
- The adapted TDH headphones cost substantially less than an audiometer.
- Teleaudiometry is performed automatically and can be administered by non-specialist health professionals who are supervised remotely by an audiologist.
- Teleaudiometry can be performed outside a soundproof booth, in a silent room.

- The results (which are automatically determined by the software) can be remotely and asynchronously analyzed by audiologists after the results are transferred via the Internet to the central database, a process that is characterized as hearing screening at a distance.
- The follow-up of children who failed can also be managed remotely.

In conclusion, teleaudiometry showed reliability and feasibility as a hearing screening method for school children. Moreover, teleaudiometry has advantages for application in remote areas where specialized professionals and equipment are not available, thereby reducing the costs of hearing screening programs.

■ AUTHOR CONTRIBUTIONS

Botasso M, Sanches SGG, Bento RF, and Samelli AG participated in the conception and design of the work, performed the data analysis and wrote the manuscript. Samelli AG revised the manuscript.

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