Original Article

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Comparison of the results of conventional and user-operated automated pure-tone audiometry

Comparação dos resultados da audiometria tonal convencional e automatizada operada pelo usuário

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ABSTRACT

Purpose: to compare the auditory thresholds obtained in the conventional pure tone audiometry exam with the thresholds obtained in the user-operated automated pure tone audiometry. **Methods:** 40 individuals of both genders, aged between 18 and 30 years old, divided into two groups participated in the study: 21 individuals with prior knowledge of how to perform audiometry - audiology undergraduates who have already taken courses in audiological assessment - (Group 1); 19 individuals without knowledge about audiometry (Group 2). The procedures involved anamnesis, inspection of the external acoustic meatus, performance of tonal audiometry airway, in the frequencies 0.25, 0.5, 1, 2, 3, 4, 6 and 8KHz, in conventional or automated form, in an acoustically treated environment, with an interval of 15 minutes between audiometries. Results were analyzed using descriptive statistics (mean, standard deviation, absolute mean difference, and percentage) and comparative analysis using the Wilcoxon test (p value <5). **Results:** all the participants in the study had tonal thresholds within normal limits in audiometry. When considering the entire evaluated population, statistically significant differences were observed between the hearing thresholds obtained in the two audiometries (conventional and automated) at the frequencies of 1 KHz (p= 0,047) in the right ear and 0.25 (p= 0,001), 3 (p= 0,037) and 8 (p= 0,019) KHz in the left ear. The percentage of automated auditory thresholds that presented a maximum difference of ±5 dB from the conventional audiometry thresholds was 82.4% and 83% in the right and left ear, respectively. Comparing the means of the absolute differences of the auditory thresholds of the audiometry, a minimum and maximum value of 2.87dB of 5.75 dB, respectively were observed. **Conclusion:** it is observed that the auditory thresholds automated by air conduction were similar to those of conventional audiometry (gold standard). New technologies are necessary, but the presence of audiologists in the diagnostic and therapeutic processes is essential.

Keywords: Audiometry, Pure-tone; Hearing tests; Speech, language and hearing sciences; Audiometry; Health technology

RESUMO

Objetivo: comparar os limiares auditivos obtidos no exame de audiometria tonal liminar convencional com os limiares obtidos na audiometria tonal liminar automatizada operada pelo usuário. **Métodos:** participaram do estudo 40 indivíduos, de ambos os gêneros, com idade entre 18 e 30 anos, divididos em dois grupos: 21 indivíduos com conhecimento prévio sobre a execução da audiometria, graduandos em Fonoaudiologia, que já haviam cursado disciplinas de avaliação audiológica - (grupo 1); 19 indivíduos sem conhecimento sobre a execução da audiometria (grupo 2). Os procedimentos envolveram anamnese, inspeção do meato acústico externo, realização da audiometria tonal por via aérea, nas frequências 0,25, 0,5, 1, 2, 3, 4, 6 e 8 KHz, de forma convencional e automatizada, em ambiente acusticamente tratado, com intervalo de 15 minutos entre as audiometrias. Os resultados foram analisados por meio de estatística descritiva (média, desvio padrão, diferença média absoluta, e porcentagem) e análise comparativa por meio do teste de Wilcoxon (valor de p <5). **Resultados:** todos os participantes do estudo apresentaram audiometria com limiares tonais dentro dos padrões de normalidade. Ao considerar toda a população avaliada, observaram-se diferenças estatisticamente significativas entre os limiares auditivos obtidos nas duas audiometrias (convencional e automatizada) nas frequências de 1 KHz (p= 0,047), na orelha direita, e 0.25 (p= 0,001), 3 (p= 0,037) e 8 (p= 0,019) KHz na orelha esquerda. A porcentagem dos limiares auditivos automatizados que apresentaram diferença máxima de ±5 dBNA dos limiares da audiometria convencional foi de 82,4% e 83% na orelha direita e esquerda, respectivamente. Comparando-se as médias das diferenças absolutas dos limiares auditivos das audiometrias, observaram-se valores mínimo e máximo de 2,87 dBNA de 5,75 dBNA, respectivamente. **Conclusão:** os limiares auditivos automatizados por condução aérea foram similares aos da audiometria convencional (padrão-ouro). Novas tecnologias são necessárias, porém, é imprescindível a presença do fonoaudiólogo nos processos diagnóstico e terapêutico.

Palavras-chave: Audiometria de tons puros; Testes auditivos; Fonoaudiologia; Audiometria; Tecnologia em saúde

Study carried out at Faculdade de Medicina, Universidade Federal de Minas Gerais – UFMG – Belo Horizonte- (MG), Brasil.

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INTRODUCTION

According to the Pan American Health Organization (PAHO) [1], an estimated 217 million people have some degree of hearing loss in the Americas, with this number expected to increase to 322 million by 2050. The first World Report on Hearing, published by the World Health Organization (WHO) in 2021, highlights the deficiency and unequal distribution of qualified professionals as the main challenges to hearing care, which can be overcome through actions and the use of technologies[2,3].

Countries such as the United States of America have already integrated programs that seek to bring telemedicine in audiological services to remote and hard-to-reach areas[4]. These measures reduce waiting times and travel costs, in addition to expanding access to health services.

Health systems need to take action to prevent, diagnose and treat hearing loss[4]. Among the technological alternatives in the diagnostic process is automated audiometry, which proposes the performance of audiometric tests operated by the user to detect hearing thresholds. Conventional pure tone audiometry has a well-defined procedure and, for this reason, is suitable for automation[5]. Automated audiometry requires less intervention from an examiner during the execution of the test, since it presents a series of stimuli at predetermined levels[5], automatically researching hearing thresholds by frequency, based on the subject's response.

Automated audiometry may have the potential to increase access to hearing tests for socially vulnerable individuals, providing greater coverage for hearing health, increasing the number of individuals tested, without increasing the number of professionals[5]. Thus, it is an alternative to the disproportion between the number of professionals available in the health system and the large number of users who need access to hearing tests, following the significant telemedicine movement[5]. However, the participation of the audiologist is indispensable, even when using user-operated assessment systems[5], since they are responsible for carrying out the patient reception, anamnesis, otoscopic examination, instructions on how to perform the tests, interpretation of the tests, referrals and necessary treatment plans.

There is currently evidence on the clinical value of automated audiometry and its possible agreement with conventional pure tone audiometry[6]. Automated pure tone audiometry must be standardized in order to ensure a methodical process to be followed, which guarantees the reliability of the results compared to conventional audiometry considered the gold standard[5,6]. Due to the scarcity of studies and lack of standardization of the methods used in automated pure tone audiometry, the objective of the present study was to compare the hearing thresholds obtained in conventional pure tone audiometry with the limits obtained in pure tone audiometry operated automatically by the user.

METHODS

This is a comparative and cross-sectional study carried out from August to December 2022, approved by the Research Ethics Committee of the Federal University of Minas Gerais – CEP-UFMG, under opinion no. 2,693,169. All participants signed the Free and Informed Consent Form (TCLE), containing the procedures to be performed, as well as their risks and benefits, and agreed to participate in the research.

The study included the participation of 40 individuals of both genders, aged between 18 and 30 years, divided into two groups: 21 individuals, undergraduates in Speech Therapy, with prior knowledge in performing an audiometry exam, who had already taken audiological assessment courses - (Group 1); and 19 individuals, undergraduates in Speech Therapy, without knowledge about audiometry, who had not yet taken audiological assessment courses, and volunteers from other areas of knowledge - (Group 2). The sample was non-probabilistic. Data collection was carried out at the Functional Health Observatory, at the School of Medicine of the Federal University of Minas Gerais - OSF/UFMG, in an acoustically treated room. To select participants, digital invitations containing study information were distributed to the academic community and the general public.

The inclusion criteria were age between 18 and 30 years and absence of alterations in the external acoustic meatus inspection. The exclusion criteria adopted were the volunteer's withdrawal from the study included a failure to perform all the exams that comprised the research.

Procedures that comprised the research:

1. Anamnesis: a fixed and predetermined script was used to answer questions regarding previous history and current complaints related to hearing.
2. Meatoscopy: examination of the external auditory canal aimed at identifying and excluding any alteration that could interfere with the performance of the exams.
3. Conventional pure tone audiometry by air conduction (gold standard): performed in an acoustically treated environment, with the calibrated AUDIOSMART ® Echodia Audiometer type 3 IEC 60645-1 and using DD65 headphones. Participants received a response button and were instructed to press the button whenever they heard the sound signal, and were positioned with their backs to the examiner. The descending search method was used to determine the hearing thresholds. Thus, the stimuli were presented in a descending manner in steps of 10 dBHL (decibel hearing level) until there was no response. After there was no response, ascending stimuli were given in steps of 5 dBHL, until there were at least two responses in four stimuli presented. The initial threshold of the examination was adjusted according to the volunteer's complaints and perception of their hearing, being 30 dBHL for individuals without hearing complaints and 50 dBHL for individuals who reported hearing complaints. The examination was started in the ear with the best hearing, as reported by the volunteers, or in the right ear, in the absence of self-perception of the best ear. The stimuli were presented in a pure and continuous tone; the frequencies tested in the air conduction were, in the respective order of presentation, 1, 2, 3, 4, 6, 8, 0.5 and 0.25 KHz.
4. Automated pure tone audiometry by air conduction: performed in the same acoustically treated environment used in conventional audiometry, with the same calibrated audiometer and using the same type of headphones used in conventional audiometry. The frequencies tested and the initial stimulus intensity were pre-selected by the examiner

before performing the test. The stimuli were presented in a pure pulsatile tone and the frequencies tested by air conduction were, in respective order of presentation, 1, 2, 3, 4, 6, 8, 0.5 and 0.25 KHz, according to that used in conventional pure tone audiometry, with the intensity of the initial test applied at 30 dBHL for individuals without hearing complaints and 50 dBHL for individuals who reported some hearing complaint. The audiometry was performed independently by the participant after explanation of how the test works. The volunteers were given a response button and instructed to press the button whenever they heard the sound stimulus. To determine the limits, the audiometer automatically scans the pre-configured frequencies, increasing or directing the intensity of the stimuli according to the participants' responses. During the test, the examiner only supervised the test, without interfering.

The individuals performed the two audiometric exams with a 15-minute interval to avoid fatigue or inattention that could interfere with the results obtained. The time spent performing the exams was controlled by a stopwatch.

The order in which the audiometries were performed was alternated, and thus, some participants began the exams with conventional audiometry (gold standard) and the other group with automated audiometry. The alternation between the audiometry modes initially aimed to exclude research bias, so that fatigue from the second exam would not interfere with the results in a systematic way. Individuals who initially underwent automated audiometry were instructed to save the exam, with the following instruction: "When the exam is finished, you will see a button called "save"; click to save the results and finish". This procedure was intended to prevent the examiner from viewing the results, thus inhibiting any bias during the search for limits in conventional audiometry (gold standard).

After collection, the data was recorded in an Excel spreadsheet and, subsequently, statistical analysis of the data was performed using the SPSS software version 23 (IBM Corporation, Armonk, NY).

The categorical variables that included gender, knowledge of audiometry and the order in which the tests were performed were verified by means of percentage and frequency. The continuous variables (age, tonal limits and duration of the test for each type of audiometry) were verified by means of measures of central tendency and variability (mean, median, minimum, maximum and standard deviation). For the absolute mean difference values, the values of the audiometry hearing thresholds were automatically subtracted from the conventional audiometry hearing thresholds. A percentage calculation was performed for the automated auditory thresholds that showed a difference of 5 and 10 dBHL compared to the conventional auditory thresholds.

The normal distribution of continuous variables was assessed using the Shapiro-Wilk test, which revealed a sample with an asymmetric distribution.

For the association analyses of the two audiometries by frequency (KHz), groups (1 and 2), order of start of examination and duration of examinations (minutes), the Wilcoxon test was used, considering a statistical significance level of 5%.

RESULTS

Two individuals recruited to participate in the study were excluded due to changes in the evaluation of the external auditory canal. Thus, 40 individuals (80 ears) were included in the study, 80% women (n=32) and 20% men (n=8), with a mean age of 23 years. No participant presented hearing complaints in the anamnesis, and hearing thresholds within normal standards were confirmed in the entire sample (100%).

Of the volunteers, 40% (n=16) were part of the group of individuals who had no knowledge about the audiometry procedures, and 60% (n=24) were part of the group who had knowledge about the exam. Regarding the alternation of exams, 52.5% (n=21) of the volunteers began the evaluation with conventional audiometry and the other 47.5% (n=19) with automated audiometry.

The descriptive analysis with the maximum, minimum, mean, median and standard deviation values of the frequency of the hearing limits obtained in conventional audiometry and in automatic audiometry at frequencies of 0.25, 0.5, 1, 2, 3, 4, 6 and 8 KHz, in both ears, is detailed in Table 1.

Comparing the median values of the hearing thresholds found in conventional audiometry and automated audiometry (Table 1), better thresholds were observed in conventional audiometry at frequencies of 0.25, 4 and 6 KHz in the right ear,

Table 1. Values of the descriptive analysis of auditory thresholds by frequency for the entire sample (G1 + G2)

	Conventional audiometry								Automated audiometry							
	Right ear															
Frequency (KHz)	0.25	0.5	1	2	3	4	6	8	0.25	0.5	1	2	3	4	6	8
Maximum	15.0	15.0	25.0	20.0	20.0	20.0	15.0	20.0	25.0	15.0	25.0	25.0	30.0	20.0	35.0	25.0
Minimum	-10.0	-10.0	-10.0	-10.0	-5.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0
Mean	2.00	2.75	4.50	0.12	6.87	2.75	2.50	6.77	2.75	3.87	3.12	-0.50	6.37	2.50	3.75	8.25
Median	2.50	5.00	5.00	0.00	5.00	0.00	0.00	5.00	5.00	5.00	5.00	0.00	5.00	2.50	5.00	5.00
Standard deviation	5.75	6.29	5.63	6.55	5.62	8.08	6.30	6.65	6.78	6.04	6.85	7.74	7.50	6.50	10.17	8.81
	Left ear															
Frequency (KHz)	0.25	0.5	1	2	3	4	6	8	0.25	0.5	1	2	3	4	6	8
Maximum	15.0	10.0	20.0	30.0	20.0	15.0	20.0	35.0	35.0	15.0	25.0	25.0	25.0	15.0	20.0	35.0
Minimum	-5.0	-10.0	-5.0	-10.0	-5.0	-10.0	-10.0	-10.0	-5.0	-10.0	-10.0	-10.0	-5.00	-10.0	-10.0	-10.0
Mean	2.75	3.12	3.87	-0.12	6.50	0.62	2.75	8.00	5.87	3.87	4.37	0.50	9.00	-0.62	4.25	10.30
Median	2.50	5.00	5.00	0.00	5.00	0.00	5.00	5.00	5.00	5.00	5.00	0.00	10.00	0.00	5.00	10.00
Standard deviation	5.30	5.02	5.36	8.12	6.71	7.52	8.46	9.45	7.58	6.45	6.71	8.07	7.86	7.08	9.09	10.64

and at frequencies of 0.25, 3 and 8 KHz in the left ear. Regarding the averages, a higher value was noted in the average of the thresholds related to automated audiometry at frequencies of 0.25, 0.5, 6 and 8 KHz in the right ear and at frequencies of 0.25, 0.5, 1, 2, 3, 6 and 8 KHz in the left ear.

In relation to the time taken to carry out the exams, it was observed that the automated audiometry showed a shorter average time, as well as lower minimum and maximum values, when compared to conventional audiometry. The descriptive data are presented in Table 2.

The mean absolute difference in hearing thresholds in dBHL, by frequency (KHz), between automated and conventional audiometry, for each ear, is shown in Figures 1 and 2 (graphs).

It was observed that the percentage of hearing thresholds obtained through automated audiometry, with a difference of up to 5 dBHL from the thresholds of conventional audiometry, corresponded to the average of 82.4% in the right ear and 83% in the left ear. Considering the differences of up to 10 dBHL, a value of 95.5% and 94.3% was noted in the right and left ears, respectively. Comparing the absolute average difference of the hearing thresholds obtained in conventional and automated audiometry, a minimum value of 2.87 dBHL and a maximum of 5.75 dBHL were observed (Table 3).

Statistical analysis using the Wilcoxon test revealed statistically significant differences ($p<0.05$) between the hearing threshold values of conventional and automated audiometry in both groups, at frequencies of 1 KHz in the right ear and 0.25, 3 and 8 KHz in the left ear. In group 1, there was no difference ($p<0.05$) at frequencies of 0.25, 3 and 8 KHz in the left ear. In group 2, a statistically significant difference was observed at the frequency of 4 kHz in both ears. The best results were obtained with conventional audiometry (Table 4).

Regarding the duration of the exams (Table 4), the results indicated a statistically significant difference in the time taken to perform conventional and automated audiometry, when both groups were analyzed, and group 1 took less time to perform automated audiometry. As for the order in which the exams were carried out, in the group that started the exam by conventional audiometry there was a statistically significant difference ($p<0.05$) between the auditory thresholds obtained in automated audiometry compared to conventional at a frequency of 6 KHz in the left ear. Already in the group that started the examinations using the automated mode, statistically relevant differences occurred in the frequencies at 0.5 KHz in the right ear and at 0.25, 3 and 8 KHz in the left ear (Table 5).

Concerning the duration of the exam, the results indicated a statistically significant difference between the execution time of conventional and automated audiometry in the group that started the exams with automated audiometry, which took less time.

DISCUSSION

Most of the study participants were female (80%), which is justified by the fact that it was a convenience sample and by the students profile in the undergraduate program in Speech-Language Pathology at the institution where the study was conducted. Likewise, group 1 had a larger number of participants than group 2, a situation that is due to the ease of recruiting individuals from the Speech-Language Pathology program due to the link with the college and ease of contact with the students.

When analyzing the air-conduction thresholds obtained in conventional audiometry and automated audiometry, it was possible to observe differences in the frequencies of 1 KHz in the right ear and 0.25, 3 and 8 KHz in the left ear. Most studies carried out under the same clinical conditions as the present study did not find differences between the thresholds of conventional and automated audiometry[7-10]. Furthermore, the

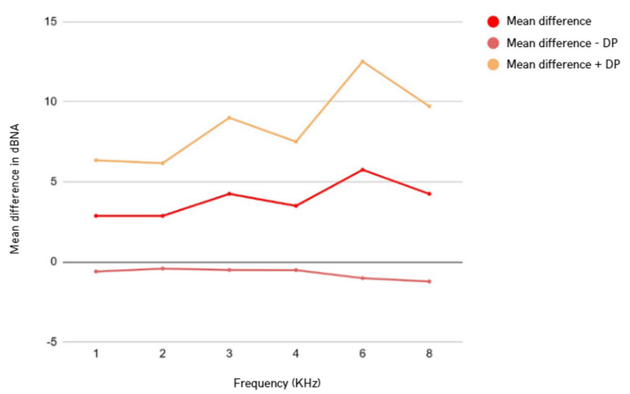

Figure 1. Graph of the absolute mean difference between auditory thresholds in dBHL by frequency (KHz) between automated audiometry and conventional audiometry of the right ear (conventional thresholds - automated thresholds)
Subtitle: SD: Standard deviation

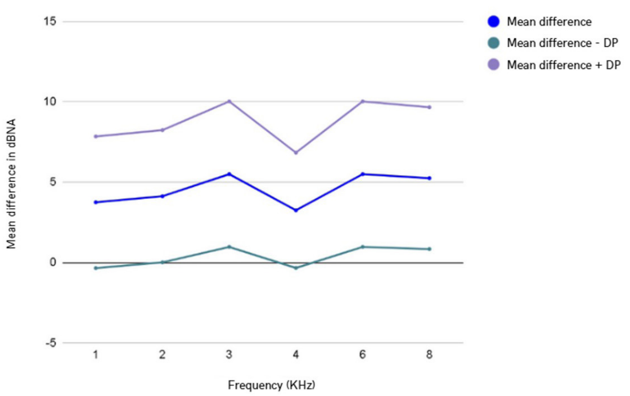

Figura 2. Graph showing the mean absolute difference between hearing thresholds in dBHL by frequency (KHz) between automated audiometry and conventional audiometry of the left ear (conventional thresholds - automated thresholds)
Subtitle: SD: Standard deviation

Table 2. Values of the descriptive analysis of the examination duration (min)

Exam	Minimum	Maximum	Mean	Median	Standard deviation
Time 1 (Conventional)	6.42	13.00	9.61	9.36	1.63
Time 2 (automated)	3.45	11.14	8.62	9.18	1.98

Table 3. Comparison of auditory thresholds with a difference of ≤5 and ≤10 dB HL in conventional and automated audiometry exams by frequency (KHz) in both ears

Ear	Right									Left								
Frequency (KHz)	0.25	0.5	1	2	3	4	6	8	Entire	0.25	0.5	1	2	3	4	6	8	Entire
MAD (dB)	3.5	3.8	2.87	2.87	4.25	3.5	5.75	4.25	-	4.5	3.25	3.75	4.12	5.5	3.25	5.5	5.25	-
MAD -SD	-0.66	-0.32	-0.59	-0.41	-0.5	-0.51	-1.01	-1.22	-	-0.28	0.02	-0.34	0.009	0.97	-0.33	0.97	0.83	-
MAD + SD	7.66	8.07	6.34	6.16	9	7.51	12.51	9.72	-	9.28	6.47	7.84	8.24	10.02	6.83	10.02	9.66	-
SD	4.16	4.20	3.47	3.29	4.75	4.01	6.76	5.47	-	4.78	3.22	4.09	4.11	4.52	3.58	4.52	4.41	-
% ≤5	87.5%	82.0%	87.5%	90%	77.5%	82.5%	79.5%	72.5%	82.4%	85%	90%	85%	85%	75%	90%	77.0%	77.0%	83%
% ≤10	97.5%	95%	100%	100%	95%	97.5%	89.7%	90%	95.5%	95.0%	100%	95%	97.5%	92.5%	97.5%	87.5%	90%	94.3%

Subtitle: SP = Standard deviation; MAD = mean absolute difference ; % = Percentage

Table 4. Statistical analysis of hearing thresholds by frequency (KHz), tested ear and execution time (min.) by group

	Right ear								Left ear							
Frequency (KHz) (Conventional/ automated)	0.25	0.5	1	2	3	4	6	8	0.25	0.5	1	2	3	4	6	8
Both groups (p-value)	0.700	0.272	0.047*	0.392	0.473	0.699	0.584	0.207	0.001*	0.273	0.521	0.599	0.037*	0.066	0.125	0.019*
Group 1 (p-value)	0.971	0.057	0.179	0.464	0.838	0.334	0.837	0.434	0.003*	0.134	0.436	0.432	0.002*	0.796	0.096	0.035*
Group 2 (p-value)	0.558	0.453	0.096	0.705	0.340	0.033*	0.559	0.433	0.101	0.763	1.000	0.943	0.773	0.020*	0.655	0.298
	Time (Conventional/automated)															
Both groups (Total) (p-value)	0.011*															
Group 1 (p-value)	0.024*															
Group 2 (p-value)	0.179															

Wilcoxon test. *Statistically significant values (p<0.05)

Table 5. Statistical analysis by order of examinations (conventional and automated), frequency (KHz), time (min.) and examination start

	Right ear								Left ear							
Frequency (KHz)	0.25	0.05	1	2	3	4	6	8	0.25	0.05	1	2	3	4	6	8
Conventional (p- Value)	0.589	1.000	0.107	0.109	0.196	0.507	0.590	0.064	0.097	0.741	0.547	0.905	0.470	0.593	0.030*	0,357
Automated (p- Value)	0.963	0.046*	0.222	0.773	0.871	0.903	0.763	0.959	0.002*	0.166	0.666	0.305	0.001*	0.064	0.836	0,025*
initial examination	Time (Conventional/automated)															
Conventional (p- Value)	0.079															
Automated (p- Value)	0.049*															

Wilcoxon test. *Statistically significant values (p<0.05)

frequency of 3 KHz was not considered in some studies[7,9,10] and the frequencies of 0.25 and 8 KHz were not considered in one of the studies[8]. In a study carried out with a population with different audiometric profiles, using a KUDUwave® automated audiometer, differences (p-value <0.05) were found between automated and conventional audiometry in the frequencies of 0.25, 0.5, 1 and 2 KHz[11], a finding more similar to that found in the present study. However, it is worth noting that this study carried out tests in an environment without acoustic treatment. The differences found in the frequencies of 0.25 and 8 KHz may have been influenced by factors such as fatigue and inattention[12,13], since they are the last frequencies to be tested. Likewise, the frequency of 1 KHz is the first to be tested in audiometric tests, and may be influenced by the learning effect[14,15].

The mean absolute differences in the thresholds of conventional and automated audiometry (0.25 to 8 KHz) were 2.8 to 5.7 dBHL in the right ear and 3.2 to 5.5 dBHL in the left ear. These values are in line with the results found in a study conducted with normal-hearing individuals in a silent environment[7], which found an overall mean absolute difference (SD) of 4.96 dBHL (6.1 dBHL) bilaterally, as well as in another study[8], also conducted with a group of normal-hearing individuals, which presented an overall mean absolute difference (SD) of 5.5 dBHL (5.5 dBHL) bilaterally. In contrast, other studies found mean absolute differences slightly smaller than those of the current study. A study carried out with normal-hearing individuals[9] found an overall mean absolute difference of 3.6 ± 3.9 dBHL for the group of normal-hearing individuals and, in another study[10], carried out with a population of normal-hearing individuals and patients with hearing loss, the absolute mean differences in air conduction between the right and left ears ranged from 3.0 to 4.5 dBHL and, in all ears and frequencies, the overall mean absolute difference was 3.6 dBHL.

The results of this study indicated that the percentage of hearing thresholds in automated audiometry with a difference of 5 dBHL from the thresholds obtained in conventional audiometry was 82.4% in the right ear and 83% in the left ear. These values increased to 95.5% in the right ear and 94.3% in the left ear, when considering the interval of 10 dBHL of the thresholds obtained in conventional audiometry. In a study[9] with normal-hearing individuals, the automated thresholds did not differ from conventional audiometry, with 87% of the thresholds in the group of normal-hearing individuals corresponding to 5 dBHL, or less, between them, in agreement with the findings obtained in the present study. Other authors[7,16], in a study with a heterogeneous population (normal-hearing and hearing-impaired individuals), found lower values when considering the thresholds of automated audiometry, with a difference of, at most, 5 dBHL from conventional audiometry thresholds, but, on the other hand, with percentage values close to those of the current study, when considering automated thresholds with a maximum difference of 10 dBHL from conventional thresholds.

These findings are important because occupational regulatory standards(17) state that a change equal to or greater than 10 dBHL at 1, 2, 3 or 4 KHz can be classified as a change in the standard threshold if confirmed in a new test(8). Furthermore, differences of up to 5 dBHL become clinically irrelevant because the thresholds are determined at the closest 5 dBHL(8-14).

The recording of the time found in both groups in the two audiometric tests showed similar times, with a slightly shorter duration in the automated audiometry, when compared to the conventional one, although there were differences between the times of the two audiometric tests for both groups and for the group with knowledge. These findings agree with the literature, which shows a similar duration of time between the two audiometric tests, as observed in a study(9) with a group with normal hearing, which found an average of 7.2 to 7.7 minutes required to test both ears. Other authors(10) also obtained records of similar duration of time between the two audiometric tests. Although the test time was not recorded for the conventional test, the authors presented data that illustrate that the time required to obtain an audiogram using the automated test is similar to that of the manual test. Another study(8) found a longer average time in the automated audiometry tests (16.1 minutes); however, the research was conducted with individuals with hearing loss.

In this study, participants with knowledge of audiometry (group 1) were Speech-Language Pathology students who had taken audiological assessment courses. These participants reported that, during the test, there were moments when their attention oscillated, in an attempt to identify which frequency and intensity were being investigated. Attention is essential during audiometric tests, since biological factors, intrinsic to individuals, will always exist, interfering with the test results(12,13). This aspect may have contributed to the increase in the difference in the group in question, observed in the frequencies of 0.25, 3 and 8 KHz only in the left ear. In the group without knowledge of audiometry (group 2), there was a difference in the frequency of 4 KHz in both ears. No studies were found that compared groups that were or were not used to the test. In the literature, there is one study that measured automated audiometry thresholds after a familiarization test(18). Another study(8), despite citing the presence of a possible learning effect, did not take such impact into account when analyzing the results.

When comparing the thresholds of automated and conventional audiometry by initial testing, differences were observed in the frequency of 0.5 KHz in the right ear and 0.25, 3 and 8 KHz in the left ear, in individuals who started the test using automated audiometry, and in the frequency of 6 KHz in the left ear in individuals who started the test using conventional audiometry. Such differences can be justified by the learning effect of the participants in performing the tests, as previously discussed(8), which is why a balance between initial tests is explained by the possible impact of learning, fatigue, attention and motivation on the test results(6,8). More research is needed to understand the effects of learning about the test, since, in clinical routine, there are patients who undergo hearing tests for the first time, and it is necessary to measure the impacts not only in terms of lack of habituation to performing the test, but also for issues related to education and age.

In the applicability of automated audiometry and inspection of the external auditory canal, the examiner must be a speech therapist or physician, in accordance with Resolution No. 367, of August 28th, 2023 of the Regional Council of Medicine of the State of São Paulo, which provides in Art. 1: "It is the exclusive responsibility of the physician and/or speech therapist to perform audiological examinations."

It is important to emphasize that, according to the manufacturer's guidelines, automated audiometry should be performed in an acoustically treated and/or noise-controlled environment. Therefore, further research should be conducted to assess the validity of the automated hearing test in an environment without acoustic treatment. This is important because automated audiometry lacks standardizations that can be used in research comparing groups with different profiles, regarding age and hearing loss.

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CONCLUSION

Automated audiometry provides air conduction hearing thresholds similar to those obtained with conventional audiometry (gold standard). The average differences between the two forms of audiometry mostly show a difference of up to 5 dBHL, although there is a statistically significant difference at some frequencies. It was also observed that automated audiometry allows for a relatively shorter execution time.

It should be noted that conventional pure-tone audiometry involves testing air and bone auditory thresholds, and therefore it is important to conduct further research in a population with the same profile to assess the reliability of automated bone conduction hearing tests. Finally, even if automated audiometry presents itself as a possible solution for increasing productivity, the presence of a speech-language pathologist is essential to interpret the test and carry out diagnostic processes.

REFERENCES

1. OPAS: Organização Pan-Americana da Saúde. Saúde Auditiva: documento de posicionamento da Organização Pan-Americana da Saúde/Organização Mundial da Saúde [Internet]. Brasília: OPAS/OMS; 2008 [citado em 2023 Mar 03]. Disponível em: https://www.paho.org/pt/topicos/saude-auditiva#:~:text=Para%20facilitar%20essa%20integra%C3%A7%C3%A3o%2C%20o%20Relat%C3%B3rio%20Mundial%20sobre,a%20audi%C3%A7%C3%A3o%20em%20seus%20planos%20nacionais%20de%20sa%C3%BAde

2. Kamenov K, Martinez R, Kunjumen T, Chadha S. Ear and hearing care workforce: current status and its implications. Ear Hear. 2021;42(2):249-57. http://doi.org/10.1097/AUD.0000000000001007. PMid:33480624.

3. WHO: World Health Organization. World report on hearing: executive summary [Internet]. Geneva: WHO; 2021 [citado em 2023 Mar 03]. Disponível em: https://www.who.int/publications/i/item/9789240021570

4. WHO: World Health Organization. World report on hearing WHO [Internet]. Geneva: WHO; 2021 [citado em 2023 Mar 03]. Disponível em: https://www.who.int/publications/i/item/9789240020481

5. Margolis RH, Morgan DE. Automated pure-tone audiometry: an analysis of capacity, need, and benefit. Am J Audiol. 2008 Dez;17(2):109-13. http://doi.org/10.1044/1059-0889(2008/07-0047). PMid:18840703.

6. Shojaeemend H, Ayatollahi H. Automated AUDIOMETRY: a Review of the implementation and evaluation methods. Healthc Inform Res. 2018 Out;24(4):263-75. http://doi.org/10.4258/hir.2018.24.4.263. PMid:30443414.

7. Bean BN, Roberts RA, Picou EM, Angley GP, Edwards AJ. Automated audiometry in quiet and simulated exam room noise for listeners with normal hearing and impaired hearing. J Am Acad Audiol. 2022 Jan;33(1):6-13. http://doi.org/10.1055/s-0041-1728778. PMid:34034339.

8. Eikelboom RH, Swanepoel DW, Motakef S, Upson GS. Clinical validation of the AMTAS automated audiometer. Int J Audiol. 2013;52(5):342-9. http://doi.org/10.3109/14992027.2013.769065. PMid:23548148.

9. Swanepoel DW, Mngemane S, Molemong S, Mkwanazi H, Tutshini S. Hearing assessment-reliability, accuracy, and efficiency of automated audiometry. Telemed J E Health. 2010;16(5):557-63. http://doi.org/10.1089/tmj.2009.0143. PMid:20575723.

10. Margolis RH, Glasberg BR, Creeke S, Moore BC. AMTAS: automated method for testing auditory sensitivity: validation studies. Int J Audiol. 2010;49(3):185-94. http://doi.org/10.3109/14992020903092608. PMid:20109081.

11. Brennan-Jones C, Eikelboom R, Swanepoel DW, Friedland P, Atlas M. Clinical validation of automated audiometry with continuous noise-monitoring in a clinically heterogeneous population outside a sound-treated environment. Int J Audiol. 2016 Set 1;55(9):507-13. http://doi.org/10.1080/14992027.2016.1178858. PMid:27206551.

12. Sahyeb DR, Costa Filho OA, Alvarenga KD. Audiometria de alta freqüência: estudo com indivíduos audiologicamente normais. Rev Bras Otorrinolaringol. 2003;69(1):93-9. http://doi.org/10.1590/S0034-72992003000100015.

13. Barros SMS, Frota S, Atherino CCT, Osterne F. A eficiência das emissões otoacústicas transientes e audiometria tonal na detecção de mudanças temporárias nos limiares auditivos após exposição a níveis elevados de pressão sonora. Rev Bras Otorrinolaringol. 2007;73(5):592-8. http://doi.org/10.1590/S0034-72992007000500003.

14. Mello LA, Silva RAM, Gil D. Variabilidade teste-reteste na audiometria tonal: comparação entre dois transdutores. Audiol Commun Res. 2015;20(3):239-45. http://doi.org/10.1590/2317-6431-2015-1582.

15. Gobbato LHFG, Costa EA, Sampaio MH, Gobbato FM Jr. Estudo do efeito aprendizagem em exames audiométricos sequenciais de trabalhadores de indústria metalúrgica e suas implicações nos programas de conservação auditiva. Rev Bras Otorrinolaringol. 2004;70(4):540-4. http://doi.org/10.1590/S0034-72992004000400016.

16. Margolis RH, Killion MC, Bratt GW, Saly GL. Validation of the Home Hearing Test™. J Am Acad Audiol. 2016 Maio;27(5):416-20. http://doi.org/10.3766/jaaa.15102. PMid:27179261.

17. Brasil. Ministério do Trabalho e Previdência. Norma Regulamentadora n. 07 - Programa de Controle Médico de Saúde Ocupacional - PCMSO. Brasília: MTP; 2023.

18. Skjonsberg Å, Heggen C, Jamil M, Muhr P, Rosenhall U. Sensitivity and specificity of automated audiometry in subjects with normal hearing or hearing impairment. Noise Health. 2019;21(98):1-6. http://doi.org/10.4103/1463-1741.278701. PMid:32098925.