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http://dx.doi.org/10.23925/2176-2724.2018v30i2p-376-384

Analysis of difference between the behavioral hearing thresholds and the results obtained through the auditory steady state response (ASSR) in young adults

Análise da diferença entre os limiares auditivos comportamentais e os resultados obtidos através do exame potencial evocado auditivo de estado estável (PEAEE) em adultos jovens

Análisis de la diferencia entre los umbrales auditivos comportamentales y los resultados obtenidos a través del examen potencial evocado auditivo de estado estable (PEAEE) en adultos jóvenes

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Abstract

Introduction: Hearing is the sense which allows us to receive auditory information; therefore it facilitates efficient social interaction. Any loss in this function damages the communicative process, so it must be diagnosed and treated as soon as possible. Nowadays, both objective and subjective hearing tests

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Received: 25/12/2017
Accepted: 01/06/2018

are available. Pure Tone Audiometry is the most widely used subjective way to evaluate this sense. However, for those who are unable to respond subjectively, we can try objective techniques like the Auditory Steady State Response. Both will search for patients' minimum hearing responses, applying different approaches. ***Objective****:* To evaluate normal-hearing young adults with no hearing complaints by analyzing their hearing sensibility and, based on statistical indicators, calculate the average of the differences between the results obtained in both procedures in order to verify the existence of correlation between them. ***Method:*** We studied the hearing responses from 30 normal-hearing subjects through Pure Tone Audiometry and Auditory Steady State Response at 500, 1000, 2000 and 4000 Hz. ***Results:*** When we calculated the average of the differences between the tested frequencies, they ranged from 10,47 to 18,22 with no strong correlation, except at 1000 Hz whose results were uncertain. ***Conclusion:*** We concluded that the average of the differences of hearing values obtained in Pure Tone Audiometry and Auditory Steady State Response were reasonably elevated mainly at 500 Hz, and at a lower level at 4000 Hz. Although the scores obtained in both tests had not shown strong correlation, they were slightly better at 500 Hz. The results for 1000 Hz are inconclusive regarding any existing correlation between these two tests.

Keywords: Hearing; Auditory Threshold; Pure Tone Audiometry; Evoked Response Audiometry.

Resumo

Introdução: A audição, sentido que nos permite receber a informação sonora, se apresenta como um dos facilitadores para uma interação social eficaz. Um déficit nessa função acarreta prejuízo no processo comunicativo, devendo ser diagnosticado e tratado precocemente. Atualmente dispomos de meios subjetivos e objetivos para avaliar o sistema auditivo. A audiometria tonal é a forma subjetiva mais aplicada para medir esse sentido. Entretanto, em populações impossibilitadas de responder subjetivamente, aplicam-se técnicas objetivas, como o Potencial Evocado Auditivo de Estado Estável. Ambos pesquisam respostas auditivas do sujeito sob teste, utilizando técnicas distintas. ***Objetivo*****:** Avaliar adultos jovens, sem queixas auditivas, pesquisando a sensibilidade auditiva e, a partir de indicadores estatísticos, calcular as médias das diferenças das respostas obtidas nesses procedimentos, verificando se há correlação entre eles. ***Método*****:** Pesquisa de respostas auditivas via Audiometria Tonal e Potencial Evocado Auditivo de Estado Estável, nas frequências de 500, 1000, 2000 e 4000 Hz, em 30 sujeitos normo-ouvintes. ***Resultados*****:** Ao calcularmos a média das diferenças entre as frequências testadas nos dois procedimentos, elas variaram de 10,47 a 18,22, não havendo forte correlação em nenhuma delas, deixando dúvidas na frequência de 1000 Hz. ***Conclusão*****:** Podemos dizer que as médias das diferenças entre os valores obtidos nos dois procedimentos foram razoavelmente elevadas, principalmente em 500 Hz e, em menor proporção, para 4 kHz. Os valores obtidos nos dois exames, embora não tenham apresentado forte correlação, apresentaram-se discretamente melhores para 500 Hz. Resultados de 1000 Hz não nos permitem afirmar, inclusive, se existe alguma correlação entre os testes.

Palavras-chave: Audição; Limiar Auditivo; Audiometria de Tons Puros; Audiometria de Resposta Evocada.

Resumen

Introducción: La audición, sentido que nos permite recibir la información sonora, se presenta como uno de los facilitadores para una interacción social eficaz. Un déficit en esta función acarrea perjuicio en el proceso comunicativo, lo que debe ser diagnosticado y tratado lo antes posible. Actualmente disponemos de medios subjetivos y objetivos para evaluar el sistema auditivo. La audiometría tonal es la forma subjetiva más aplicada para medir ese sentido. Sin embargo, en poblaciones imposibilitadas de responder subjetivamente, se aplican técnicas subjetivas como el Potencial Evocado Auditivo de Estado Estable. Ambas investigan las respuestas auditivas del sujeto bajo test, utilizando técnicas distintas. ***Objetivo*****:** Evaluar a adultos jóvenes, sin quejas auditivas, investigando la sensibilidad auditiva y, a partir de los indicadores estadísticos, calcular los promedios de la diferencias de las respuestas obtenidas en esos procedimientos, y comprobar si existe correlación entre ellos. ***Método*****:** Pesquisa de respuestas auditivas vía Audiometría Tonal y Potencial Evocado Auditivo de Estado Estable en las frecuencias de 500,1000, 2000 y 4000 Hz, en 30 sujetos oyentes normales. ***Resultados*****:** Tras el cálculo del promedio de las diferencias entre las frecuencias testadas en los dos procedimientos, se pudo verificar una variación de 10,47 a 18,22, donde no se ha registrado fuerte correlación en ninguna de ellas, dejando duda en la frecuencia de 1000 Hz. ***Conclusión*:** Podemos decir que los promedios de las diferencias entre los valores obtenidos en los dos procedimientos fueron razonablemente elevados, sobre todo en 500 Hz y, en menor proporción, para 4kHz. Los valores que se obtuvieron en los dos exámenes, aunque no hayan presentado fuerte correlación, se presentaron discretamente mejores para 500 Hz. Resultados de 1000 Hz no nos permiten afirmar, incluso, si hay alguna correlación entre los testes.

Palabras clave: Audición; Umbral Auditivo; Audiometría de Tonos Puros; Audiometría de Respuesta Evocada.

Introduction

Hearing is the sense which allows us to receive and react to sound.[1] It plays an important role in an individual's integration into a society where oral communication prevails.

Audiometry is the most commonly indicated and widely applied test to assess hearing through the measurement of the air and bone conduction thresholds whose values in normal-hearing patients are no higher than 20 dB HL (Hearing Level). It is performed in an acoustic booth and the sound stimuli are produced by an audiometer. The responses obtained in the test are described in a graph (audiogram) in which we research the minimum audibility threshold per frequency. [1,2,3]

A newer technique used to research auditory responses is the Auditory Steady State Response (ASSR), which corresponds to periodic brain electrical activities in reaction to acoustic stimuli presented at a repetition rate that is high enough to cause consecutive responses to overlap. This neural response follows the same waveform of the continuous stimulus presented to the subject, a pure tone containing a carrier frequency that can be modulated by amplitude and/or frequency. The auditory sensibility is determined through an analysis of the neural response using statistical indicators.[4,5] These responses are recorded by electrodes placed on the skull surface. It is possible to study them both bilaterally and simultaneously at several frequencies (usually 500, 1000, 2000 and 4000 Hz) where the response is automatically detected and analyzed objectively. [4]

Therefore, this study aimed to compare the values obtained through pure tone audiometry and auditory steady state response at the frequencies of 500, 1000, 2000 and 4000 Hz, in young adults, by calculating the average of the differences between the responses and verifying the existence of correlation between them.

Method

This research has been approved by Ethics Committee, under the number 17536313.0.0000.5257. The study population comprised 15 males and 15 females, whose ages ranged from 18 to 40 years old, without hearing complaints or reports of previous otologic pathologies. Each subject had both right and left ears assessed, resulting in 60 tested ears.

The selected individuals saw an otorhinolaryngologist who performed an otoscopy and removed cerumen when necessary.

The audiometer MA 42 - Maico and the Eclipse EP25 – Interacoustics equipment were used for the tests. We searched the psychoacoustic thresholds in a *Scher Acústica* audiometric booth while the auditory steady state response was performed in a silent and low-lit environment with electric isolation. Both procedures took approximately 40 minutes altogether.

For the research of the psychoacoustic thresholds, the initial intensity was 30 dB HL, reduced in 10 by 10 dB until there was absence of response. Only then, the intensity was increased in 5 by 5 dB until the minimum hearing threshold could be confirmed. We first researched the frequency of 1000 Hz, followed by 2000 Hz, 4000 Hz and 500 Hz.

For the auditory steady state response analysis, the first step was to clean the patient's skin so that the surface electrodes could be set. The active electrodes (Fz – located at the midline, close to the scalp) and the ground electrode (Fpz – located on the side, approximately 3 cm from the active electrode) were placed on the patient's forehead. Then, the reference electrodes were placed on the right (M2) and left (M1) mastoids, composing two channels: Fz/M1 and Fz/M2, according to the IES norm (International Electrode System).[6] The impedance between electrodes did not exceed 3 KOhms. Insert earphones were used with simultaneous air-conducted binaural stimulation.

As participants were awake during the tests, the parameters of the acoustic stimuli used in the ASSR recording were: carrier frequencies of 500, 1000, 2000 and 4000 Hz modulated in amplitude and frequency of 39 Hz (500 Hz), 42 Hz (1000 Hz), 43 Hz (2000 Hz), 45 Hz (4000 Hz) in the right ear, and 46 Hz (500 Hz), 47 Hz (1000 Hz), 48 Hz (2000 Hz) and 50 Hz (4000 Hz) in the left ear, evaluated in a six-minute time frame. High-pass filters and softeners were used in this study, the frequencies of 1 kHz and 5 kHz remained unchanged. In addition to Fast Fourier Transform – FFT analysis (1024 points), the records were subjected to the equipment's statistical method. The level of significance adopted is speed (95%).

The test began with the intensity of 30 dB nHL, being gradually reduced (in 10 by 10 dB) as responses were identified. Whenever there was absence of response, the intensity was increased in 5 by 5 dB until the minimum hearing sensibility could be confirmed. The lowest intensity at which a response was recorded was taken into consideration and served as point of reference to compare with the psychoacoustic threshold recorded at the same frequency.

Regarding the statistical methodology, this has been a quantitative cross-sectional study in which we sampled from an infinite population. The main variable of interest for this research was the difference between the responses recorded in both methods (ASSR response minus PTA response). As it is impossible to establish the variation within the population or make an estimate that would allow us to calculate a sample size with a previously determined sampling error, the sample used for this research was determined based on the operational viability of subsequent analysis and possible adjustment of an occasional sampling error. Thus, convenience sampling was the chosen method. Adjustments were dismissed since the sampling error of the average between the differences was small enough (smaller than 0,3 dB HL in the four frequencies) to ensure an accurate inference.

Table 1. Margin of error of the average of the differences in PTA and ASSR by frequency

Frequency	Margin of error (dB HL)
500 Hz	+-0,29
1 kHz	+-0,26
2 kHz	+-0,23
4 kHz	+-0,21

95% confidence interval

A brief exploratory data analysis of the results will be presented. After that, we will use Pearson correlation coefficient to analyze the correlation between the results of both tests. The coefficient significance was tested through T-test.

Results

1) Age and Gender description

The sample was composed by 15 female individuals, whose ages ranged from 21 to 38 years old with the average of 28 years old, and 15 male individuals whose ages varied from 20 and 39 years of age with the average of 28 years old.

The age average was 28,7 years old and median age was 28.

2) Average of the difference per frequency and correlation between both methods

The main variable of interest in this study is the difference between the responses obtained through ASSR and PTA (ASSR response minus PTA response) which will be referred to as Difference. The main statistical analysis is the average of the Difference.

However, we must remark that the tests in question present distinct minimum thresholds. PTA checks hearing at the minimum intensity of -10 dB, whereas ASSR starts at 0 dB. Having in mind that a patient that responds to stimulus lower than 0 dB certainly responds to a 0 dB stimulus, the discrepancy was solved by applying a 0 dB response to every response recorded on PTA at this same intensity or below. This strategy was also employed on the ASSR corrected values which came up negative.

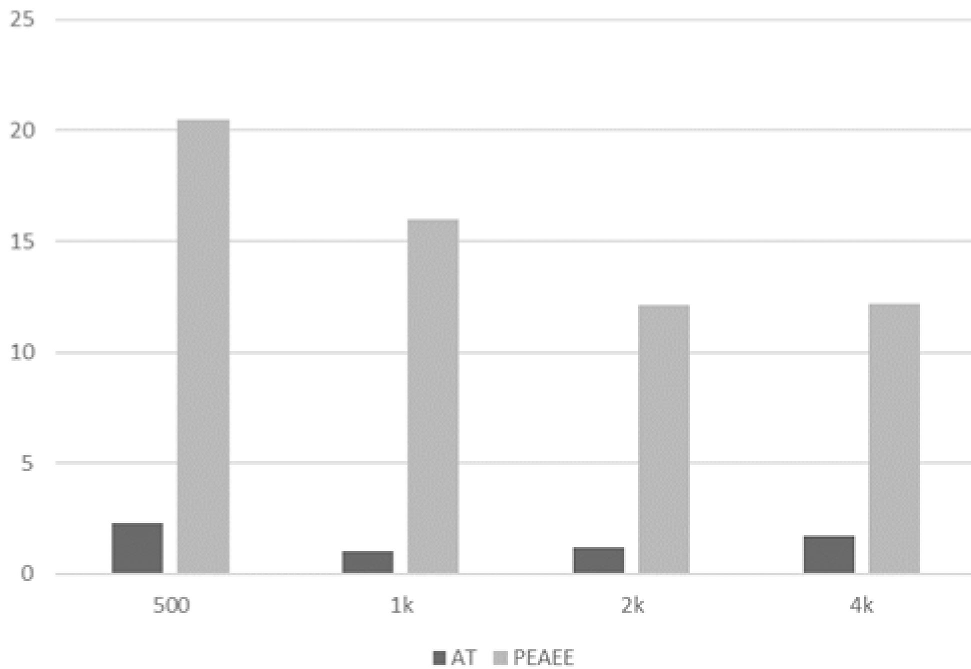

Figure 1. Average between the auditory thresholds (in dB HL) in pure tone audiometry and the electrophysiological thresholds in the auditory steady state response (dB nHL), by frequency (Hz).

A considerable distinction between the auditory response obtained in ASSR and the one recorded in PTA per researched frequency (0.5, 1, 2 and 4 kHz) is perceived. It means that the electrophysiological thresholds are higher than the psychoacoustic ones.

Table 2. Average (dB HL), standard deviation and median of the differences between PTA and ASSR identified by frequency.

Frequency (Hz)	Average	Standard Deviation	Median
500	18,22	8,74	20,00
1k	15,18	8,07	15,00
2k	11,08	6,94	10,00
4k	10,47	6,43	10,00

The table shows findings such as average (dB HL), standard deviation and median of the differences between PTA and ASSR by frequency.

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Table 3. Pearson correlation coefficient[1] for the ASSR and PTA responses per frequency; hypothesis testing under H_0 (confirming whether the correlation between the ASSR and PTA responses equals zero)

Frequency (Hz)	Correlation coefficient (r)	$t_{(58;0,05)}$	p-value	Decision about H_0	Classification
500	0,44	3,689	0,000	rejects	Medium correlation
1K	0,20	1,524	0,133	accept	Very weak correlation
2K	0,29	2,301	0,025	rejects	Weak correlation
4K	0,35	2,856	0,006	rejects	Weak correlation

[1] Pearson Linear Coefficient (r) is nondimensional and ranges from -1 and 1, where r = -1 suggests perfect negative linear correlation, r = 1 suggests perfect positive linear correlation and r = 0 indicates the absence of linear correlation. [7]

No strong correlation is observed in any of the researched frequencies, as confirmed by the Pearson correlation coefficients presented on Table 3.

Nevertheless, hypothesis testing leads to the conclusion that the correlation is different from zero at almost all the frequencies, except 1 kHz. The correlation coefficient at this frequency (r=0,20) is close to zero, indicating that we cannot disregard the hypothesis that, in fact, there is no correlation.

Therefore, some positive linear correlation exists between the values obtained in both tests at frequencies of 500, 2 k and 4 kHz. In other words, at these three frequencies, the bigger the response recorded in ASSR, the bigger is the one recorded in PTA. Such statement cannot be made about 1 kHz.

Discussion

This research is based on procedures that assess different responses: while pure tone audiometry evaluates the subject's auditory function, the ASSR relies on the structure of the auditory system that generates such response. [8]

ASSR yields an objective evaluation of the auditory sensibility per frequency. Even though pure tone audiometry is the gold standard, it might not be conclusive in certain cases, especially with young children or adults with conditions that affect the test progress.[9]

As for the ASSR, results are presented in an electrophysiologic audiogram.[9] They may vary according to number or type of stimuli and modulation presented, age and type of population, level of relaxation, state of consciousness, electrical artifacts, encephalographic alterations, environmental noise, electrode placement, etc. [10]

Moreover, this procedure facilitates the recording of responses in an empirical way for statistical analysis. [11]

Rabelo and Schochat (2011) state that ASSR has been widely used to estimate psychoacoustic thresholds, confirm auditory thresholds and to compare it to behavioral thresholds. [12]

It has been acknowledged as the only method capable to measure residual hearing at low frequencies in children or patients whose pure tone assessment is either inaccurate or unreliable. [13]

Nowadays, researchers strive to establish correction factors for the differences found between the behavioral audiometry and ASSR values in order to use electrophysiologic results to estimate psychoacoustic values. [14]

We found average ASSR threshold of 20,5/16/11,8/12 dB at 500/1000/2000/4000 Hz. When comparing normal-hearing adults and children, Casey (2014) found the average thresholds of 40/30/20/20 dB for adults and 40/30/30/30 dB for infants. His findings were slightly larger for lower sounds, which also happened in our research. [14]. Luiz (2016) observed values between 6 and 16 dB, admitting that they are smaller than what is usually obtained in most studies. [15] Calil (2006) identified values between 6 and 17,2 dB [16] whereas Garcia (2014) recorded 17,2/26,2/22,7/19,8 dB [17], even though other authors have found values between 24,3 and 32,5 dB in normal hearing children.[18] Another study shows that D'haenes and col. (2009) found values between 0 and 50 dB, with the higher prevalence (42%) around 20dB. [19]

It is important to mention that the findings at 500 Hz have been constant. However, Lins and Picton (1996) advise to interpret these results with caution. [20] Several authors report that a larger difference between the pure tone and ASSR thresholds may happen at lower frequencies. [9,15,16,19,21,22] They defend that it happens because the stimulus take longer to go through the cochlea (cochlear tonotopy), and any environmental noise might cause auditory masking. [11,18,19] In addition, not only the response amplitude is smaller in this region, but the electric artifacts are recorded at the 500 Hz interval and its modulation adjacents. [22] Hosseinabadi and Jafarzadeh (2015) infer that neural synchronization might be decreased at the frequency in question. [23] The largest difference between both methods was observed precisely at 500 Hz in our research. On the other hand, Rodrigues and Lewis (2010) [24] and Beck and col. (2014)[9], found it at 4 kHz without any statistical significance nonetheless.

According to some authors, the values found through ASSR are around 10 dB above the ones found through pure tone audiometry [9,14,15,24], in general. This is the reason the equipment employs a correction factor to estimate behavioral thresholds. [9,13] Luiz (2014) defends that the distance between the responsive cochlear regions and the surface electrodes justify this fact since the response amplitude that must be removed from the background noise is small. [11,15]

As the values are higher in ASSR, we cannot ignore the possibility of a behavioral threshold overestimate, especially at normal hearing levels or mild hearing losses. [8] Ozdek (2010) noticed that 83,7% of the ASSR performed on normal-hearing adults had overestimated results in his study. [10] However, Rabelo and Schochat (2011) found cases in which ASSR underestimated the behavioral thresholds in the subjects with the same characteristics. [12]

In our research, the average of the difference by carrier frequency (500, 1000, 2000, 4000 Hz) between the ASSR and the PTA (pure tone audiometry) resulted in 18,2/15,1/11/10,4 dB, so, the biggest difference was noticed at lower stimuli (500 Hz) while the smallest was observed at higher sounds (4 kHz). The study conducted by Beck and col. (2014) found the difference of 7,1/7,6/8,2/9,7 dB[9] while Casey (2014) identified differences ranging from 15 to 22 dB[14] in children, Stapells (2010) found results ranging from 14 to 27 dB [25] and Tlumak, Rubinstein and Durrant (2007) records range from 11 a 17 dB.[26] Ozdek (2010) reported differences of 15/10/14/15 dB between both types of test [10] whereas Luts (2006) found 8/6/7/9 dB [27], and D'haenens and col. (2009), studying the same procedures, obtained the differences of 20/15/10/13 dB.[19] Luiz (2016) found values between -0,3 and 12 dB in a group with normal hearing, and between -9 e 2 dB in a group whose members experience moderate to moderately severe hearing loss.[15] After comparing the data collected through ASSR and VRA (visual reinforcement audiometry) in children with cochlear hearing losses, Rodrigues and Lewis (2010) found differences of -1,7/1,5/-0,1/-4,5 dB. The negative values indicate that the ASSR presented better auditory results at some point. [24]

With reference to the correlation between both methods, the frequencies researched did not produce strong evidence on this matter, except at 1000 Hz. As the lowest value was found at this frequency, we cannot affirm nor deny the existence of correlation. Although we searched for homogeneous sample, with young individuals with normal hearing, without hearing complaints and/or alterations, our values were 0,44/0,20/0,29/0,35 at 500, 1000, 2000 e 4000 Hz, respectively. In contradiction to several studies, we identified slightly better correlation at 500 Hz. Luiz (2016) did not notice any correlation between the electrophysiologic and behavioral thresholds in the research with normal hearing individuals participating. [15] Attias and col. (2014) have also found small correlation results (smaller than 0,63) after comparing ASSR records to the psychoacoustic thresholds in adults. [28] Linares (2010) noticed significant correlation in the infant population, 0,8/0,9/0,7/0,8 [21] as did Luts (2006), 0,82/0,84/0,89/0,91[27], and D'haenens and col. (2009) with 0,82/0,91/0,94/0,94.[19] Regarding the adult population, Ozdek (2010) found 0,92/0,93/0,95/0,77[10] which also represent good correlation.

Many authors affirm that hearing losses produce better correlation, which increases in proportion to the degree of loss, in comparison to normal hearing. [8,9,10 ,11,13,23,24] .After comparing ASSR and VRA (visual reinforcement audiometry) responses of children with cochlear hearing losses, Rodrigues and Lewis (2010) obtained the correlation coefficients 0,90/0,93/0,93/0,89 for the same frequencies researched in our study. [24] It seems that presence of recruitment may result in an increased response amplitude when dealing with sensorineural hearing losses. [9,10]

Ahn (2007) suggests that ASSR may not be the best choice to assess normal-hearing subjects [13] because this population may present varied responses.[14]

There are authors who found an average difference ranging from 20 dB [29] to 32 dB [30] between PTA and ASSR in normal-hearing individuals. Casey (2014) says that such variation may be explained by the environmental noise affecting the response recording at a low auditory threshold. This is not an issue when dealing with hearing losses because the threshold is increased and would not be affected by this environmental condition. [14] Rabelo and Schochat (2011), however, found distinct results in their sample. They did not identify statistically significant differences between the electrophysiologic and PTA thresholds in normal-hearing subjects which leads them to suggest that the ASSR is a useful resource to estimate auditory thresholds. [12] Even though our populations are similar in number and age, the authors conducted their research only at 500 and 2000 Hz, with the same modulation frequency (46 Hz). We cannot evaluate to which extent these parameters may have influenced the authors' research conclusions.

Although the ASSR is currently performed to predict pure tone thresholds, we must bear in mind that its results will be more accurate when dealing with hearing losses. It is a useful method in clinical routine, especially to patients who do not respond to subjective assessments. ASSR may assist audiologic diagnosis, but it cannot be the only resource as it adds to the evaluation, and does not replace the others (immittanciometry, otoacoustic emissions, BERA, etc.). [15] It is important to say that the possibility to estimate auditory thresholds through electrophysiological means does not reduce the importance of behavioral evaluation, which must remain gold-standard. [24]

Conclusion

We have concluded that the average of the differences between the responses obtained through Pure Tone Audiometry and Auditory Steady State Response were reasonably high: mostly at 500 Hz and at lower ratio for 4 kHz.

The values obtained in both tests did not present any strong correlation in the studied sample, being discreetly better at 500 Hz, in contradiction to several recent studies. In addition to that, results from the frequency of 1000 Hz make it impossible to affirm whether there is any correlation between both tests.

Additional research involving a higher number of subjects, or a multicenter study, will always be necessary to confirm or add new data about the Brazilian population, allowing us to evaluate the efficacy of new tests that contribute to more accurate audiological diagnosis.

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