CORRELATION BETWEEN THE HEARING LOSS CLASSIFICATIONS AND SPEECH RECOGNITION

Correlação entre as classificações de perdas auditivas e o reconhecimento de fala

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ABSTRACT

Purpose: to check the correlation between Speech Reception Threshold and Index of Speech Recognition with mean audiometric results. **Methods:** we selected 241elderly patients who underwent examinations of the pure tone audiometry and speech audiometry. As inclusion, audiometry should have a sensorineural hearing loss. The tone thresholds for air obtained were classified according with the following averages: Average 1 – Average of frequencies of 500, 1000 and 2000 Hz; Average 2 – Average of frequencies of 500, 1000, 2000 and 4000 Hz; Average 3 – average of frequencies of 500, 1000, 2000 and 3000 Hz; and 4 average – average of frequencies of 500, 1000, 2000, 3000 and 4000 Hz. The data were compared with Speech Reception Threshold and Index of Speech Recognition, and treated statistically. **Results**: Average 1 showed higher correlation with the Speech Reception Threshold (rho = 0.934, CI = 0.901 to 0.958; eqm = 52.2). In relation to the Index of Speech Recognition, it was observed that the average 3 showed the highest degree of correlation with the test (rho = – 0.768, CI = –0.807 to –0.721; eqm = 245) followed averages 2 and 4. **Conclusion**: for elderly people with ski slop sensorineural hearing loss, the Speech Reception Threshold has the strongest correlation with the average frequencies 500 Hz, 1000 Hz and 2000 Hz, while the Index of Speech Recognition has the highest correlation with the average which include the frequencies 3000 Hz and 4000 Hz.

KEYWORDS: Hearing Loss; Presbycusis; Audiometry; Aged; Speech Intelligibility

INTRODUCTION

Speech discrimination is essential for human communication and, in order for it to be effective, unimpaired hearing is critical. Hearing losses negatively impact the quality of life by restricting social interactions, especially in noisy environments[1,2]. Those afflicted by hearing impairments tend to avoid contact, develop low self-esteem, have few friends and limited participation in social relations[3].

Ski slope sensorineural hearing loss is the most common type to be found in clinical audiology practice; it includes presbycusis and is frequently related to difficulties in speech intelligibility[4-6]. The frequencies 500 Hz, 1000 Hz and 2000 Hz are considered to be the most relevant for speech. Vowels and consonants, the building blocks of speech, have different spectral characteristics. Vowels are naturally more intense and carry acoustic energy at low frequencies (400–500 Hz), which are favored by the range of human audibility[7]. Consonants, in turn, are sounds having spectral energy at high frequencies, above 2000 Hz, albeit 20–35 dB weaker than vowels[8]. However, speech intelligibility depends on consonant sounds, which

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contribute 60 % of it, while vowels contribute only 40%[9]. Due to the spectral characteristics of these sounds and the range of human audibility, one can understand why individuals with hearing loss at high frequencies have impaired speech recognition.

In audiology, speech recognition ability is measured by the tests *Speech Reception Threshold* (SRT) and *Speech Discrimination Score* (SDS). The SRT corresponds to the softest sound intensity level at which an individual can recognize 50% of the common words given. Typically, SRT and SDS values are consistent with the average of the hearing thresholds obtained for the speech-related frequencies. The SDS evaluates speech discrimination using a list of monosyllables and bisyllables 40 dB above the SRT thresholds[10].

The classification of hearing losses is a widely discussed topic in speech-language pathology and audiology. In Brazil, hearing losses have been predominantly classified on the basis of the frequencies of speech relative to the tritone average of the air-conduction thresholds for 500 Hz, 1000 Hz and 2000 Hz[11,12]. However, a number of authors have advocated the use of hearing loss classifications by frequency ranges in order to include the high frequencies in composing these averages, especially for elderly individuals[13,14].

The *Bureau Internacional d' Audiophonologie (*BIAP, 2005) recommended that the classification of hearing losses should take into account the averages of the pure-tone thresholds for air conduction at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz in order to encompass the high frequencies, as these are the most compromised in the pathologies of hearing[15].

Because the frequency ranges of consonants above 2000 Hz are the chief constituents of speech intelligibility, Russo proposed, in 2009, that the degree of hearing loss should be classified based on the average audibility threshold obtained over the frequencies of 500 Hz to 4000 Hz[13].

The classifications of hearing losses relying on the tritone average as suggested by Lloyd & Kaplan (1978)[12] and Davis & Siverman (1970)[11] were found to be adequate to classify the hearing losses with a flat audiometric configuration. However, in ski slope hearing losses, such as presbycusis, this classification is not always consistent with the patients' complaints, as these refer to difficulties in speech recognition, mostly.

Given that the major auditory function concerns verbal communication and speech recognition abilities, it is paramount that the speech tests be considered in the classification of hearing losses, thus expressing the actual hearing impairment of the patients. The aim of the present study was to assess which pure-tone averages have a stronger correlation with the speech recognition threshold (SRT) and with the speech discrimination score (SDS).

METHODS

The present study was approved by the Research Ethics Committee of the Federal University of Minas Gerais (UFMG) under protocol no. 155 09. An informed consent form was prepared explaining the theme of the study, its aims and the importance of analyzing the audiometric tests of the individuals selected for the study.

This comparative study based on the results of audiometric tests was conducted with an elderly population who received care at the Instituto Jenny de Andrade Faria, an annex to the UFMG Hospital das Clínicas.

The study employed a convenience sample of all the elderly individuals with a complaint of hearing loss who underwent audiometric evaluation with measurements of pure-tone hearing thresholds for air and bone conduction and speech audiometry consisting of the SRT and SDS tests between April 2011–April 2012. Some exclusion criteria were established: individuals with mixed or conductive hearing loss in at least one ear, or incomplete/inconclusive tests, e.g, when pure-tone thresholds over the frequencies of 500 Hz to 4000 Hz were not obtained or speech audiometry was not performed.

In total, 241 tests were analyzed: 153 (63.5%) of female patients and 88 (36.5%) of male patients. Ages ranged from 60 to 97 years (mean, 77.9 years). The results of 482 ears were evaluated.

The present study examined the pure-tone hearing thresholds for air conduction obtained through the analysis of pure-tone audiometry based on the following averages:

- Average 1: tritone average of frequencies 500 Hz, 1000 Hz and 2000 Hz according to Davis and Silverman, 1970[11] and Lloyd and Kaplan, 1978[12];
- Average 2: pure-tone average of frequencies 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz according to Recommendation 02/1 of the *Bureau Internacional d'Audiophonologie* (BIAP)[15];
- Average 3: pure-tone average of frequencies 500 Hz, 1000 Hz, 2000 Hz and 3000 Hz, and
- Average 4: pure-tone average of frequencies 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz and 4000 Hz.

The data were treated statistically using the R software. Distribution of frequencies was performed for the categorical variable (sex). For the continuous variables (age, frequencies, SRT and SDS), measures of central tendency (mean and median) and variability (standard deviation, minimum and maximum) were used.

The four averages and the individual frequencies 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz and 4000 Hz were correlated with the SRT and SDS values obtained in the audiometric tests in order to assess which pure-tone average or individual frequency best represents speech recognition ability. To that end, Spearman's coefficient of correlation was used, with a confidence interval of 95%. To determine the strength of the correlation, the following classification scale was used[16]: 0–0.2: very poor correlation; 0.21–0.4: poor correlation; 0.41–0.6: moderate correlation; 0.61– 0.8: good correlation, and 0.8 –1.0: very good correlation.

In addition, the mean squared error (MSE) was calculated. The MSE is inversely related to the coefficient of correlation, i.e., the greater the correlation, the lower the MSE (lower prediction error); consequently, the better the variable as a predictor.

To ascertain whether the correlations obtained were statistically different, comparison of correlations was the method adopted for hypothesis testing. The correlation values were compared both for the SRT and the SDS, and the results were obtained using *p*-values, with statistical significance defined by $p<0.05$.

RESULTS

The mean values obtained in the audiologic evaluation of the 482 ears can be found in Figure 1.

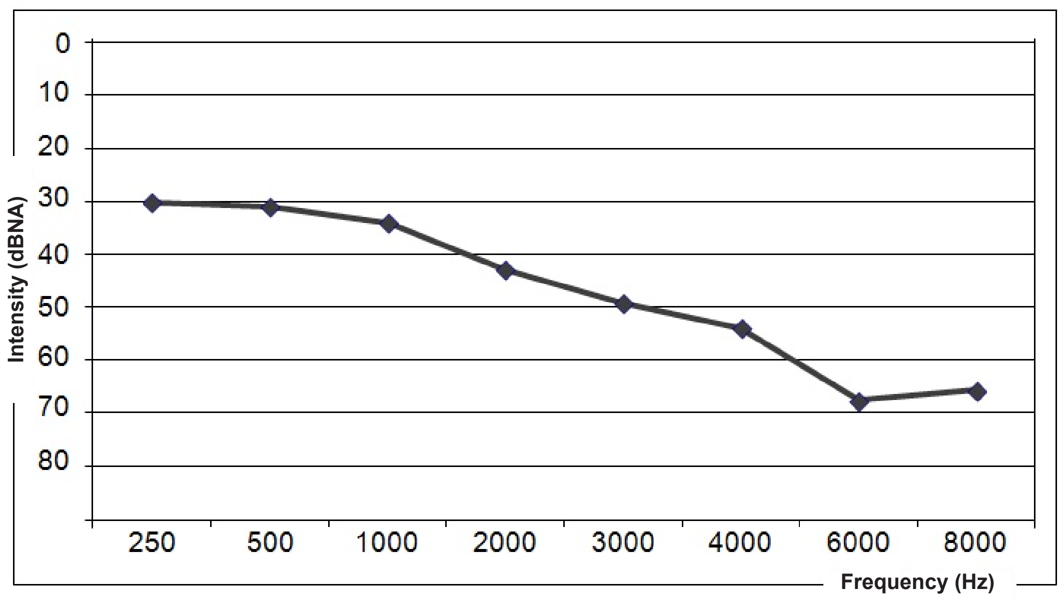

Figure 1 – Means for the pure-tone thresholds by frequency of 482 ears

Table 1 shows the descriptive analysis of the threshold averages by frequency, the four calculated pure-tone averages, the SRT in dBHL, and the SDS in percent values.

Correlations were established for the individual frequencies 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, Average 1, Average 2, Average 3 and Average 4 with the SRT and SDS. In addition, confidence intervals and mean squared errors were calculated, which served to identify the analyses with the highest predictive value for the SRT and SDS. The results can be seen in Table 2.

Table 1 – Descriptive analysis of the pure-tone frequencies, calculated means, mean SRT and SDS in the study sample

Descriptive	Mean (dB HL)	Median (dB HL)	SD (dB HL)	Minimum (dB HL)	Maximum (dB HL)
250 Hz	30.36	25	15.53	0	100
500 Hz	31.05	30	16.08	0	95
1000 Hz	33.98	35	16.85	0	100
2000 Hz	42.99	45	18.04	5	120
3000 Hz	49.42	50	19.29	0	120
4000 Hz	54.08	55	19.47	0	115
6000 Hz	67.75	70	19.47	10	120
8000 Hz	65.81	65	18.43	5	110
Average 1	36.01	35	15.50	3.33	90
Average 2	40.53	40.63	15.31	2.5	87.5
Average 3	39.36	40	15.54	2.5	88.75
Average 4	42.30	43	15.68	2	94
SRT	41.29	40	16.57	10	110
SDS*	75.99*	84*	22.66*	0*	100*

* – values in %

Table 2 – Correlations of the individual frequencies 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz and 4000 Hz, Average 1, Average 2, Average 3 and Average 4 with the SRT and the SDS

Variable	SRT				SDS			
	Rho	CI		MSE ($dBHL^2$)	Rho	CI		MSE ($dBHL^2$)
		CI.inf	CI.up			CI.inf	CI.up	
500 Hz	0.807*	0.765	0.844	108.4	-0.569	-0.634	-0.501	322.9
1000 Hz	0.889*	0.857	0.915	71.5	-0.675**	-0.720	-0.620	284.2
2000 Hz	0.841*	0.800	0.875	88.8	-0.735**	-0.778	-0.688	282.1
3000 Hz	0.700	0.633	0.752	138.2	-0.696**	-0.745	-0.637	323.4
4000 Hz	0.636	0.574	0.691	162.4	-0.653**	-0.706	-0.589	348.1
Average 1	0.934*	0.901	0.958	52.2+	-0.734**	-0.776	-0.683	251.6
Average 2	0.918*	0.887	0.941	59.0	-0.768**	-0.811	-0.720	245.3
Average 3	0.922*	0.886	0.944	56.4	-0.768**	-0.807	-0.721	245.0+
Average 4	0.895*	0.861	0.921	68.7	-0.773**	-0.813	-0.725	251.2

Average 1- mean of frequencies 500 Hz, 1000 Hz and 2000 Hz
Average 2- mean of frequencies 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz
Average 3- mean of frequencies 500 Hz, 1000 Hz, 2000 Hz and 3000 Hz
Average 4- mean of frequencies 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz and 4000 Hz
Rho- Spearman's coefficient of correlation
MSE- Mean Squared Error
SRT- Speech Reception Threshold
SDS- Speech Discrimination Score
CI- Confidence Interval
CI inf- lower limit of Confidence Interval
CI up- upper limit of Confidence Interval
*very good correlation
**good correlation
+best variable as a predictor of correlation
Spearman's coefficient of correlation test
Mean Squared Error test

In Figure 2, a matrix with hypothesis testing *p*-values is presented. Using that matrix, it is possible to assess whether the correlations found in Table 2 are statistically different, both for the SRT and SDS.

	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	Average 1	Average 2	Average 3	Average 4
500 Hz		0,000	0,084	0,001	0,000	0,000	0,000	0,000	0,000
1000 Hz	0,000		0,003	0,000	0,000	0,000	0,003	0,001	0,336
2000 Hz	0,000	0,014		0,000	0,000	0,000	0,000	0,000	0,000
3000 Hz	0,003	0,278	0,053		0,001	0,000	0,000	0,000	0,000
4000 Hz	0,048	0,296	0,004	0,020		0,000	0,000	0,000	0,000
Average 1	0,000	0,000	0,479	0,108	0,011		0,001	0,003	0,000
Average 2	0,000	0,000	0,022	0,001	0,000	0,000		0,114	0,000
Average 3	0,000	0,000	0,022	0,001	0,000	0,000	0,297		0,000
Average 4	0,000	0,000	0,006	0,000	0,000	0,002	0,146	0,200	

- *p*-value for the SDS
- *p*-value for the SRT

Average 1- mean of frequencies 500 Hz, 1000 Hz and 2000 Hz.
Average 2- mean of frequencies 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.
Average 3- mean of frequencies 500 Hz, 1000 Hz, 2000 Hz and 3000 Hz.
Average 4- mean of frequencies 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz and 4000 Hz.
Hypothesis testing of the equality of the correlations of Spearman's coefficient of correlation.
Level of significance: $p<0.05$.

Figure 2 – Correlation matrix with hypothesis testing *p*-values comparing the significance of the correlations for the SRT and SDS

DISCUSSION

The aim of the present study was to identify which pure-tone average has the greatest correlation with speech recognition. To that end, the pure-tone thresholds for air conduction were classified using four different averages: Average 1 (500 Hz, 1000 Hz and 2000 Hz), average 2 (500 Hz, 1000 Hz, 2000 Hz and 4000 Hz), average 3 (500 Hz, 1000 Hz, 2000 Hz and 3000 Hz) and average 4 (500 Hz, 1000 Hz, 2000 Hz, 3000 Hz and 4000 Hz). These averages were correlated with the tests of speech recognition, SRT and SDS, obtained in the audiologic evaluation.

The curve depicted in Fig. 1, which shows the average pure-tone thresholds of all the study patients by frequency, is similar to a typical audiogram of elderly individuals, as expected. In this population, a ski slope configuration is commonly found, with a high-frequency hearing loss and preserved low-pitch sensitivity[14,17-20]. Presbyacusis is defined as a bilateral sensorineural hearing loss that is more pronounced for high-pitched sounds due to the degenerative and physiologic changes in the auditory system that arise with aging[17,21]. In elderly individuals with presbyacusis, the apical coil of the cochlea, responsible for the detection of low-pitched sounds, is more preserved compared with the basal coil, which detects the high-pitched sounds[17].

Regarding speech discrimination, Table 1 shows that the mean for the SDS was 75.99%, which was expected for elderly patients[22-26]. Studies suggest that the difficulty in speech comprehension, demonstrated by the lower SDS, occurs as a result of the structural and physiologic changes in the auditory system with aging[22,23].

Table 2 shows the correlation values for the individual frequencies 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz and 4000 Hz, Average 1, Average 2, Average 3 and Average 4 with the SRT and SDS. Although all the averages showed very good correlation, it was found that Average 1 had greater correlation with the SRT (0.934). For that reason, Average 1 was considered to be the most adequate estimator of the threshold of speech recognition[16]. This fact was corroborated by the mean squared error found in the correlation of Average 1 with the SRT (52.2). This lower mean demonstrated the lower prediction error of Average 1 relative to the SRT. In other words, Average 1 is the best predictor of SRT values. Additionally, Fig. 2 shows that the correlation of SRT and Average 1 differs statistically from the correlations between SRT and the other averages. This proves that, even with such narrow confidence intervals (Table 2), the correlation of Average 1 with the SRT can be regarded as the strongest. Thus, this result indicates that the averages of 500 Hz, 1000 Hz and 2000 Hz used to compose Average 1 are key frequencies to estimating the SRT. This fact can be confirmed by the analysis of the individual frequencies in Table 2.

The correlation values for the SDS are negative, since they are inversely proportional: as averages increase, SDS percentages decline. All the averages had good correlation with the SDS, with statistically superior correlation values for Averages 2, 3 and 4 (Table 2 and Fig. 2). As Fig. 2 illustrates, the correlation between Average 1 and the SDS, albeit good, is statistically inferior. On the other hand, no statistically significant difference was found when comparing the correlations between Averages 2 and 3; 2 and 4, and 3 and 4. This finding indicates that the correlations of the SDS and Averages 2, 3 and 4, in addition to being superior, are also quite similar; therefore, it is impossible to infer which of these three averages is the best predictor. Nevertheless, these results allow us to conclude that the frequencies 3000 Hz and 4000 Hz are important for speech recognition, since the correlation of Average 1 was lower with the SDS, and statistically different as compared with the other three averages. To corroborate these findings, the MSE (Table 2) was lower for Average 3, followed by Average 2—albeit with quite similar values. This shows that both averages, 2 and 3, have a greater predictive value regarding the SDS, i.e., the more severe the impairment at 3000 Hz and 4000 Hz, the worse the performance in the SDS test. This finding is explained in the literature[7,9] which indicates that 60% of speech intelligibility relies on frequencies above 1000 Hz.

The contribution of high frequencies to speech recognition was more evident in the SDS than in the SRT. We believe this occurred because in the SDS test, whose purpose is to assess the percentage of speech recognition, one-syllable words are used, as they provide fewer clues in speech and are less redundant, which reduces the likelihood of correct guesses. In the SRT evaluation, the purpose is to assess the threshold of speech recognition; therefore, three-syllable words are used, as they are more frequent in the patient's vocabulary, which increases redundancy and the chances of correct guesses. This makes guessing with the SRT test easier than with the SDS.

A recent study compared the audiologic performance of elderly individuals based on the classifications of Davis and Silverman, 1970[11] and on the Recommendation 02/1 of the *Bureau Internacional d'Audiophonologie (BIAP)*[15]. The authors reviewed the records of 140 elderly individuals focusing on the clinical history and the pure-tone audiometry results. Predominance of mild to moderate sensorineural hearing loss was found, with slight differences regarding its prevalence depending on the hearing loss classification adopted. Based on Davis and Silverman, 99 cases of ears with normal thresholds were found, while only 66 cases were identified according to the *BIAP* recommendation. The study concluded that the classifications achieved similar results; however, the *BIAP* recommendation was found to be more sensitive in detecting hearing losses in the elderly[27]. A study conducted in Finland with 5400 volunteers aged 55–75 years demonstrated a remarkable difference between the hearing loss classification by the World Health Organization (WHO) criteria compared with the European Union criteria. In that study, the percentage of individuals with normal hearing was greater when the WHO classification was used[28].

The results of the analyses enabled us to conclude that speech discrimination as measured by the SDS is influenced by the frequencies 3000 Hz and 4000 Hz. For that reason, the importance of including these frequencies in the pure-tone average used for classifying the hearing loss should be emphasized, since one of the objectives of this classification is to reflect a person's hearing abilities and difficulties especially with regard to communication.

CONCLUSION

For the elderly population with ski slope sensorineural hearing loss, the SRT is more strongly correlated with the average of frequencies 500 Hz, 1000 Hz and 2000 Hz, while the SDS shows greater correlation with the average that includes frequencies 3000 Hz and 4000 Hz.

RESUMO

Objetivo: verificar quais médias tonais possuem maior correlação com o Limiar de Recepção da Fala e com o Índice de Reconhecimento da Fala. **Métodos:** foram selecionados 241 exames de pacientes idosos com perda auditiva neurossensorial que realizaram audiometria tonal liminar e logoaudiometria. As avaliações audiométricas foram classificados com base nos limiares tonais de via aérea das seguinte formas: Média 1- Média das frequências de 500, 1000 e 2000 Hz; Média2-Média das frequências de 500, 1000, 2000 e 4000 Hz; Média 3 – Média das frequências de 500, 1000, 2000 e 3000 Hz e Média 4 –Média das frequências de 500, 1000, 2000, 3000 e 4000 Hz. Os dados foram comparados com os testesLimiar de Recepção da Fala e Índice de Reconhecimento da Fala e tratados estatisticamente. **Resultados:** a Média 1 apresentou maior valor de correlação com o Limiar de Recepção da Fala (rho=0,934; IC=0,901 a 0,958; eqm=52,2). Em relação ao Índice de Reconhecimento da Fala, foi observado que amédia 3 apresentou omaior grau de correlação com o teste(rho= – 0,768; IC= –0,807 a –0,721; eqm = 245) seguido das médias 2 e 4. **Conclusão:** para a população idosa com perda auditiva neurossensorial descendente, o Limiar de Recepção de Fala possui correlação mais forte com a média das frequências 500 Hz, 1000 Hz e 2000 Hz, enquanto o Índice de Reconhecimento de Fala possui maior correlação com as média que incluem as frequências de 3000 Hz e 4000 Hz.

DESCRITORES: Perda Auditiva; Presbiacusia; Audiometria; Idoso; Inteligibilidade da Fala

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