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CORRELATION BETWEEN PURE TONE THRESHOLDS AND SPEECH THRESHOLDS

Original scientific paper

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ABSTRACT

Speech detection threshold (SDT) depends on audibility alone, whereas speech recognition threshold (SRT) requires the stimuli to be heard and identified. The aim of the study was to determine the difference between SDT and SRT, and to analyze the correlation between pure tone thresholds and speech thresholds. Difference between SDT and SRT was ≤ 12 dB in majority of cases (p = .018). SDT was strongly correlated with the best pure tone threshold. Pearson correlation coefficient was the highest in "Inverted U" shape (r = .99). There was strong correlation between SRT and PTA (500-2000), PTA (500-4000), and PTA (500-1000), especially in Rising configuration (r = .997, r = .992 r = .989, respectively), as well as, between SRT and frequency of 1000 Hz (r = .989). SRT is in the highest correlation with PTA (500, 1000, 2000 Hz) and with the hearing threshold at frequency of 1000 Hz.

Keywords: *correlation, hearing threshold, speech threshold*

INTRODUCTION

Pure tone audiometry involves finding the lowest sound pressure levels for different pure tones that a person is barely able to hear. The lowest sound pressure level of a pure tone to which a person reliably responds at least 50% of the time is called a hearing threshold for that frequency (Kramer & Brown, 2019). Pure tone thresholds are an example of a psychophysical measure relating the physical characteristics of a tone to a behavioral threshold. Conventional pure tone audiometry typically assesses thresholds for frequencies between 250 (or 125) and 8000 Hz (Schlauch & Nelson, 2015). An auditory range of the human ear riches up to 20000 Hz. Threshold measurements at extended high-frequencies between 9000 and 20000 Hz may be useful in early diagnosis of hearing loss in certain conditions (Rodriguez Valiente et al., 2016).

Speech audiometry evaluates a person's ability to hear and understand speech (Shipley & McAfee, 2016). There are two types of threshold measures using speech stimuli: speech detection threshold (SDT) and speech recognition threshold (SRT). SDT is an estimate of the level at which an individual perceives speech to be present 50% of the time (McArdle & Hnath-Chisolm, 2015). SRT is the softest level at which an individual can repeat back spondaic words 50% of the time (Tye-Murray, 2020). Spondaic words or spondees are two-syllable words with equal stress on both syllables (Bess & Humes, 2008). The most common suprathreshold measure in quiet is word recognition score (WRS) and is generally measured in percent correct at a level relative to the SRT (Gelfand, 2016).

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There is a relationship between SDT, SRT and pure tone thresholds. The important clinical value of the SDT is that it should agree closely with the best pure tone threshold within the audiometric frequency range (Stach, 2010). The SRT and SDT represent different criteria: intelligibility vs. detectability. Speech can be detected at intensity levels lower than it can be understood, on the order of 8 to 12 dB (Diefendorf, 2015).

Because speech is used to determine speech thresholds, the thresholds of the pure tone frequencies that are most important for speech understanding should closely match the SRT. Specifically, an average of the pure tone thresholds at 500, 1000, and 2000 Hz, known as the pure tone average (PTA) should match the SRT within 7 to 10 dB (DeRuiter & Ramachandran, 2017). It is also considered that the SRT is in agreement with the PTA if there is less than 12 dB difference between these measures (Dutta et al., 2016).

SRTs obtained using spondaic words agree well with pure tone thresholds for low frequencies. Spondees are easily recognized. Listeners only need to recognize the vowels to identify these words correctly. Because of the importance of the vowels at low frequencies, spondee thresholds are found to agree closely with the average of pure tone thresholds for 500 and 1000 Hz. In the case of a rising audiogram, better agreement between the spondee and pure tone thresholds is the average for 1000 and 2000 Hz (Schlauch & Nelson, 2015).

The aim of the study was to determine the difference between SDT and SRT, and to analyze the correlation between pure tone thresholds, SDTs and SRTs.

METHODS

This prospective study included a sample of 110 patients with hearing loss, 50 males and 60 females, aged 5 to 75 years (mean age of 51.2±19.5 years), examined at the Department of Otorhinolaryngology, Division of Audiology, City General Hospital "8th September" Skopje. Inclusion criteria were: unilateral or bilateral hearing loss, mild, moderate or severe hearing loss. Exclusion criteria were: age under 5 years in children and above 75 in adults, as well as deafness. Pure tone audiometry and speech audiometry were performed with MADSEN Astera2 audiometer and Sennheiser HDA 300 (Sennheiser electronic, Germany) circumaural earphones in sound proof booth. Hearing threshold was obtained with modified Hughson-Westlake technique for frequencies from 125 to 8000 Hz. Normal hearing was defined as thresholds ≤ 20 dB HL for frequencies from 250 to 8000 Hz.

Audiometric configuration was defined in the following way:

Rising – hearing threshold at low frequencies is at least 20 dB poorer than hearing threshold at high frequencies;

Sloping – hearing threshold at high frequencies is at least 20 dB poorer than hearing threshold at low frequencies;

Flat – the difference between the maximum hearing threshold and the minimum hearing threshold is ≤ 20 dB;

Notch – a sharp drop in the hearing sensitivity at 4000 Hz of at least 15 dB in relation to both, the threshold at 2000 Hz and the threshold at 8000 Hz;

U shape – hearing threshold at 1000 Hz and/or 2000 Hz is 20 dB poorer than hearing threshold at 500 Hz and threshold at 4000 Hz;

Inverted U shape – hearing threshold at 1000 Hz and/or 2000 Hz is 20 dB better than hearing threshold at 500 Hz and threshold at 4000 Hz.

Speech detection threshold, speech recognition threshold, and word recognition score were determined in all patients. Speech audiometry was performed with the recorded speech material: Ristovska and Jachova Monosyllabic Test 1 and Test 2; Ristovska and Jachova Disyllabic Test 3 and Test 4. For statistical data analysis we used Chi-square test, Fisher's exact test and Pearson correlation coefficient with level of significance $p < .05$. The study was approved by the Ethics committee of City General Hospital "8th September" Skopje. The Protocol number of Ethical approval is: 24/89-1/2019.

RESULTS

Our study included a sample of 110 patients, 12 children (10.9%), and 98 adults (89.1%). We displayed demographic and clinical characteristics of patients (Table 1). Unilateral hearing loss was present in 26 patients (23.6%), and 84 patients (76.4%) had bilateral hearing loss. A total of 220 ears were analyzed. In terms of the degree of hearing loss, mild hearing loss was the most common (65.5%). Sensorineural hearing loss was the most common type of hearing loss (80.4%).

Table 1. Demographic and clinical characteristics of patients

Characteristics	No (%)
Age (Years)	
5-14	12 (10.9)
22-30	6 (5.5)
31-40	5 (4.5)
41-50	19 (17.3)
51-60	24 (21.8)
61-70	34 (30.9)
71-75	10 (9.1)

Table 1. Continued

Characteristics	No (%)
Gender	
Male	50 (45.5)
Female	60 (54.5)
Side of hearing loss	
Unilateral right	10 (9.1)
Unilateral left	16 (14.5)
Bilateral	84 (76.4)
Degree of hearing loss (220 ears)	
Normal	26 (11.8)
Mild	144 (65.5)
Moderate	34 (15.5)
Severe	16 (7.3)
Type of hearing loss (194 ears)*	
Conductive	24 (12.4)
Sensorineural	156 (80.4)
Mixed	14 (7.2)

*Normal hearing ears were excluded

We determined the difference between SDT and SRT in terms of the audiometric configuration (Table 2). There was a difference ≤ 12 dB in majority of cases. A statistical analysis shows that there is not statistically significant difference between the intensity level of speech thresholds and audiometric configuration (χ^2 = 6.578, df = 5, p = .254).

Table 2. Difference between SDT and SRT in terms of the audiometric configuration

Audiometric configuration	≤ 12 dB		> 12 dB		Total	
	No	%	No	%	No	%
Rising	5	2.6	5	2.6	10	5.2
Sloping	68	35.1	27	13.9	95	49
Flat	31	16	10	5.2	41	21.1
Notch	21	10.8	6	3.1	27	13.9
U shape	6	3.1	5	2.6	11	5.7
Inverted U	5	2.6	5	2.6	10	5.2
Total	136	70.1	58	29.9	194	100

Chi-square test (p = .254)

We also calculated the difference between SDT and SRT in normal hearing ears and cases of hearing loss (Table 3). There was a difference ≤ 12 dB in majority of cases. A statistical analysis with Fisher's exact test shows that there is statistically significant difference between the intensity level of speech thresholds and patient's hearing (p = .018).

Table 3. Difference between SDT and SRT in cases of normal hearing and hearing loss

Patient's hearing	≤ 12 dB		> 12 dB		Total	
	No	%	No	%	No	%
Normal hearing	24	10.9	2	.9	26	11.8
Hearing loss	136	61.8	58	26.4	194	88.2
Total	160	72.7	60	27.3	220	100

Fisher's exact test (p = .018)

We analyzed the correlation between SDT and hearing thresholds in different audiometric configuration (Table 4).

Table 4. Correlation between SDT and hearing thresholds in different audiometric configuration

Audiometric configuration	Best threshold		PTA (500-4000)		PTA (500-2000)		PTA (500-1000)	
	r	p	r	p	r	p	r	p
Rising	.987	< .00001	.978	< .00001	.976	< .00001	.966	< .00001
Sloping	.945	< .00001	.894	< .00001	.927	< .00001	.924	< .00001
Flat	.971	< .00001	.96	< .00001	.958	< .00001	.944	< .00001
Notch	.973	< .00001	.854	< .00001	.842	< .00001	.872	< .00001
U shape	.95	< .00001	.82	.001978	.848	.000976	.632	.036965
Inverted U	.99	< .00001	.923	< .00001	.967	< .00001	.949	.000028

SDT was in the highest correlation with the best pure tone threshold in all types of audiometric configuration. Pearson correlation coefficient was highest in "Inverted U" shape ($r = .99$, $p < .00001$).
Correlation between SRT and PTA in different audiometric configuration was analyzed (Table 5).

SRT was in the highest correlation with PTA at frequencies 500, 1000, and 2000 Hz in all types of audiometric configuration. Pearson correlation coefficient was the highest in Rising configuration ($r = .997$, $p < .00001$).

Table 5. Correlation between SRT and PTA in different audiometric configuration

Audiometric configuration	PTA (500-4000)		PTA (500-2000)		PTA (500-1000)	
	r	p	r	p	r	p
Rising	.992	< .00001	.997	< .00001	.989	< .00001
Sloping	.947	< .00001	.97	< .00001	.957	< .00001
Flat	.975	< .00001	.976	< .00001	.97	< .00001
Notch	.94	< .00001	.962	< .00001	.951	< .00001
U shape	.91	.000109	.945	.000012	.662	.026394
Inverted U	.969	< .00001	.981	< .00001	.951	.000023

We analyzed correlation between SRT and hearing thresholds for speech frequencies 500, 1000, 2000, and 4000 Hz in different audiometric configuration (Table 5).

SRT was in the highest correlation with hearing threshold at frequency of 1000 Hz in all types of audiometric configuration. Pearson correlation coefficient was the highest in Rising configuration ($r = .989$, $p < .00001$).

Table 6. Correlation between SRT and hearing threshold for speech frequencies

Audiometric configuration	500		1000		2000		4000	
	r	p	r	p	r	p	r	p
Rising	.987	< .00001	.989	< .00001	.988	< .00001	.869	.00109
Sloping	.933	< .00001	.951	< .00001	.937	< .00001	.712	< .00001
Flat	.964	< .00001	.969	< .00001	.961	< .00001	.911	< .00001
Notch	.916	< .00001	.961	< .00001	.91	< .00001	.712	.000032
U shape	.499	.118245	.754	.007373	.725	.011606	.621	.041568
Inverted U	.923	.00014	.95	.000026	.944	.000039	.855	.001609

Speech recognition threshold was the starting point for word recognition score. In Figure 1 we displayed tonal and speech audiogram of patient with conductive hearing loss in the left ear. In this case, SDT was 30 dB HL, the same level as the best pure tone thresholds (frequency of 2000 and 4000 Hz). SRT was 36 dB HL.

Speech audiogram shows a psychometric function of word recognition performance as a function of percent correct (ordinate) and presentation level (abscissa). The curve in conductive hearing loss has the same shape as curve in normal hearing ear with WRS 100%, but it is obtained at higher intensity levels.

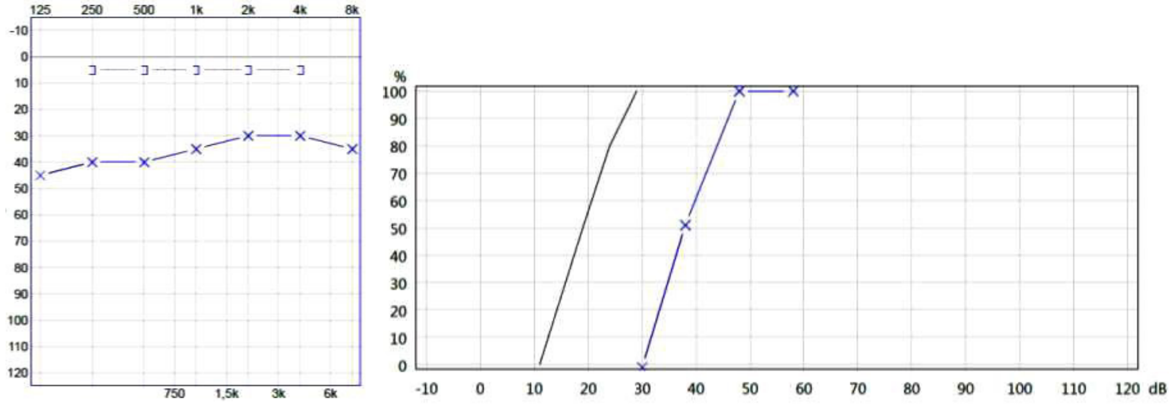

Figure 1. Tonal and speech audiogram of patient with conductive hearing loss

In Figure 2 we displayed tonal and speech audiogram of patient with sensorineural hearing loss in the left ear. In this case, maximal WRS is 78% and the curve is typical for cochlear hearing loss.

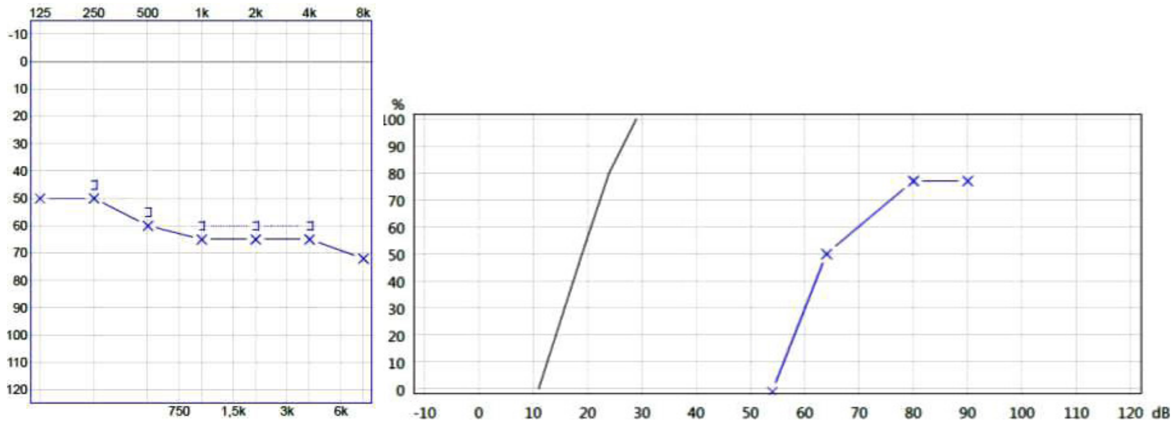

Figure 2. Tonal and speech audiogram of patient with sensorineural hearing loss

DISCUSSION

We determined the difference between SDT and SRT in terms of the audiometric configuration, and difference between speech thresholds related to presence of hearing loss. There was a difference ≤ 12 dB in majority of cases. SDT is lower because it depends on audibility alone, whereas SRT requires the stimuli to be heard and identified (Gelfand, 2016).

We analyzed the correlation between pure tone thresholds, SDTs, and SRTs in patients with hearing loss. There was the highest correlation between SDT and the best hearing threshold in all types of audiometric configuration. When using the SDT as a cross-check with the PTA, we must consider whether there is good agreement with the best pure tone threshold between 250 and 4000 Hz (Kramer & Brown, 2019).

In our study there was the highest correlation between SRT and PTA calculated at frequencies 500, 1000, and 2000 Hz. The SRT is normally 10 dB higher than PTA at 500, 1000, and 2000 Hz of the corresponding audiogram. A difference of more than 10 dB raises questions about test reliability and pseudohypoacusis (Hamid & Brookler, 2006). Kim et al. (2016) explored the relationship between the SRT and several variations of PTA. They found high correlation between SRT and PTA calculated at frequencies 500, 1000, and 2000 Hz. The addition of frequencies higher than 2000 Hz to a PTA formula seems to have impeded the PTA-SRT agreement, especially for high-frequency steeply sloping audiograms.

Variance from the best SRT-PTA (500, 1000, 2000) agreement can be seen in pseudohypoacusis or in steeply sloping hearing loses where the SRT may be closer to the best tones in the PTA than the average of 500, 1000, and 2000 Hz (Babu, 2013). According to Gelfand (2016) adequate speech recognition actually depends on a much wide range of frequencies. Moreover, this three-frequency average often fails to agree with the SRT, especially when the shape of the pure tone audiogram slopes sharply.

Under these circumstances SRT is in higher correlation with the two-frequency pure tone average, usually 500 and 1000 Hz (Gelfand, 2016). If the PTA and the speech thresholds do not correlate well, it is important to consider the possibility of malingering or central auditory dysfunction. If the speech thresholds are much better than the PTA, pseudohypoacusis should be considered. If the PTA is significantly better than the speech thresholds, the possibility of central involvement should be considered (Squires, Colombo & McKinney, 2019).

There was high correlation between SRT and PTA at 500, 1000, 2000, and 4000 Hz in our study. Some authors found the highest correlation between SRT and PTA at more than three frequencies. In cases of rising and sloping audiometric configuration in patients with sensorineural hearing loss, de Andrade et al. (2013) concluded that frequencies 500, 1000, 2000, and 4000 Hz were most significant for predicting the SRT. Maeda et al. (2018) found high correlation between SRT and PTA calculated at all frequencies tested (125, 250, 500, 1000, 2000, 4000, and 8000 Hz).

When we compared the SRT separately with speech frequencies 500, 1000, 2000, and 4000 Hz, we found the highest correlation between SRT and frequency of 1000 Hz. Chien et al. (2006) found the highest correlation between SRT and frequency of 1000 Hz, followed by 500, 250, and 2000 Hz. The highest correlation between SRT and frequency of 1000 Hz was found in cases of sloping audiometric configuration (dos Anjos et al., 2014). We found the highest correlation between SRT and frequency of 1000 Hz in all audiometric configurations.

CONCLUSION

Speech detection threshold is in the highest correlation with the best pure tone threshold. Speech recognition threshold is in the highest correlation with the pure tone average at frequencies of 500, 1000, and 2000 Hz, as well as, with the hearing threshold at frequency of 1000 Hz. The well-known agreement between pure tone thresholds and speech recognition thresholds makes the speech thresholds an excellent check on the reliability of the audiogram.

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