UDK: 159.946.3:616.28-072.7

Г-3

CROSS VALIDATION OF THE PURE TONE THRESHOLD WITH SPEECH AUDIOMETRY

Ristovska L., Jachova Z., Kovacevic J.

City General Hospital "8th September", Department of Otorhinolaryngology, Division of Audiology, Skopje, Republic of North Macedonia

Ss. Cyril and Methodius University in Skopje, Faculty of Philosophy, Institute of Special Education and Rehabilitation, Skopje, Republic of North Macedonia

University of Belgrade, Faculty of Special Education and Rehabilitation, Belgrade, Republic of Serbia

Introduction: *Speech audiometry is a method of evaluating how well a patient can hear and understand specific types of speech stimuli. One of the clinical functions of speech thresholds is cross validation of pure tone thresholds.*

Subject of the study: *The subject of the study is the correlation between speech detection threshold (SDT), speech recognition threshold (SRT) and pure tone thresholds, as well as the difference between SDT and SRT.*

Methodology: *This prospective study included a sample of 52 children with hearing loss, 30 males (57.7%) and 22 females (42.3%), aged 5 to 14 years (mean age of 6.1 ± 1.7 years). Pure tone audiometry and speech audiometry were performed. For statistical data analysis we used Pearson correlation coefficient and Chi-square test with a level of significance* $p < .05$.

Results: *SDT is strongly correlated with the best pure tone threshold. The highest value was found in sloping audiometric configuration (r = .993). There was strong correlation between SRT and pure tone average PTA (500-2000), PTA (500-1000), and PTA (500-4000), especially in rising configuration (r = .978, r = .91, r = .909, respectively), as well as between SRT and frequency of 1000 Hz (r = .986). Difference between SDT and SRT was ≤ 12 dB in majority of cases (p = .033).*

Conclusion: *SDT is in the highest correlation with the best pure tone threshold. SRT is in the highest correlation with PTA at frequencies of 500, 1000, and 2000 Hz, as well as with the hearing threshold at frequency of 1000 Hz. The well-known correlation between pure tone threshold and speech thresholds makes the speech thresholds an excellent cross-check of the tonal audiogram.*

Keywords: *speech threshold, pure tone threshold, correlation*

Introduction

Pure tone audiometry is a standard method of determining hearing threshold. 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 (Schlauch & Nelson, 2015). One of the best ways to describe hearing ability is by its sensitivity to sound. Hearing sensitivity is usually defined by an individual's threshold of audibility of the sound (Stach, 2010). Pure tone audiometry typically assesses thresholds for frequencies between 125 and 8000 Hz (DeRuiter & Ramachandran, 2017).

Threshold information at each frequency is plotted on a graph known as an audiogram. Thresholds are obtained by both air conduction and bone conduction. In air conduction measurement, the different pure-tone stimuli are transmitted through earphones. The signal travels through the ear canal, across the middle ear cavity via the three ossicles to the cochlea, and on to the auditory central nervous system. In bone conduction measurement, signals are transmitted via a bone vibrator that is usually placed on the mastoid prominence of the skull. A signal transduced through the vibrator causes the skull to vibrate. The pure tone directly stimulates the cochlea, which is embedded in the skull, effectively bypassing the outer ear and middle ear systems (Bess & Humes, 2008). The propagated wave can be triggered intentionally, when a bone vibrator is placed on the mastoid bone, or inadvertently when testing hearing of one ear by air conduction while disregarding transmission of the sound to the other side (Dauman, 2013).

When describing hearing loss, we generally look at three aspects: type, degree, and configuration of hearing loss. There are three basic types of hearing loss: conductive, sensorineural, and mixed (Cunningham & Tucci, 2017).

Speech audiometry is a method of evaluating how well a patient can hear and understand specific types of speech stimuli (Kramer & Brown, 2019). There are two types of speech threshold measures: speech detection threshold (SDT) and speech recognition threshold (SRT). SDT is the level at which an individual perceives speech to be present. The objective is to determine the lowest intensity level at which the signal is heard. This can be achieved in an ascending manner, initially presenting the signal well below the anticipated response level and raising the intensity of the signal in 5 dB steps (DeRuiter & Ramachandran, 2017). SRT is the softest level at which an individual can repeat back spondaic words 50% of the time (Gelfand, 2016). SDT is established by presenting familiar words, connected speech, spondaic words, or even repeated nonsense syllables. Spondaic words or *spondees* are also used for determining the SRT. Spondees are two syllable words that have equal stress on each syllable (Stach, 2010). SRT is starting point to determine word recognition score which is a supra threshold measure (Shipley & McAfee, 2016).

Speech materials are presented by monitored live voice or recorded speech materials are used (Lawson & Peterson, 2011). In terms of the response to the stimuli, there is an *open-set* format of the test, which means that the patient must respond without any prior knowledge of what the possible alternatives might be, or a *closed-set* format, which means that the patient is provided with a choice of several possible response alternatives (Gelfand, 2016). The speech stimuli are presented in quiet or with addition of background noise (McArdle & Hnath-Chisolm, 2015).

There is a relationship between pure tone thresholds and speech 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). Speech can be detected at intensity levels lower than it can be understood, on the order of 8 to 12 dB (Diefendorf, 2015). That is the difference between SDT and SRT.

The aim of the study is the correlation between SDT, SRT and pure tone thresholds, as well as the difference between SDT and SRT.

Methodology

This prospective study included a sample of 52 children with hearing loss, 30 males (57.7%) and 22 females (42.3%), aged 5 to 14 years (mean age of 6.1 ± 1.7 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. Pure tone audiometry and speech audiometry were performed with MADSEN Astera[2] audiometer (Otometrics, Denmark) 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 thresholds and speech recognition thresholds were determined with the recorded speech material: *Ristovska and Jachova Disyllabic Test 3 and Test 4*. For statistical data analysis we used Pearson correlation coefficient and Chi-square test, 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: 24-89/19.

Results

We displayed demographic and clinical characteristics of the children (Table 1). Unilateral hearing loss was present in 12 children (23.1%), and 40 children (76.9%) had bilateral hearing loss. A total of 104 ears were analysed. In terms of the degree of hearing loss, mild hearing loss was the most common (83.7%). Conductive hearing loss was the most common type of hearing loss (83.7%).

Table 1
Demographic and clinical characteristics of the children

Characteristics	No (%)
Age	5 to 14 years (mean age of 6.1 ± 1.7 years)
Gender	
Male	30 (57.7)
Female	22 (42.3)
Side of hearing loss	
Unilateral right	5 (9.6)
Unilateral left	7 (13.5)
Bilateral	40 (76.9)
Degree of hearing loss (104 ears)	
Normal	12 (11.5)
Mild	87 (83.7)
Moderate	3 (2.9)
Severe	2 (1.9)
Type of hearing loss (92 ears) *	
Conductive	77 (83.7)
Sensorineural	15 (16.3)

*Normal hearing ears were excluded

Difference between SDT and SRT in normal hearing ears and cases of hearing loss was determined (Table 2). There were 12 normal-hearing ears because of the unilateral hearing loss in some children. A difference between SDT and SRT was ≤ 12 dB in majority of cases (75%). A statistical analysis with Chi-square test shows that there is statistically significant difference between the intensity level of speech thresholds and hearing sensitivity in children ($\chi^2 = 4.522$, $df = 1$, $p = .033$).

Table 2
Difference between SDT and SRT in cases of normal hearing and hearing loss

Hearing sensitivity	≤ 12 dB		> 12 dB		Total	
	No	%	No	%	No	%
Normal hearing	6	5.8	6	5.8	12	11.5
Hearing loss	72	69.2	20	19.2	92	88.5
Total	78	75	26	25	104	100

Chi-square test ($p = .033$)

The correlation between SDT and hearing thresholds in different audiometric configuration (rising, sloping, flat, notch, U-shaped, and inverted U shape) was analysed (Table 3). Pure tone average (PTA) was calculated in three different ways. SDT was compared with the best pure tone thresholds, PTA calculated at frequencies 500-4000 Hz, 500-2000 Hz and 500-1000 Hz. SDT was in the highest correlation with the best pure tone threshold in all types of audiometric configuration. Pearson correlation coefficient was the highest in Sloping configuration ($r = .993$, $p < .001$).

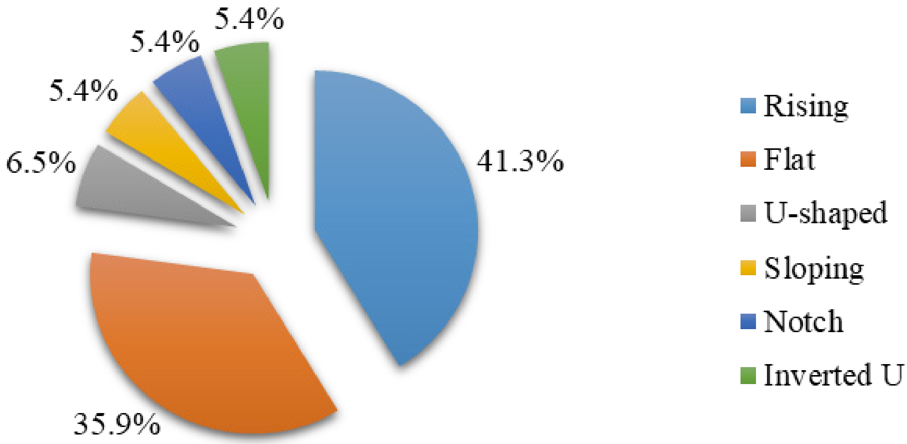
Table 3
Correlation between SDT and hearing thresholds in different audiometric configuration

Audiometric configuration	Best threshold		PTA (500-4000)		PTA (500-2000)		PTA (500-1000)	
	r	p	r	p	r	p	r	p
Rising	.979	< .001	.651	< .001	.842	< .001	.97	< .001
Sloping	.993	.008	.975	.005	.982	.003	.984	.002
Flat	.968	< .001	.875	< .001	.879	< .001	.886	< .001
Notch	.913	.03	.106	.865*	.443	.455*	.732	.16*
U-shaped	.989	< .001	.984	< .001	.98	< .001	.921	.009
Inverted U	.976	.004	.97	.006	.928	.023	.913	.031

*$p > .05$

The percentage of different audiogram shapes in cases of hearing loss is displayed in Figure 1. Rising and flat audiometric configuration were present in majority of children.

Figure 1
Percentage of different audiogram shapes in cases of hearing loss



Correlation between SRT and PTA at different frequencies was analysed (Table 4).

Table 4
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	.909	< .001	.978	< .001	.91	< .001
Sloping	.97	.006	.977	.004	.976	.004
Flat	.788	< .001	.914	< .001	.832	< .001
Notch	.816	.092*	.885	.046	.757	.139*
U-shaped	.968	.002	.975	< .001	.892	.017
Inverted U	.965	.008	.976	.005	.921	.026

*p > .05

The audiograms were analysed according to the audiometric configuration. 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 ($r = .978$, $p < .001$).

We analysed 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 U-shaped audiograms ($r = 0.986$, $p < 0.001$).

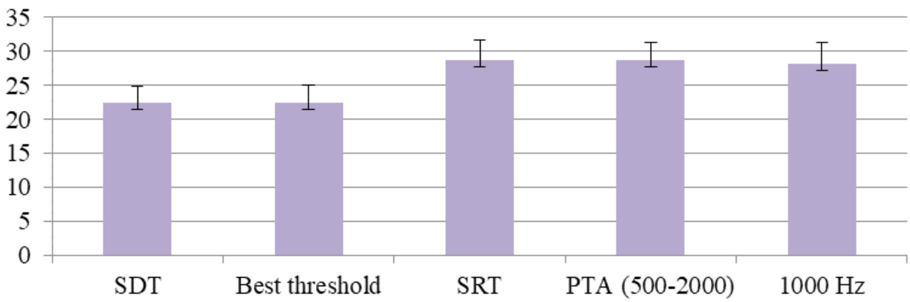
Table 5
Correlation between SRT and hearing threshold for speech frequencies

Audiometric configuration	500 Hz		1000 Hz		2000 Hz		4000 Hz	
	r	p	r	p	r	p	r	p
Rising	.736	< .001	.936	< .001	.644	< .001	.765	< .001
Sloping	.958	.01	.968	.007	.944	.016	.945	.015
Flat	.744	< .001	.864	< .001	.616	< .001	.722	< .001
Notch	.8	.104*	.955	.011	.492	.399*	.376	.533*
U-shaped	.966	.002	.986	< .001	.943	.005	.863	.027
Inverted U	.948	.014	.985	.002	.94	.017	.927	.023

*p > .05

In Figure 2 we displayed the mean thresholds with standard deviation error bars in rising configuration as the most frequent audiometric configuration in the sample.

Figure 2
Mean thresholds with standard deviation error bars in rising audiometric configuration



The similarity between SDT and the best pure tone thresholds as well as SRT and PTA (500-2000) and thresholds at frequency of 1000 Hz is noticeable.

Median speech and hearing thresholds in rising, sloping and flat configuration are displayed (Table 6). The table also shows the range of speech and hearing thresholds in different audiometric configuration.

Table 6
Median speech and hearing thresholds in Rising, Sloping and Flat configuration

Speech / hearing thresholds	Rising (n=38)	Sloping (n=5)	Flat (n=33)
	Median (min-max)	Median (min-max)	Median (min-max)
SDT	21 (20-26)	36 (18-62)	20 (18-24)
SRT	30 (25-36)	46 (27-68)	26 (24-30)
Best threshold	22 (20-25)	35 (20-65)	20 (20-25)
PTA (500-4000)	26 (25-36)	41 (27-75)	25 (21-27)
PTA (500-2000)	29 (26-35)	40 (25-73)	26 (23-30)
PTA (500-1000)	30 (25-34)	37 (20-70)	27 (20-30)
500 Hz	30 (25-35)	30 (20-65)	30 (25-30)
1000 Hz	30 (25-35)	40 (25-75)	30 (25-30)
2000 Hz	27 (20-30)	45 (30-80)	25 (20-30)
4000 Hz	22 (20-30)	50 (35-80)	20 (20-25)

n = number of cases

Median speech and hearing thresholds in notch, U-shaped and inverted U configuration are displayed in Table 7.

Table 7
Median speech and hearing thresholds in Notch, U-shaped and Inverted U configuration

Speech / hearing thresholds	Notch (n=5)	U-shaped (n=6)	Inverted U (n=5)
	Median (min-max)	Median (min-max)	Median (min-max)
SDT	18 (17-20)	26 (18-40)	24 (18-30)
SRT	24 (23-27)	33 (26-47)	34 (23-40)
Best threshold	10 (10-20)	25 (25-40)	25 (25-35)
PTA (500-4000)	24 (22-27)	26 (22-42)	28 (21-35)
PTA (500-2000)	20 (18-24)	27 (23-43)	34 (23-36)
PTA (500-1000)	18 (17-19)	25 (22-42)	30 (25-38)
500 Hz	10 (10-20)	22 (20-40)	30 (25-40)
1000 Hz	20 (15-20)	30 (25-45)	30 (25-35)
2000 Hz	20 (15-20)	25 (20-45)	25 (20-25)
4000 Hz	35 (30-50)	22 (15-400	30 (25-35)

n = number of cases

Discussion

Difference between SDT and SRT in cases of normal hearing and hearing loss and correlation between speech thresholds and hearing thresholds were determined. There was a difference ≤ 12 dB in majority of cases. A previous study showed similar findings (Ristovska et al., 2021).

We analysed the correlation between pure tone thresholds, SDT, and SRT in patients with hearing loss. There was the highest correlation between SDT and the best hearing threshold in all types of audiometric configuration. The most important clinical value of SDT is that it should be similar to the best hearing threshold (Stach, 2010).

In our study there was the highest correlation between SRT and PTA calculated at frequencies 500, 1000, and 2000 Hz. Our findings are similar to results from the study that included sloping audiometric configuration (dos Anjos, et al., 2014). Kim et al. (2016) investigated 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 SRT should be within 10 dB of the patient's PTA. If the difference between SRT and PTA is more than 10 dB, it could indicate that the patient is exaggerating his pure-tone hearing loss; however, we should rule out the possibility of it being related to the steep sloping audiogram, language or dialect issues, or improper peaking of the VU meter (Kramer & Brown, 2019).

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. There was the highest correlation between SRT and frequency of 1000 Hz in all audiometric configurations. Another study also found the highest correlation between SRT and frequency of 1000 Hz, followed by 500, 250, and 2000 Hz (Chien et al., 2006).

Conclusion

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

References

1. Bess, F.H., & Humes, L.E. (2008). *Audiology: The fundamentals*. Philadelphia: Lippincott Williams & Wilkins.
2. Chien, C.-H., Tu, T.-Y., Chien, S.-F., Li, A.C.-I., Yang, M.-J., Shiao, A.-S., & Wang, Y.-F. (2006). Relationship between Mandarin speech reception thresholds and pure-tone thresholds in the geriatric population. *Journal of the Formosan Medical Association, 105*(10), 832-838. doi.org/10.1016/S0929-6646(09)60270-9
3. Cunningham, L.L., & Tucci, D.L. (2017). Hearing loss in adults. *New England Journal of Medicine, 377*(25), 2465-2473. doi: 10.1056/NEJMra1616601
4. Dauman, R., (2013). Bone conduction: an explanation for this phenomenon comprising complex mechanisms. *European Annals of Otorhinolaryngology, Head and Neck Diseases, 130*(4), 209-213. DOI: 10.1016/j.anorl.2012.11.002
5. DeRuiter, M., & Ramachandran, V. (2017). *Basic audiometry learning manual.* 2nd ed. San Diego: Plural Publishing.
6. Diefendorf, A.O. (2015). Assessment of hearing loss in children. In: J. Katz, M. Chasin, K. English, L.J. Hood & K.L. Tillery, eds. *Handbook of clinical audiology.* Philadelphia: Lippincott Williams & Wilkins. Ch.24.
7. Dos Anjos, W.T., Labanca, L., de Resende, L.M., & Costa-Guarisco, L.P. (2014). Correlation between the hearing loss classifications and speech recognition. *Revista CEFAC, 16*(4), 1109-1116. doi.org/10.1590/1982-0216201423512
8. Gelfand, S.A. (2016). *Essentials of audiology*. New York: Thieme Medical Publishers.
9. Kim, J.M., Na, M.S., Jung, K.H., Lee, S.H., Han, J.S., Lee, O.H., & Park, S.Y. (2016). The best-matched pure tone average and speech recognition threshold for different audiometric configurations. *Korean Journal of Otorhinolaryngology-Head and Neck Surgery, 59*(10), 725-729. doi.org/10.3342/kjorl-hns.2016.59.10.725
10. Kramer, S., & Brown, D.K. (2019). *Audiology: science to practice.* 3rd ed. San Diego: Plural Publishing, Inc.
11. Lawson, G. D., & Peterson, M. E. (2011). *Speech audiometry.* San Diego: Plural Publishing.
12. McArdle, R. & Hnath-Chisolm, T. (2015). Speech audiometry. In: J. Katz, M. Chasin, K. English, L.J. Hood & K.L. Tillery, eds. *Handbook of clinical audiology*. Philadelphia: Lippincott Williams & Wilkins. Ch.5.
13. Ristovska, L., Jachova, Z., Kovacevic, J., Radovanovic, V., & Hasanbegovic, H. (2021). Correlation between pure tone thresholds and speech

thresholds. *Human Research in Rehabilitation, 11*(2), 120-125. DOI: 10.21554/hrr.092108

14. Schlauch R.S., & Nelson, P. (2015). Puretone evaluation. In J. Katz, M. Chasin, K. English, L.J. Hood & K.L. Tillery, eds. *Handbook of clinical audiology*. Philadelphia: Lippincott Williams & Wilkins. Ch.3.
15. Shipley, K.G., & McAfee, J.G. (2016). *Assessment in speech-language pathology, a resource manual.* 5^{th} ed. Boston: Cengage Learning.
16. Stach, B.A. (2010). *Clinical audiology: an introduction*. Clifton Park: Delmar Cengage Learning.

ВКРСТЕНА ВАЛИДАЦИЈА НА ПРАГОТ НА ЧИСТ ТОН СО ГОВОРНА АУДИОМЕТРИЈА

Ристовска Л.[1], Јачова З.[2], Ковачевиќ Ј.[3]

Градска болница „8 Септември"[1], Универзитет „Св. Кирил и Методиј"-Скопје, Филозофски факултет-Институт за специјална едукација и рехабилитација[2], Универзитет во Белград, Србија[3]

Апстракт

Вовед: *Говорната аудиометрија е метод со кој се евалуира како пациентот слуша и разбира специфични типови говорни стимули. Една од клиничките функции на праговите на говорот е вкрстена валидација на тоналните прагови.*

Предмет на студијата: *Предмет на студијата е корелацијата помеѓу прагот на детекција на говорот (SDT), прагот на препознавање на говорот (SRT) и тоналните прагови, како и разликата помеѓу SDT и SRT.*

Методологија: *Оваа проспективна студија вклучува примерок од 52 деца со редукција на слухот, 30 машки (57,7%) и 22 женски (42,3%), на возраст од 5 до 14 години (средна возраст од 6,1 ± 1,7 години). Изведени се тонална лиминарна аудиометрија и говорна аудиометрија. За статистичка анализа на податоците користевме Пирсонов коефициент на корелација и Хи-квадрат тест со ниво на значајност $p < .05$.*

Резултати: *SDT е силно корелиран со најдобриот тонален праг. Највисока вредност е регистрирана кај десцендентната аудиометриска конфигурација ($r = .993$). Постоеше висока корелација помеѓу SRT и средната вредност на прагот на слухот PTA (500-2000), PTA (500-4000) и PTA (500-1000), особено кај асцендентната конфигурација ($r = .978$, $r = .91$, $r = .909$; последователно), како и помеѓу SRT и фреквенцијата од 1000 Hz ($r = .986$). Разликата помеѓу SDT и SRT беше ≤ 12 dB кај најголем број од случаите ($p = .033$).*

Заклучок: *SDT е во највисока корелација со најдобриот тонален праг. SRT е во највисока корелација со PTA на фреквенциите of 500, 1000 и 2000 Hz, како и прагот на слухот на фреквенцијата од 1000 Hz. Добро познатата корелација помеѓу тоналниот праг и праговите на говорот ги прави праговите на говорот одлична вкрстена проверка на тоналниот аудиограм.*

Клучни зборови: *праг на говор, тонален праг, корелација*