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Investigation of hearing aid users' speech understanding in noise and their spectral-temporal resolution skills

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ABSTRACT

Purpose: Our study aims to compare speech understanding in noise and spectral- temporal resolution skills with regard to the degree of hearing loss, age, hearing aid use experience and gender of hearing aid users.

Methods: Our study included sixty-eight hearing aid users aged between 40-70 years, with bilateral mild and moderate symmetrical sensorineural hearing loss. Random gap detection test, Turkish matrix test and spectral-temporally modulated ripple test were implemented on the participants with bilateral hearing aids. The test results acquired were compared statistically according to different variables and the correlations were examined.

Results: No statistically significant differences were observed for speech-in-noise recognition, spectral-temporal resolution among older and younger adults in hearing aid users ($p>0.05$). There wasn't found a statistically significant difference among test outcomes as regards different hearing loss degrees ($p>0.05$). Higher performances were obtained in terms of temporal resolution in male participants and participants with more hearing aid use experience ($p<0.05$). Significant correlations were obtained between the results of speech-in-noise recognition, temporal resolution and spectral resolution tests performed with hearing aids ($p<0.05$).

Conclusion: Our study findings emphasized the importance of regular hearing aid use and it showed that some auditory skills can be improved with hearing aids. Observation of correlations among the speech-in-noise recognition, temporal resolution and spectral resolution tests have revealed that these skills should be evaluated as a whole to maximize the patient's communication abilities.

1. Introduction

Speech is quite dynamic in terms of its spectral and temporal aspects. Rapid reach to these clues facilitates speech perception however requires a fast-moving auditory system. Hearing loss alters the rapid movement process and impairs speech perception (Mohan and Rajashekhar, 2019). Speech understanding and identifying in the presence of competing signals can be difficult for persons with hearing impairments, particularly those with sensorineural hearing loss (SNHL). Because most parts of speech are inaudible, or the speech signals themselves are distorted for individuals with hearing loss. The reduced temporal and frequency resolution probably brings out the fact that noise will mask speech more than in people with normal hearing (Kodiyath et al., 2017).

Hearing aids are devices designed and adjusted to reduce the specific problems faced by people with hearing loss and improve the quality of life (Dillon, 2012). Restoring audibility through frequency specific amplification is the principal purpose of a hearing aid (DeSilva et al., 2016). In other words, hearing aids provide gain at different frequencies according to the audiometric thresholds of users while keeping stimuli within the dynamic range (Dillon, 2001).

Auditory objects are characterized mainly by their spectrum and by the way their spectrum changes over time. Frequency selectivity

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helps us separate speech components from noise components. The reduction in frequency selectivity can have a big impact on performance in noisy environments (Plack, 2013).

Temporal resolution refers to the minimum time required to separate or resolve acoustic events (Matos and Frota, 2013). Auditory temporal resolution is very sharp and even level changes lasting less than 5 ms can be detected (Plack, 2013). Since temporal resolution is intimately concerned with speech intelligibility which is a complicated acoustic signal wealthy in both temporal and spectral features, and individuals with hearing loss can grumble about not being able to understand speech, it can be assumed that temporal resolution is impaired in auditory disability. Matos and Frota have shown that this ability is affected by SNHL (Matos and Frota, 2013). Therefore, the use of speech-in-noise recognition tests in combination with audiometry and potentially with other tests can help to define and understand the hearing loss more thoroughly and determine management plans (Spyridakou and Bamiou, 2015).

The goal of our research is to compare the speech understanding in noise and spectral-temporal resolution skills with regard to the age, gender, degree of hearing loss and hearing aid use experience of hearing aid users. Our hypotheses are:

Is there a difference between the speech understanding in noise and spectral-temporal resolution skills according to the age of the hearing aid users?

Is there a difference between the speech understanding in noise and spectral-temporal resolution skills according to the gender of the hearing aid users?

Is there a difference between the speech understanding in noise and spectral-temporal resolution skills according to the degree of hearing loss of the hearing aid users?

Is there a difference between the speech understanding in noise and spectral-temporal resolution skills according to the hearing aid use experience of the hearing aid users?

Is there a relationship between hearing aid users' ability to understand speech in noise, spectral resolution and temporal resolution?

2. Methods

Our research was performed with the confirmation of the Clinical Research Ethics Committee of Istanbul University-Cerrahpaşa (Reference No: 08.10.2020–132,965). All participants were given detailed information about the study and a consent form was signed on a voluntary basis.

2.1. Participants

Our research included sixty-eight hearing aid users aged between 40 and 70 years, with bilateral mild (26–40 dB HL) and moderate (41–55 dB HL) symmetrical (the ears have similar thresholds) sensorineural hearing loss. This research contained 30 women and 38 men; the average age of the participants is 51.47. Participants have at minimum 6 months of hearing aid use. Other inclusion criteria of the participants: having normal otoscopic and immitansmetric results; having a speech discrimination score of 60% and over; absence of retrocochlear pathology.

2.2. Procedure

First, otoscopic examinations and immitansmetric measurements of all the participants included in the study were performed. The tests were carried out by the attendees for pure-tone/speech audiometry and other assessment methods were performed in a silent cabin with due regard to the standards with Natus Medical Inc. (Denmark)-MADSEN Astera2 computer-controlled multichannel audiometer. The hearing thresholds of all individuals were measured within the range of 500–4000 Hz, and the resulting values were averaged to obtain the pure tone averages. The severity of hearing loss was then classified according to Clark's classification system (Clark, 1981), which is based on the degree of hearing loss at different frequencies within this range. Later the assessments, the persons who were specified to be proper for the research terms were received for the hearing aid fitting. In this research, bilateral Opn 1 receiver-in-the-ear (RITE) model 64-channel hearing aid (Oticon. Smorum, Denmark) was used. Real ear measurements were made with the GN Otometrics A/S (Denmark)-Aurical Free Fit device of the participants. After these measurements, an appropriate gain target was established for every client and the hearing aids were fitted agreeingly. Noise reduction software was turned off in hearing aids, NAL-NL2 algorithm and fixed directional microphone were used. Supplemental features (frequency lowering etc.) were deactivated (To avoid the confounding variable effect, a single brand/model hearing aid was used and software features that could change the parameter to be measured were turned off.). After all adjustments to the hearing aids were done, the free-field hearing evaluation with hearing aids was made and the gains were checked. Then, random gap detection test, Turkish matrix test and spectral-temporally modulated ripple test were carried out on the attendees with bilateral hearing aids. Our all tests were performed in silent cabins that are suitable for the maximum noise levels determined by ANSI for audiological equipment and test environments. The test results achieved were compared according to different variables and evaluations were made.

2.3. Random gap detection test (RGDT)

In our study, RGDT was utilized to assess temporal resolution abilities. Pairs of tonal stimuli were employed in the range of 500–4000 Hz. The spaces among the stimuli were presented in random order at intervals of 0–40 ms (0, 2, 5, 10, 15, 20, 25, 30, 40). RGDT was initiated with a 1000 Hz practice test which the gap between stimuli in ascending order. Then, measurements were made with randomly presented gaps in the range of 500–4000 Hz, in order of. The audio files used for RGDT were presented to the attendees at a distance of 1 m, at 0° azimuth, at the level of comfortable listening (50 dB SL) with a free field loudspeaker. The attendee was desired to orally express that he heard one or two tones. The responses of the individuals were recorded in writing, and the lowest gap that could be consistently detected between pairs of stimuli given at each frequency was determined as the threshold (ms). In addition, the composite RGDT threshold was obtained by averaging the gap detection thresholds across all measured frequencies (Braga et al., 2015).

2.4. Spectral-temporally modulated ripple test (SMRT)

SMRT was utilized to evaluate the spectral resolution skills of the attendees. Three stimuli were offered to the attendees in the SMRT. The attendee was requested to find out the target stimulus that differs in terms of ripple intensity per octave from the other two reference stimuli. In the wake of the test, the spectral fluctuations number per octave that can be noticed by the attendee was determined. The scores were presented by the software in ripple per octave (RPO). Therefore, higher scores are indicative of better spectral resolution ability. SMRT was applied in the free field and SMRT V.1.1.3 software (www.ear-lab.org) was used for testing. An audiometer connection was provided with the software installed computer and the stimuli were presented via loudspeaker. The participant was seated at 1 m from the loudspeaker and at an angle of 0° to the loudspeaker. The test was applied at a 65 dB (A) intensity level. Before the test started, the participant was informed about the test and was told how to do the test. While applying SMRT, 3 measurements were made for each participant. The first measurement was made as a short training stage for the participant to understand the test. SMRT scores were calculated by taking the average of the last two measurements (Aronoff and Landsberger, 2013).

2.5. Turkish matrix test (TMT)

TMT was applied to evaluate the participants' ability to speech-in-noise recognition. The matrix test was performed using the Oldenburg Measurement Application (Hörtech; Oldenburg, Germany) software. Participants were placed in a silent cabin at 0° azimuth and at 1 m from the speaker. The speech and noise signals were submitted from the front.

In the adaptive test, the 50% speech reception threshold (SRT) in noise was determined as SNR. The first sentence was sent to the individual at 0 dB SNR, and the speech stimulus level was automatically changed by the software pursuant to the client's responses. According to the procedure, if the individual can repeat three of the five words presented, the speech intensity level decreases; if the number of repeated words is less than three, the speech stimulus level increases in the next sentence presented. According to these situations, the SNR was determined, in which 50% of the stimuli could be detected correctly. In the non-adaptive test, speech intelligibility (SI) was calculated at a constant signal-to-noise ratio of 0 dB. Pursuant to the number of accurately repeated words, speech intelligibility was determined as a percentile score. The test results were automatically presented on the screen by the software (Zokoll et al., 2015).

2.6. Statistical analysis

IBM SPSS Statistics Version 26.0 software was used in the statistical analysis of the test results. Comparisons of the obtained data between groups were implemented using non-parametric (Kruskal–Wallis H test and Mann–Whitney*U* test) or parametric (One-Way ANOVA ("analysis of variance") and Independent Samples T-Test) tests, depending on whether the data showed a normal distribution. Spearman Correlation analysis was used to determine the direction and strength of the relationship between the variables. Statistical significance was interpreted by keeping the confidence interval at 95% and comparing the analysis results with the $p < 0.05$ level.

3. Results

As a consequence of the tests applied with hearing aids, there wasn't found a statistically significant difference between participants 55 years and younger and participants above 55 years old in terms of SMRT score, composite RGDT threshold and SRT/SI in noise ($p > 0.05$). Despite there wasn't an observed statistically significant difference, higher composite RGDT thresholds, higher SRT in noise, lower SMRT scores and lower SI in noise were obtained in individuals over 55 years of age compared to individuals 55 years and younger (Table 1).

As a result of the tests applied with hearing aids, there wasn't an observed statistically significant difference between male and female participants in SRT/SI in noise and SMRT score ($p > 0.05$). Statistically, significantly lower RDGT thresholds were found in male participants compared to females ($p < 0.05$). Although there wasn't a found significant difference, higher average SMRT scores were obtained in males compared to females (Table 2).

As a result of the tests performed with hearing aids, no statistically significant difference was found between the participants with mild, moderate and moderately severe hearing loss for SMRT score, composite RGDT threshold, and SI values in noise ($p > 0.05$). Although there wasn't found a statistically significant difference for SI value in noise, it was observed that SI decreased as the degree of hearing loss increased ($p = 0.068$). There wasn't an observed statistically significant difference between mild and moderate hearing loss groups ($p = 0.070$), moderate and moderately severe hearing loss groups for SRT in noise ($p > 0.05$). It was determined that an increase in the hearing loss degree between mild and moderately severe hearing loss groups statistically significantly increased the SRT ($p < 0.05$) (Table 3).

As a consequence of the tests applied with hearing aids, there wasn't found a significant difference between the participants with 1 year or under and over 1 year of hearing aid experience in terms of SMRT score and SRT/SI in noise ($p > 0.05$). Statistically, significantly lower RDGT thresholds were found in participants with more than 1 year of experience compared to those with 1 year or under experience ($p < 0.05$). Although there was no significant difference, it was observed that there was lower SRT and higher SI in noise in individuals with over 1 year of experience compared to 1 year or under experience (Table 4).

According to the correlation analysis between the test results applied with hearing aids, a weak negative correlation was obtained between SMRT score and composite RGDT threshold ($p < 0.05$). There was obtained a weak negative correlation between SRT in noise and SMRT score ($p < 0.05$). There wasn't an observed statistically significant correlation between SI in noise and SMRT score ($p = 0.186$). There was found a moderate positive correlation between SRT in noise and composite RGDT threshold ($p < 0.01$). There was found a weak negative correlation between composite RGDT threshold and SI in noise ($p = 0.050$). There was found a strong negative correlation between SRT and SI in noise ($p < 0.01$) (Table 5).

4. Discussion

Aging can be correlated with a decrease in the sensitivity of neural phase locking and neural representation of the temporal fine structure skill of sounds (Hopkins and Moore, 2011). Elderly individuals have more hardship in speech recognition than younger people, especially in noisy situations, due to problems such as poor frequency and temporal resolution, as well as decreased peripheral hearing sensitivity (Martin and Jerger, 2005; Phillips et al., 2000). Neural representations of speech stimuli in the left hemisphere have been shown to be greater in younger individuals, but this asymmetry is not pronounced in adults with normal hearing over 55 years of age due to reduced interhemispheric function (Bellis et al., 2000). Therefore, we grouped our study findings by age based on this information. In our study, in the comparison of two groups consisting of 34 individuals 55 years and younger and 34 individuals above 55 years old; although lower performances were obtained in the SMRT score, composite RGDT threshold and SRT/SI in noise results applied with the hearing aids in older adults, there wasn't an observed statistically significant difference between the groups ($p > 0.05$). There weren't serious differences in the abilities of temporal-spectral resolution and speech-in-noise recognition, which normally show significant age-related declines in elderly people using hearing aids compared to young adult individuals in our study. This has revealed the importance of regular hearing aid use.

In their study, Szymaszek et al. found the temporal ordering threshold was lower in males than in females (Szymaszek et al., 2006). Some authors have shown that males have a lower

Table 1
Comparison of the tests applied with the hearing aids as regards the age of the attendees.

Tests applied with the hearing aids	55 years and younger (n = 34)			Above 55 years old (n = 34)			P
	Mean ± SD	Min.	Max.	Mean ± SD	Min.	Max.	
SMRT Score (RPO)	5.25 ± 1.37	3.3	7.56	4.54 ± 1.21	2.73	6.6	.120[a]
Composite RGDT Threshold (ms)	17 ± 7.8	2	30	20.2 ± 10.6	2	40	.224[b]
SRT in TMT (SNR-dB)	−0.98 ± 2.59	−5.1	6.1	0.05 ± 2.34	−2.6	6	.179[b]
SI in TMT (%)	67 ± 16	30	91	64.8 ± 10.6	40	79	.644[a]

*p < 0.05. Min: Minimum; Max: Maximum; SD: Standard deviation; ms: Millisecond; RPO: Ripples per octave; SMRT: Spectral-temporally modulated ripple test; RGDT: Random gap detection test; TMT: Turkish matrix test; SI: Speech intelligibility; SNR: Signal-to-noise ratio; SRT: Speech reception threshold; a: Independent Samples T Test, b: Mann-Whitney *U* Test.

Table 2
Comparison of the tests applied with the hearing aids as regards the gender of the attendees.

Tests applied with the hearing aids	Women (n = 30)			Men (n = 38)			P
	Mean ± SD	Min.	Max.	Mean ± SD	Min.	Max.	
SMRT Score (RPO)	4.58 ± 1.56	2.73	7.56	5.08 ± 1.14	3.23	7.33	.292[a]
Composite RGDT Threshold (ms)	20.5 ± 8.6	5	40	17.4 ± 9.7	2	40	.027*[b]
SRT in TMT (SNR-dB)	−0.55 ± 2.91	−4.1	6.1	−0.41 ± 2.27	−5.1	6	.312[b]
SI in TMT (%)	66.7 ± 14.1	30	85	65.3 ± 13.3	40	91	.775[a]

*p < 0.05. Min: Minimum; Max: Maximum; SD: Standard deviation; ms: Millisecond; RPO: Ripples per octave; SMRT: Spectral-temporally modulated ripple test; RGDT: Random gap detection test; TMT: Turkish matrix test; SI: Speech intelligibility; SNR: Signal-to-noise ratio; SRT: Speech reception threshold; a: Independent Samples T Test, b: Mann-Whitney *U* Test.

Table 3
Comparison of the tests applied with the hearing aids as regards the hearing loss degrees.

Tests applied with the hearing aids	Hearing loss degree	Number	Mean ± SD	Min.	Max.	P
SMRT Score (RPO)	Mild	18	4.94 ± 1.32	2.73	6.60	
	Moderate	26	5.05 ± 1.43	3.16	7.56	
	Moderately severe	24	4.67 ± 1.27	2.83	7.33	
	Total	68	4.89 ± 1.32	2.73	7.56	.771[a]
Composite RGDT Threshold (ms)	Mild	18	18.7 ± 8.2	5	40	
	Moderate	26	19 ± 10.9	2	40	
	Moderately severe	24	18.1 ± 8.3	2	40	
	Total	68	18.6 ± 9.4	2	40	.949[b]
SRT in TMT (SNR-dB)	Mild	18	−1.6 ± 1.9	−4.1	2.5	
	Moderate	26	−0.9 ± 1.6	−5.1	2	
	Moderately severe	24	0.8 ± 3.1	−3.4	6.1	
	Total	68	−0.4 ± 2.4	−5.1	6.1	.054[b]
SI in TMT (%)	Mild	18	70.2 ± 8	60	85	
	Moderate	26	69.5 ± 10.4	51	91	
	Moderately severe	24	58.7 ± 16.9	30	77	
	Total	68	65.9 ± 13.4	30	91	.068[a]
SRT in noise (SNR-dB) within the scope of TMT applied with hearing aids						
Group Comparison	Mild	18	−1.6 ± 1.9	−4.1	2.5	.070[c]
	Moderate	26	−0.9 ± 1.6	−5.1	2	
Group Comparison	Mild	18	−1.6 ± 1.9	−4.1	2.5	.045*[c]
	Moderately severe	24	0.8 ± 3.1	−3.4	6.1	
Group Comparison	Moderate	26	−0.9 ± 1.6	−5.1	2	.165[c]
	Moderately severe	24	0.8 ± 3.1	−3.4	6.1	

*p < 0.05. Min: Minimum; Max: Maximum; SD: Standard deviation; ms: Millisecond; RPO: Ripples per octave; SMRT: Spectral-temporally modulated ripple test; RGDT: Random gap detection test; TMT: Turkish matrix test; SI: Speech intelligibility; SNR: Signal-to-noise ratio; SRT: Speech reception threshold; a: ANOVA, b: Kruskal-Wallis Test, c: Mann-Whitney *U* Test.

temporal ordering threshold than females, while others have not found a gender difference in this task (Wittmann and Szelag, 2003). The gender differences were attributed specifically to a greater gray matter versus white matter ratio in males than female brains, a higher internal clock rate associated with a hypothetical neurotransmitter eventuating in a much better temporal resolution in males, and a powerful hemispheric asymmetry pattern in man's brains (Szymaszek et al., 2006). In the comparison of the different tests applied in our study for the 30 female and 38 male groups as regards gender, there wasn't found a statistically significant difference between the gender groups for the SMRT score and SRT/SI in noise results applied with the hearing aids ($p > 0.05$). Composite RGDT thresholds were observed statistically significantly lower in male individuals than in females ($p < 0.05$). This has shown that temporal resolution performance with hearing aids was better in males than females (Table 2).

As the hearing loss degree rising up, the frequency resolution gradually decreases, and people with hearing loss have difficulty

Table 4
Comparison of the tests applied with the hearing aids as regards the hearing aid experience of the attendees.

Tests applied with the hearing aids	1 year or under experience (n = 34)			Over 1 year of experience (n = 34)			P
	Mean ± SD	Min.	Max.	Mean ± SD	Min.	Max.	
SMRT Score (RPO)	4.83 ± 1.41	2.73	7.33	4.95 ± 1.27	3.16	7.56	.799[a]
Composite RGDT Threshold (ms)	20.7 ± 10.9	2	40	16.5 ± 7.1	2	30	.031*[b]
SRT in TMT (SNR-dB)	0.09 ± 2.55	−4.1	6,1	−1.02 ± 2.37	−5.1	6	.158[b]
SI in TMT (%)	61.8 ± 14.6	30	85	70 ± 11.1	40	91	.091[b]

*p < 0.05. SD: Standard deviation, Min: Minimum, Max: Maximum, ms: Millisecond, RPO: Ripples per octave, SMRT: Spectral-temporally modulated ripple test, RGDT: Random gap detection test, TMT: Turkish matrix test, SRT: Speech reception threshold, SNR: Signal-to-noise ratio, SI: Speech intelligibility, a: Independent Samples T Test, b: Mann-Whitney *U* Test.

Table 5
Correlations of tests applied with the hearing aids.

CORRELATIONS			
r	Composite RGDT Threshold	SRT in TMT	SI in TMT
SMRT Score	−.370*	−.358*	.233
Composite RGDT Thresholds		.483**	−.339*
SRT in TMT			−.712**

* The correlation is significant at the 0.05 level (two-tailed), ** The correlation is significant at the 0.01 level (two-tailed), r: Correlation coefficient, TMT: Turkish matrix test, RGDT: Random gap detection test, SMRT: Spectral-temporally modulated ripple test, SNR: Signal-to-noise ratio, SI: Speech intelligibility, SRT: Speech reception threshold, Spearman's rho Correlation Test.

distinguishing sounds of different frequencies at the same time. The capability to hear poor sounds at brief intervals gradually declines as the hearing loss degree rises up, and people with hearing loss generally experience less temporal resolution. This causes a further decrease in their speech intelligibility (Kates, 2008). In our study, in the tripartite comparison of the participants as regards mild, moderate and moderately severe hearing loss; there wasn't an observed statistically significant difference in the SMRT score and composite RGDT threshold results applied with the hearing aids as regards the hearing loss degrees ($p > 0.05$). Although there wasn't found a statistically significant difference in terms of speech understanding in noise among different degrees of hearing losses, the performance of understanding in noise decreases with the increase in hearing loss but no statistically significant difference could be reached with our current data ($p > 0.05$). It has been determined that the increase in hearing loss for SRT in noise increases SRT ($p = 0.054$). It was observed that an increase in hearing loss between mild degree and a moderately severe degree in the comparison of the two groups significantly increased the SRT and reduced performance ($p < 0.05$) (Table 3).

Saji et al. have reported that for individuals to show better speech understanding results, the minimum hearing aid familiarization time is three months (Saji et al., 2017). Hearing aid users have been shown to obtain preferable performance in noisy environments after just a few months of use experience (Kuk et al., 2003). In the research evaluating temporal processing abilities with hearing aids, there wasn't found a performance difference between experienced and inexperienced clients (Mohan and Rajashekhar, 2019). In line with this information in the literature, our research was included individuals with at minimum 6 months of hearing aid experience. As a consequence of the tests carried out with the hearing aids in this research, there wasn't found a statistically significant difference for SMRT score and SRT/SI in noise values between the participant groups with 1 year or under and over 1 year of hearing aid experience ($p > 0.05$). Statistically significant lower RDGT thresholds were observed in participants with over 1 year of experience compared to 1 year or less ($p < 0.05$) (Table 4). Although there wasn't found a statistically significant difference, it was observed that SRT was lower, and SI was higher in individuals with over 1 year of experience compared to those with 1 year or under. In our study, the fact that experienced participants had higher performance temporal resolution and speech-in-noise recognition showed that the use of hearing aids could improve these skills, and it was thought that it may make important contributions to the literature in this respect.

Simpson et al. stated that spectral troughs and peaks, which are substantial clues for the spectral properties' perception in speech, become concealed by noise (Simpson et al., 1990). DeSilva et al. also reported that noise alters the spectral content of speech (DeSilva et al., 2016). It has been observed that those who perform well in the spectral ripple discrimination tasks from adults with normal hearing, hearing loss, and cochlear implants incline to show better speech recognition scores (DiNino and Arenberg, 2018). Spectral resolution measures have been displayed to be mightily associated with open-ended speech recognition in postlingual deaf adult cochlear implant clients (Horn et al., 2017). Performance on the SMRT was noted to be extremely associated with speech comprehension for cochlear implant clients tested (Landsberger et al., 2019). In our study, statistically significant correlations were obtained between the SMRT score and composite RGDT threshold as a result of the tests carried out on individuals with hearing aids. Correlations were also obtained between speech-in-noise recognition and SMRT score ($p < 0.05$). In general in individuals with higher SMRT scores, the threshold for speech understanding in noise and the RGDT thresholds were lower (Table 5). This situation in accordance with the literature has shown that in hearing aid users as well, spectral resolution was associated with temporal resolution and speech-in-noise recognition.

Temporal resolution is important for resolving short drops in the noise intensity and therefore critical for speech understanding in noisy situations. Studies have shown links between temporal resolution and the understanding of acoustically impaired speech (Roberts and Lister, 2004)·(Strouse et al., 1998). In our research, as a consequence of the tests carried out on the participants with hearing aids, statistically significant correlations were obtained between the composite RGDT threshold and the SMRT score. Correlations were also obtained between the composite RGDT threshold and speech-in-noise recognition ($p < 0.05$). In individuals with lower RGDT thresholds, speech understanding in noise and SMRT scores were higher. This situation has shown the relationship of temporal resolution with spectral resolution and speech intelligibility in noise in hearing aid users in accordance with the literature. Besides, there was found a strong negative correlation between the SNR threshold required for an understanding of speech and speech intelligibility in noise ($p < 0.01$) (Table 5). This situation has highlighted the importance of SNR for speech understanding in noise. Moreover, it is thought that the correlation analyses of these tests evaluating different skills in individuals using hearing aids will make important contributions to the literature.

5. Conclusions

For spectral-temporal resolution and speech-in-noise recognition, which can show significant decreases with increasing age, no significant differences were observed in these skills in older individuals using hearing aids compared to younger adults in our study ($p > 0.05$). This has highlighted the importance of regular hearing aid use. Better temporal resolution performance was obtained in participants with more hearing aid experience ($p < 0.05$), suggesting that hearing aid use may improve this skill. Observing correlations between the results of spectral resolution, temporal resolution, and speech-in-noise recognition tests performed with the hearing aids ($p < 0.05$) revealed that these skills should be evaluated as a whole to maximize the communication abilities of the clients.

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