

The Effect of Multichannel and Channel-Free Hearing Aids on Spectral-Temporal Resolution and Speech Understanding in Noise

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Abstract

Background Identifying and understanding speech is difficult for individuals with sensorineural hearing loss, especially in noisy environments. Possible causes include less audibility of the signal, impaired temporal resolution, and low selectivity of frequency. The hearing aid is the most common option used to minimize the problems faced by individuals with sensorineural hearing loss.

Purpose This article investigates the effects of multichannel and channel-free hearing aid signal processing techniques on spectral-temporal resolution and speech understanding in noise.

Research Design An experimental study was used in which the determined tests were applied to the participants.

Study Sample Thirty-four individuals with bilateral symmetrical sensorineural hearing loss between the ages of 18 and 70 were included in our study.

Data Collection and Analysis Spectral-temporally modulated ripple test, random gap detection test (RGDT), and Turkish matrix test were applied to the participants using multichannel and channel-free hearing aids. All the data obtained were compared statistically in terms of the performances of the hearing aids.

Results There was no significant difference between multichannel and channel-free hearing aids for spectral resolution and speech understanding in noise tests ($p > 0.05$). While there was no significant difference between the two hearing aids for 500 and 4,000 Hz RGDT in temporal resolution measurement ($p > 0.05$), for 1,000 Hz ($p = 0.045$), 2,000 Hz ($p = 0.046$), and composite RGDT ($p = 0.001$), statistically significant better performances were obtained with the channel-free hearing aids.

Conclusion It is thought that faster processing of the incoming signal in the channel-free hearing aids improves the temporal resolution performance. It is predicted that our study findings might help to determine the signal processing technique that will maximize the communication skills of the patients in various conditions.

Keywords

- ▶ multichannel hearing aid
- ▶ channel-free hearing aid
- ▶ speech in noise
- ▶ spectral resolution
- ▶ temporal resolution

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There are many problems associated with hearing loss, so simple sound amplification is insufficient.¹ Because hearing loss reduces speech intelligibility (SI), as well as audibility, modern hearing aids contain different signal processing algorithms.² Multichannel and channel-free hearing aids have similar goals but differ significantly in terms of signal processing.

Multichannel hearing aids separate the incoming signal into different frequency bands, and each band of the signal passes through different amplification channels. In multichannel compression, each channel contains its compression.³ Multiple channels in the hearing aid allow the signal level to be estimated and independent control of gain over relatively narrow frequency ranges.⁴ The time constants used in these hearing aids may force the user to choose between SI (fast-acting system) and listening comfort (slow-acting system).⁵

In light of concerns related to multichannel hearing aids (i.e., channel interaction, channel summation, spectral smearing, and altered temporal information), channel-free hearing aids have been developed. The channel-free hearing aid processes the wideband signal 20,000 times per second. At a basic level, it continuously adjusts the gain of the hearing aid to amplify each phoneme separately, while maintaining sound quality. Also, it does this without splitting the signal into fixed channels or bands. It performs parallel processing by measuring the sound pressure level of the input signal and assigns a gain to the fed signal into the filter control at any moment as dictated by the measured sound pressure level. Finally, it amplifies the soft input signal and maintains the comfort sound for high-level sound without changing the temporal speech envelope.^{6,7} While both signal processing strategies are currently available in hearing aids, it is unclear whether differences in these signal processing strategies affect user performance and preference.

The aim of our study is to compare the effects of multichannel and channel-free signal processing techniques used in hearing aids on spectral and temporal resolution, which is important in speech perception. Nevertheless, it is aimed to evaluate speech comprehension skills in noisy environments, which individuals with hearing loss frequently encounter in daily life, for two different signal processing techniques.

Method

Our study was performed in the Audiology, Language and Speech Disorders Clinic of Istanbul University-Cerrahpaşa Faculty of Medicine, with the approval of the ethics committee dated 08/10/2020 and numbered 132965. All participants were informed about the methods to be applied voluntarily and their written consents were obtained.

Participants

Having at least 6 months of regular hearing aid use experience and in the 18 to 70 age range, 34 individuals with bilateral symmetrical mild to moderate-to-severe sensorineural hearing loss (SNHL) were included in the study. The study involved 13 female and 21 male participants, with an

average age of 51.47. Subjects with normal otoscopic and immittance findings and speech discrimination scores (SDSs) of 56% and above were included in the study. All participants are multichannel hearing aid users for at least 6 months (multichannel hearing aids dominate the sector and have the strongest market penetration, so it was not possible for us to reach enough channel-free hearing aid users).

Procedure

Within the scope of audiological evaluation, immittance examination, pure-tone audiometry, and speech tests were performed. After the evaluations, the individuals who were determined to be suitable for the working conditions were included in the hearing aid trial. Real ear measurements were performed and the fittings of the hearing aids to be used were made. Free-field hearing assessment, Turkish matrix test (TMT), spectral-temporally modulated ripple test (SMRT), and random gap detection test (RGDT) were performed with multichannel and channel-free hearing aids after the necessary hearing aid adjustments were made. After the fitting procedure of both hearing aids was applied in random order, the performances were evaluated separately for all participants.

Audiological Assessment

Acoustic immittance evaluations were performed with the GSI TymStar V.2 Middle-Ear Analyzer (Grason-stadler Inc. Tiger/USA) device to evaluate middle ear functions of all individuals participating in the study.

The tests applied to the participants for pure-tone audiometry and other evaluation methods were performed in a soundproof room in accordance with the standards, using the Otometrics-MADSEN Astera² (Natus Medical Inc., Taastrup, Denmark) computer-controlled multichannel clinical audiometer. Pure-tone averages were obtained by averaging the hearing thresholds of all participants in the range of 500 to 4,000 Hz, and the degrees of hearing loss were determined according to the Clark's classification.⁸ In speech audiometry evaluation, speech reception threshold (SRT), most comfortable loudness (MCL), SDS, and uncomfortable loudness (UCL) tests were applied, respectively.

Hearing Aid Selection and Fitting

In our study, *Oticon Opn 1* miniRITE-64 channels (Smorum, Denmark) as multichannel hearing aid and *Bernafon Zerena 9* miniRITE (Bern, Switzerland) as channel-free hearing aid were used bilaterally. These hearing aids were selected because they have the same characteristics according to the technical specifications and factory output measurements reported by the manufacturer. Oticon and Bernafon are hearing aid companies that are part of Demant Holdings. These hearing aid manufacturers belonging to the same holding use similar technologies, hardware architecture, and firmware. During the measurements, to ensure equality in terms of hearing aid features, applications were performed by adjusting all features in the same way, including noise reduction mode off, fixed/full directional microphone

mode, and NAL-NL2 gain algorithm in both hearing aids. Additional features such as frequency lowering, wind noise reduction, etc., were disabled. The real ear measurement applications of the participants were performed with the Aurical Free Fit (GN Otometrics A/S, Denmark) device. Based on real ear responses, appropriate gain targets were set for each patient, and hearing aids were programmed accordingly.

Free-Field Hearing Assessment with Hearing Aids

In free-field conditions, a warble tone stimulus was sent from a speaker at 0-degree azimuth and 1-m distance, and hearing threshold (in the range of 500–4,000 Hz), SRT, MCL, SDS, and UCL assessments were made with hearing aids.

Spectral-Temporally Modulated Ripple Test

SMRT Version 1.1.3 (www.ear-lab.org) software was used to evaluate the spectral resolution. The SMRT software was installed on the laptop and the computer was connected to the clinical audiometer and the signals were sent as calibrated. The test was conducted in a soundproof room via free-field speakers. The stimuli were presented at 65 dB (A) with the listener 1 m away from the speaker and the loudspeaker angle 0 degree.⁹ Participants were seated in front of the computer screen. During the test, three boxes numbered 1, 2, and 3 appear on the screen and the relevant box lights up red when the stimulus is given. Participants were presented with three stimuli consisting of two references and one target stimulus, and they were asked to choose which of the three stimuli on the screen was perceived differently by pressing the relevant number on the keyboard. Scores in test results are reported numerically by the software as ripples per octave.

Random Gap Detection Test

RGDT was used to evaluate participants' temporal resolution skills. In the application of the test, in subtest 1, while the stimulus was given in which the intervals were presented gradually, from small to large, for the participants to practice; in subtest 2, stimuli were presented at random intervals at frequencies of 500, 1,000, 2,000, and 4,000 Hz, and to the standard test part was passed. Audio files of the RGDT stimuli were uploaded to the computerized audiometer and given to the participants with a free-field speaker at 1 m distance and 0 degree azimuth. Stimuli were presented at a most comfortable listening level (50 dB sensation level).¹⁰ Participants were asked to indicate that they heard one or two voices, and each response was marked on the RGDT form. In this way, it is aimed to determine the shortest time interval that can be detected by the individual, namely the temporal acuity threshold. The smallest gap (ms) determined for each of the 500 to 4,000 Hz frequencies tested was detected. The participants' composite RGDT threshold for both hearing aids was determined as the average of reported results across four test frequencies of 500 to 4,000 Hz.

Turkish Matrix Test

Adaptive noise and nonadaptive noise procedures of the TMT were used to evaluate speech understanding skills in noise.

Tests with both hearing aids were performed in the free field with a speaker at a distance of 1 m and an azimuth angle of 0 degree. Both noise and speech signals were presented in such a way that they come from in front of the participant (the most difficult listening condition). TMT was administered via the Oldenburg Measurement Application software and an audiometer that supports this software.

In the adaptive procedure, the SRT in which 50% of the stimuli are correctly repeated in noise is determined as the signal-to-noise ratio (SNR). The noise level for this test was presented as a constant at the level of 65 dB. For each procedure, 20 sentences of 5 words were presented and the participants were asked to repeat all the words they understood.¹¹ Correctly repeated words were marked on the software by the researcher. The speech level was automatically changed by the software until it finds the critical SNR threshold (the value reached to distinguish 50%). The level of speech decreased as the participants repeated the sentences correctly, while it increased automatically when they gave incorrect answers. After all the sentences of the test are completed, the test result is presented as SNR (dB) by the software. In the nonadaptive procedure, SI in certain fixed SNRs is determined as the percent correct score. In our study, 0 dB SNR (challenging listening condition) was used. The speech stimulus was sent by adding 40 dB to the pure-tone averages and the noise level was adjusted on the computer according to the determined SNR.

Statistical Analysis

According to the results obtained by applying normality tests to the data, appropriate parametric (independent samples *t*-test, one-way analysis of variance) or nonparametric (Mann-Whitney *U*, Kruskal-Wallis) tests were selected and used, and their results were interpreted statistically. Spearman's correlation analysis was applied to define the direction and degree of relations between variables. All research data were analyzed with the IBM SPSS Statistics 26.0 program at a $p = 0.05$ significance level. According to the GPower analysis performed, 96.9% power was obtained for the research with $n = 34$ people at a significance level of 0.05.

Results

Right/left ear average pure-tone threshold values according to frequencies, air/bone conduction pure-tone averages, and speech audiometry results of the participants are shown in ►Fig. 1. No statistically significant difference was observed between the right and left ears in pure-tone and speech audiometry results ($p > 0.05$).

There was no statistically significant difference between the two hearing aids in the results of free-field hearing assessment and speech audiometry according to the frequencies applied with multichannel and channel-free hearing aids ($p > 0.05$) (►Fig. 2).

No statistically significant difference was observed between the two hearing aids in the SMRT results applied with multichannel and channel-free hearing aids ($p > 0.05$) (►Fig. 3).

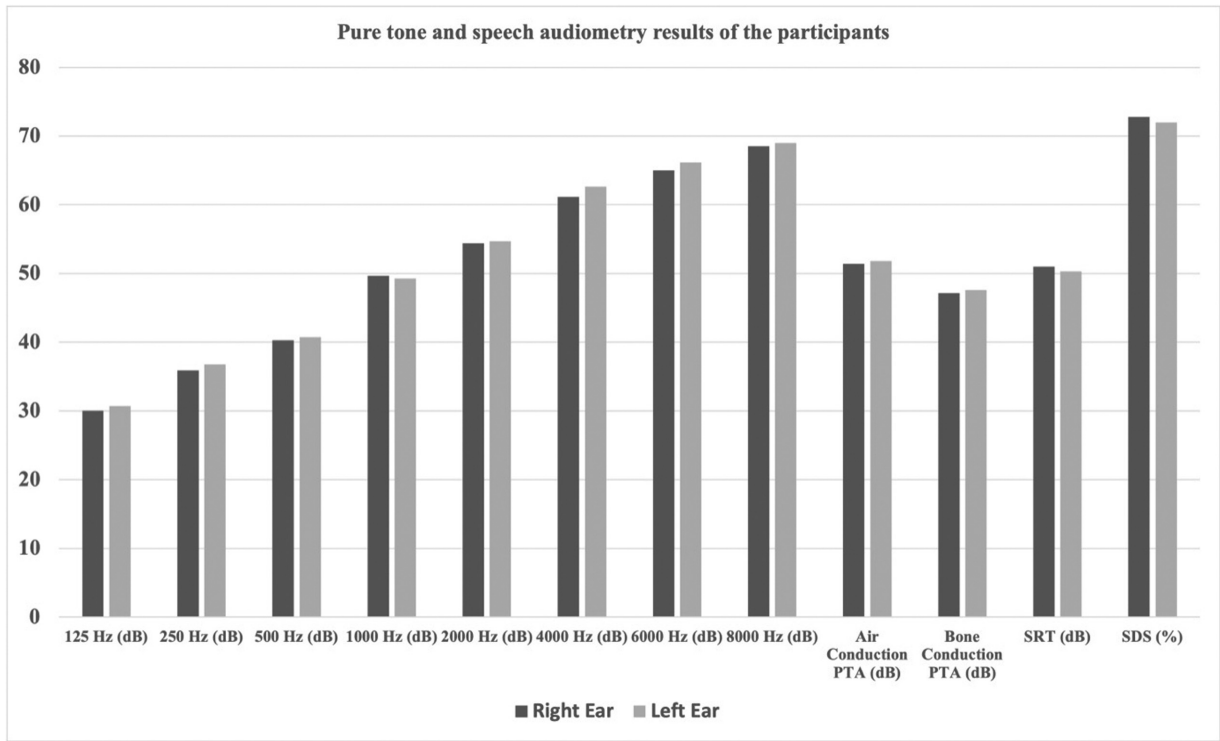


Fig. 1 Pure-tone and speech audiometry findings of the participants. (* $p < 0.05$. Hz: hertz, dB: decibel, PTA: pure-tone average, SRT: speech reception threshold, SDS: speech discrimination score, Mann-Whitney U test).

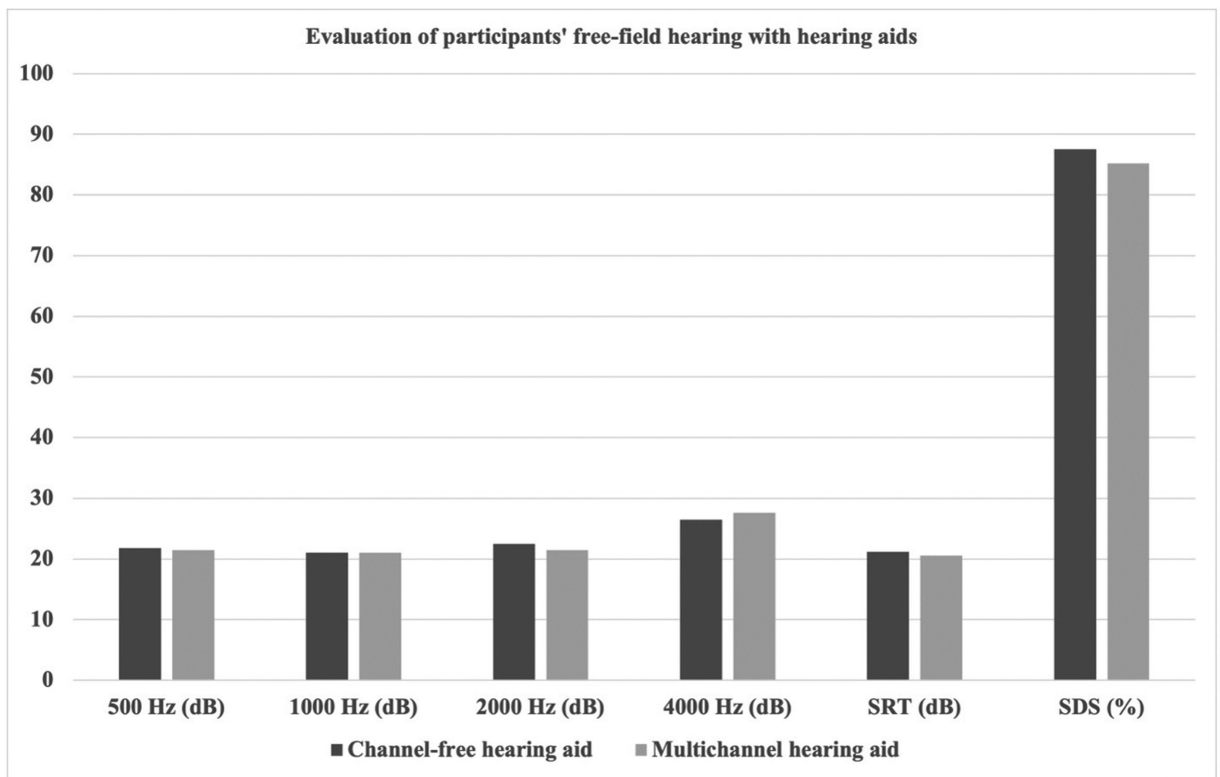


Fig. 2 Evaluation of participants' free-field hearing with hearing aids. (* $p < 0.05$. Hz: hertz, dB: decibel, SRT: speech reception threshold, SDS: speech discrimination score, Mann-Whitney U test).

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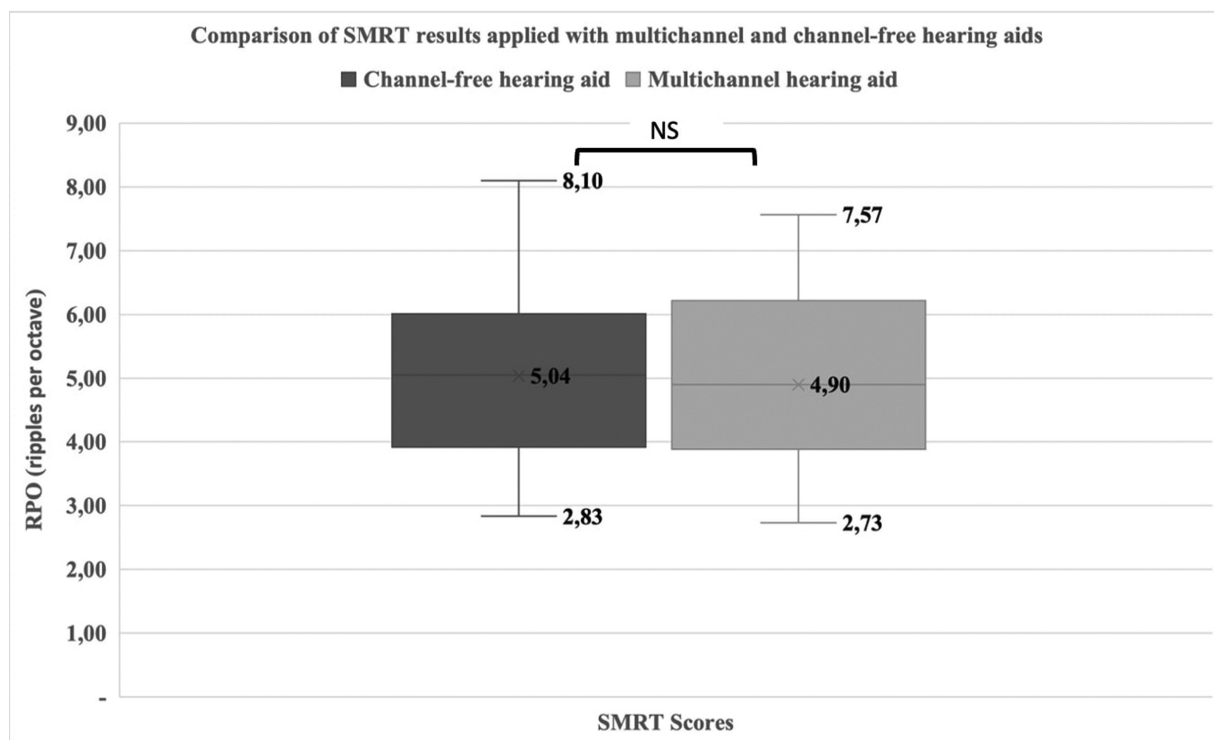


Fig. 3 Comparison of SMRT results applied with multichannel and channel-free hearing aids. (* $p < 0.05$. RPO: ripples per octave, SMRT: spectral-temporally modulated ripple test, NS: not significantly different, independent samples t -test).

In the RGDT results applied with multichannel and channel-free hearing aids, statistically significant differences were observed between the two hearing aids for the 1,000 Hz ($p = 0.045$), 2,000 Hz ($p = 0.046$), and composite RGDT ($p = 0.001$) thresholds. For the 1,000 Hz, 2,000 Hz, and composite RGDT thresholds, lower RGDT thresholds were obtained

with channel-free hearing aids compared with multichannel hearing aids. There was no statistically significant difference between the two hearing aids for the 500 and 4,000 Hz RGDT thresholds ($p > 0.05$) (► Fig. 4).

In the comparison of composite RGDT thresholds obtained with multichannel and channel-free hearing aids according to

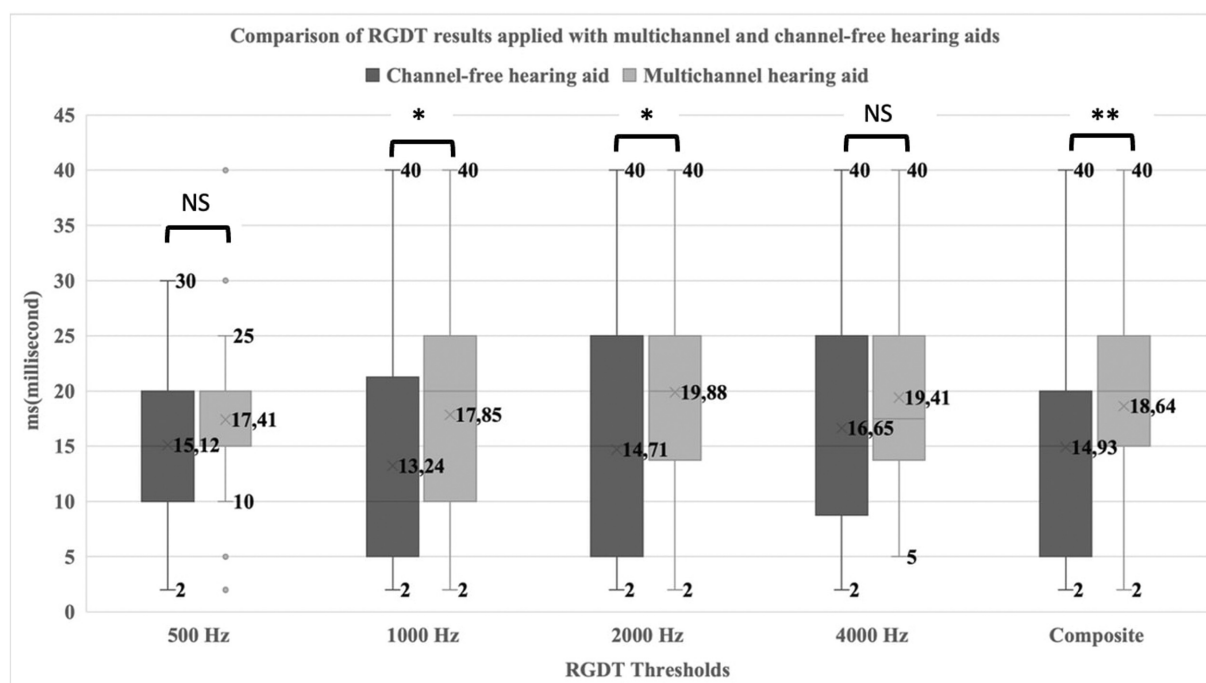


Fig. 4 Comparison of RGDT results applied with multichannel and channel-free hearing aids. (* $p < 0.05$, ** $p < 0.01$, ms: millisecond, Hz: hertz, RGDT: random gap detection test, NS: not significantly different, Mann-Whitney U test).

Table 1 Comparison of composite RGDT results for multichannel and channel-free hearing aids according to different parameters

| Composite RGDT thresholds | | Mean ± SD (ms) | Min | Max | p |
|---|--------------------------|----------------|-----|-----|--------------------|
| Mild hearing loss (n = 8) | Multichannel hearing aid | 18.7 ± 8.2 | 5 | 40 | 0.092 |
| | Channel-free hearing aid | 15 ± 10.2 | 2 | 40 | |
| Moderate hearing loss (n = 14) | Multichannel hearing aid | 19 ± 10.9 | 2 | 40 | 0.037 ^a |
| | Channel-free hearing aid | 14.5 ± 9.8 | 2 | 40 | |
| Moderately severe hearing loss (n = 12) | Multichannel hearing aid | 18.1 ± 8.3 | 2 | 40 | 0.046 ^a |
| | Channel-free hearing aid | 15.2 ± 8.8 | 2 | 40 | |
| 55 years and younger (n = 17) | Multichannel hearing aid | 17 ± 7.8 | 2 | 30 | 0.025 ^a |
| | Channel-free hearing aid | 13.9 ± 8.1 | 2 | 30 | |
| Above 55 years old (n = 17) | Multichannel hearing aid | 20.2 ± 10.6 | 2 | 40 | 0.012 ^a |
| | Channel-free hearing aid | 15.9 ± 10.7 | 2 | 40 | |
| Female (n = 13) | Multichannel hearing aid | 20.5 ± 8.6 | 5 | 40 | 0.080 |
| | Channel-free hearing aid | 17.3 ± 10.5 | 2 | 40 | |
| Male (n = 21) | Multichannel hearing aid | 17.4 ± 9.7 | 2 | 40 | 0.005 ^a |
| | Channel-free hearing aid | 13.4 ± 8.6 | 2 | 40 | |
| 1 year or less experience (n = 17) | Multichannel hearing aid | 20.7 ± 10.9 | 2 | 40 | 0.326 |
| | Channel-free hearing aid | 18.5 ± 10.3 | 2 | 40 | |
| More than 1-year experience (n = 17) | Multichannel hearing aid | 16.5 ± 7.1 | 2 | 30 | 0.000 ^a |
| | Channel-free hearing aid | 11.3 ± 7 | 2 | 30 | |

Abbreviations: Max, maximum; Min, minimum; ms, millisecond; RGDT, random gap detection test; SD, standard deviation.

Note: Mann-Whitney *U* test.

^a*p* < 0.05.

the degrees of hearing loss, there was no statistically significant difference between the two hearing aids in the mild degree (*p* > 0.05). Although there was no significant difference, lower composite RGDT thresholds were observed with channel-free hearing aids compared with multichannel hearing aids. Statistically significantly lower composite RGDT thresholds were observed with channel-free hearing aids compared with multichannel hearing aids in groups with moderate (*p* = 0.037) and moderately severe (*p* = 0.046) hearing loss (► **Table 1**).

In the comparison of composite RGDT thresholds obtained with multichannel and channel-free hearing aids according to the age of the participants, statistically significantly lower composite RGDT thresholds were observed with channel-free hearing aids compared with multichannel hearing aids

in both individuals aged 55 years and younger (*p* = 0.025) and above 55 years of age (*p* = 0.012) (► **Table 1**).

In the comparison of composite RGDT thresholds obtained with multichannel and channel-free hearing aids according to the gender of the participants, while there was no statistically significant difference between the two hearing aids in female participants (*p* > 0.05), lower composite RGDT thresholds were observed with channel-free hearing aids compared with multichannel hearing aids. In male participants, statistically significantly lower composite RGDT thresholds were observed with channel-free hearing aids compared with multichannel hearing aids (*p* = 0.005) (► **Table 1**).

In the comparison of the composite RGDT thresholds obtained with multichannel and channel-free hearing aids according to the hearing aid use experience of the

Table 2 Comparison of Turkish matrix test results applied with multichannel and channel-free hearing aids

| Turkish matrix test | Multichannel hearing aid | | | Channel-free hearing aid | | | p |
|-----------------------|--------------------------|------|-----|--------------------------|------|-----|--------------------|
| | Mean ± SD | Min | Max | Mean ± SD | Min | Max | |
| SRT in noise (SNR-dB) | -0.46 ± 2.49 | -5.1 | 6.1 | -0.39 ± 2.52 | -4.9 | 4.4 | 0.912 ^a |
| SI in noise (%) | 65.91 ± 13.45 | 30 | 91 | 61.65 ± 13.63 | 32 | 88 | 0.199 ^b |

Abbreviations: Max, maximum; Min, minimum; ms, millisecond; SD, standard deviation; SI, speech intelligibility; SNR, signal-to-noise ratio; SRT, speech reception threshold.

^aMann-Whitney *U* test.

^bIndependent samples *t*-test.

participants, while there was no statistically significant difference between the two hearing aids in participants with 1 year or less experience ($p > 0.05$), statistically significantly lower composite RGDT thresholds were observed with channel-free hearing aids compared with multichannel hearing aids in participants with more than 1-year experience ($p < 0.001$) (► **Table 1**).

No statistically significant difference was observed between the two hearing aids in the results of the SRT in noise and SI in noise within the scope of the TMT applied with multichannel and channel-free hearing aids ($p > 0.05$) (► **Table 2**).

Discussion

In our study, multichannel and channel-free hearing aids were compared in terms of spectral resolution using SMRT, and an innovative approach was presented to the literature in this respect. According to the results we obtained, no statistically significant difference was observed between the two hearing aids in terms of SMRT scores ($p > 0.05$) (► **Fig. 3**). In a study in which acoustic analyses of hearing aid signal outputs were performed, channel-free hearing aids also showed spectral distortion, similar to multichannel hearing aids. These results support our study findings.⁷ Plomp has suggested that multichannel hearing aids assign different compression ratios to different channels depending on hearing loss at each frequency, which reduces spectral contrast and changes the spectral shape of speech, resulting in lower speech recognition scores.¹² Schaub suggested that spectral contrast is preserved in channel-free hearing aids as the gain is quickly adjusted according to the incoming signal.¹³ Despite the different opinions in the literature, both hearing aids showed similar performance in terms of spectral resolution in our study.

Kodiyath et al showed that individuals with hearing loss derive significant benefits from channel-free hearing aids over multichannel hearing aids in providing temporal cues for signal detection in background noise.¹⁴ In a study comparing the temporal processing skills of 21 individuals with SNHL with channel-free and multichannel hearing aids, except for comodulation masking release-comodulated condition (CMR-CM), there was no statistically significant difference between the two hearing aids for temporal modulation transfer function, gap detection test, and CMR-uncomodulated condition. For the CMR-CM task, the channel-free hearing aid performed statistically significantly better than the multichannel hearing aid. Moreover, in the acoustic analysis of the hearing aid signal outputs, channel-free hearing aids also showed temporal distortion, similar to multichannel hearing aids.⁷ In our results, 1,000 Hz ($p = 0.045$), 2,000 Hz ($p = 0.046$), and composite RGDT ($p = 0.001$) thresholds were found to be statistically significantly lower with channel-free hearing aids. This has shown that temporal resolution performance is better than multichannel hearing aids. Although the 500 and 4,000 Hz RGDT threshold averages were also found to be lower for channel-free hearing aids, they did not reach statistical significance

($p = 0.152$ at 500 Hz and $p = 0.293$ at 4,000 Hz). Although differences were found in significance according to frequencies, strong statistical significance with the lower threshold in composite RGDT results clearly showed that the temporal resolution performance of channel-free hearing aids was superior ($p = 0.001$) (► **Fig. 4**). The reason for this is thought to be that channel-free hearing aids can make faster gain adjustments according to frequency.

Plyler et al have revealed that listeners who prefer channel-free processing have more hearing loss than listeners who prefer multichannel processing.⁵ In comparison of the composite RGDT results of our study, while there was no statistically significant difference between the two hearing aids in the mild hearing loss group ($p > 0.05$), better temporal resolution performance was observed with channel-free hearing aids, with statistically significantly lower composite RGDT thresholds, compared with multichannel hearing aids in groups with moderate ($p = 0.037$) and moderately severe ($p = 0.046$) hearing loss (► **Table 1**). When using multichannel hearing aids, listeners with more hearing loss will need higher compression ratios to ensure the audibility of low-level signals and the comfort of high-level signals. High compression ratios have been shown to increase temporal envelope distortion and reduce spectral contrast.¹⁵ As a result, it was thought that listeners with more hearing loss may have performed better with channel-free hearing aids due to the additional temporal and spectral distortion in the multichannel hearing aid.

Better temporal resolution performance was observed with statistically significantly lower composite RGDT thresholds in channel-free hearing aids compared with multichannel hearing aids for both young adults ($p = 0.025$) and older adults ($p = 0.012$). This has shown that age does not have a significant effect on the comparison of different hearing aids. In addition, although there was no significant performance difference between the two hearing aids in female participants ($p = 0.080$), the observation of better temporal resolution performance with channel-free hearing aids in males ($p = 0.005$) has shown that gender may be related to signal processing technique (► **Table 1**).

In the study of Kodiyath et al, channel-free hearing aids were preferred more by first-time users than experienced users.¹⁴ Mohan and Rajashekhar have shown that while first-time hearing aid users prefer channel-free processing, experienced users prefer multichannel processing. However, no performance difference was observed for first-time and experienced users.⁷ In the comparison of the composite RGDT results we obtained, there was no statistically significant difference between the two hearing aids in the participants with 1 year or less of experience ($p > 0.05$); in participants with more than 1-year experience, better temporal resolution performance was observed with statistically significantly lower composite RGDT thresholds in channel-free hearing aids compared with multichannel hearing aids ($p < 0.001$) (► **Table 1**).

The results of a study that applied Pascoe's high-frequency word list in noise and hearing in noise test showed that scores were not significantly different between multichannel

and channel-free hearing aids.⁵ In the results of another study on speech recognition in noise, it was determined that channel-free hearing aid outperformed the 8-channel hearing aid at 0 dB SNR; no difference was found at 10 dB SNR. No statistically significant difference was observed in the study.¹⁶ Mohan and Rajashekhar found that the performance between multichannel and channel-free hearing aids did not show a statistically significant difference for speech perception in noise test.⁷ According to the results we obtained, no statistically significant difference was observed between multichannel and channel-free hearing aids for SRT in noise and SI in noise within the scope of TMT ($p > 0.05$) (– **Table 2**). The results of our study are generally compatible with the literature. Unlike the literature, mean scores for SI in noise was higher with multichannel hearing aids than channel-free hearing aids but did not reach statistical significance. Although multichannel hearing aids use syllable compression and channel-free hearing aids use phonemic compression with gain adjustment up to approximately 20,000 times per second, the use of channel-free processing did not significantly improve or reduce speech perception ability compared with multichannel processing.

Conclusion

As a result, no significant difference was found between multichannel and channel-free hearing aids for spectral resolution and speech understanding in noise ($p > 0.05$). In temporal resolution measurement, statistically significantly better performances were observed with channel-free hearing aids ($p < 0.05$). It is thought that faster processing of the incoming signal in channel-free hearing aids improves temporal resolution performance.

Performing the measurements with a larger number of participants for the subgroups of hearing loss degree, age, gender, and hearing aid use experience and applying the tests in different loudspeaker positions may allow the results to be evaluated in a more detailed and consistent manner. It is anticipated that our study findings may help hearing care professionals to choose the optimal hearing aid signal processing technique according to different situations.

Authors' Contributions

Mert Kılıç: Conception, design, data collection and/or processing, literature review, analysis and/or interpretation, writing.

Eyyup Kara: Design, data collection and/or processing, literature review, writing.

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Conflict of Interest

The authors report no declarations of interest. The authors do not have any personal or financial relationships with participants and with the organizations in the research.

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