

Research Article



Comparing the Effect of Digital Noise Reduction Technique on Frequency Gain of Behind-the-Ear Digital Hearing Aids

Majid Shiroei^{1,2} , Nariman Rahbar^{1,2*} , Seyyed Jalal Sameni^{1,2}

¹ Rehabilitation Research Center, Iran University of Medical Sciences, Tehran, Iran

² Department of Audiology, School of Rehabilitation Sciences, Iran University of Medical Sciences, Tehran, Iran



Citation: Shiroei M, Rahbar N, Sameni SJ. Comparing the Effect of Digital Noise Reduction Technique on Frequency Gain of Behind-the-Ear Digital Hearing Aids. Aud Vestib Res. 2022;31(2):121-8.

<https://doi.org/10.18502/avr.v31i2.9117>

Highlights

- One of the methods used to control noise is digital noise reduction technique
- The study aimed to investigate the effect of DNR on the frequency gain of BTE in HAS
- The advanced HAS have better noise control due to the of modern DNR

Article info:

Received: 26 Aug 2021

Revised: 29 Sep 2021

Accepted: 06 Oct 2021

* Corresponding Author:

Rehabilitation Research Center, Iran University of Medical Sciences, Tehran, Iran.
rahbar.n@iums.ac.ir

ABSTRACT

Background and Aim: Background noise as a serious challenge mainly affects the speech perception in people with hearing loss. One of the methods used to control noise is digital noise reduction (DNR) technique. The present study aimed to investigate the effect of DNR program (activated and deactivated) on the frequency gain of basic and advanced behind-the-ear (BTE) Oticon hearing aids, using different DNR strategies to reduce background noise.

Methods: Two behind-the-ear Oticon hearing aids (Opn1 S105 and GetP) were used in this study. The Affinity 2.0 test box was first used to measure their DNR (off/on) gains using the national acoustic laboratories-non linear2 (NAL-NL2) and desired sensation level multi-stage [input/output] (DSLm[I/O]) formulas at sound pressure levels of 45, 65 and 85 dB SPL at a frequency range of 250-8000 Hz for three hearing loss (HL) patterns using the international speech test signal and broad band noise.

Results: There was a significant difference in DNR performance between the Opn1 S105 and GetP models for all three HL patterns at 45 and 65 dB SPL and most frequencies.

Conclusion: The DNR performance of advanced and basic hearing aids is different for different HLs at 45 and 65 dB SPL and most frequencies. The performance of advanced hearing aids is significant using the DSLm[I/O] formula at most frequencies.

Keywords: Digital noise reduction; international speech test signal; frequency response; broad band noise



Introduction

People suffering from hearing loss complain about two main problems including a decline in their audibility and hearing problems in the presence of noise due to the decline in their dynamic range, frequency resolution, and temporal resolution, as well as the occurrence of dead regions in the cochlea due to damage to the critical auditory bands and filters. The main and conventional solution to address the first problem is to amplify hearing through digital hearing aids, but the second problem (i.e. background noise reduction) is difficult in all types of hearing aids [1]. According to the 2007 report of the American Academy of Audiology task force on the health-related quality of life (HRQoL) about the benefits of hearing amplification in adults, people with hearing loss who use hearing aids experience a better quality of life [2]. Hearing loss is independently associated with rapid cognitive decline and cognitive impairment in the elderly [3]. Unfortunately, a decline in speech comprehension and destruction of the target signal reception in the presence of background noise is observed in those suffering from hearing loss due to the following reasons: widening of the masking and tuning curves, upward spread of masking, and reduction of redundancy in speech signal [4-6].

The most important goal of an audiologist in prescribing and fitting hearing aids for people with a sensorineural hearing loss is to increase their speech intelligibility in noisy environments, their comfort in noise or both with the use of directional microphones (DMs) and digital reduction algorithms [7]. Noise-reduction circuitry has become available as a feature in most hearing aids since 1970. The primary noise reduction processing program encompassed low-frequency density and did not provide the expected speech comprehension improvement in the presence of noise [8]. Speech recognition scores may not be improved much when activating digital noise reduction (DNR), but hearing in the presence of noise may be improved in the elderly and children in areas such as acceptable noise level (ANL), input/output signal-to-noise ratio (SNR), memory coding, working memory, and listening effort [9, 10]. The signal processing systems in most hearing aid brands have increasingly become complex with technological advancement. In this regard, the Oticon company traditionally used a noise reduction algorithm in its basic hearing aid models as a modulation-based noise reduction algorithm. This algorithm can detect and reduce the noise amplitude by using an amplitude modulation. It is capable of identifying human speech in the presence of stable noise resources such as ventilation systems, fans, electric engines, etc. [11, 12]. In 2016, the company used new technology in Opn1 hearing aid models to reduce noise.

This technology is called multi-speaker access technology (MSAT) whose goal is to selectively reduce disturbing noises while maintaining access to all distinct speech sounds, and to support the ability of the user to choose the voice they want. This technology processes sound in three stages: analysis of the acoustic environment, maintaining the optimal SNR, and noise removal [11]. Unfortunately, there is a scant research in this field to reveal how much gain should be reduced at each SNR; therefore, most hearing aid designers leave it to audiologists to control the performance of this system and they have no choice but to rely on their knowledge or adjust the performance of the system in a trial-and-error manner [3, 12]. In various studies, the effects of DNR on speech perception, ease of listening, less listening effort, and other cases have been investigated. For example, Wong et al., Desjardins, and Borns et al. in several studies examined the effect of noise reduction system performance on a variety of hearing aids. Their results showed no improvement in speech perception using any of the noise reduction algorithms. However, in most hearing aids, it reduced hearing effort and noise annoyance [13-15]. Since no study has investigated the difference in the efficiency of DNR technique in terms of acoustic changes in frequency response in basic and advanced Oticon hearing aids, this study aims to investigate the acoustic changes in frequency responses resulted from the difference in DNR performance in basic and advanced Oticon hearing aids.

Methods

Initially, two behind-the-ear hearing aids were prepared from the Oticon company (GetP basic model and Opn1 S105 advanced model). The hearing aid fitting software included Oticon Genie2 (For Opn1 S105) and Genie1 2017 (For GetP). To select the hearing aid model, three conditions were considered: availability, new brand, and inclusion criteria. The hearing aids could cover moderate to severe hearing loss (HL). After selecting and preparing the hearing aids, their fitting range set for moderate to severe HLs. Their DNR systems were disabled and adjusted for the following HLs: severe ascending to mild HL (Figure.1), mild sloping to severe HL (Figure. 2), and moderate to severe flat HL (Figure.3). Subsequently, hearing aid frequency response in octave and ½ octave bands were measured at frequency range of 250-8000 Hz by using Affinity 2.0 test box (attached to the hearing aid coupler 2) with international speech test signal (ISTS) and broad band noise (BBN) stimulus in different input levels of 45 dB SPL (soft), 65 dB SPL (medium), and 85 dB SPL (loud), and the mean of three repetitions was considered as the final result.

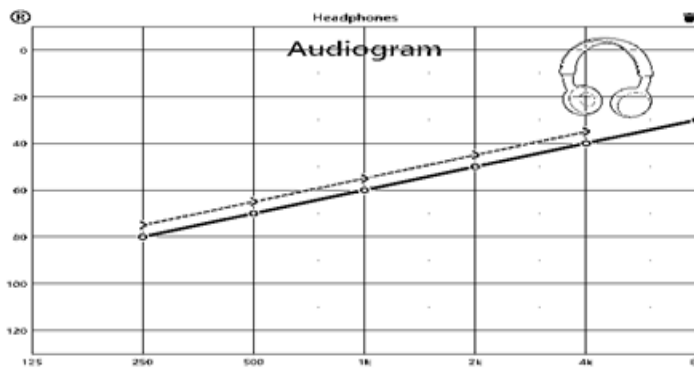


Figure 1. Audiogram depicting severe ascending to mild sensory/neural hearing loss

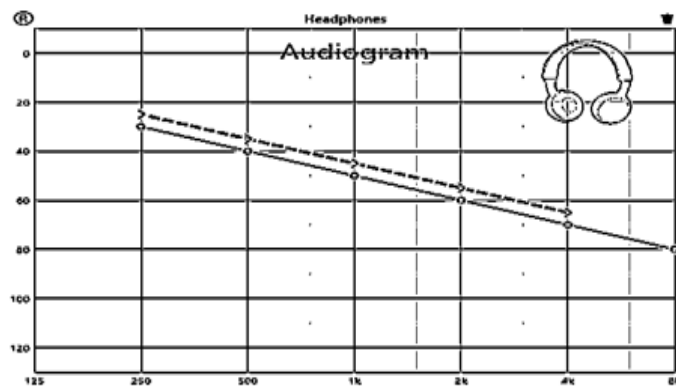


Figure 2. Audiogram depicting mild sloping to severe sensory/neural hearing loss

In the next phase, the DNR of the hearing aids was activated and the frequency response was measured as mentioned above by using Affinity 2.0 test box. The final responses in noise reduction in the on and off states of the hearing aids placed in the test box was similar to that of the conventional BTE hearing aids. The hearing aids' microphones were in omnidirectional mode. In order to prevent the unwanted changes, the volume control, program selection key, and all adaptive circuits such as feedback management in hearing aids were deactivated. Age, gender, and hearing aid use in all participants were set as 25 years, male, and inexperienced, respectively. Data analysis was performed in SPSS v. 17 software, considering a significance level at $p < 0.05$. After confirming the abnormality of data distribution by

Kolmogorov-Smirnov test, General Linear Model (GLM), as an ANOVA procedure, was used to measure the main effect and the interaction effect of various variables as well as Tukey's post hoc test for pairwise comparison between the groups in case of a difference. To facilitate the study, octave and half-octave frequency bands were divided into three ranges: low (250, 500, 750 Hz), mid (1 and 2 kHz), and high frequencies (3, 4, 6, 8 kHz).

Results

Tables 1 and 2 present the results of testing two models of hearing aids using the Affinity 2.0 test box. There was a difference in the gains of activated and deacti-

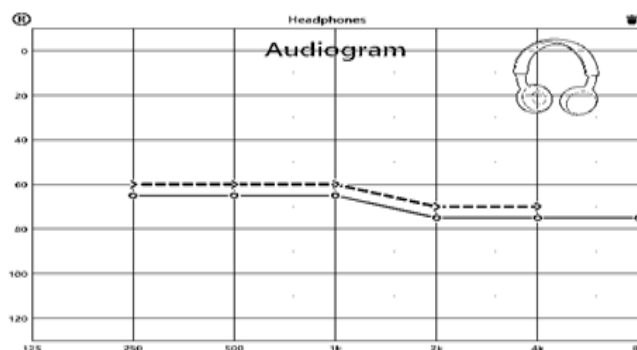


Figure 3. Audiogram depicting moderate to severe flat sensory/neural hearing loss

Table 1. Average frequency gain of the Opn1 S105 behind-the-ear under digital noise reduction/off-digital noise reduction/ on using the DSLm[I/O] and NAL-NL2 formulas under different hearing loss patterns and sound stimuli and sound pressure levels in the frequency range of 250–8000 Hz

DNR	Hearing loss	Prescription formula	Stimulus	SPL	Frequency (kHz)									
					dB	0.25	0.5	0.75	1	2	3	4	6	8
OFF-ON	Moderately severe flat	NAL-NL2	BBN	45	3	1.75	0	-0.25	-0.5	0.25	1.5	-1	-1	
				65	2	0	2	3.5	0.75	0.5	1.5	0.75	1	
				85	3.25	-1.5	0	1	1.25	2	0	1	0	
			ISTS	45	2	-1	0.5	1	1.75	0.75	0.75	3	0	
				65	1.75	0	0.25	0.75	-0.25	0.25	3	1	0	
				85	1	1	2.5	1	-1	0.5	2.5	1.75	0	
OFF-ON	Moderately severe flat	DSLm[I/O]	BBN	45	-2	0.75	4	7	0.25	1	3.25	2.75	1.5	
				65	-3.75	1.75	4	8	-0.25	1	1.25	1.25	1.75	
				85	0	0.75	2.5	5	3	1.75	3.23	0.5	1	
			ISTS	45	-4.25	0	2.5	3.75	6.5	3.25	0.75	0.25	0	
				65	-4.5	-1	4.5	8	-0.5	3.5	3.75	1.5	0	
				85	-2.75	0.75	4	3.5	2.75	-0.75	2.25	1	0	
OFF-ON	Severe ascending to mild	NAL-NL2	BBN	45	1.75	2	2.5	1.25	-0.5	2.25	3.25	-0.75	1	
				65	2.75	0.75	-0.75	3	0.5	2	2	-1.25	0	
				85	4.25	0.5	-1.5	1	2.25	2.75	3	1	1.5	
			ISTS	45	4	5	4.25	3.75	1.5	0.75	1.75	-0.75	0	
				65	1.75	1	4	-1.25	0.25	1.25	1.75	-1	0	
				85	2	0	0	2.25	1.75	1.75	2.25	-0.25	0	
OFF-ON	Severe ascending to mild	DSLm[I/O]	BBN	45	2.5	1.75	1	3.25	1.25	2.75	3.25	3.25	0	
				65	3.75	2.75	0	1.25	3	2	2.5	2.75	0.5	
				85	0.5	1	4.25	2	3	-1	0	1.5	1.5	
			ISTS	45	0.5	-2	0	2	0.25	-0.5	1	0.5	0	
				65	6.75	-0.5	4.5	0.75	1.75	0.25	3	0.25	0	
				85	1.75	1.25	2	1.5	1	2.25	2	1.5	0	
OFF-ON	Mild sloping to severe	NAL-NL2	BBN	45	5.5	3.5	2	2.25	2	0.25	1.5	3	1.25	
				65	0	1.25	1.25	2.5	2	0.75	0.75	3	1	
				85	2.5	-2.75	0	2.75	3.5	-0.25	2.25	3	1	
			ISTS	45	2.75	0	1.75	1.5	2.25	2.25	0.5	2	0	
				65	1	0.5	3.75	1.25	2	2	-0.5	2.75	0	
				85	0.75	1	2.5	4.75	0.75	2.5	-0.5	2	0	

DNR	Hearing loss	Prescription formula	Stimulus	SPL	Frequency (kHz)								
					0.25	0.5	1	2	3	4	6	8	
OFF-ON	Mild sloping to severe	DSLm[I/O]	BBN	45	-7	-0.25	-5.25	-2.75	-5	0.75	4	0	0.25
				65	-3.5	-2.75	-4.25	-3	-1	0.25	2.5	1	-2
				85	0.25	2.75	0	2.5	-1	0.25	-0.25	0.5	-1.25
			ISTS	45	-1.75	-5.25	-3.75	-6	-0.5	3	3	-2.75	0
				65	-5	-4.25	-3	-3.5	-2.25	2.5	5	-2.25	0
				85	2	-2.5	-1.5	-1.75	-3.5	0.5	3	-0.25	0

DNR; digital noise reduction, SPL; sound pressure level, NAL-NL2; national acoustic laboratories-non linear2, BBN; broad band noise, ISTS; international speech test signal, DSLm[I/O]; desired sensation level multi-stage[input/output]

vated DNR program under the same conditions. Results of GLM test (Table 1) for the Opn1 S105 model, showed that the DNR performance was significantly different at all sound pressure levels (45, 65 and 85 dB SPL) for all three HL patterns at 250 Hz (p=0.010), 1000 Hz (p=0.027), 2000 Hz (p=0.019), 3000 Hz (p=0.014), 4000 Hz (p=0.006), 6000 Hz (p=0.004), but not at 500, 750 and 8000 Hz (p>0.05). Using the (DSLm[I/O] algorithm, the NAL-NL2 ratio varied significantly at the sound input level of 85 dB SPL at 750 Hz (p=0.014), 1 kHz (p=0.029), 2 kHz (p=0.012) and 4 kHz (p=0.023).

Results for the GetP model (Table 2) showed that DNR performance was not significantly different for three HL patterns at any sound pressure levels and frequencies (p>0.05). In this model, using the DSLm[I/O] algorithm, the DNR performance was significantly different at the input level of 45 dB SPL and frequency of 1000 Hz (p=0.019) and at the input level of 65 dB SPL and frequency of 4000 Hz (p=0.049).

Discussion

The DNR is vastly underused but is a vitally important feature of modern hearing aid models. It is recommended that the DNR should not be used except for hearing aid fittings. There are two most common reasons why hearing care professionals do not use DNR for every patient is: 1) they're concerned DNR may take away speech sounds, 2) they cannot find a direct audiologic measure to indicate and validate DNR [9]. The purpose of this study was to investigate the acoustic changes in the frequency responses resulted from the difference in DNR performance in both activated and deactivated modes in two basic and advanced hearing aid models using three sound pressure levels of 45, 65, 85 dB SPL at a frequency range of 250-8000 Hz in octave and half-octave bands based on three moderate flat, severe descending, and moderate ascending sensorineural hearing loss using the DSLm[I/O] and NAL-NL2 formulas and ISTS and BBN stimuli.

Results revealed a significant difference between the study hearing aids in the DNR performance using the DSLm[I/O]

Table 2. Average frequency gain of the GetP behind-the-ear under digital noise reduction/on using the DSLm [I/O] and NAL-formulas under different hearing loss patterns and sound stimuli and sound pressure level in the frequencies range 250 to 8000 Hz

DNR	Hearing loss	Prescription formula	Stimulus	SPL	Frequency (kHz)								
					0.25	0.5	0.75	1	2	3	4	6	8
OFF-ON	Moderately severe flat	NAL-NL2	BBN	dB	0.25	0.5	0.75	1	2	3	4	6	8
				45	1	0	-0.25	0.75	-0.5	-0.5	0.75	0.25	-1
				65	-1.25	-1	-0.25	-0.75	0.25	-0.25	-1	-2	3
			ISTS	85	0	-1	0	1	0.75	0.5	-0.25	0.5	1
				45	0	-1	0.25	-0.75	0.75	1.25	1.75	-0.25	1
				65	-0.25	-1	0.5	0	-0.75	-1	1	2	1
85	0	0	1	0	0.75	1.5	0.5	-0.75	0				

DNR	Hearing loss	Prescription formula	Stimulus	SPL		Frequency (kHz)							
OFF-ON	Moderately severe flat	DSLm[I/O]	BBN	45	0	-0.25	-0.75	0	-0.5	1.5	-1.75	-0.75	-1
				65	-1.5	1	-0.25	0.75	0	1.5	-1	2.5	0
				85	-1.75	0.25	-1.5	0.25	-1	1.5	-0.75	0	0
			ISTS	45	0.25	0.5	-1	1	-0.75	0	-3	0	3
				65	0.25	-0.25	-1	0	-2.5	1.5	2	-1.5	0
				85	-0.25	-1.25	0	1	0	2	-3	-1.75	0
OFF-ON	Severe ascending to mild	NAL-NL2	BBN	45	3	3	0	1	0	1	-1	2.5	1
				65	1	1.5	2.5	1.25	0	1.75	0.25	6	1
				85	-1	0	-1.25	-1	-1	1.5	0.25	2.25	1
			ISTS	45	1.25	0.5	0.5	0.5	0	-0.5	-1.75	3	3
				65	0.25	-0.25	-0.5	0.25	-0.25	0.25	-6	2	1
				85	0	1	-1	0	-1	-1	-1	1.5	1
OFF-ON	Severe ascending to mild	DSLm[I/O]	BBN	45	1.25	0	0.75	1.5	-1.5	0	-1.75	2	1
				65	-0.5	0.5	-0.5	1	4	0	-3.5	5	1
				85	0.75	2	0.5	-1	2	0.5	-0.5	2.5	1
			ISTS	45	2.75	4	2.75	2.5	7.5	1.25	-2.75	1.25	0
				65	1	0.25	-1.25	1.75	-1.5	-1.25	-1	6	0
				85	0	1.75	-0.5	3	1	-0.5	1.75	-1.5	0
OFF-ON	Mild sloping to severe	NAL-NL2	BBN	45	2	1	0	2	-0.5	1.5	2.75	1	-1
				65	0	-1.5	-0.5	1	-1.25	1	0.25	1.5	-1
				85	-0.5	1	0.5	1.25	0.25	0.25	-0.25	1.25	1
			ISTS	45	3.5	1.5	2	1.5	-0.75	0	2.75	1.25	0
				65	0	1	-0.5	2	0.5	1.75	3	1	0
				85	-0.25	0	-2	2	-0.5	-0.5	0.25	-1.5	0
OFF-ON	Mild sloping to severe	DSLm[I/O]	BBN	45	2	2	-0.5	0.5	-0.75	1.5	-1.75	5	-1
				65	2	0	0	0	-0.5	1.5	-1	1	-1
				85	2.5	0	-0.25	0	0.25	0.5	-1.75	0.75	0
			ISTS	45	0.25	-1.25	0.25	1.5	0.75	-1	-4	1.5	0
				65	0	0.5	0	0	0.75	0	-1	1.5	0
				85	1	-0.25	1	1.25	-0.75	1.25	-1.25	0.25	0

DNR; digital noise reduction, SPL; sound pressure level, NAL-NL2; national acoustic laboratories-non linear2, BBN; broad band noise, ISTS; international speech test signal, DSLm[I/O]; desired sensation level multi-stage[input/output]

algorithm compared to the NAL-NL2 formula. The DNR performance using the DSLm[I/O] algorithm was significantly different in the Opn1 S105 model at input levels of 45 and 65 dB SPL at frequency of 1 kHz, and at input level of 85 dB SPL at 750 Hz, mid frequencies, and 4 kHz. In the GetP model, there was significantly different at input levels of 45 and 65 dB SPL at frequencies of 1 and 4 KHz.

Furthermore, the difference in DNR performance was not significantly different in the two study hearing aid models at any sound pressure levels and frequencies using the two types of stimuli; therefore, no difference in DNR performance is observed by changing the stimulus type in basic and advanced hearing aids.

The difference in DNR performance was significant at input levels of 45 and 65 dB SPL at 250 Hz (declined) under all three HL patters, and at mid frequencies under flat and descending HL patterns. Moreover, the DNR performance was significantly different in the Opn1 S105 model at 85 dB SPL under flat HL at high frequencies. Therefore, it can be said that the DNR performance is significantly different in advanced hearing aid models at the sound pressure levels of 45 and 65 dB SPL for all three HL patters. In the basic hearing aid models, the DNR performance is similar for all three HL patterns at all input levels and most of the frequencies. Thus, these models probably use the same amount of DNR.

Conclusion

The advanced hearing aids have better noise control than basic hearing aids due to the use of modern and optimal technology for the digital noise reduction (DNR). Advanced hearing aids have different DNR performance at levels of 45, 65 and 85 dB SPL using the DSLm [I/O] formula. The DNR performance is similar in basic hearing aids using the DSLm[I/O] and NAL-NL2 formulas for moderate flat, severe descending, and moderate ascending sensorineural hearing loss at most frequencies, indicating that manufacturers use the same DNR program for DNR in the basic hearing aids; hence, the audiologists are recommended to take advantage of this technique as an easy and suitable approach for better noise control. Moreover, further studies are recommended to examine the effect of DNR technique in people with different ages using hearing aids.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of Iran University of Medical Sciences (Code: IR.IUMS.REC.1398.1352).

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

Authors' contributions

MS: Acquisition of data, interpretation of the results, and drafting the manuscript; NR: Study design, acquisition of data, interpretation of the results; SJS: Interpretation of the results and statistical analysis.

Conflict of interest

The authors declared no conflicts of interest.

Acknowledgements

This article has been extracted from M. Shiroei MSc. thesis on Audiology submitted to Iran University of Medical Sciences.

References

- [1] Dillon H. Hearing aids. 2nd ed. Turramurra, NSW, Australia: Boomerang press Sydney; 2012.
- [2] Chisolm TH, Johnson CE, Danhauer JL, Portz LJP, Abrams HB, Lesner S, et al. A systematic review of health-related quality of life and hearing aids: final report of the American Academy of Audiology Task Force on the Health-Related Quality of Life Benefits of Amplification in Adults. *J Am Acad Audiol.* 2007;18(2):151-83. [DOI:10.3766/jaaa.18.2.7]
- [3] Lin FR, Yaffe K, Xia J, Xue Q-L, Harris T B, Purchase-Helzner E, et al. Hearing loss and cognitive decline in older adults. *JAMA Intern Med.* 2013;173(4):293-9. [DOI:10.1001/jamaintern-med.2013.1868]
- [4] Humes LE. Understanding the speech-understanding problems of the hearing impaired. *J Am Acad Audiol.* 1991;2(2):59-69.
- [5] Plomp RA. Signal-to-noise ratio model for the speech-reception threshold of the hearing impaired. *J Speech Hear Res.* 1986;29(2):146-54. [DOI:10.1044/jshr.2902.146]
- [6] Levitt H. Noise reduction in hearing aids: A review. *J Rehabil Res Dev.* 2001;38(1):111-21.
- [7] Taghavi SMR, Geshani A, Rouhbakhsh N, Habibzadeh Mardani S. Acceptable noise level test: bases and theories. *Aud Vestib Res.* 2017;26(4):184-94.
- [8] Bentler R, Chiou L-K. Digital noise reduction: An overview. *Trends Amplif.* 2006;10(2):67-82. [DOI:10.1177/1084713806289514]
- [9] Beck DL, Behrens T. The Surprising Success of Digital Noise Reduction. *Hearing Review.* 2016;23(5):20.

- [10] Mueller HG, Weber J, Hornsby BWY. The effects of digital noise reduction on the acceptance of background noise. *Trends Amplif.* 2006;10(2):83-93. [DOI:10.1177/1084713806289553]
- [11] Beck DL, LeGoff N. Speech-in-noise test results for Oticon Opn. *Hearing Review.* 2017;24(9):26-30.
- [12] Ramirez P, Jons C, Powers TA. Optimizing noise reduction using directional speech enhancement. *Hearing Review.* 2013;11(7):14-8.
- [13] Wong LLN, Chen Y, Wang Q, Kuehnel V. Efficacy of a hearing aid noise reduction function. *Trends Hear.* 2018;22:2331216518782839. [DOI:10.1177/2331216518782839]
- [14] Desjardins JL. The effects of hearing aid directional microphone and noise reduction processing on listening effort in older adults with hearing loss. *J Am Acad Audiol.* 2016;27(1):29-41. [DOI:10.3766/jaaa.15030]
- [15] Brons I, Houben R, Dreschler WA. Effects of noise reduction on speech intelligibility, perceived listening effort, and personal preference in hearing-impaired listeners. *Trends Hear.* 2014;18:2331216514553924. [DOI:10.1177/2331216514553924]