ORIGINAL PAPER
DOI: 10.5935/0946-5448.20200016

International Tinnitus Journal. 2020;24(2):86-91.

Evaluation of the Effect of Frequency-Shifting Technique Used in Hearing Aids for Speech Discrimination

Gökhan Palabıyık [1]
Selim Ünsal [2]
Mehmet Gündüz [3]

ABSTRACT

Background: To evaluate the effect of frequency-shifting techniques recently used in hearing aids for speech discrimination scores and hearing thresholds.

Methods: Thirty individuals (16 men and 14 women) with sensorineural hearing loss who used normal fitting monaural hearing aids and frequency-shifting feature for at least 2 months and whose 4000–8000 Hz hearing threshold was over 70 dB participated. The average age was 69.73 ± 10 (range: 65–80 years). We detected the types and degree of each participant's hearing loss. Measurements with and without hearing aids were made in a free field. For speech discrimination scores, 6 listings consisting of 25 monosyllables have been used. It has been avoided to learn words thanks to presentation of words in different listings to subjects.

Results: Pure-tone averages of the participants were measured using a supra-aural headphone, normal fitting hearing aid, and frequency-shifting feature. The results were 55.93 ± 6.89, 40.47 ± 5.48, and 36.73 ± 5.72 dB, respectively (p□0.05). Speech discrimination scores for hearing aids worn on the right ear were measured as 67.73 ± 12.42%, 77.33 ± 10.33%, and 82.13 ± 10.46% with supra-aural headphones, normal fitting hearing aids, and frequency-shifting feature, respectively. Scores for hearing aids worn on the left ear were 68 ± 7.56%, 76.80 ± 6.96%, and 82.13 ± 6.67% with supra-aural headphone, normal fitting hearing aid, and frequency-shifting feature, respectively ($p<0.05$).

Conclusion: Elderly individuals using hearing aids had low speech discrimination scores. The frequency-shifting feature recently used in hearing aids significantly increased the scores, making a significant contribution to the solution of speech reception and communication problems in cases of high-frequency hearing loss caused by presbyacusis in elderly individuals..

Keywords: Hearing aid, speech discrimination, frequency shifting.

[1]Department of Audiology, Academy Hearing Center, Bursa, Turkey
[2]Department of Audiology and Speech Pathology, İstinye University, Faculty of Health Sciences, İstanbul, Turkey
[3]Department of Otolaryngology Head and Neck Surgery, Wakayama Medical University, Japan

*Send correspondence to:
Selim Ünsal
Department of Audiology and Speech Pathology, İstinye University, Faculty of Health Sciences, İstanbul, Turkey, E-mail: sunsal@istinye.edu.tr
Phone: +905535938536
Paper submitted on August 06, 2020; and Accepted on November 20, 2020

INTRODUCTION

Evaluating hearing sensitivity with a speaking test is crucial as evaluating hearing disorders using only pure-tone audiometry tests is insufficient [1]. Speech tests developed for this purpose [2] are used in differential diagnosis of hearing loss, in determining how hearing loss effects speech reception, choosing hearing aid, and determining audiological rehabilitation and its benefit. Hearing and comprehending speech are different concepts. Speech Reception Threshold (SRT) [3], a part of speech audiometry, is crucial as it shows the relationship between hearing sensitivity and speech and is also of great importance in estimating the accuracy of pure-tone hearing threshold. Fifty one-syllable words are used for measuring the speech discrimination score. The test is generally performed with 25 words from a list, and scores are determined as a percentage of correctly repeating the phonetically balanced words. The test is conducted at the Most Comfortable Level (MCL) [4]. Recorded speech discrimination score evaluates the high-frequency speech energy (2000–4000 Hz) depending on the rhythmic pattern of speech and reflects the deficiencies in the information on low-frequency (250-500 Hz) hearing [5]. High-frequency words are responded to more quickly than low-frequency words. This effect is known as "word frequency effect" [6]. While more voices are heard by means of low-frequencies, understanding speeches is made by high-frequencies. While low-frequencies are normal or close to normal especially in presbyacusis, hearing loss is observed in high-frequencies. This situation causes the case of "I hear voices but I don't understand" in terms of the geriatric group. This study aimed to survey the frequency-shifting feature recently used for high-frequency hearing loss in elderly individuals in terms of its effect in speech discrimination and pure-tone hearing threshold with hearing aids.

METHODS

This study was conducted in the clinic of audiology and speech disorders of our tertiary academic medical center. The clinical research initiated after approval from the ethical committee. All participants signed the "participant informed consent form". Participants were 30 individuals (16 men and 14 women) with sensorineural hearing loss who used normal fitting monaural hearing aids and frequency-shifting feature for at least 3 months and whose 4000–8000 Hz hearing threshold was over 70 dB. The participants were 65–80 years old (average, 69.73 ± 10 years). The type and degree of hearing loss were determined by pure-tone and immittance audiometry tests. The study included patients having normal middle ear functions (Jerger Type A tympanogram) and an uncomfortable level above 100 dB. They had no difficulty in using a hearing aid and voluntarily agreed to participate. Individuals who are using one-sided hearing aids have participated into the study. It is required to use hearing aids binaural normally. Although Ear-Nose and Throat physicians and audiologists suggest to use two-sided hearing aids, subjects tend to use one-sided hearing aids. Following factors can be considered as being related to one-sided preference or none-utilization of hearing aids: economic reasons, sense of shame, being difficult for usage, not being able to talk on the phone and making various noises. Besides, some portion of fees of hearing aids are compensated by the government in our country. Six-months period should have passed for adult subjects who have bought their first hearing aids, to purchase second one and it was required to 20 % benefit within this six-months period. While this situation was a valid reason between dates in which this study was conducted, it is not implemented as of yet. Due to these reasons, it is quite difficult to access people who regularly use two-sided hearing aids. Individuals with conductive or mixed hearing loss and those who had otologic surgical operations were excluded from the study. Their hearing thresholds and speech discrimination scores with hearing aid were measured in a free field using a normal fitting hearing aid and frequency-shifting feature. The feature of frequency-shifting in hearing aids starts with the software to decide whether frequency-shifting is necessary based on the entered audiogram (The software has been programmed based on hearing loss which is equal to or greater than 70 dB on 4000 Hz frequency and over). In this system which only becomes active when required, the information with high-frequency is transferred from the determined range towards the lower-frequency range with better hearing. Thus, frequency transfer increases the audibility of speech clues. What the important is the bandwidth belongs to the signal to remain stable. It is shown that amplified /s/ phoneme has been shifted from an inaudible frequency range to an audible frequency range as a result of frequency-shifting. Frequency-shifting feature operates by determining high-frequency clues on ranges determined as source. Source range is the range where high-frequency amplification will be insufficient with normal operation. Frequency-shifting feature copies high-frequency input selected in source range in a way not to lose any information. Later, the content of the copied frequency is compressed and shifted to the pre-selected low frequency transfer range. The transferred range is the best audible range depending on the subject audiogram. Researches have proven that frequency-shifting techniques are more efficient although there isn't dead zone in cochlea[7,8]. All participants in the study have been controlled in terms of dead zone by means of Threshold-Equalizing Noise (TEN) test. According to the TEN test, to ensure standardization, subjects who don't have dead zone in cochlea have been included in the study. Subjects participating into the study have not been specifically tested for central aural dysfunction. However, speech discrimination scores collected vary approximately between 60 and 75 %. Collected speech discrimination scores at this level have been evaluated to be a sufficient score to rule out central pathology.

Audiological Evaluation without Hearing Aid

Acoustic immittance measurements of the participants were taken using a Resonance R36 M clinical tympanometry device (MGE Health Technologies, Zervex, Singapore). Their middle ear pressure and bilateral acoustic reflexes were checked. Pure-tone hearing thresholds were measured in the range of 125–8000 Hz according to the Industrial Acoustics Company (IAC) standards in a double-walled cabin using a Resonance R37 HF HH clinical audiometry device and TDH 49 earphones. Bone-conduction thresholds were measured in the frequency range of 500–4000 Hz using a Radioear

B71 bone vibrator. Hearing loss was rated according to the average pure-tone threshold in the range of 500–4000 Hz using four octave frequencies as a base [9]. (Table 1)

Speech reception threshold (SRT) was measured using the three-syllable words list developed for Turkish patients. Speech reception scores were measured using a phonetically balanced one-syllable words list. The one-syllable words were presented in a monitored live voice to the hearing aid users without using carrier sentences. Twenty-five one-syllable words were read to the patients at their MCL. Different lists of 25 one-syllable words were read in each test performed. 6 different listings with monosyllable 25 words have been used in below conditions and learning situation of subjects has been removed. Different word listings have been presented to subjects based on below conditions.

Used

1. 1.In determination of speech discrimination scores when performing audiometric examination (2 listings for right and leaf ear)
2. Without frequency-shifting feature of the hearing aid (1 listing)
3. In measurements by using frequency-shifting feature (1 listing).

Audiological Evaluation with Hearing Aid for Normal Fitting

Patients were fitted with a hearing aid after the audiological evaluation was conducted without the hearing aid. Gain curves of the hearing aid were obtained by entering the pure-tone air-conduction thresholds measured without the hearing aid into the fitting computer program. In programming hearing aids, National Acoustics Labs, Non-Linear, Version 1 (NAL-NL1) application formula has been used. Functional gain curves have been obtained by NAL-NL1. Obtained gain curves were confirmed with Real Ear Measurement (REM). After the patients used the hearing aids for 2 months, their speech discrimination score when using the device was measured in a free field using warble tone stimulus in the range of 125–8000 Hz. By taking their averages in the range of 500–4000 Hz, the aided pure-tone averages and the aided speech discrimination scores were determined.

Audiological Evaluation with Hearing Aid for Frequency-Shifting Feature

For both the normal fitting and frequency-shifting feature, the same procedure was conducted. Normal gain curves were checked with REM. National Acoustics Labs, Non-Linear, Version 1 (NAL-NL1) application formula has been used for frequency-shifting feature. Frequency-shifting has been decided by means of speech recognition threshold test. The patients used the hearing aids for at least 2 months for adaptation after applying frequency-shifting feature. Subsequently, calculations were made in a free field. After applying the frequency-shifting feature, their hearing thresholds and speech discrimination scores were measured while they listened to warble tones in the range of 125–8000 Hz. Their aided pure-tone averages and aided speech discrimination scores with the frequency-shifting feature were obtained. The free field tests were performed in quiet rooms using Resonance R37 Model Studio speakers. The speakers were placed 1 m away from the patient at a 90 degree angle to the ear with hearing aid. All subjects participated into the study were using one-sided hearing aid and tests were performed with a hearing aid. Normally, measurements with hearing aid are performed with 45 or 90 degree angles. In pre-assessment performed with 45, 60 and 90 degree angles in our study, the best responses have been obtained in 90 degrees. Therefore, the study has been completed by using 90 degree angle.

Statistical Analysis

Descriptive analyses were conducted to provide information on the general characteristics of study groups. Data on continuous variables are given as average ± standard deviation, and data on categorical variables are given as n (%). Student's t-test and one-way analysis of variance were used to compare the means of the quantitative variables between groups. Post hoc tests were used for multiple comparisons. Chi-square test was used to evaluate the association between qualitative variables. A p value of <0.05 was regarded as statistically

Table 1: High-Frequency Hearing Threshold of Ears with Hearing Aid of Individuals Participated into the Study

	Frequencies (Right Ear)				Frequencies (Left Ear)		
Subject	**4000 Hz**	**6000 Hz**	**8000 Hz**	Subject	**4000 Hz**	**6000 Hz**	**8000 Hz**
1	75	85	NB	1	75	85	100
2	70	80	85	2	70	75	95
3	75	75	80	3	90	100	105
4	75	80	85	4	75	100	NB
5	85	100	105	5	70	75	105
6	75	90	95	6	80	75	85
7	90	95	95	7	75	75	80
8	75	90	85	8	90	95	100
9	70	75	80	9	70	75	85
10	80	90	85	10	75	75	NB
11	75	75	90	11	95	100	105
12	75	75	95	12	80	90	85
13	90	100	105	13	80	95	105
14	75	90	105	14	80	95	100
15	70	75	100	15	90	100	105

significant. Available statistical software programs (IBM SPSS Statistics 19, SPSS Inc., an IBM Co., Somers, NY) were used for the calculations.

RESULTS

Table 2 shows the results of the audiological tests, which were performed in a free field by activating the normal fitting and frequency-shifting features, along with the pure-tone averages of the patients with a supra-aural headphone (without hearing aid). The audiological test results performed in a free field with normal fitting hearing aid, without hearing aid, and by activating the frequency-shifting feature were statistically different. The difference between the pure-tone averages of the left and right ears was due to the difference (p<0.001) between all three conditions (pure-tone averages, normal fitting hearing aid, and frequency shifting). Speech discrimination scores analyses were conducted without hearing aid, with normal fitting hearing aid, and by activating the frequency-shifting feature. The results are shown in Table 3.

DISCUSSION

Hearing loss is one of the most important problems occurring in elderly individuals. Previous studies have shown that presbyacusis occurs in people over 40 years of age [10], and its occurrence is more obvious at the age of 60 years [11]. The audiological and clinical findings of hearing loss occurring with increasing age in the geriatric population are not the same[12]. Thus, the approach used in this study aimed to minimize hearing loss, provide the use of a hearing aid, and increase their life quality. If the hearing aid used did not improve the patient's life quality in terms of hearing, it could not be considered successful. Performance and benefits of hearing aids are measured via audiological evaluations and variable surveys. Despite the amplification technology developed for hearing aids, resisting or avoiding the use of hearing aids are among the most serious problems. Dissatisfaction rates in such countries as USA and Brazil are as high as 47%, whereas the rate of hearing aid use is as low as 18% [13]. In Turkey, the incidence of hearing loss according to population distribution was reported as 0.37%, and this rate increased to 1.70% for those who are older than 70 years. Furthermore, only 20.84% of the people with hearing loss use hearing aid [14]. When the hearing loss is diagnosed earlier, the acceptance and use of hearing aid is more positive, which improves the success and satisfaction with the device. Sub-factors that affect this success and satisfaction include the expectations of the patients, cost of the device, psycho-social factors, physical and acoustical characteristics of the hearing aid, and cosmetic problems[15]. Many studies and surveys on the benefits of hearing aids have been conducted evaluating and comparing several hearing aid users [16-18]. These studies mainly aimed to plan appropriate fitting programs and to evaluate the efficiency of the hearing aids. Another factor that affects the use of hearing aid is background noise. Better results were achieved with hearing aids in the speech discrimination tests when assessed with or without background noise[19]. One study has shown that background noise causes older people to avoid using hearing aid, resulting in a decrease in their speech scores. Hearing aids have a positive effect on speech discrimination scores, and higher scores are achieved compared with the scores measured without hearing aids. Several studies have shown a significant difference between speech discrimination scores measured with and without hearing aids. Daily use of the hearing aid and the duration of use during the day increase the speech discrimination scores. The duration of use of hearing aid and speech discrimination score are positively correlated [20-22]. In our study, we demonstrated that the use of hearing aids results in an increase in the speech discrimination scores. This increase was observed to be higher with the frequency-shifting feature. The findings obtained were found compatible with the literature. Hearing aids are insufficient for high-frequency amplifications and decrease in gains. Nowadays, even digital signal processors with the best bandwidth developed may be useless at high frequencies. The decrease in gain efficiency in the high-frequency area prevents hearing aid users from understanding and discriminating speech sounds. Accordingly, communication problems occur in the elderly, and this causes an unwillingness to use hearing aids [23]. To solve this problem, new techniques, such as frequency shifting, can be used in hearing aids. According to the results of our study, we achieved speech discrimination scores higher than 80% when using the frequency-shifting feature. When we consider that speech discrimination scores, which were 88% or higher, fall within the normal range for the individuals with normal hearing, the frequency-shifting feature is required for the geriatric population to achieve normal communication. Dead regions in cochlea can be detected via tests, such as threshold equalizing noise (TEN) and psychophysical

Table 2: 500–4000 Hz Pure-Tone Averages.

	Ears	Supra-Aural Earphones TDH 49 (dB)	Normal Fitting with Hearing Aid (dB)	Frequency Shifting (dB)	F	p value
Groups	Right Ear	56.47±8.18	41.13±7.00	37.07±7.44	25.517	<0.001
	Left Ear	55.40±5.57	39.80±3.51	36.40±3.48	83.383	<0.001

Data are given as M ± SD; p: One-way analysis of variance

Table 3: Speech Discrimination Scores Analysis.

	Ear	Supra-Aural Earphones (%)	Normal fitting with Hearing Aid (%)	Frequency Shifting (%)	F	p value
Groups (Patient Ear)	Right Ear	67.70±12.42	77.33±10.33	82.13±10.46	6.53	0.003
	Left Ear	68.00±7.56	76.80±6.96	82.13±6.67	11.98	<0.001

Data are given as M ± SD; p: One-way analysis of variance tuning curves (PTC). The cochlea has a tonotopic (frequency-specific) organization. While testing the high-frequency areas, the responses of side frequencies can be received; for instance, while 2000 Hz is tested, it is possible to obtain the response for 1000 Hz along with the high-intensity stimulus. In a study conducted by Vinay and Moore (2007), they indicated that sensorineural hearing loss higher than 70 dB can be an indicator of a cochlear dead region21. In the previous studies, it was recommended that high-frequency amplification be diminished, whereas Cox et al. (2011) [24] argued that the opposite is true and that high-frequency amplification provides benefit to dead regions in the cochlea [24]. Loudness discomfort (tolerance problem) is observed especially in the geriatric population due to presbyacusis. The dynamic range of these patients (the difference between hearing thresholds and uncomfortable loudness level) decreases. This requires that selected sounds be increased for the hearing aid user while also requiring that selected sound be lowered so that the patients do not find them uncomfortably loud. The frequency-shifting feature prevents the users from being uncomfortable with the sound, enabling their speech discrimination scores to be improved. According to our results, obtaining high speech discrimination scores with the frequency-shifting feature represent the presence of a dead region in the geriatric population. Checking the dead regions in the cochlea, especially before the use of hearing aids, will increase the benefit provided by hearing aids. Spectrogram records made when frequency transfer is off can provide us with useful information regarding the benefits of the frequency-shifting feature to the high-frequency areas. REM helps control the appropriate signal frequency also when it is lowered to the level required by the patient [25]. A decrease in high frequencies and an increase in hearing loss can cause speech reception and speech discrimination scores to decrease[26]. In this conducted study, not performing real ear measurement (REM) arises suspicion on the fitting not to be done properly and reduces the reliability of results [27-28].

CONCLUSION

The study was performed on geriatric patients who regularly used monaural behind-the-ear hearing aids during the day. The tests with hearing aids were performed on one brand of hearing aid with the frequency-shifting feature chosen by the clinician. The tests and evaluations made on this brand were used in all the cases. In the tests performed with normal fitting hearing aid with the frequency-shifting feature and without hearing aid, a statistically significant difference was observed both in their pure-tone average and speech discrimination scores. The results were found to be in compliance with the literature. Consequently, according to the results of the tests performed with normal fitting hearing aid, without hearing aid, and by activating the frequency-shifting feature, there is a statistically significant difference in pure-tone averages and speech discrimination scores. The frequency-shifting feature and regular use of hearing aids by the patients during the day results in an increase in speech discrimination scores. The major problem faced by the elderly individuals with hearing loss is that they hear the sounds but cannot understand them. This problem appears to be improved using hearing aids with the frequency-shifting feature. The unwillingness to use hearing aids is the second main problem. An increase in auditory perception with the use of the frequency-shifting feature can lead patients to use hearing aids longer by increasing the speech scores. Elderly patients may have difficulty in adapting to hearing aids. Thus, their communication skills are improved as a result of improved speech reception, speech discrimination, and adaptation due to use of hearing aids via the frequency-shifting feature. Therefore, the elderly individuals who avoid social interactions because of hearing loss can be reintroduced to society. This can also help to make them social and improve their life quality.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

REFERENCES

1. Giolas TG. “The measurement of hearing handicap” revisited: a 20-year perspective. Ear Hear 1990;11: 2-5.
2. Smoorenburg GF. Speech reception in quiet and in noisy conditions by individuals with noise-induced hearing loss in relation to their tone audiogram. J Acoust Soc Am. 1992; 91:421-37.
3. Ramkissoon I, Proctor A, Lansing CR, Bilger RC. Digit speech recognition thresholds (SRT) for non-native speakers of English. Am J Audiol. 2002;11(1): 23-8.
4. Carney E, Schlauch RS. Critical difference table for word recognition testing derived using computer simulation. J Speech Lang Hear Res. 2007;50:1203-9.
5. Bilger RC, Matthies ML, Meyer TA, Griffiths SK. Psychometric equivalence of recorded spondaic words as test items. J Speech Lang Hear Res. 1998;41: 516-26.
6. Bosman AJ, Smoorenburg GF. Intelligibility of Dutch CVC syllables and sentences for listeners with normal hearing and with three types of hearing impairment. Audiology. 1995;34:260-84.
7. Cox RM, Johnson JA, Alexander GC. Implications of high-frequency cochlear dead regions for fitting hearing aids to adults with mild to moderately severe hearing loss. Ear Hear. 2012;33:573-87.
8. Cox RM, Alexander GC, Johnson J, Rivera I. Cochlear dead regions in typical hearing aid candidates: prevalence and implications for use of high-frequency speech cues. Ear Hear. 2011;32:339-48.
9. Cox RM, Stephens D, Kramer SE. Translations of the International Outcome inventory for Hearing Aids (IOI-HA). Int J Audiol. 2002;41:3-26.
10. Gates GA, Mills JH. Presbycusis. Lancet 2005; 366:1111-20.
11. Arnesen AR. Presbyacusis-loss of neurons in the human cochlear nuclei. J Laryngol Otol 1982;96:503-11.
12. Rizzo SR Jr, Gutnick HN. Cochlear versus retrocochlear presbyacusis: clinical correlates. Ear Hear. 1991;12:61-3.
13. Arakawa AM, Picolini MM, Sitta ÉI, de Oliveira AN, Bassi AKZ, Bastos JRM, et al. Evaluation of user satisfaction of hearing aids (HA) in the Amazon. Intl Arch Otorhinolaryngol. 2010;14:38-44.

14. State Institute of Statistics Prime Ministry Republic of Turkey and Turkish Prime Ministry Presidency of Administration on Disable People. Turkey Disability Survey 2002. State Institute of Statistics, Printing Division – Ankara. 2009:75-109.

15. José MR, Campos PD, Mondelli MF. Unilateral hearing loss: benefits and satisfaction from the use of hearing aids. Braz J Otorhinolaryngol. 2011;77: 221-8.

16. Stephens D. The International Outcome Inventory for Hearing Aids (IOI-HA) and its relationship to the Client-oriented Scale of Improvement (COSI). Int J Audiol. 2002; 41: 42-7.

17. Walden TC, Walden BE. Predicting success with hearing aids in everyday living. J Am Acad Audiol. 2004;15:342-52.

18. Vestergaard MD. Self-report outcome in new hearing-aid users: Longitudinal trends and relationships between subjective measures of benefit and satisfaction. Int J Audiol. 2006;45:382-92.

19. Humes LE, Wilson DL, Barlow NN, Garner C. Changes in hearing-aid benefit following 1 or 2 years of hearing-aid use by older adults. J Speech Lang Hear Res. 2002;45:772-82.

20. Souza PE, Yueh B, Sarubbi M, Loovis CF. Fitting hearing aids with the Articulation Index: impact on hearing aid effectiveness. J Rehabil Res Dev. 2000; 37:473-81.

21. Taubman LB, Palmer CV, Durrant JD, Pratt S. Accuracy of hearing aid use time as reported by experienced hearing aid wearers. Ear Hear. 1999;20:299-305.

22. Bille M, Parving A. Expectations about hearing aids: demographic and audiological predictors. Int J Audiol. 2003;42:481-8.

23. Vinay, Moore BC. Prevalence of dead regions in subjects with sensorineural hearing loss. Ear Hear. 2007;28:231-41.

24. Cox RM, Alexander GC, Johnson J, Rivera I. Cochlear dead regions in typical hearing aid candidates: prevalence and implications for use of high-frequency speech cues. Ear Hear 2011;32:339-48.

25. Stelmachowicz PG, Pittman AL, Hoover BM, Lewis DE. Effect of stimulus bandwidth on the perception of normal- and hearing-impaired children and adults. J Acoust Soc Am. 2001;110:2183-90.

26. Phillips SL, Gordon-Salant S, Fitzgibbons PJ, Yeni-Komshian G. Frequency and temporal resolution in elderly listeners with good and poor word recognition. J Speech Lang Hear Res. 2000;43:217-8.

27. Strong WJ, Palmer EP. Speech coding hearing aid system utilizing formant frequency transformation. 1977;40:13-31.

28. Cox RM, Johnson JA, Alexander GC. Implications of high-frequency cochlear dead regions for fitting hearing aids to adults with mild to moderately severe hearing loss. Ear Hear. 2012;33:573-87.