Original Article

The relationship between hearing aid frequency response and acceptable noise level in patients with sensorineural hearing loss

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Abstract

Background: When fitting hearing aid as a compensatory device for an impaired cochlea in a patient with sensorineural hearing loss (HL), it is needed to the effective and efficient frequency response would be selected regarding providing the patient's perfect speech perception. There is not any research about the effects of frequency modifications on speech perception in patients with HL regarding the cochlear desensitization. The effect (s) of modifications in frequency response of hearing aid amplification on the results of acceptable noise level (ANL) test is the main aim of this study.

Materials and Methods: The amounts of ANL in two conditions of linear amplification (high frequency emphasis [HFE] and mid frequency emphasis [MFE]) were measured. Thirty-two male subjects who participated in this study had the moderate to severe sensorineural HL.

Results: There was not any significant difference between ANL in linear amplification of hearing aid with HFE frequency response and ANL in linear amplification of hearing aid with MFE frequency response.

Conclusion: The gain modification of frequency response not only does not affect the patient's performance of speech intelligibility in ANL test. This indicates that we need to note to the cochlear desensitization phenomenon when fitting hearing aid as a compensatory device for an impaired cochlea in a patient. The cochlear desensitization has not been considered properly in hearing aid fitting formula which is needed to be explored more about the bio-mechanisms of impaired cochlea.

Key Words: Acceptable noise level, hearing aid frequency, sensorineural hearing loss

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INTRODUCTION

The most common type of hearing loss (HL) among the patients is the sensorineural HL. In this type of HL, typically the cochlea has dysfunction (for example, loss of outer hair cells [OHCs] and or inner hair cells). People with cochlear HL perform more poorly than the normal people regarding speech intelligibility, especially in noisy environments. It has been shown that in various noisy conditions, the people with cochlear HL compared to the normal people need more amount of signal to noise ratio (SNR) for understanding the speech. For example, when having the mild sensorineural HL, the patient needs a little

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higher of SNR (about 2.5 dB more) to understand speech in noise, which this amount of SNR needs to be much higher (7 dB or more) when the amount of HL is increased to the moderate or severe level.[1]

From the other side, the normal people can take the advantage of temporal and spectral “dips” in signals (speech) when there is a competing noise. This is due to the cochlear compression functions. But when there is a sensorineural HL, patients do not take this advantage of cochlear function.[2-7] For this reason, the role of hearing aid amplification is very important to get back the patient to (near to) the normal level of speech intelligibility. According to the matters above, when fitting the hearing aid for a patient, the frequency response of amplification needs to be considered very precisely, especially regarding the shape of frequency response.

For this reason, when the sensorineural HL is to be compensated by wearing the hearing aid, it is needed to provide the best frequency selective amplification via a hearing aid. This fact helps more effectively if the patient with HL gets the effective frequency response of hearing aid.[7,8] The most patients with hearing aid still have problems in understanding the speech in noise.[9-13] Hearing aids with various technologies have not been satisfying the patients with sensorineural HL completely. But, fitting a hearing aid in a best way and finding the best frequency response of amplification for a patient can help him/her significantly. There has been provided many fitting rationales for hearing aid which are currently common when a hearing aid is fitted by an audiologist. Among the various fitting rationales, National Acoustic Laboratories (NAL) formula (NAL-revised for severe/profound [NAL-RP], NAL-nonlinear 1 [NAL-NL1], and NAL-nonlinear 2 [NAL-NL2]) is the most famous rationale when considering speech intelligibility, especially in noisy and real conditions. NAL-RP is a fitting formula for linear amplification of sounds; whereas NAL-NL1 and NAL-NL2 are for nonlinear amplification. The original concept behind these formulae is fairly same, especially when amplifying the medium loudness of sounds, which speech is the main.

In real conditions of fitting hearing aid for patients with HL, there are some conditions that the audiologist has to modify the shape of frequency response because of patient’s comfort, no experience to amplification, acoustic feedback, cochlear dead regions, recruitment, and desensitization.[14] In this, there is maybe some concern from audiologist’s side on the negative effect of these kinds of modifications on speech intelligibility in noise and the amount of hearing aid usage by the patient. Because the main goal of a good fitting is amplifying sounds (mainly speech) according to shape of frequency response which is recommended by the selected fitting rational like NAL formula. By this reason, the most audiologists hardly try to make the hearing aid frequency response exactly based on rationale targets of amplification without any a little difference. But, from the other side, the audiologists usually have to modify this frequency response based on patients’ needs and the individual conditions.

At now, there are various tests of speech intelligibility in noise for verifying the amplification and the effects of different modification of the amplification. One of these verification tests, which can predict the real results of amplification usage for a patient effectively, is the acceptable noise level (ANL) test. The ANL is a test for determining the preferable SNR. Whenever the ANL is lower, the patient has more speech intelligibility in noisy environments and he/she will be a full time user of the hearing aid. The biggest advantage of ANL test among the other speech in noise tests is its capability to predict the hearing aid usage in the real life conditions, especially in noisy environments.[17] The ANL test is highly reliable,[15] and some of such characteristics including the independence of age, gender, hearing sensitivity, middle ear function,[16] OHC function, or efferent pathways of the medial olivocochlear bundle[16] make ANL test a special test for assessment of patient acceptance of hearing aid usage in noisy environment. Also, some researches associated the ANL results to the higher brainstem, cortical efferent, and afferent processing centers.[16,17-20] Regarding to these advantages, using the ANL test as a strong test for verification of any modification in amplification can indicate the effects of various amplification modifications. In other words, it can confirm the modifications of amplification when fitting the hearing aid for the patient. In this way, an audiologist can manage his/her modifications of amplification when fitting the hearing aid such that they result in patient’s benefit. Since the ANL test can predict both the degree of successful usage of hearing aid in the real world as well as the preferable response of hearing aid,[19,21,22] the ANL was chosen from the audiological tests of speech in noise. The other speech in noise tests cannot be effective prediction of hearing aid usage in the real life conditions.[21]

The main goal of this study was to find the effects of modifications in frequency response of hearing aid which is determined by NAL-RP for patients with moderate to severe sensorineural HL.

MATERIALS AND METHODS

Subjects

Participants of this study were patients with HL and with at least 2 years of experience of hearing aid. They have been getting hearing aid services from Department of Audiology in Iran University of Medical Sciences. All subjects were male. The inclusion criteria were postlingual moderate to severe sensorineural HL for at least 5 years, age of 30–60 years old, full day users of hearing aid, word recognition score higher than 72%, no history of head trauma, and dominant right handed. All subjects were underwent basic audiological tests, audiometry and immittance tests. The audiometry for air and bone conductions as well as speech audiometry was carried out by instrument OB822 (MADSEN Co., Sweden). The immittance test (tympanometry and acoustic reflex) was carried out by instrument AZ7 (Interacoustic Co., Denmark).

Hearing aid

In this study, a behind-the-ear (BTE) hearing aid (Motion 700 *P* BTE, Siemens Co., Germany) was used as a test instrument. The hearing aid was fit monaurally for all patients. The test ear was the same ear that had experience of hearing aid usage. To prevent the effects of vent on the ANL results, the closed fitting was carried out and all patients' earmolds did not have any vent. During the test time, the nontest ear was closed by an individual ear impression. The hearing aid Siemens Motion 700 *P* BTE was fitted by NAL-RP formula in fitting software, (Connexx v. 6.4, Siemens Co., Germany), for every patient. Two programs for hearing aid were configured: The first program was a frequency response of amplification based on the NAL-RP, and the second program was the same frequency response but with an amplification modification [Figure 1]. The frequency response of the second program was same as the first one but with a modification of 3 dB gain reduction after 4 kHz as well as 3 dB gain increase between frequency ranges of 1 and 4 kHz. The frequency of the first program was named as high frequency emphasis (HFE). The frequency of the second program was named as mid frequency emphasis (MFE).

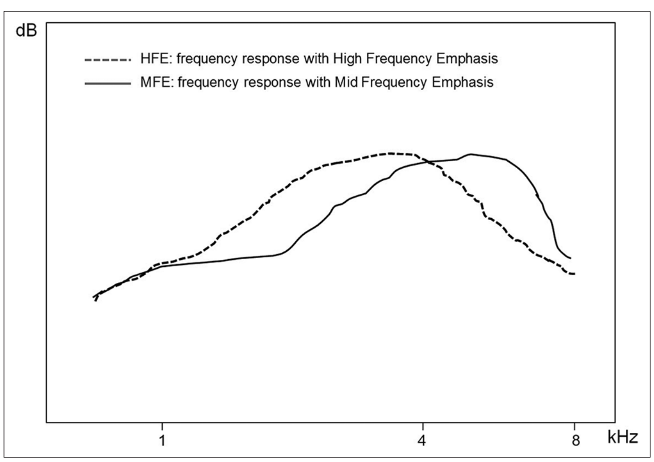

Figure 1: Two various frequency response of amplification are used. High frequency emphasis: A frequency response of amplification in which high frequencies are emphasized regarding National Acoustic Laboratories-revised for severe/profound targets. Mid frequency emphasis: A frequency response of amplification in which high frequencies are reduced and the amount of amplification is increased in mid frequencies

In two programs, hearing aid was fitted in linear amplification and amplitude compression was off. All adaptive settings of hearing aid like feedback cancelling, automatic microphone, speech and noise management, and ewind screen were switched off. The microphone was fixed in the omnidirectional mode. Finally, the real ear measurement was carried out for every condition in all patients. All subjects in the two conditions of frequency responses (HFE and MFE) underwent real ear measurement by FP35 instrument (Frye Electronics Co., USA). The measurements for input 65 dB sound pressure level (SPL) have to be within ± 1 dB of targets in frequency range of 250–8000 Hz.

Acceptable noise level method

For the ANL testing, the Persian version of ANL test was used (TUMS, Ahmadi, 2013). This test is about 20 min of a female running story speech. Also, a 12 talker babble noise was used as the competing noise. The running speech and noise stimuli were presented patients via a compact disc player through a clinical audiometer (OB822, Sweden) to the same speaker which was located in front of and 1 m away from subject (0° of azimuth). The test was carried out in an audiometric test room. The audiometer and sound field were calibrated based on ANSI S3.6-2004. The levels of speech and noise were based on dB HL.

Before starting the test, the subject was instructed in verbal and written way. The description was about the goal of experiment, stages of the test, and the task of subject during the test. At first, the subject's MCL was measured for the running speech. The starting level of speech was 30 dB HL, and according to the patient's signal, the level was increased or decreased in steps of 5 dB until his most comfortable level. For the precise measurement of MCL, the levels of higher and lower than the selected MCL level were presented to the patient for more clarification and selection of the exact MCL level. Finally, the level steps of speech presentation changed to 2 dB for finding the exact MCL in fine way. The final level of presentation, which selected by the patient, was recorded as his MCL. Then, the background noise level (BNL) was measured. For this case, at first, the running speech was presented in the recorded MCL and the 12 talker babble noise was presented in 30 dB HL, simultaneously. Then, the level of noise increased in the 5 dB steps until a level that patient could not tolerate the noise higher than that level. As the final part of the test, the level of noise was adjusted in 2 dB steps. BNL level was measured for 3 times and the average was recorded as the final level of BNL. Finally, the amount of ANL was obtained by subtracting the BNL from MCL (ANL = MCL – BNL).

The time for testing a subject was 2 – 2.5 h in average.

Statistical methods

For extracting and analyzing the results, we used the SPSS software (version 22, IBM Co., USA). The statistical descriptive parameters like mean and standard deviation were used. To assess the statistical significant differences between the various conditions of MCL, BNL, and ANL, the repeated-measurement analysis of variance test was used.

RESULTS

All participants were between 40 and 59 years old (51.5 ± 6.0) and were full day users of hearing aid with experience range of 2–30 years (8.7 ± 7.1). Their mean audiograms indicated the sensorineural HL ranging from moderate to the severe [Figure 2]. Results showed that the average of MCL in HFE and MFE conditions was 50.5 ± 10.3 and 48.6 ± 11.5, respectively [Figure 3]. The average of MCL for HFE condition was higher than MFE condition, but there was not any statistical significant difference between the MCL in HFE and MFE conditions ($F_{(1,31)}$ =2.091, P = 0.158). For BNL conditions, the average of BNL in HFE and MFE conditions was 40.9 ± 11.0 and 41.1 ± 9.7, respectively [Figure 3]. The average of BNL for HFE condition was lower than MFE condition, but there was not any statistical significant difference between the BNL in HFE and MFE conditions ($F_{(1,31)}$ =0.108, P = 0.745). Finally, for the ANL conditions, the average of ANL in HFE and MFE conditions was 8.9 ± 4.3 and 8.6 ± 4.0, respectively [Figure 4]. There was not any statistical significant difference between the ANL in HFE and MFE conditions ($F_{(1,31)}$ =0.521, P = 0.476).

DISCUSSION

Traditionally, in the past, hearing aids have a typical frequency range up to 5–6 kHz, but currently, the new modern hearing aids available in the market have frequency bandwidths up to 8–12 kHz, which can help the patients with HL to perceive every components of speech. However, this wide range of bandwidths increases the sound quality and probably affects the speech intelligibility in some cases, but there is some clinical situation that we need to reduce the gain in high frequency range or reduce the hearing aid bandwidth. The main question is about the effects of these frequency response modifications on our fitting results. Our results showed that the gain modification

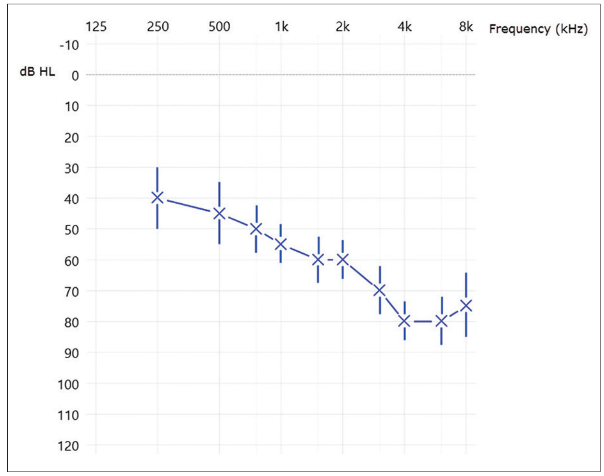

Figure 2: The mean (± standard deviation) of hearing thresholds of subjects in this study (n = 32)

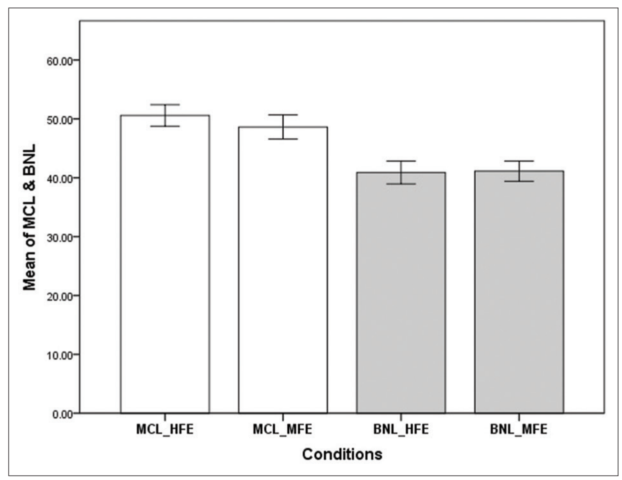

Figure 3: The mean of most comfortable level and background noise level in two conditions of high frequency emphasis and mid frequency emphasis (n = 32)

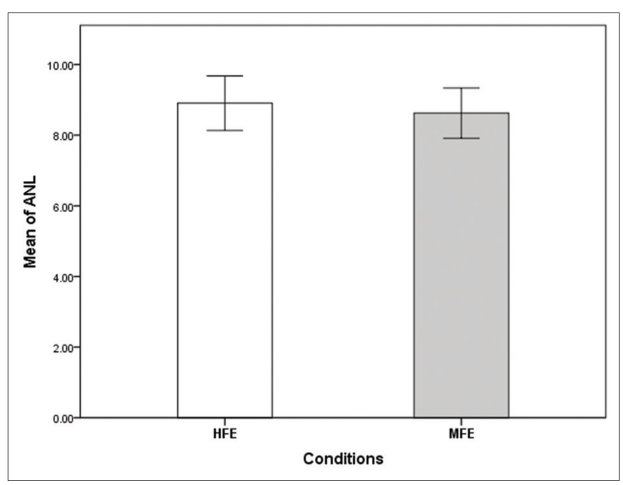

Figure 4: The mean of acceptable noise level in two conditions of high frequency emphasis and mid frequency emphasis (n = 32)

of frequency response, as both a gain reduction in high frequency range and a gain increase in mid frequency range, does not affect the patient's ANL results. It means that this modification at least does not have a negative effect on speech perception of the patient. Thus, it can be concluded that in clinical practice, if it is needed to reduce the target gain for high frequency ranges because of some problems or matters (like auditory desensitization, acoustic feedback, cochlear dead region, new user of hearing aid, patient comfort); there would be not any concern about its effect on speech perception in noise. This case is applicable if we, instead of it, compensate the reduction by gain increase in mid frequencies. This is a finding which is consistent to the other studies accomplished on the gain reduction of high frequency range.[14,23]

The frequency shape of amplification by a hearing aid is the most important item when fitting the hearing aid for a patient, especially regarding speech intelligibility in noise. For this reason, it is always tried to follow the frequency response which is suggested by the fitting formulas like desired sensation level, NAL-NL2, NAL-NL1, and NAL-RP. But, sometimes, the audiologists have to modify the suggested frequency response. In these conditions, there is very strong concern about its effect on patient's auditory performance, especially his/her speech intelligibility in noise. This is while our results show that if we compensate the gain reduction of high frequency as an increase of the gain in mid frequency range, the patient's performance (i.e. speech intelligibility) is preserved.

Also, the current study shows that the ANL test has a strong potential for being as a clinical test for comparing the various types of gain modifications and assessing their effects on patient's preferable SNRs. Currently, many studies have been showed that the ANL test has many capabilities which cause the ANL as a special and reliable test in clinical practice when fitting the hearing aid for the patient. In addition to the above studies, our study showed that the ANL test can be used as a reference test for comparing the effect of frequency response and gain modifications on our results of hearing aid fitting.

Recall that in this study we changed the frequency response of hearing aid just for medium levels of input sounds (65 dB SPL). Also, we compensate the gain reduction of high frequency ranges by the increase of gain in mid frequencies. For this reason, the current results are applicable just for the levels of medium inputs (for conventional level of speech). The results maybe are not applicable to soft as well as loud levels of input sounds. Also, they are not applicable to cases which there are high frequency cut in the frequency range of hearing aid without any compensation of the reduction in the other ranges of frequency. For these conditions, it is needed to perform comprehensive researches on these conditions and possible effects. Whatever the results, since the level of speech in the most real situations of life is at medium level of intensity (65 dB SPL) in both quiet and noise, the modification of frequency response-such as the one used in this study – can beneficial to the patient's auditory performance. Also, since the levels of both MCL and BNL were not significantly different. It could be claimed that the modification of frequency response does not change the patient's level preference for both speech and noise. This result suggests that some frequency components of speech (mid frequencies) can have the role of compensated function for the other frequency components (high frequencies) without causing the difference in preference levels of sounds. In other words, changing the shape of a frequency response does not have negative effects on speech perception, especially if we compensate the reduced frequencies with the other alternative frequencies. In this study, the mid frequencies were amplified 3 dB more than the targets which are suggested by NAL-RP. Since the mid frequencies have the most important role in speech intelligibility, the relatively more amplification of these frequencies results in preservation of patient's speech intelligibility while the patient has not access to the higher frequencies of speech due to the gain reduction in the higher frequencies. Of course, there is may be due to the other causes for example the differences of language and the importance of every frequency range in speech intelligibility index. For this reason, it needs to be studied more. Our results are just applicable for medium levels of input, which the conventional speech is in this range. For more comprehensive evaluation of the effects of frequency response on ANL score and speech understanding in noise, the comprehensive study for the other levels of input (soft and loud levels) is needed to be accomplished.

CONCLUSION

Some gain modification in frequency response of hearing aid, which is suggested by NAL-RP rationale, does not affect the patient's performance of speech intelligibility in noise. This is applicable if the gain reduction of high frequencies is compensated by the gain increase in mid frequencies. The most important mid frequencies can preserve the patient's performance in speech intelligibility. Thus, in some clinical situations, we need to reduce the gain in high frequencies; we can compensate it by gain increase in mid frequencies. This kind of change does not affect the patient's performance.

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