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RESEARCH ARTICLE

Gain measurement from two methods of NAL- NL2 and DSLm[i/o], using two Persian fricative consonants in coupler

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Abstract

Background and Aim: As the most perceived and articulated errors of hearing aid users occur in high frequency speech phonemes, this study aimed to find a way to amplify and reconstruct the errors. Thus, the study first prepared a recorded form of two Persian fricative consonants as stimulus; then, the rate of the prescribed gain of the two methods of National Acoustic Laboratories-Nonlinear 2 (NAL-NL2) and the Desired Sensation Level Multistage Input/Output (DSLm[i/o]) were compared.

Methods: This study was performed using eight programmed hearing aids for severe sensorineural hearing loss in three configurations: flat, raising, and sloping. After fitting the hearing aids upon the NAL-NL2 and DSLm[i/o] methods, the rate of their gain for the consonants of /s/ and /f/, using Affinity 2.0 analyzer, was determined in 2 cc coupler at the three different levels.

Results: In the flat and raising audiograms, the prescribed gain of DSLm[i/o] for the two consonants in all three speakers and intensity level was more than NAL-NL2 ($p< 0.05$). In the sloping audiogram, the significance of the difference of prescribed gain of these methods disappeared; however, the DSL m[i/o] in the low frequency area was higher than NAL-NL2 ($p< 0.001$).

Conclusion: The average prescribed gain of methods in the three frequency regions for the two consonants is different, and the prescribed gain of DSLm[i/o] in all frequencies, especially in the low frequency areas, is higher than NAL-NL2.

Keywords: Coupler gain; hearing aid; prescriptive method; fricative consonants; Persian language

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Introduction

Hearing loss is one of the most prevalent congenital abnormalities that occurs approximately 1:1000 live births [1]. Normal hearing is important for the development of speech and language skills within the first six months of life [2]. Therefore, hearing loss in the first years of life without early intervention may adversely affect the infant's speech and language skills. Since hearing aid is the most widely used assistive listening device, it should have appropriate electroacoustic characteristics for reconstruction of speech phonemes [3]. The primary purpose of amplification is to provide an audible signal across all speech frequencies and this issue is of great importance in infants and children as they have specific amplification requirements [4]. In hearing impaired children high frequency phonemes articulation skills is significantly delayed compared to low frequency ones. Such consequences are observed in spite of early diagnosis and intervention in this group of children [3].

Primary hearing aid fitting for children is typically based on methods such as National Acoustic Laboratories-Non-linear 2 (NAL-NL2) (2008) and Desired Sensation Level Multistage DSLm Input/Output (DSLm [i/o]) (2005). In these fitting methods gain is prescribed based on the audiogram and the lower frequency limits for gain prescription in these two methods are up to 6 and 8 kHz respectively [5]. Numerous studies have demonstrated the efficiency of amplification across this frequency range [6-8].

Nonlinear hearing aids change the gain as a function of input signal. Such changes occur for both stimulus intensity level and its spectral shape. The primary objectives of hearing aids are to preserve speech information, total reconstruction of speech and make it more intelligible [9]. Speech signals have also significant roles in designing different prescriptive formulas for gain [10,11]. Therefore, it seems reasonable to use speech like stimuli for measurement and verification of hearing aids [12]. Furthermore hearing aids' gains for real stimuli in life such as speech and music are considerably different from those for signals like tone and noise. Such differences depends on the number of factors such as hearing aid channels, compression rate and compression thresholds [13, 14] and also some features like noise reduction or feedback cancellation. Thus, the recent attempts have been made to design some stimuli in order to simulate natural speech spectral and intensity characteristics. Phonemes are speech stimuli that have been used subjectively in Ling 6 Sound Test to evaluate hearing aid daily performance. This test assesses the health of child's hearing system and its function from hearing aid to brain. Phonemes are used in this test as a signal for evaluating low, mid and high frequency range [15]. Few research have studied the mode of amplification and speech construction through hearing aid [16] and no studies have been carried out by using phoneme stimuli while it seems that like Ling 6 Sound Test phonemes can also be used for hearing aid electroacoustic assessments to evaluate hearing impaired people objectively.

Garolla et al. designed a Brazilian Portuguese speech stimulus for electroacoustic and real ear measurements. This was an early effort to design and make speech specific stimulus [17]. Stelmachowicz et al. measured coupler gain of 20 commercial hearing aids using pure tone sweeps, swept warble, speech like noise, simulated noise and speech modulated noise at 50 to 80 dB SPL. Results of the study demonstrated that non-speech stimuli underestimate hearing aid gain than speech stimuli. Such discrepancies were more considerable at high frequencies and exceeded 10 to 14 dB. Therefore the importance of using speech stimuli for more accurate hearing aid gain estimation was proved [12]. Keidser et al. evaluated nine different speech stimuli in five analyzing systems. In this study at the first step, speech spectra of the nine speech stimuli were calculated and then were used for some of hearing aids' gain estimation. The difference between calculated insertion gains, using these stimuli exceeded 8 dB. The difference was more at high frequency gains and less at low frequency gains. The results of their research revealed that more attention must be devoted to when choosing test stimuli for determining and verification of hearing aid gain, and stress the importance of producing speech specific test materials [18].

The above-mentioned updating hearing aid prescription software on one hand and speech features interventions of each language on the other hand are the reasons of research in this field of audiology. Thus the goal of present study was to prepare recorded samples of two

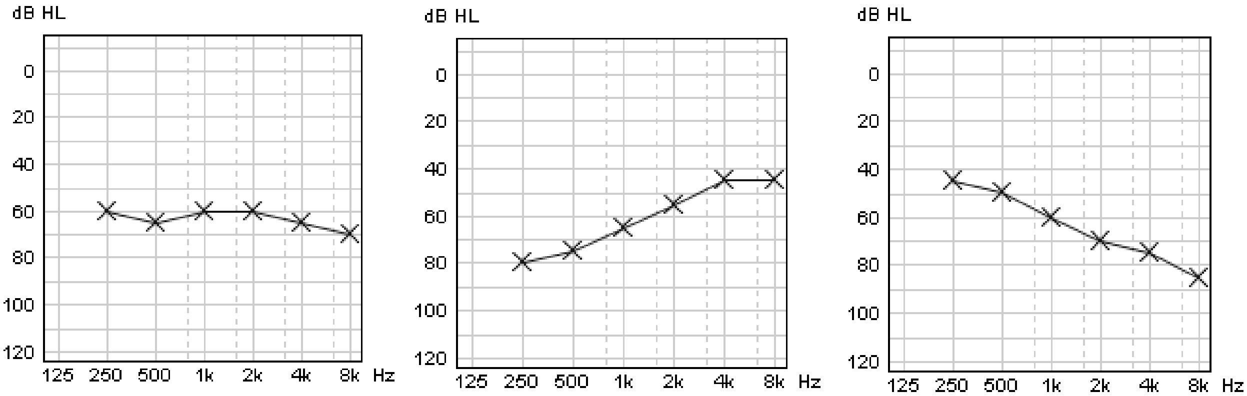

Fig. 1. Selected audiograms configuration

Farsi fricative consonants preliminarily and then to examine prescribed gain of two DSLm [i/o] and NAL-NL2 methods for severe hearing loss using these phonemes and omission of effective variables on gain (such as external auditory canal effects, head and body barrier etc.) in three configurations.

Methods

This study was carried out on eight hearing aids (selected from Belton, Phonak, Siemens and GN Resound companies) for three types of flat, rising and sloping severe sensorineural hearing loss. Since hearing aids with 4 to 6 channels are adequate for speech reconstruction [19] and speech phonemes were used as stimuli in this study, measurements were obtained on similar 6 channel hearing aids. Hearing loss types were chosen on the basis of Hawkins and Cook study in which the common types of hearing losses were determined [20]. The selected audiograms are shown in Figure 1. (a bit changed by the researcher).

In this study two fricative consonants (/f/ and /s/) were chosen with regard to frequency spectrum and their frequency in daily conversation (1.08 and 2.72 respectively) according to suggestions of some experts (linguist, phonetician, and speech and language pathologist) [21]. These two consonants have the highest frequency spectrum in Farsi. Selected test materials were recorded at the level of conventional verbal communication (65 dB SPL) with three male, female and child speakers; the intensity level was monitored with an internal sound level meter (SPL) to avoid exceedance in considered value. Speech phonemes were prepared by wave and mono format with the sampling rate of 44 Hz. In order to have accurate articulation male and female speakers were chosen from speech and language pathologists and the child speaker was a 6 year-old girl with normal speech and language development and without any articulation problems. During recording, the distance between speaker's mouth and microphone was kept at 12 cm and the duration of phoneme articulation was 4 seconds at all stages [22]. The process of test-retest was considered five times.

The recorded phonemes were given to a speech and language pathologist to assess their spectrograms via Praat v.4.2.1 software. Test materials and their spectrograms were assessed and validated by 15 experts including 5 audiologists, 5 speech and language pathologists and 5 phoneticians. Validity assessment was done with a questionnaire including different items on articulation quality, articulation accuracy, correct selection of phonemes on the basis of frequency spectrum, correct selection of phonemes on the basis of frequency in daily conversation etc. Questionnaire items were considered according to these experts. Test materials validity in all aspects was approved by all of experts. Then, these test materials were played in an AC40 audiometer (Intra acoustic

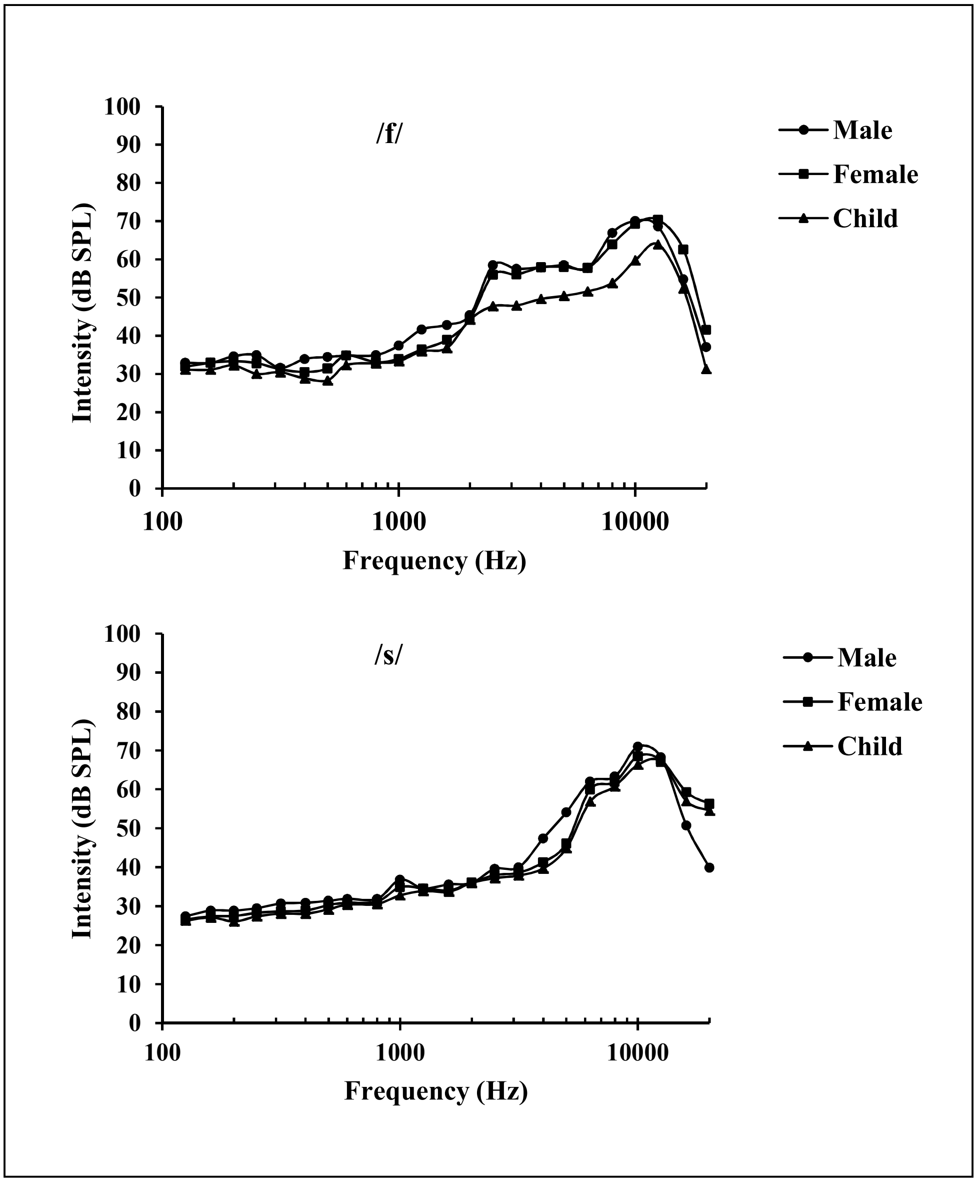

Fig. 2. Spectrograph of for both phonemes, articulated by three speakers

Co., By Denmark) and TDH49 headphone at 35 dBSL for 52 subjects with normal hearing (26 males and 26 females) in the age range of 28 to 38 years (mean: 32.35) for auditory identification. There were no errors in auditory recognition of the phonemes. All participants could identify test materials correctly.

A Nor140 SLM was used as in Keidser et al. study to detect the two consonants' energy range [18]. For that the sound level meter microphone was used in the analyzer test box in place of a hearing aid and was connected to the SLM body, outside the test box by a preamplifier cable (1410A), so that the test environment array was similar to hearing aid evaluation steps. The SLM settings were as follows: z frequency weighting network, 1/3 band octave filters and 40 sec. duration of evaluation. Then each of the two phonemes was run by the three speakers at intensity level of 60 dB SPL by analyzer and spectrography was performed by SLM. Figure 2 shows the results

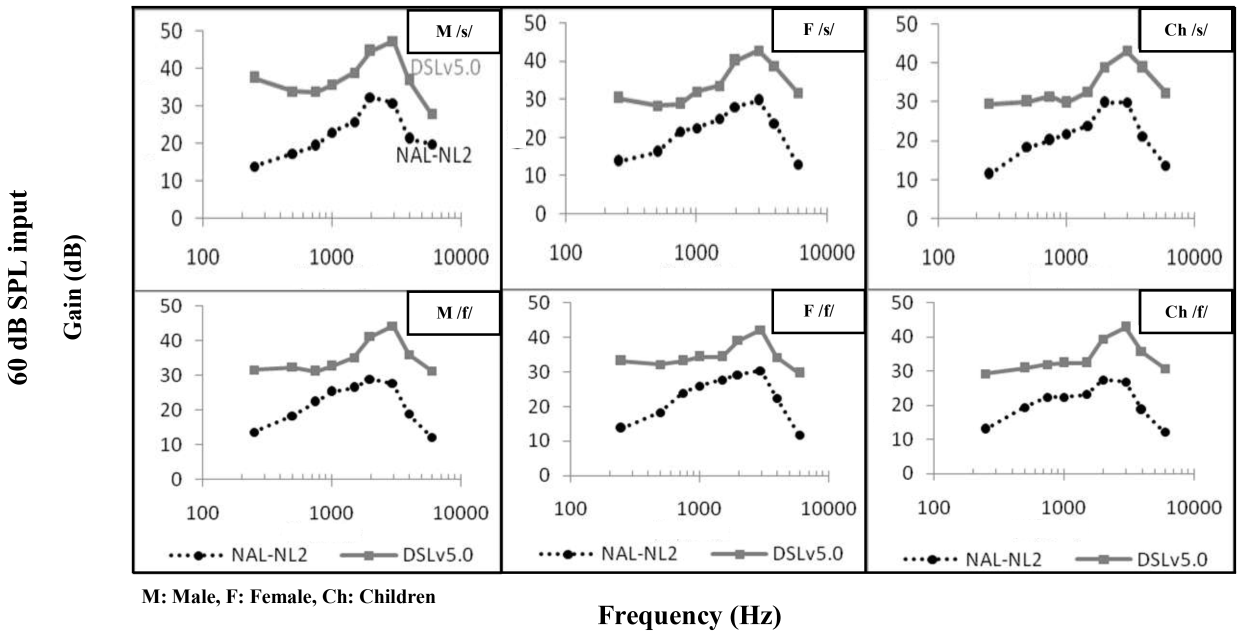

Fig. 3. Prescribed gain of two DSL v5.0 and NAL-NL2 methods for flat hearing loss

of this stage.

In this study an analyzer was used to present phonemes so that no changes in spectrum was expected at different stimulus levels. This led to the rising movement of spectrum curve parallel to vertical axis. One of human vocal tract features is changing in spectral shape of phonemes at different intensity levels. In this system subglottal pressure increased to amplify intensity level so that phonemes spectral shape changed [21]. Furthermore, if the spectrum of presented phonemes through analyzer changed at different intensity levels, no results comparison at those levels were possible. At each stimulus level, a stimulus with new frequency spectrum was presented to hearing aid so that we could not attribute the changes in the results to prescriptive method or stimulus frequency spectrum.

Two speech phonemes /f/ and /s/ have the highest energy at high frequency (higher than 2000 and 2500 Hz respectively) and maintain their energy after 1000 Hz. Onset frequency of highest energy range changes from male speaker to female speaker in two consonants and become a bit higher but it is not the case when child speaker changes into female speaker.

To measure hearing aid gains analyzer set, Affinity 2.0 was used because of its ability to add an external stimulus and make intensity calibration. At all evaluation stages, the level of intensity was increased ascendingly. The positioning of the hearing aid in the test box was similar to the position of a behind the ear (BTE) hearing aid and the distance between the measurement microphone and the front inlet hearing aid microphone was 2-3 mm. At all stages, the pressure method was used for evaluation. After finishing of evaluation, the curve of the hearing aid gain was recorded at 1/3 octave band accuracy, at 3 frequency regions of low (125, 160, 200, 250, 315, 400, 500, 630 Hz), mid frequencies (800, 1000, 1250, 1600, 2000, 2500Hz) and high (3200, 4000, 5000, 6400 Hz). The mentioned frequency regions were chosen on the basis of fitting software for the hearing aids. Frequency of 6400 Hz was chosen as upper limit of the high frequency region because of limitations in maximum amplification of hearing aids.

Each of the hearing aids was first tested using

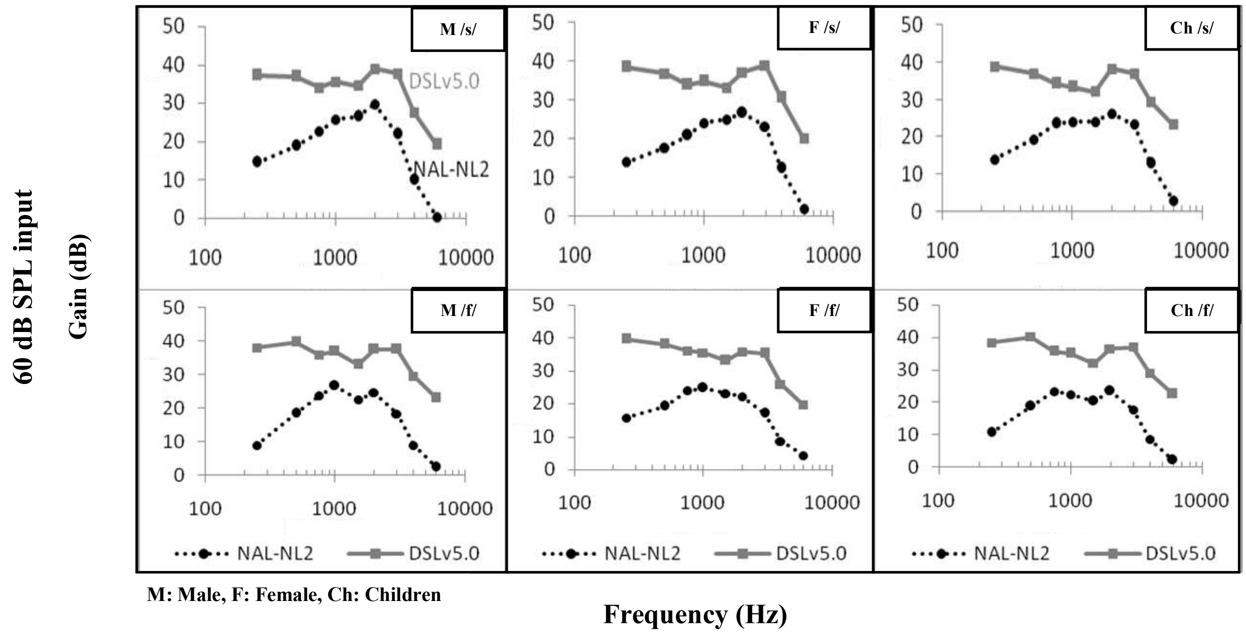

Fig. 4. Prescriptive gain values of DSLv5.0 and NAL-NL2 for rising hearing loss

ANSI S3.22- 2003 standard test sequence. Then the results were compared with information from the hearing aid data sheet to assure its functional accuracy.

In this research, two evaluation stages were taken. In the first stage, each hearing aid was fitted with the NAL-NL2 prescriptive formula for all audiograms using companies' software. In the second stage, the same measurements were obtained with DSLm [i/o] formula. The microphone array was omni-directional for all hearing aids and adaptive circuit- like feedback management and noise reduction were inactive. Furthermore, to prevent any changes, the volume control and program change button were made inactive and only one program was defined for hearing aid. The recorded age for fitting of hearing aids was 5 years (child) in all fitting software. New hearing aid user option was selected to control for experience of using the hearing aid.

Data were analyzed using Microsoft Excel 2007 and SPSS 17. For comparing the mean of prescriptive gains for the two speech phonemes, the independent t-test was used since the data distribution were normal.

Results

Figures 3, 4 and 5 show the average gains of two prescriptive formulas at 60 dB SPL for the each speaker in each audiogram. For flat hearing loss, prescriptive gain values of DSLm [i/o] formula were higher than those of NAL-NL2 for both phonemes, for the 3 speakers and intensity levels ($p<0.05$; Figure 3). For example, for middle frequencies, the average gain of NAL-NL2 was lower than the gain for DSL at 60 dB SPL for the female speaker ($p=0.01$, $p<0.001$ respectively). At low frequency range, mean gain for NAL-NL2 at 40 dB SPL for the male speaker and for phonemes /s/ and /f/ was less than the average gain for of DSLm [i/o] ($p<0.001$). At high frequencies, the average gain for NAL-NL2 for 80 dB SPL for the child speaker was less than that of DSL for phonemes /s/ and /f/ ($p=0.007$, and $p<0.001$ respectively).

For rising hearing loss, prescriptive gain values of DSLm [i/o] formula were higher than those of NAL-NL2 for both phonemes, by 3 speakers and intensity levels ($p<0.05$; Figure 4). For instance, at middle frequencies, the mean gain of NAL-NL2 was less than that for DSL at 60dB SPL for the male speaker ($p<0.001$). At

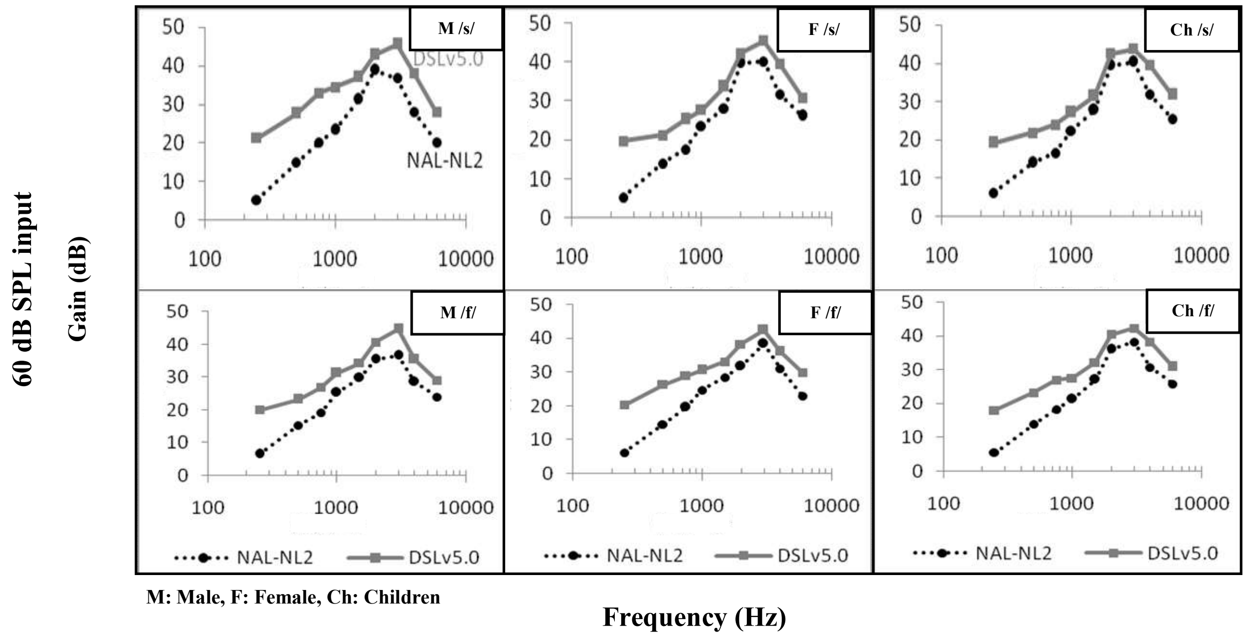

Fig. 5. Prescriptive gain values of DSLv5.0 and NAL-NL2 for sloping hearing loss

high frequencies, the mean gain for NAL-NL2 at 80 dB SPL for the female speaker was less than that of DSLm [i/o] for phonemes /s/ and /f/ ($p=0.002$, $p<0.001$ respectively). At low frequency range, mean gain for NAL-NL2 at 40 dB SPL for the child speaker and for both phonemes were less than the mean gain of DSLm [i/o] ($p<0.001$).

Figure 5, shows the gain curve at 80 dB SPL for sloping hearing loss. In this audiogram, the mean prescriptive gains were close to each other as hearing thresholds increase in middle and high frequencies. And there was no statistically significant difference at the 95% confidence level between both prescriptive gains. But the difference at low frequencies for the two phonemes and intensity levels was statistically significant for all 3 speakers. In this frequency range NAL-NL2 mean gains was less than that of DSLm [i/o] for the two phonemes ($p<0.001$). As an example, In middle frequencies, the difference in the average gain for NAL-NL2 and DSLm [i/o] procedures at 60 dB SPL for the child speaker was not statistically significant for the two phonemes ($p=0.2$, $p=0.1$ respectively). At low frequencies, the mean gain for NAL-NL2 at 40 dB SPL for the female speaker was lower than DSLm [i/o] for the two phonemes ($p=0.003$, $p=0.002$, respectively). At high frequencies, there was no significant difference between the two prescriptive procedures at 80 dB SPL for the male speaker ($p=0.7$, $p=0.9$, respectively).

Discussion

The aim of various fitting methods (formulas) was to measure the gain needed for people with hearing loss. For developing successful fitting, it is necessary that hearing aids has sufficient amplification for maximum speech recognition for a wide range of inputs and to improve the loudness close to normal hearing. Hawkins and Cook used 2cc coupler to minimize ear canal effect, body barrier etc. They found that hearing aid assessment in 2cc coupler is a more suitable method than amplification estimated for confirmation of hearing aid function. In this study the insertion gain results show the results from 2cc coupler with correction factor [20]. Therefore measurements with 2cc coupler were used to minimize the intervening factors.

The results of present study indicated that the descriptive gains for the two methods at three frequency ranges for the two phonemes were different and generally the average gain for DSLm [i/o] is higher than for NAL-NL2. The difference between mean gains of the two methods was maximum at low frequencies but at middle frequencies, the gains were closer. Therefore, in falling hearing loss, middle frequency range is the first frequency range in which the difference between gains is not statistically significant. These results are consistent with those of Johnson and Dillon (2011) and Rajkumar et al. (2013). In the mentioned studies speech like noise had been used to determine gains for different configurations and degrees of hearing loss. The results of these studies showed that prescriptive gain and general loudness of DSLm [i/o] method was higher than for NAL-Nl2 in all frequencies ranges. This difference was significant at low frequencies, while it reduces at middle frequencies [23,24]. According to study conducted by Dillon (2012) similar results were obtained for flat audiograms and he concluded that DSLm [i/o] procedure prescribe more gain than NAL-NL2 for loudness normalization while less amplification is prescribed with NAL-NL2 method because low frequencies do not have a key role in speech intelligibility [25].

In our research the results for the sloping audiogram showed that with increasing hearing thresholds the average prescriptive gains of the two methods become closer for both phonemes at all frequency ranges. While for rising and flat hearing loss configurations, the differences remain significant at 3 frequency ranges.

Spectrogram of the two phonemes showed that the peak energy for consonant /f/ is at 2500 to 12500 Hz while for /s/ is at higher frequencies, i.e. 5500 to 16000 Hz. With regard to frequency range of commercial hearing aids (100 to 6000 Hz), it seems that hearing aids amplify wider parts of the spectrum for consonant /f/ than for /s/. Unfortunately, there is no information on the amount of spectrum which must be amplified for phonemes /s/ and /f/ to have accurate reception and perception of both phonemes under different listening conditions. It seems that if the whole spectrum of phonemes is amplified, they can be understood and recognized without mistake. For example, consonant /m/ is a nasal and low frequency phoneme [21], thus it can be amplified in the frequency range of a hearing aid and its full spectrum. That is why children with hearing loss have difficulty understanding and recognizing this consonant; whereas clinical experiences show that they have the highest numbers of errors in understanding and recognizing /s/. It seems that consonant /f/ is a better stimulus than /s/ for subjective assessment of amplification at high frequency spectrum of a hearing aid. Therefore, this phoneme is a suitable alternative to consonant /s/ in Ling 6 Sound Test; although further research is required in this area.

We can conclude that for full amplification of high frequency speech phonemes, the frequency range of commercial hearing aids must be increased (at least up to 12 kHz). Also, suitable prescriptive methods must be designed to be able to determine the mean gain in this frequency range.

Conclusion

The prescriptive gain for DSLm [i/o] was greater than for NAL–NL2 for two phonemes /s/ and /f/ at three frequency ranges, especially at low frequencies. One of the reasons may be the basic logic of the two formulas formation; one is on the principle of loudness normalization and the other is on the loudness equalization, respectively. The average gains for these formulas are closer at mid frequencies. This indicates that most amplification for NAL-NL2 for these phonemes presents at middle frequencies. NAL-NL2 formula prescribes gains more conservatively for these two high frequency phonemes than DSLm [i/o] formula. In other words, DSLm[i/o] method consider more gain for high frequencies and on the basis of this study such results are independent of speaker variables. For flat and rising hearing loss, the results of the study were the same at low, mid and high frequencies but for sloping hearing loss prescriptive gain of both formulas were close to each other at middle and high frequencies. The two formulas put emphasis on middle and high frequencies amplification in sloping hearing losses.

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REFERENCES

1. Watkin PM, Baldwin M. Confirmation of deafness in infancy. Arch Dis Child. 1999;81(5):380-9.
2. Robinshaw HM. The pattern of development from non-communicative behaviour to language by hearing impaired and hearing infants. Br J Audiol. 1996;30(3):177-98.
3. Stelmachowicz PG, Pittman AL, Hoover BM, Lewis DE. Aided perception of /s/ and /z/ by hearing-impaired children. Ear Hear. 2002;23(4):316-24.
4. Stelmachowicz PG, Pittman AL, Hoover BM, Lewis DE. Effect of stimulus bandwidth on the perception of /s/ in normal- and hearing-impaired children and adults. J Acoust Soc Am. 2001;110(4):2183-90.
5. Füllgrabe C, Baer T, Stone MA, Moore BC. Preliminary evaluation of a method for fitting hearing aids with extended bandwidth. Int J Audiol. 2010;49(10):741-53.
6. Killion MC, Tillman TW. Evaluation of high-fidelity hearing aids. J Speech Hear Res. 1982;25(1):15-25.
7. Ricketts TA, Dittberner AB, Johnson EE. High-frequency amplification and sound quality in listeners with normal through moderate hearing loss. J Speech Lang Hear Res. 2008;51(1):160-72.
8. Moore BC, Füllgrabe C, Stone MA. Effect of spatial separation, extended bandwidth, and compression speed on intelligibility in a competing-speech task. J Acoust Soc Am. 2010;128(1):360-71.
9. Chung K. Challenges and recent developments in hearing aids. Part I. Speech understanding in noise, microphone technologies and noise reduction algorithms. Trends Amplif. 2004;8(3):83-124.
10. Seewald R, Moodie S, Scollie S, Bagatto M. The DSL method for pediatric hearing instrument fitting: historical perspective and current issues. Trends Amplif. 2005;9(4):145-57.
11. Byrne D, Dillon H, Ching T, Katsch R, Keidser G. NAL-NL1 procedure for fitting nonlinear hearing aids: characteristics and comparisons with other procedures. J Am Acad Audiol. 2001;12(1):37-51.
12. Stelmachowicz PG, Kopun J, Mace AL, Lewis DE. Measures of hearing aid gain for real speech. Ear Hear. 1996;17(6):520-7.
13. Souza PE. Effects of compression on speech acoustics, intelligibility, and sound quality. Trends Hear. 2002;6(4):131-65.
14. Henning RW, Bentler R. Compression-dependent differences in hearing aid gain between speech and nonspeech input signals. Ear Hear. 2005;26(4):409-22.
15. Jarollahi F. A practical guide to Tavana test. 1st ed. Tehran: Pars book; 2010. Persian.
16. Holube I, Fredelake S, Vlaming M, Kollmeier B. Development and analysis of an International Speech Test Signal (ISTS). Int J Audiol. 2010;49(12):891-903.
17. Garolla LP, Scollie SD, Martinelli Iório MC. Development of the speech test signal in Brazilian Portuguese for real-ear measurement. Int J Audiol. 2013;52(8):572-6.
18. Keidser G, Dillon H, Convery E, O'Brien A. Differences between speech-shaped test stimuli in analyzing systems and the effect on measured hearing aid gain. Ear Hear. 2010;31(3):437-40.
19. Lewis DE, Eiten LR. Hearing instrument selection and fitting in children. In: Valente M, Hosford-Dunn H, Roeser RJ, editors. Audiology treatment. 2nd ed. New York: Thieme Medical Publishers Inc; 2007.p.94-119.
20. Samare Y. Phonology of Persian language. 2nd ed. Tehran: Markaz Nashre Daneshgahi; 2000. Persian.
21. Yadav N, Kumar SB, Annapurna SB, Vinila VJ. The effect of stimulus bandwidth on perception of fricative /s/ among individuals with different degrees of sensorineural hearing loss. Theory and Practice in Language Studies (TPLS). 2011;1(12):1679-87.
22. Hawkins DB, Cook JA. Hearing aid software predictive gain values: How accurate are they? Hear J. 2003;56(7):26,28,32,34.
23. Johnson EE, Dillon H. A comparison of gain for adults from generic hearing aid prescriptive methods: impacts on predicted loudness, frequency bandwidth, and speech intelligibility. J Am Acad Audiol. 2011;22(7):441-59.
24. Rajkumar S, Muttan S, Jaya V, Vignesh SS. Comparative analysis of different prescriptive formulae used in the evaluation of real ear insertion gain for digital hearing aids. Universal Journal of Biomedical Engineering. 2013;1(2):32-41.
25. Dillon H. Hearing aids. 2nd ed. New York: Thieme; 2012.