Journal of Rehabilitation Sciences and Research

Journal Home Page: jrsr.sums.ac.ir

Original Article

Comparison of Auditory Localization Ability between Preschool Bilateral Hearing-Impaired Children and Normal Hearing Children

Nasrin Gohari[1*], PhD; Zahra Hosseini Dastgerdi[2], PhD; Foozieh Dehghani[1], BSc; Ehsan Negin[3], MSc; Atta Heidari[1], PhD

[1]Department of Audiology, School of Rehabilitation, Hamadan University of Medical Sciences, Hamadan, Iran
[2]Department of Audiology, Isfahan University of Medical Sciences, Isfahan, Iran
[3]Department of Audiology, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran

ARTICLE INFO

Article History:
Received: 23/04/2022
Revised: 04/06/2022
Accepted: 28/06/2022

Keywords:
Hearing loss
Sound localization
Hearing aid
Children

Please cite this article as:
Gohari N, Hosseini Dastgerdi Z, Dehghani F, Negin E, Heidari A. Comparison of Auditory Localization Ability between Preschool Bilateral Hearing-Impaired Children and Normal Hearing Children. JRSR. 2023;10(2):100-105.

ABSTRACT

Background: Sound localization is a valuable skill whose maturation is influenced by auditory experience and is limited by bilateral sensorineural hearing loss. No study has assessed auditory localization in bilateral hearing-impaired children (BHIC) aged 5-6 years. The present study aimed to investigate the auditory localization skill in children with moderate-to-severe bilateral hearing loss and using hearing aids compared to their normally hearing peers.
Methods: This cross-sectional study recruited 19 participants aged 5-6 years (60-72 months) with a mean age of 65.31±3.83 months as the BHIC group and 21 participants aged 5-6 years with a mean age of 60.21±3.02 months as the normally hearing children (NHC) group. The localization ability of both groups was tested in 24 positions with 15-degree intervals by a speaker connected to a laptop and a calibrated speech stimulus named "test." A score of +0.5 for each 15 degrees of error on the right side of the position and -0.5 on the left side of the position were considered.
Results: The results revealed a significant difference in the error rates between the two groups in four (out of 24) positions (P<0.05). Differences were not statistically significant in other positions.
Conclusion: The BHIC had a defect in the localization skill in some situations. Therefore, localization test and localization training are recommended for these children.

Introduction

A critical role of the auditory system is the spatial representation of auditory objects to reconstruct the auditory scene [1, 2]. This provides selective hearing, a mechanism contributing to the extraction of desired signals in complex acoustic environments, e.g., a party [3-5]. Considering all its advantages, auditory localization is a valuable skill for children in their learning, academic achievement, socializing, and safety; therefore, sound localization deficit can be a major factor causing hearing disability [6]. Auditory localization depends on both monaural and binaural spatial cues. Binaural interaction is essential for accurate horizontal localization [7-9].

The head acts as an obstacle to sounds coming from one side and induces the head shadow effect. This phenomenon alters the time and intensity of sounds arriving at both ears, known as the interaural time difference (ITD) and interaural intensity difference (IID), respectively [9]. To localize more complex sounds, e.g., speech or broadband noises, a combination of ITD and ILD is in use [10]. It has been shown that cortical and subcortical structures (brainstem circuits) are involved in extracting and processing the necessary information in spatial hearing, especially localization [11].

Corresponding author: Nasrin Gohari, Department of Audiology, School of Rehabilitation, Hamadan University of Medical Sciences, Hamadan, Iran.
Email: rasacenter@yahoo.com

Spatial hearing depends mainly on the peripheral auditory system to be sensitive enough to detect the smallest ITD and ILD within the range of 10-700 µs and 10-20 dB, respectively. Sensorineural hearing loss (SNHL) is associated with a decrease in auditory resolution and temporal processing skills that negatively affects the processing of spatial cues [12]. Congenital hearing loss limits the sound localization skill, even if hearing-impaired people start using hearing aids from an early age [13]. If the development of brainstem neural circuits as a prerequisite and processor of localization depends on the effective function of afferents in early development, compensation for hearing loss with a hearing aid may not be sufficient to restore the localization skill. In fact, a hearing aid may not provide all the cues necessary for localization [13]. The independent compression pattern, time delay, and noise reduction pattern of hearing aids could have a debilitating effect on binaural cues. This may negatively impact the localization skill and all the relevant essential skills, including selective attention and speech comprehension in challenging situations [14].

Several studies have examined localization in unilateral hearing loss [15-18] and the effect of bilateral cochlear implantation or the combined use of cochlear implantation and hearing aids on the localization skill of children with SNHL. The results were based mostly on the evaluation of speech perception rather than a direct exploration of localization [6, 13]. However, few studies have examined localization in children with varying degrees of SNHL using bilateral hearing aids [13, 19]. Therefore, more research should be conducted to directly investigate the localization skill of children using bilateral hearing aids compared to normally-hearing children (NHC).

The present study was motivated by the critical role of auditory localization in speech perception in noise [20, 21], its significance in auditory scene analysis [1, 22, 23], the contradictory findings of previous studies, and the importance of its assessment in hearing-impaired children before school age and performing early interventions. Herein, the auditory localization skill of preschool bilateral hearing-impaired children (BHIC) with moderate-to-severe hearing loss was compared with NHC.

Methods

Participants

This cross-sectional study sampled 19 BHIC and 21 NHC aged 5-6 years (60-72 months). The BHIC were selected by convenience sampling from Niusha Hearing Rehabilitation Center based on the inclusion criteria. This study was approved by the Ethics Committee of the Hamedan University of Medical Sciences. To comply with ethical considerations, the participants' parents provided written informed consent for their children's participation.

The inclusion criteria for BHIC were: congenital moderate-to-severe SNHL, a threshold of 55-70 dB HL in 500-8000 Hz in the conditional play audiometry, symmetrical extent and frequency patterns of hearing loss in both ears with threshold< 10 dB difference between the two ears [24] and gradually falling audiogram; average threshold of 0.5 and 1 KHz which is 15 dB better than the average of 4, 6, and 8 KHz [25] normal tympanograms (Type An); right-handedness (assessed by the Edinburgh Handedness Inventory, Oldfield, 1971) [37]; use of hearing aids for >12 months [26]; absence of auditory neuropathy (based on auditory brainstem response and otoacoustic emission results); and receiving behind the ear (BTE) identical hearing aids with 6-8 channels, DSL fitting formula, nonlinear, single microphone, omni directional and shell earmold, With the microphone positioned above the hearing aid and below the hook; and receiving regular auditory training programs for > 12 months. Because the statistical populations in some articles was evaluated for uniformity after 12 months of auditory training (Conventional auditory training includes detection, discrimination, recognition, and comprehension [27]), the criterion of 12 months was used here as well [28, 29].

The inclusion criteria for NHC were: normal hearing sensitivity (threshold of ≤20 dB HL in audiometric frequencies), normal otoscopy, normal tympanograms (Type An), normal acoustic reflex test (ipsilateral and contralateral), and right-handedness (assessed by the Edinburgh Handedness Inventory Oldfield, 1971) [30]. The exclusion criteria for both groups were an unwillingness to participate at any stage of the research or the inability to perform the tests.

Procedure

A complete case history was first taken. Then, the following stages were conducted respectively using the following equipment: otoscopy examination (by Riester GmbH, Germany), tympanometry, acoustic reflex (by Madsen Zodiac 901, USA), and conditional play audiometry (by Siemens SD 28, Germany).

After these basic assessments, the localization test was performed to evaluate the localization skill of all participants. The test was performed in a medium-sized room with an almost quiet environment (background noise of <30 dBA) [31]. The stimuli were presented in the horizontal plane in 24 positions in a circle of 8 feet (2.43 meter) in diameter with 15-degree spacing between positions similar to a clock. Positions were marked by hours (e.g., 12, 12:30, 1, 1:30, 2, 2:30, etc.). The stimulus was the word "test," recorded by a female (one of the authors) and calibrated and delivered (Plus XS.2., Canton, Weilrod, Germany) with the presentation level of 55-60 dBSPL for NHC and 95-105 dBSPL for BHIC [32] connected to a laptop (Lenovo-Idea pad L340). The speaker's position changed in different places with a stand of suitable length (1 meter). The children were seated equidistant from each position on a chair of appropriate height and asked to face the central position (number 12) with their backs to number 6 [33] while listening for each trial with their eyes closed (not to see the location of the speaker). The signal was randomly delivered to the participants from each position, and the participants were asked to point toward the corresponding number from which side they heard the sound. Then, they were asked to open their

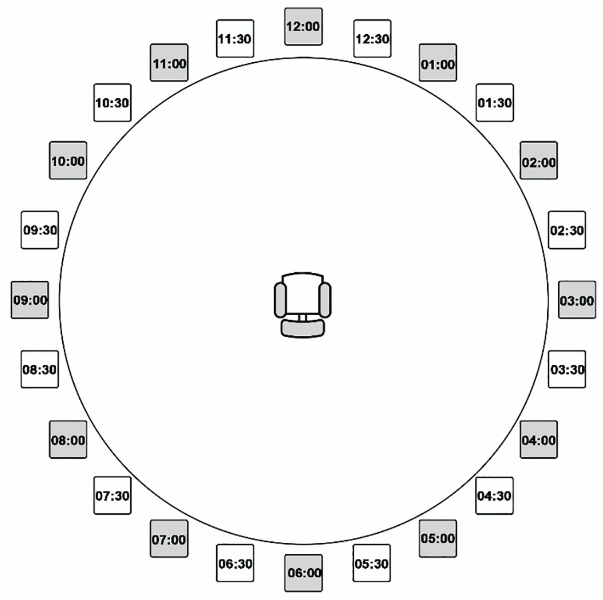

Figure 1: Localization test setup. The child sits on a chair facing 12:00.

eyes and observe their responses (Figure 1). They were instructed to return to the midline ('Look at position 12') as soon as they pointed toward the speaker, so that they would be positioned in the center when the next stimulus was presented. Music was played while the speaker was being moved so that children would not notice the speaker moving. To increase the validity of the test, we repeated this process a second time and analyzed a second time to decrease the possibility of error. Each child was assessed in 24 positions. Prior to testing, the children were familiarized with the test by listening to the stimuli from each loudspeaker and being told the location of each sound. During testing, which lasted an average of 20 minutes, their participation was praised regardless of accuracy, and they were encouraged to listen when needed.

The scoring procedure was as follows: If the child correctly identified the desired location, no error would be recorded; however, when the child failed to locate correctly, a score of 0.5 and 1 would be considered for each 15- and 30-degree erroneous angle, respectively. If the misdiagnosis of the position was to the right of the target place, a positive sign, and if it was to the left side, a negative sign would be assigned. For example. if the sound was presented from the 2 o'clock and the child pointed to the position of 1 o'clock, the score would be -1; if the child pointed to the position of 3 o'clock, the score would be +1 [33].

Data Analysis

Data were analyzed in SPSS 23 (IBM, Armonk, NY, USA). The Kolmogorov–Smirnov test was performed to assess the normal distribution of data. An independent t-test was run to analyze and compare the data between groups. For all statistical tests, a P value <0.05 was regarded as statistically significant.

Results

The participants consisted of two groups, one comprising 19 BHIC, including 9 boys and 10 girls with a mean age=65.31±3.83 months, and 21 participants, including 11 boys and 10 girls with a mean age of 60.21±3.02 months as the NHC group. Table 1 lists the demographic information in terms of age; sex; average hearing loss in three frequencies of 500, 1000, and 2000 Hz; age at hearing aid use; type of hearing aid fitting; and duration of rehabilitation. There was no significant difference between the two groups in terms of age range (P>0.05).

Table 2 summarizes the localization accuracy findings and their comparison between the BHIC and NHC groups at different hours based on the symbolic clock. There was a significant difference between the two groups in only four (out of 24) positions (P=0.023 for 1:30 o'clock, P=0.019 for 5:30 o'clock, P=0.032 for 6:30 o'clock, and P=0.031 for 11 o'clock). In other positions, no statistically significant difference was observed. The findings also revealed that the difference was significant at the front and back compared with the other positions.

Table 1: Demographic information of hearing-impaired children

Number	Gender	Age (month)	Duration of Auditory training (month)	Age of hearing aid use (month)	Average hearing loss in three frequencies)500, 1000, 2000 Hz((dB)
1	Boy	72	38	28	60
2	Boy	60	39	20	65
3	Girl	62	29	29	65
4	Girl	65	44	4	63
5	Boy	61	38	18	68
6	Girl	70	43	16	59
7	Boy	72	36	28	65
8	Boy	71	22	34	69
9	Boy	65	36	21	70
10	Boy	64	38	16	61
11	Girl	66	48	7	57
12	Boy	68	32	26	58
13	Girl	67	40	17	66
14	Boy	65	20	44	67
15	Girl	64	31	32	70
16	Girl	65	38	18	64
17	Girl	61	37	21	59
18	Girl	61	48	5	57
19	Girl	62	29	31	57

Table 2: Comparison of localization errors between bilateral hearing-impaired children and normally-hearing children

Time (symbolic clock)	Hearing impaired children	Normal hearing children	P value
12:00	0.61±1.66	0.14±0.36	0.501
12:30	0.33±1.14	0.05±0.22	0.421
01:00	0.25±1.30	0.10±0.30	0.625
01:30	0.71±0.94	0.05±0.22	0.023*
02:00	-0.12±1.11	0.14±0.36	0.612
02:30	-0.17±1.01	0.19±0.40	0.412
03:00	0.32±1.34	0.05±0.22	0.601
03:30	0.10±9.00	0.29±0.46	0.325
04:00	-0.29±1.39	0.24±0.44	0.283
04:30	0.75±1.14	0.14±0.36	0.193
05:00	0.59±0.86	0.10±0.30	0.156
05:30	0.94±1.02	0.05±0.22	0.019*
06:00	0.52±1.30	0.33±0.58	0.619
06:30	-0.28±1.04	0.43±0.68	0.032*
07:00	0.69±0.56	0.62±0.74	0.891
07:30	0.17±1.21	0.05±0.22	0.810
08:00	0.57±1.24	0.33±0.58	0.318
08:30	0.81±1.19	0.14±0.36	0.161
09:00	0.55±1.63	0.33±0.58	0.709
09:30	0.13±1.52	0.43±0.51	0.502
10:00	0.24±1.39	0.05±0.22	0.211
10:30	0.89±1.42	0.38±0.67	0.251
11:00	1.10±1.31	0.14±0.36	0.031*
11:30	0.40±0.9	0.05±0.22	0.471

*Independent t-test

Discussion

The present study investigated spatial hearing in moderate-to-severe BHIC and compared their abilities with those of age-matched NHC. Based on the findings, the BHIC showed a reduced accuracy in the localization skill in four positions located in the front and back.

The difference between the experimental protocol and the use of different stimuli prevents the comparison of the present results with those of previous studies. Previous studies on auditory localization mostly investigated adult participants, and the localization skill was often examined on the frontal horizontal plane [13]. Herein, however, the entire 360-degree space around the child was examined with a resolution of 15 degrees.

Meuret et al. (2017) evaluated the localization skill in unaided moderate BHIC aged 7-17 years. In their study, low- and high-frequency noise bursts by forty-five custom-designed speakers with a distance of 4.3° spanning from 94° left to 94° right were presented. Deficit in minimum audible angle was apparent in frontal. Thus, children with SNHL do not seem to benefit from frontal position compared to NHC [13]. Although in said study the evaluations were on children without hearing aids, the results are consistent with the current study; in other words, the use of hearing aids has not been able to compensate this defect.

Van et al. (2006) studied 10 healthy adults and 10 hearing-impaired individuals aged 44-79 years. They examined -90^{o} to +90^{o} angles with a spacing of 15^{o} and found that hearing-impaired individuals had poorer performance in localization than normally hearing individuals, especially when using binaural hearing aids. The hearing-impaired people who used hearing aids (commercial BTE hearing aids) could not localize half of the targets presented in the frontal region correctly, whereas normally hearing subjects excelled in these regions [4]. The method of this study was different from the current study, and the age of the participants was different between the two studies. Nonetheless, their results are consistent with ours, confirming a localization deficit in hearing-impaired individuals with binaural hearing aid.

Van et al. (2011) studied the effect of different types of hearing aids, e.g., in-the-ear-canal (ITC), behind-the-ear (BTE), and in-the-pinna (ITP), on the localization performance of adults in the frontal and full horizontal plane and in the frontal vertical plane [4]. It was observed that the localization performance in the right-left side and in the vertical plane were accurate in all hearing aids. However, there was a large difference in front-back localization accuracy between hearing aids. BTE devices reduced the amount of spectral information more than the ITC and ITP devices. In sound sources positioned in the front and the back hemispheres generating almost identical interaural properties, the auditory system relies on spectral information, specifically the pinna, to accurately recognize the front and back positions [14]. In the present study, the localization skill of aided BHIC was poor in both front and back positions. Degraded localization accuracy in front and back positions in the present study can be explained by the participants' inability to access spectral information (especially from the pinna).

In contrast to this study, Van et al. (2009) evaluated the localization ability of seven adults who received different hearing aids [4] and investigated the left-right and front-back positions. Their findings indicated that the use of different types of hearing aids affects the localization skill, but the localization of front and back position was better than that of left and right. Because the researchers used an adaptive directional microphone, the front and back positioning was better than the left and right directions [3]. This study differs from the present study in terms of localization defects in children, but it shows that people who use hearing aids demonstrate a localization deficit. Differences in the position of localization in various studies can be attributed to hearing aid settings and fittings, especially the type of microphone as well as the duration of using hearing aids, processing delay, and the algorithm of binaural hearing. In the present study, all participants utilized an omnidirectional microphone, so the results differed from those of Van et al. (2009).

Amplification improves the audibility of sounds which, in turn, enhances localization. The current results strongly support the use of bilateral hearing aids, especially in children with mild to severe hearing loss, to improve localization. Despite all their conveniences, however, hearing aids do not provide all the cues necessary for localization. Some features of hearing aids and the earmolds affect the localization skill and the use of binaural and monaural spatial cues. For example, the inherent delay in processing circuits, independent and adaptive processing of right and left ear hearing aids, the use of a different placement, and the directivity mode of the microphone have negative impacts on localization [14].

The current study results are consistent with those of Gorodensky et al. (2019) who reported that ITD perception is abnormal in BHIC when utilizing bilateral hearing aids [34]. In the present study, the BHIC were evaluated after 12 months of hearing aid use and had received at least 12 months of conventional auditory training, but localization deficits were still found in some situations. The existence of a spatial resolution defect in hearing-impaired children highlights the need for earlier and better access to accurate localization skill in hearing aids and also localization training at all angles in conventional rehabilitation programs.

Conclusion

It can be concluded that the BHIC who used bilateral hearing aids demonstrated poor auditory localization acuity in some situations. Because of the significance of localization in auditory scene analysis (ASA) including speech in noise perception, localization assessment at all angles and with short distances, and the use of advanced localization technologies that improve localization defects specially in front-back positions is essential. Future studies should also assess localization after advanced technologies and localization training.

Acknowledgment

The authors would like to thank Mr. Naser Kamyari for his valuable guidance on statistical analysis, Ms. Soheila Ghadimi, Head of Niusha Hearing Rehabilitation Center, and all the parents and children who participated in this study.

Conflict of Interest: None declared.

References

1. Cusack R, Decks J, Aikman G, Carlyon RP. Effects of location, frequency region, and time course of selective attention on auditory scene analysis. Journal of experimental psychology: human perception and performance. 2004;30(4):643.
2. Zhong X, Yost WA. How many images are in an auditory scene? The Journal of the Acoustical Society of America. 2017;141(4):2882-92.
3. Van den Bogaert T, Carette E, Wouters J, editors. Sound localization with and without hearing aids. NAG-DAGA International Conference on Acoustics; 2009.
4. Van den Bogaert T, Klasen TJ, Moonen M, Van Deun L, Wouters J. Horizontal localization with bilateral hearing aids: Without is better than with. The journal of the acoustical society of America. 2006;119(1):515-26.
5. Giard M-H, Fort A, Mouchetant-Rostaing Y, Pernier J. Neurophysiological mechanisms of auditory selective attention in humans. Frontiers in bioscience. 2000;5(1):84-94.
6. Killan CF, Harman S, Killan EC. Changes in sound-source localization for children with bilateral severe to profound hearing loss following simultaneous bilateral cochlear implantation. Cochlear implants international. 2018;19(5):284-91.
7. Byrne D, Noble W, LePage B. Effects of long-term bilateral and unilateral fitting of different hearing aid types on the ability to locate sounds. J Am Acad Audiol. 1992;3(6):369-82.
8. Matthews N, Todd J, Budd TW, Cooper G, Michie PT. Auditory lateralization in schizophrenia–mismatch negativity and behavioral evidence of a selective impairment in encoding interaural time cues. Clinical Neurophysiology. 2007;118(4):833-44.
9. Meyer A, Pawłowski P, Dąbrowski A, Loba W, Hojan-Jezierska D, Kubisz L, editors. Interactive virtual sound source for auditory localization tests. 2018 Baltic URSI Symposium (URSI); 2018: IEEE.
10. Lotfi Y, Dastgerdi ZH, Moossavi A, Mehrkian S, Bakhshi E. Evaluation of auditory lateralization ability and its development in normal children with 8 to 11 years of age. Audiology. 2014;23(4).
11. van der Heijden K, Rauschecker JP, de Gelder B, Formisano E. Cortical mechanisms of spatial hearing. Nature Reviews Neuroscience. 2019;20(10):609-23.
12. Wiggins IM, Seeber BU. Effects of dynamic-range compression on the spatial attributes of sounds in normal-hearing listeners. Ear and hearing. 2012;33(3):399-410.
13. Meuret S, Ludwig AA, Predel D, Staske B, Fuchs M. Localization and spatial discrimination in children and adolescents with moderate sensorineural hearing loss tested without their hearing aids. Audiology and Neurotology. 2017;22(6):326-42.
14. Van den Bogaert T, Carette E, Wouters J. Sound source localization using hearing aids with microphones placed behind-the-ear, in-the-canal, and in-the-pinna. International Journal of Audiology. 2011;50(3):164-76.
15. Johnstone PM, Náblek AK, Robertson VS. Sound localization acuity in children with unilateral hearing loss who wear a hearing aid in the impaired ear. Journal of the American Academy of Audiology. 2010;21(8):522-34.
16. Firszt JB, Reeder RM, Dwyer NY, Burton H, Holden LK. Localization training results in individuals with unilateral severe to profound hearing loss. Hearing research. 2015;319:48-55.
17. Asp F, Jakobsson A-M, Berninger E. The effect of simulated unilateral hearing loss on horizontal sound localization accuracy and recognition of speech in spatially separate competing speech. Hearing research. 2018;357:54-63.
18. Kumpik DP, King AJ. A review of the effects of unilateral hearing loss on spatial hearing. Hearing research. 2019;372:17-28.
19. Meuret S, Berger T, Fuchs M, Ludwig AA. Auditory localisation in hearing impaired schoolchildren with and without hearing aids. Laryngo-Rhino-Otologie. 2020.
20. Liu Y-W, Cheng X, Chen B, Peng K, Ishiyama A, Fu Q-J. Effect of tinnitus and duration of deafness on sound localization and speech recognition in noise in patients with single-sided deafness. Trends in hearing. 2018;22:1-14
21. Moteki H, Kitoh R, Tsukada K, Iwasaki S, Nishio S-Y, Usami S-I. The advantages of sound localization and speech perception of bilateral electric acoustic stimulation. Acta oto-laryngologica. 2015;135(2):147-53.
22. Kerber IS, Seeber IBU. Sound localization in noise by normal-hearing listeners and cochlear implant users. Ear and hearing. 2012;33(4):445.
23. Brown GJ, Cooke M. Computational auditory scene analysis. Computer Speech & Language. 1994;8(4):297-336.
24. Lee HJ, Lee JM, Na G, Moon YM, Lee C, Jung J. Which patients with a unilateral hearing aid for symmetric sensorineural hearing loss have auditory deprivation? Clinical and Experimental Otorhinolaryngology. 2020;13(1):23.
25. Hederstierna C, Hultcrantz M, Collins A, Rosenhall U. Hearing in women at menopause. Prevalence of hearing loss, audiometric

configuration and relation to hormone replacement therapy. Acta oto-laryngologica. 2007;127(2):149-55.
26. Sarant J, Harris D, Busby P, Maruff P, Schembri A, Lemke U, et al. The effect of hearing aid use on cognition in older adults: can we delay decline or even improve cognitive function? Journal of clinical medicine. 2020;9(1):254.
27. Jarollahi F, Alinejad Kashani A, Keyhani M, Kamalvand A. The effects of auditory training by Erber method on improvement of the auditory skills in 3-4 year-old hearing-impaired children. Function and Disability Journal. 2018;1(4):36-44.
28. Bettison S. The long-term effects of auditory training on children with autism. Journal of autism and developmental disorders. 1996;26(3):361-74.
29. Rubinstein A, Boothroyd A. Effect of two approaches to auditory training on speech recognition by hearing-impaired adults. Journal of Speech, Language, and Hearing Research. 1987;30(2):153-60.
30. Moosavi A, HOSSEINI DZ, Lotfi Y, Mehrkian S, Bakhshi E, KHAVAR GB. Auditory lateralization ability in children with (central) auditory processing disorder. 2014.
31. Lotfi Y, Dastgerdi ZH, Farazi M, Moossavi A, Bakhshi E. Auditory temporal processing assessment in children with developmental stuttering. International Journal of Pediatric Otorhinolaryngology. 2020;132:109935.
32. Moossavi A, Mehrkian S, Gohari N, Nazari MA, Bakhshi E, Alain C. The effect of harmonic training on speech perception in noise in hearing-impaired children. International Journal of Pediatric Otorhinolaryngology. 2021;149:110845.
33. Katz J. Therapy for auditory processing disorders: simple effective procedures: J. Katz; 2009.
34. Gorodensky JH, Alemu RZ, Gill SS, Sandor MT, Papsin BC, Cushing SL, et al. Binaural hearing is impaired in children with hearing loss who use bilateral hearing aids. The Journal of the Acoustical Society of America. 2019;146(6):4352-62.