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The Effects of Spatial Auditory Training on Speech Perception in Noise in the Elderly

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Abstract

Objectives: Studies have shown that spatial processing disorders can be the reason for hearing impairment in the elderly but none of the auditory training programs has addressed it. This study investigated the effect of a novel auditory training on speech perception in noise among the elderly and its maintenance.

Materials and Methods: The spatial versions of the Persian quick speech in noise (QuickSIN) test were developed and its face validity and reliability were evaluated. Thirty-six old subjects with normal hearing ability who expressed problem in speech perception were randomly divided into the study and control groups. The study group received 5 weeks of spatial auditory training. The spatial versions of the QuickSIN test, and Iranian version of the speech, spatial, and qualities of hearing scale (SSQ), as well as the middle latency response (MLR) test were done pre and post training. The same evaluations were carried out for the control group without training.

Results: Test-retest reliability and face validity of the spatial versions of Persian QuickSIN test were confirmed. Signal to noise ratio for 50% correct score (SNR50) significantly decreased and spatial release from masking (SRM) and binaural interaction component of MLR percentage (BIC-MLR%) significantly increased. The average scores of SSQ improved in all the three domains. These changes, except for BIC-MLR and SNR50a had short-term maintenance.

Conclusions: Spatial auditory training can improve speech perception in noise by enhancing the representation of binaural cues at the thalamocortical level. Spatial hearing evaluation and training are recommended to be incorporated into audiology services for serving the geriatric population.

Keywords: Aging, Auditory training, Speech perception

Introduction

The elderly experience difficulties in verbal communication in complex auditory environments because they do not fully understand the speech signals despite normal hearing abilities (1-4). This difficulty affects the quality of their individual and social lives and may lead to isolation, anxiety, and cognitive impairments (5-7). Therefore, efforts to improve the speech perception in the elderly are worthy of attention.

The auditory system segregates target signals from background noises using spatial cues in complex multi-talker auditory environments (8-11). Therefore, spatial auditory processing plays an important role in speech perception in noise (7,12,13). This skill helps the listener in the spatial separation of speech and noise sources to recognize speech efficiently though it is poorer in the elderly compared to the young people (14-16).

Neuroscience studies have revealed that the central nervous system has strong plasticity and training can improve auditory skills (17,18). Therefore, auditory training approaches may be adopted to improve speech perception in noise. However, except for LiSN & Learn auditory training, none of these programs has addressed spatial processing, that is, spatial separation of signal from noise (6,19-21). The LiSN & Learn software has been designed for spatial auditory training to children and its beneficial effects have been established (22), but the results are different in adults and no significant changes have been reported (23).

Considering population aging and increasing the referral rate of older people to otology clinics for searching a solution for their speech perception problems, the main objective of this study was to investigate the effect of a novel auditory training approach, based on spatial processing that simulates the hearing conditions of everyday life on speech perception in noise for the elderly. The researchers hypothesized that the training creates neurophysiological changes and improves speech perception through impacting the binaural processing in the central auditory system. The other objective of the study was to examine

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the maintenance of the effects of spatial auditory training up to one month after the completion of training .To test the hypothesis, a complete collection of objective and subjective measures including signal to noise ratio for 50% correct score (SNR50), spatial release from masking (SRM), binaural interaction component of middle latency response (BIC-MLR), and the responses on the speech, spatial, and qualities of hearing scale (SSQ) that underlie binaural auditory processing were used. To calculate SRM, we needed to compare the SNR50 of the spatial versions (co-located and spatially separated) of the Persian quick speech in noise (QuickSIN) test, which were designed and administered in this study for the first time.

Materials and Methods

Participants

Overall, 2 groups participated in this study. The first group consisted of 40 young adults (19 males, 21 females) aged 18-25 years (mean = 22 years, SD = 2.31 years) who were students of University of Social Welfare and Rehabilitation Sciences, Tehran, Iran. The second group included 36 volunteers aged 60-75 years with a complaint of difficulty in speech perception in noisy environments, and no history of neurologic diseases and a normal cognitive ability based on the mini-mental state examination (MMSE) (24) who were recruited from health centers of Tehran Municipality to test the hypothesis of the study.

The auditory system evaluations, including diagnostic otoscopy, acoustic immittance, and audiometry were carried out for all the participants, and the inclusion criteria were normal middle ear pressure and compliance, pure tone average better than 20 dB (500, 1000, 2000, and 4000 Hz) while none of the thresholds were worse than 40 dB and symmetric hearing thresholds (≤10 dB difference between the ears at any audiometric test frequency).

Materials

QuickSIN test: This is a simple and efficient test, which can rapidly determine the minimum SNR required by a listener to correctly identify 50% of the words in the presence of a four-talker babble noise (SNR50) (25). The valid and reliable Persian version of this test was available (26). In the present study, we needed to assess the listener's ability to utilize binaural cues to perceive speech so the stimuli of the Persian QuickSIN which included audio files from sentences read by a male speaker and four-talker babble noise (two women and two men) were modified to develop the co-located (the sentence and babble noise was heard from 0˚ azimuth) and spatially separated (the sentence was heard from 0˚ azimuth and 2 different sequences of babble noise were heard from ±90˚ azimuth simultaneously) versions by using acoustics in such a way that virtual auditory space was perceived through headphones. Using MATLAB software, the root mean squares of the sentence and noise signals were normalized by preventing peak clipping. Then, speech and noise signals were convolved with head-related transfer functions (HRTFs) recorded at 0 and ±90 azimuth to produce spatial perception. We used the HRTF set which had been measured in the Anechoic Chamber of the Acoustics Laboratory at TH Koln and was freely available for download (27); these signals were used to track continuously running sentences. There was a 5-second silence between the sentences for response. A pause between the sentences was considered if more time was needed. The Sound Forge software was used to play these audio files which were delivered through Sennheiser HD-25 headphones (Hanover, Germany).

SSQ: This questionnaire has been designed to evaluate an individual's ability in 3 domains of speech perception, spatial hearing, and quality of hearing, and involves rating of perceived listening difficulty in real-life situations on a scale of 0 to 10 for 49 items (28, 29). In the current study, the valid and reliable Iranian version of SSQ which consists 47 items (29) was completed by the researcher in an interview session.

BIC-MLR: The MLR test reflects the activity of auditory nuclei which are involved in binaural processing (30). In the present study the MLR was recorded as an objective assessment to evaluate the effects of spatial auditory training on central nervous system function.

The MLR test was carried out in a semi-dark sound booth using Bio-logic Navigator Pro Auditory Evoked Potentials system (Natus Medical Inc., Mundelein, IL). While recording, individuals lied in a bed and were asked to be comfortable and calm. Silver electrodes were attached to the skin in different areas of vertex (noninverting), lower forehead (ground), and earlobes which were joined by a dangling jumper (inverting). The stimulus was a click with rarefaction polarity, which was heard by insert earphones at an intensity level of 70 dBnHL and a rate of 9.1 per second. Epoch time was 106.6 milliseconds and the maximum of averages was 1000. Responses were recorded in the 3 modes of monaural (right and left ears) and then binaural, that is, simultaneous stimulation of the right and left ears. To evaluate repeatability, each recording was performed twice. Na and Pa waves were marked on the obtained responses. Finally, BIC-MLR was calculated according to the formula BIC = B - (R + L), that is, subtracting the sum of the two monaural Na-Pa amplitude from the binaural evoked response.

The spatial auditory training: In the present study, the spatial auditory training as a novel approach was designed with a focus on formal training activity in order to improve speech perception in noise. The purpose was to strengthen the ability of segregating the target speech stream from the simultaneous intervening noise based on spatial separation. The task was sentence recognition in noise; each item was an audio file in which a sentence with 5 key words was presented simultaneously with a four-talker babble noise and for each correct word, one point was awarded. To prevent the effect of learning on the results of evaluations, the list of sentences in the training program was different from that in the QuickSIN test. Similar to the spatially separated versions of QuickSIN, the items were designed to create a three-dimensional auditory environment under headphone, meaning target sentences were always heard from 0 azimuth and competing signals were heard from ± 90. Training was begun from +10 SNR that was easily recognizable and the difficulty of the task was determined by changing SNR (4 dB increase and 2 dB decrease) adaptively.

Procedures

To evaluate the face validity of spatial versions of Persian QuickSIN, the designed tests were administered for the participants of first group and verbal comments about the spatializing the stimuli were obtained for both co-located and spatially separated target sentences in noise. To assess test-retest reliability, the evaluations were repeated in one-week intervals.

The subjects of second group were randomly assigned to the study (spatial auditory training) and control groups. In the study group, 16 females and 2 males [mean = 66.11 years, standard deviation (SD) = 4.54 years] participated in the spatial auditory training that included fifteen 30-minute sessions for 5 weeks (31). The study group was subjected to objective and subjective measures before and after the onset of spatial auditory training. Moreover, to assess the maintenance of the changes due to spatial training, the evaluations were repeated one month after the completion of the program. On the other hand in the control group, 14 females and 4 males [mean = 64.11 years, standard deviation (SD) = 3.86 years] participated. The evaluations were performed for the control group at the beginning of the study and then repeated after 5 weeks without training.

This interventional case-control study was conducted in the Audiology Unit of Rofaideh hospital, Tehran, Iran, from April to July 2018.

Data Analysis

Data were analyzed using PASW Statistics version 18. The Shapiro–Wilk test confirmed normal distribution of the data. In addition, to measure the test-retest reliability of spatial versions of Persian QuickSIN test, interclass correlation coefficient was computed. Furthermore, analysis of covariance was administered to assess the effect of training. Finally, to determine the retention of spatial auditory training effects, paired t test was run and $P \leq 0.05$ was considered statistically significant.

Results

Face Validity and Reliability

Participants' verbal feedback determined positive results. Thirty-seven out of 40 participants reported that the spatial versions of Persian QuickSIN test made it possible to perceive the speech and noise co-location, as well as separation. The reliability of the spatial versions of Persian QuickSIN test was also evaluated. The interclass correlation coefficient was indicative of high reliability ($P < 0.001$). Table 1 presents the mean and SD of SNR50a and SNR50b in the first group during the two sessions.

Training Benefits

Table 2 shows the demographic and hearing loss data for the study and control groups. The results indicated no significant differences.

To assess the effects of the spatial auditory training, the analysis of covariance was administered, the results of which indicated spatial auditory training–related significant improvements ($P < 0.001$) in objective and subjective measures. The effects of the training in the study versus the control group are displayed in Figure 1.

Objective Measures: QuickSIN and MLR Tests

Figure 1A shows SNR50 in the spatial versions of QuickSIN test and SRM. SNR50 was decreased in both the co-located (improvement of 1.72 dB) and spatially separated versions (improvement of 4.78 dB), while SRM was increased (improvement of 3.06 dB). Figure 1C shows the results of MLR test. The BIC-MLR percentage was increased post training (9.66%).

Subjective Measure: SSQ Questionnaire

Figure 1B presents the average scores improved in all the three domains of speech perception (0.61), spatial hearing

Table 1. The Mean and SD of SNR50a and SNR50b in the First Group During 2 Sessions

	Test		Retest		ICC	*P* Value
	Mean	SD	Mean	SD		
SNR50a	-1.32	0.9	-1.37	0.82	0.71	0.000
SNR50b	-8.25	±1.00	-8.37	±0.79	0.83	0.000

Note. SD: Standard Deviation, SNR50a: Signal to Noise Ratio for the recognition of 50% in co-located version, SNR50b: Signal to Noise Ratio for the recognition of 50% in spatially separated version.

Table 2. Demographic and Hearing Loss Data of the Participants of the Study and Control Group

Group	Age (y) Mean ± SD	Gender F/M	PTA Right Ear (dB) Mean ± SD	PTA Left Ear (dB) Mean ± SD
Study (n=18)	66.11±4.45	2/16	10.87±5.42	11.59±6.06
Control (n=18)	64.11±8.63	4/14	10.09 ±4.02	9.70 ±3.62

Note. F: Female, M: Male, SD: Standard Deviation, PTA: Pure Tone Average, dB: decibel.

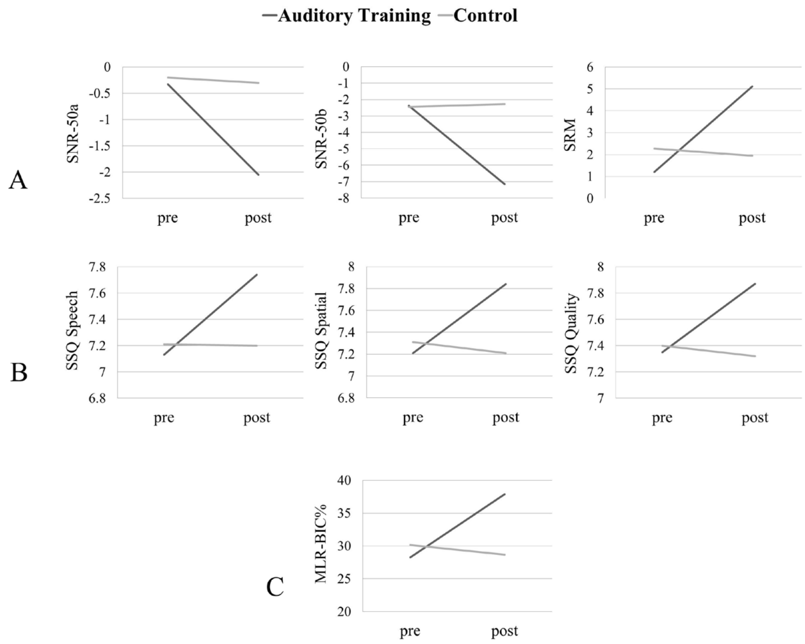

Figure 1. The Mean Values Obtained From QuickSIN Test (A), SSQ (B), and MLR (C) Tests.
Note. The lighter line is the first and second evaluations (after 5 weeks) in the control group and the darker line is the pre and post training evaluations in the study group. QuickSIN test: Quick Speech in Noise Test, SSQ: Speech, Spatial, and Qualities of Hearing Scale, BIC-MLR%: Binaural Interaction Component for Middle Latency Response Percentage.

(0.63), and hearing quality (0.52).

Retention

To assess the retention of spatial auditory training effects, the data obtained post-training and one month after the completion of training were compared for the study group. Figure 2 shows the average improvements in the QuickSIN test, MLR test, and SSQ for the study group. Scores depicted in Figure 2 indicate the average improvements post-training and after one month. The results, except for SNR50a and the percentage of BIC-MLR, were not significantly different (P>0.05). Therefore, it showed the behavioral improvements were maintained by one month.

Discussion

Five weeks of spatial auditory training enabled old listeners to noticeably improve their speech perception in noise. The study group succeeded in recognizing sentences at a lower SNR in situations similar to everyday auditory environments where in addition to the target sentence other noise sources are present.

Furthermore, the present study showed that spatial auditory training could help the elderly to benefit from the spatial separation of target and noise sources for better speech recognition. Previous studies have shown that aging is associated with a deficit in spatial processing, such that in the elderly SRM is declined (14,32,33). In this study, SRM increased after training, and it can be concluded that spatial auditory training reduced the deficit of spatial processing.

Previous studies have revealed that the LiSN & Learn software can remediate spatial processing disorders in children up to 6 years of age (22). But there is a lack of studies on the effect of spatial auditory training for the elderly, who constitute a significant part of the clients referred to otology and audiology clinics. The studies that administered conventional word-in-noise tasks for old people indicated that the trained words recognition in noise improved but this improvement was not generalized to words in sentence (6,34,35) while ultimate goal of aural rehabilitation is the improvement of conversational

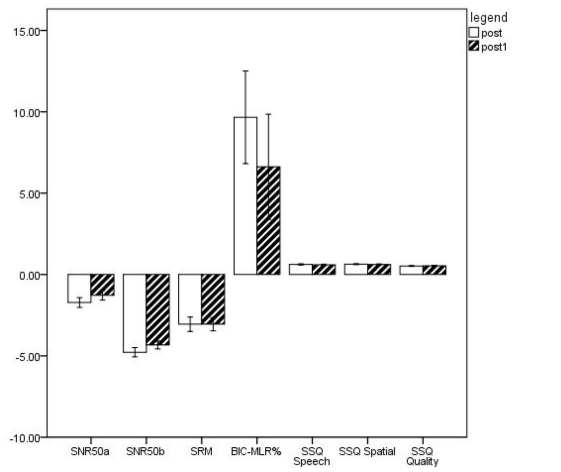

Figure 2. The Means of Improvements for the Study Group
Note. White bars represent post-training improvement and patterned bars represent after 1 month (post1) improvement. Error bars show ± 1 standard error.

speech perception which includes the sentences (21). The strength of the present study was that the training included sentence - based tasks. The Listening and Communication Enhancement (LACE) is a sentence-based training program and Sweetow and Sabes reported significant improvement for the QuickSIN in the trained group (36), but the LACE consists cognitive tasks other than sentence in babble exercises which could have top-down effects on speech perception, besides that the trained group included a wide age range (28-85 years) so the reported results are not specified to auditory training for old people.

The spatial training affected the electrophysiological parameters and increased the BIC-MLR percentage. Studies have shown that neural structures at MLR level process the binaural information (37), and the larger the BIC, the more efficient the inhibitory processes involved in binaural stimulations (38). To add to previous reports on plasticity in auditory processing (17,39-41), it can be concluded that spatial auditory training increased the coding of binaural cues and improved their representation at the thalamocortical level which underlies spatial processing and is essential for speech perception in noise. The key difference is that the training in the past studies was wide in that a variety of auditory and cognitive procedures was used, but the training in our study directed auditory spatial processing.

The results of the SSQ revealed that the training increased the ability and experience of individuals in different auditory situations, and since most of the changes were in speech perception followed by spatial hearing and quality of hearing items, it seems that the main objective of spatial auditory training was achieved with a significant effect on speech perception and spatial hearing.

The efficiency of spatial auditory training in speech recognition, SRM, and the scores of the SSQ were maintained up to one month after the end of training, indicating that the learning process is beyond remembering and short-term memory and is the result of improvement in auditory processing. The maintenance of increased speech perception in noise that was obtained through training has also been reported in a number of studies utilizing speech in noise tasks (34, 42).

The training program of this study, which was implemented three times a week for 5 weeks, did not yield sustained neurophysiology plasticity. Treatment schedule in this study was determined based on a study in which the effective number and duration of training sessions were evaluated for the geriatric population (31) .They have reported that training 2 or 3 times a week for a minimum of 5 weeks would be beneficial. Since these researchers used behavioral and not electrophysiological evaluations to examine the efficacy of training and did not address the maintenance of the benefits, it seems that in order to achieve sustained changes at the neurological level, longer treatment duration rather than the minimum used in this study is required. Moreover, holding reinforcement sessions after the end of the training period can help stabilize neurophysiological changes.

Limitations of the Study

The current results do not offer information regarding long-term effects, owing to a variety of reasons such as lack of time, illness, loss of interest, difficulties encountered in getting the subjects to return for long-term follow-up testing.

Suggestions for Future

Further studies on evaluating the effects of spatial auditory training for hearing impaired old people are suggested.

Conclusions

Aging impairs speech perception of listeners by degrading their ability to process spatial cues for separating speech and noise sources. Our results supported that the spatial auditory training, addressing daily hearing challenges, improved speech perception in elderly who despite normal hearing and cognitive abilities, complained of poor speech perception in noise due to impaired auditory processing in sub-cortical auditory centers.

This research verified the efficacy of auditory training in the geriatric population, as well as giving clinicians an idea to optimize the audiological services through integrating with spatial auditory measurement and training.

Conflict of Interests

Authors have no conflict of interests.

Ethical Issues

The study protocol was approved by the Ethics Committee of University of Social Welfare and Rehabilitation Sciences (code of ethics: IRUSWR. REC.1395.391).

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References

1. Freigang C, Richter N, Rübsamen R, Ludwig AA. Age-related changes in sound localisation ability. Cell Tissue Res. 2015;361(1):371-386. doi:10.1007/s00441-015-2230-8
2. Martin JS, Jerger JF. Some effects of aging on central auditory processing. J Rehabil Res Dev. 2005;42(4 Suppl 2):25-44. doi:10.1682/jrrd.2004.12.0164
3. Ralli M, Greco A, De Vincentiis M, et al. Tone-in-noise detection deficits in elderly patients with clinically normal hearing. Am J Otolaryngol. 2019;40(1):1-9. doi:10.1016/j.amjoto.2018.09.012
4. Skoe E, Kraus N. Auditory brain stem response to

complex sounds: a tutorial. Ear Hear. 2010;31(3):302-324. doi:10.1097/AUD.0b013e3181cdb272
5. Brodie A, Smith B, Ray J. The impact of rehabilitation on quality of life after hearing loss: a systematic review. Eur Arch Otorhinolaryngol. 2018;275(10):2435-2440. doi:10.1007/s00405-018-5100-7
6. Ferguson MA, Henshaw H, Clark DP, Moore DR. Benefits of phoneme discrimination training in a randomized controlled trial of 50- to 74-year-olds with mild hearing loss. Ear Hear. 2014;35(4):e110-121. doi:10.1097/aud.0000000000000020
7. Glyde H, Cameron S, Dillon H, Hickson L. Remediation of spatial processing deficits in hearing-impaired children and adults. J Am Acad Audiol. 2014;25(6):549-561. doi:10.3766/jaaa.25.6.5
8. Dobreva MS, O'Neill WE, Paige GD. Influence of aging on human sound localization. J Neurophysiol. 2011;105(5):2471-2486. doi:10.1152/jn.00951.2010
9. Kidd G Jr, Mason CR, Rohtla TL, Deliwala PS. Release from masking due to spatial separation of sources in the identification of nonspeech auditory patterns. J Acoust Soc Am. 1998;104(1):422-431. doi:10.1121/1.423246
10. Koehnke J, Besing JM. The effects of aging on binaural and spatial hearing. Semin Hear. 2001;22(3):241-254. doi:10.1055/s-2001-15629
11. Rimmele J, Schröger E, Bendixen A. Age-related changes in the use of regular patterns for auditory scene analysis. Hear Res. 2012;289(1-2):98-107. doi:10.1016/j.heares.2012.04.006
12. Bronkhorst AW. The cocktail-party problem revisited: early processing and selection of multi-talker speech. Atten Percept Psychophys. 2015;77(5):1465-1487. doi:10.3758/s13414-015-0882-9
13. Neher T, Behrens T, Carlile S, et al. Benefit from spatial separation of multiple talkers in bilateral hearing-aid users: effects of hearing loss, age, and cognition. Int J Audiol. 2009;48(11):758-774. doi:10.3109/14992020903079332
14. Besser J, Festen JM, Goverts ST, Kramer SE, Pichora-Fuller MK. Speech-in-speech listening on the LiSN-S test by older adults with good audiograms depends on cognition and hearing acuity at high frequencies. Ear Hear. 2015;36(1):24-41. doi:10.1097/aud.0000000000000096
15. Dubno JR, Ahlstrom JB, Horwitz AR. Binaural advantage for younger and older adults with normal hearing. J Speech Lang Hear Res. 2008;51(2):539-556. doi:10.1044/1092-4388(2008/039)
16. Glyde H, Buchholz JM, Dillon H, Cameron S, Hickson L. The importance of interaural time differences and level differences in spatial release from masking. J Acoust Soc Am. 2013;134(2):EL147-152. doi:10.1121/1.4812441
17. Shinn-Cunningham B. Models of plasticity in spatial auditory processing. Audiol Neurootol. 2001;6(4):187-191. doi:10.1159/000046830
18. Sweetow RW, Henderson-Sabes J. The case for LACE: listening and auditory communication enhancement training. Hear J. 2004;57(3):32-35. doi:10.1097/01.HJ.0000292371.26838.91
19. Kuchinsky SE, Ahlstrom JB, Cute SL, Humes LE, Dubno JR, Eckert MA. Speech-perception training for older adults with hearing loss impacts word recognition and effort. Psychophysiology. 2014;51(10):1046-1057. doi:10.1111/psyp.12242
20. Pizarek R, Shafiro V, McCarthy P. Effect of computerized auditory training on speech perception of adults with hearing impairment. Perspectives on Aural Rehabilitation and Its Instrumentation. 2013;20(3):91-106. doi:10.1044/arri20.3.91
21. Woods DL, Doss Z, Herron TJ, et al. Speech perception in older hearing impaired listeners: benefits of perceptual training. PLoS One. 2015;10(3):e0113965. doi:10.1371/journal.pone.0113965
22. Cameron S, Dillon H. Development and evaluation of the LiSN & learn auditory training software for deficit-specific remediation of binaural processing deficits in children: preliminary findings. J Am Acad Audiol. 2011;22(10):678-696. doi:10.3766/jaaa.22.10.6
23. Glyde H, Hickson L, Cameron S, Dillon H. Problems hearing in noise in older adults: a review of spatial processing disorder. Trends Amplif. 2011;15(3):116-126. doi:10.1177/1084713811424885
24. Foroughan M, Jafari Z, Shirin Bayan P, Ghaem Magham Faraahani Z, Rahgozar M. Validation of mini-mental state examination (MMSE) in the elderly population of Tehran. Advances in Cognitive Science. 2008;10(2):29-37.
25. Killion MC, Niquette PA, Gudmundsen GI, Revit LJ, Banerjee S. Development of a quick speech-in-noise test for measuring signal-to-noise ratio loss in normal-hearing and hearing-impaired listeners. J Acoust Soc Am. 2004;116(4 Pt 1):2395-2405. doi:10.1121/1.1784440
26. Moossavi A, Javanbakht M, Arbab Sarjoo H, Bakhshi E, Mahmoodi Bakhtiari B, Lotfi Y. Development and psychometric evaluation of Persian version of the quick speech in noise test in Persian speaking 18-25 years old normal adults. J Rehabil Sci Res. 2016;3(3):51-56. doi:10.30476/JRSR.2016.41099
27. Arend JM, Neidhardt A, Pörschmann C. Measurement and perceptual evaluation of a spherical near-field HRTF set. Proceedings of the 29th Tonmeistertagung - VDT International Convention; 2016.
28. Gatehouse S, Noble W. The speech, spatial and qualities of hearing scale (SSQ). Int J Audiol. 2004;43(2):85-99. doi:10.1080/14992020400050014
29. Lotfi Y, Nazeri AR, Asgari A, Moosavi A, Bakhshi E. Iranian version of speech, spatial, and qualities of hearing scale: a psychometric study. Acta Med Iran. 2016;54(12):756-764.
30. Weihing J, Musiek F. The influence of aging on interaural asymmetries in middle latency response amplitude. J Am Acad Audiol. 2014;25(4):324-334. doi:10.3766/jaaa.25.4.4
31. Humes LE, Kinney DL, Brown SE, Kiener AL, Quigley TM. The effects of dosage and duration of auditory training for older adults with hearing impairment. J Acoust Soc Am. 2014;136(3):El224. doi:10.1121/1.4890663
32. Divenyi PL, Haupt KM. Audiological correlates of speech understanding deficits in elderly listeners with mild-to-moderate hearing loss. I. Age and lateral asymmetry effects. Ear Hear. 1997;18(1):42-61. doi:10.1097/00003446-199702000-00005
33. Murphy DR, Daneman M, Schneider BA. Why do older adults have difficulty following conversations? Psychol Aging. 2006;21(1):49-61. doi:10.1037/0882-7974.21.1.49
34. Burk MH, Humes LE, Amos NE, Strauser LE. Effect of training on word-recognition performance in noise

for young normal-hearing and older hearing-impaired listeners. Ear Hear. 2006;27(3):263-278. doi:10.1097/01.aud.0000215980.21158.a2
35. Humes LE, Burk MH, Strauser LE, Kinney DL. Development and efficacy of a frequent-word auditory training protocol for older adults with impaired hearing. Ear Hear. 2009;30(5):613-627. doi:10.1097/AUD.0b013e3181b00d90
36. Sweetow RW, Sabes JH. The need for and development of an adaptive Listening and Communication Enhancement (LACE) Program. J Am Acad Audiol. 2006;17(8):538-558. doi:10.3766/jaaa.17.8.2
37. Furukawa S, Maki K. Sensitivity of the auditory middle latency response of the guinea pig to interaural level and time differences. Hear Res. 2006;212(1-2):48-57. doi:10.1016/j.heares.2005.10.009
38. Weihing J, Musiek FE. An electrophysiological measure of binaural hearing in noise. J Am Acad Audiol. 2008;19(6):481-495. doi:10.3766/jaaa.19.6.4
39. Anderson S, White-Schwoch T, Choi HJ, Kraus N. Training changes processing of speech cues in older adults with hearing loss. Front Syst Neurosci. 2013;7:97. doi:10.3389/fnsys.2013.00097
40. Schochat E, Musiek FE, Alonso R, Ogata J. Effect of auditory training on the middle latency response in children with (central) auditory processing disorder. Braz J Med Biol Res. 2010;43(8):777-785. doi:10.1590/s0100-879x2010007500069
41. Tremblay KL, Shahin AJ, Picton T, Ross B. Auditory training alters the physiological detection of stimulus-specific cues in humans. Clin Neurophysiol. 2009;120(1):128-135. doi:10.1016/j.clinph.2008.10.005
42. Oba SI, Fu QJ, Galvin JJ 3rd. Digit training in noise can improve cochlear implant users' speech understanding in noise. Ear Hear. 2011;32(5):573-581. doi:10.1097/AUD.0b013e31820fc821