Research Article

# Effects of Auditory Lateralization Training on the Speed Processing and Speech Perception in Noise in the Elderly

**Jafar Aghazadeh[1], Saeideh Mehrkian[1*], Abdollah Moossavi[2], Enayatollah Bakhshi[3]**

*[1] Department of Audiology, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran*
*[2] Department of Otolaryngology, Head and Neck Surgery, School of Medicine, Iran University of Medical Sciences, Tehran, Iran*
*[3] Department of Biostatistics, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran*

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## Highlights

- The most effective lateralization training was at the sentence level
- Lateralization training can improve the speed of speech processing in the elderly
- Auditory rehabilitation based on ITD training can improve speech perception in noise

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* **Corresponding Author:**
*Department of Audiology, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran.*
*sa.mehrkian@uswr.ac.ir*

## ABSTRACT

**Background and Aim:** Structural and functional changes in the auditory and cognitive system caused by aging can lead to impaired speech perception and speed processing, especially in the presence of noise. This study aimed to enhance cognitive system performance including speed processing and speech perception by improving the temporal information through lateralization training.

**Methods:** In this interventional study, 36 participants aged 65–75 years with normal hearing, who complained about speech perception in noise, were randomly assigned to the intervention group and the control group. The intervention group received twelve 45-minute sessions of auditory lateralization training. The quick speech-in-noise, words-in-noise, and consonant-vowel-in-noise tests are used as behavioral tests of speech perception in noise at the sentence, word and phoneme levels, respectively. The time-compressed speech test was adopted to measure processing speed. The repeated measures ANOVA was used to analyze the test results before, after, and one month after rehabilitation.

**Results:** A significant decrease in the lateralization errors, and signal-to-noise ratio loss in both the quick speech-in-noise and words-in-noise tests were observed in the intervention group ($p<0.001$). Moreover, a considerable increase in the word recognition score in the time-compressed speech test and the consonant-vowel in noise test were observed ($p<0.001$). Coefficient effects were obtained for the quick speech-in-noise test (0.74), the words-in-noise test (0.59) and the consonant-vowel in noise test (0.12). Statistical analyses revealed the stability of the outcomes one month after rehabilitation.

**Conclusion:** Auditory lateralization training can improve the speed of processing and speech perception in noise in the elderly.

**Keywords:** Auditory lateralization training; speech perception in noise; speed processing; aging

## Introduction

One of the most obvious problems in the elderly is the problem of speech perception in the presence of noise. Its prevalence reaches from 16% at the age of 60 to nearly 100% at the age of 86. Age-related deficits in speech perception are thought to be related to alteration in the coding of sounds in both the peripheral and central auditory system or cognitive impairment [1]. The temporal information of the signal is important for speech perception and contains important information about the boundaries of vowels, consonants, syllables, and phrases. Speech information is transmitted through fine temporal structures (rapid fluctuations in amplitude over time) and changes in temporal envelope (relatively slow changes in amplitude over time) [2]. These temporal changes are responsible for several aspects of auditory perception, including loudness, pitch perception and spatial hearing [3]. One of the manifestations of temporal processing deficits is spatial processing. Spatial information is conveyed by subtle acoustic cues that can indicate the localization of sound. Sound localization refers to the ability to identify the location of a sound source in a sound field, whereas lateralization refers to the similar auditory ability in which the listener determines the location of sounds, presented through headphones, in their head [4]. During spatial processing, the auditory stream is formed and separated from the background noise [5]. This ability is less in the elderly than in the young [6]. The reduction of spatial processing ability in the elderly population leads to poor understanding of speech in noise. Horizontal sound localization depends on discrimination of the Interaural Intensity Difference (IID) and Interaural Time Difference (ITD) [7]. The first stage of binaural processing occurs in the medial and lateral superior olive respectively to encode interaural time differences and interaural intensity differences. [8]. Many studies have pointed out the significant role of ITD in sound localization [4, 9]. A specific path for sound localization (a "where" pathway) in the auditory cortex [8].

Furthermore, aging is associated with reduced cognitive abilities, including speed processing, which is believed to be important for speech-in-noise perception [10]. When the quality of the auditory signal is suboptimal, achieving speech perception more depend to cognitive abilities. Therefore, it would be important to improve the quality of auditory signals especially, in temporal aspects of hearing. According to recent neuroscience studies, the central auditory system is pervasively malleable, and training can improve hearing skills. Auditory spatial training helps compensate for degradation in the auditory signal. Auditory localization training enhances spatial-behavioral sensitivity by changing the balance between excitation and inhibition. Normal localization ability results in an improvement of about 15 dB in the signal-to-noise ratio [11]. In fact, per 1 dB increase in signal-to-noise ratio results in 17% better speech perception [12], which reveals the importance of localization in speech perception in noise. Hence, evaluating localization processing, particularly ITD, seems necessary for the elderly to provide them with essential rehabilitation. In this study, it was assumed that the rehabilitation-based intervention for auditory localization through the improvement of the localization path, particularly the time difference-based localization, can lead to an improvement in the speed of information processing and subsequently improved speech perception in noise in the elderly.

## Methods

### Participants

In this intervention study, 36 elderlies (9 females and 27 males) participants who complained about the difficulty in speech perception in noise, were enrolled. Participants were divided based on the block randomization method into the interventional and control groups with mean ages of 66.94±2.60 and 66.17±1.34 years respectively. After the informed written consent forms were obtained from participants, the auditory system evaluations, including diagnostic otoscopy, acoustic immittance, and audiometry were carried out with all the participants using a GSI AudioStar Pro audiometer and TympStar Pro tympanometer Manufactured by Interacoustic, Denmark in an acoustic chamber. The inclusion criteria were normal middle ear pressure and compliance and pure tone average better than 20 dB (500, 1000, 2000, and 4000 Hz). All the older adults had Mini-Mental State Evaluation (MMSE) scores greater than 25, so they had no apparent cognitive problems [13]. All the subjects had a Persian version of the Speech, Spatial, and Qualities of Hearing Scale (P-SSQ) questionnaire score of less than 7.

### Study design

Twelve sessions of lateralization training, three times per week for 45 minutes were performed for the intervention group. The training effects were assessed by the ITD test and behavioral speech perception in noise tests including Quick Speech in Noise (Q-SIN), Word in Noise (WIN), and Consonant Vowel in noise (CV-in noise), for evaluation of the three levels of sentence, word, and phoneme. Also, the Time-Compressed Speech Test (TCST) was adopted to measure the speed of processing. To perform the tests precisely at the fixed level of 70 dB HL, the laptop's output (H.P. Probook 4540s) and a Supraoral headphone (A4TECH HS-800) were calibrated through an analog 1.3-octave band sound-level meter. Moreover, P-SSQ was used to evaluate auditory perception, spatial hearing, and qualities of hearing. To measure the reliability of the rehabilitation, all tests were repeated one month after the completion of the rehabilitation.

### Assessments

### Speech, spatial, and qualities of hearing scale

SSQ was designed to measure a range of hearing disabilities under adverse conditions, particularly in the elderly, with a specific focus on binaural processing. It was used to assess people's ability in speech perception and some qualities related to hearing and includes scaling of perceived hearing difficulty in real everyday situations on a scale of 0 to 10. Lower scores obtained by the examiner in the interview session indicate a more significant hearing disability [14].

### Localization test

In this study, the localization ability of the participants was assessed by headphones. The high and low pass noise stimuli (cut-off: 2 kHz) were used to measure lateralization error. The stimuli were presented binaurally and by applying delay times of 880, 660, 440, 220, 0, –220, –440, –660, and –880 microseconds between the two ears. Therefore, sounds were perceived in nine different positions and a semicircle. Errors were measured and evaluated in each position [15].

### Speech perception tests

The Q-SIN test is a simple speech-in-noise test that can calculate the minimum Signal-to-Noise Ratio (SNR), at which a listener can correctly indicate 50% of the words in the presence of four talkers. The WIN test measures the listener's ability to recognize monosyllabic words in the presence of noise. The test is executed within a range of SNRs (the speech material decreases in 4 dB step to vary SNR from +24 to 0 dB) and at a fixed babble noise [16]. The CV-in Noise is less dependent on contextual, syntactic, and semantic features and focuses more on auditory processing pathways. This stimulus structure was selected to avoid the confounding effects of textual cues, increase the participation of acoustic factors, and more closely examine the bottom-up and subcortical pathways involved in processing speech stimuli [17].

### Speed processing tests

The TCST is the most common monaural test that examines auditory closure and temporal discrimination [18]. In the present study, the word recognition score was measured with three time-compressed ratios of zero (without compression), 40%, and 60%.

### Intervention

The bottom-up auditory lateralization training was performed three times per week for 45 minutes and 12 sessions through high-pass and low-pass noise. The lateralization training stimuli were designed using Sound Forge 10 software. The characteristics of the stimuli were similar to the test stimuli. The participants were trained to point to the location of the sound source on the picture in front of them or to say the number of the source after hearing the sound through headphones. The stimuli were presented binaurally. Each ITD was practiced several times until it was well identifiable for the listener and could localize the sound source. In the lateralization training, the sound source was initially positioned at 0°, +90° azimuths (a position to the subject's right), and –90° azimuths (a position to the subject's left). First, lateralization training was done non-randomly from right to left and left to right (from the initial three sound sources, which increased to five, seven, and nine). In the final stage, the number of sound sources increased randomly. The difficulty of exercises in each stage increased gradually with obtaining 70% of the scores. The control group did not receive any rehabilitation program.

### Statistical analysis

Data analysis was done in SPSS 17 at a significance level of 0.05. The Shapiro-Wilk test was conducted to analyze data normality. The repeated measures ANOVA was employed to analyze the test results before, after, and one month after rehabilitation. The Mann-Whitney U test and independent t-test were employed to compare pre-rehabilitation results. The ANCOVA was utilized to compare the results between the two groups before and after the rehabilitation.

## Results

The results of this study indicated no significant differences between the two groups in age and auditory threshold of the left and right ears ($p<0.05$). Table 1 shows the mean scores and standard deviations of three subscales of speech perception, spatial hearing, and hearing qualities in the P-SSQ test before, after, and one month after rehabilitation. The results indicated a lower score of auditory perception than the two other domains in the questionnaire. The independent t-test indicated no significant between-group difference in the mean scores and standard deviation of each of the three sections of the P-SSQ questionnaire before rehabilitation ($p>0.05$). The ANCOVA results revealed a significant between-group difference in the mean scores of each of the three sections of the P-SSQ questionnaire after rehabilitation ($p<0.001$).

Table 2 shows the results of Q-SIN, WIN, and CV-in-noise tests for both ears before and after rehabilitation. According to the Mann-Whitney U test, there were no significant between-group differences in the mean score and standard deviation of the Q-SIN, WIN, and CV-in-noise tests before training ($p>0.05$). There was a significant between-group difference in all three tests before and after training ($p<0.001$). Further analyses of the results one month after the rehabilitation program did not show a significant difference, indicating the stability of rehabilitation outcomes ($p>0.05$).

As shown in Table 3, there are no significant between-group differences in the localization tests ($p>0.05$). The Wilcoxon test revealed that the auditory localization error was more significant for low-pass than high-pass noise ($p<0.001$). There was a significant difference between the localization error before and after training in the intervention group ($p<0.001$). Moreover, there is no significant difference in the findings after the rehabilitation program and one month after, indicating a stable rehabilitation outcome ($p>0.05$).

Table 4 shows the mean TCS scores for both ears. The repeated measures ANOVA indicated a significant difference in the TCST with three time-compressed

**Table 1.** Comparison of mean scores for Persian version of speech, spatial and qualities scale before, after, and one month after the training program (n=18 in each group)

| P-SSQ items | Group | Mean±SD | | | p* |
|---|---|---|---|---|---|
| | | Pre-training | Post-training | One month after | |
| Percep-tion | Intervention | 0.37±6.83 | 0.15±7.65 | 0.16±7.56 | ≤0.001 |
| | Control | 0.32 ±6.82 | 0.35±6.81 | | |
| Spatial | Intervention | 0.23±7.06 | 0.14±7.59 | 0.15±7.54 | ≤0.001 |
| | Control | 0.29±7.12 | 0.28±7.17 | | |
| Quality | Intervention | 0.32±7.20 | 0.21±7.77 | 0.22±7.68 | ≤0.001 |
| | Control | 0.22±7.12 | 0.22±7.14 | | |

P-SSQ; Persian speech, spatial, and qualities of hearing scale

* ANCOVA

**Table 2.** Comparison of mean scores of the quick speech in noise, consonant-vowel in noise, and words in noise tests before, after, and one month after training (n=18 in each group)

| Speech tests | Group | Mean±SD | | | p* |
|---|---|---|---|---|---|
| | | Pre-training | Post-training | One month after | |
| Q-SIN (S/N) | Intervention | 5.25±0.92 | 0.70±3.36 | 0.62±3.58 | ≤0.001 |
| | Control | 5.14±1.07 | 5.33±0.91 | | |
| WIN* (right ear) | Intervention | 4.58±1.72 | 2.31±1.10 | 2.44±1.11 | ≤0.001 |
| | Control | 4.36±1.11 | 4.31±1.22 | | |
| WIN (left ear) | Intervention | 4.84±1.61 | 2.63±1.22 | 2.93±1.24 | ≤0.001 |
| | Control | 4.93±1.31 | 4.89±1.20 | | |
| CV-in noise* (right ear) | Intervention | 93.11±4.91 | 4.22±96.22 | 3.43±96.67 | ≤0.001 |
| | Control | 93.78±4.59 | 3.61±93.37 | | |
| CV-in noise (left ear) | Intervention | 92.44±2.33 | 3.75±96.22 | 3.94±95.33 | ≤0.001 |
| | Control | 91.78±5.03 | 4.64±91.63 | | |

Q-SIN; quick speech in noise, WIN; word in noise, CV-in noise; consonant-vowel in noise
* ANCOVA

**Table 3.** Comparison of the mean and standard deviation of lateralization errors before, after, and one month after training (n=18 in each group)

| | Stimuli | Group | (Mean±SD) | | | p* |
|---|---|---|---|---|---|---|
| | | | Pre-training | Post-training | One month after | |
| Lateralization/error | ITD/low pass | Intervention | 20.22±2.73 | 11.78±1.83 | 12.39±2.10 | ≤0.001 |
| | | Control | 20.39±2.09 | 19.89±2.27 | | |
| | ITD/high pass | Intervention | 18.56±1.95 | 11.61±2.38 | 11.89±2.27 | ≤0.001 |
| | | Control | 18.28±1.41 | 17.89 ±1.68 | | |

ITD; interaural time difference
* ANCOVA

ratios (0%, 40%, and 60%) in both the intervention and control groups (p<0.001). The Wilcoxon tests revealed no significant differences between the left and right ears in all three time-compressed ratios (p>0.05). ANCOVA showed a significant difference in TCS results only in the time-compressed ratios of 40% and 60% post-intervention (p<0.001). The repeated measures ANOVA indicated no significant differences between the training outcomes immediately after the training and one month after, indicating the stability of the program outcomes (p>0.05).

## Discussion

This study aimed to investigate the effects of auditory lateralization training on speech perception and speed processing in the elderly with complaints of speech perception in noise. For this purpose, a four-week ITD-based auditory lateralization training program was administered to the intervention group. The mean SSQ scores indicated an improvement in the intervention group's auditory perception, spatial hearing, and hearing qualities. The signal-to-noise ratio loss index decreased

**Table 4.** Comparison of mean time compressed speech test score with time-compressed ratios of 0%, 40%, and 60% before, after, and one month after training (n=18 in each group)

| TCST | Ratio of compression | Group | (Mean±SD) | | | p* |
|---|---|---|---|---|---|---|
| | | | Pre-training | Post-training | One month after | |
| Right ear | 0% | Intervention | 99.33±1.53 | 99.78±0.94 | 1.29±99.56 | 0.38 |
| | | Control | 98.67±2.37 | 99.11±1.71 | | |
| | 40% | Intervention | 75.3±34.39 | 99.11±1.71 | 82.89±3.58 | ≤0.001 |
| | | Control | 74.67±4.33 | 73.78±4.65 | | |
| | 60% | Intervention | 53.33±6.72 | 62.67±6.02 | 6.12±62.44 | ≤0.001 |
| | | Control | 52.67±6.47 | 52.89±5.41 | | |
| Left ear | 0% | Intervention | 98.44±2.43 | 99.56±1.29 | 99.78±0.94 | 0.47 |
| | | Control | 98.67±1.94 | 99.33±1.54 | | |
| | 40% | Intervention | 74.44±3.91 | 82.22±3.69 | 81.11±3.31 | ≤0.001 |
| | | Control | 73.56±5.33 | 72.89±4.24 | | |
| | 60% | Intervention | 51.33±7.29 | 60.89±5.58 | 61.11±5.10 | ≤0.001 |
| | | Control | 51.67±6.07 | 52.89±5.58 | | |

TCST; time compressed speech test
* ANCOVA

after rehabilitation in the intervention group's Q-SIN and WIN tests. Also, the time-compressed speech test observed a significant decrease in localization error.

### Effects of auditory lateralization training on Persian version of the speech, spatial, and qualities

Training generally improved auditory perception, spatial hearing, and qualities of hearing by 0.81, 0.54, and 0.57 dB. The most significant training effect was on auditory perception. The findings are consistent with the findings of Lotfi et al. [19]. Given that training increased the ability and experience of people in different hearing conditions and that most of the changes were observed in speech perception, followed by the qualities of hearing and spatial hearing, it seems that localization training resulted in a significant improvement in speech perception.

### Effects of Auditory lateralization training on the quick speech-in-noise

The SNR loss decline was 3.5 dB in previous study [20]. Differences observed in various studies can be attributed to high variability in speech tests and the high dependence of such experiments on individual and cognitive factors, noise, sex, and material of the test. In the present study, the SNR in the Q-SIN test decreased by 3.36±0.69 dB after rehabilitation. Rehabilitation had a significant impact on speech-in-noise perception in the elderly.

### Effects of auditory lateralization training on the word in noise test

In the WIN test, the mean SNR of 50% in the elderly was greater for left ear than right ear, indicating the dominance of the right ear in this test. The findings are consistent with the findings of Wilson and Watts (5.1–4.3 dB) [21]. In contrast, the results are inconsistent with the findings of Kam and Fu, who reported an SNR of –3.5 dB [22]. This difference can be due to the type of stimuli (two-syllable words) and the noise level used in the tests. In this study, the intervention group's post-training SNR reduced from 4.58±0.41 dB to 2.31±0.26

dB. In addition, the difference between the right and left ear scores was reduced. No significant post-training differences were observed in the SNR between the right and left ears, indicating the improvement of binaural processing and the effectiveness of the localization rehabilitation program.

### Effects of auditory lateralization training on consonant-vowel in noise test

Two acoustic cues of speech, temporal Envelope (ENV) with slow variation in the amplitude of the speech signal over time and Temporal Fine Structure (TFS) with rapid changes, are influential in the perception of consonants. Due to the imbalance and inconsistency in the excitatory and inhibitory functions in the hearing-impaired elderly, encoding these two cues is disrupted. The changes induced by auditory localization training facilitate the adjustment of neurotransmitter levels, allowing for encoding subtle consonant-vowel disorders. In the present study, the rehabilitation results were significant only in the SNR of 0 dB. The aging has less impact on the auditory system at the syllable level and more at the higher stimulus levels, such as words and sentences requiring more auditory and cognitive processing.

### Effects of auditory lateralization training on time compressed speech test

Studies have shown that the central auditory system of people changes at the age of 50–60 years, leading to a gradual weakness in the processing of monaural and binaural sound signals. Temporal processing disruption is a significant change that occurs [23, 24]. Having suitable temporal acuity of the auditory system is necessary for speech perception because it provides information about the boundaries of vowels, consonants, syllables, and phrases. Word recognition in the elderly reduces with increasing speech rate; however, it is hardly affected by the speech rate in the youth, indicating that cognitive ability weakens with aging [24]. To interpret the effect of compression ratio on word recognition score, the redundancy of upper brain structures and speech information can partially neutralize the negative effect of the speech rate increase. At higher speeds of stimulus presentation, we need more signal-to-noise ratio to improve the speech recognition score [25], which can be achieved by improving localization ability. The present study showed a significant difference in the word recognition score between the compression ratios of 0%, 40%, and 60%.

In the present study, no significant difference was observed in stimulus recognition scores with a time compression of 0% before and after the training due to the ceiling effect. However, the word recognition scores for the time compression of 40% and 60% showed a significant difference before and after the training, indicating the effectiveness of the rehabilitation program in increasing the time compression score and temporal processing. In the present study, three levels of speech stimuli, phonemes, monosyllabic words and sentences were used in different noise conditions. The effect size of rehabilitation was obtained for the Q-SIN (0.74), WIN (0.59) and CV-in noise tests (0.12). The results of the present study showed that the effect of rehabilitation on sentence stimuli was greater than the other stimuli. Picora-Fuller found that the elderly uses their cognitive resources in a different way than adults, they compensate for the reduction of speech input resources by allocating more cognitive resources such as attention and memory [26]. In the present study, the bottom-up strategy beyond the conventional path of localization has probably led to the improvement of interhemispheric communication and facilitated access to fast linguistic information processing and has helped to increase speech understanding.

### Effect of auditory lateralization training on lateralization error

Auditory localization is based on the detection and processing of binaural and spectral cues. Studies have shown that IID and ITD processing is associated with more problems among the elderly than the youth [7, 8, 23]. ITD processing is more complicated than IID processing, requiring precise temporal processing at the superior olivary complex level [27]. In the present study, the localization errors with low-pass noise (20.44±2.70) were higher than with high-pass noise (18.6±2.06). It might be due to changes in the central and peripheral hearing systems, which increase with aging; in addition, high-pass noise localization is done more through the signal envelope than the fine structure of the signal [28]. According to the findings, auditory localization training reduced the low-pass noise localization error (11.78±1.83) and high-pass noise localization error (11.61±2.38). Localization deficiency results in less suppression of undesired competitive information in the presence of noise; in addition, the reduction of neural activity and asynchrony are the leading causes of spatial and temporal cues encoding defects in the elderly [28]. It can be inferred that auditory localization training may result in improved binaural processing and facilitation of the bottom-up pathway, leading to improved speed processing and speech perception. Future research could investigate the usefulness of the combination of bottom-up auditory lateralization training and top-down training on speech perception in the elderly.

## Conclusion

Speech perception in noise is a common cause of complaints among the elderly, leading to communication disabilities and social isolation. Creating effective communication in environments with excessive noise requires the excellent performance of peripheral hearing systems, central auditory pathways, and cognitive systems. Spatial processing has a significant role in speech-in-noise perception. Given the reciprocal interactions between the bottom-up and top-down processing pathways and the findings of this study, auditory localization rehabilitation is thought to be capable of reducing sound localization errors in the elderly and increasing speech perception in the presence of noise. This rehabilitation program can enhance cognitive abilities such as speech-in-noise processing and speed processing in the elderly.

## Ethical Considerations

### Compliance with ethical guidelines

The study protocol was approved by the Ethics Committee of the University of Rehabilitation Sciences and Social Health (Iran; code I.R. USWR. REC.1398.162). After the informed written consent forms were obtained from participants.

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### Authors' contributions

JA: Conceptualization, data collection, interpretation of the results, drafting the manuscript; SM: Conceptualization and design of the study, analysis and interpretation of data and editing; AM: Design of the study; EB: Statistical analysis.

### Conflict of interest

The authors declared no conflict of interest.

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