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RESEARCH ARTICLE

Evaluating the effectiveness of dichotic training in the elderly adults: a single subject study

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Abstract

Background and Aim: Elderly people usually show poor performance in dichotic listening tasks. In this condition, the left ear being often the weaker one shows a performance below the normal limits. Studies have shown the effectiveness of dichotic listening training in auditory and language processing for adults and children with neurological disorders. This study aimed to develop a home-version of dichotic training and investigate its effectiveness in elderly adults.

Methods: Participants in this single-subject interventional study (AB design) were four elderly subjects (two males and two females) aged 65−75 years. The main inclusion criteria were dichotic listening deficit demonstrated by the dichotic digit test (DDT), no neurological or cognitive disorders, and normal hearing threshold. Dichotic listening training was performed with an informal home-version of dichotic interaural intensity difference (DIID) training program for seven weeks. DDT was performed seven consecutive weeks before (phase A) and after the intervention (phase B) at the end of each week.

Results: Data were analyzed by single-subject study statistics. Findings demonstrated an improvement in DDT scores for the left ear and decrease in right ear advantage scores in all the elderly adults after DIID training program. It seems that this training program could remediate poor performance in dichotic listening tasks in elderly people.

Conclusion: The advantage of this method is that it can be easily done at home and is cost-effective. However, further studies are needed to approve the neuroplasticity and structural changes in the brain after the DIID training program in this population.

Keywords: Auditory rehabilitation; dichotic training; dichotic listening; elderly; single-subject study

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Introduction

Aging is often accompanied by progressive deficits in many sensory organs, especially in the auditory system. This process can reduce the ability of speech understanding. Speech processing problems can deteriorate the quality of life and cause depression and isolation in the elderly population [1]. A significantly increased incidence of speech perception problems is often observed during aging even in the elderly with normal hearing thresholds. Studies have demonstrated the involvement of both peripheral and central auditory systems in age-related hearing loss [2,3]. Given the association between central auditory deficits and speech perception problems in normal hearing elderly, it is necessary to assess central auditory processing disorders and design a deficit-specific rehabilitation program for this population.

Dichotic listening means hearing of two different stimuli simultaneously by two ears. One of the symptoms of central auditory disorders is poor performance in dichotic listening tasks, which is also a common finding in normal hearing elderly adults without any neurological disorders [4,5]; and is usually associated with speech perception problems, especially in noisy environments [5]. In this condition, the left ear being often the weaker one shows a performance below the normal limits, with a strong performance in the right ear. The proper transmission of auditory information between two hemispheres of the brain is important in dichotic listening. Transmission failure can affect the function of the left ear, which in turn can result in the right ear superiority, also known as right ear advantage (REA). Because of the left hemisphere specialization for speech processing, good performance in the processing of dichotic signals is important in speech perception, especially in the presence of the background noise [6,7]. A significant negative correlation was found between ear asymmetry and corpus callosum size, which begins to atrophy in the age range of 55−60 years. Specifically, asymmetry between the two ear test results increases as the corpus callosum atrophies increase in the isthmus and splenium regions during the aging [8]. However findings from a large number of dichotic listening tests indicate that asymmetry of speech processing increases in elderly people, regardless of hearing loss [4,8,9].

Dichotic ability can be evaluated using several tests of central auditory system that involve listening to competing signals challenging the auditory system and cognitive function. One of the dichotic tests is the dichotic digit test (DDT) that assesses binaural integration skill. Dichotic signals are two various auditory stimuli that are presented simultaneously to both ears and the listener is required to state what was perceived in one ear (directed recall condition) or both ears (free recall condition) [10]. In DDT, two pairs of digits are delivered to both ears dichotically and subjects are asked to recall them in either directed or free recall.

The dichotic listening training (DLT) methods were introduced to reduce the asymmetry between two ears, the dichotic interaural intensity difference (DIID) training program is one of the DLT methods with confirmed effectiveness in different disorders such as head trauma [11], brain surgery [12], central processing disorders [13], children with dichotic problem in left ear [13], and neurologic patients [14]. The goal of DIID is to bring the performance of the weaker ear into the normal range while maintain the performance of the stronger ear. Furthermore, it seems that the effectiveness of the DIID procedure is not limited to only children or people with neurological disorders. Because of common problems of dichotic performance in the elderly, the effectiveness of this method in normal elderly subjects has not been investigated. Moreover, although auditory training is one of the critical elements of aural rehabilitation for hearing-impaired people, but the use and popularity of that has declined over recent years due to the time-cost implications and because there is not strong evidence about the effectiveness of aural rehabilitation in this population [15]. Thus, the aim of the present study was to design and evaluate the effectiveness of the DIID training in elderly people without neurological disorders or hearing loss.

A single-case experimental design was implemented because the present study piloted a novel intervention (the first home-version of DIID in Persian language for normal-hearing elderly adults) and needed to be completed within seven weeks. The effectiveness of a single-case experimental design for assessing intervention in rehabilitation has been demonstrate in previous study.

Table 1. Demographics data of four elderly subjects

Subject	Age at enrollment	Gender	Handedness	Number of baseline sessions (week)	Number of intervention sessions (week)
SA	65	Female	Right	7	7
SB	75	Female	Right	7	7
SC	70	Male	Right	7	7
SD	67	Male	Right	7	7

SA; subject A, SB; subject B, SC; subject C, SD; subject D

In this method, which usually uses a small number of patients (typically 1−3), the trend of changes can be observed in patients in detail [16].

Methods

Participants

Four elderly adults aged 65−75 years who met the inclusion criteria were selected by the convenience sampling in this study named subject A (SA), subject B (SB), subject C (SC) and subject D (SD). Inclusion criteria were right-handedness (by Edinburgh inventory), monolingual (Persian-speaking), no cognitive impairment approved by the mini-mental status examination (MMSE) score of above 24 [17] no professional artistic and musical skills, normal peripheral auditory system, and abnormal right ear advantage in DDT. Exclusion criteria included major neurological and mental disorders and taking drugs, such as antiepileptic and antidepressants, which affect the function of central nervous system (CNS). Peripheral auditory evaluations were performed to ensure the health of the peripheral auditory system, including otoscopy examination (Reister, Jungingen, Germany), pure tone audiometry, speech reception threshold (SRT), speech discrimination score (SDS) test, (AC40, Interacoustic, Denmark), tympanometry and acoustic reflex tests (Zodiac, Madsen Co., Taastrup, Denmark). The dichotic ability was evaluated using the Persian version of DDT [17]. The test consists of dichotically presenting two-paired numbers, one through ten, (except four, which is two syllables) in most comfortable level (55 dB HL). Subjects are asked to recall them in either directed recall or free recall conditions. The score of each ear was calculated separately and asymmetry was obtained from the difference between the right and left ear scores. A prominent interaural asymmetry was defined as a difference of more than 10% or greater on dichotic listening tasks [13]. Demographic characteristics of subjects, and number of baseline and intervention sessions are shown in Table 1.

Study design

A single -subject design was used in the present study due to the heterogeneity of the elderly people and to show their changes during the rehabilitation program. The study was planned as AB design based on the guideline for single-subject studies [16]. In phase A, multiple baseline designs were administered in all the subjects so that we had a series of repeated measurement of DDT in baseline phase at the end of each weeks and for a total of seven weeks (no auditory training). In phase B, four subjects entered the auditory training plan for seven week and DDT was performed at the end of each week. In order to show changes, phase A was compared to phase B.

Auditory rehabilitation intervention

Auditory training was performed using the DIID training program. Participants used this program in about 30-min sessions three times per week for overall seven weeks. Abnormal interaural asymmetries were determined through the participant's performance in the DDT and compared to the mean percent cutoff score [18]. A prominent interaural asymmetry was defined as a difference of more than 10% or greater on dichotic listening tasks [13]. First, dichotic processing deficit was documented in all the cases and then crossover performance level was established as described below. The intensity level of sound in the better (right) ear decreased systematically. The crossover level was determined and then training was began when the performance of the left ear exceeded the right ear.

Seven weeks of rehabilitation three sessions per week including 42 different standard audio stories that have been reconstructed in a dichotic manner, and a total of 21 dichotic story sessions were made and performed. Therefore, a different story was presented to each ear by different narrators. The narrator was of both sexes, but the same narrator (male or female) was used for the two stories (right and left ear).

A home-version of DIID training program was designed in Persian for the elderly adults. Stimuli were two short Persian stories constructed dichotically with Cool Edit software and WAV format with 16 bit-44100 Hz sampling rate. Stories were recorded with predetermined interaural intensity differences. In the first session, the interaural level difference was began with 21 dB, meaning that the intensity in the left ear (with weaker dichotic function) was 21 dB more than that of the right ear. In every session, interaural intensity difference was decreased 1 dB up to last session when the interaural intensity level ultimately reached 0 dB. A comfortable level in CD-player volume was determined for every case and remained stable up to end of the sessions. Subjects used a headphone connected to a CD-player and marked for the left ear. Patients were required to attend to the story in the left ear while ignoring that in the right ear. Participants had to listen to the stories, and to ensure their attention, questions about the stories were asked at the end of each session in predefined forms.

They were instructed in the first session to accomplish this training program at home for seven weeks with three times a week (21 sessions), and each session lasted for 30 minutes. They were asked to avoid activities that could improve corpus callosum function during the study. At the end of each week, meetings were held with the individuals to review the process correctly.

To assess the effectiveness of dichotic auditory training, they were evaluated by DDT at end of every week (after three sessions). Scores of the right ear, left ear, and REA were three items of analyzed DDT.

Data analysis

Data were analyzed using single-subject case study methods, including celeration line, C-statistics, and percentage of non-overlapping data (PND).

Results

The effect of dichotic interaural intensity difference on dichotic digit test

The effectiveness of the DIID training program on three items of DDT (scores of the left and right ears and REA) in all subjects was shown using different analyses of the single-subject method (celeration line, C-statistics, and PND as follows.

Celeration line analysis

Figures 1 and 2 show the celeration trend line in four cases that provide visual inspection of the behavioral changes. In order to analyze the celebration-line, the most aligned line was drawn with the baseline phase scores of the right ear, left ear, and REA, and then extended to the intervention phase for four subjects. All the subjects in the intervention phase showed improvements in the left ear score whereas decreases occurred in REA. A consistent pattern was not observed in the right ear score.

SA performance showed that 57% of data points were above the line in both the baseline phase and the treatment phase in the right ear score. In the left ear score, SA showed 42% of data points above the line in baseline phase, whereas 100% of the data points were above the line in the treatment phase. This subject showed 57% of data points below the line of the baseline phase, whereas 100% of the data points were below the line in the treatment phase in the REA. SB performance showed 42% and 71% of data points above the line of the baseline phase for the right and left ear scores, respectively, whereas 100% of the data points were above the line in the

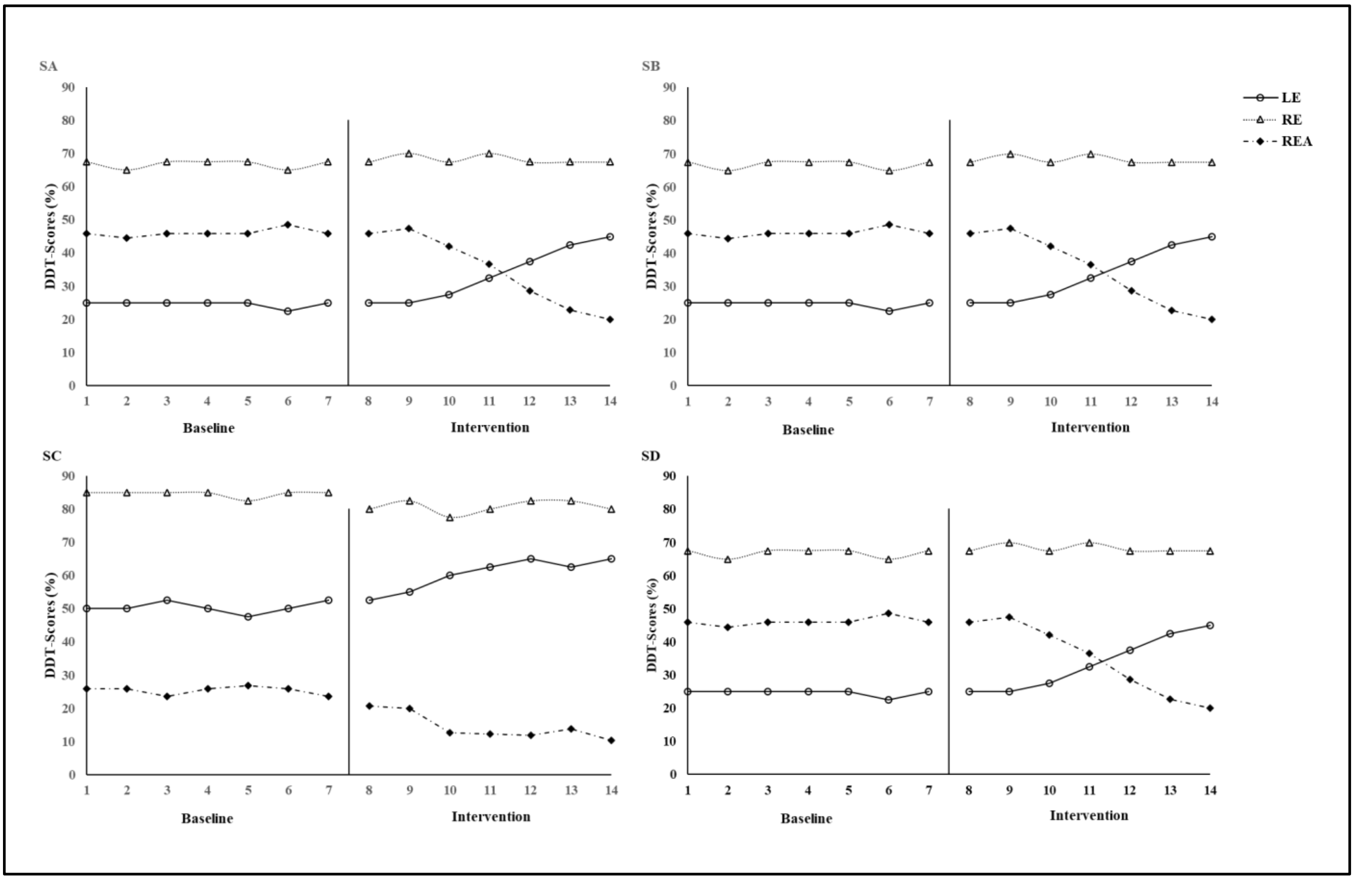

Fig. 1. The trend of changes in dichotic digit scores of three conditions in every session of baseline and intervention phases in all cases. DDT; dichotic digit test, RE; right ear, LE; left ear, REA; right ear advantage, SA; subject A, SB; subject B, SC; subject C, SD; subject D.

treatment phase. SB also showed 71% of data points below the line of the baseline phase, whereas 100% of the data points were below the line in the treatment phase in REA. SC performance was 85% and 28 % of data points above the line of the baseline phase, and 0% and 100% of the data points were above the line in the treatment phase in right and left ear scores. SC also showed 28% of data points below the line of the baseline phase, whereas 100% of the data points were below the line in the treatment phase in REA. SD performance showed 71% and 28% of data points above the line of the baseline phase, whereas 14% and 85% of the data points were above the line in the treatment phase for the right and left ear score. This subject showed 28% of data points below the line of the baseline phase, whereas 100% of the data points were below the line in the treatment phase in REA.

C-statistic

Another statistical method applied here was the C-statistic (Table 2) to initially evaluate baseline data in the scores of the right ear, left ear, and REA.

SA, SC, and SD baseline data showed no significant trend in the scores of the right ear, left ear, and REA in the baseline phase and the right ear score in the treatment phase ($p > 0.05$). However, statistically significant differences were observed for the left ear score and REA ($p < 0.05$). SB baseline data showed no significant trend in baseline phase, but statistically significant differences were observed in treatment phase for the scores

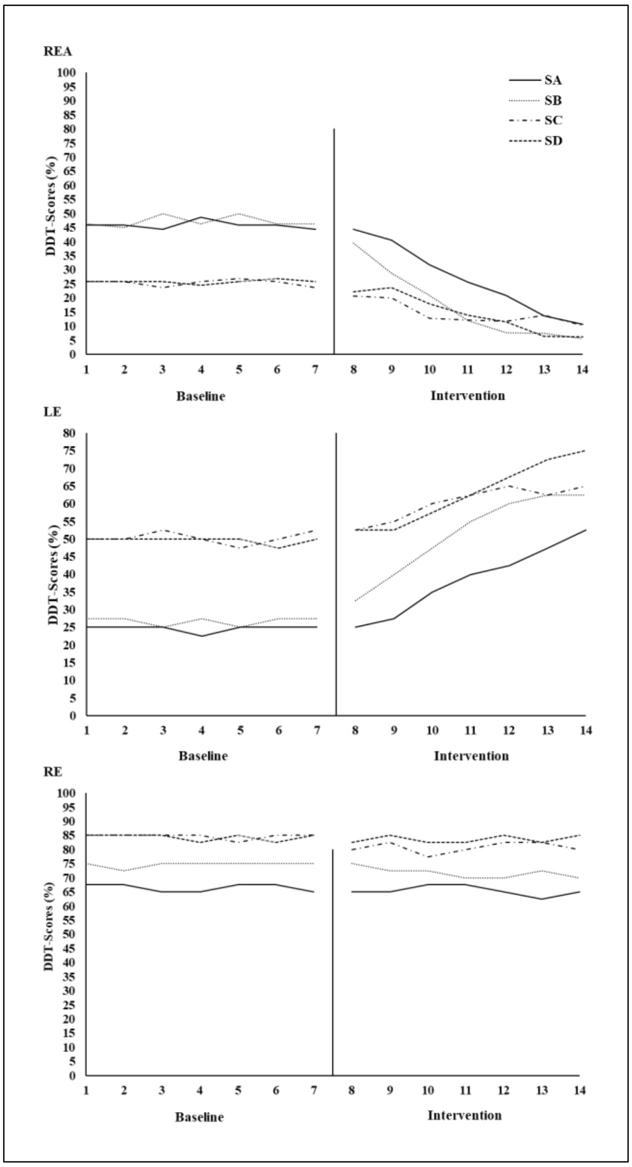

Fig. 2. The trend of changes in dichotic digit scores of four cases in each condition (RE, LE and REA) in baseline and intervention phases (1−14 sessions) DDT; dichotic digit test, RE; right ear, LE; left ear, REA; right ear advantage, SA; subject A, SB; subject B, SC; subject C, SD; subject D.

of the right ear, left ear, and REA ($p < 0.05$).

Percent of non-overlapping data principle
Best SA performance (lowest error) in baseline phase in right ear score and REA were 67.5 and 44.44, respectively. Also, 100% and 85% of the findings were below the horizontal line. The best function (lowest error) was 25 in the left ear score and 85% of findings were above the horizontal line.

Best SB performance (lowest error) in baseline phase in the right ear and REA scores were 75 and 45, respectively. The findings (100%) were below the horizontal line. The best function (lowest error) was 27.5 in the left ear score and 100% of findings were above the horizontal line.

Best SC performance (lowest error) in baseline phase in the right ear and REA scores were 85 and 23.46, respectively. The findings (100%) were below the horizontal line. The best function (lowest error) was 52.5 in the left ear score and 85% of findings were above the horizontal line.

Best SD performance (lowest error) in baseline phase in the right ear and REA scores were 85 and 24.53, respectively. The findings (100%) were below the horizontal line. The best function (lowest error) was 50 in the left ear score and 100 % of findings were above the horizontal line.

Discussion

Some elderly people show central auditory deficits even without reports of hearing loss [3]. As mentioned above, dichotic listening deficit is also a common finding in this group. Auditory rehabilitation could address the central auditory disorders in this population. Accordingly, dichotic training has been found to improve the dichotic listening deficits in several neurological disorders and also in children [19]. However, the effectiveness of this method on normal elderly people has not been shown previously.

Based on the celeration trend line method**,** all the subjects in the intervention phase showed improvements in the left ear score but they presented decreased REA. A consistent pattern was not observed in the right ear score. The results of the present study showed that the dichotic training has considerable potential for the treatment of dichotic deficits in the elderly.

C-analysis and PND analysis methods were used here in addition to visual inspection of change trend graph in single-subject studies because multiple statistical analysis is necessary for a comprehensive evaluation of training effects

Table 2. C-statistics results in quantitative score of dichotic digit test

	RE		LE		REA	
	z	p	z	p	z	p
SA						
Baseline	0.36	0.711	0.49	0.620	−0.73	0.460
Baseline and training	1.15	0.242	3.30	0.001	3.33	0.001
SB						
Baseline	−0.49	0.621	−1.18	0.230	−1.26	0.200
Baseline and training	2.36	0.021	3.36	0.001	3.35	0.001
SC						
Baseline	−0.49	0.622	0.36	0.710	0.23	0.810
Baseline and training	1.61	0.101	0.001	0.360	0.001	0.230
SD						
Baseline	−1.18	0.230	−0.49	0.620	0.02	0.980
Baseline and training	1.61	0.100	3.32	0.001	3.27	0.001

RE; right ear, LE; left ear, REA; right ear advantage, SA; subject A, SB; subject B, SC; subject C, SD; subject D

[19]. In C-analysis, significant differences were not observed in the left ear, right ear, and REA scores in baseline phase. In the intervention phase, however, significant differences were observed in the left ear and REA scores for all the subjects. In PND analysis (Table 3), the results of the left ear showed an appropriate treatment in SA and SC and a definite treatment in the SB and SD. REA results also showed an appropriate treatment in SA and a definite treatment in SB, SC, and SD. No treatment was shown for the right ear in four cases.

With regard to the aim of the dichotic training that reinforces the weaker ear (typically the left ear), an improvement in dichotic listening based on the left ear and REA results after the training program demonstrates that our dichotic training was effective in this group. This is in line with previous studies that showed significant effects of DIID on dichotic deficits in other populations [12,20]. Musiek et al. [21] suggest that DIID could result in plasticity and positive long-term changes in the central auditory system. They also showed that dichotic listening for speech stimuli was extremely dependent on the corpus callosum. Dichotic listening performance enhances with the development of the corpus callosum and callosal integrity. There may be some advantage to considering dichotic performance and what it reflects of underlying callosal integrity in the context of rehabilitative audiology in elderly subjects because they usually shows poorer performance in dichotic listening than younger people [22].

The structural model proposed by Kimura [23] described the asymmetry in dichotic listening as follows. Due to the dominance of the contralateral auditory pathways and greater number of fibers, the ipsilateral auditory pathways are suppressed during dichotic stimulation. The stimuli are presented to the right ear and travel directly to the left hemisphere, which is the predominant

Table 3. Guide for interpreting results of non-overlapping analysis

Training status	Percent of non-overlapping results
Complete/definite treatment	Score over 90%
Appropriate treatment	Score 70−90%
Treatment is available but it should be used cautiously	Score 50−70%
No treatment	Score below 50%

hemisphere in speech processing. A greater transmission time is required due to the transmission of the verbal information from the right to the left hemisphere through the corpus callosum. Therefore, the left ear requires more corpus callosum contribution to be efficient in language information processing. In the case of the elderly, the progressive deterioration of the corpus callosum affects the inter-hemispheric transfer efficiency, which causes the ear asymmetry [24].

In the elderly, imaging study showed a reduction in the size of the corpus callosum, which caused inefficiency in the conduction of the speech information from the left ear to left hemisphere, resulting in REA in the elderly compared with young people (because of the reduction of the left ear contribution) [7]. Reductions in dichotic listening begin within ages of 55−60 years and is related to the size of the corpus callosum [25]. However, the potential for plasticity are preserved throughout the life. In different studies utilizing various training methods, the CNS and corpus callosum showed learning-dependent structural changes [26,27]. Lövdéna et al. [28] studied the effect of cognitive training on 12 elderly adults and 20 young controls. They showed that training increased myelination in the anterior part of the corpus callosum, which was similar in the two groups. Similarly, McCullagh and Palme [14] found improvements in DDT scores after DIID training in a subject with a neurological problem. This is in agreement with the result of the present study that showed improvements in DDT after an informal DIID home-version in elderly people without neurological disorders or hearing loss.

One of limitations of the present study was that we only used two dichotic digit lists one by one. However, learning effect is possible. Although, improvement was achieved in only one ear, which ruled out the possibility of a learning effect, which should have affected the results of both ears. This is a pilot study, and due to the limited available materials, it is better to consider this point in the future studies and use various materials for single-subject studies which requires periodic evaluation.

Conclusion

The findings of this study suggest that dichotic training could improve the dichotic listening abilities in normal elderly adults without having neurological disorders or hearing loss. It may be a promising method for solving the common speech recognition problems especially in the noise of the elderly people. This is because there is high correlation between dichotic listening and speech in noise and dichotic listening has been reported as a reliable indicator of speech in noise in the older adults. The advantage of this method is that it can be easily done at home and is cost-effective. However, further studies are needed to approve the neuroplasticity and structural changes in the brain after dichotic interaural intensity difference training program in this population.

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Conflict of interest

The authors declared no conflicts of interest.

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