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RESEARCH

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Effects of neurofeedback training on the alpha activity in quantitative electroencephalography, cognitive function, and speech perception in elderly with presbycusis: a quasi-experimental study

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Abstract

Background This study aimed to investigate the effects of neurofeedback training (NFT) on alpha activity in quantitative electroencephalography (QEEG), cognitive function, and speech perception in elderly with presbycusis.

Methods This study was conducted from June 15 to November 30, 2020. The experimental group ($n = 28$) underwent NFT, while the control group ($n = 31$) was instructed to continue with their routine daily life. The NFT conducted for 40 min, two times a week, for a total of 16 sessions and was performed using Neuroharmony S and BrainHealth 2.7. The alpha activity was measured as alpha waves using QEEG. The cognitive function was measured using the Korean version of Mini-Mental Status Examination, digit span forward and backward (DSF and DSB). The speech perception was measured using the word and sentence recognition score (WRS and SRS) using an audiometer with the Korean Standard Monosyllabic Word Lists for Adults.

Results The experimental group demonstrated improvement in the alpha wave of the left frontal lobe measured as alpha activity (t=-2.521, $p = .018$); MMSE-K (t=-3.467, $p < .01$), and DSF (t=-2.646, $p < .05$) measured as cognitive function; and WRS (t=-3.255, $p = .003$), and SRS (t=-2.851, $p = .008$) measured as speech perception compared to the control group.

Conclusions This study suggests that NFT could be considered an effective cognitive and auditory rehabilitation method based on brain and cognitive science for improving alpha activity, cognitive function, and speech perception.

Keywords Cognitive function, Elderly, Electroencephalography, Neurofeedback, Presbycusis

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Background

According to the "2022 Statistics on the Aged," the number of elderly individuals aged 65 years and older in Korea was 9,018,000, accounting for 17.5% of the total population, and Korea is expected to become a super-aged society in 2025 [1]. Therefore, social interest in aging and geriatric health problem is increasing. In particular, presbycusis, which is the gradual loss of hearing, is a sensorineural illness that occurs from degenerative changes attributed to aging. In addition, it is one of the three common age-related chronic diseases [2].

Especially, presbycusis has negative consequences, such as social avoidance resulting in poor interpersonal relationships; psychological problems, such as alienation and depression, and poor quality of life in the elderly [3–6]. Based on the cognitive load hypothesis, since hearing loss leads to degraded auditory signals, which result in limited communication skills and difficulty in communication, more cognitive resources for auditory perceptual processing are warranted; thus, resources used for other cognitive demands are altered for listening effort. Thus, individuals with hearing loss should always make a listening effort, which refers to the attention and concentration required to understand speech [7]. An excessive cognitive load dedicated to auditory perceptual processing in everyday life causes brain structural changes and neurodegeneration relevant to the detriment of other cognitive processes; subsequently, a vicious cycle is created that results in cognitive decline [8].

Previous studies suggested that a significant association exists between presbycusis, a condition that is highly prevalent in elderly individuals and poorer cognitive function [9, 10]. Among prospective studies have observed that hearing loss is associated with accelerated cognitive decline in individuals with prevalent dementia [11, 12]. Supporting previous hypotheses suggest that the association may be mechanistic, for example, age-related hearing loss causing cognitive decline through impaired speech perception [10].

Cognitive function comprises continuous activities of the brain cells. The electrical impulse that occurs when neurons share information with each other is referred to as a brainwave [13]. Thus, brainwaves are effective in understanding brain activity. Especially, the alpha (α) brainwave is a unique rhythm domain with amplitudes of 20–50 μV and frequencies of 8–12 Hz [14]. When α waves are high, attention and mental activity are good, and thinking, concentration, and memory reportedly improve [15]. The brain activity tends to slightly decrease before and after the ages of 50s and 60s and markedly declines after the age of 70 [16]. Thus, α waves increase from early childhood to adulthood but decrease upon aging or in senile neurological diseases.

Based on the frontal lobe hypothesis, the frontal lobe function of the anterior cerebellum preferentially declines owing to normal aging; especially the prefrontal lobe function greatly declines due to aging. Therefore, a decline in function in this region attributed to aging can be detected early compared to the functions based on other regions [17]. However, the brain has an ability to change (neuroplasticity) by reacting to environmental stimulation and education [18]. In this regard, neurofeedback training (NFT) has been demonstrated to be effective in various pathological disorders associated with the brain, such as epilepsy, attention-deficit hyperactivity disorder, anxiety disorder, sleep disorder, and cognitive decline not only in the elderly but also in healthy individuals [15, 19–22]. However, there is insufficient research to verify the effects of NFT in community dwelling elderly with presbycusis. Thus, our study aims to verify the effects of NFT on α activity in quantitative electroencephalography (QEEG), cognitive function, and speech perception in elderly with presbycusis. We aim to establish source data on cognitive and auditory rehabilitation based on brain and cognitive science.

The following hypotheses were formulated:

Hypothesis 1 Compared to before participation, α activity in the elderly with presbycusis will improve after participation.

Hypothesis 2 Compared to before participation, cognitive function in the elderly with presbycusis will improve after participation.

Hypothesis 3 Compared to before participation, speech perception in the elderly with presbycusis will improve after participation.

Methods

Study design and participants

This is a quasi-experimental research using a pretest-posttest experimental design. This study was conducted in an auditory rehabilitation center in Gyeonggi-do, South Korea and used posters to recruit participants. Elderly volunteers aged ≥ 65 years with presbycusis and wearing a hearing aid expect for sleeping who fully understood the study's purposes and procedures and were willing to participate in the study were included. Using the G*Power 3.1 program, the minimum number of the samples were calculated based on a significance level α of 0.05, a power of 0.80, and an effect size of 0.8 [23]. This yielded a minimum number of 26 samples for each group, which is a total of 52. A total of 66 participants were enrolled by considering a dropout rate of 20%. Patients with functional disability of the external and middle ear, such as a foreign body in the external auditory canal that could affect corrected hearing impairment by hearing aids, eardrum holes, otitis media, and mental illnesses that affect brainwaves, were excluded. A total of five patients were excluded. Of the 61 participants, 30 and 31 participants were randomized into the experimental and control groups, respectively. Of them, two participants in the experimental group dropped out of the study. Finally, the data of the 59 participants were analyzed (Fig. 1).

Research tools

General characteristics

Age, sex, pure tone average (PTA), and length of hearing aid use were considered variables of the general characteristics. The PTA is the method of determining the degree of hearing loss; when signals using pure tones at 125 Hz, 250 Hz, 0.5 kHz, 1 kHz, 2 kHz, 4 kHz, and 8 kHz were presented as a modified method of limits, two of the three positive responses were determined to be the thresholds. The degree of hearing loss was divided into four-frequency PTA (PTA4) based on 0.5 kHz, 1 kHz, 2 kHz, and 4 kHz, and the degree of hearing loss was interpreted as mild (26–40 dB), moderate (41–55 dB), moderately severe (56–70 dB), severe (71–90 dB), and profound (91 dB above) [24].

Alpha (α) activity

For brainwaves, investigators with Board Certification in Neurofeedback measured the α waves in both the left and right brain using Neuroharmony S (Panaxtos, Korea), a two-channel electroencephalogram (EEG), that has been approved by the Food and Drug Administration. The participants wore a gold-plated hairband for brain wave measurement.

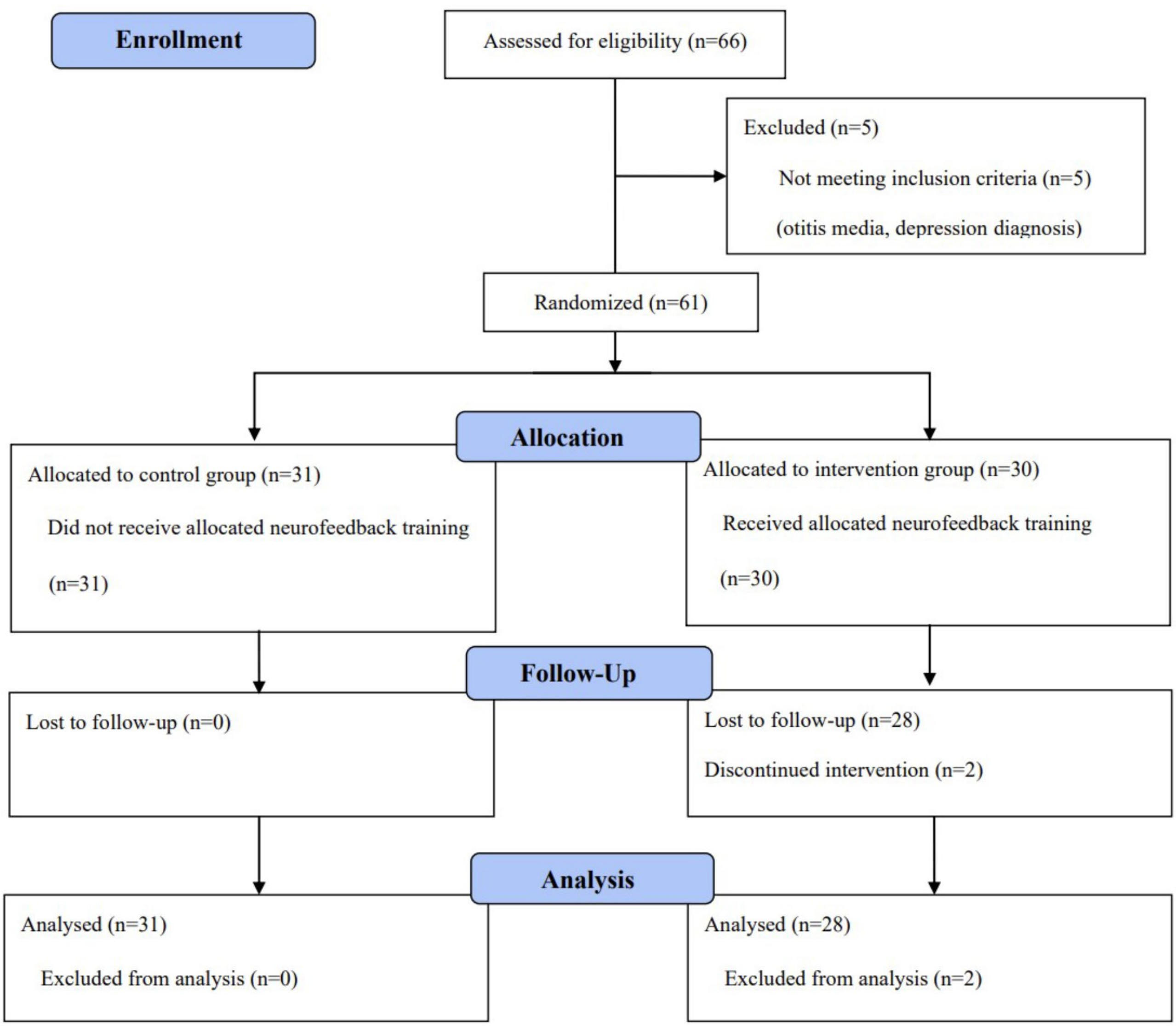

Fig. 1 Consort flow diagram

According to the international 10–20 electrode placement system, the active, ground, and reference electrodes were placed on Fp1 and Fp2, Fpz, and A1 of the left earlobe, respectively, to measure brainwaves (Fig. 2). In 1958, International Federation in Electroencephalography and Clinical Neurophysiology adopted standardization for electrode placement called 10–20 electrode placement system [25]. Each English letter implies the regions of the brainwave measurements, such as frontal pole (Fp), frontal (F), central (C), parietal (P), temporal (T), and occipital (O). In terms of numbers, left side of the head refers to odd numbers, right side refers to even numbers, and midline refers to Z. This EEG is being widely used for medical purposes in the US. The reliability was established at 0.916 ($p<.001$) compared with the Grass Neurodata Amplifier System (USA), as an EEG measurement device.

Cognitive function

Cognitive function was assessed using the Korean version of Mini-Mental Status Examination (MMSE-K) [26] and the Digit Span Test (DST) [27]. The MMSE-K incorporates a range of elements that include Orientation to Time (5 points; year, month, day, days of week, season), Orientation for Place (5 points; Province [city], district [county], myeon [dong], floor (name of the current place), what is a place for), Registration (3 points; repeating names of three objects), Attention and Calculation (5 points; subtracting 7 from 100 five consecutive times or saying a word "Samchunrigangsan" backward), Recall (3 points; recalling the names of three objects), Language (6 points; naming a paper and clock, obeying a three-step command, and repeating tongue twisters such as 'Peter Piper picked a peck of pickled peppers'), Visual Construction (1 point; copying the intersecting pentagon), and Understanding and Judgement (2 points; the reason for washing clothes and how to return someone's resident registration card if one picks it up from the street). The measure yields a total score of 20, and higher scores mean better cognitive ability. The MMSE-K is a tool with modified questions and scoring methods in consideration that many older Korean adults are uneducated. If the participants are uneducated, up to four extra points will be given by adding 1 point for Orientation to Time, 2 points for Attention and Calculation, and 1 point for Language. According to a study examining the validity of MMSE-K in the elderly that was conducted at the time of developing MMSE-K [28], the cut-off scores of 23/24 points (sensitivity=92.0%, specificity=91.5%) was the optimal level to diagnose dementia based on Diagnostic and Statistical Manual of Mental Disorders, Third Edition-Revised (DSM-III-R). Participants with scores of ≥24 points were diagnosed as "definite normal," 20–23 points were "suspected dementia," and ≤19 points were "definitive dementia."

The DST is a neuropsychological test in most common use for measuring attention-concentration and working memory capacity [27]. The DST is useful for assessing the impact of age-related hearing loss on cognitive function among elderly, since it is easy to be administered [27, 29]. It consists of Digit Span Forward (DSF) and Digit Span Backward (DSB). In the DSF test, digit sequences of increasing length (containing three to nine digits) were presented auditorily for immediate verbal recall, whereas in the DSB test, digit sequences of increasing length (containing two to eight digits) had to be recalled

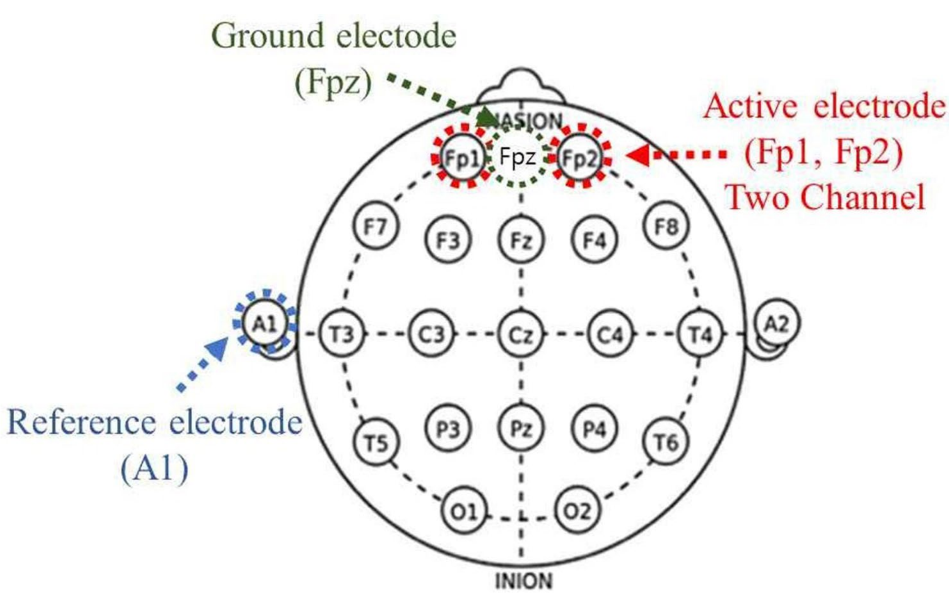

Fig. 2 International 10–20 electrode placement system

in reverse order. There were two trials for each sequence length. The DSF and DSB scores corresponded to the digits of the steps performed correctly by the participants. The test-retest reliability coefficients were 0.72 and 0.57, respectively [27].

Speech perception

Speech perception was measured using the Word Recognition Score (WRS) and Sentence Recognition Score (SRS) tests. These tests were performed in a soundproof audiometric booth, and the noise level of the audiometric booth measured by a sound level meter, SC-2 C (Cesva, Spain), was approximately 30 dB. Harp basic (Inventis, Italy), an audiometer, and DD-45 (RadioEar, USA), a headphone, were used to present the stimulation tone. Both ears of the participants were tested through PTA, and the better hearing ear was selected in accordance with the method from the previous study [24]. If both ears are the same, the one mainly with a hearing aid was selected [24].

First, based on a study by Joo & Jang [30], we measured the WRS to examine the degree of speech perception for participants with general hearing impairment. To measure the WRS, an audiologist presented 50 monosyllable words at a participant's most comfortable level (MCL), and the participant was instructed to listen carefully and repeat exactly as the audiologist said. The measurement was presented as a percentage (%). For words presented at WRS, The Korean Standard Monosyllabic Word Lists for Adults (KS-MWL-A) was used [31]. The WRS was classified as very poor (<50%), poor (≧50–<70%), fair (≧70–<80%), good (≧80–<85%), very good (≧85–<95%), and excellent (≧95–100%) [32].

For measuring the SRS, the participants were instructed to listen and repeat sound sources of SRS presented along with a multi-talker babble noise, in a noise environment, through headphones. Signal-to-Noise Ratio (SNR) was set to 10 dB and 0 dB. Sound source from the Korean Standard Sentence List for Adults (KS-SL-A), the presented sentences, is a tool that has been verified with equivalency of levels between test lists in auditory only situations. In this study, multi-talker babble noise used in a study by Park et al. [33] was utilized. The multi-talker babble noise that was used was recorded by healthy adults with normal hearing function (10 men, 20 women, mean age: 21.7 years) by reading scripts of soap opera, TV news, and newspapers for 2 min in a soundproof booth in the Auditory Research Institute of Hallym University. When the recording was conducted, the Shure microphone was used as a transmitter, and the distance between the mouth of the reader and the microphone was maintained at 10 cm. The sampling frequency was 45,000 Hz. Data recorded by each person was synthesized using the computerized speech lab. The SRS test scores range from 0 to 100 points, and a higher score indicates better function.

Table 1 Neurofeedback training and characteristics

Training	Game mode	Brain reaction area
Relaxation Training	Spoon Flection	Whole Brain
Concentration Training	Archery	Frontal Union Somatosensory cortex Motor cortex
Memory Training	Planetary Array	Prefrontal lobe Temporal lobe Hippocampus

Neurofeedback training

NFT was conducted using the Neuroharmony S (Panaxtos, Korea) and BrainHealth 2.7 programs in a soundproof booth optimized for avoiding electromagnetic waves or noise. The training was conducted for 40 min, two times a week, for a total of 16 sessions. For each participant, relaxation, concentration, and memory training were conducted simultaneously as possible. Game modes in the training device and brain reaction areas are provided in Table 1 [34]. During the training, the participants were instructed to minimize their movement while they were in a comfortable position. For the NFT mode for each participant, the attention and concentration training modes were selected, after self-control ability assessment in the brain quotient analysis.

Data collection

This study was conducted in an auditory rehabilitation center in Gyeonggi-do, South Korea from June 15, 2020 to November 30, 2020. This study was conducted by trained investigators with a Master's degree in Audiology, audiological specialist license, and nationally certified brain trainer license. Participants volunteered based on the announcement of the posters in the center. Data from NFT and structuralized questionnaires and brainwaves measurement were collected. An interval between the pre-test and post-test in both groups was eight weeks, considering the intervention period. Especially, it's crucial to ensure that an adequate interval between two tests was provided to mitigate any potential learning effects and allow participants to sufficiently rest administrations. Trained investigators verbally explained the principles and procedures of NFT to the elderly taking into consideration that the older adults were not familiar with the NFT provided to the experimental group, and assisted them in training and data collection. In contrast, the control group was instructed to maintain daily life in the same condition as usual.

Data analysis

Data were analyzed using the SPSS/WIN 25.0 program. The participants' general characteristics and variables were analyzed using descriptive statistics. Homogeneity between the experimental and control groups was analyzed using an independent sample t-test and Chi-square test. The effectiveness of the intervention was tested using paired sample t-test. *P*-value of <0.05 was considered statistically significant.

Ethical considerations

This study was approved by the Institutional Review Board of S University (No. 27004121AN01-202006-HR-063-02). The investigators thoroughly explained the study objectives and methodology verbally using an information sheet describing the study to the participants to provide voluntarily consent to participation. The collected data were used only for study purposes, and all the data were anonymized and encoded to protect personal information. For reference, since the study was conducted during the coronavirus disease 2019 (COVID-19) pandemic period, all the participants were assessed for body temperature and COVID-19-related symptoms; infection control (periodic ventilation) and safety were prioritized.

Results

General characteristics

The participants' general characteristics are shown in Table 2. The mean age of the participants in both the experimental and control groups was 77.54±6.37 and 76.35±6.09 years, respectively, showing no significant differences between the two groups (*p*>.05). Considering the age, 14 (50.0%) men and 14 (50.0%) women were present in the experimental group, while 20 (64.5%) men and 11 (35.5%) women were present in the control group; no significant differences were observed between the sexes in both groups (*p*>.05). The mean PTAs of the experimental and control groups were 53.25±15.94 dB and 56.32±14.89 dB, respectively, which demonstrated no significant differences between the two groups (*p*>.05). The length of hearing aid use was no significant differences between the two groups (*p*>.05).

Prior homogeneity

The prior homogeneity test showed no statistically significant differences in the α activity in QEEG, cognitive function, and speech perception between the two groups (Table 3). The two groups were found to be homogeneous (*p*>.05).

Intervention effects

Hypothesis 1. Compared to before participation, a activity in the elderly with presbycusis will improve after participation

The experimental group that participated in the NFT showed a statistically significant improvement in α activity of the left frontal lobe compared to before participation (t=-2.521, *p*=.018), whereas the control group did not show any statistically significant difference (*p*>.05). Thus, Hypothesis 1 was approved (Table 4).

Hypothesis 2. Compared to before participation, cognitive function in the elderly with presbycusis will improve after participation

The experiment group that participated in the NFT showed a statistically significant improvement in the MMSE-K (*t*=-3.467, *p*<.01) and DSF (*t*=-2.646, *p*<.05) compared to before participation, whereas the control group did not show a statistically significant difference (*p*>.05). Thus, Hypothesis 2 was approved (Table 4).

Hypothesis 3. Compared to before participation, speech perception in the elderly with presbycusis will improve after participation

The experiment group that participated in the NFT showed a statistically significant improvement in the WRS (t=-3.255, *p*=.003) and SRS at the noise level of SNR=10 dB (t=-2.851, *p*=.008) compared to before participation, whereas no statistically significant difference was observed in the SRS at the noise level of SNR=0 dB (*p*>.05). Thus, Hypothesis 3 was partially approved (Table 4).

Table 2 General characteristics of the participants (*N*=59)

Characteristics	Categories	Exp. (*n*=28)	Con. (*n*=31)	t or χ2	*p*
		M±SD or *n* (%)	M±SD or *n* (%)		
Age (years)	-	77.54±6.37	76.35±6.09	0.727	0.470
Sex	Male	14(50.0)	20(64.5)	1.270	0.260
	Female	14(50.0)	11(35.5)		
PTA (dB)	-	53.25±15.94	56.32±14.89	-0.765	0.447
Length of hearing aid use (years)	<1	18(58.1)	18(62.1)	0.503	0.481
	≧1 and <5	4(12.9)	6(20.7)		
	≧5 and <10	6(19.3)	3(10.3)		
	≧10	3(9.7)	2(6.9)		

N: number, M±SD: mean±standard deviation, Exp.: Experimental group; Con.: Control group, PTA: Pure tone average

Table 3 Prior homogeneity test between the groups ($N=59$)

Variables		Group	*n*	M ± SD	t	*p*
Alpha (α) activity	α wave, L (Hz)	Exp	28	6.25 ± 1.04	-1.621	0.110
		Con	31	6.74 ± 1.26		
	α wave, R (Hz)	Exp	28	6.46 ± 1.26	-0.468	0.649
		Con	31	6.61 ± 1.23		
Cognitive function	MMSE-K	Exp	28	27.18 ± 1.66	1.841	0.071
		Con	31	26.03 ± 2.89		
	DSF	Exp	28	6.00 ± 1.52	-0.154	0.878
		Con	31	6.06 ± 1.69		
	DSB	Exp	28	3.46 ± 1.10	0.162	0.872
		Con	31	3.42 ± 1.03		
Speech perception	WRS (%)	Exp	28	71.00 ± 21.65	1.038	0.303
		Con	31	65.23 ± 21.03		
	SNR = 10 dB SRS	Exp	28	34.61 ± 8.21	-0.070	0.945
		Con	31	34.74 ± 6.60		
	SNR = 0 dB SRS	Exp	28	11.57 ± 10.40	1.158	0.252
		Con	31	8.35 ± 10.88		

M ± SD: mean ± standard deviation, Exp.: Experimental group; Con.: Control group, L: left, R: right, MMSE-K: Korean version of Mini-Mental Status Examination, DSF: Digit Span Forward, DSB: Digit Span Backward, WRS: Word Recognition Score, SRS: Sentence Recognition Score, SNR: Signal-to-Noise Ratio

Table 4 NFT effects

Characteristics	Exp. ($n=28$)			Con. ($n=31$)		
	M ± SD		t(*p*)	M ± SD		t(*p*)
	Pre-test	Post-test		Pre-test	Post-test	
Alpha (α) activity						
α wave, L	6.25 ± 1.04	6.82 ± 1.16	2.521* (0.018)	6.74 ± 1.26	6.90 ± 1.33	0.681(0.501)
α wave, R	6.46 ± 1.26	6.89 ± 1.10	1.759 (0.090)	6.61 ± 1.23	6.97 ± 1.22	1.321(0.196)
Cognitive function						
MMSE-K	27.18 ± 1.66	28.39 ± 1.31	3.467** (0.002)	26.40 ± 2.08	27.13 ± 1.68	1.898(0.068)
DSF	6.00 ± 1.52	6.50 ± 1.45	2.646* (0.013)	6.06 ± 1.69	6.03 ± 1.20	0.107 (0.916)
DSB	3.46 ± 1.10	3.68 ± 1.06	1.236 (0.227)	3.42 ± 1.03	3.35 ± 0.98	0.338 (0.738)
Speech perception						
WRS (%)	71.00 ± 21.65	76.86 ± 17.70	-3.255** (0.003)	65.23 ± 21.03	63.74 ± 19.04	0.810 (0.424)
SNR = 10 dB SRS	34.61 ± 8.21	37.93 ± 3.14	-2.851** (0.008)	34.74 ± 6.60	33.35 ± 9.80	1.204 (0.238)
SNR = 0 dB SRS	11.57 ± 10.40	13.25 ± 12.18	-1.304 (0.203)	8.35 ± 10.88	6.13 ± 9.18	1.987 (0.056)

NFT: neurofeedback training, M ± SD: mean ± standard deviation, Exp.: Experimental group; Con.: Control group, L: left, R: right, MMSE-K: Korean version of Mini-Mental Status Examination, DSF: Digit Span Forward, DSB: Digit Span Backward, WRS: Word Recognition Score, SRS: Sentence Recognition Score, SNR: Signal-to-Noise Ratio

**$p<.01$, *$p<.05$

Discussion

This study demonstrated the effects of NFT on the α activity in QEEG, cognitive function, and speech perception in elderly with presbycusis.

First, there was a statistically significant increase in the α wave of the left frontal lobe compared to before participation. The increased α wave of the left frontal lobe due to NFT imply the possibility of neuroplasticity in the elderly even though the mean age of the older adults participating in NFT was 76.35±6.09 years. In particular, a previous study reported that the brain in the left frontal lobe is a key region for language working memory and the brain in the right lobe is a key region for visual-spatial working memory, an increase in α wave of the left frontal lobe helps the elderly improving language working memory [35]. There is a previous study that predicts visual-spatial working memory performance through the characteristics of an EEG in the resting state [35]. However, few studies have analyzed brain activity based on the prefrontal lobe in relation to language working memory. Therefore, further studies are warranted to establish the basis for understanding the activities of brainwaves on working memory in detail. Furthermore, current study measured just brain waves, not other types, such as functional Near Infra-red Spectroscopy (fNIRS) which is a non-invasive brain functional analysis system using near infrared, which measures brain metabolism and changes in cerebral blood flow [36]. In future research, it is necessary to use the hybrid functional neuroimaging technique to evaluate different features from QEEG and fNIRS.

Cognitive function in the elderly individuals who participated in the NFT significantly increased compared to before participation, and a significant improvement in memory items, such as memory recall, the sub-item of MMSE-K was observed. Furthermore, the experimental group showed a statistically significant increase in the DSF. In this study, MMSE-K scores of ≥24 points were diagnosed as "definite normal" [28] and DSF scores of ≥6 were above average (Mean±SD=5.44±1.41) of Korean older people aged≥55 years [27]. Both short-term-memory and working-memory capacities were significantly lower in the hearing loss condition [29]. According to the hemispheric encoding/retrieval asymmetry (HERA) model, the left prefrontal cortex (PFC) is more involved than the right PFC in episodic memory encoding, whereas the right PFC is more involved than the left PFC in episodic memory retrieval [37]. For example, when the participants were instructed to memorize words, the words became verbal episodic memory, and an increase in the left PFC activation was observed. The PFC and hippocampus support complementary functions in episodic memory. Connections between the PFC and the hippocampus are particularly important for episodic memory. Moreover, we believe that the increased α wave correlated with an improvement in the cognitive function [15, 38]. Further studies are warranted to evaluate brain activity as per the degree of hearing loss and further compare neuroplasticity following NFT. Furthermore, systematic NFT should be developed based on the scientific and objective analysis of brainwaves in the elderly with cognitive decline due to profound hearing loss or long-term hearing loss.

However, this study measured changes in cognitive function using the MMSE-K for the participants whose existing cognitive function is close to normal. The MMSE-K is the most widely used impaired cognitive function screening tool in Korea and has the advantage of being able to easily assess the intellectual condition and cognitive function of the subject in a short time [39, 40]. According to the results of preceding researches, MMSE-K scores significantly increased after intervention with cognitive tasks in cognitively normal elderly [41]. After intervention, there was also a significant difference in the comparison of variation in MMSE-K scores between the experimental and control groups [42]. Accordingly, the results of this study in the elderly are significantly meaningful and these findings are consistent with the prior results of a various program based on cognitive training in the elderly in which MMSE-K scores improved. Nevertheless, as a limitation, this quasi-experimental study recruited participants using convenience sampling from an auditory rehabilitation center; therefore, the results should be carefully interpreted and generalized by repeating studies that target a large sample of elderly with presbycusis according to cognitive function.

In this study, only the experimental group showed a statistically significant increase in the WRS. Especially in the experimental group, WRS increased from 71.00±21.65 to 76.86±17.70. According to the criteria of David & Constance [32], a significant improvement in the "fair (≧70–<80%)" category was observed. However, the mean pre-WRS was 65.23±21.03 and the post-WRS was 63.74±19.04 in the control groups corresponding to the "poor (≧50–<70%)" category. In the control group, the WRS was decreased. In particular, for WRS, the participants listen and repeat the one-syllable word. This rehearsal is carried out by working memory. Therefore, speech perception is related to the improvement in cognitive function as supported by a previous study [10, 39].

Since WRS can distinguish cognitive ability by phonemes, it provides information on word recognition ability in objective information about the possibility of rehabilitation in cases of hearing loss in older adults. In addition, diagnostic information related to the location of the lesion and information about each frequency of brainwaves by phoneme can be obtained. Thus, WRS test should be further conducted [43]; however, the WRS is a speech perception that is performed at a pleasant level to hear in a soundproof booth instead of a noise environment. Therefore, attention resources that were presented in the human information processing model of Wickens et al. [44] are less distributed. Thus, speech perception in actual daily life of the elderly with hearing loss cannot be perfectly reflected. Therefore, it needs to be considered by comparing with SRS at noise levels of SNR=10 dB and SNR=0 dB. In this study, SRS at the noise level of SNR=10 dB statistically significantly increased in the experimental group.

For the SRS at the noise level of SNR=10 dB, the SRS was confirmed at the level of multi-talker babble noise, very little noise, and the results were determined to be attributed to improvement in the working memory through brain activity (such as α wave, left). This is supported by a previous study that reported that working memory is highly correlated with sentence recognition level [45, 46]. Moreover, listening to what another person says under noise conditions largely requires attention resources. Especially, the elderly listens in less audible environment due to the aging of the auditory system compared to young adults [47]. However, a study reported that the elderly can also overcome the difficulty of auditory processing by understanding the context based on the long experience of listening [24]. The prefrontal lobe plays an important role in this process, which could be attributed to the interrelationship between the prefrontal lobe regions and attention control and working memory. Thus, an improvement in the SRS under multi-talker babble noise is the result of the effects of NFT on the mutual relations of the prefrontal lobe regions and the improvement in the working memory and attention. Moreover, both groups did not show statistically significant changes in the SRS under the multi-talker babble noise at the large noise level of SNR=0 dB. This is attributed to the size that reached the limit, which can distribute attention resources. However, the experimental group showed an increase in the SRS at the noise level of SNR=0 dB, whereas the control group showed a decrease. The SRS under noise conditions was favorable when the measurement was closed to the normal score (100 points), while the elderly with presbycusis in this study showed lower mean values. This is because distorted factors caused by auditory processing disorder under noise conditions act more strongly in the elderly with presbycusis. Based on the results, we suggest that future studies should establish an actual rationale that can set the direction of auditory training and rehabilitation in the elderly with presbycusis according to the degree of hearing loss.

Conclusions

This study implies that the NFT can improve α activity in QEEG, cognitive function, and speech perception in elderly with presbycusis; thus, NFT can be a novel method of cognitive and auditory rehabilitation. Considering that decline in the prefrontal lobe in relation to aging of the elderly is noticeable, the NFT improves α activity by maintaining the plasticity and homeostasis of the brain resulting in positive effects on cognitive function and speech perception. Moreover, brainwave activity can be used as an objective tool for auditory assessment based on the relationships between α activity in QEEG, cognitive function, and speech perception in elderly individuals with presbycusis. However, since the participants of this study were aged 65 years and older, trainers need to assist older adults who are not familiar with computer-based NFT. Motivation is extremely necessary for participating in and maintaining NFT. Thus, NFT should be improved and its effects should be verified to increase its accessibility, familiarity, sustainability, and effectiveness in elderly individuals with presbycusis.

Abbreviations

OR	Odds ratio
CI	Confidence interval
NFT	Neurofeedback training
PTA	Pure tone threshold average
EEG	Electroencephalogram
MMSE-K	Korean version of Mini-Mental Status Examination WRS: Word Recognition Score
SRS	Sentence Recognition Score
SNR	Signal-to-Noise Ratio
PFC	Prefrontal cortex

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Author contributions
HJK and HWW conceptualized and designed the study and analyzed the data. HJK and HKS wrote the manuscript, and supervised the team. All the authors revised the manuscript critically for the enhancement of intellectual content and assisted in the final write-up of the manuscript.

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Data availability
The data presented in this study are available upon reasonable request from the corresponding author. The data are not publicly available owing to privacy and ethical restrictions.

Declarations

Ethics approval and consent to participate
The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of Seoul University of Buddhism (No. 27004121AN01-202006-HR-063-02). Before starting data collection, we explained all the aspects of the study to the participants. Informed consent was obtained from all the participants involved in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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