

Effect of auditory temporal processing training on behavioral and electrophysiological functions in central presbycusis

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Objective

Age-related changes in the central auditory system, particularly auditory temporal processing abilities, were considered among most important factors affecting speech understanding performance in older adults. Once these factors are identified, clinical management procedures could be developed for prevention and treatment. The aim of this study was to determine the effects of short-term auditory training on the behavioral and electrophysiological measurements of auditory function in individuals with age-related temporal processing deficit.

Participants and methods

A prospective study of 20 individuals aged 60–67 years with either normal or bilateral symmetric high-frequency hearing loss was conducted. Evaluations of auditory temporal processing using behavioral tests (Pitch Discrimination Test, Pitch Pattern Sequence Test, Auditory Fusion Test-Revised, and Time Compressed Speech Test), P300 potential, and the administration of ‘Amsterdam inventory for auditory disability and handicap’ were performed before and after short-term auditory training.

Results

All participants demonstrated poor pretraining Pitch Pattern Sequence Test results which were significantly improved after remediation. All patients showed normal pretraining performance on Pitch Discrimination Test, Auditory Fusion Test-Revised, and Time Compressed Speech Test tests. There was a statistically significant increase in P300 amplitude and shortening in latency after remediation.

Conclusion

Short-term auditory training in older adults with auditory temporal processing deficit led to improvements in temporal sequencing skills and communication in noisy environments. P300 potential has been proved to be an objective indicator of neurophysiologic changes in the central auditory system resulting from auditory experience.

Recommendation

Short-term auditory training is an efficient rehabilitative tool for elderly people with auditory temporal processing deficit. However, maintenance of treatment effects over time should be evaluated.

Keywords:

auditory temporal processing deficit, auditory training, behavioral central tests, P300 amplitude and latency

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Introduction

The structural and functional changes in the auditory system owing to aging ‘central presbycusis’ can limit speech comprehension during difficult listening situations in elderly people [1]. Recent investigations have sought to elucidate the factors that affect speech understanding [2]. Previous studies have demonstrated poor performance of elderly people compared with young people during different auditory tasks, including temporal processing, listening in noisy environments, and dichotic listening [3–5].

Processing of temporal cues takes place mainly in the auditory cortex [6]. Accurate speech discrimination requires precise temporal processing, an ability that

is compromised in older adults compared with younger adults. There are many potential biological causes for this loss of precision, including loss of myelin integrity [7], delayed neural recovery time [8], decreased brain connectivity [9], decreased levels of inhibitory neural transmitters [10], and loss of neural synchrony [11].

Because peripheral hearing loss often accompanies advanced age, it is difficult to rule out the influence of hearing loss on perceptual central processing.

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Moreover, cognitive deficits can exacerbate slight declines in hearing sensitivity, thus further contributing to the older adult's speech-in-noise perception deficits [12]. Despite these findings, there is evidence supporting the remediation of central auditory processing in older adults. Training-driven neuroplasticity, which can reverse the effects of aging, may provide a means to accomplish this [13].

Previous studies on auditory training (AT) have demonstrated favorable results in auditory and cognitive perception among adults with central auditory processing deficits, consequently improving their social participation and quality of life [14–16].

Both behavioral and electrophysiological tests of auditory processing have been widely used to monitor auditory interventions. Significant changes in bioelectrical activity within the auditory system are observed after AT [17,18]. P300 is a long-latency potential that occurs ~300 ms. after the stimulus presentation. It can be elicited by the oddball paradigm, which involves detection and discrimination of a rare stimulus amid a series of frequent stimuli. P300 can be influenced by higher cognitive functions, including attention and memory, and originates in the primary and secondary areas of the cortex. However, the exact elicitors are unknown [19,20]. Therefore, this study was motivated by the need to evaluate the effects of short-term training on the aging auditory system. This study investigated the effectiveness of short-term AT in the elderly using behavioral measures of auditory temporal processing and P300 event-related potential measurement.

Participants and methods

The present study was carried out on 20 elderly participants (17 women and three men), and their age was ranged between 60 and 67 years. Participants were recruited from the audio-vestibular outpatient clinic, complaining of poor speech discrimination with or without concomitant hearing impairment. An informed written consent was obtained from all participants, including a detailed explanation of the study, benefits, and adverse effects.

Each participant was subjected to a basic clinical assessment by history taking, otoscopic examination, neurological examination, basic audiological evaluation using a dual channel clinical audiometer (Madsen Astera; GN Otometrics, Copenhagen, Denmark), immittance measurement using impedance audiometer (by Interacoustics AT 235, Assens,

Denmark), cognitive assessment using the Mini-Mental State Examination, and self-reported assessment of auditory disability using the Amsterdam Inventory for Auditory Disability and Handicap (AIADH). The inclusion criteria for elderly participants were as follows:

- (1) Men and women older than 60 years, complaining of difficult speech recognition.
- (2) Bilateral pure-tone averages (average threshold from 0.5 to 2 kHz) ≤ 25 dB hearing level (HL), and ≤ 50 dB HL at 4000 and 8000 Hz.
- (3) A significant positive score (≥ 50) in the 'Amsterdam inventory for auditory disability and handicap'.
- (4) Normal scores on the Mini-Mental State Examination.
- (5) Free from known neurological disorders that interfere with the methodology.

All participants of the present study were subjected to the following protocols.

Preremediation assessment

Self-assessment with 'Amsterdam inventory for auditory disability and handicap'

AIADH consists of 30 items and aims to assess the participants' self-perception of their performance in daily listening situations. The maximum score for AIADH is 112. Higher scores indicate more auditory disability, whereas lower scores reflect the opposite [21].

Selected behavioral auditory temporal processing tests

The participant was seated comfortably in a quiet room, and the test materials were presented from a Compaq-PC CD player and delivered through headphones. The materials were presented binaurally at the most comfortable level of the patient. Participants received instructions regarding the task performance and a training phase, with an easy task provided before the administration of each tool. The selected behavioral central tests included the following:

Pitch Discrimination Test (PDT): PDT is a test of auditory cortical discrimination of spectral aspects of sound. It consists of 20 pairs of 150-ms tone bursts with a 200-ms intertone interval. Each pair is a combination of two frequencies, 880 and 1122 Hz [22]. The task was to judge whether the two tones are similar or different in pitch.

Pitch pattern Sequence Test (PPST): PPST is a test assessing the temporo-spectral discrimination and ordering processed by the auditory cortex [23].

PPST consists of a series of three tones presented at either of two frequencies (880 and 1220 Hz). The test contains 60 units of different frequency patterns [24]. The participant's task was to name the pitch of each tone in the sequence.

Auditory Fusion Test-Revised (AFT-R): AFT-R measures the shortest separation between two tones that results in a listener's perception of a single stimulus rather than two separate stimuli. This minimum duration is identified as the auditory fusion threshold ($AFT^{\text{threshold}}$) and is measured in ms. $AFT^{\text{threshold}}$ is determined as the mean of the ascending and descending IPI that is perceived as a single fused stimulus [25].

Time Compressed Speech Test (TCST): TCST was designed to determine the individual's ability to process a speech signal that is presented at rapid rates, through reduction of signal's duration (compression) without undue distortion of its frequency characteristics [26]. The test was carried out using Arabic phonetically balanced monosyllabic word list [27]. This word list '25 words' was compressed at 45% time compression ratio using Audacity computer based program by the Audacity Team from Carnegie Mellon University, Pittsburgh, Pennsylvania, USA.

P300 event-related potential

Eclipse auditory evoked potential recording system was used to record the P300. The potential was evoked using a tone burst stimulus. The stimuli were presented using insert earphones, and the electrodes were positioned at Cz (vertex), A2 (right mastoid), and fpz (forehead). A sequence of acoustic stimuli was monaurally presented, with two signals of the same intensity (70 dB nHL) and different frequencies (1000 and 2000 Hz). Within the sequence, the frequent stimulus (1000 Hz) was triggered 80% of the time, and rare stimulus (2000 Hz) was triggered 20%, at a rate of 1.1/s [28]. Participants were instructed to count the rare stimuli perceived.

The analysis window was 600 ms with a low-pass filter of 17 Hz and high-pass filter of 1 Hz. Latency (ms) and amplitude (mV) values were analyzed in addition to visual analysis of the waves. P300 was considered to be the highest positive peak between 250 and 500 ms [28].

Remediation phase: Pitch Sequencing Training Program: Training sessions were performed in a quiet room. The training materials were presented from a Compaq-PC CD player and delivered through headphones. Training was started with an easy task, before shifting to the next more difficult phase. Each session lasted for 1–2 h.

Sessions were scheduled every second day for the entire 3 months.

- (1) In Pitch Sequencing Training program, three tones with specific frequency pairs were presented, separated by a certain interstimulus interval. The task was to sequence 'verbally' the presented tones in the same order. The tone burst stimuli used were recorded using CoolEdit 2000 computer based program by Adobe Systems Inc., San Jose, California, USA. These stimuli were arranged in temporal ordering pattern consisting of three tone bursts, two of them are similar in frequency. The temporal sequencing training program consists of five sequential phases. Each phase comprises 60 stimuli. For the participant to shift from one phase to the next, a correct score of at least 90% must be achieved [29].
- (2) A wide spectral difference between stimuli was applied primarily (2000 Hz) 'easy task' in the first training phase. Subsequently, the spectral differences between stimuli were gradually narrowed in 500 Hz step, to steadily increase the difficulty of the task, until a difference of 232 Hz is reached in the fifth (last) training phase.

Postremediation assessment: In this assessment, all behavioral and electrophysiologic measurements were re-evaluated after the end of the training program.

Results and discussion

The present study was conducted on 20 elderly participants, three (15%) men and 17 (85%) women who were complaining of poor speech discrimination. Participants' age ranged between 60 and 67 years, and they had either bilateral normal hearing [13 (65%) participants] or bilateral mild-moderate high-frequency sensorineural hearing loss [seven (35%) participants]. All participants were evaluated before and after the short-term AT program, regarding their temporal auditory processing abilities using a set of behavioral tests, P300 event-related potential as well as self-perception of auditory disability. Results of the study are presented as follows:

Amsterdam inventory for auditory disability and handicap

On comparing the performance of participants on the AIADH before and after AT, the difference was found to be statistically significant, as shown in Table 1. This indicates an improvement in communication in noisy environments after AT. In addition, some individuals reported improvements in their day-to-day living, especially regarding attention. This finding is in

Table 1 Comparison between preresmediation and postremediation phases according to Amsterdam Inventory for Auditory Disability and Handicap scores (n=20)

AIADH	Preresmediation	Postremediation	t	P
Minimum–maximum	59.0–89.0	45.0–82.0	15.147*	<0.001*
Mean±SD	76.4±8.71	68.0±9.80		
Median	77.5	70.5		

AIADH, Amsterdam Inventory for Auditory Disability and Handicap; t, P, t and P values for paired t-test for comparing between preresmediation and postremediation scores; *Statistically significant at $P \leq 0.05$.

agreement with previous studies that found an improvement in daily living following AT as reported by both patients and family members [30].

Behavioral assessment of auditory temporal processing abilities

Performance on Pitch Discrimination Test, Auditory Fusion Test-Revised, and Time Compressed Speech Test

All participants showed baseline normal scores on PDT (93.25 ± 3.35), AFT-R (13.75 ± 1.29), and TCST (94.6 ± 2.98) at the pretraining phase, and hence no significant change was found on comparing their performance before and after AT. These results suggest that some aspects of auditory temporal processing, like temporal resolution and temporal integration, could be spared during the aging process of the central auditory nervous system (CANS).

To date, the results of temporal resolution studies conducted with elderly listeners have produced equivocal findings. Several studies have reported small age-related deficits in gap detection thresholds and concluded that poorer temporal resolution does not seem to be a consequence of aging [31,32]. However, others revealed that older listeners' gap thresholds were highly variable and were two times greater than that of young listeners [33]. However, differences among these gap detection studies may reflect stimulus effects that can have an important influence on gap resolution in general.

Performance on Pitch Pattern Sequence Test

All participants in the present study had shown poor performance when the PPST was assessed at the preresmediation phase. Table 2 shows means and SDs of the PPST scores at preresmediation and postremediation phases. The difference between the performance of participants on PPST before and after AT was found to be statistically significant.

The processing of sequential stimuli may involve four basic components: pitch detection (or identification), temporal resolution, pitch discrimination, and

Table 2 Comparison between preresmediation and postremediation phases according to Pitch Pattern Sequence Test scores (n=20)

PPST (%)	Preresmediation	Postremediation	t	P
Minimum–maximum	28.0–43.0	40.0–78.0	18.344*	<0.001*
Mean±SD	35.0±0.04	67.0±0.10		
Median	35	69		

PPST, Pitch Pattern Sequence Test; t, P, t and P values for paired t-test for comparing between preresmediation and postremediation scores; *Statistically significant at $P \leq 0.05$.

temporal order judgments [34]. As all participants in the present study showed normal performance on pitch discrimination, temporal resolution, and normal scores on the cognitive function examination, temporal order judgment deficit with aging is thought to be the one responsible for the poor PPST results found in the baseline phase of this study.

Temporal ordering difficulties among elderly people have been corroborated by several studies. For all experiments, a poor performance was exhibited by the elderly listeners, a result that did not change across a range of stimulus presentation rates, or with increased practice. None of the results were correlated with the small differences in hearing sensitivity between elderly participants who were tested [35–39].

Following the short-term AT in the present study, performance of all participants (except two) on PPST had shown a substantial improvement. Eighteen (90%) of the 20 participants had completed successfully all phases of the training program in a duration ranged between 6 and 8 weeks and achieved an improvement (% of change) on PPST scores ranged between 77 and 123%. The remaining two (10%) participants could not complete the pitch sequencing AT program successfully. Accordingly, the program was stopped after 12 weeks (predetermined maximum duration). These two participants did not achieve more than 43% improvement (% of change) on PPST after AT.

The participants' improvement on the behavioral performance in the present study can be explained by the fact that brain has the ability to change and adapt based on individual auditory experiences, that is exhibits neuroplasticity which proved to occur even during the degenerative processes caused by aging.

Results of the present study are supported by a previous research, which reports a significant improvement in auditory skills after directed stimulation using a short-term AT in a group of elderly participants; this

improvement was observed through many behavioral tests, and PPST was one of them. They concluded that neuroplasticity is the intrinsic property of the nervous system that allows the development of structural changes in response to experiences and environmental changes [16]. Neural plasticity refers to changes in neural pathways and synapses, which are because of changes in behavior, environment, and neural processes [40].

In the human central auditory system, plasticity is altered by AT through repetitive listening tasks over a period of time [41]. Considering the difficulties experienced by older participants regarding auditory processing and pattern changes during poststimulation auditory processing, it is now believed that AT can promote changes in behavioral performance in elderly people for many auditory skills [42].

Electrophysiological measurement (event-related P300)

On comparing P300 mean amplitude value at preremediation versus postremediation phases, a statistically significant increase (11.80 ± 3.27) was revealed. In addition, a statistically significant shortening in P300 mean latency was also revealed when preremediation and postremediation values were compared, both are shown in the Table 3. Figure 1 shows P300 wave morphology of one patient at preremediation and postremediation phases, on which increased P300 amplitude (12.2 vs. 9.3 μ V) and shorter latency (293.1 vs. 334. ms) can be observed in the postremediation wave (B) when compared with the preremediation one (A).

The electrophysiological (P300) changes described in the present study suggest that, after AT, neurophysiological changes had occurred in the CANS. These changes probably occur in response to auditory experiences and manifest themselves through improved neural synchronicity and/or nerve cell specificity differentiation and reorganization and/or increase in the number of neurons responding to auditory information;

these changes are based on the plasticity of the central nervous system [41].

These results are in agreement with the findings of several studies which have demonstrated the effectiveness of auditory evoked potentials (short, medium, and long latency) to monitor the neurophysiological changes arising from AT [43–45].

Using late auditory evoked potentials to evaluate neurophysiological changes following AT, many studies have reported improvements in amplitude, latency, and/or wave shape after auditory stimulation. However, there is no consensus on whether amplitude or latency is more appropriate for confirming neuronal plasticity [45,46].

In contrast, Morais and colleagues investigated the efficacy of short-term AT in elderly patients through behavioral measures and P300 evoked potential. A significant difference was observed between the pretraining and post-training conditions for all auditory skills according to the behavioral methods. However, the same result was not observed for P300 potential measurements [42].

Correlational statistics

Correlation of participants' hearing levels with improvement on the Pitch Pattern Sequence Test results after auditory training

Table 4 shows a significant negative correlation between participants' hearing thresholds and the improvement on PPST scores after AT ($P=0.043$). This means that participants with the age-related hearing loss had achieved degrees of improvement on the PPST after AT less than that achieved with normal hearing participants.

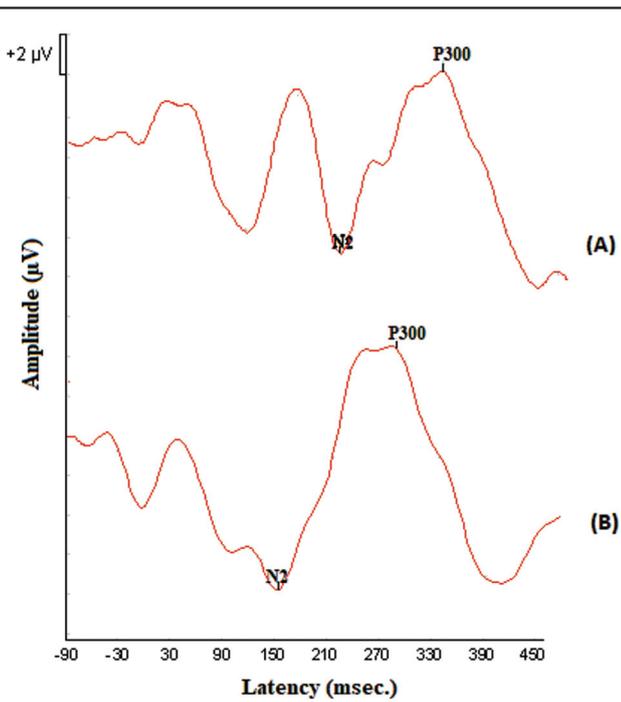
The present finding reinforces Strouse *et al.* [47] and others who reported that older adults (with or without hearing loss) have more difficulty than younger adults

Table 3 Comparison between preremediation and postremediation phases according to P300 amplitude (μ V) and latency (ms) (n=20)

P300 indices	Preremediation	Postremediation	t	P
P300 amplitude (μ V)				
Minimum–maximum	9.3–18.1	11.9–20.3	14.067*	<0.001*
Mean \pm SD	13.86 \pm 2.31	15.49 \pm 2.62		
Median	13.2	14.65		
P300 latency (ms)				
Minimum–maximum	334.8–376.5	293.1–370.8	14.912*	<0.001*
Mean \pm SD	354.81 \pm 13.03	350.09 \pm 13.36		
Median	351.9	346.8		

t, P, t and P values for paired t-test for comparing between preremediation and postremediation value; *Statistically significant at $P \leq 0.05$.

Fig. 1



P300 wave morphology of one participant at the pre-remediation phase (wave A) and post-remediation phase (wave B). Note shorter latency and greater amplitude of P300 potential after remediation.

Table 4 Correlation between hearing with percent of change in Pitch Pattern Sequence Test (%)

PPST (%)	Hearing thresholds		MW	P
	Normal (n=13)	HL (n=7)		
Minimum–maximum	79.07–123.33	34.38–103.03	20.0*	0.043*
Mean±SD	96.80±14.79	74.10±25.76		
Median	95.0	81.82		

MW, P, U and P values for Mann–Whitney test for comparing between the two groups; PPST, Pitch Pattern Sequence Test; *Statistically significant at $P \leq 0.05$.

perceiving temporal cues, and the presence of age-related hearing loss appears to compound the problem because older adults with hearing loss performed more poorly on auditory temporal evaluations than did older adults without hearing loss [11,32].

Correlation of the increase in P300 amplitude with the improvement on Pitch Pattern Sequence Test scores after auditory training

Table 5 shows a positive correlation between the increase in P300 amplitude with PPST improvement after AT ($r_s=0.437$, $P=0.054$). This is consistent with earlier studies which stated that AT led to changes in the central nervous system, confirmed by the improved performance of participants in the behavioral tests and by the changes observed in electrophysiological

Table 5 Correlation between percent of change in P300 amplitude (µV) with improvement on Pitch Pattern Sequence Test

	P300 amplitude (µV)	
	r_s	P
PPST (%)	0.437	0.05*

r_s , Spearman's coefficient; *Statistically significant at $P \leq 0.05$.

measurements [48,49]. Tremblay and colleagues showed that physiologic changes in central auditory function could be improved with training, and that behavioral changes are likely to follow neurophysiologic changes resulting from AT. Therefore, it was suggested that these neurophysiological measures would serve to determine the efficacy of AT [17].

To sum up, the present study was carried on a group of elderly participants who were complaining of poor speech discrimination. On the baseline evaluation, a central auditory processing deficit, specifically a temporal ordering deficit, was revealed in all participants. After directed stimulation using short-term AT, a significant improvement was observed in the temporal ordering skills, as demonstrated by achievements in the behavioral test as well as changes in the electrophysiologic (P300) measurements. We believe that neural plasticity is the intrinsic property of the CANS that underlies these behavioral and electrophysiological changes. However, the presence of age-related hearing loss appears to compound the problem, as older adults with hearing loss performed more poorly than those without hearing loss on the rehabilitative program.

Conclusion

- (1) Aging affects temporal properties of central auditory responses, resulting in deficits in behaviorally and electrophysiologically-assessed central auditory functions, even in the absence of any clinically significant elevation in pure-tone audiometric thresholds.
- (2) Short-term AT had provided a strategy to ameliorate auditory temporal deficits in older adults as participants demonstrated improved auditory temporal processing abilities at the end of the training.
- (3) Short-term AT resulted in changes in the amplitude and latency of P300, suggesting that P300 evoked potential may serve as an objective indicator of neurophysiologic changes in the central auditory system resulting from learning or auditory experience.

Recommendations

- (1) Short-term AT can be considered as an efficient rehabilitation tool in elderly people with auditory temporal processing deficit. Accordingly, auditory temporal processing abilities are recommended to be evaluated in all elderly people complaining of poor speech recognition.
- (2) The maintenance of treatment effects over time should be evaluated, using self-assessment and quality-of-life questionnaires, to confirm the incorporation of these improved auditory skills into daily life.

All authors have an experience in the field of central auditory processing disorders.

The manuscript has been read and approved by all the authors, the requirements for authorship have been met, and each author believes that the manuscript represents honest work.

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Conflicts of interest

There are no conflicts of interest.

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