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Effects of Auditory Training on the Development of Auditory Processing Skills in Individuals with Normal Hearing

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ABSTRACT

Objective: Central auditory processing, a function of the hearing system extending from the cochlea to the cortex; acoustic signals are processed by the central hearing system to make them meaningful. Auditory processing skills include mechanisms for sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition, auditory performance with competing acoustic signals, and auditory performance with degraded acoustic signals. Auditory processing disorder (APD) refers to a decrease in performance in one or more of these skills and difficulties in the perceptual processing of auditory information. To provide an alternative training model for supporting central auditory processing skills by applying training to improve auditory processing skills, comparing pre- and post-training performance to individuals with normal hearing with auditory processing problems.

Methods: In this study, 40 individuals (subject group (n = 20), control group (n = 20)) were included between 18 and 24 years of age who were found to have auditory processing difficulties although their hearing is within normal limits. Participants were given 4 hours of training each week for 3 weeks, and changes in pre-determined auditory skills (auditory memory, reading comprehension in noise, dichotic listening, etc.) of all individuals were evaluated. Frequency Pattern Test (FPT), Duration Pattern Test (DPT), Random Gap Detection Test (RGDT), and electrophysiological tests (P1-N1-P2 Complex and P300) were applied to all participants before and after training.

Results: There was a significant difference in FPT, DPT, and RGDT, P300, and P1-N1-P2 complex values pre- and post-auditory training (AT) ($P < .05$). In comparisons made before and after training, there was an improvement in the auditory performance after the training according to the AT follow-up program.

Conclusion: The AT program used in this study was found to be effective for improving auditory processing skills in individuals with normal hearing. It is thought that it would be useful to use the same program in the rehabilitation of individuals with hearing loss and APDs.

Keywords: Auditory late latency response, auditory processing, auditory training, duration pattern, frequency pattern

Introduction

One of the most important functions of the hearing system is to distinguish target acoustic stimuli from other stimuli during communication to ensure intelligibility of the message. The central auditory system, on the other hand, consists of neural structures at the level of and above the brainstem responsible for the transmission, analysis, and interpretation of this auditory information from the axons of spiral ganglion cells that synapse with hair cells to the upper center.[1] Functions of central auditory processing are localization and lateralization of sound, auditory discrimination, auditory pattern recognition, temporal processing, and increasing auditory performance with competing or degraded acoustic signals.

Temporal processing means the processing of auditory information over time. As the auditory stimuli change continuously, speech perception in quiet and noisy environments requires fine temporal processing. There are basically four types of temporal processing: temporal resolution, temporal masking,

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temporal integration, and temporal ordering. Temporal resolution refers to the ability of the auditory system to respond to rapid changes in verbal stimuli;[2] *temporal masking includes the ability to mask a sound before or after another sound. Temporal integration refers to the ability of the auditory system to collect information over time or to a critical time*.[3] Temporal ordering, also known as auditory sampling, is the listener's ability to distinguish acoustic components of sound.[4] Perceiving the prosodic properties of sound due to rhythm, emphasis, and intonation requires healthy temporal processing and temporal sequencing skills.

There are some highly sensitive and easy-to-perform tests to evaluate auditory temporal processing and ordering which are Frequency Pattern Test (FPT), Duration Pattern Test (DPT), and Random Gap Detection Test (RGDT). These tests are performed to evaluate hemispherical and interhemispheric central auditory processing function.[5] In addition, these tests are easy to perform and have high sensitivity. They are widely used for ear-specific evaluation and temporal processing.[6]

Electrophysiological methods to provide detailed information about the central auditory system are Audiotory Braintem Response (ABR), Audiotory Middle latency Response (AMLR), P1-N1-P2 Complex, P300, and MMN.[7] They are auditory evoked potentials which are neuroelectric activity generated by auditory regions located at levels of the brainstem, midbrain, and cortex in response to auditory stimuli.

Poor performance seen in one or more of the skills used by the central hearing system while processing auditory information is called central auditory processing disorder (APD). Subjects with APD have normal hearing but find it difficult to understand spoken language that is complex or under noisy conditions. They also have poor sound localization, impaired dichotic listening, and auditory perceptual deficits.[8]

Auditory training (AT), applied in cases of APDs, is an appropriate intervention approach that aims to improve the individual's speaking and listening skills through a variety of listening exercises.[9] Auditory training programs, which may favor bottom-up (analytical) and top-down (synthetic) approaches, aim to develop skills such as discriminating sound contrasts and detecting auditory cues by providing effective feedback to central auditory centres.[10,11]

Auditory training is a valuable intervention tool, especially for individuals with language impairment and APD. A continuum of AT approaches is recommended, including those that do not require instrumentation and can be applied by speech–language pathologists and audiologists through clinical practice. AT approaches are categorized as formal and informal. Official AT is run by a professional in a controlled environment.

Main Points

- Auditory processing skills can be increased with training.
- Individuals receiving auditory processing training experience changes in auditory cortical potentials.
- With auditory training, duration and pattern perception skills increase.

Informal AT can be conducted as part of a home or school management program for APD. Formal AT uses bottom-up tasks that are acoustically controlled, using tones and speech elements, as well as language-based or top-down tasks. Informal AT is designed to develop auditory-perceptual skills through language-based, predominantly top-down tasks. Combining formal and informal AT will maximize treatment effectiveness as skills are applied toward mastery and automatism in real-world settings that establish functional significance and provide repeated opportunities for skills generalization.[12]

In the study of Fuller et al,[13] AT was given to older adults who had relatively less hearing loss but had difficulty listening to noise. There is a new imperative to complement education to increase bottom-up processing of the signal, with more ecologically valid education to increase top-down information processing based on knowledge of language and words. It has been emphasized that the development of increasingly complex educational systems that include complex meaningful materials such as advances in digital technologies, music, audio-visual interactive displays, and speech will increase auditory processing skills.

The aim of the study is to provide an alternative training model for supporting central auditory processing skills by applying training to improve auditory processing skills and comparing pre- and post-training performance to individuals with normal hearing with auditory processing problems.

Methods

The study was approved by the İstanbul University-Cerrahpaşa Ethical Committee for Non-Interventional Clinical Trials (Approval No: 127729, Date: April 04, 2018) and was conducted in accordance with the ethical principles of the Declaration of Helsinki. Written consent was obtained after all participants were informed about the study.

Participants

This study included 20 adults with normal hearing between the ages of 18-24 (19.7 ± 0.97) years who complained of listening problems in everyday life. In addition, 20 participants aged between 18 and 24 years for the control group were included in the study.

All participants (control and study group) with normal otoscopic findings who had hearing levels of 20 dB HL or better at 500, 1000, 2000, and 4000 Hz in audiological evaluations, normal immitansmetric results, and good correlation of speech discrimination score and pure tone threshold were included in the study. The Turkish version of the University of Cincinnati Auditory Processing Inventory (UCAPI) was applied to detect APD and to include the participants in the control and subject groups according to the presence of APD.[14]

Procedure

Participants were assessed in three sessions (audiological assessment, behavioral auditory processing assessment, and electrophysiological auditory processing assessment). In order not to affect the performance of the participants due to fatigue, 10-minute breaks were given between the sessions. The whole procedure lasted 1 hour and 30 minutes.

Following audiological (pure tone audiometry 125-8000 Hz, speech audiometry), immitance, behavioral, and electrophysiological central auditory processing assessments, the subject group was given 4 hours of training and homework per week and a 10-step AT program was applied for 3 weeks. Although all steps of the training program were studied every week, all behavioral and electrophysiological central auditory processing tests (FPT, DPT, RGDT, P1-N1-P2 Complex, and P300) were applied to the subject group again after AT was completed.

For behavioral central auditory processing assessment, frequency pattern, duration pattern, and RGDTs were used. In FPT, 60 tonal stimuli at frequencies of 880 Hz and 1000 Hz with a duration of 200 msec were presented to participants who were asked to distinguish the sounds in terms of low or high. In DPT, 33 tonal stimuli at a frequency of 1 kHz, duration of 500 msec, and 250 msec were presented to all participants. They were asked to distinguish sounds in terms of length. In RGDT, dual tonal stimuli series with frequencies of 0.5, 1, 2, and 4 kHz were used. Gaps between stimuli were 0-40 msec, and these stimuli were presented randomly. The minimum detectable interval between stimulus pairs was determined at each frequency, and the responses of the participants were recorded as thresholds of gap detection. All tests were applied with Madsen® Astera² clinical audiometer.

For electrophysiologic evaluation, P300 and P1-N1-P2 Complex were used. P1-N1-P2 measurements were made by using the HEARLab device ACA module. Recordings were made in a quiet and comfortable condition while participants were awake and stable, 1 meter from the speaker placed at 0 degrees. / m /, / g /, and / t / speech stimuli were presented at 55 dB SPL intensity. / m /, / g /, and / t / speech stimuli are located in the low (0.25-0.5 kHz), medium (0.8-1.6 kHz), and high (2-8 kHz) frequency regions, respectively. To perform the P300 Test, a single-channel stimulus was presented to the participants by TDH-39 headphones. Before the test, the individuals were asked to pay particular attention to high-frequency sounds. Tonal stimuli were used at frequencies of 1000 Hz and 4000 Hz at 90 msec condensation polarity at 85 dB intensity level in the test. The probability of rare stimulation was determined as 30%. The probability of the standard stimulus was determined as 70%.

Auditory Training Program

After the pre-tests, AT was applied to the subject group for 4 hours a week for 3 weeks. Acoustic stimuli used in the exercises within the scope of AT were presented to the participants through Madsen® Astera² clinical audiometer.

The program consists of 10 parts:

1. **Auditory Memory:** In order to increase the permanence of acoustic information stored in the working memory, participants were asked to repeat sentences that have no context between words. Five-word distracting sentences were presented to participants at Most Comfortable Loudness (MCL). During this period, cocktail party noise was presented to create hard listening conditions. At the end of the period, participants were asked to repeat the sentence.
2. **Auditory–Visual Integration:** In order to increase the interaction between auditory and visual memory of the word, which is effective in the connection between Wernicke's gyrus and angular gyrus, groups of words that the participants had seen and heard were repeated. At first, nine words which are monosyllabic, disyllabic, and trisyllabic were presented to participants twice. After the presentation of stimuli, cocktail party noise was sent during 20 msec at MCL. Then, 18 pictures were given to participants. They were asked to select pictures of words in their mind. In the second step, 9 pictures were shown first. Participants looked at this picture for 10 seconds. Then pictures were taken back, and cocktail party noise was sent at MCL for 20 seconds again. After the end of the noise presentation, 18 words were said in sequence. Participants were asked to press the answer button when they heard words in the picture.
3. **Comprehension Reading in Noise:** Questions were asked to participants about the instructional text which was read in the presence of noise, and information processing skill in noisy environments was evaluated. The chosen text was read by participants in the presence of cocktail party noise at MCL level. Participants had 1 minute for reading. Texts consist of 200 words on average. After reading the text, 10 questions were asked to participants, and they were asked to answer these questions.
4. **Discrimination of Similar Words in Noise:** Acoustic stimuli that are difficult to process and perceive in noisy environments are studied for increasing participants' perception skills. Similar monosyllabic words are presented to participants at MCL level, and cocktail party noise is given at the same intensity level. In the meantime, similar words are presented through the loudspeaker, and then participants are asked to repeat them.
5. **Dichotic Listening:** The ability to perceive 2 different auditory stimuli presented simultaneously was studied. Disyllabic words were presented at MCL to 2 ears at the same time. Participants were asked to say words first from the right and then from the left in sequence.
6. **Accelerated Speech:** The increasing ability to perceive impaired acoustic stimuli was studied. A 20% accelerated version of a text was sent by an audiometer, and participants were asked to repeat the same at the end of each sentence.
7. **Localization:** In order to improve the ability of participants to determine the direction of sound, 0-360° azimuth speakers were used. A warble tone stimulus was sent in a random sequence to evaluate all directions in the 0-360° azimuth range, and the ability to determine the direction of sound in the presence of noise was studied.
8. **Auditory Pattern Recognition:** Discrimination ability of frequency and duration differences of the acoustic stimuli was studied. Stimuli consist of tonal stimuli at frequencies of 880-1000 Hz and durations of 250-500 msec. Twenty stimuli were presented for both time and frequency discrimination exercises. Participants were asked to repeat stimuli in the correct pattern order.
9. **Binaural Integration:** The ability to integrate binaural information in which the corpus callosum plays an important role was studied. Eight disyllabic stimuli were presented consecutively at MCL. The first disyllabic stimulus

was sent by the headphone's right side; the second disyllabic stimulus was sent by the headphone's left side, and the third disyllabic stimulus was sent by the headphone's right side again. When the presentation of the preceding stimulus ended, the next stimuli were sent instantly. This sequential presentation was continued during all disyllabic stimuli' presentation. After all stimuli were sent, participants were asked to repeat phrases that consisted of a combination of acoustic information from both sides.

10. **Recognition of Fresh Noise Stimuli in Presence of Speech Noise:** Improve participants' ability to perceive deviant stimuli and ability to divide attention were studied when a speech stimulus which is the dominant stimulus in the left hemisphere is used as a distracting continuous stimulus. At MCL, a conversation about any subject that has already been prepared was presented as noise. In the meantime, fresh noise stimuli (min. 2.19 msec - Max. 7.93 msec intervals) were embedded in this audio file. When participants heard the stimulus which was fresh noise, they were asked to press the answer button.

Statistical analyses were performed using SPSS version 21. The Mann–Whitney *U*-test and Wilcoxon signed-rank test were used for all comparisons. A significance level of $P < .05$ was considered statistically significant.

Results

The study included 40 (23 female, 17 male) normal-hearing individuals aged between 18 and 24 (19.7 ± 0.97) years.

P1-N1-P2 responses applied to all participants were applied to the subject group both before and after the training. The significance values obtained when pre- and post-training values are compared are given in Table 1. A statistically significant difference was observed in P1 latency and P2 amplitude for /m/ stimulus ($P = .032$; $P = .042$), N1 latency and the P2 latency for /g/ stimulus ($P = .008$; $P = .030$), and latencies of all wave components for /t/ stimulus ($P = .011$; $P = .036$; $P = .025$) between pre- and post-training.

P1-N1-P2 responses of the subject group before training were compared with the control group and significance values are given in Table 2. A statistically significant difference was found in P1 latency for /m/ stimulus, N1 latency for /g/ stimulus, and P2 latency for /t/ stimulus in the control group compared to pre-training ($P = .001$; $P = .024$; $P = .047$). The significance values obtained in P1-N1-P2 responses of the subject group pre-training compared with the control group are given in Table 3. A statistically significant difference was observed in P1 latency for /m/ stimulus in the control group compared to after the training ($P = .038$).

P300 Test was applied to all participants pre- and post-training for the subject group. Significance values obtained when comparing between groups in terms of latency and amplitude for P300 responses are given in Table 4. It was found that P300 latency was prolonged in the pre-training condition compared to the control group ($P = .044$). However, a significant improvement was observed in P300 responses after training, characterized by a shortening of latencies compared to pre-training ($P = .006$).

Table 1. Comparison of P1-N1-P2 Responses for Pre- and Post-AT

P1-N1-P2 Complex	P1 Latency	N1 Latency	P2 Latency	P1 Amplitude	N1 Amplitude	P2 Amplitude
/m/	**$P^a = .032$**	$P^a = .140$	$P^a = .601$	**$P^a = .225$**	$P^a = .614$	**$P^a = .042$**
/g/	$P^a = .061$	**$P^a = .008$**	**$P^a = .030$**	$P^a = .390$	$P^a = .970$	$P^a = .086$
/t/	**$P^a = .011$**	**$P^a = .036$**	**$P^a = .025$**	$P^a = .232$	$P^a = .852$	$P^a = .086$

P^a: It is *P* value of Wilcoxon signed-ranks Test.

Table 2. Comparison of P1-N1-P2 Responses for Pre-AT and Control Group

P1-N1-P2 Complex	P1 Latency	N1 Latency	P2 Latency	P1 Amplitude	N1 Amplitude	P2 Amplitude
/m/	**$P^a = .001$**	$P = .341$	$P^a = .482$	$P^a = .925$	$P^a = .705$	$P^a = .507$
/g/	$P^a = .070$	**$P^a = .024$**	$P^a = .060$	$P^a = .213$	$P^a = .735$	$P^a = .507$
/t/	$P^a = .060$	$P^a = .107$	**$P^a = .047$**	$P^a = .935$	$P^a = .735$	$P^a = .114$

P^a: It is *P* value of Mann–Whitney *U*-Test.

Table 3. Comparison of P1-N1-P2 Responses for Post-AT and Control Group

P1-N1-P2 Complex	P1 Latency	N1 Latency	P2 Latency	P1 Amplitude	N1 Amplitude	P2 Amplitude
/m/	**$P^a = .038$**	$P^a = .440$	$P^a = .925$	$P^a = .152$	$P^a = .715$	$P^a = .516$
/g/	$P^a = .498$	$P^a = .524$	$P^a = .705$	$P^a = .402$	$P^a = .425$	$P^a = .482$
/t/	$P^a = .776$	$P^a = .343$	$P^a = .579$	$P^a = .267$	$P^a = .871$	$P^a = .818$

P^a: It is *P* value of Mann–Whitney *U*-Test.

Table 4. Comparison of P300 Responses in Terms of Latency and Amplitude for Pre-At, Post-AT, and Control Group

P300	Pre-AT Post-AT Latency	Post-AT Control Latency	Pre-AT/ Control Latency	Pre-AT/ Post-AT Amplitude	Post-AT Control Amplitude	Pre-AT/ Control Amplitude
	P^a = .006	P^a = .946	**P^a = .044**	P^a = .391	P^a = .190	P^a = .091

P^a: It is *P* value of Wilcoxon Signed Ranks Test.

Table 5. Comparison of RGDT Responses to Ear Specific at Frequencies of 500, 1000, 2000, and 4000 Hz for Pre-At, Post-AT, and Control Group

RGDT	500 Hz (Left)	1000 Hz (Left)	2000 Hz (Left)	4000 Hz (Left)	500 Hz (Right)	1000 Hz (Right)	2000 Hz (Right)	4000 Hz (Right)
Pre-AT/Post-AT	**P^a = .000**	**P^a = .002**	**P^a = .001**	**P^a = .003**	**P^a = .000**	**P^a = .015**	**P^a = .046**	**P^a = .001**
Post-AT/Control	**P^a = .003**	**P^a = .013**	P^a = .903	**P^a = .002**	**P^a = .000**	P^a = .128	P^a = .416	**P^a = .022**
Pre-AT/Control	P^a = .161	P^a = .214	P^a = .091	P^a = .708	P^a = .679	P^a = .689	P^a = .332	P^a = .227

P^a: It is *P* value of Wilcoxon signed-ranks test.

Random Gap Detection Test is applied to all participants in the right and left ears separately; the gap detection threshold was determined at frequencies of 500, 1000, 2000, and 4000 Hz. Significance values obtained as a result of comparisons between groups are given in Table 5. A statistically significant difference was not observed when the control group and subject group pre-training were compared (respectively from left to right, from 500 to 4000 Hz, *P* = .161; *P* = .214; *P* = .091; *P* = .708; *P* = .679; *P* = .689; *P* = .332; *P* = .227). When gap detection thresholds pre- and post-training were compared, improvement in post-training responses at all frequencies was found to be statistically significant for both ears (respectively from left to right, from 500 to 4000 Hz, *P* = .000; *P* = .002; *P* = .001; *P* = .003; *P* = .000; *P* = .015; *P* = .046; *P* = .001). When the subject group and control group were compared post-training, a statistically significant difference was obtained at frequencies of 500, 1000, and 4000 Hz in the left ear and 500 and 4000 Hz in the right ear (respectively, *P* = .003; *P* = .013; *P* = .002; *P* = .000; *P* = .022).

When applied to the participants, the values obtained in FPT and DPT tests were compared between the groups, and the significance values obtained are given in Table 6. When the data obtained in FPT were examined, both the post-training group and control group displayed statistically higher auditory performance compared to the pre-training group (*P* = .000; *P* = .021). On the other hand, no statistically significant difference was found between the control group and the subject group post-training (*P* = .067).

Performances of participants recorded in the training program applied to the subject group were compared from week to week, and significance values regarding differences between performances are given in Table 7. When first and

Table 6. Comparison of FPT and DPT Responses for Group 1, Group 2, and Group 3

	Pre-AT/ Post-AT	Post-AT/ Control	Pre-AT/Control
FPT	**P^a = .000**	P^a = .067	**P^a = .021**
DPT	**P^a = .001**	P^a = .123	P^a = .056

P^a: It is *P* value of Wilcoxon signed-ranks test.

Table 7. Comparison of Training Program Performance for Week 1, Week 2, and Week 3

Training Program	Week 1-2	Week 2-3	Week 1-3
Auditory Memory	P^a = .355	**P^a = .011**	**P^a = .008**
Auditory-Visual Integration	P^a = .304	**Pp^a = .002**	**P^a = .001**
Comprehension Reading in Noise	**P^a = .001**	P^a = .265	**P^a = .015**
Discrimination of Similar Words in Noise	P^a = .060	P^a = .501	**P^a = .010**
Dichotic Listening	**P^a = .000**	P^a = .375	**P^a = .000**
Accelerated Speech	P^a = .058	P^a = .229	**P^a = .009**
Localization	**P^a = .031**	**P^a = .015**	**P^a = .000**
Auditory Pattern Recognition	**P^a = .040**	**P^a = .024**	**P^a = .004**
Binaural Integration	**P^a = .003**	**P^a = .008**	**P^a = .000**
Recognition of Fresh Noise Stimuli in Presence of Speech Noise	P^a = 1.0	P^a = 1.0	P^a = 1.0

P^a: It is *P* value of Wilcoxon signed-ranks test.

second weeks of education are compared; the improvement in performance in training stages of Comprehension Reading in Noise, Dichotic Listening, Localization, Auditory Pattern Recognition, and Binaural Integration was statistically significant (P = .001; P = .000; P = .031; P = .040; P = .003). When second and third weeks are compared; the improvement in performance in training stages of Auditory Memory, Auditory-Visual Integration, Localization, Auditory Pattern Recognition and Binaural Integration was statistically significant (P = .011; P = .002; P = .015; P = .024; P = .008). Compared to the first week of the education, the improvement in auditory performance was found statistically significant in all education stages (P = .008; P = .001; P = .015; P = .010; P = .000; P = .009; P = .000; P = .004; P = .000) except Recognition of Fresh Noise Stimuli in Presence of Speech Noise at third week (P = 1.0).

Discussion

Central APD (CAPD) refers to a dysfunction of the central auditory nervous system (CANS) that contributes to difficulties in the perceptual processing of auditory information.[15] There are studies in the literature on auditory and cognitive skills commonly observed in CAPD. This study aimed to create a holistic training program that includes both bottom-up and top-down mechanisms to support the auditory processing skills that were reported to be affected and to create a training program that would provide an effective improvement in processing skills in a short time. The effectiveness of the training program was examined using FPT, DPT, and RGDT, which assess temporal processing skills; P300 and P1-N1-P2 Complex tests, which assess cortical skills such as auditory attention and perception.

The effectiveness of the AT program that develops auditory processing capacity and listening skills is related to the minimum amount of time applied. There are different opinions in the literature regarding the effectiveness and duration of AT such as 4 sessions over 2 weeks (Iwarsson & Petersen, 2012), 58 minutes[16] or 7 hours.[17] Many studies, however, did not specify the length of training.[18] In this study, in contrast to the significant improvements observed in some sub-levels of AT in the first and second weeks, at the end of the third week of AT, a significant improvement was observed in the auditory performance in all education levels. As a result of these findings, it is thought that the education period should be at least 3 weeks (4 hours a week) in order to provide effective training services to individuals with APDs.

Individuals with CAPDs experience difficulties in auditory skills such as localization and lateralization, auditory discrimination, and auditory pattern awareness.[19] Some tests and surveys can be organized for screening purposes.

Musiek et al. conducted a study examining the auditory processing maturation with one hundred and fifty participants between the ages of 7 and 16 with normal hearing. According to the study, there is no difference between the right ear and the left ear in frequency and time pattern tests. There was no difference between men and women in terms of gender.[20] In our study, based on this study, gender and right-left ear factors were ignored.

In a study conducted with individuals with normal hearing, it was found that individuals performed better in FPT than in DPT.[21] However, in Tuz's study, participants observed higher auditory performance in DPT compared to FPT.[22] In this study, it was observed that in the study group before the training, higher performances were obtained in DPT compared to FPT, and findings supporting the results of Tuz's study were obtained. The lack of significant difference in the post-AT group was thought to be related to the fact that the improvements in FPT were found to be statistically significantly higher than DPT in the post-training evaluations.

The results of the RGDT in a study by Owens et al[23] show that young adults can detect the gaps between low-frequency stimulus pairs better than the elderly. In contrast, gap detection thresholds of young adult groups were evaluated specifically on frequency in our study, and it was observed that they were more successful than low frequencies in detecting gaps between high-frequency stimuli. Individuals with normal hearing can perceive gaps between 0 and 20 msec. Gap detection thresholds above 20 msec are considered pathological.[3] In the study conducted by Dias et al[24] on individuals with CAPD aged 5-25 years, decreased temporal resolution and low RGDT performance were observed in half of the 131 participants. Unlike the studies of Dias et al,[24] in the study, RGDT thresholds before and after training were found in the range of 0-20 msec. In addition, it was found that the RGDT performance improved with AT applied to the subject group (P < .05).

In the study conducted by Loo et al[25] with 39 children with CAPD between the ages of 7-11 years, it was observed that computer-based AT increased their processing skills in noise and real-life listening skills. In this study, it was found statistically significant that at the end of AT, participants showed improvement in their reading comprehension skills in noise.

All behavioral evaluation results in the study showed statistically significant differences before and after AT. The results show that AT applied in our study improves auditory skills such as auditory pattern recognition, localization, auditory and visual integration, and speech perception in the presence of rival stimuli. In the literature, findings supporting our study and observing positive improvements in auditory performance related to behavioral CAPD tests applied after AT programs were reported.[26]

Although behavioral CAPD tests can be used to measure the effects of AT on central auditory processing skills, auditory evoked potentials allow for a relatively more objective and sensitive assessment of training-related neurophysiological changes.[27] In this study, electrophysiological data suggest that neurophysiological beneficial changes probably occur in the central nervous system after AT. These changes likely occur in response to sensory experiences and are manifested by an increase in the number of neurons that respond to sensory information and/or differentiation, rearrangement, or an increase in neuronal specificity. These changes are based on the plasticity of the central nervous system.[28] Central nervous system plasticity is fundamental to success in AT, and specifically late latency auditory evoked potentials, P300, is a useful tool in monitoring central nervous system changes that occur after AT.[29,30] Alonso et al[31] applied AT to children with CAPD

and found that P300 latencies were shortened. The shortening of the latencies of P300 responses in our study was found to be statistically significant after AT compared to before and showed that AT induces changes in the central nervous system and provides benefits.

In the study, which investigated the effect of spectro-temporal psychophysical training on cortical responses in individuals with cochlear implants in 3 one-hour sessions for 1 week, no significant correlation was found, although there were some changes in N1 and P2 amplitudes after training.[31] In the study, unlike Barlow's, P1, N1, and P2 responses that improved with AT were obtained. In terms of amplitude, significance was obtained only in P2 for the /m/ stimulus; in terms of latency, statistically significant improvements were observed in P1 for /m/ stimulus, /g/ stimulus N1 and P2, and all wave components for /t/ stimulus. These findings, especially obtained in the /t/ stimulus simulating the high-frequency region, suggest that AT is more effective in improving the ability to process high-frequency auditory stimuli in the short term.

In future studies, although beneficial results in our study, it is recommended to conduct studies that investigate longer training periods, examine parameters such as hemispherical dominance, and use standardized inventories in evaluating the effectiveness of training.

Both behavioral and electrophysiological methods have shown that AT applied in our study is beneficial in improving auditory skills in individuals with normal hearing who are thought to have APDs. Also, it is predicted that AT, which improves auditory performance in individuals with normal hearing, will contribute to the development of auditory skills and speech perception in difficult listening conditions in the presence of CAPD comorbidities or hearing loss. The fact that AT is versatile and supports complex auditory skills in a holistic manner has led to effective results in a short time. Considering the lack of commonly accepted approaches to CAPD in the literature, it is thought that our study and AT can guide CAPD in the process of the clinical approach, rehabilitative applications, and management services.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

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