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REVIEW ARTICLE

Efficacy of auditory training in older adults by electrophysiological tests

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Abstract

Background and Aim: Most elderly people in noisy environments complain of speech comprehension. At present, hearing aids or cochlear implants are the main treatment options. However, these devices merely enhance sound audibility and do not compensate for central processing changes caused by aging, hearing loss, or cognitive decline. This article reviewed plasticity topic in the auditory system and the use of auditory evoked potentials to prove the effectiveness of auditory training.

Recent Findings: The search for relevant articles in the Google Scholar, PubMed, Springer, and ProQuest databases was conducted with the keywords of “auditory education,” “electrophysiology,” “plasticity,” and “aging.” A total of 107 articles were found with these keywords, and finally, 98 articles, published between 1977 and 2018, were used. Existence of plasticity in the central auditory system, regardless of age, has been proven. Therefore, cognitive and auditory training to reduce cognitive problems and improve central hearing processing in appropriate cases can positively affect the quality of hearing and social communication of the elderly. Because efficacy is an important component of any therapeutic approach, the assessment of the benefits of hearing training can be demonstrated by electrophysiological tests.

Conclusion: Auditory training may play an important role in the elderly treatment program with speech perception defects. The usefulness of this rehabilitation can be objectively evaluated through cortical and subcortical electrophysiological methods.

Keywords: Auditory training; electrophysiology; plasticity; aging

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Introduction

Aging is one of the main challenges of human societies and due to the promotion of the health system, the population of the elderly is rising all over the world. The number of people aged 65 years and older will increase from 516 million in 2009 to 1 billion in 2030, which calls for special attention in all areas of health, including hearing ability [1]. The aging process affects the central nervous system (CNS) with the greatest effect on the prefrontal area and the smallest on the occipital lobe [1]. The impact of aging on the central auditory nervous system [2] is very

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tangible [2] and the most pronounced hearing auditory disorder in the elderly is speech perception deficits in the presence of background noise [3,4].

Several biological causes are accounted for reducing this ability, including the loss of myelin integrity [5], prolonged neural refractory times [6], decreased brain connectivity [7], decreased inhibitory neurotransmitters [8], and the loss of nervous synchrony [9].

Weak speech perception in the presence of background noise is a common complaint of people referring to audiology clinics. Although speech perception in the presence of background noise reduces in all individuals, this problem is more noticeable in people with auditory processing deficits and in elderly people [10,11], in other words, aging has a major impact on the ability to understand speech in challenging environments such as background noise, presence of several speakers, reverberation condition, and dichotic listening [12]. Defects in speech perception, due to its role in verbal communication, affects the quality of individual and social life of the elderly and can lead to loss of social communication, reduced job productivity, isolation, negative behaviors, anxiety, and eventually cognitive impairment [4,13,14].

Sensory deprivation and plasticity

Regardless of age, plasticity in the central auditory nervous system (CANS) is a proven feature, and with auditory/cognitive training, cognitive deficits can be reduced and the central auditory processing in appropriate cases can be improved. This training has a positive effect on the quality of hearing and social communication of the elderly. Moreover, efficacy is an important component of any therapeutic approach, and assessment of auditory training benefits can be demonstrated by electrophysiology tests.

Amplification is usually the first recommendation for people who experience speech perception difficulties. Despite tremendous advances in hearing aids technology, including digital processing, noise reduction technology, directional microphones, and improved feedback management, elderly are still continuing to struggle with hearing problems in noisy environments [4,15,16]. Although the hearing aids enhance audibility, speech perception is influenced by the processes beyond the peripheral auditory system. Perception of the acoustic signal is influenced by the coding and integration of signals at the levels of the auditory system as well as the cognitive system [15].

All signals entering the auditory system, including the most important ones, i.e. speech, pass through a series of bandpass filters. The output of each filter is in two forms of the general fluctuations of the sound phenomenon over time, i.e. envelope and temporal fine structures [17]. The envelope reflects slow amplitude fluctuations that convey vowel formant information, loudness, the manner of articulation, and voicing information [18]. The temporal fine structure reflects faster fluctuations of sound pressure that convey spectral information and play a role in listening in the presence of background noise [19]. Sensorineural hearing loss affects the representation of the envelope and temporal fine structures of speech in the auditory brainstem [20]. Inadequate sensory stimulation in both qualitative and quantitative terms damage perception and cause sensory deprivation [21]. Webster (1977) showed that hearing sensory deprivation impairment reduces the number of auditory sensory neurons in the brainstem [22]. Studies indicate that both features of temporal fine structure and envelope are important for speech recognition so that in a quiet situation, one of these two features is sufficient to understand speech, but to understand speech in a noisy environment, both of these features are essential [17,23].

The results of brain imaging and electrophysiological studies in humans and other mammals show that in the brain stem and auditory cortex neurons are sensitive to both temporal envelope and temporal fine structure [24]. Too much encoding of the envelope and too little encoding of the temporal fine structure have been reported in the auditory nerve and midbrain of chinchilla. In the hearing-impaired elderly, there is an imbalance between the representation of these two qualities, so that the envelope is represented more often and the temporal fine structure decreases [25,26]. Studies have shown that auditory training significantly reduces the envelope encoding in the hearing-impaired elderly so that the difference in the representation of envelope between hearing-impaired and normal people is reduced or eliminated [15,27]. Because the CANS of the human is plastic and flexible, rehabilitation methods were used to treat CANS disorders [28].

The plasticity of the central auditory system has been investigated in various studies and two important factors of time and stimulation (input) in plasticity have been mentioned [23,29-31]. Because sensory and cognitive systems interact with each other at the core level, the highest degree of plasticity is reported in the cortex [30]. In the early years of human development, neuroplasticity reaches its highest levels due to developmental physiological changes. Neurons in the area of visual, auditory, and prefrontal cortex proliferate rapidly in the first 3.5 years of life [32,33]. This growth leads to increased synapses or connections between neurons. Rapid myelination of axons occurs during this time as well. Neurotrophins are a family of proteins that play a major role in plasticity in both the peripheral and CNS, and these activity-dependent proteins are largely responsible for molecular changes within the neurons and changes in neuronal connectivity such as axonal branching, dendritic modification, and mediation of a number of synapses [34]. Once excitatory activity (i.e. long-term potentiation) was considered to be the main factor of development and plasticity, now it appears that inhibitory activity in the CANS also plays a role in plasticity [34]. The auditory system plasticity was also found in studies that examined linguistic and musical experiences [35]. Plasticity is referred to as changes in neuronal cells for better adaptation to environmental changes, and these changes are usually associated with behavioral changes [10]. Auditory training and other behavioral interventions can be justified on the basis of Hebb's (1949) theory [36] that long-term potentiation (LTP) is the mechanism responsible for learning and memory, leading to increased synaptic activity, thereby facilitating behavioral changes, and these changes can be measured even months after discontinuing stimuli. The types of plasticity are briefly summarized [37] as follows:

- Developmental plasticity is the result of the maturity of the nervous system and it occurs by establishing more communication between neurons and progressing myelination. Depending on the stimulus, the rich stimulation increases the speed of the development.
- Compensational plasticity occurs during damage to the nervous system, during which other areas of the brain will take over the affected area.
- Learning-based plasticity is obtained through exercise and training. Achieving success in auditory training is most likely due to learning-induced nerve plasticity.

With the development of neurological studies, our knowledge about the phenomenon of sensory deprivation and its complications, as well as the plasticity feature of the nervous system (hearing) have been increased. In the meantime, with the development of technology, auditory training has been combined with the hearing aids programs. Studies on animal and humans have shown that success of auditory training programs depends on the neural plasticity, in other words, the CNS must be plastic and flexible [10]. Progressive negative behavioral changes in normal aging are accompanied by a complex series of physical and functional declines expressed in the cerebral cortex. In a study conducted on the A1 region of the rats' brains, the rats who received an auditory temporal discrimination training, compared to the control group, showed a higher level of parvalbumin and the somatostatin inhibitory neurons. Results indicate that a simple form of training in younger rats slows down the natural course of age-related changes compared to the control group and produces lower auditory brainstem response (ABR) thresholds with evident training impacts on the hippocampus [38].

In another study localization cues for the bat were changed by reducing the amount of stimulation to one ear (with the insertion of the mold in the ear). In the beginning, the ability to localization in the animal decreased, but its performance gradually returned to normal because the CNS adapted itself to this new stimulation pattern. When the mold was removed from the ear and the one-sided reduction was corrected, the localization function was disrupted again and an abnormal anatomical projection in the auditory cortex was observed [39]. If the animal is repeatedly exposed to acoustic stimulation, its LTP increases and thus improves the ability to understand repeated stimulation. The auditory training and other behavioral interventions increase synaptic activity, thereby facilitating behavioral changes, and, as noted, even after months of terminating continuous interventions, can still be tracked. These findings clearly indicate that long-term survival is observed immediately after treatment. The results of stimulation-training on animal models in the CNS suggest that neurophysiologic effects in humans are possible [10].

Auditory training

Auditory training is a set of acoustic conditions or audio exercises whose purpose is to activate the auditory system and other related systems to improve recovery and performance and related behavior [40]. Systematic auditory training programs have begun with Itard's efforts since the 18th century [10]. After World War II, and because of a large number of soldiers returned with hearing impairment, auditory training was considered a method of treatment by scientists such as Carhart and Ling [3]. There are different views on the type of auditory training, but the focus of all methods is to promote patient communication skills. Of course, given the wide range of auditory and learning defects associated with auditory processing disorder, auditory training should only be considered as part of the comprehensive management of auditory processing improvement.

The auditory training theory is based on the brain's plasticity in response to auditory stimuli [41]. Brain's plasticity creates new pathways and neural networks whose frequent use, are represented in everyday life and behavior. Neurophysiologic studies using auditory evoked potentials have proven the changes caused by auditory training in the auditory cortex [42,43].

Nevertheless, neuroplasticity is not necessarily limited to the cerebral cortex. Generally, it is believed that there is also subcortical plasticity but it is of short-term kind. However, the association between sounds with their meanings in the cerebral cortex causes long-term changes in the cortex, as well as interactions between the afferent and efferent pathways [44]. Based on the plasticity of the CNS, studies have been done in the area of elderly auditory training. For example, Song et al investigated the effect of auditory training on improvement speech in a noisy environment on the elderly people [45]. Although the benefits of plasticity have been identified, many questions about optimal auditory methods are still unanswered. For example, what aspect of perception changes when speech recognition improves, how long should be the duration of hearing training, whether there is a difference between the elderly and the younger, what can be done to better accept auditory training, and what aspects of computer-based programs are responsible for recovery. Questionnaires, behavioral tests, imaging methods, and electrophysiological tests are used to evaluate neuroplasticity.

Electrophysiology tests

Auditory processing from the eight nerve to the auditory cortex can be measured by auditory brainstem response (ABR) tests; Auditory Middle Latency Response (AMLR); and auditory late latency response (ALLR) such as P300 and mismatch negativity (MMN) [27,46,47]. Several studies have documented the effect of auditory training on improving speech processing, as well as improving behavioral outcomes [48,49]. Auditory training leads to a significant improvement in behavioral functions [50-52]. This improvement could be due to the reorganization of learning-dependent nerve cells that promote or build new neural communication after auditory training [28]. Objective electrophysiologic changes somewhat confirm the results of rehabilitation without intervening the behavioral response. It is a relatively simple method for fast tracking of the outcomes. Since neurophysiologic changes resulting from auditory training precede behavioral changes, these tests are preferred to behavioral evaluations [53]. Contrary to speech tests and other behavioral hearing processing tests, auditory evoked potentials can be recorded regardless of linguistic level, stress, attention, and motivation.

Changes in auditory brainstem response during auditory training

ABR is one of the auditory evoked responses that is recorded in response to short-term transient acoustic stimuli (such as a click). It is originated from the eight nerve and auditory brainstem structures. This response consists of 5 to 7 peaks that show the function of the nucleus and the auditory nerves pathways. In clinical conditions, the effects of various brainstem involvement often affect the latency or interpeak interval of the ABRs and the high precision in distinguishing normal cases from abnormal is the main reason for using this test along with other clinical assessments [54,55]. The limitation of this test is its performance with very short-term acoustic stimuli and the inability to respond to natural stimuli with a long duration, such as speech, resulting in a lack of coordination of its outcomes with behavioral tests. In a study on seven high-frequency hearing loss patients, the results of auditory training did not show any changes in the waves of ABR, but the results of the behavioral tests showed a significant improvement [46,56]. Many researchers have reported that neuroplasticity is common in cortical regions, so few studies have used this response to examine changes resulting from hearing impairment [57]. The main functions of the CANS are nerve encoding of speech sounds. The speech signal is composed of long duration, spectral, and temporal characteristics, and it is difficult to check electrophysiology and hence the use of speech stimuli has its own advantages and limitations. One of these semi-speech complicated stimuli, which has a relatively limited duration (40 ms), is synthetic syllables like /da/. In the ABR record in response to synthetic syllable /da/, two broad classes of time-locked responses can be defined within the brainstem, namely transient and sustained. Transient and periodic stimulus features evoke transient responses, whereas periodic features elicit sustained phase-locked responses [58,59]. This stimulus evokes seven characteristic response peaks that we have termed V, A, C, D, E, F, and O. They are related to major acoustic landmarks in the stimulus. The auditory training improves the nervous system encoding of speech signals in the elderly. Anderson and Jenkins used the auditory-based cognitive program to assess subcortical neuroplasticity in the elderly people. They recorded frequency-following responses to the speech syllable /da/ in the silent and noisy environment before auditory training. The auditory training program was designed to improve the speed and accuracy of auditory processing and took eight weeks. After auditory training, the latencies of the peaks of the frequency-following responses were formed earlier and interpeak variability in noise decreased. The results indicate that the responses to the destructive effects of the noise are more resistant. Along with these results, speech in noise test function and short-term memory and processing speed were also studied. The improvement was observed in all tests in the auditory training group [15].

In the study of Anderson and Kraus, the subcortical representation of two components of the speech signal (temporal envelope and temporal fine structure) were evaluated before and after the auditory training. Before the intervention, it was found that older people with hearing loss showed an exaggerated representation of the temporal envelope and lower representation of the temporal fine structure. Following auditory training, there was a significant reduction in the envelope encoding in the people with hearing loss to the extent that differences in the envelope representation between individuals with and without hearing loss were eliminated. This reduction was not seen in normal-hearing listeners and the control group [25]. In the study of Song et al, after administrating the listening and communication enhancement (LACE) hearing program on 60 individuals aged 19–35 for 4 weeks, 5 days a week, and 30-min auditory training sessions, brain stem responses with speech stimuli were studied in a quiet and noisy background. The results indicated stronger representation of the fundamental frequency (F0) only in noise but not in the quiet environment, suggesting that the auditory training increased the robustness of subcortical speech representation and making it more resistant to the degradative effects of noise [45]. In the study of Sweetow and Sabes, the behavioral results of the LACE auditory training were also significantly improved on 65 people aged 28–85 years old. The results indicate that auditory training improves central processing and to some extent compensates for age-related and hearing changes in auditory function [60].

Changes in the auditory middle latency response during auditory training

The auditory middle latency response (AMLR), appear about 10 to 50 ms after the stimulus is presented, reflecting the activity of the primary auditory cortex. Its four main waves are Na, Pa, Nb, and Pb. These responses originate from thalamic hearing nuclei, primary and secondary cortical areas and reticular formation [61]. This test is less dependent on synchrony compared to ABR, and it mainly assesses the thalamus and the beginning of the auditory cortex and is less affected compared to the late auditory responses by the cognitive and mental state of the individual [62]. The best example of the application of AMLR is in neurological disorders and central auditory processing disorder (CAPD). So it is a good tool for measuring the thresholds of hearing at low frequencies, functional hearing loss assessment, and higher levels of auditory functions [63-65]. The AMLR amplitude is large and has a significant binaural interaction component (BIC). Therefore it is expected to display the activity of the neural structures that process the binaural information. In the study of Lotfi et al., the results of auditory lateralization training on BIC wave indicated an increase in BIC amplitude but decrease in latency of BIC wave reflecting the neurological changes due to hearing impairment [64]. A study by Schochat et al. aimed to determine the changes in the middle auditory potentials following auditory training in children with CAPD, the AMLR amplitude increased after auditory training which expressed auditory plasticity [66]. In the study of Chamberz after auditory training, the peak to peak amplitude of both Pa and Pb waves in the elderly group was significantly increased [67].

Changes in the auditory late latency response during auditory training

Late latency auditory evoked response or auditory late latency response (ALLR) is revealed after 50 ms and consists of positive and negative waves: P1, N1, and P2. The N1-P2 complex is theoretically of particular interest because its existence confirms the detection of the signal in the cerebral cortex and is only apparent when the transient auditory stimuli are audible [27]. The N1-P2 complex is one of the main components of event-related potentials (ERP) and can be used to reflect the representation of speech sounds in a central auditory system without an active human interfere. Increasing the amplitude of N1-P2 reflects the increase in neuronal synchronization, and changes in nerve discharge patterns that occur with the changes in behaviors, are consistent with the principles of Hebbian neuroplasticity [68,69].

The results of the Tremblay and Kraus research on seven normal subjects to differentiate between two stimuli with different voice onset time (10 and 20 ms) showed a change in the N1-P2 wavelength after auditory training. Of course, the display of these changes was different in each component of this wave. The wave amplitude of P1 reduced in the frontal electrode and the N1 wave amplitude increased in all other electrode locations. Changes in N1 and P1 were observed only in the right hemisphere and P2 changes in both hemispheres. The researchers' inference was that learning evidence is more acoustic-processing than linguistic processing and changes in the N1-P2 wave amplitude have been the result of an increase in neuronal synchronization after acoustic evidence-based training [42].

In a study by Reinke et al., the time domain of neurological activity related to the isolation of vowels was investigated simultaneously. The results confirmed the behavioral outcomes and indicated an increased ability of the listeners to identify both vowels by increasing the difference between the two vowel fundamental frequencies. It was also found that the listeners' ability to identify two vowels improved simultaneously with training, and this improvement is associated with a decrease in the latency of N1 and P2 waves and an increase in the P2 amplitude [70]. The N1-P2 complex reflects synchronous neural activity from thalamic-cortical structures within the CNS in response to the auditory stimulus. Out of this, the neurological changes can be used to monitor any type of auditory training [53,68,69].

Mismatch negativity changes in auditory training

This wave represents a kind of pre-attentive encoding in the central processing of very small differences in auditory stimuli. In the ALLR test, during the presentation of some repetitive aspect of stimuli such as intensity, frequency, duration, or phonemic characteristics, if a discriminable change occurs in the stimulus, a negative component, deeper than the N1, is elicited about 100 ms after the stimulation onset. It is recorded after N1, in the P2 area [71]. This wave may be seen as enlarged N1 [72]. MMN is also evoked without the attention of the person being tested and is an objective and very good indicator of auditory discrimination ability [73]. The anatomical origin of this wave is the auditory and forehead cortex. Clinical applications of MMN can be used to monitor the effects of auditory rehabilitation and early diagnosis of central disorders. Although MMN provides information on the physiological processes of speech and plasticity from auditory training, this response cannot be regarded as the most effective response to the examination of the representation of speech sounds [74,75]. Extracting this response from electroencephalic noise is difficult and it often takes a long time to do the test and offline analysis. In one study, MMN test was used to prove the efficacy of auditory training. The subjects who studied one month after auditory training showed a significant increase in speech discrimination [69]. In a study after a 5-day training period, MMN responses increased, indicating an increase in neural perception of syllable differences, and this training was also generalized to an untrained alveolar syllable [53]. The MMN test is used to evaluate the time course of neuroplasticity. In a study, 10 elderly people were trained to discriminate two syllables on the basis of voice onset time (VOT), so that on days 1 and 2, testing was conducted to establish test-retest variability for neurophysiological and behavioral measures and follow-up testing was performed on days 4, 6, 8, and 10, alternating with training on days 3, 5, 7 and 9. In all subjects, the auditory training led to changes in MMN responses (duration, area, and latency). These results suggest that electrophysiologic measures may be used to predict behavioral gains [68].

P300b changes in auditory training

If during the ALLR test, the presentation of a uniform stimuli chain, a rare change in the acoustic components of the stimulus, such as frequency, intensity, latency, and response to speech stimuli, such as phonetic changes (oddball), occurs in case of individual attention to this change, the P300b wave is recorded. Since the presence of the P300 wave represents the detection and processing of the difference between the standard and the deviant stimuli, it is often referred to as a cognitive evoked response. This response is influenced by higher cognitive functions, including attention and memory [76]. P300b is affected by test parameters such as stimulus type, inter-stimulation interval, type of tasks, cognitive factors (memory and attention), hormonal factors, and so on [77,78]. These features may change in older people and consequently change test results [12]. In two studies after the auditory training program, wave latency was significantly different [79,80]. However, in another study after auditory training, despite changes in behavioral responses, no

Table 1. Some studies on the efficacy of auditory training by electrophysiologic tests

Authors	Year	Study population	Assessment tool	Outcome
Santos et al. [46]	2014	76 subjects 46–57 years	ABR	A significant difference was observed
Anderson and Kraus N [25]	2013	58 subject, aged 55–79 years	Speech ABR	Decrease envelope representation after rehabilitation
Song et al. [45]	2012	60 subject 19–35 years		Stronger F0 representation in noise
Chambers [67]	1992	27 subject	AMLR	Significant increase in Pa, Pb amplitude
Reinke et al. [70]	2003	16 subjects 19–34 years	ALLR	Decrease the latency of N1 and P2 waves and increase the amplitude of P2
Song et al. [45]	2012	60 subject 19–35 years		Stronger F0 representation in noise
Chambers [67]	1992	27 subject	AMLR	Significant increase in Pa, Pb

significant change was observed in P300 results [12]. In Table 1, examples of studies on the efficacy of auditory training using electrophysiologic tests are presented.

Discussion

The speech perception difficulties experienced by older adults cannot be entirely attributed to the peripheral deficits, rather a combination of audibility of acoustic stimuli, higher-order neural processing within the CNS, and cognitive function play a role in this perceptual impairment [81,82]. Compared to younger ones, older people experience more hearing difficulty in the presence of background noise [82,83]. Animal and human studies on the effect of age on the auditory system confirm the theory that slower neural processing is associated with subcortical timing, so it is an important factor in the ability to understanding speech is in the presence of noise [6,84]. In addition, the exact timing of both spectral and temporal aspects of speech is necessary to identify the target in the presence of other speakers [85]. In various behavioral studies, the evidence has been found suggesting temporal processing disorder in the elderly, but its neural mechanisms have not yet been fully identified [86-90]. The reduction of neural fibers [91,92], the change in the balance of inhibitory and excitatory neurotransmitters [8], and the prolonged neural refractory times are the possible factors for loss of temporal processing [93]. A hearing aid cannot compensate for the age-related hearing loss in temporal processing and tonotopic reorganization with other neurological changes. Therefore, it is essential to consider ways to eliminate the communication deficits caused by the central auditory processing deficit. Due to the characteristic of neuroplasticity, continuous auditory stimulation during auditory training affects the function of the auditory system and leads to positive behavioral changes [94]. At present, the number of sessions and duration of rehabilitation for optimal and ideal auditory training have not been determined [95]. Due to the differences in auditory training duration, the number of sessions, type of stimulus, and methods of auditory training, the comparison between some studies is difficult. Proof of rehabilitation results with electrophysiological changes is a relatively simple way to quickly follow up the results. According to the method, the stimulus type, and the purpose of the auditory training, an appropriate electrophysiological test must be selected [15]. Each of these tests has its own advantages and limitations. Frequency-following response [96], which is the potential source of the inferior colliculus, is used to examine the efficacy of auditory training [97]. It has a good test-retest reliability similar to the ABR [98,99]. However, by repeating the stimulus during recording, spectral amplitudes of FFR may increase [100]. Various studies have shown that the changes are specific to training and are more resistant to passive exposure than cortical potentials, with a precision of milliseconds, so it is used in clinical diagnostics [15,25].

ALLR are used to evaluate the neurophysiological changes following auditory training. Several studies have reported improvements in amplitude, latency, or waveform after auditory stimulation. However, there is no general consensus on which of the amplitude or latency criteria is more appropriate for verifying neuroplasticity [42,43]. MMN provides information on the physiologic processes of speech discrimination and the plasticity of auditory training and is used to assess the time of plasticity [15,93]. However, the extraction of this response from electroencephalic noise is difficult and often requires a long time to do the test and offline analysis. The P300 test is also influenced by various factors [78] like the ABR test and is not used to evaluate the efficacy of auditory training in the elderly.

Overall, research results show that electrophysiological tests can be used to predict behavioral outcomes. According to neural plasticity ability, in designing the auditory tasks, the ability of the existing auditory system function, especially with regard to the age of elderly people to train the auditory process should be considered and appropriate stimuli and functions should be used. Tasks should be systematically presented and the difficulty of the exercise be gradually increased to be challenging and motivating. Also, the clinicians should identify the appropriate criteria for each patient. Although evoked potential tests can be used to assess the effects of auditory training even in short-time scales, it is important to use this information when it comes to decide on continuing of the intervention. However, longer sessions seem necessary to generalize and maintain the effect of auditory training.

Conclusion

The plasticity of the central auditory nervous system remains until older adulthood, suggesting that auditory training can play an important role in the therapeutic remediation of older adults with speech perception deficits and improves neural encoding, including speech signals in noise, and these improvements are associated with enhanced abilities in behavioral speech performance measures. These benefits can be objectively measured using both subcortical and cortical electrophysiologic methods.

Conflict of interest

The authors declared no conflicts of interest.

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