

## REVIEW ARTICLE

# Auditory processing and auditory rehabilitation approaches in autism

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### Abstract

**Background and Aim:** Concerning the prevalence of autism spectrum disorder, many studies have examined the various aspects of this disorder. One of the major problems in autism is the sensory processing deficit, and in particular the abnormalities of auditory processing. In this review article, we have tried to explain the neurological features of auditory processing and abnormalities in auditory evoked responses in autism, finally recount some of the main methods of auditory rehabilitation.

**Recent Findings:** We searched for articles in databases with keywords of “autism,” “auditory processing” and “auditory rehabilitation.” A total of 102 articles were initially found in this field. Some articles were not about our study topic, thus in the end, only 79 articles were entered the study published from 1989 to 2018. Based on these studies, autism associates with a weakness in sensory integration due to abnormal interactions between different neural networks. This condition of auditory modality are being manifested as different abnormalities in evoked responses, especially for complex stimuli at the level of the brainstem and cortex.

Language and speech problems are prevalent in many patients with autism, which has already been mentioned in numerous studies. To treat these deficits, appropriate auditory rehabilitation techniques (often using music to improve the symptoms) have been developed.

**Conclusion:** In order to know more about autism and adopt appropriate interventions, doing audiometric, behavioral and electrophysiological evaluations are recommended on a regular basis. Rehabilitation in this disorder generally include music therapy, signal-to-noise enhancement strategies, and cognitive behavioral therapies.

**Keywords:** Autism spectrum disorder; auditory processing; auditory rehabilitation

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### Introduction

Autism is a developmental disorder with increasing prevalence [1,2] which is characterized by impairments in social and linguistic interactions. The patients also have stereotyped behaviors and limited interests. These people are disabled to understand and respond to social and emotional signals. This situation is likely caused by disconnection in the function of the networks involved in social cognition and behavioral

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control, which leads to impairment in the integrity of sensory information [1,3].

Sensory processing changes, especially the auditory sense, have a wide range in autism spectrum disorder (ASD), and based on neurobiologically-based theories, abnormalities in the processing of time features of sensory inputs can contribute to the main complaints in this disorder [4-6]. Abnormalities in the processing and integration of sensory inputs cause unusual sensory responses and socio-cognitive impairment in patients with autism [3,7-9]. Sensory symptoms in patients with ASD include atypical sensory sensitization (hypersensitivity or hyposensitivity), which seems to be more prevalent in the auditory domain [10]. It should also be noted that in patients with autism, simple sensory stimuli processing is usually normal or sometimes enhanced, but the processing of complex stimuli is often significantly abnormal. For example, auditory tasks such as simple stimulus (pure tone) and low-level functions (such as detection and labeling) that are processed in the primitive auditory cortex can be done well in the ASD. But functions requiring higher levels of auditory processing (evaluation, attention), including comprehension of spatio-temporal compound stimuli like speech, are not particularly well executable in ASD [6,8,10,11-15]. Such a finding supports the major theories related to this disorder, including the weak central coherence which means the inability to combine information and their perceptual integration [13,16,17]. Various interventions and therapies have been designed and recommended because of the heterogeneity of patients with ASD [3]. Some methods of auditory rehabilitation in this field use music to improve the complaints of these patients [1,3]. Also, given that children with autism have difficulty in understanding noise in speech, those auditory interventions that can minimize the stress from mishearing are important for the health of children with autism and seem desirable to be taken into account at school [9,13,17]. Other methods include dichotic listening training, neurofeedback, and cognitive behavioral therapy (CBT).

In this review article, we have tried to highlight the quality of auditory processing, as well as neurological and electrophysiological fields in ASD, and finally the methods of auditory rehabilitation available for autism will be presented.

### **Proposed theories on autism**

In the scientific literature, various theories for ASD have been proposed, including theory of mind deficit, executive dysfunction theory, amygdala theory, weak central coherence (WCC), enhanced perceptual function (EPF), and neural complexity hypothesis (NCH). Of these theories, the last three ones attempted to provide an explanation for the autistic pattern of auditory complaints in this disorder. These three theories are mainly based on the perceptual differences of the disease resulting from the enhancement of detailed information processing [18,19].

The WCC theory was first described by Frith in 1989 about patients with autism. According to this theory, in addition to increasing attention to details, there is little tendency to integrate separate information into a coherent whole. This mode reduces the processing of content and text information [20].

Based on the EPF theory, which was first proposed by Mottron and Burack in 2001, the understanding of low and simple information increases in patients with autism. This theory has more followers than WCC theory [13]. However, two theories agree that superior processing of local elements is a major component of autistic cognition and is likely to affect autistic behavior [17].

The NCH hypothesis, is also used to explain auditory processing in autistic patients. This hypothesis suggests that the perception of simple auditory impulses increases simultaneous with a more defective understanding of more complex auditory information [16].

Various studies show evidence of an enhancement of pitch perception in children as well as in adults with autism, especially in those with linguistic deficits [13]. The causal relationship between linguistic deficits and pitch perceptions

of autism is unclear. One possibility is that enhancement of pitch perception may be the result of a reduction in attention to linguistic information during growth. Equally, it is likely that increased pitch perception will cause incomplete language growth. Because having a problem in perception can reduce the understanding of the information in later stages and this decrease causes one to have difficulty in speaking. Interestingly, though increasing pitch perceptions correlates with decreasing in linguistic abilities, some people with autism take advantage of this enhanced ability to understand pitch, for example, in music. With regard to increased sensitivity to loudness, according to some studies, the increase in the sensitivity to the loudness of voice in a group of patients with autism seems to decrease by aging [13,21].

In autism, in addition to general reviews, special studies have been conducted regarding the performance of the auditory apparatus. We have noticed neurological findings, changes in auditory evoked responses, and the difference in hemisphere superiority in autism based on magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG), respectively.

### Neurological findings

Based on the evidence, there is some problems with the peripheral auditory system and central nervous system in autism (both at cortex and the brainstem level) [6,20,22]. Several studies have examined sound intolerance in order to find the potential causative mechanisms of autism disorder. They reported that auditory sensitivity of people with autism may depend on a decrease in the function of the medial olivocochlear (MOC) system or the unusual asymmetry of the MOC system and argued that this asymmetry indirectly reflects the changes in the central auditory processing [23,24]. Studies also showed that distortion product otoacoustic emissions (DPOAEs) were more prominent in children at the age of one to three years than in adolescents, and DPOAE levels decrease in the first six years of life faster than the subsequent years [25-27]. Another study finding suggests

that intolerance of noise in early childhood in autistic children decreases by approaching puberty. The findings suggest that the activity of outer hair cells may be higher in a child with autism, especially in the early stages of life, and this is what makes them sensitive to auditory impulses [21]. In another study, MOC reflex in children with ASD was evaluated by measuring the amount of suppression of transient evoked otoacoustic emission (TEOAEs) simultaneously with the stimulation of MOC. Strong correlation was found between the scores of hyperacusis and MOC strength in children with ASD. Suppression of TEOAEs due to the stimulation of MOC was greater on average at all frequencies in children with autism compared with normal children. According to the results, MOC reflex can be used to estimate hyperacusis in children with ASD [28]. In a study by measuring the temporal modulation transfer function in this group of patients, it was determined that people with ASD did not display temporal modulation processing normally, and have a weaker function than normal group in the time of listening speech in the presence of temporally modulated noise. Abnormality of this function is according to processing abnormalities in inferior colliculi of brainstem or increased levels of internal neural noise [29].

### Changes in auditory evoked responses in autism

Delayed auditory processing has been detected at the level of brainstem of the autistic people compared to normal people. Auditory brainstem response (ABR) test is routinely used as a clinical tool for evaluating the performance of the auditory system at the brainstem level [20]. In various studies, the prolongation or lack of latency difference in the ABR response in ASD children has been shown in comparison with the normal group, which probably indicates a difference in the inclusion and exclusion criteria in studies [30]. This delay is mainly seen in the wave V latency or III-V interpeak latency and is more significant when complex stimuli such as speech are used [20]. Research on premature infants hospitalized in the neonatal intensive

care units (NICU) has indicated that prolonged ABR latency in the neonate is correlated with behavioral symptoms of social-communicative deficits including lack of eye contact, repetitive behaviors, and behavioral inhibition. A study reported that most neonates who were later diagnosed with autism had a long latency of ABR in the first three months of life, even with normal auditory thresholds. This confirms the previous findings of social maladaptive behaviors in high risk infants with increased latency and suggests that increased latency of ABR is a common occurrence in neonates who later diagnosed with autism. Comparing the response of ABR in toddlers with autism with clinical norms in some studies suggests that the increased latency of ABR remains throughout the early stages of ASD growth. Current results indicate that abnormalities in ABR may be a relatively stable indicator of autism spectrum disorder throughout the whole growth time [30].

Patients with autism also have anomalies in the results of the auditory responses of the brainstem to speech, which increases with the increasing complexity of the stimulus pattern, indicating a poor coding of complex auditory information at the brainstem level in these individuals [20,31,32].

The middle latency response (MLR) waves have shown different results in children with autism. In a study, latency and amplitude of Pa were not different significantly between the three groups with autism and those with receptive language deficit and normal individuals [33]. In a study, Pa component displayed no significant difference between autistic and normal group [34]. In another study there was no difference between the normal group and autism group in terms of suppression of P50 for the second stimulus. However, Pb wave abnormality has also been reported in patients with autism [34,35].

There is a wealth of evidence that the cortical processing of auditory information in autism is abnormal. Weak cortical responses to speech sounds and abnormal discrimination of speech can limit language learning in autistic children. N1 is an event-related potential specific to

auditory that indicates the basic auditory processing. N1 represents the stimulus presentation changes and the physical properties of the stimulus. In related studies, differences in the amplitude and latency of N1 have been reported between the affected and the normal group, including increasing or sometimes decreasing the amplitude of the waves in autistic group compared with the normal group. These findings, along with the results of similar studies, indicates inefficient regulation of auditory sensory input in autism [1,7,36]. In some studies, N1 amplitude variations were associated with the severity of autistic complaints [7,37]. In a study of patients with Asperger syndrome, which are included in the ASD, latency of P2, N2, and P3 components increased in both ears. The results of this study indicate that changes in auditory late response (ALR) of these patients indicate changes in auditory function at their cortex level. More research is needed to diagnose and intervene more effectively in this group of patients [37].

Overall, the above findings are important evidence for abnormal neural coding and main orientation in focusing on low-level features of acoustic stimuli in people with autism. These processing problems have been observed both in speech and non-speech stimuli [20].

The defect in the automatic processing of auditory information, especially auditory information outside the scope of attention, can have a negative effect on the establishment of social relationships and the specific aspects of language development. Defective processing of important auditory information plays an important role in the clinical complaints of autism.

In a study by Kemner et al., the results of the normal mismatch negativity (MMN) were reported in high function autistic children [38]. In another study, the MMN peak in the left hemisphere was shorter in autistic individuals than in the control group. Also, the MMN topography was different in this group. In the group with autism, the MMN of the left hemisphere had a shorter latency than the right hemisphere, and also a positive abnormal activity related to the deviant stimulus was revealed in the

left prefrontal cortex, which was produced by non-primary thalamocortical projections. It has been suggested that this thalamocortical pathway produces a greater brain reaction to the deviant stimulus and causes the autistic children to be sensitive to acoustic changes [39]. The study by Ferri et al. showed similar results. They found significant increases in amplitude and decreases in latency of MMN in relation to deviant stimuli in the group with autism. Therefore, their results support a functional impairment that affects the pre-perceptual sensory auditory information processing [40]. Generally speaking, MMN-related findings in autistic people indicate poor processing of linguistic elements changes and a defect in the processing of acoustic changes in using complex stimulus patterns [18]. MMN defects in patients with autism also indicate that they have difficulty in encoding information in their transient memory [1]. An important feature of patients with autism is their resistance to new changes [41]. A number of studies have reported small amplitude of P3a or even lack of it following presentation of unexpected speech stimuli in children with autism, suggesting a reduction in their ability to change the involuntary attention to speech. It has been suggested that the use of repetitive sequences of standard speech stimuli may reduce the general interest in stimuli in these children and subsequently reduce the amplitude of new non-verbal stimuli. It is unclear whether the reduction of the P3a amplitude to rare speech stimuli really indicates an impaired involuntary attention to new spoken stimuli or is simply a consequence of the reduced attention to frequent repetition of the standard stimulus [20,42-44].

In the majority of patients with autism, the amplitude of P3b has decreased abnormally. Therefore, in these individuals, P3b can reflect a reduction in the allocation of attention to auditory stimulation or an inappropriate allocation of attention to standard stimuli instead of rare stimuli as well as selective attention defects [1,20]. This decrease in amplitude can also indicate a problem to notice the rare stimulus or a deficit in adjusting expectations based on pre-

vious experience. Therefore, the reduction of the P3b amplitude can explain the difficulty in extracting information for re-integrating pre-learned information in patients with autism. P3b latency has been reported normal in autistic patients [20,41,42,45]. In several studies, the small amplitude of N400 with speech stimuli was seen in children with ASD in comparison with the normal group. This difference was not seen in non-spoken tonal stimuli between the two groups. These results are likely to reflect the abnormal classification of semantic information in patients with autism. In functional terms, reducing the N400 amplitude in people with ASD can reflect the abnormal integrity of speech and semantic information in context or the abnormal matching of verbal materials with semantic representations in long-term memory [20,46-48].

The findings indicate that neural sensitivity and attentional change in autism may be different in speech and non-speech processing, depending on acoustic, linguistic and social aspects of stimuli. Therefore, the use of both evaluations in speech and non-speech domains will be valuable in research and in the clinical setting of autism [16]. Obviously electrophysiological findings are sometimes inconsistent; the possible reasons for the heterogeneity can be the methods of examination and the individual differences studied in terms of the severity of autism

### **The different hemisphere superiority and some auditory complaints in autism**

Linguistic deficits and abnormal sensitivity to sound may be related to cortical auditory processing abnormalities in autistic children. In people with autism, right hemisphere predominantly processes auditory information, while in normal people, this process is mainly done in the left hemisphere [1,13]. In a study using the fMRI imaging technique, presenting auditory stimuli showed lower left auditory cortex activity in patients with autism spectrum compared to normal people [14]. The greater activity of the right hemisphere in autism in the case of verbal stimuli may indicate abnormal growth of

the linguistic regions of the left hemisphere [20]. In a study with positron emission tomography (PET), a group with autism presented inverse hemisphere superiority during verbal auditory stimulation and decreased auditory cortical activity during sound stimulation in comparison with the control group. However, the results of this study should be cautiously generalized to the whole population of autism [13,20,49]. Corpus callosum, which directly affects the transmission of auditory information among the cerebral hemispheres, has a small size or functional inefficiency in autism. Perhaps for this reason, patients with autism have difficulty in dichotic listening. Failure in dichotic listening will lead to speech defects and learning disorders in these children [50]. In order to investigate the developmental changes in the auditory system in the left and right hemispheres, MEG studies indicated an evidence of developmental trend differences, especially in the right hemisphere of children with autism, compared with normal children [51].

The pattern of enhancements and hearing impairment in patients with ASD can be related to abnormal patterns of superiority of the right hemisphere in the brain. Because right and left hemispheres are specially designed for spectral and temporal hearing processing respectively, the superiority of the right hemisphere in autism can enhance the pitch processing. While left-hemisphere defects explain the problems of speech recognition and temporal processing deficits [13].

Recently, it has been assumed that the impaired interactions between the regions of the brain are likely to be responsible for deficiencies in the cognition and social behavior of neurodevelopmental disorders that are described as underconnectivity theory in ASD. The direct reflection of this abnormal brain connection is that the high-level auditory-vision integration in autistic patients becomes defective. Also, it seems that the problems in social behavior that depends on multi-sensory interactions is associated with defects in superior levels of cognition in patients with ASD [52]. It is reported that alpha wave of

the brain in the temporal region (T3) increases in patients with autism, which can be related to linguistic and communication impairments (We know that in normal people, the alpha wave is related to the posterior brain regions). These results consistent with other studies based on electroencephalography (EEG), MRI and fMRI suggesting that neural connection abnormalities are main defects which cause the autistic complaints [53].

There is also the hypothesis that increased local connectivity in the auditory regions of the brain can explain some aspects of auditory processing in autism such as increased pitch perception and hyperacusis. In contrast, defective long-range connectivity between the primary auditory cortex and the auditory association regions can be a reason for the abnormal perception of complex stimuli dependent on complicated neural circuits. Evidence also suggests that possibly there is an impaired connection of frontal regions (which is associated with attention) to the auditory cortex. The difficulty of understanding speech in noise can also be the complication of this problem [20,54].

### **Auditory rehabilitation in autism**

ASD is generally not curable and usually requires long-term management and rehabilitation for its sufferers [55]. Biological signs or biomarkers of this disorder (genetic, neuroanatomic or neurophysiologic) can be measured objectively and systemically. Biomarkers can be very useful in classifying this heterogeneous disorder and will be effective in planning specific and individual interventions in order to maximize the impact and increase the effectiveness of the interventionism terms of strengths and weaknesses of the individual [7].

Given the heterogeneity of the ASD and the uncertainty of a single cause for it, a number of interventions and therapies are provided [3]. Scientific evidence-based rehabilitation interventions in patients with autism include behavioral management, cognitive training, cognitive behavioral therapy, practical behavioral analysis, speech therapy, occupational therapy, physiotherapy, play therapy, music therapy and

parental counselling. It has been reported that initiation of these interventions prior to the age of three greatly influence the successful management of this disorder. Thus, early detection of autism is also important. In this regard, psychologists and psychiatrists try to devise methods that can identify and diagnose autism at age two or earlier [56]. It has been determined that patients with autism generally have cognitive impairment in terms of attention, memory, awareness of themselves and others, metacognitive abilities, abstract thinking, and problem-solving skills. Therefore, understanding the complexities of autism in terms of brain involvement and genes during the infant's developmental period is important for the application of various management strategies. The first goal of these strategies is to minimize the major symptoms of this disorder and its related deficiencies, maximizing functional independence and quality of life, and reducing the family anxiety about these individuals. The treatment of autism is usually multidisciplinary and the management of autism should not only focus on the child but also on his or her family, because parents have a key role in effective treatment of these patients [55].

A noteworthy point in the discussion of autism rehabilitation is that in addition to early intervention for children with ASD, there is also an obvious need for effective intervention for the problems of adults with autism [57]. However, this article focuses more on children's rehabilitation.

With the belief that sensory processing problems affects children's behavior, the recommended interventions are often the ones that use sensory features to help the patient for self-regulation, reaching to an adequate level of arousal, promoting behavioral organizing and reduction of excessive reactions [8]. In ASD clinical management, it is recommended to consider the issue of sensory processing throughout life [58]. In children with autism, some of the standard assessments, such as Short Sensory Profile (SSP), the Sensory Processing Measure (SPM), and the Infant Toddler Sensory Profile (ITSP), can be used to evaluate sensory

processing before rehabilitation [59,60]. Speech-based interventions also use verbal strategies to target the ability to use sounds, words, and sentences to express feelings of the individual. These interventions include child-centered and practical-developmental approaches to structured teaching methods [61].

Auditory-Motor Mapping Training (AMMT) interventions that intensify interactions between hearing and motor systems can be an effective therapeutic strategy through which autistic patients can develop their communication skills. In particular, this method stimulates the hearing-performance network that overlaps with the components of the mirror neurons system. Strategies that involve areas of the brain that are part of the mirror neurons system can potentially modify some communication deficits [62].

#### *Music therapy and music-based methods for autism spectrum disorder*

Music therapy is defined as a systematic interventional process in which the therapist helps the patient to improve his mental and physical condition using musical experiences. Among the positive results of music therapy, the improvement of verbal communication and social interaction can be pointed out. Neurological music therapy is used for healing cognitive, sensory and motor impairment due to neurological disability or disease. This therapy has been developed with the help of neuroscience models of musical production and comprehension. Neurological music therapy focuses on the use of rhythm and musical stimuli to induce cortical plasticity [63,64].

For over two decades, researchers have examined the basis of music neurology in the brain and have proven that music processing and production has spread throughout the cortex, subcortex, and the cerebellum. On the other hand, the areas of perception and production of music are not exclusive, but overlap with non-musical networks. For example, the auditory rhythm can be activated by moving the brain regions including the pre-motor cortex, the supplementary motor area, the pre-supplementary motor area and the lateral cerebellum [65]. In

addition to activating the motion areas of the brain by rhythm, there is evidence that external rhythmic patterns result in rapid motor synchronization in individuals with or without neurological disease [66,67]. Therefore, rhythm is used as a temporal cue in the therapeutic application of music for motor rehabilitation purposes and is essential for hearing-motor synchronization. The first evidence of auditory-motor synchronization led to auditory-motor pathway investigation, and suggesting interference of reticulospinal connections, cerebellum, brainstem and basal ganglia in this pathway. This unique relationship between rhythm and motor function has been studied as an effective treatment for motor rehabilitation over a decade. The two main factors for the success of rhythm in auditory rehabilitation include rhythmic synchronization and some evidence of facilitation cortical plasticity by rhythm [66]. Music can affect the limbic system and the brainstem reticular formation and thus improve the neural cells ability to excitation [68].

A type of auditory stimulation called rhythmic auditory stimulation (RAS) is used in rehabilitation and neurological treatment. In this method, rhythm acts as a sensory cue to induce time stability and intensifies patient movement patterns. Given that music in the autistic population has a history of having therapeutic effects in terms of psychological and physical problems, it has been suggested that rhythmic music by linking the elements of sound and emotion and increasing activity in the pre-motor cortex can be used as an effective stimulant for emotional and motor responses in children with autism [69].

Based on scientific literature, music therapy is a promising way of treating people with autism. Traditionally, music therapy in children with ASD is used to improve cognitive, communicational, and social needs [63]. In addition, rhythm training, singing, playing music, musical plays and listening to music can restore, maintain, and develop physical and mental health of the person, and ultimately lead to better understanding and cognition in children with autism. When using music therapy in children

with autism, you should pay attention to the specific type of music selected. Appropriate music composition and rhythm should be selected based on the age and condition of the individual and the group-therapy can be included in the program in addition to the individualized training. Group music activity is a multi-sensory activity that affects areas of the brain that greatly overlap with the system of mirror neurons. Interventions involving such music methods may be a possible approach to facilitate the expressive language in children with autism with little linguistic abilities. The music therapy course in these patients is usually at least 3 months [54,62,68-70]. The rhythmic music tool may provide useful patterns for organizing motor output in children with ASD [64,68]. Music-based speech therapy techniques may also be used as a new and promising interventional approach to oral language instruction in those children with ASD with little verbal ability [71]. However, more studies are needed to generalize the results of music therapy in these patients and to determine the mechanisms for changing the behavior of this disorder following the use of music therapy. Further studies are also needed to compare the music therapy with other forms of therapies in patients with ASD [63].

Several methods of sound-based and music-based rehabilitation have been proposed for a group of speech, behavioral, and psychological problems in autism that we will have a quick reference to them.

Efforts to overcome changes in auditory sensitivity (a common symptom in patients with autism) have led to a therapeutic approach called auditory integration training (AIT) [3] which is one of the methods of musical rehabilitation in autism, developed by the French physician Guy Berard in 1982. The Berard method, which is almost a "retraining" of the auditory process, improves the integrity of received sound in children with autism and is based on the assumption that abnormal sensitivity to certain frequencies of sound waves (regardless of auditory thresholds) is associated with behavioral and learning problems in children with

autism. The AIT uses filtered and modulated frequencies that are embedded in a pleased music to suppress or modify the peaks of frequency that a person is hypersensitive to, so through the retraining of the auditory system, auditory input processing in the brain will be normalized, so that the ear and the auditory system can be trained to function more correctly. Filtered music is modulated by random damping of high and low frequencies [1,72].

In practice, in this method, a musical stimulator that is electronically modified is provided to the affected person through the earphone within 10 days (each day in two half-hour sessions). It is very likely that if a child with autism can hear and process sounds more accurately, he or she can understand them more correctly and subsequently have clearer speech, thus improve his or her social skills and communication [1,72]. Tomatis sound therapy, developed by the physician Alfred A. Tomatis in the 1950s, is another method that uses the human voice and music with electronic modifications that are provided by a device called the "electronic ears." Samonas sound therapy, introduced by Ingo Steinbach in the late 1980s, also involves listening to a packed CD of filtered music, human voices, and sounds taken from nature that are delivered through a headphone to patient [3].

In general, these three methods require listening to electronically modified music for different times in order to improve the auditory processing impairment and promoting concentration [1]. It should be noted that more controlled studies are needed to explain the neural mechanisms of the AIT effect and the two types of sound therapy of Tomatis and Samonas on the physiological behavior and responses in children with autism [1,3,72].

Sound-based interventions (SBIs) are also similar to AIT, which includes 10 weeks of using psychoacoustically modified classical music. The results of studies using these methods indicate a decrease in the number of abnormal behaviors of autistic patients. The Listening Program (TLP) is one of several SBI methods used to manage behavioral disorders related to

sensory processing in children with autism. In spite of reporting the positive trend in previous studies on this method in children with autism, further research is still needed [59,73].

#### *Other therapies*

Here are some other methods of training, rehabilitation, and hearing assistive technologies that can be used in patients with autism.

According to the results of a research, Qur'anic recitation similar to the music therapy method has positive predictive effects on speech, learning, and communication of individuals with autism. It has been pointed out in this research that Quran therapy is expected to have better results than conventional sound therapy, because in this method, larger alpha waves are created compared to listening to music [70].

New research suggests that in children with ASD and hearing loss, cochlear implants improve expressing and receiving language. This language development may not be as good as in hearing impaired children with no other disease [74].

Dichotic listening training is a method for improving dichotic listening deficits in children with ASD. When performing dichotic listening tasks, some children with ASD do not show the usual dominance of the right ear for speech stimuli, instead prefer their left ear to listen to musical and speech stimuli. Dichotic auditory training is expected to help children with autism through reorganization and strengthening of neural infrastructures involved in dichotic listening with subsequent improvements to other linguistic and auditory processing skills [50]. Based on a study, the dichotic interaural intensity difference (DIID) training improves the abnormal auditory processing of autistic children due to deficits of binaural integration, and the benefits of this method can be generalized to different auditory and linguistic processing skills [51]. Long-term dichotic auditory intervention along with speech therapy and language training for children with autism and auditory impairment is beneficial and effective. In other words, dichotic hearing training does not reduce the importance of providing speech and

linguistics services [75].

Another method used in the treatment of autism is neurotherapy or neurofeedback. Neurotherapy is reported to be effective in improving the entire range of autistic problems in most cases. Neurotherapy facilitates brain self-regulation and helps regenerate the patterns of impaired brain waves in patients with autism [76,77]. Neurofeedback treatment is a non-invasive method that has been shown to enhance metabolic function and nerve regulation in ASD and subsequently cause behavioral change through effective conditioning process. In this method, while patients with autism perform their tasks in the form of games to stimulate brain waves, brain activity is visible by the examiner. Information about the activity of brain waves is given to the computer so that this information can be converted into games that can be audible, visual, or both [77]. In a study, neurotherapy was performed with AIT for an autistic person. Results indicate improvements in language and speech indicators. In this study, an increase in activity of the Broca area, an improvement in auditory perception, and progress in speech was observed in the autistic person [76].

Recently, there is evidence that cognitive behavioral therapy (CBT) is effective in reducing autism complaints. But more research with standard methods is needed for certain conclusions in this area. CBT is mainly used for children with high-functioning autism. CBT focuses on communicative-social, behavioral and emotional problems in patients with ASD. This method essentially consists of three main assumptions: cognitive activity affects behavior, cognitive activity can be monitored and changed, and behavioral change can be influenced subsequently by cognitive change [77,78].

As noted, children with autism has problems in speech recognition in the presence of background noise. It has been reported that the use of ear muffs for children with ASD has been beneficial in reducing the effects of noise even if they have been used for a short time. However, the performance of noise-cancelling headphones is not as high as ear muffs. Noise-cancelling headphones cannot

eliminate auditory stimuli except low-frequency noise, and human sounds and some other sounds will not vanish by passing through these phones. Therefore, these headphones cannot be effective for autistic patients who are sensitive to voices [12]. The use of the ear-level remote microphone and classroom amplification systems also provide useful results for improving hearing and social interactions and reducing the amount of physiological stress in both individual and group teaching places in children with autism [9].

Technology has opened a new world to children with autism. Research has shown that technology can motivate learning. Today, iPads are widely used to educate children with autism. Further research is needed to understand the impact of iPads use on communication and learning in children with ASD. More than 700 applications are developed for children with autism and sold in app stores [79].

### Conclusion

Autism is a disorder associated with various problems, including auditory processing abnormality. Auditory tests on the cortex and brainstem and even the lower auditory pathways are helpful in identifying the dimensions of auditory cognition and processing deficits of this disorder. Different evaluations of auditory function in autism patients seems necessary and important in order to take proportional interventions. Among the main methods for hearing rehabilitation in autism is music therapy as these patients have enhanced musical abilities. In addition, methods such as cognitive-behavioral approaches, use of assistive listening devices and modification of the classroom environment to promote speech-perception in noise have been raised in the field of auditory rehabilitation of ASD.

### Conflict of interest

The authors declared no conflicts of interest.

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