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Review

Treatment approaches of central auditory processing deficit

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Summary

Central auditory processing disorder (CAPD) disrupts the brain ability to interpret sound signals despite normal peripheral hearing function. This article aims to identify and analyze various treatment approaches, which are used in the treatment of CAPD and to provide an overview of available empirical evidence on the effectiveness of these approaches. Google Scholar, PubMed and Research Gate were used for literature review. Treatment approaches vary and depend on the individual characteristics of children themselves, and one of the most commonly used approaches in the treatment is auditory training, through which children learn to identify and discriminate auditory stimuli. Apart from choosing the appropriate approach, it is crucial to commence the treatment of children with central auditory processing deficit in time in order to overcome and eliminate this deficit.

Key words: auditory processing, auditory processing disorder, auditory training

Introduction

Central auditory processing disorder (CAPD) disrupts the brain ability to interpret sound signals despite normal peripheral hearing function. The exact cause and morphological substrate of CAPD remains unknown, but potential contributing factors include various neuropathological conditions, developmental disturbances in the CANS, or insufficient myelination (insulation) of auditory pathways in young children. Also it seems that chronic ear infections or early hearing aid use might also hinder auditory pathway organization.

The interest for central auditory processing and functioning of complex auditory system went back to 50s, while the clinical interest for making a diagnosis of auditory processing disorder appeared sometime later, to be precise, in 70s. Researchers believe that plasticity of

the auditory system is largely related to the process of stimulation and that some auditory pathways are activated and made and that they become complex due to the hearing experience (being exposed to stimuli) [1]. It is believed that it is easy to identify problems of ''hearing'', because they are manifested in poor perception and understanding of the language and because they cause learning problems in school-aged children [2]. In order to understand auditory processing deficits in the best way, we need to know what auditory processing actually entails. Some authors say that auditory processing is the complex ability to hear, understand and respond to information coming from our environment [3]. These pieces of information are transmitted to the ''basis'' used for processing, that is to the primary and secondary auditory areas which are located in the temporal lobe.

According to some authors, auditory processing is the process consisting of active and passive detection, identification, monitoring, differentiation and transmission of information through peripheral and central nervous systems, which simultaneously entails combination and classification of information on the appropriate perceptive and conceptual level [4]. Deficits that occur on the level of auditory processing, consequently lead to problems in interpretation and comprehension of a speech sound (human speech that we hear), even though a person has preserved auditory abilities. According to this, what we need for normal auditory processing is the adequate functioning of auditory structures which participate in perception, processing, transmission and understanding of the received sound or auditory stimulus.

CAPD often co-occurs with conditions like ADHD or learning disabilities, necessitating careful differentiation during diagnosis. Further research is needed to elucidate the causes of CAPD and to develop more targeted treatment approaches.

Most researchers agree that we need a multidisciplinary approach in making a investigation diagnosis and therapy/rehabilitation of the auditory disorder [2]. Collaboration between audiologists, speech-language pathologists, psychologists, and physicians is crucial for the accurate diagnosis.

The aim of this paper is to review and analyze the available literature and give insight to treatment approaches of central auditory processing deficit.

The Central Auditory Nervous System (CANS): Structure and Function

The central auditory nervous system (CANS) is a network of structures in the brain responsible for processing sound. It encompasses parts of the brainstem and the auditory cortex, enabling us to localize sound (identify its source), discriminate between similar sounds, understand the order and duration of sounds, and integrate sounds from both ears.

The complex network of brain regions that makes up the Central Auditory Nervous System (CANS) plays a crucial role in our ability to hear and understand sound. By working together, these regions process sounds from our environment and enable us to perform essential tasks such as sound localization, sound discrimination, and speech comprehension.

Information about sound travels through complex auditory pathways consisting of series of relay stations:

1. Spiral Ganglion: Contains cells that convert the transformed energy of sound waves into electrical signals.
2. Cochlear Nuclei: Located in the medulla oblongata and processes information about sound frequency.
3. Superior Olivary Complex, Trapezoid Body, and Lateral Lemniscus Nucleus: Situated in the pons, these structures further process sound location and intensity.
4. Inferior Colliculus: Found in the midbrain, it plays a role in integrating auditory signals from both ears.

5. Medial Geniculate Body: Located in the thalamus, it relays the signal to the primary auditory cortex.
6. Auditory Cortex: Situated in the temporal lobe, it is responsible for the conscious perception of sound, including speech and music recognition.

The auditory system is functionally organized based on several key features, such as:

- Binaural Representation: From the medulla onwards, both ears are represented on both sides of the auditory pathway.
- Ascending and Descending Pathways: In addition to ascending pathways carrying information towards the cortex, there are also descending pathways that modulate sound processing.
- Reflexes: The auditory pathways are involved in reflexes such as the stapedial and auropalpebral reflexes.
- Tonotopic Organization: Different sound frequencies are processed at specific locations along the auditory pathways.
- Columnar Organization: The auditory cortex contains columns of neurons specialized for certain auditory features
- Hemispheric Specialization: For example, Brodmann's area 22 is more active in the left hemisphere for speech processing.

Diagnostic

Today the lack of a standardized screening method hinders early identification.

Determining deficit existence in the process of auditory processing is a major challenge for scientists, mostly due to the heterogeneous nature of the deficit and the fact that there is no gold standard for evaluation of that frequently underedminated brain damages [5]. Mostly in the diagnostics of central auditory processing deficit, behavioral methods are used, whereby a special attention is given to conduction of this procedure among children up to eight years old [6].

It is quite important to point out that auditory processing disorder is not etiologically caused by hearing impairment or reduced abilities of cognitive functioning, but it entails limits in transmission, evaluation, analysis, transformation, organization, processing, conserving and later recalling and reuse of auditory information [7].

Behavioral testing remains the cornerstone of diagnosing Central Auditory Processing Disorder (CAPD) and assessment of functional auditory processing abilities. Behavioral testing remains the gold standard for CAPD diagnosis.

In specific cases, electrophysiological testing (auditory evocated brain response) may be used to measure electrical activity in the auditory pathway. Neuroimaging Techniques in CAPD research offer a window into the brain to potentially identify structural or functional abnormalities associated with CAPD. Neuroimaging techniques are emerging as valuable tools for providing additional insights into the underlying neural mechanisms. They directly visualize the brain structures involved in CAPD. Magnetic Resonance Imaging (MRI) especially diffusion-tensor MRI can assess white matter integrity, which is crucial for efficient signal transmission within the CANS. Functional Magnetic Resonance Imaging (fMRI) measures brain activity during auditory tasks, revealing which brain regions are activated during sound processing in individuals with CAPD compared to controls and otherwise can identify potential areas of dysfunction in the auditory cortex. Positron Emission Tomography (PET) evaluates brain metabolism by measuring glucose uptake. It may reveal areas with altered metabolic activity in the CANS in individuals with CAPD. Studies suggest potential structural abnormalities in the auditory cortex and brainstem in some individu-

als with CAPD. Altered activation patterns in the auditory cortex during sound processing tasks and reduced metabolic activity in certain brain regions associated with auditory processing have been observed. Neuroimaging is not currently recommended for routine CAPD diagnosis due to its high cost and ongoing research. Neuroimaging holds promise for enhancing our understanding of the neural basis of CAPD and future advancements might enable the development of neuroimaging-based treatment strategies for CAPD.

Epidemiology and etiology

Auditory processing difficulties include difficulties in speech comprehension, even though the hearing and cognitive abilities of the child are preserved [4]. Results of the research, which strived to establish a prevalence of auditory processing disorder among children in lower grades of elementary school show 5,7% of children with this disorder [14]. The mentioned results of authors from this area are in accordance with the results of some foreign studies, which have shown 5-7% of children in a population with auditory processing deficits [15] or 7% [16]. Mastilo and associates [17] examined the ability of auditory and visual memory of young school aged children with typical development in their research. Results of the research showed that younger school aged children had better achievements in visual memory compared to the auditory, and that at older age there is a gradual rise in the ability of remembering a list of numbers and words. However, children with auditory processing disorder had a worse attention and concentration, became exhausted faster, had difficulties in remembering and recitation of poems, memorizing and repeating phone numbers, sentences etc. As the mentioned characteristics are not only closely related to auditory processing disorder, it is necessary to use the multidisciplinary approach within the diagnostics and the treatment, which entails that apart from a speech therapist, the audiologist and psychologist should be part of the team as well.

Heine and Slone [18] state that auditory processing disorder is not rare even among adults, but symptoms may be subtle or hidden and the disorder remains untreated for a long period. During the adult treatment, what is necessary is a cooperation of experts of different profiles, so as to overcome the existing auditory processing deficits and reach the set social, academic and personal aims [18].

Authors mostly describe the three causes which may lead to malfunction of central auditory processing, and those are: late development of central auditory processing, neurological deficits or certain neuromorphological disorders in the structure of this system [8]. The brain plasticity is highest during childhood, allowing targeted auditory training programs to improve processing plasticity of auditory pathways. There exists a great plasticity in the auditory pathways, i.e. they are modified by experience. Examples of individuals who become deaf before language skills are fully developed view sign language activates as auditory association areas. Conversely, individuals who become blind early in life are demonstrably better at localizing sound than individuals with normal eyesight. In right-handed individual Planum temporal i.e. a portion of the posterior superior temporal gyrus involved in language related auditory process is larger in left cerebral hemisphere than in right. Musicians have an increase in the size of auditory area activated by musical tones. They also have larger cerebellum than non-musicians, presumably because of learned precise finger movements.

Neuroplasticity of the auditory system after injury refers to the brain ability to adapt and reorganize its auditory pathways following damage. This process can involve the rerouting of auditory signals, changes in the sensitivity of neurons, and the recruitment of

alternative neural circuits to compensate for the injury. Rehabilitation, auditory training, and other interventions can help promote this neuroplasticity and improve auditory function after injury [19].

Central Auditory processing deficit related events

The available literature and our experiences show that auditory processing has a significant role in speech and language development, and that deficits and disorders in this area lead to a high risk for appearance and development of speech and language disorders [9][10]. Poor auditory processing leads to reduced ability of sound discrimination or impedes the person to have a conversation in the conditions of background noise. Children with this diagnosis have difficulties in auditory processing in the noisy environment [11].

This deficit may affect various aspects of a personality, primarily an individual's self-respect, social life and academic achievements [12]. Further on, auditory processing disability results in psychological difficulties, so it may give rise to stress, anxiety or depression, which additionally increases the risk for appearance of different psychopathology in the child [13]. Central auditory processing deficit is frequently diagnosed in children who are also diagnosed as having an autism spectrum disorder (often hypersensitive to sound), attention deficit hyperactivity disorder (ADHD), language-learning disabilities, and dyslexia [20].

Treatment approaches of auditory processing deficit

The diagnosis of auditory processing deficit is established by using a set of criteria, which entail poor achievement at tests of auditory processing of received information as well as the existence of specific symptoms which are related to hearing difficulties in the presence of background noise [21].

In most studies, it is stated that the treatment implies a team approach, which includes cooperation of various experts of different profiles (speech therapist, surdologist and audiologist), parents, teachers and other close individuals from the child's environment. Association of hearing and speech therapists believes that the early intervention is necessary, as we have to take into consideration the timely plasticity of the brain, or the CNS, in order that the selected treatment should have a maximum effect, but also to impact the reduction and suppression of the existing auditory deficits [22]. Establishing the diagnosis of auditory processing disorder is done by the audiologist with the support of the speech therapist, who has the leading role in determining the differential diagnostics of auditory processing disorder in relation to other possible hearing disorders [7]. When all the levels of the auditory system, which might be damaged, are assessed and when the damage is detected, the approaches and aims that will be used in the treatment are then determined [23]. The direct intervention in the treatment may include different methods and techniques: listening to speech, attention exercises, auditory memory, phonemic analysis and synthesis, phonemic identification, segmenting sounds, the auditory connection, rhyming etc. [23]. The same authors claim that the treatment aims may include expressive use and organization of language, meaning of words and comprehending their mutual semantic relation. The American Speech-Language-Hearing Association [22] points out three leading approaches, which are often used in the treatment of patients diagnosed with central auditory processing disorder: direct skills remediation (*Bottom up approach*), compensatory strategies (*Top-down approach*) and environmental modifications (*bottom-up and top-down approaches*).

The Bottom-up approach, in the context of the central auditory processing deficit, refers to the therapeutic strategies, which focus on enhancement of specific auditory abilities as well as processing abilities on the fundamental level. This approach usually includes exercises and activities designed to improve the auditory discrimination, identification, auditory sequencing, localization of sound as well as temporal processing. These interventions aim to strengthen the auditory processing abilities and enhance the ability of the brain to interpret and comprehend the incoming auditory information correctly, which at last enhances communication and auditory abilities of the individual with the central auditory processing deficit [22].

Compensatory strategies (Top-down approach) enable exploitation of compensatory mechanisms so as to reduce the effect of auditory processing deficit. This is done by strengthening the complex structure and functions of higher level, e.g. attention, memory and language, as well as through the training of the central auditory system [24].

Environmental modification (bottom-up and top-down approaches) entails improvement in the approach to auditory information in the environment where the child passes time (e.g. classroom), which is done by the reduction of noise in the environment and the use of auditory technology [22]. This is a complex process that entails integration of the previous two approaches, in terms of the use of strategies for supporting the child in various auditory contexts [24].

These three approaches are significant in terms of improving the complex system of skills needed for auditory processing. Environmental modification may include the emphasis of important words while speaking, elimination and neutralization of all redundant sounds and the reduction of echo while speaking as well as the use of more frequent pauses in speech [22]. Lanc and associates [25] state that this process is done through four steps, which include the following: assessment of good and bad sides of central auditory processing; the choice of the FM system according to individual characteristics of the child and implementation of the training; detailed analysis and evaluation of acoustic characteristics of a room, in which the child passes the time; and continued recording, monitoring and observation of the child's improvement. By using this treatment approach, a vast improvement of auditory abilities is possible.

The type of treatment, which will be used in individuals with auditory processing disorder, is primarily dependent on individual characteristics of the person, so the program should be constructed for the specific type of auditory processing deficit, existing in a patient [25]. In order that the treatment should have the best possible outcome, it is desirable that the close individuals from the patient's environment and those who are in a continuous contact with him/her, should be included in the process. The outcome depends on the adequate realization of the treatment as well as the persistence and perseverance of the treated patient.

There are numerous treatments applied to the central auditory processing deficit patients, and the one which is very significant is the auditory therapy that entails the use of exercises based on sound processing improvement and those that contribute to better comprehension [26]. The technology has the potential to reduce isolation, improve independence, enable educational, financial and social opportunities for the users. However, there might be certain obstacles, especially for the individuals with difficulties or sensory deficits and because of this, it is important to determine what science has done so far in the area [27]. In modern times, the power of technology, which is used for elimination of the existing auditory difficulties, is very significant and the FM system is mostly used. Specifically, the FM systems help in reduction or

neutralization of loud sounds and noise in the environment, which enables the clearer transmission of sound [26]. The treatment of individuals with auditory processing disorder often implies education as one of ways that these individuals learn about the disorder itself as well as acceptance and comprehension of its symptoms and learning to develop strategies that aim to manage this problem [28]. Some authors state that the improvement of learning abilities by means of auditory learning may be very quick [29]. In fact, the regular and continuous training may affect the improvement of perception of any sound [30].

The American Association [22] explains that both the children and adults with central auditory processing deficit have the special deficit conditioned by difficulties in functioning of several areas, e.g. difficulties in sound localization and lateralization (damaged ability to identify the location of sound), ability to process the acoustic sound in the particular unit of time, sound discrimination (which implies the ability to discriminate the sounds quickly), as well as speech identification in case where there are other, surrounding sounds [22].

The following exercises are often used during the auditory processing training:

1. Attention exercises – imply paying attention to the surrounding environment of the person with auditory processing deficits. The patient is often asked to identify the certain sound in noise conditions, follow verbal directions in the noisy environment and try to identify various sounds (instruments bells, sirens, birds chirping, animal sounds, etc.).
2. Exercises of visual and auditory integration – imply association of sound that the patient hears with certain pictures and this is mostly done in a way that the rehabilitator e.g. shows the picture of a dog and then plays the barking sound in order that the patient associates the sound with its picture. In that way, practicing association of hearing stimulus with its source is done and the patient gets an idea about the source of the sound.
3. Memory exercises – imply repeating short sets of numbers, sounds or words, as in this way we can practice the short-term memory. Gradually, we may lengthen the set and make it more complex so as to encourage auditory processing.
4. Sound comprehension exercises – they are mostly done by listening to the therapist's stories and responding to questions about the story. These exercises are done in order to help the patient improve the auditory abilities, auditory memory and the latter recalling and application of verbal information.

These exercises often imply the use of various didactic and modern school aids as well as interactive exercises on a computer [31]. Through individual approach in the treatment, it is possible to reach the positive outcome and improve the quality of life of children and adults suffering from central auditory processing disorder. Not only do we need the intervention fully aimed at individual auditory processing, but also the multidisciplinary approach [32]. In relation to children, it is necessary to pay attention to the process of learning, as its normal functioning requires adequate auditory processing. Aims in the treatment of auditory processing are reached with the aid of the mentioned approaches, whereby the auditory training is particularly significant.

Auditory training

Due to neuroplasticity of the brain, the interest for implementation of the auditory training methods at the earliest stage of development has increased [33]. The literature points out significance of the auditory training for children with developmental language disorders and central processing disorder [22].

Auditory training implies enhancement of damaged or reduced abilities in the process of auditory processing and it aims to reduce or eliminate auditory processing disorder [22]. During auditory training process, children are taught to identify and discriminate the auditory stimuli by the speech therapist or the audiologist [30]. By analyzing the literature, we may conclude that there are a large number of auditory training methods which can be classified according to the set of criteria: in relation to the approach of working with children with damaged hearing, in relation to the aim of auditory training and in relation to the components of auditory training [34]. British Society of Audiology [35] suggests the following exercises which are used as part of auditory training: computer based auditory training – these exercises use the computer which determines the difficulty of the task and in that way enhances phonological awareness, language and attention; auditory discrimination improvement programs – refer to interviews and their use in reading difficulties (dyslexia) and damaged phonological awareness; auditory training aided by headphones and a loudspeaker– most often in a form of binaural integration and separation, whereby the child is asked to repeat what he/she has heard or to repeat what has been heard by only one ear.

Case studies confirm success of auditory treatment of auditory processing deficit [36, 37]. The first study [36], describes the case of the fifteen-year-old boy, who has the central auditory processing deficit and the following difficulties, which implies inability to comprehend auditory stimuli as well as precise hearing in inadequate acoustic environment. The boy goes through auditory training during summer holidays, whereby the intensity of the treatment entails three weekly sessions lasting for an hour. The second study [37] describes the twelve-year-old girl, Maddy, suffering from central auditory processing deficit, which is manifested in difficulties while completing multi-instruction tasks and the conditions of background noise. This case achieves success in the area of auditory processing by using the auditory training methods.

Conclusion

Auditory processing disorders affect the very complex process of speech and language development due to difficulties in processing and storage of auditory information. In order to overcome the existing difficulties in auditory processing, it is necessary that the child is included in the continuous and goal-directed speech treatment. With the increase in the use of modern technology, a number of methods and techniques used in the treatment have also increased. Treatment approaches are different and they depend on individual characteristics of the child, and one of the most used approaches during treatment is auditory training, through which children learn to identify and discriminate auditory stimuli. Further on, apart from selection of the appropriate approach, the timely commencement of the treatment in children with central auditory processing deficit is essential in overcoming and eliminating this deficit.

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Pristupi u tretmanu centralnog auditivnog procesuiranja

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O poremećaju auditivnog procesuiranja govorimo ukoliko se jave teškoće u percipiranju i obradi slušnih informacija u mozgu. Ovaj rad ima za cilj da identifikuje i analizira različite tretmanske pristupe koji se koriste u tretmanu poremećaja centralnog auditivnog procesuiranja, te da pruži pregled dostupnih empirijskih dokaza o djelotvornosti tih pristupa. Za pregled literature korišćeni su pretraživači Google Scholar, PubMed i Research Gate.

Tretmanski pristupi su različiti i zavise od individualnih karakteristika samog djeteta, a jedan od najčešće korišćenih pristupa u tretmanu jeste auditivni trening, kroz koji djeca uče da prepoznaju i razlikuju auditivne podražaje. Takođe, pored odabira odgovarajućeg pristupa, pravovremenost započinjanja tretmana kod djece sa deficitom centralnog auditornog procesuiranja ključna je u prevazilaženju i otklanjanju ovog deficita.

Ključne riječi: auditivno procesuiranje, deficit auditivnog procesuiranja, auditivni trening