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Neural mechanism, prognosis, and rehabilitation of central auditory processing disorder: a review

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ABSTRACT

Central Auditory Processing Disorder is a disorder in which individuals have normal hearing thresholds, but have difficulty in linguistic and auditory analysis that requires metacognitive processes, impaired dichotic listening and sound localization skills are observed. The neurobiological mechanism underlying the disease is thought to be immaturity or deficit in the central auditory pathways. In this study, studies in the literature on the underlying neural mechanism, prognosis and rehabilitation of Central Auditory Processing Disorder were evaluated.

Key words: central auditory pathway disorders, auditory pathways, auditory processing, audiologic rehabilitation

ÖZ

Sentral işitsel işlemleme bozukluğunun nöral mekanizmaları, prognozu ve rehabilitasyonu: bir derleme

Santral işitsel işlemleme bozukluğunda bireyler normal işitme eşiklerine sahiptir ancak üst bilişsel süreçler gerektiren dilsel ve işitsel analiz, dikotik dinleme ve ses lokalizasyonu becerilerinde bozulma gözlenir. Hastalığın altında yatan nörobiyolojik mekanizmanın santral işitsel yollarda problem ile ilişki olduğu düşünülmektedir. Bu çalışma, altta yatan nöral mekanizma üzerine literatürdeki çalışmalar ile santral İşitsel İşlemleme bozukluğunun prognozunu ve rehabilitasyonunu değerlendirilmiştir.

Anahtar Kelimeler: santral işitme yolu bozuklukları, işitme yolları, işitsel işleme, odyolojik rehabilitasyon

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INTRODUCTION

Central Auditory Processing Disorder (CAPD) is a disorder that causes difficulty in analyzing the auditory signals. In this study, studies in the literature on the underlying neural mechanism, prognosis and rehabilitation of CAPD were evaluated

Definition of Central Auditory Processing

Central Auditory Processing Disorder (CAPD) is a disorder that can be observed in both individuals who have normal pure tone average (PTA) thresholds (< 20 dB HL) and individuals with hearing disability whose PTAs are > 20 dB HL The common symptoms of the disorder are to have difficulty in linguistic and auditory analysis that requires metacognitive processes, impaired dichotic listening and sound localization skills (American Speech-Language-Hearing Association, 2005). The neurobiological mechanism underlying the disease is thought to be immaturity or deficit in the central auditory pathways (Cameron, et al., 2006). Among the effects of CAPD in pediatric groups and adults, it can be listed as difficulty in listening in noisy environments, difficulties in academic reading, comprehension and writing performances, difficulty in musical processing (frequency, duration, rhythm), and focusing problems.

Neurobiological Mechanism and Prognosis

Top – Down and Bottom – Up Processing

In order to understand central auditory processing more clearly, it would be more accurate to first examine the processing and interpretation processes of the acoustic signal. These processes are known as bottom-up and top-down processing. Top-down and bottom-up processing are processes that are effective in central auditory processing. Bottom-up processing includes the acoustic signals reaching the ear, starting from the outer ear and reaching the cortical level along the central auditory pathways. Top-down processing, on the other hand, describes the interpretation of acoustic signals at the subcortical level, together with prior information with the activation of executive cognitive processing.

Anatomically located, a large cortical network, including the superior temporal gyrus and sulcus, the angular gyrus, and the prefrontal cortex, is involved in complex listening tasks. Different studies show that projections are seen in these areas in Top down processing tasks (Obleser, 2014). Studies conducted in different groups, such as the elderly or cochlear implant

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users, reveal that projections in these regions are affected in challenging listening tasks such as phonemic discrimination and comprehending words embedded in the distorted spectral structure (Lesicko & Llano, 2017).

Especially the processing of acoustic signals of speech is a very complex process. In the top-down processing process, many contexts come into play and cause the acoustic information heard to be perceived in different ways. These factors are listed as syntactic, semantic, phonemic and other linguistic factors (Obleser, 2014). In order for the top-down process to work effectively, auditory memory and auditory attention must also be involved in the interpretation of acoustic information. The lack or absence of any of these auditory mechanisms causes a disconnection of context between the heard and interpreted auditory information.

Different studies reveal that when there is any change in the descending structure, changes are observed in neurons located in the subcortical region (Bajo & King, 2013; Gilbert & Li, 2013; Stebbings, et al.; Suga, 2012). Neuronal changes are also observed in temporal and spectral context-dependent responses (Jones, et al.; 2015).

It is important that both processes work simultaneously for a correct auditory processing. Bottom-up processing generally involves acoustic processing of the incoming signal and generalization of speech characteristics and characteristics. In top-down processing, it is seen that phonetic, semantic and syntactic processing have an effect on the upper stages of perception in the definition process (Shuai & Gong, 2014).

Projection zones

Primary auditory cortex (Heschl's gyrus [HG]) and planum temporal activation stand out in the processing of simple acoustic stimuli such as pure tone (Binder, et al., 1996); There is activation of the superior temporal gyrus (Binder, et al., 1996) and anterior superior temporal sulcus in interpreting more complex stimuli such as speech signals (Binder, et al., 1996; Sharp, et al., 2004; Specht & Reul, 2003).

The regions responsible for top-down processing are thought to be the anterior cingulate cortex and the dorsolateral prefrontal cortex, where higher cognitive processing and goal-oriented behaviors are controlled (Mühlau M, et al., 2005; Vanneste, et al., 2010). These regions are also responsible for parts of auditory attention and play a role in modulation of top down processing (Voisin, 2006).

The hierarchy of speech signals begins with sensory processing in the superior temporal gyrus and progresses to the inferior frontal gyrus, where there are abstract linguistic and cognitive processing (Binder, et al., 1996; Hickok & Poeppel, 2007).

CAPD and Auditory Electrophysiological Tests

Electrophysiological test methods such as MisMatch Negativity (MMN) and Middle Latency Response (MLR) are the methods in which CAPD can be observed best. Jerger and Johnson (1988) claimed that MLR is the most effective auditory evoked response for diagnosing and understanding CAPD. Studies of children with learning, speech, and language problems (Schulte-Körne, et al., 1998); and adults with CAPD (Schulte-Körne, et al., 2001) or with cortical lesions (Pialarissi, et al., 2007) have found MLR abnormalities.

Ankmnal-Veeranna et al. (2019) studied on ABR findings of children with CAPD and their peers with normal hearing (Ankmnal-Veeranna et al., 2019). Authors claimed that significantly longer wave I latencies were observed in CAPD group, while there were no differencies in wave III and V. Use of ABR for the diagnosis of CAPD is not very common in the literature due to the lack of evidence.

Many researchers state that evaluations such as MMN or MLR that will be made during different clinic visits of children will provide important information about the course of the disorder (Jirsa, 1992; Martin, et al., 2008). Kraus et al. (1993) reported that individuals with normal hearing showed congruent responses in both MMN and behavioral discrimination scores in tasks such as speech contrast testing after intense training. In the next study of the researchers, it was observed that there were generalizations in responses to other stimuli in both MMN and behavioral listening performance after the training. Menning et al. (2002) observed improvements in behavioral responses in the frequency discrimination task, as well as an increase in N1 and MMN amplitudes, after training on the frequency discrimination task.

Klein et al. (1995) investigated patients with verbal auditory agnosia using ABR, MLR, and cortical auditory evoked potentials. Using an oddball discrimination paradigm, the researchers presented stimuli to patients in both tonal and consonant-vowel syllable structures. Their results showed that patients exhibited normal ABR and MLR responses, while abnormalities in the CAEP – N1 component were noted throughout the lateral temporal cortex for both tones and speech stimuli.

Hayes et al. (2003) used standard ABR protocols and cortical potentials to examine central auditory pathways in children with learning disabilities. Cortical responses in the trained group improved compared to the control group, but there was no change in ABR responses. In another study, Fujioka et al. (2006) examined the auditory late latency potentials in children aged 4-6 years and after music education, and they obtained higher P1 amplitudes after music education.

Cortical Auditory Evoked Potentials (CAEP) is also another effective way to observe the auditory maturation in hearing and listening tasks. Tomlin compared latencies of P1 and N1 waves and their interpeak amplitude in children with CAPD and children with normal hearing (Tomlin & Rance, 2016). According to the results, children with CAPD had significantly increased latencies in both waves by about 10 ms and a decrease in interpeak P1 - N1 amplitude by about 10 µV.

On the other hand, in studies conducted with participants with a diagnosis of adult CAPD, it was reported that when speech stimuli were presented, patients had delayed neural timings for stimulus onset and offset in brainstem responses (Clinard & Tremblay, 2013) and that they had reduced amplitudes in gap detection tasks in cortical responses (Harris, et al., 2012).

Prognosis of CAPD

It is stated, in many state organizations of USA, that the CAPD battery should be applied after 7 years of age for the definitive diagnosis. In the pediatric group observed difficulties are as following;

- Discriminating speech signals in noise,
- Difficulties in tasks related to auditory memory,
- Difficulties in performing phonemic discrimination,
- Difficulties in temporal fine structure (TFS) analyzes, which are important acoustic clues in pitch perception and discrimination in both simple and complex sounds.

In the literature, there are auditory processing studies on different groups with language acquisition, reading and writing difficulties, learning and reading comprehension problems. According to different studies, phonological processing problems observed in CAPD cause difficulties in acquiring language and learning skills (Protopapas, 2014). In another study, it was reported that children with a diagnosis of CAPD also had complaints about language acquisition, reading, writing and learning (Protopapas, 2014). In another study conducted with children with reading difficulties, it was observed that the scores of the participants in the auditory skill tasks were correlated with the false-word readings they used in the tests measuring their reading skills, and the reason for this was the lack of phonemic decoding of speech at younger ages (Protopapas, 2014).

On the other hand, different studies claiming that there is no significant relationship between temporal processing problem, which is a dimension of CAPD, and learning skills are observed in the literature. For example, there have been studies reporting that the elevated “backward masking thresholds” observed in children with language problems are not significantly different from the control group (Bishop, et al., 1999), and studies reporting that children with developmental language problems perform better than expected on temporal processing tests compared to their grammatical or phonological skills (Marshall, et al., 2001). There are also different studies in the literature stating that children with auditory processing problems do not have language or reading difficulties in the long-term examination (Bishop, et al., 1999).

In adults with CAPD, the most common symptoms are inability to distinguish speech in noisy environments and difficulty in phonemic discriminations. Studies conducted with adults with complaints of listening in noisy environments reveal that they perform poorer in the applied CAPD test batteries (dichotic listening, auditory memory, listening in noise test) than the control group (Obuchi, et al., 2017). In another study, temporal and spectral processing tests were applied to participants with dyslexia, one of the most important comorbidities of CAPD, and it was observed that the participants performed significantly poorer than the control group (Fostick, et al., 2012).

The most common challenge faced by many clinicians in the diagnosis of CAPD is the lack of a clear consensus on whether the disease exists alone or in conjunction with cognitive functions such as attention and memory. In addition, comorbidities such as Attention Deficit Hyperactivity Disorder or dyslexia are also observed in many individuals with a diagnosis of CAPD (Sharma, et al., 2009). The difficulties experienced by clinicians in the differential diagnosis of the disease also negatively affect the treatment process of the patients.

CAPD Treatment and Rehabilitation

CAPD treatment and rehabilitation is shaped by direct and indirect methods. These;

- Direct improvement of skill (auditory training, “bottom-up”)
- Compensatory strategies (improving metacognitive skills to compensate for the impairment. “top-down”)
- Environmental modifications (changing the learning or communication environment) (Speech-Language-Hearing Association, 2005)

Among these strategies, direct improvement methods and compensatory strategies are direct intervention methods. Some of the Direct Skill Improvement methods include sub-items such as auditory and phonemic discrimination, temporal dimensions of hearing, sound localization and lateralization, listening training for the recognition of auditory patterns.

The main purpose of these treatment methods is to rehabilitate the damaged auditory dimensions with listening training. Here, bottom-up, in other words, the rehabilitation of a process that progresses from the periphery to the central is in question. Basically, it can be summarized as the training process for generalization and presenting the correct form of the acoustic cue that the individual listens incorrectly.

In the second strategy, compensatory strategies, there is more linguistic and metacognitive rehabilitation with direct training. In this method, there is the idea of minimizing the effects of CAPD by increasing the deficiencies of attention and consciousness. In this treatment, it is aimed to activate the central auditory processing in different listening, social and communication tasks by improving the semantic, phonological and lexical dimensions of the language. Apart from this, it is aimed to compensate the negative effects of CAPD in the upper central pathways with metacognitive purposes such as problem solving, memory strengthening, and improving organizational skills. This treatment method aims to change the top down processing.

Environmental modifications, which are among the indirect methods, aim to make changes regarding the behavior of the individual with CAPD in the listening and communication environment, the acoustic quality of the environment or the S/R level in the environment. Environmental modification can be achieved by FM systems, the use of microphones in large places, which can provide the best condition for the ability to understand the S/R level in noise, and the placement of sound absorbing materials in the rooms.

There are different studies in the literature showing the effect of auditory training programs on CAPD. In one study, children between the ages of 8 and 14 with a diagnosis of CAPD were included; After the auditory training given for frequency, duration and loudness discrimination, MLR C3, A1 and A2 amplitudes were measured before and after the training. According to the data obtained, an increase was observed in the amplitudes of the patients after the training (Schochat, et al., 2010). Researchers also reported that higher scores were obtained after training in behavioral tests measuring central auditory processing skills, although this was not one of the aims of the study.

Tremblay et al. conducted auditory training on syllable patterns in speech and reported that after the training, the syllable perceptions of the participants improved and their N1 – P2 responses to these stimuli increased (Tremblay et al., 2001). Jirsa, on the other hand, reported that increased p300 amplitudes were observed after the auditory training program in children with CAPD (Jirsa, 1992). In another study, a study was conducted involving two school children diagnosed with CAPD, and the effect of auditory training on ABR responses in speech was examined. According to the data obtained by the researchers, amplitude and latency values of both patients reached normative values after auditory training (Krishnamurti, et al., 2013).

The use of assistive technologies that increase listening skills in the treatment of CAPD has also started to increase in recent years. On the other hand, studies involving treatment programs based only on CAPD are very few. Hornickel et al., in a 2012 prospective study, followed dyslexic children for one year in an environment where technologies that assisted listening skills were used and reported that participants had an increase in their phonological awareness, reading and spelling skills at the end of one year (Hornickel, et al., 2012).

CONCLUSION

CAPD, which is a common subject of study in many fields such as audiology, psychology, pediatrics, and speech disorders, continues to be one of the most striking fields of study in the field of audiology due to the difficulties in the diagnosis and rehabilitation process and draws attention to the importance of audiologists. In neural network, Primary auditory cortex (Heschl's gyrus [HG]) and planum temporal activation for the simple acoustic stimuli and the superior temporal gyrus anterior superior temporal sulcus for the complex signals are the regions that are thought to be related to CAPD. Difficulties in the discrimination of auditory signals may lead to impairment in language, listening and cognitive tasks in the progression of disorder. Personalized direct and indirect rehabilitation approaches and alterations in the auiditory environment are the existing interventions of the disorder.

Knowing more profoundly about the underlying neural mechanisms and prognosis with long-term follow-up will enable clinicians to detect the disease and start early rehabilitation and to develop more effective therapy techniques in the future. Its relationship with learning difficulties, specific language disorders, hearing loss, etc. will also contribute to the treatment process of these disorders.

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