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# Electrophysiology and Auditory Training

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## Abstract

Electrophysiology is an objective evaluation method that allows investigating the responses of the central auditory nervous system arising from the capture of neuronal responses through surface electrodes. In addition to the possibility of investigating and diagnosing different pathologies, electrophysiology proves to be an effective and effective instrument in monitoring auditory intervention programs. Auditory rehabilitation programs is based on the premise of neuroplasticity that derives from a capacity for neuronal change due to intense sound stimulation, specific and directed to the patient's needs. Throughout this chapter, current studies that correlate electrophysiology with auditory training programs in different clinical populations will be presented, such as: hearing in typically developed individuals, hearing and school difficulties, hearing and CAPD, hearing and otitis media, hearing and hearing loss, and hearing and voice. Electrophysiological tests are important objective measures in predicting the gains to be expected from auditory training programs.

**Keywords:** auditory processing, electrophysiology, auditory training, auditory evoked potential, auditory rehabilitation

## 1. Introduction

Central auditory processing (CAP) refers to the processes involved in the analysis and interpretation of auditory stimuli. It encompasses the perceptual processing of auditory information by the central auditory nervous system and the neurobiological activity underlying it that gives rise to auditory evoked potentials. It is a well-defined and consolidated entity, both from a clinical and research point of view, as well as in terms of its disorders and associated diagnosis and rehabilitation. In this chapter, we describe aspects of CAPD, including its diagnosis through behavioral and electrophysiological testing. We will cover auditory rehabilitation procedures such as auditory training, and monitoring procedures which include the analysis of electrophysiological findings.

## 2. Central auditory processing disorder

Central auditory processing disorder (CAPD) is a deficit in “the perceptual processing of auditory information in the central nervous system (CNS) and the

neurobiologic activity that underlies that processing” [1]. CAPD affects the perceptual and neural processes in the CNS which underlie sound localization and lateralization, auditory discrimination of speech and nonspeech signals, auditory performance when there is competing or degraded acoustic information, a variety of auditory temporal processing and patterning abilities, as well as others [2].

CAPD diagnosis can be performed at any age group, from childhood to adulthood. Alterations present in childhood may persist into adolescence and adulthood, may result from an acquired CNS event (traumatic brain injury, cerebrovascular accidents) and as part of the natural aging process. The estimated prevalence of CAPD may vary across age groups. In school age children the prevalence ranges from 2 to 5% [3] as a primary diagnosis. In cases where the CAPD co-runs with other difficulties such as learning disabilities (approximately 43%) and reading disorders (from 25 to 45%) [4] prevalence increases. While in adults, the prevalence increases with age to 17% at 50–54 years and may be greater than 70% after 60 years [5].

Signs and symptoms of CAPD include one or more behavioral characteristics—reading and writing difficulties, speech and language difficulties, difficulty hearing in background noise, difficulties in perceiving prosodic elements of speech as prosody, difficulty in following complex oral instructions, requesting repetitions of oral information, poor musical skills, sound localization difficulties, and others. This list is illustrative, not exhaustive, and it has to be remembered that these behavioral characteristics are not exclusive to CAPD [1, 6].

CAPD often occurs concurrently with other learning or developmental disabilities and is often associated with related cognitive, linguistic, or behavioral disorders. Sharma et al. [7] reported a high degree of comorbidity between APD and specific language and reading disorders. Individuals with autism spectrum disorder (ASD) and attention deficit hyperactivity disorder (ADHD) often have processing disorders [8], as well as dyslexia [9], and visual processing disorder [10].

The purpose of diagnosing testing is to identify presence of CAPD and delineate its characteristics and nature. Given the heterogeneity of the profiles of individuals who are referred for CAP assessment and their possible comorbidities, several auditory processing tests have been developed as tools for assessing different central auditory processing abilities. When selecting tests, the audiologist must recognize that a symptom may result from many underlying central auditory processing deficits (e.g., temporal processing, localization, spatial release of masking, performance with concurrent/degraded auditory signals), as well as language processing or cognitive problems. For that, diagnostic tests of central auditory function have been shown to be sensitive and specific for identification of CANS disorders.

The diversity of central hearing deficits supports the need for comprehensive test battery to track the various functions of the CANS. There is currently no universally accepted battery of APD tests. Currently, it is recommended that the behavioral assessment battery include non-verbal stimuli (temporal ordering, temporal resolution, and binaural interaction) and verbal stimuli (low redundancy dichotic and monaural listening). The battery should include tests representative several auditory processes as well as temporal processing, binaural separation, binaural integration, auditory closure, auditory discrimination, and sound localization [1].

Accompanying the behavioral assessment there should also be a carefully selected battery of behavioral tests with documented sensitivity and specificity. In a complementary way, there should be detailed observations of the case history and electrophysiological procedures, which together can provide a better understanding of CANS dysfunction [1, 6]. Even though (C)APD involves difficulties in the perceptual

processing of auditory information in the central nervous system, electrophysiological auditory potentials reflect the neurobiologic activity that underlies that processing [6].

In individuals whose auditory processing skills are not developing normally, their auditory processing skills can improve with appropriate treatment. The principle underlying this improvement is called neuroplasticity. Neuroplasticity is the result of experience and stimulation and involves reorganization of the cortex and brainstem. Studies show that the central nervous system's plasticity allows for reorganization and re-mapping following experience (i.e., either cortical or brainstem stimulation), and that this neural modification is reflected in behavioral changes [11, 12]. Plasticity allows the CANS to accommodate and improve central auditory processing skills [13, 14], with continual practice resulting in learning that automatically leads to better listening skills.

## **2.1 Principles of CAPD intervention**

Some principles are fundamental and should serve as guidelines for CAPD intervention. First, the intervention must be specific to the deficit, and personalized considering the patient's difficulties and strengths. The deficits should be clear from the results of the behavioral assessment, and the diagnosis should be given in terms of the original behavioral complaints.

The intervention should also be multidisciplinary, in most cases involving a variety of domains other than audiological, particularly if there are coexisting disorders. Checking whether CAPD is the primary disorder will help in specifying the focus of intervention and assist in prioritizing the different components and the order of their implementation.

While it is necessary to customize interventions for each individual, to maximize treatment effectiveness the treatment should incorporate both bottom-up and top-down approaches [1, 15–17]. A top-down approach focuses on auditory signal access and acquisition and includes direct auditory remediation strategies such as auditory training, as well as environmental modifications to increase signal clarity and improve the listening environment. Top-down treatments include training in core resources such as language, memory, and cognition along with environmental modifications and educational interventions [1, 16].

## **2.2 Comprehensive CAPD intervention**

Intervention for CAPD should start as soon as possible after confirmation of diagnosis. It is important that the intervention is comprehensive and multidisciplinary, adding issues related to listening, academic and language, in addition to higher order processes such as attention, memory and executive control in auditory tasks, domains that are commonly affected by CAPD.

When planning an effective approach to treating CAPD, three main components should be included: (a) environmental changes, (b) compensatory strategies, and (c) direct intervention—that is, auditory training. All three areas must be addressed in any intervention plan for individuals with CAPD [1, 15, 16], regardless of the co-occurrence with other disorders or the subject's age group.

In addition to these three components, some guidelines in the area also recommend the use of auxiliary listening systems, such as FM systems, in the process of auditory processing rehabilitation. This is especially true if the diagnostic exam shows impairment in auditory closure skills, figure-background, and selective attention [6].



### *2.2.1 Environmental modifications*

Environmental modifications aim to improve the individual's access to auditory information. This will involve increasing signal clarity and facilitating listening and learning in environments such as school, work, or social situations. Including bottom-up and top-down approaches based on acoustic aspects such as the use of assistive technology, environmental management that includes architectural interventions, removal of noise sources and consequently improvement of signal-to-noise ratios, and interventions for teachers and speakers including manner as information is transmitted and learned, highly redundant language aspects and listening and learning environments are highly recommended. The selection of modifications must be done systematically and must be based entirely on the difficulties presented by the individual and hearing deficits and the effectiveness of the implemented modifications must be continuously monitored [2].

### *2.2.2 Compensatory strategies*

Compensatory strategies, also known as core resource training, are designed to address secondary deficits, strengthening higher-order functions, language, cognitive skills, and academic deficits often seen in individuals with CAPD [1, 6, 15]. Through these strategies, the individual with CAPD is encouraged to take responsibility for their own success in the listening and learning processes, encouraged to paraphrase instructions to clarify misunderstandings, and advanced problem-solving techniques are taught. Involving metacognitive (thinking about thinking) and metalinguistic (thinking about language) strategies that aim to provide compensatory methods to minimize deficits in functional listening, monitor your understanding, identify your difficulties, devise alternative solutions, and be an active listener rather than a passive listener [1, 5, 17].

### *2.2.3 Auditory training*

Auditory training as related to CAPD aims to improve the function of the affected auditory process, the goal being to minimize or eliminate the alteration in auditory processing. Auditory training consists of an intensive series of challenging tasks based on the difficulties presented by the patient during the CAPD assessment [18].

Neuroplasticity is a great ally in the auditory training process. The nervous system is plastic and its capacity for reorganization and re-mapping by experience—neuronal modification—is reflected by behavior change [11, 12]. Changes in the neural substrate are facilitated by the presentation of stimuli in an organized, frequent, and intense way that progressively challenges the patient. The level of difficulty is appropriately graded and the stimuli are integrated into everyday activities. To maximize neuroplasticity, active participation of the patient in training is required. The inclusion of immediate feedback is important, as this gives positive reinforcement. Activities should be at or near the limit of the patient's ability [3].

Auditory training can be done formally or informally. The difference between the approaches is in the degree of control over the presentation of the stimuli and the environment. In formal training, stimuli are presented through an audiometer, allowing precise control of the level of stimulation and the types of stimuli (normally recorded). There needs to be control of intensity, frequency, stimulus duration, and inter-stimulus interval. Informal training is not concerned with stimulus control: stimuli are presented without the use of an audiometer and can be presented

in person, without recordings. Informal training is carried out without the fixed “controls” needed for formal auditory training.

For auditory training to be effective, tasks must be presented systematically and graded by difficulty so that they are challenging and motivating without being exhausting. The level of difficulty is adjusted to allow the patient to achieve correct scores of approximately 70% but not less than 30% [19]. Training should be frequent and intense, considering the lengths of the sessions, the number of sessions, the intervals between sessions, and the timeframe over which the training will be performed [3, 5, 19]. To maximize motivation, performance gains, and generalization, the patient’s active participation is necessary, and should be accompanied by immediate feedback and positive reinforcement. Variation of stimuli and tasks are key factors in successful auditory training [3]. The training programs that prompt these structural and functional changes must be done with auditory material different to those used in the diagnostic tests, which must be reserved only for evaluations [19].

Recent studies suggest that auditory training can serve as a valuable intervention tool for individuals with language deficit CAPD, learning difficulties, alterations in spatial processing, and adult subjects using hearing aids [6, 20–25].

Software programs are increasingly being used as strategies for auditory training. Computer-based auditory training (CBAT) provides age-appropriate strategies and presentations to keep the patient engaged. Some authors who examined children with CAPD [26], learning difficulties [26], and language and reading problems [26] have demonstrated benefits of this type of training for children with CAPD and associated issues.

### **3. Electrophysiology**

Electrophysiology is the branch of neuroscience that explores the electrical activity of neurons and makes it possible to investigate how molecular and cellular processes react to a given stimulus. Neuronal communication takes place through electrical and chemical signals [27].

#### **3.1 Hearing electrophysiology**

The electrophysiology of hearing involves small electrical changes that can be collected through electrodes placed on different regions of the scalp. The responses are generated by structures located throughout the auditory pathway and their analysis allows us to understand the normal patterns existing in the processing of auditory information [28].

Electrophysiological techniques allow us to assess auditory information processing, giving us more information about the functioning of the central auditory nervous system. These assessment techniques have provided great advances in neuroaudiology—the field that studies the relationship between the ears and the brain [28]. Other researchers see the need for a whole new field of study related to cognitive auditory sciences which is able to provide information about the correlation between hearing and cognition. They emphasize that hearing disorders need to be treated in an interdisciplinary context, one which should include, depending on the case, the following professionals: speech therapist, psychologist, audiologist, and neurologist [3]. In this way, electrophysiological assessments can play an important role both in the process of assessing auditory processing and also in monitoring auditory rehabilitation programs, such as auditory training [29].

Electrophysiological assessment is a way of analyzing the central auditory nervous system both of patients who actively participate in behavioral assessments and in individuals whose responses appear to be unreliable. There is already a consensus that the assessment and monitoring of auditory processing is only complete when there is a combination of behavioral and electrophysiological methods.

Neuroplasticity is the basis of auditory training programs, and it acts on the connections between neurons and the myelination of neurons as a result of performing auditory tasks. The on-going benefits of auditory training programs can be monitored by performing electrophysiological assessments, measuring neurophysiological changes which occur in both the peripheral and central auditory nervous systems. Electrophysiological assessments are therefore a useful and effective tool in monitoring training programs.

Below are the results of some studies that correlated electrophysiology and auditory training. The results come from researchers who are engaged in studying the effects of auditory training through electrophysiology in different clinical populations.

### **3.2 Hearing electrophysiology and auditory training**

#### *3.2.1 Hearing in typically developed individuals*

Research on neurophysiological changes resulting from auditory-perceptual learning for adults with normal hearing suggests that, although the auditory system responds to training, there is a substantial degree of variability among individuals in their ability to make use of physiological cues [30]. Training of auditory skills, even in individuals without complaints of alterations in the processing of auditory information, shows that changes take place in cognitive potentials (notably a reduction in latency of the P300 potential) after a program of auditory intervention [31].

#### *3.2.2 Hearing and school difficulties*

Learning results from the process of assimilating written and spoken language, and this process involves acoustic processing, phonemic processing, and linguistic processing. Integrated processing (acoustic, phonemic, and linguistic) must be complemented by the child's auditory and linguistic experience, which will be decisive for the learning of reading and writing. Researchers have found that the presence of learning difficulties is often associated with hearing deficits in children, and it is possible to monitor certain electrophysiological responses after auditory training. The results have shown an increase in the amplitude and a decrease in the latency of cortical potentials, although no changes were seen in brainstem responses [32]. The frequency following response (FFR) seems to be a very promising instrument to monitor patients with school difficulties, as well as to analyze the effectiveness of treatments, and it can be used as a biological marker of these changes [33, 34].

#### *3.2.3 Hearing and CAPD*

CAPD is defined as a disorder in one or more auditory skills involving sound localization and lateralization, auditory discrimination and recognition, temporal aspects, resolution, masking, integration, and temporal ordering. Kraus et al. [35] have reported altered responses in the following assessments: (a) brainstem auditory evoked potentials (ABRs) with click stimuli; (b) middle latency auditory evoked potentials (MLAEPs); and (c) N1 and P2 components of the long latency auditory

evoked potential (LLAEP). Results have shown that there seems to be an impairment in auditory discrimination that can be observed in electrophysiological tests (mismatch negativity, MLAEP, and N1 and P2 components), as well as alterations in neural synchrony evidenced by alterations in the ABR that can impact temporal coding and the perception of sounds in the presence of noise.

### *3.2.4 Hearing and otitis media (OM)*

Hearing deprivation, derived from multiple OM episodes in childhood, can compromise the normal development and maturation of the brainstem, as well as other cerebral and cortical structures. Diminished auditory signals can lead to desynchronization in the auditory cortex both for non-verbal and verbal sounds [36, 37]. Changes in auditory evoked potentials provide objective evidence that the auditory system has been modified [38]. One auditory evoked potential that seems to be more sensitive to deprivation from OM effects is the P300 cognitive potential [39]. The use of verbal stimuli when recording long latency auditory evoked potentials also seems to be very effective, providing additional information about auditory information processing [40].

### *3.2.5 Hearing and hearing loss*

Hearing loss is a highly prevalent disability and, importantly, studies have shown a correlation between hearing loss and cognition. Typically, the use of a hearing aid is associated with an improvement in the speech perception. It has been observed that auditory training programs improve both the processing of auditory information and of cognitive information in individuals with hearing loss, especially in competitive listening environments [41]. Auditory training programs that include training which requires increased memory demand seem to improve speech perception in noise and, in the process, improve neural response time [42]. Electrophysiology can therefore be an extremely useful tool for recording these changes in neural velocity. Mismatch negativity (MMN) can also be used as an electrophysiological measure for monitoring changes resulting from auditory training, especially in the auditory rehabilitation of patients with hearing loss who use a hearing aid or cochlear implant [43].

### *3.2.6 Hearing and voice*

The multisensory nature of music can have an impact on vocal production because it involves motor, auditory, and vocal mechanisms [44]. Hearing and voice are interrelated, so that the integrity of the auditory system is important for developing vocal behavior and maintaining vocal quality [45]. Individuals who sing in tune seem to have a particular pattern of responses in their FFR, showing lower latencies and stronger amplitudes than in individuals who sing out of tune. This shows that daily, long-term musical training can modify brain structures and improve the quality of auditory information processing [46].

## **4. Final considerations**

Electrophysiological tests are important objective measures to verify the effectiveness of auditory training. In addition, it is important to emphasize that an electrophysiological evaluation plays an important role in predicting the gains to be expected from



auditory training programs. Evaluation makes it possible to gauge whether the auditory training program should be continued, adjustments should be made, or a whole new intervention program begun. Thus, electrophysiological assessment is extremely important: it can indicate whether neural plasticity is possible (through improved synaptic efficiency and increased neural density) or measure the degree of functional plasticity (from behavioral changes brought about by training in auditory skills).

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