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REVIEW

Auditory Processing Disorder in Children: Definition, Assessment and Management

Sanem Sahli

Department of Otorhinolaryngology, Head and Neck Surgery, Section of Audiology and Speech Pathology, Hacettepe University Faculty of Medicine, Ankara, Turkey

Hearing is a complex process that is often taken for granted. As sounds strike the eardrum, the sounds (acoustic signals) begin to undergo a series of transformations through which the acoustic signals are changed into neural signals. These neural signals are then passed from the ear through complicated neural networks to various parts of the brain for additional analysis, and ultimately, recognition or comprehension. Auditory Processing Disorder (APD) previously known as "Central Auditory Processing Disorder" (CAPD) is a such disorder that auditory information is incorrectly processed in the brain. It is not a sensory hearing impairment; individuals with APD usually have normal peripheral hearing ability. APD is an umbrella term that describes a variety of problems with the brain that can interfere with processing auditory information. APD is assessed through the use of special tests designed to assess the various auditory functions of the brain. In APD, the approaches to remediation or management fall into three main categories: (1) enhancing the individual's auditory perceptual skills, (2) enhancing the individual's language and cognitive resources, and (3) improving the quality of the auditory signal

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Auditory processing disorder (APD), also known as central auditory processing disorder (CAPD) is a term used to describe individuals with normal hearing who have auditory-based receptive communication or language problems. While some individuals are more difficult to assess because of distorsions from the central auditory nervous system.

Auditory processing disorder refers to difficulties in the perceptual processing of auditory information in the CNS (Central Nervous System) as demonstrated by poor performance in one or more of the auditory and temporal skills (sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition) [1].

Although abilities such as phonological awareness, attention to and memory for auditory information, auditory synthesis, comprehension and interpretation of auditorily presented information and similar skills may be reliant on or associated with intact central auditory function, they are considered higher order cognitive-communicative and/or language related functions and, thus, are not included in the definition of CAP [1].

Auditory processing disorders (APDs) have received considerable attention over the past few decades. APD is not a new entity in audiology. For many years, professionals have been aware that some individuals with normal results on tests of peripheral function report difficulty in speech understanding. Since APD involves processing of auditory signal, audiologists are called on to make this diagnosis of APD based upon a battery of tests.

Much of the recent attention has focused on the controversy surrounding the operational definition of APD, the heterogeneous nature of APD, and an appropriate test battery for APD assessment [2].

Corresponding address:
Sanem Sahli
Department of Otorhinolaryngology, Head and Neck Surgery, Section of Audiology and Speech Pathology,
Hacettepe University Faculty of Medicine, Ankara 06100, Turkey
Phone : +90 312 305 42 00; Fax: +90 312 310 27 30; E-mail:ssahli@hacettepe.edu.tr

APDs are wide-spectrum disorders. Investigators have attempted to document the heterogeneous nature of APDs by sub-grouping APD or describing the characteristics in terms of commonalities [3-5].

Although this may be beneficial in management, no sub-grouping system or model is universally accepted. In addition, APD may exist with other learning, language, or reading disorders. This comorbidity has created controversial debate on differential diagnosis of APD or if the diagnosis of APD should only be made when it is a single entity.

Most investigations of APD have not described the specific auditory deficits or characteristics of their subjects. This may have led to some of the conflicting results in both behavioral and electrophysiological measures in children with APD. The research reported in this dissertation represents is a first-step in addressing some of the confounding issues surrounding APD. Specifically, this investigation will address a subgroup of children with APD who have specific temporal processing deficits [2].

Temporal processing refers to the processing of acoustic stimuli over time. Temporal processing is very important for us to be able to understand speech in quiet and in background noise, since speech stimuli and other background sounds vary over time.

Speech and hearing professionals need to be familiar with the various aspects of temporal processing for two reasons. Some children with auditory processing problems have difficulty in temporal processing of auditory stimuli. Such difficulties can hinder the acquisition of speech, language and reading. Older individuals can also have temporal processing deficits which can affect their ability to understand speech and to benefit from amplification in the presence of hearing loss [6].

Temporal processing deficits have also been associated with learning disabilities. Tallal's works [7-9] demonstrate that impaired temporal processing may result in language disorders, speech processing disorders and reading disorders. Tallal reports, "The phonological and language difficulties of language-learning impaired children may result from a basic deficit in processing rapidly changing sensory inputs" [9]. These investigators hypothesize that impaired temporal processing disrupts the normal development of an efficient phonological system and these phonological difficulties result in language and reading disorders [2].

Poor temporal processing is one of the characteristics of APD and is a key component of auditory function [10]. Temporal processes are critical in a number of auditory functions "including auditory discrimination, binaural interaction, pattern recognition, localization/ lateralization, monaural low-redundancy speech recognition, and binaural integration" [11].

The underlying physiological neural mechanisms for temporal processing may be assessed by behavioral and electrophysiological means. Behavioral tests "stress" the auditory system by degrading the acoustic environment or signal by introducing background or speech noise or by filtering the signal. Behavioral tests may require multiple auditory processes such as attention, memory, and perception [12]. Further, behavioral tests may be confounded by learning, attention, fatigue, hearing sensitivity, intelligence, developmental age, motivation, motor skills, language experience, and language impairments [13].

Terminology

Auditory Processing Disorder (APD) refers to how the brain recognizes and interprets auditory information. When a child's auditory processing ability is disordered, he is unable to properly analyze the words or sounds he hears. Auditory processing disorders are unrelated to hearing impairment and children with auditory processing disorders typically present with normal hearing ability.APD is also referred to as central auditory processing disorder [14].

It was not until the late 1960s and 1970s that the term 'central auditory processing disorder' was used to describe children with similar symptoms as adults with a central auditory nervous system lesion [15-20]. Since then, interest has continued to grow as numerous

articles, conferences, books and special committees have been devoted to this topic.

One of the controversies surrounding APD has been the terminology used to describe the disorder. "Central" has been used to distinguish the VIII nerve, brainstem and cortical areas as the anatomical site of dysfunction in contrast to the cochlea as a"peripheral" site of lesion. Central auditory processing is used interchangeably with central auditory function, central auditory perception, auditory language processing, and auditory language learning. This has caused many investigators to adopt APD which relates to no specific anatomical site of dysfunction [13].

However, other investigators continue to use "central" to emphasize the disorder occurs central to the peripheral hearing mechanism [21]. Other terminology used to describe auditory processing disorders include central hearing loss, auditory perception disorder, central deafness, word deafness, auditory agnosia, auditory memory deficit, auditory sequencing problem and auditory dysfunction [2].

One of the problems in defining auditory processing disorders is that it is a description of symptoms of functional deficits [22]. Auditory processing, as stated simply is "what we do with what we hear" [4]. Butler (1983) defined auditory processing as the abstraction of meaning from an acoustic signal and the retrieval of that meaning [23].

The American Speech-Language-Hearing Association (ASHA) 1996 Task Force defines central auditory processing as "the mechanisms and processes responsible for the following behavioral phenomena:

- Sound localization and lateralization,
- Auditory discrimination,
- Auditory pattern recognition,
- Temporal aspects of audition including temporal resolution, temporal masking, temporal integration, temporal ordering,
- Auditory performance decrements with competing acoustic signals and
- Auditory performance decrements with degraded acoustic signals.

'A central auditory processing disorder' is an observed deficiency in one or more of the above-listed behaviors [22].

The ASHA published their first definitive Technical Report "(Central) Auditory Processing Disorders" in January 2005 as an update to the "Central Auditory Processing: Current Status of Research and Implications for Clinical Practice"[22] and complements the UK's "Medical Research Council's Institute of Hearing Research's" Auditory Processing Disorder (APD) pamphlet, 2004 [24].

The 2000 Bruton Consensus Conference on the "Diagnosis of Auditory Processing Disorders in School Aged Children" defined an auditory processing disorder as "a deficit in the processing of information that is specific to the auditory modality [2].

The problem may be exacerbated in unfavorable acoustic environments. It may be associated with difficulties in listening, speech understanding, language development, and learning. In its pure form, however, it is conceptualized as a deficit in the processing of auditory input" [13].

Subgroups of APD

There are many models that attempt to describe APD. Investigators have attempted to document the heterogeneous nature of APDs by sub-grouping APD or describing the characteristics in terms of commonalities [3,5]. Based on the functions and test signs that are associated with various sites of lesion, APD categories were developed [4,25]. As in most fields, categories enable us to break down complex problems into smaller understandable units. Although this may be beneficial in management, no sub-grouping system or model is universally accepted [2].

One such model designed at the University at Buffalo is "The Buffalo Model". The Buffalo Model focuses on the relationship between patterns of performance on one particular test of auditory processing and learning difficulties in children. This model contains

four subtypes: Decoding, Tolerance-Fading Memory, Integration and Organization [4,26].

Decoding describes individuals who "have difficulty in keeping up with the flow of communication, have poor phonemic skills, are slow responders, often have articulation errors, have difficulty in following directions, and have weak oral reading and spelling skills" [27].

Persons with tolerance-fading memory have difficulty in speech understanding with competing background noise and have short-term memory problems. These individuals are often described as impatient and are easily over-stimulated. They tend to have poor reading comprehension and may have handwriting difficulty.
Integration refers to how auditory information is integrated with other factors in one's environment Integrating what you hear with what you see, or recognizing two sounds in one's environment, but focusing on the most salient of the two are examples of the integration process [28].

Organization, the last model, describes persons who have difficulty in sequencing events and have sequencing errors. These individuals are often disorganized at home or school. Often a person will exhibit characteristics of more than one sub-type [26].

The Bellis/Ferre model describes a method of subprofiling APD. Each subprofile is related to its underlying neurophysiologic region of dysfunction in the brain as well as to its higher-level language and learning implications and sequelae. This model includes three primary profiles and two secondary profiles. The three primary profiles (Auditory Decoding Deficit, Prosodic Deficit, Integration Deficit) represent auditory and related dysfunction in the primary auditory cortex (usually left hemisphere), nonprimary auditory cortex (usually right hemisphere) and corpus callosum (interhemispheric dysfunction).

Secondary profiles (Associative Deficit and Output Organization Deficit) represent dysfunction and associated sequelae that may be considered to represent higher-level language, attention, and/or executive function and, therefore, some may argue against their inclusion under the umbrella of APD [21].

Auditory decoding refers to persons with "poor auditory closure abilities, characterized by poor performance on tests of monaural low redundancy speech and speech-in-noise" [29]. Integration Deficit refers to difficulties in interhemispheric transfer.

Associative Deficit refers to "an underlying inability to apply the rules of language to incoming acoustic information" [29]. Output-Organization Deficit is a deficit in organizing, planning, and sequencing responses. Again, it is possible that a person may have more than one sub-type [2].

Except these models, Musiek & Gollegly report three types of APD in children with learning disabilities. These three types are based on an underlying neurophysiological deficit or neuromaturational delay: neuromorphological disorder, maturational delay of the CNS and finally neurologic diseases and insults. These types are theoretical and have not been directly investigated due to the invasive nature of necessary research procedures [5].

Etiology

The cause of APD is often unknown. In children, auditory processing difficulty may be associated with conditions such as dyslexia, attention deficit disorder, autism, autism spectrum disorder, specific language impairment, pervasive developmental disorder or developmental delay. Sometimes this term has been misapplied to children who have no hearing or language disorder but have challenges in learning [30].

There are many possible causes of APD. Causes of APD in children are not completely understood. Often, these children do not show any neurological disease or any neurological abnormality.

Not all cases of APD have an underlying structural deficit, therefore, APD may be difficult to diagnose with computerized tomography or magnetic resonance imaging scans of the brain. Researchers have

suggested that the problem underlying APD "may be invisible to many neurologic and radiologic studies" [31].

Other prenatal or perinatal factors that may be indicated in APD are: hyperbilirubinemia, ototoxic drugs, anoxia, low birth weight, RH incompatibility, prematurity, abnormal secretion that affects brain cell development prior to birth, and unspecified birth problems. Maternal factors which may adversely affect development of the central nervous system include diabetes, rubella, syphilis cytomegaloviruses and toxemia [32].

Hereditary factors may also play an important role[32,33]. Future brain imaging studies such as functional magnetic resonance imaging may prove of value in further understanding the mechanisms involved in brain function and auditory processing in normal children and children with APD [2].

Comorbidity of APD

APD has been observed in diverse clinical populations, including those where central nervous system (CNS) pathology or neuromorphological disorder is suspected (e.g. developmental language disorder, dyslexia, learning disabilities, attention deficit disorder) and those where evidence of CNS pathology is clear (e.g.aphasia, multiple sclerosis, epilepsy, traumatic brain injury, tumor and Alzheimer's disease). Moreover, these conditions are not mutually exclusive and may be characterized as co-morbid: an individual may suffer from APD, attention deficits and learning difficulties. Whether these disorders are causal to one another remains unclear [10].

There is an intimate relationship between language, attention and auditory skills. Auditory processing disorders often coexist with learning disabilities, language disorders, attention deficit disorders and dyslexia[10,34]. Children with Attention Deficit/Hyperactivity Disorder manifest behaviors strikingly similar to children with Auditory Processing Disorder [35]. DiMaggio and Geffner (2003) showed that 84% of children with APD had confirmed or suspected AD/HD. Co-occurrence between AD/HD and APD is 41% for children with confirmed diagnosis of AD/HD, and 43% for children suspected of having AD/HD [36]. Children with dyslexia are often "wrongly diagnosed" because symptoms that characterize dyslexia appear to be indistinguishable from APD. Dyslexia is defined by the International Dyslexia Association (2000) as a language-based disability in which a person has trouble with understanding words, sentences or paragraphs where both oral and written language are affected. An APD can influence a child's ability to read since specific auditory performance deficits will prevent a child from developing good reading skills. In one sample of 94 children with learning disabilities, only one child was free from central auditory processing dysfunction [4,37].

All of these groups are heterogeneous in nature. However, it is important to note that not all children with a language, learning or attention disorder will have an auditory processing disorder. APDs have also been linked to children with chronic otitis media [38-41] and also the elderly and aging population [42]. This has led some investigators to question if auditory processing deficits underlie language disorders, or if auditory processing disorders are one type of language disorder [22,43-46].

Controversy exists about the label of APD in children with multi-sensory deficits. Some investigators argue that if multi-sensory deficits are present, then the diagnosis of APD is inappropriate, and the diagnosis is only appropriate where there is a single auditory deficit [34]. However, given the interconnections of the nervous system and the influence of higher-level functions such as language, cognition and attention, the single modality-specific definition for APD is not logical [21].

Oral language acquisition depends upon the efficient processing of acoustic stimuli [22]. Some children with specific language impairments have difficulties in perceiving rapid acoustic events and have difficulty in processing auditory information of brief duration

relative to surrounding segments. This difficulty will not only affect phoneme recognition, but also affect the listener's ability to segment speech. A degraded acoustic environment may hinder speech processing. This degraded environment has also been theorized to be one of the etiologies of specific language impairments in that the amount and type of linguistic input necessary for optimal language acquisition is not present [2,47,48].

However, it is important to note that not all children with specific temporal processing deficits show language or speech disorders. There are two contrasting models regarding the influence of lower order perceptual processing and higher order cognitive processing on language and learning disabilities [43,44]. Models describe how listeners perceive the acoustic signal, conduct auditory analysis involving complex pattern recognition, match acoustic patterns to some internal representation(s), extract meaning from strings of lexical representations, and construct a message level interpretation [2,49].

Assessment

An auditory processing assessment must accomplish three things: first, it must be determined if auditory processing is affected; second, if auditory processing is deficient, then the severity of the APD must be assessed; third, the clinician must determine if the APD can account for the person's communication and learning difficulties. These three goals of an APD assessment are not without controversy.

A. Dependant variable measures

Presenting symptoms were based on parental report during the initial case history interview. Additionally, listening difficulties were quantified using the following two questionnaires

1. Symptoms

A child with APD typically exhibits the following behaviors;

* The child behaves as if a peripheral hearing loss was present, despite normal hearing
* The child has difficulty in auditory discrimination and has diminished ability to discriminate among speech sounds (phonemes).
* The child has difficulty in remembering phonemes and manipulating them (e.g. on tasks such as reading, spelling and phonics as well as phonemic synthesis or analysis)
* The child has difficulty in understanding speech in the presence of background noise.
* The child has difficulty in auditory memory (either span or sequence). Unable to remember auditory information or follow multiple instructions.
* The child demonstrates scatter across subtests with domains assessed by speech-language and psychoeducational tests, with weaknesses in auditory-dependent areas.
* The child has poor listening skills characterized by decreased attention for auditory information, distractible or restless in listening situations.
* The child responds inconsistently to auditory information (some times responds appropriately, sometimes not) or has inconsistent auditory awareness (one-to-one conversation is better than in a group setting) The child has a receptive and expressive language disorder; there may be a discrepancy between expressive and receptive language skills.
* The child has a receptive and expressive language disorders; there may be a discrepancy between expressive and receptive language skills.
* The child has difficulty in understanding rapid speech or persons with an unfamiliar dialect.
* The child has poor musical abilities and does not recognize sound pattems or rhythms; has poor vocal prosody in speech production.

These examples are only a few of the behaviors that are associated with APD. Not every child with auditory processing problem will exhibit all of the behaviors mentioned. The number of problems

experienced by a given child will be an expression of the severity of their auditory processing problems [50].

Recognizing children who have Auditory Processing Disorder

In children with APD, general characteristics, physical features and emotional-social difficulties described in Table 1 [51].

2. Children's Auditory Performance Scale (CHAPS) and Fisher's Auditory Checklist

The CHAPS[52] is a screening questionnaire for listening difficulties. Parents or teachers are asked to compare the child's listening in a range of conditions such as 'Multiple Inputs', 'Ideal' or 'Noise'. The CHAPS provides average scores for each condition as well as a total score. The CHAPS recommends referral for APD evaluation if the average total score or any of the average scores for each condition are lower than < 0.05.

Fisher's auditory checklist[53] is a screening questionnaire for listening difficulties that can be completed by parents or teachers. It is comprised of the list of 25 statements, such as "Says "Huh?" and "What?" at least five or more times per day" and "Experiences problems with sound discrimination". However, many of these statements are not specific for APD, such as "Has a short attention span", "Has a language problem (morphology, syntax, vocabulary, phonology)" and "Has an articulation (phonology) problem". The number of items checked is scored as a percentage, which can be compared against norms for 5-11 years old. The authors recommend referral to an audiologist for APD examination if a child's score is poorer than 72%, close to one standard deviation below the mean.

B. Assessment tests used for diagnosis of APD

1. SCAN

The SCAN is a US-produced standardised test of auditory processing, and is the most commonly used instrument for diagnosis of APD [54]. It is composed of four subtests including (a) discrimination of

Table 1. General characteristics, physical features and emotional-social difficulties in children with APD.

General Characteristics;	
* Says "huh" or 'what' freguently	* Has difficulty in phonics and speech-sound discrimination
* Gives inconsistent responses to auditory stimuli	* Has poor auditory memory (span and sqeuence)
* Often misunderstands what is said	* Has poor receptive and expressive language
* Constantly requests that information be repeated	* Gives slow or delayed response to verbal stimuli
* Has poor auditory attention	* Has reading, spelling and other academic problems
* Is easily distracted	* Learns poorly through the auditory channel
* Has difficulty in following oral instructions	* Exhibits behavior problems
* Has difficulty in listening in the presence of background noise	
Physical Features	**Emotional and Social Difficulties**
* Poor general health	* Temper tantrum/explosive behaviour
* Enuresis/encopresis	* Low self-esteem
* Increased incidence of otitis media	* Low frustration tolerance
* Increased frequency of allergies/food sensitivities	* Mood swings
* Greater frequency of disturbance in sleep/wake cycles	* Hyperactivity
* Poor motor coordination	* Poor peer relations
* Suspected underaroused central nervous system	* Problem with taking turns
* Greater frequency of minor physical anomalies	* Poor self control
	* Poor general social skills
	* Agressiveness
	* Impulsiveness

monaurally presented single words against background noise, (b) acoustically degraded single words and (c) dichotically presented single words and (d) sentence stimuli. The child version, the SCAN-C [50] is for use with children aged 5-11 years and the SCAN-A [55] for those aged 11 years plus.

2. Random Gap Detection (RGD) Test

The RGDT[56] is a standardised test that assesses an individual's gap detection threshold of tones and white noise. The test includes stimuli at four frequencies (500, 1,000, 2,000, and 4,000 Hz) and white noise clicks of 50 ms duration. This test provides an index of auditory temporal resolution. In children, an overall gap detection threshold greater than 20 ms constitutes failure 50. This point is slightly below <2 SD, based on US population-based normative data for children aged 5-11 years published with the RGDT.

3. Gaps in Noise (GIN) Test

The GIN is another measure of auditory temporal resolution. The test assesses an individual's gap detection threshold in white noise. Comparative performance data exist for adult normal-hearing listeners and adults with confirmed neurological involvement of the auditory nervous system [57].

4. Pitch Patterns Sequence (PPS) Test and Duration Patterns Sequence (DPS)Test

The PPS and DPS are measures of auditory pattern identification [31,58-60]. The PPS consists of series of three tones presented at either of two pitches, for example 'high high low' or 'low low high'. The DPS consists of series of three tones that vary in duration rather than pitch, for example, 'two short, one long' or 'one long, one short, one long'. Individuals are asked to describe the pattern of pitches presented. US population-based normative data are provided for children aged 6 years through 9 for the PPS, though only adult performance norms are available for the DPS.

Strategies for Auditory Processing Disorder

Several strategies exist which may positively impact a student in their educational environment. These strategies are divided into parent, teacher and student approaches. The team may choose to utilize these strategies during an early intervening, assessment or intervention stage.

A. Teacher Modification Strategies

1. Classroom environment

* Reduction of noise/minimize distractions
* Preferential seating away from noise
* Use of classroom amplification system

2. Teaching techniques

* Clear enunciation at a slow-moderate rate of speech
* Insert purposeful pauses between concept
* Shortened verbal instructions; only pertinent content
* Provide visual cues during lecture and/or oral directions
* Provide repetition of oral information and steps of assignment
* Give breaks between intense concepts taught for comprehension
* Check for comprehension early and often
* Have student repeat directions to the teacher
* Preview and review concepts for lecture

3. Peer assistance

* Use of a positive peer partner for comprehension of directions
* Use of cooperative learning groups
* Use of a note-taker

4. Assingment modifications

* Allow extended time to complete assignments and/or tests
* Provide visual instructions
* Preview language of concept prior to assignment
* Frequent checks for comprehension at pre-determined points
* Vary grading techniques

B. Student Modification Strategies

* Teach use of visual cues to supplement auditory information

* Teach use of short and long term memory techniques (i.e. rehearsal, chunking, mnemonics, visual imagery)
* Teach student to listen for meaning rather than every word
* Teach active listening behaviors
* Teach student to advocate for themselves by asking frequent questions about the material, asking for multiple repetitions or requesting speaker to "write it down"
* Use of tape recorder for assignments
* Teach organizational strategies for learning information

C. Parent Modification Strategies

* Keep directions or commands short and simple
* Use praise often and be positive
* Use visuals or gestures at home to compensate for listening difficulties
* Assist the student in asking clarification questions and being their own advocate
* Preview and review classroom material
* Review tape recorded information with the student

Other specific skill strategies which focus on auditory remediation exist in the literature in auditory processing disorders [61].

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