# Auditory Processing Disorders I: definition, diagnostic, etiology and management.

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## Abstract

Auditory Processing Disorder (APD) is a condition in which patients are experiencing listening difficulties in the absence of clearly identifiable peripheral auditory deficit. Therefore, patients with APD typically have normal pure tone thresholds but experience difficulties in various auditory tasks including mainly sound localization or speech comprehension in noisy environments. Over the last 20 years, the interest of the scientific and clinical community for APD has been growing constantly. This was due mainly to the fact that this classification shed new lights on the diagnosis and management strategies selection, primarily in the context of APD itself, but also increasingly in a number of co-morbid conditions including attention deficits / hyperactivity disorders (ADHD), specific language impairment (SLI), dyslexia or even recently autism. In the present paper, we propose to review current assumptions and consensus on the definition, diagnosis, etiology and management of APD. In a second companion paper (see Hoen, Rogiers and Mülder, current issue) we reviewed recent experimental work on the use of personal frequency modulation (FM) assistive devices for the management of APD. Although there is still a general lack of large scale evidence to support the current views on APD diagnosis and long term outcomes of proposed management strategies, first support do exist that stress the relevance of multidisciplinary and individualized treatment approaches with good hopes of significant improvements for concerned patients.

**Keywords:**

Auditory Processing Disorders; APD; ADHD; Learning Disabilities; Dyslexia; Specific Language impairment; SLI

## Introduction

Hearing is one of our most important senses as it gives us access to spoken language, necessary for the development of speech, language and communication in general. Development of speech and language in children is a continuous process, in which the first years of life are of the greatest importance (see, amongst many others, de Boysson-Bardies, 2001 or Pinker, 1994, for reviews). Normal function of the auditory sensory organs and the central auditory pathways is a prerequisite for the normal development of speech and language in children. For a number of children the process of developing speech and language is hampered and their ability to communicate effectively does not develop in a straightforward fashion. During the past decade the subject of (central) auditory processing disorders has received a growing amount of attention because of the possible link between auditory processing disorders and learning disabilities in general, and language impairment in particular. To better understand Auditory Processing Disorders, it is important to understand auditory processing of spoken language and the way it influences a person's ability to communicate and learn. Some school-aged children have normal auditory thresholds yet appear to have a hearing impairment. They are described by their parents and teachers as children who are uncertain about what they hear, have difficulty listening in the presence of background noise, struggle to follow oral instructions and find understanding rapid or degraded speech difficult. In a significant proportion of these children, the listening problems result from an auditory processing deficit: the defective processing of auditory information in spite of normal auditory thresholds (Jerger and Musiek, 2000). Auditory Processing Disorder or APD has been erroneously confused with other disorders such as dyslexia, learning disabilities, attention deficit disorders, etc. Recent developments show a growing awareness of the disorder on the part of professionals, parents, educators, and the general public. Numerous sites have emerged on the internet. Clinical programs, addressing auditory processing and its disorders are being developed, focusing on interdisciplinary collaboration between audiologists, speech-language pathologists, neuroscientists, neuropsychologists, as well as professionals and scientists in countless other disciplines. They are united in their quest to define, understand, diagnose, and treat auditory processing disorders (Bellis, 2003).

## *Auditory Processing of Spoken Language*

Between the arrival of speech at the eardrum and our perception of it, a very large number of mechanical and neurobiological operations intercede (Chermak & Musiek, 1997). The act of hearing does not end with the mere detection of an acoustic stimulus. Information processing theory states that both bottom-up factors (or sensory encoding) and top-down factors (or cognition, language and other higher-order functions) work together. Both factors have an influence on processing auditory input and thus determine a person's ability to understand auditory information. Furthermore, much of what is considered to be central auditory processing is preconscious; that is, it occurs without the listener being aware of it. At the same time, even the simplest auditory event is influenced by higher level cognitive factors such as memory, attention, and learning (Bellis, 2003). Our understanding of how the brain processes auditory input, especially spoken language, has improved, largely due to the advent of more advanced imaging technology and electrophysiological measuring techniques. Findings in neurogenesis and neuroplasticity may ultimately lead to treatment of auditory processing and related disorders through actually changing the function of the neural pathways of the brain (Bellis, 2003). Neurons are active, dynamic, and plastic in their functions and connections. They "learn" through experience. Similarly, the auditory functions we ascribe to the central auditory system are also complicated and numerous. The business of detecting a sound, evaluating it on a number of dimensions, segregating it from the background, attending to it, recognizing it as familiar, comprehending its meaning, are all functions of the brain (Chermak & Musiek, 1997).

## *The central auditory nervous system (CANS): Bottom up functions and Pathways*

The two cerebral hemispheres are separated by the longitudinal fissure and each hemisphere exhibits some degree of specialization for certain types of tasks and functions (Bellis, 2003). For a general overview of hemispheric specific functions the reader is referred to Table 1.

| Right Hemisphere | Left Hemisphere |
|---|---|
| • Some linguistic processing abilities but they tend to be more simply and more randomly organized. Some meta-linguistic communication abilities, processing of prosodic or emotional information.<br><br>• More adept at detection and recognition of faces, especially unfamiliar ones, and responsible for the interpretation of many involuntary facial expressions.<br><br>• Examines a visual environment in a less organized matter. Appears to be better in disengaging, shifting and re-engaging attention or allocation of attention.<br><br>• Dominant for part-to-whole gestalt synthesis, sequencing, visual-spatial abilities, mathematics calculation, art and music skills, abstract reasoning, and similar types of tasks. | • Usually the language-dominant hemisphere responsible for the storage of lexical information, generation of syntax, phonological processing and the production of speech.<br><br>• Able to generate voluntary facial expressions.<br><br>• Regarding spatial attention and visual search abilities: very systematic in detecting a visual target in a background of foils.<br><br>• More analytic, better at breaking down a whole into its constituent parts. Also more phonologic and linguistically oriented (particularly related to semantics and syntax), and better able to engage in concrete thought processes. |

Table 1) Schematic overview of right and left hemisphere functions (adapted from Bellis, 2003, p. 8–9).

Individual differences may however occur. The cerebrum can be divided into four primary lobes, each of which serves different functions. Although general functions can be ascribed to each lobe in the typical brain, a tremendous amount of cross-modality integration and interplay occurs in all areas. For example, although the superior temporal lobe is generally considered to "house" the auditory portions of the brain, auditory responsive regions are found throughout the brain and subcortical structures (Bellis, 2003). The following description of the function of specific parts of the auditory ascending pathway is based on Bellis (2003). It aims at emphasizing that, rather than serving as simple relays, each level of the ascending auditory pathways contributes a significant amount of processing which results in extraction and enhancement of important speech features. The primary role of the auditory nerve is to break down the incoming acoustic signal into components and to relay accurately all information to the central auditory nervous system for further processing and extraction of relevant, perceptually salient, components. Within the CANS, a key function of the cochlear nucleus appears to be contrast enhancement. The superior olivary complex appears to be fundamental to the processing of binaural input, important for localization of auditory stimuli, and essential for hearing in the presence of background noise. The lateral lemniscus constitutes the primary ascending auditory pathway and contributes to further feature extraction and enhancement. The inferior colliculus (in the midbrain) is another structure with profound implications on the ability to localize sound sources and other binaural processes. Its primary contribution to speech encoding appears to be the further enhancement of modulations in the acoustic signal. The auditory nucleus of the thalamus represents the primary auditory way station for information between the brainstem and the cortex. Its primary role consists of multimodality integration. Neurons that respond to auditory stimuli have been found in virtually every region of the cerebrum, including the parietal, frontal, and occipital cortex in addition to the expected temporal lobe region (see Poremba et al., 2003; Scott, 2005 for recent work in animals and humans respectively). Cortical neurons in the primary auditory cortex are organized tonotopically and fibers are organized in ear-dominance bands. Cortical neurons are able to faithfully represent the timing of phonetically important components of speech, such as voice onset time and place of articulation. Rapid spectrotemporal transitions and binaural representation functions are also strong at the cortical level. Wernicke's area is referred to as the auditory association cortex. It is concerned with the recognition of linguistic stimuli and comprehension of spoken language and contributes to language formulation. In addition, the portion of Wernicke's area extending into the parietal lobe is also implicated in reading and writing. The *corpus callosum* serves to integrate information between the two hemispheres both within and across modalities, and may also serve to diminish the possibility of interhemispheric competition in selected tasks. Studies of brain development show that sensory stimulation of the auditory centers of the brain is critically important, and influences the actual organization of auditory brain pathways (see Flexer, 1999 for review). The neurological foundations that we foster during the first critical years of a child's life provide the "velcro" for the attachment of later linguistic, literary and academic competencies. Anything that we do to "program" those critical and powerful auditory centers of the brain with acoustic detail will expand children's opportunities. Therefore, anything that has a negative effect on the auditory signal will adversely affect the individual's ability to process auditory information (Bellis, 2003). In this way, long-term conductive hearing loss in young children can lead to prolonged auditory processing disorders (see Stollman, 2003, for review and Gravel and Wallace, 1992; Mody, Schwartz, Gravel and Ruben, 1999; Demanez, Boniver, Dony-Closon, Lhonneux-Ledoux and Demanez, 2003). Or, if a child has congenital sensorineural hearing loss, it is reasonable to assume that the poorer neural representation will lead to serious problems in the maturation of the auditory pathways and hence the development of auditory processing abilities (e.g. Stollman, 2003). In computer analogy words: Data input precedes data processing. If data are entered inaccurately, incompletely, or inconsistently, the child will have incorrect or incomplete information to process. Said another way, if a child cannot hear speech sounds clearly, or if a child does not have the skills to listen, or if the learning environment does not allow instruction to be heard clearly, any communication towards the child using speech as the vehicle for interaction is likely to fall far short of its projected goals.

## *The central auditory nervous system: Top-down functions and Pathways*

In the process of speech processing, several levels can be distinguished, namely acoustic, phonetic, phonological, syntactic, semantic and pragmatic levels. In an attempt to clarify or even quantify the complexity of speech processing and the mysteries it still holds, we distinguish between bottom-up and top-down factors. Bottom-up factors contribute to the acoustic analysis of speech. Semantic and syntactic levels represent the linguistic analysis of speech that is seen as one of the top-down, higher order functions (Miller, Delaney and Tallal, 1995). The precise point at which auditory processing stops and language processing begins is unclear, and still constitutes a point of conjecture (e.g. Bellis, 2003 and see Uppenkamp, Johnsrude, Norris, Marslen-Wilson and Patterson, 2006 for recent findings). Flexer (1999) underlines the significant role language plays in speech processing by stating that children bring a different "listening" to a communication/learning situation than adults, in two main ways. Firstly, human auditory brain structure is not mature until about age 15 years. Bellis (2003) suggests that neuromaturation of some portions of the auditory system may not be complete until age 12 or later. Secondly, children differ from adults in the way they "listen" because they do not have the years of language and life experience that enable adults to fill in the gaps of missed or inferred information. Flexer (1999) concludes by saying that these factors mean children require more complete, detailed auditory (or acoustic) information than adults. Aside from language, Bellis (2003) lists other top-down factors such as cognition, attention and executive function that will influence the ability to listen and to process auditory input. She states that processing of any type of sensory stimulus is reliant on general arousal state and attention. This means that poor attention skills or a too high arousal level may inhibit a child from being able to attend to and process auditory input. Similarly, auditory processing is also reliant on adequate executive function. Like a general overlooking his troops, executive functioning can be thought of as "overseeing" or coordinating problem solving, learning, memory, attention, planning and decision making, and goal-directed behavior (including listening and acting upon what is heard). As a last top-down factor, Bellis also describes the McGurk effect, in which visual input modulates what is perceived auditorily. In a study by Sams et al. (1991), subjects listened to the syllable /pa/, presented with a videotape of a speaker saying /ka/. The subjects reported hearing either what was seen (/ka/) or a syllable somewhere between the auditory and the visual input (e.g. /ta/) (see also Brancazio, Best and Fowler, 2006 for recent observations). In conclusion, even if basic sensory encoding is perfect at all levels of the ascending pathways, higher-order dysfunction or inadequate top-down factors will have a negative effect on the individual's ability to process, and ultimately comprehend spoken language.

## Auditory Processing Disorders (APD)

### *Definitions of APD*

The National Institute on Deafness and other Communication Disorders (NIDCD) in the USA describes children with auditory processing disorders as typically having normal hearing and normal intelligence (National Institute on Deafness and other Communication Disorders, 2001). As outlined before, in order to be able to describe Auditory Processing Disorder more precisely, we need to understand and define "normal" auditory processing and the way it influences a person’s ability to communicate and learn. In the broadest terms, (central) auditory processing can be defined as "What we do with what we hear” (Stecker, 1998). Musiek (see http://www.ldonline.org/articles/5927) has described the integrity of auditory processing as "How well the ear talks to the brain and how well the brain understands what the ear tells it”. In its successive technical reports and consensus statements, the American Speech-Language-Hearing Association Consensus Committee (see ASHA, 1995; 2005) defines auditory processing as difficulties in the processing of auditory information in the central nervous system (CNS) as demonstrated by poor performance in one or more of the following skills: sound localization and lateralization; auditory discrimination; auditory pattern recognition; temporal aspects of audition, including temporal integration, temporal discrimination (e.g., temporal gap detection), temporal ordering, and temporal masking; auditory performance in competing acoustic signals (including dichotic listening); and auditory performance with degraded acoustic signals. An Auditory Processing Disorder should therefore be defined as an “observed deficiency in one or more of the above-listed behaviors”. This definition succeeds in segmenting audition into some of its constituent auditory behaviors. However, it fails to highlight the underlying mechanisms responsible for such behaviors. Furthermore, it does not explain how deficiencies in such behaviors may lead to difficulties in higher-level language, learning and communicative tasks (Bellis, 2003). The Bellis/Ferre model (Bellis and Ferre, 1999), 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 sequels. This model may be described as both neurophysiologic and neuropsychological, in which subprofiles are derived that encompass the whole of audition, from underlying auditory mechanisms to language, learning, and other high-level, complex behaviors. It includes three primary profiles and two secondary profiles. The three primary profiles represent auditory and related dysfunction in the – primary auditory cortex (usually left hemisphere) – non primary auditory cortex (usually right hemisphere) – corpus callosum (interhemispheric dysfunction). Secondary profiles represent dysfunction and associated sequels 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. Finally, even if the "central" compound of APD is certainly a major characteristic of these disorders and might well be a critical aspect of most of its forms, recent observations on the perceptual consequences of cochlear hearing loss (Moore, 1995; 1998) or the role of the olivocochlear efferent system regulation on outer hair cells functions (Suga, Gao, Zhang, Ma, and Olsen, 2000), raise the issue of potential peripheral influences on degraded auditory performances not reflected in audiometric measurements (Moore, 2006). Therefore, the term APD was preferred in the later years too CAPD or even (C)APD for (central) auditory processing disorders, which may well prove to be anatomically imprecise, as long as our detailed knowledge on the close relationship between peripheral and central auditory processing will not be significantly increased, the more general and cautious term of APD is certainly more adequate, even if this term increases the likelihood of seeing always more pathologies fall under the already wide scope of APD.

## *Prevalence and etiologies of APD*

First, it is worth mentioning that although the original definitions and most of the research on APD considered these disorders in the context of childhood, APD can occur in people of any age, with different etiologies and prevalence.

In school aged children and despite an evident lack of large scale multi-site observations, the prevalence of APD can be estimated at 5 to 7%, with a 2:1 ratio between boys and girls (Chermak and Musiek, 1997; Bamiou, Musiek and Luxon, 2001). In children, main etiologies include: (see Bamiou et al., 2001, for review) premature birth and low birth weight (Demanez et al., 2003; Demanez & Demanez, 2003), damage to the brain caused by infectious diseases as bacterial meningitis, herpes simplex encephalitis or Lyme disease, or damages caused by head trauma (Benavidez et al., 1999; Flood, Dumas, and Haley, 2005) or cerebrovascular disorders. Numerous observations now also corroborate the hypothesis that transient hearing deprivation or transient hearing loss during early childhood, caused for example by prolonged otitis media or other reversible middle or inner ear pathologies can lead to APD symptoms at older ages (Gravel and Wallace, 1992; Mody et al., 1999; Bamiou et al., 2001; Demanez et al., 2003). Recently, children with autistic syndromes have been more and more identified as having auditory deficits that could not be accounted for by any peripheral auditory deficit (Gravel, Dunn, Lee and Ellis, 2006). In adults, the main identified causes of APD are traumatic or cerebrovascular brain injury as well as Brain tumors and Parkinson's (Pollak and Tranchant, 2000), Alzheimer's disease (Eustache et al., 1995; Iliadou and Kaprinis, 2003) or multiple sclerosis (Lewis et al.,2006, for review). The prevalence of APD in older adults is estimated from very low 17% to extremely high 90% estimates, depending on the type psychoacoustic tests employed and because again large scale data are non available (Chermak and Musiek, 1997; Cooper and Gates, 1991).

## Diagnosing APD - current challenges

When a child does not react (appropriately) to sounds or does not develop the way he or she is expected to, an audiologist needs to determine whether a hearing problem is present. The main purpose of the audiologist's test battery is to determine the type of auditory disorder (conductive, sensorineural, mixed, central, or functional) and to what degree this auditory disorder manifests itself (Flexer, 1999). In doing so, the audiologist seeks to determine a child's hearing sensitivity and the age-appropriateness of his or her auditory behaviors. However, the finding of normal hearing acuity does not eliminate the need for further evaluation of speech, language, auditory processing and other areas of development. There are many ways in which an auditory (processing) problem may manifest itself. Various aspects such as type, degree and onset of the disorder as well as the (developmental) age of the child, determine the symptoms a child may show. As described by Musiek and Chermak (1997), age is one of the most significant sources of individual variability that influences the choice of management strategies. More information on management is presented further in this text. Parents whose children are identified as having APD often report that as infants, they did not readily alert or respond to voices and seemed to "tune out" in the crib. At the other end of the spectrum, are those infants who alert and attend to sounds in a manner that makes them appear to be hypersensitive. This latter group often develops difficulty with sound sensitivities and has problems understanding speech in noise, which interferes with peer socialization, group function, and learning in large classes. Some children make it through the preschool years without their listening or auditory-attending difficulties being noticed. They use compensating skills such as being alert to visual cues, picking up on body language, and anticipating what will be said. First grade is often the first time children are educated in large classrooms where oral instruction is one of the primary means of teaching. By the end of the first grade these children will fall behind and will be identified. However, for others – because of the different and varying behaviors of children with APD – their APD characteristics are often misinterpreted as behavior problems, adjustment difficulties, and immaturity. Table 2 shows a schematic overview of different signs leading to a possible diagnosis of APD (based on Bellis, 2002a).

| Profile | Region of Dysfunction | Associated sequelae |
|---|---|---|
| Auditory Decoding Deficit | Primary (left) Auditory Cortex | Difficulties with:<br>- spelling<br>- hearing in noise<br>- sound blending<br>- poor analytical skills<br>- mimics hearing loss |
| Prosodic Deficit | Nonprimary (right) Auditory Cortex and associated areas | Difficulties with:<br>- spelling<br>- judging communicative intents<br>- perception and use of prosody<br>- monotonic speech<br>- visuospatial and mathematics calculation<br>- socio-emotional behaviors |
| Integration Deficit | Corpus Callosum | Difficulties with:<br>- linking prosody and linguistic content<br>- speech-in-noise<br>- phonological tasks<br>- auditory language and memory<br>- bimanual coordination<br>- interhemispheric integration |
| Auditory Associative Deficit | Left (associative) Cortex | Difficulties with:<br>- receptive language including semantics and syntax<br>- comprehending information of increasing linguistic complexity<br>- reading comprehension<br>- math application |
| Output/Organization Deficit | Temporal-to-frontal and/or efferent system | Difficulties with:<br>- hearing in noise<br>- organizational skills<br>- motor planning with expressive language and word retrieval<br>- sequencing and follow-through |

Table 2) Detailed overview of the primary and secondary profiles of the Bellis/Ferre model (Bellis, 2002).

It is important to note that these symptoms and signs may be indications that an Auditory Processing Disorder is present. Diagnosis of APD is presently complicated by three factors (Jerger and Musiek, 2000):

1. Other types of childhood disorders may exhibit similar behaviors. Examples are attention deficit/hyperactivity disorder (ADHD), language impairment, reading disability (dyslexia), learning disability, autistic spectrum disorders, and reduced intellectual functioning.
2. Some of the audiological procedures presently used to evaluate children suspected of APD fail to differentiate them adequately from children with other problems.
3. In assessing children suspected of having an APD, one is likely to encounter other processes and functions that affect the interpretation of test results. Examples are lack of motivation, lack of sustained attention, lack of cooperation, and lack of understanding. It is vital to ensure that such confounding factors do not lead to the erroneous diagnosis of an auditory problem. Because of these factors, the differential diagnosis of APD requires the systematic acquisition of information sufficient to identify an auditory-specific deficit.

Considerations with regard to neuromaturation and neuroplasticity of the auditory system also need to be taken into account. Many central tests may not be appropriate for use with children under the age of 7. As neuromaturation of some portions of the auditory system may not be complete until age 12 or later, age-appropriate normative data should be obtained for any assessment tools utilized clinically (Bellis, 2003; and see Moore, 2006 for recent developments). Audiologists engaged in central auditory assessment should have access to a well-chosen test battery. This, as well as information supplied by associated professionals and other individuals in a multidisciplinary manner, will result in the ability to:

1. Delineate those processes that are dysfunctional;
2. Evaluate the impact of the dysfunction on children's educational, medical, and social status;
3. Make appropriate recommendations for deficit-specific management that will address an individual child's needs.

Based on central auditory test findings, clinicians should be able to determine the presence or absence of a disorder. Bellis (2003) recommends that the identification of APD is based on abnormal findings on one or more test tools, combined with significant educational and behavioral findings. In addition to identifying the presence of the disorder, all attempts should be made to identify the underlying process or processes that are dysfunctional. Both considerations should allow the development of a multidisciplinary, deficit-specific management plan addressing each child's individual needs. APD and other disorders 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 (see Musiek & Chermak, 1997, for review). Individuals with diagnoses of APD, attention deficit/hyperactivity disorder, and learning disabilities commonly experience some degree of spoken language processing deficit. Individuals diagnosed with ADHD, learning disabilities, and language impairment frequently experience some deficit in central auditory processing. Furthermore, the frequently observed co-occurrence of APD and learning disability has led to the speculation that at least some portion of learning disability is due to central auditory deficits. Similarly, the co-occurrence of language impairment and APD has led to the suggestion that these two deficits may be causally related (Chermak & Musiek, 1997).

## *Differentiating APD from other learning disabilities*

### **APD and ADHD**

Children with Attention Deficit/Hyperactivity Disorder manifest behaviors strikingly similar to children with Auditory Processing Disorder (e.g. Keller, 1998; Keller and Tillery, 2002). Although some evidence suggests that APD and ADHD reflect a single developmental disorder, recent research studies have shown that APD and ADHD have distinctly different diagnostic profiles (Chermak & Musiek, 1997). Behavioral characteristics of the two disorders have been clearly differentiated. However, two behavioral phenomena are common to both conditions: inattention and distractibility. Whereas ADHD is described as an output disorder that involves the inability to control behavior, APD is considered to be an input disorder that impedes selective and divided auditory attention. Furthermore, inattention and/or distractibility tend to be symptoms "at the top of" the list for ADHD and "further down" on the list for APD.

### **APD and Dyslexia**

Children with dyslexia are often "wrongly diagnosed" because symptoms that characterize dyslexia appear to be indistinguishable from APD (e.g. Breier et al., 2003; King, Lombardino, Crandell and Leonard, 2003; Sharma et al., 2006). Dyslexia is defined by the International Dyslexia Association as a language-based disability in which a person has trouble 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 (Keller, 1998). Keller (1998) furthermore states that learning disabilities do not constitute a singular developmental disorder. This is because the factors preventing a child from learning to read are different from those preventing a child from learning to spell, from learning to make arithmetic calculations, and so on. Similar to the management of APD, management of children with specific learning disabilities needs to be tailored to the child's specific deficiencies.

**Management of APD**

Recent research in neuroplasticity suggests that neuroplasticity and neuromaturation are dependent (at least in part) on stimulation (Bellis, 2003). Therefore, comprehensive management of APD should include auditory stimulation designed to bring about functional change within the central auditory nervous system or CANS (Chermak & Musiek, 1995 in Bellis, 2003). Given the diverse nature and occurrence of APD, it is necessary to ask several questions regarding its management (Chermak & Musiek, 1997). The authors distinguish three important questions of which we will discuss the latter two:

1. Can distinctive intervention strategies be formulated to manage APD within a constellation of language or cognitive deficits?

2. Should management strategies differ as a function of a client's age?
3. How can we customize intervention to the specific profile?

Age is one of the most significant sources of individual variability. The slow but sustained loss of neurons begins in adolescence, continues throughout the aging process and is coupled with some reduction in brain plasticity associated with aging. This renders neural "repair" following injury or disease less likely in older adults. In contrast, young children may benefit from a great degree of neuroplasticity. They do not, however, possess the wealth of language and world knowledge or the metacognitive knowledge that can reduce the impact of APD. Furthermore, children experience increasing and more complex central auditory processing demands as they face more intellectually and linguistically challenging academic and social demands. The impact of APD may vary significantly as the individual develops and implements compensatory strategies and meets other life challenges, including educational, employment, and family obligations. For some youngsters with APD, symptoms attenuate to some degree, for others the impact persists or changes (Chermak & Musiek, 1997; Baran, 2002). As Bellis (2003) describes, any management program should be as deficit-specific as possible. Auditory areas shown to be dysfunctional should be remediated, while building upon each child's auditory strengths. In addition, the management program also should address behavioral, educational, and communicative aspects so that maximum functional benefit may be achieved. Therefore, management of APD should be multi-disciplinary in nature. The extent to which each discipline (audiologist, speech-language pathologist, psychologist, social worker, teacher, parent, others) is involved depends on the nature of the disorder and the functional manifestations of the disorder. An integrated collaborative management approach should produce the best results for the person with APD. Several authors (Bellis, 2002b; Bellis, 2003; Rosenberg, 2002; Ferre, 2002) describe APD management as a tripod consisting of the following three "legs”:

1. Direct therapeutic remediation;
2. Environmental modifications;
3. Compensatory strategies.

Environmental modifications and compensatory strategies are designed to improve children’s access to and use of auditory information. In contrast, remediation techniques are designed to provide direct intervention for deficit areas (Bellis, 2003). The purpose of direct remediation activities is to maximize neuroplasticity and improve auditory performance by changing the way the brain processes auditory information (see Bellis, 2002b for review). They are meant to remediate the disorder (Bellis, 2003). Such remediation activities may consist of techniques designed to enhance (phonemic) discrimination, localization/lateralization training, and intonational aspects of speech. Recently, there has been renewed interest in auditory therapy (AT) due to the substantial body of literature demonstrating the plasticity in the auditory system. Recent reports confirm the value of AT as an intervention tool, particularly for individuals with language impairment and APD (see Chermak & Musiek, 2002 for review). The same authors categorize AT approaches as formal and informal. Formal AT is conducted by the professional in a formal setting. Informal AT can be conducted as part of a home or school management program for APD. Coupling formal with informal AT should maximize treatment efficacy as skills are practiced in real world settings. This establishes functional significance and provides repeated opportunities for generalization of skills. Environmental modifications are designed to improve acoustic clarity and enhance learning/listening (Bellis, 2002b). For a detailed presentation of environmental modifications and recent experimental evidence in favor of the usage of personal FM systems, readers are referred to a dedicated paper in the same issue (Hoen, Rogiers and Mülder, same issue).

Finally, teaching children compensatory strategies will also help them to live with the residual effects of their disorders, and to succeed in spite of them. Compensatory strategies training will include the strengthening of active listening techniques, and linguistic, metalinguistic and metacognitive abilities. Strengthening metacognitive and metalinguistic skills enable the child to recognize conditions that interfere with learning. They also allow the use of executive control strategies and linguistic resources, enabling the child to improve listening outcomes for his- or herself (Chermak & Musiek, 1997). Finally, it is important that the audiologist and other professionals working with the child and parents help them understand the nature of the child's auditory processing difficulty. This helps the child and parents to comprehend how these difficulties impact learning and academic performance. The role of the audiologist in the comprehensive and multidisciplinary assessment and management of APD is described as follows by the Recommended Professional Practices for Educational Audiologists (Educational Audiology Association, EAA, 1997):

1. Evaluation and/or interpretation of auditory processing test results and educational relevance;
2. Communication with members of the multidisciplinary team;
3. Monitoring of the classroom environment;
4. Management of FM-equipment;
5. Counseling of parents and teachers on APD and the consequences, on

strategies and modifications.

In summary, the management of each child or adult with APD must be specific to the individual and must address the particular profile and region of dysfunction.

**Conclusion**

In the present article we have reviewed current views on the definition, diagnosis and management of APD. Despite the growing interest that emerged over the last twenty years in regard to the characterization of APD symptoms, disorders and accompanying behavioral or psychoacoustic disorders and despite the growing amount of evidence in favor of the diagnosis and management relevance of a pathological entity as APD, a lot of efforts are still necessary in order to better understand this condition. First, an important amount of efforts will be required in order to improve, standardize and normalize diagnosis procedures for APD. Despite its mostly important impact on speech processing, APD is today mainly diagnosed on the basis of non speech specific, psychoacoustic tests and no dedicated test battery exist, despite the potential language independence of advised diagnosis procedures. The need of clearly defined diagnosis procedures and well established, normalized, sets of psychoacoustic tests is evident, as well the related need for large scale data on different populations of APD patients. Second, extensive and large scale neuroscientific research will be required to better specify the neurophysiological foundations of this syndrome, which may shed light on the developmental, accidental or genetic etiology of APD. Finally, important efforts will have to be conducted in order to facilitate diagnosis and multidisciplinary and individualized management of APD patients, in particular during childhood, so that a primary listening disorder does not systematically equate to a dramatic learning impairment with extremely heavy social-behavioral effects.

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