Review Article

Understanding Auditory Processing Disorder: A Narrative Review

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Abstract

Auditory processing disorder (APD) is defined as difficulty in listening despite possessing hearing thresholds within the normal limit. Understanding rapid speech, following complex instructions, and listening in the existence of background noise are some of the difficulties in APD. APD has been observed in diverse clinical populations with suspected or diagnosed disorders, such as attention deficit–hyperactivity disorder, dyslexia, aphasia, and Alzheimer's disease; however, it should be differentiated from these disorders. Despite the research on APD, its awareness is limited, resulting in it often being undiagnosed. Therefore, improving the awareness and understanding of APD is important. The current paper aims to review the literature on APD with a focus on school-age children. The prevalence, etiology, screening, and diagnosis of APD are discussed along with correlated disorders, interpretation of tests, and management strategies.

Keywords: Audiology, auditory perception, auditory processing disorder, hearing, speech-language pathology, verbal stimuli

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INTRODUCTION

Auditory processing has been described as "what we do with what we hear," which means how the central nervous system (CNS) uses auditory information it receives.[1] The auditory system is divided into two systems: the peripheral auditory system, which receives and conducts the acoustic waves through the auditory nerve and the auditory pathways to the brain, and the central auditory system, which includes the brainstem, thalamus, and cortex and analyzes the acoustic stimulus. Auditory processing disorder (APD) can be diagnosed in children and adults if one or more of the following auditory behaviors are affected: auditory discrimination, sound localization and lateralization, 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.[2,3] APD is a breakdown between the hearing mechanism and the part of the brain that processes this information. Although APD is a result of the audition processes dysfunction, APD was suggested to be a result of global deficits (e.g., language deficits, memory deficits, and attention deficits).[4,5]

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Currently, there is limited consensus regarding the exact definition of APD, diagnostic standards, or the efficacy of intervention techniques. Therefore, improving awareness and understanding of APD, particularly among audiologists, speech-language pathologists (SLPs), pediatricians, ear-nose-throat physicians, psychologists, teachers, and parents, are needed. Accordingly, this narrative review provides the prevalence and etiologies of APD, its correlated disorders, screening and diagnosis of APD, interpretation of tests, and management strategies, including the existence of Arabic testing materials and treatment approaches.

For this review, the author searched primary, secondary, and tertiary literature using PubMed, Web of Science, Scopus, and Google Scholar using the following keywords: auditory processing disorder or APD and prevalence, etiology, screening, diagnosis, or management. The final search for this review was conducted in April 2023.

PREVALENCE AND ETIOLOGY

APD, which can affect both children and adults, can negatively impact several areas of life. Studies have reported the prevalence of APD to be about 2–3% among children and up to 70% among older adults.[6-8] Further, studies have estimated that APD affects approximately 0.5–1% of the general population[9] and 1.94 per 1000 children.[7] However, it should be noted that the rates of prevalence can vary based on the diagnostic criteria being used, as demonstrated by Wilson and Arnott, who estimated the prevalence of APD as 7.3% when they used the strictest criteria and 96% with the most lenient criteria.[10] In terms of gender, the male-to-female ratio of APD has been reported to be about 2:1.[6,8]

The cause of APD remains unidentified in most children diagnosed with the disorder. While some causes of APD have been theorized, there is limited literature available to provide definitive evidence. Inefficient interhemispheric information transfer and imprecise neural synchrony have been suggested as possible causes of APD.[11] Neurological disorders, abnormalities, or damage that affect the areas of the brain responsible for auditory processing could also possibly cause APD.[12] Cigarette smoking during pregnancy, ingestion of lead in early childhood, and otitis media (OM) with effusion before the age of 2 years have also been found to cause APD.[13-15]

OM causes conductive hearing loss and is usually seen in early childhood, which is the critical period of maturation of the central auditory system. This conductive hearing loss may lead to sensory deprivation and inconstant acoustic stimulation of the central auditory system. Consequently, distorted sound perception occurs. Compared with children without a history of OM, children with OM performed poorly on tests of temporal ordering and resolution auditory capabilities.[16] Children with OM have shown difficulty recognizing words in competing speech background and reduced masking-level differences (MLDs), which entail the individual being tested to detect at threshold usually tonal or speech signals embedded in noise.[17,18] The reduced MLDs may be related to abnormal brainstem processing.[19] Binaural interaction, localization, and lateralization abilities are reduced in those children.[20] Although periods of normal hearing may occur, the effect of OM on the central auditory system may persists due to OM's fluctuating nature, which causes disruptive sound stimulation of the auditory central system, and as a result, distorts how sound is perceived.[18]

Although each of the aforementioned reported factors may be linked to APD, other factors, such as attention deficit and hyperactivity disorder (ADHD) and learning disabilities, should also be considered.[21,22] Thus, research on the etiology of APD is needed to differentiate APD from other childhood pathologies that could lead to poor performances on central auditory processing tasks. The location of lesion in the central auditory nervous system can help clinicians identify what central auditory processing is affected. For instance, abnormalities in the primary auditory cortex may affect dichotic listening tasks.[23] Although the major characteristic of APD is central, observations have shown the involvement of cochlear hearing loss (i.e., peripheral hearing loss) in degrading auditory performances.[11] Accordingly, the use of APD or (C)APD terms has been preferred recently.

NATURE OF AUDITORY PROCESSING DISORDER

The CNS is responsible for processing auditory information in addition to other functions, such as memory, attention, and language. It is arguable whether an observed central auditory deficit is a primary cause of a child's problems, or a secondary result of another disorder. Therefore, it is crucial to point out that APD is an auditory deficiency that can exist on its own or in conjunction with other illnesses like ADHD and dyslexia.[22] APD can be a result of the central auditory system lesions, such as strokes and other neurological etiologies.[4] Patients with cognitive and sensory integration disorders may show listening and comprehension difficulties. However, these difficulties occur because of deficits not in the neural processing of auditory stimuli, but in the higher order (cognitive and/

or language). APD was classified into three categories: (a) developmental APD that presents in childhood with normal hearing, (b) acquired APD that is linked with known causes, such as head trauma or infections, and (c) secondary APD that occurs as a result of peripheral hearing loss.[4] Research is mostly focused on developmental APD, which can result in learning difficulties and poor school performance.

It might be difficult, yet crucial, to differentiate APD from other associated disorders, such as ADHD, language impairment, dyslexia, and autism spectrum disorder since children with these disorders may exhibit similar behaviors. For example, with a prevalence of 5.3% among school-aged children, ADHD is thought to be the most prevalent mental illness among children.[24] ADHA impacts a range of perceptual processes, including auditory processing.[24] APD is thought to be either an aspect of ADHD or a cause of ADHD because APD is believed to be part of the sensory processing deficits presented by children with ADHD.[25] Early studies suggested that APD behavioral tests (e.g., temporal patterning tests, dichotic speech tests, and binaural interaction tests) were basically measuring symptoms of ADHD because children with ADHD exhibit sensory processing deficits.[26] Although APD and ADHD have overlaying clinical features, both are separate disorders and APD tests measure different aspects from that of attention.[27] Symptoms of dyslexia also appear to be indistinguishable from APD.[28] Children with dyslexia show performance deficits in a few areas of auditory processing including temporal/timing sequencing of information, auditory figure/ground problems, and interaural asymmetry in competition.[29] It is believed that APD may increase the likelihood of language and learning impairments, while other researchers support that APD can be entirely separate from language impairment because of the existence of children with auditory deficits and no language impairment and children with language impairment and no auditory deficits.[6] APD is commonly accompanied by language impairment and reading disorders.[29]

Any auditory deficit seen in children with autism is not necessarily produced by a difficulty in identifying or differentiating auditory characteristics. Children with autism have been described as unresponsive to some sounds (e.g., not responding when their name is called out) because they lack the semantic meaning of the stimuli, which is important in their auditory processing due to the top–down influences.[30] Moreover, children with autism were reported to have hyperacusis and listening difficulties with poor speech performance in noisy environments.[31] Therefore, Ludwing *et al*. suggested revising the existing diagnostic procedures that assess APD to clearly distinguish between central auditory processing deficits and higher-order processing deficits.[32] Consequently, it is incorrect to apply the APD label to patients with higher-order processing deficits, even if many of their behaviors appear remarkably similar to those associated with APD.[33]

SCREENING

A multidisciplinary approach for accurate screening, diagnosing, and managing APD is extremely important, and should include audiologists, SLPs, psychologists, physicians, teachers, and parents. There are four approaches to screening APD: (a) audiological tests, (b) speech and language tests, (c), cognitive capacity and psychoeducational function tests, and/or (d) behavioral checklists and questionnaires.[3] Screening for APD contains organized observations of listening behavior and/or performance on tests of auditory function to detect those who are at risk for APD. There are a few screening protocols, questionnaires/checklists, and other procedures to identify those who should undergo an auditory processing evaluation.[3,6,33,34] For instance, audiologists perform screening tests, such as screening test for auditory processing disorders for children (SCAN-C) and for adolescents and adults (SCAN-A), auditory continuous performance test, and comprehensive APD tests, such as random gap detection test and the gaps in noise test to determine or rule out APD.[35-37] SLPs have to collect history and look at the existing symptoms, behaviors, and other academic issues, which could indicate a potential APD. Currently, no screening method for APD is widely accepted, indicating the need for valid and effective APD-specific screening tools.

DIAGNOSIS

The diagnosis of APD aims to (a) examine the central auditory system's integrity and (b) identify the presence of APD by reporting its symptoms. Audiologists diagnose APD through the evaluation of a variety of auditory performance areas using a battery of tests to tap as many of central auditory processes as possible and identify auditory strengths and weakness.[33,38] Furthermore, audiologists also recommend management and training services and counsel parents/guardians. While APD is not diagnosed by SLPs, they may screen patients with APD to determine if they are receiving an intact auditory signal.[38] Children's language development stabilizes after the age of 7 years; therefore, APD diagnosis can only be made after that age. A language or attention disorder can significantly affect the child's performance on auditory processing tasks and lead the child to fail auditory processing assessments due to language or attention problems rather than auditory perceptual difficulties. The SLP works to determine if the child's deficits in higher-order language, such as processing of oral directions, and auditory-based language aspects, such as auditory memory, may impact the auditory processing of language.[33]

A child with APD may have various sets of symptoms due to the extensive evaluation of auditory skills. Many professionals in the field prefer to use subcategories when diagnosing APD, based on the symptoms and outcomes of the tests.[39,40] First, for diagnoses and management of APD, it is critical to take a comprehensive case history through direct interview of the child being tested and a family member. Then, audiologic assessments of peripheral auditory system and of central auditory system are used. Routine audiological assessments (e.g., tympanometry, acoustic reflexes, otoacoustic emissions, pure-tone audiometry, speech audiometry, and auditory evoked potentials) are conducted to identify peripheral hearing loss, which may differentially affect testing.[41] In patients with peripheral hearing loss, central auditory tests that use stimuli slightly affected by peripheral hearing loss should be used, whenever possible; however, such tests cannot be carried out in patients with profound hearing loss.[42]

The lack of a standardized central auditory test battery is the current dilemma. However, the selection of such a test battery should be tailored considering the referred complaints and additional information obtained. Auditory processing skills can be tested by (a) behavioral measures that assess the functional capabilities of the central auditory system and (b) electrophysiologic measures that examine the neural processes in the central auditory pathway.

The available behavioral measures for central auditory processing include (1) auditory discrimination tests that examine the ability to distinguish similar acoustic stimuli, (2) auditory temporal processing and patterning tests that evaluate the ability to analyze acoustic events over time (e.g., gap detection), (3) dichotic speech tests that measure the ability to binaurally integrate or separate auditory signals presented to each ear simultaneously (e.g., dichotic digits or words), (4) monaural low-redundancy speech tests that measure recognition of degraded speech stimuli presented to one ear at a time (e.g., speech in noise), and (5) binaural interaction tests that assess binaural processes depending on the intensity or time differences of acoustic stimuli (e.g., MLDs and lateralization).[3,43] The behavioral tests are classified into four categories: (a) dichotic speech test, (b) monaural low-redundancy tests, (c) temporal ordering tests, and (d) binaural interaction test.[6,44,45] The minimal battery test for central auditory assessment was suggested to be as follows: (a) a dichotic task, (b) a temporal patterning task, and (c) a gap detection task, along with electrophysiologic measures.[46] Audiologists explore any abnormalities that appear during latencies and amplitude measurements resulting in ear and electrode effects.

Most auditory processing tests that use verbal stimuli were first developed in the English language.[3] In addition, researchers have created auditory processing test batteries in other languages, such as French, Portuguese, and Dutch.[47-49] There is a scarcity of research in testing auditory processing and managing APD in Arabic. Nonetheless, significant efforts have been made in Egypt with regard to APD practice, including the development of Arabic protocols for diagnosing APD in adults, Arabic test materials for children, and intervention programs.[50-52] For instance, normative values of binaural integration tests (i.e., dichotic digits and dichotic rhyme tests) in Arabic-speaking children aged 6–12 years old were standardized.[52] Arabic adaptive auditory speech test (AAST) in quiet and in noise were developed.[50,51] However, because other aspects of the child's performance must be tested to diagnose APD, only using these tests is not a valid indicator of APD. Furthermore, the validity of using English speech auditory processing tests is debatable when used among those with a non-English speaking background. Therefore, standardized Arabic verbal stimuli that can be used in auditory processing tests are needed.

On the other hand, the electrophysiologic measures include auditory brainstem response (ABR), middle latency response (MLR), late latency response (LLR), P300, and mismatch negativity (MMN). ABR is a broadly used diagnostic tool, but it has limited benefits in terms of diagnosing APD. The majority of patients with APD have normal ABRs.[3,33] The MLR is more useful to evaluate APD because it provides information regarding the integrity of the thalamocortical pathway and the primary auditory cortex. The LLR including the P300 complex is valuable in terms of detecting cortical dysfunction in the central auditory system. The MMN may provide acoustic change at the thalamocortical level, but its role in central auditory evaluation is still arguable.[3] The electrophysiologic assessments might be useful when behavioral procedures are not possible (e.g., infants and very young children), there is suspicion of neurologic disorder, or when a confirmation of behavioral findings is needed. However, APD cannot be diagnosed by using electrophysiological measures alone.

Instead, a combination of the results of these tests and behavioral tests should be utilized to diagnose APD.[46]

TEST INTERPRETATION

A gold standard for APD test interpretation has yet to be established. The most common method for assessing an individual's performance in relation to normative group data is norm-based interpretation. Patient-based interpretation is another approach used to judge an individual's performance on a specific test to his or her own baseline. It includes inter- and intra-test analyses and cross-discipline analysis, in which the results of the APD diagnostic tests and non-audiological disciplines (e.g., speech-language pathology and psychology) are compared.[53] When performance deficiencies are present in one or both ears of at least two standard deviations (SDs) below the mean on two or more battery tests that examine different behavioral auditory processing tests, APD is diagnosed.[6] Although it is recommended that the test cutoff score to diagnose APD should be three SDs below the mean if poor performance is seen on just one test,[2,3] a second similar test that evaluates the same process should be performed to confirm the primary diagnosis of APD.[3]

To better understand individuals with APD and assist audiologists in connecting test results with symptoms, several models were established (e.g., Bellis–Ferre model, Buffalo model, Lucker model, Spoken-Language Processing model, MN "Department of Education" model, Chermak model, Walter Reed model (Head Injury), Museik model, and HealthPartners Multidisciplinary Team model). Each model helps create a profile based on the findings of the central auditory tests, making it easier to choose deficit-specific intervention strategies. Bellis and Ferre model and Buffalo model are the most used APD models.[54] The combination of both models with electrophysiologic measures appear to be the most feasible model to tap most central auditory processes.

At least one test is required for each central auditory nerve system function in the Bellis–Ferre model.[44] This model consists of (a) sub-profile categories including auditory decoding deficit, prosodic deficit, and integration deficit, and (b) secondary profiles containing associative deficit and output-organization deficit. This model detects the auditory process that is most likely affected, typical findings, primary auditory complaints, related sequelae, and management and intervention strategies. The Buffalo model includes (a) a battery of tests including staggered spondee word, phonemic synthesis test, speech-in-noise test modified W-22/noise and words in the same ear, and (b) four categories involving decoding, tolerance-fading memory, integration, and organization.[55] Although these models may be useful to facilitate the interpretation of central auditory test results and develop intervention plans, they are not commonly used. Additional research is needed to determine the effectiveness of using these models.

MANAGEMENT

APD can decrease the quality of life because of its effects on listening, communication, psychosocial wellness, and academic achievement. The major goal of therapeutic intervention is to improve the patient's ability to effectively communicate daily. According to the patient's needs, a team including an audiologist, a SLP, teachers, and parents are used in the management of APD. APD intervention should include both bottom–up (e.g., auditory training) and top–down (e.g., cognitive and language strategies) approaches and address the presented auditory deficits. A combination approach, such as the intervention that facilitates higher-order (top–down) linguistic and cognitive skills (e.g., metacognitive strategies or vocabulary development) with the remediation of the underlying auditory deficits (bottom–up), is considered more effective than a singular approach.[38,53] Nonetheless, many children with APD need therapy for receptive language and auditory-based language deficits, which do overlap in some areas; however, receptive language development is not a replacement for APD therapy. Three APD treatment approaches have been suggested: (a) direct skills remediation, (b) compensatory strategies, and (c) environmental modifications.[3,33] Age is one of the most significant factors when choosing the appropriate management strategy.

Direct remediation aims to change how the brain processes the sound through auditory training (i.e., maximize neuroplasticity), so the auditory function improves.[33] For example, word missing and vocabulary building are remediation activities for auditory closure deficits. Dichotic listening training is a remediation activity for binaural separation/integration deficits. For achieving better results, this training must be concentrated and repeated.[4,33] Direct skills remediation uses computer-based training programs that focus on both auditory and language components, and interhemispheric transfer training of information underlies binaural hearing and processing.[56-58] Formal and informal auditory training programs in Arabic have been developed to manage APD.[59,60] Children with APD who used computer-based auditory training programs for the treatment have shown improvements throughout short- and long-term follow-ups.[61] Compensatory strategies that aim to improve the strength of cognitive, language, and other higher-order functions and reduce the impact of APD on language, cognition, and academics should also be considered.[3] Metalinguistic strategies (e.g., active listening) and metacognitive strategies (e.g., mind mapping) have been used; for example, memory and attention training helps the listener to be aware of his own auditory comprehension and develop problem-solving skills.

The environmental modifications assist in improving the acoustic signal quality and make the listening environment (e.g., classroom or home) listener friendly.[3] This intervention category includes acoustic-based, bottom–up and top–down environmental modifications. The utilization of a sound-field amplification system (e.g., frequency modulated [FM] system) to reduce background noise and hear the speaker better is an example of the acoustic-based, bottom–up modifications.[54,62] Preferential seating in the classroom and reverberation management to increase the signal-to-noise ratio are other examples. Education of teachers about APD and reducing classroom noise levels and echoes by use of soft furniture, acoustic ceiling tile, wall boards, etc., are recommended.[63] The top–down environmental modifications section comprises several approaches, such as the use of visual cues, slow speaking rate, and written instructions.

Potential pharmacological treatment for auditory processing has been discussed in the literature. Research has shown that audition aspects (e.g., selective auditory attention and signal detection in noise) were physiologically and behaviorally improved after pharmacologic intervention.[64-66] Children who use stimulant medications for treating ADHD performed better in hearing and listening tests compared to children with ADHD who took no medication.[67] However, no medication has been proven to be beneficial for treating APD nor approved by the United States Food and Drug Administration (FDA) or any governing body for the purpose of APD treatment, despite the fact that various medications have been demonstrated to enhance performance on a few behaviors, including auditory processing.[68]

FUTURE RESEARCH

Future research should focus on establishing standardized Arabic verbal stimuli, including different dialects, for screening and diagnosing APD. OM with effusion or other etiologies that generate acoustic deprivation should be researched in longitudinal studies to confirm whether APD is a result of such diseases. The effectiveness of current APD therapeutic techniques needs further investigations. Research is also needed to determine the usefulness of the existing software programs used in the management of APD.

CONCLUSION

APD is a complex disorder that diminishes the ability to perceive both speech and non-speech sounds; however, there is no broadly agreeable definition of APD. The lack of understanding of the causes of APD has resulted in some researchers identifying auditory processing as a single modality disorder and others identifying it as a group modality disorder. However, it should be noted that not all speech, language, and learning deficits are caused by APD. Clear agreement regarding the battery of tests that can diagnose APD is essential. A multidisciplinary team approach is vital to recognize the group of problems related to APD; however, the diagnosis of APD can only be made by audiologists. Although several APD speech tests exist in English, there is no standardized Arabic verbal stimuli for screening and diagnosing APD, and thus should be developed. The treatment plan for APD should be individualized, as no single treatment approach can fit all children with APD. Finally, audiologists are encouraged to include the evaluation and therapeutic intervention of APD in their clinical practice, and public awareness about APD must be promoted.

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Author contributions

A.A.A. was solely involved in the Conceptualization, Methodology, Writing– original draft preparation, and Writing – review and editing.

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