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Differential Diagnosis of Auditory Processing Disorder in Children: A Literature Review

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Differential Diagnosis of Auditory Processing Disorder in Children: A Literature Review

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Abstract

Although there is no consensus on the definition of auditory processing disorder (APD), it is typically characterized by listening difficulties resulting from deficits in auditory perceptual processing of sounds in the central auditory nervous system. APD often co-occurs with other disabilities such as ADHD, dyslexia, and specific language impairment. Presenting symptoms can be very similar to these other disorders, complicating diagnosis. Due to the overlap of symptoms between APD and various other deficits, there are concerns that professionals in different fields are providing children with different labels for the same group of symptoms. Therefore, the aim of this literature review is to discuss the challenges in identifying APD and distinguishing it from other developmental disorders, especially in children. As part of the recommended clinical protocol in audiology, several test batteries are commonly used to diagnose APD through a combination of clinical observation, behavioral assessments with and without speech stimuli, electrophysiological assessments of brain activity in response to sound stimulation, and speech-language assessments. Although there is evidence supporting comorbidity between APD and other disorders, current test batteries alone do not have the specificity to distinguish APD from some other types of developmental delay. There is a need for the development of improved assessment techniques that are both sensitive to the presence of APD and at the same time do not result in false positive diagnoses of APD in children with other disorders. In the meantime, a multidisciplinary approach is emphasized for the assessment and intervention of APD in an attempt to reduce the risk of erroneous diagnosis of APD in children with other developmental disabilities.

Introduction

Auditory processing disorder (APD) is an accepted audiological diagnosis that is commonly defined as "a deficit in one or more of the fundamental, constituent auditory phenomena that underlie a wide variety of auditory perceptual and related skills" (Bellis, 2011). The position statement of the American Speech Language Hearing Association (ASHA) defines auditory processing disorder as "difficulties in the processing of auditory information in the central nervous system 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, temporal ordering, and temporal masking; auditory performance in competing acoustic signals; and auditory performance with degraded acoustic signals" (ASHA, 2005).

Several assessment areas are recommended in the process of diagnosing APD, including clinical observation, behavioral assessments using speech and non-speech sound stimuli, electrophysiological assessments, and speech-language assessments (Dawes & Bishop, 2009; Jerger & Musiek, 2000). In a study completed by Emanuel (2002), the majority of audiologists include the following assessments in their APD test battery: basic audiometric evaluation, monaural low-redundancy speech tests, dichotic speech tests, temporal processing tests, and questionnaires.

Several test batteries are utilized by clinical audiologists, with the cooperation of speech language pathologists, child psychologists, educational specialists, and other professionals, to make a diagnosis of APD. Due to the hypothesized neural and auditory nature of APD, it is desirable to consider the contributions of listener age, language ability, and general cognitive abilities on performance of behavioral and electrophysiological auditory processing assessments when making a diagnosis.

Electrophysiological assessments have taken precedence in APD research over the last decade. These assessments include, but are not limited to, non-speech and speech evoked auditory brainstem response (ABR), mismatch negativity, and obligatory cortical potentials. These efforts have examined whether or not characteristic patterns can be identified in individuals diagnosed with APD during electrophysiological assessments.

This literature review will discuss the typical maturation of the auditory processing system and how age, language ability, and general cognitive abilities affect a child's performance on a variety of behavioral and electrophysiological auditory processing assessments. Establishing the effects of maturation and variability in general cognitive skills on children's performance on APD assessments is a prerequisite step in evaluating the adequacy of those assessments in detecting APD. Additionally, this literature review will examine how APD assessments aid in differentiating children with APD from those with other developmental disorders that are not strictly auditory in nature.

Methodology

Database searches (Table 1) yielded approximately 300 relevant papers and books. Roughly 170 literature sources were selected for review. Of the 170 articles and books reviewed, 82 were selected as appropriate resources for the purpose of this literature review. Out of the 82 articles selected for review, only 56 were included in the entirety of this literature review. There is an extensive literature on the topic of auditory processing disorder dating back to 1954; therefore, it was not possible to discuss every paper of interest. We attempted to focus on literature that was published in the past twenty-five years and which included at least one of the following criteria:

- Studies focused on children
- Studies which included normative data
- Studies comparing children with different presenting concerns (i.e. auditory processing disorder vs. dyslexia, specific-language impairment, etc.)
- Studies which compared auditory processing disorder test performance to general cognitive skills

The following are criteria which excluded literature from review:

- Studies focused on adults
- Studies which included adults with defined retrocochlear lesions
- Published before 1992

The approach utilized was to examine the literature in order to identify what it could contribute towards answering the following questions:

- What is the most popularized definition of APD?
- What test batteries are utilized in the process of diagnosing APD?
- Which APD tests have published normative data for children across the age range?
- What are the typical characteristics of APD?
- What is the anatomy/development of the central auditory pathway?
- What is the effect of different presenting concerns on APD test performance?
- What is the impact of cognitive abilities on APD on test performance?
- What is the accuracy of utilizing electrophysiological tests in the diagnosis of APD?
- How does attention affect behavioral APD assessments?

Table 1
Databases Searched and Search Terms Used

Database	Search Terms
PubMed	Auditory processing disorder; electrophysiological tests; SCAN; behavioral assessments; children; specific language impairment; autism spectrum disorder; dyslexia; ADHD
Milner Library Database	Auditory processing disorder; electrophysiological tests; SCAN; behavioral assessments; children; cognition; specific language impairment; autism spectrum disorder; ADHD; dyslexia
PsychINFO	Auditory processing disorder; cognition

Search terms were utilized in conjunction with each other (i.e. "auditory processing disorder AND electrophysiological tests").

Anatomy and Physiology of the Central Auditory Pathway

The central auditory pathway processes incoming auditory stimuli through an intricate interaction between several structures in the central auditory nervous system. It is composed of a series of connected sets of neurons, including bipolar neurons. Bipolar neurons are located in the spiral ganglion and have one peripheral dendrite, which extends into the Organ of Corti, and a central dendrite. The central dendrite is also known as the cochlear nerve, and it is responsible for transmitting the afferent acoustic signals to the brainstem (Adunka & Buchman, 2011).

The cochlear nerve extends into the brainstem at the medulla oblongata where it synapses with the cochlear nucleus (Adunka & Buchman, 2011). The cochlear nucleus is the most caudal structure of the central auditory nervous system. It is located on the postero-lateral aspect of the brainstem and is covered by the cerebellum just rostral to the ponto-medullary junction (Musiek & Baran, 2007). The cochlear nucleus has two primary nuclei, the ventral cochlear nucleus (VCN) and the dorsal cochlear nucleus (DCN). Both the VCN and the DCN are tonotopically organized within the cochlear nucleus with the higher frequencies located in the dorsomedial aspect and the lower frequencies located in the ventrolateral aspect (Adunka & Buchman, 2011).

From the cochlear nucleus, the VCN ascends to the ventral and dorsal trapezoid nuclei of the superior olivary complex (SOC) (Adunka & Buchman, 2011). This connection accurately transmits temporal detail necessary for localization and lateralization of acoustic stimuli. The SOC is the first structure within the central auditory nervous system where timing and loudness differences from each ear are processed, which results in binaural fusion (Adunka & Buchman, 2011). Binaural fusion is process in which the brain integrates the auditory stimuli received form each ear to form one cohesive signal. From the SOC, the lateral lemniscus extends to the inferior colliculus (IC) (Adunka & Buchman, 2011).

The DCN, on the other hand, extends to the dorsal acoustic stria and continues across midline to the contralateral lateral lemniscus. The DCN fibers then terminate in the dorsal nucleus of the lateral lemniscus in the inferior colliculus (IC). This intricate connection provides an individual the ability to detect spectral characteristics of the incoming acoustic stimuli, specifically sound localization cues, as well as subtle difference cues within the vertical plane (Adunka & Buchman, 2011; Musiek & Baran, 2007; Young & Davis, 2002).

As previously stated, the lateral lemniscus terminates in the IC, which is the midbrain portion of the central auditory pathway. The central nucleus of the IC is tonotopically organized with the lower frequencies being superficial and the higher frequencies being preserved deep in the IC (Adunka & Buchman, 2011). The IC is the main structure in this pathway responsible for temporal processing. Temporal processing includes sound duration sensitivity, gap detection, and low frequency phase locking (Musiek & Baran, 2007).

A structure referred to as the pedunculus colliculi inferioris connects the IC to the medial geniculate body (MGB), which then projects to the primary auditory cortex of the transversal gyrus of the temporal lobe. The transversal gyrus of the temporal lobe is more commonly known as Heschel’s gyrus or Brodmann area 41. The primary auditory cortex is responsible for the identification of frequency and intensity of acoustic stimuli (Adunka & Buchman, 2011).

The auditory cortex is divided into three portions: the primary auditory cortex, which was previously discussed, the secondary auditory cortex, and the tertiary auditory cortex. The secondary auditory cortex is thought to process harmonics, melodic, and rhythmic patterns, while the tertiary cortex integrates the information collected form the primary and secondary auditory cortexes (Adunka & Buchmann, 2011).

In some cases, acquired APD is associated with a detectable lesion located in the central auditory nervous system. However, developmental APD in children tends not to be associated with any detectable anatomical difference in any of the previously mentioned structures (Dawes & Bishop, 2009).

Development of Auditory Processing Abilities

Although the cochlea is mature at birth (Jeffrey & Spoor, 2004), adult-like listening skills take time to develop with some arising earlier in development than others. Previous research indicates that the auditory periphery system is functionally mature before the age of two-years-old (Moore, 2002). Conversely, studies suggest that latency maturation of event-related potentials (ERPs) are developed by two-years-old and middle-latency ERPs by four-years-old (Ponton et al., 1992). Long latencies N1 and P1 were shown to continue maturing until at least the second decade of life (Ponton et al., 2000). These developmental trends in evoked potentials reflect a protracted period of development in the central auditory system, which may contribute to age-related differences in auditory task performance during development. When assessing a child for APD it is therefore crucial for health care professionals to have a basic understanding of when auditory processing abilities reach maturation. Several studies have been completed to further understand typical development of auditory processing capabilities in children.

In a study completed by Jensen & Neff (1993), behavioral measurements were completed to determine if four, five, and six-year-old children displayed differences in maturation as it relates to the discrimination of intensity, frequency, and duration of auditory input. No significant correlations were found between intensity discrimination and age. This auditory ability was therefore considered to be matured for a portion of the four-year-old participants. Contrarily, age was significantly correlated with frequency and duration discrimination, which was confirmed through a one-way analysis of variance. It was concluded that these auditory abilities reached maturation at different times during development. This study revealed a progressive pattern of development for these three auditory abilities. It was established that intensity discrimination matures early in development, followed by frequency discrimination, and duration discrimination being the last of the three to reach maturation. Jensen & Neff (1993) hypothesized that intensity and frequency discrimination reach maturation earlier in life because both are processed in the lower auditory brainstem, while duration discrimination is processed centrally in the central pathways and cortex. Overall, this study established that frequency and duration discrimination have not reached maturation in typically developing four and five-year-old children.

Moore et al. (2011) completed a study to determine developmental standards for temporal, spectral, and binaural auditory processing assessments. These behavioral assessments aimed to evaluate the following auditory skills: temporal integration, sound detection, spectral resolution, temporal resolution, modulation detection, and binaural interaction. Previous research indicated that children were less reliable and had more variability than adult listeners on these types of behavioral assessments (Moore et al. 2008, 2010, 2011). Moore et al. (2011) suggested that this was due to the immature auditory system of children up to approximately seven to nine-years of age. This is consistent with the notion that even typically developing young children perform more poorly on behavioral auditory processing tasks than adults. Furthermore, evidence from this study implied that immaturity of the auditory system in children six to eleven-years-old could be directly correlated to the individual differences between children and that the pattern of auditory development is not consistent across all children in that age group.

As a whole, Moore et al. (2011) found that six to seven-year-old children were not reliable when detecting low-level tones in quiet. This age group, as well as the eight to nine-year-old group of children, had higher detection thresholds for pure tone stimuli in quiet, particularly for very brief stimuli, than older children and adults. These thresholds tended to be more elevated when the tone was shorter in duration. These findings were interpreted to suggest that the difficulties related to this task are directly correlated to the perception, memory storage or retrieval of, or action in response to a sound (Moore et al., 2011), in addition to development of the auditory system.

Evidence suggested that the frequency discrimination (FD) assessment proved to be difficult feat for young children due to their inability to complete the task. It was concluded that this auditory ability was the last to reach maturation due to the variability of responses found in the adult participants. There were many six to seven-year-old children who did not have the capabilities to complete the FD assessments due to poor performance or inability to understand the task (Moore et al., 2011). Outcomes regarding temporal processing in this study were similar to those establish in previous research. Backwards masking (BM) was found to reach maturation by the age of ten-years-old; however, performance on this assessment was discovered to vary for both children and adult participants (Buss et al., 1999). Results indicated no significant correlation between age and binaural interaction, which is consistent with previous research that suggested development of masking level differences was mature by approximately five to six-years-old. Furthermore, assessments of temporal integration and frequency resolution revealed that these auditory skills develop past the age range examined in this study (six to eleven-years-old) (Moore et al., 2011).

Overall, the consensus of both behavioral and electrophysiological studies indicate that auditory processing abilities develops over a protracted period of time during the first two decades of life. Past results also indicate divergent patterns of development for different aspects of auditory processing, in addition to considerable variability in performance between typically developing children.

Background of Auditory Processing Disorder

APD was first proposed as a diagnostic label in adults with normal hearing sensitivity and acquired lesions in the central auditory system who experienced difficulties with sound perception (Hinchcliffe, 1992). The diagnosis was eventually expanded to include children who had normal peripheral hearing and academic difficulties without defined lesions of the auditory system (Dawes & Bishop, 2009). According to the ASHA, APD may only be diagnosed independent of any attention disorder or other higher-order impairment. Currently, ASHA (2005) defines APD as poor performance in at least one of the following areas: temporal aspects of audition; temporal integration; temporal discrimination; temporal ordering; temporal masking; sound localization and lateralization; auditory performance with degraded acoustic signals; auditory performance in competing acoustic signals; auditory pattern recognition; and auditory discrimination. It has been argued, however, that poor performance resulting from APD will most likely present as poor performance on auditory figure ground discrimination and temporal resolution (Jerger, 1998). Auditory figure ground discrimination assesses a child's ability to understand speech in the presence of background noise; temporal resolution determines the ability of a child to distinguish two consecutive auditory stimuli and different entities or to detect gaps between auditory stimuli. The hypothesis regarding auditory figure ground discrimination is based on the theory that APD is fundamentally a breakdown of binaural processing in the brain, which research has shown is an area of concern for many individuals diagnosed with APD (Jerger, 1998).

ASHA's criteria for APD has been disputed to be insufficient evidence of APD. Rosen et al. (2010) argued that an audiologist must be able to delineate the cause of a listening problem in order to construct an appropriate diagnosis. This involves separating auditory problems from poor cognition, language learning, and attention deficits because these deficits may result in similar assessment performance on auditory tasks (Rosen et al., 2010).

The British Society of Audiology (BSA) also has a viewpoint that is skeptical of the current state of differential diagnosis by ASHA. The BSA Position Statement (2011) specifies that cognitive factors play a crucial role in listening. Currently, the BSA argues that APD is diagnosed based upon the results of a variety of assessments, which do not have established scientific validity. Therefore, a "gold standard" cannot be determined due to this lack of validity. Additionally, the symptoms related to APD vary significantly throughout literature. Thus, core symptoms of APD need to be determined, as well as the aspects of auditory perception that contribute to the clinical presentation in order to properly assess the auditory processing abilities of children. Since there is no international consensus on the quality of evidence supporting the existence of developmental APD as a discrete disorder or the adequacy of audiological tests used to detect it, an objective assessment was recommended as a “gold standard” for APD (BSA, 2011).

Although the etiology of APD remains controversial, several theories have been put forth. These include delayed maturation of the central auditory nervous system, ectopic cells in the auditory system, and a lesion in the central auditory nervous system (Weihing, 2015). It has been suggested that approximately 65 to 70% of children diagnosed with APD have a neurodevelopmental delay directly associated with the deficit. However, this remains a speculation due to the inability to confirm the underlying cause in a majority of cases (Domitz & Schow, 2000).

In addition to the etiology being unknown in most cases, the definition of APD is constantly evolving (Silman et al., 2000). One of the most current definitions of APD stresses the presence of a neural auditory processing deficit of non-speech stimuli without the existence of any insufficiency in attention, cognition, and language ability (Ferguson et al., 2011). Several assessments may be utilized to control for the influence of these factors on auditory processing assessments, including non-speech auditory tasks and electrophysiological evaluations.

One aspect related to APD that tends to be consistent across children are the difficulties described by these individuals’ parents and teachers. Individuals with APD are typically described to have difficulties listening in the presence of background noise, being disorganized, and having trouble understanding degraded speech stimuli in spite of normal hearing sensitivity (Jerger & Musiek, 2000). However, APD symptoms such as poor attention, high distractibility, language difficulties, reading difficulties, and trouble following multiple step instructions, commonly overlap with other disorders. These disorders include, but are not limited to attention deficit hyperactivity disorder (ADHD), specific language impairment (SLI), and dyslexia.

Symptoms that are considered unique to APD include difficulty understanding speech in the presence of background noise, difficulty understanding degraded speech, and communication difficulties (Ferguson et al., 2011).

Clinical Presentations

Dawes et al. (2008) examined a group of children to investigate symptoms that are commonly reported in an intake for children with suspected APD. The most commonly reported symptom was difficulties with speech in noise, which occurred in 20 (out of 32), or 63%, of the children who were subsequently diagnosed as having APD. Other characteristic symptoms associated with APD that were stated include reading problems (47%), difficulties with spoken instruction (34%), spelling problems (37%), poor concentration and memory (22%), hyperacusis (19%), needing the television to be loud (19%), and social problems (13%). However, there were no symptoms that were unique for children who received an APD diagnosis and those who did not (Dawes et al., 2008).

Questionnaires

The Children's Auditory Processing Performance Scale (CHAPPS) is the most commonly used questionnaire for evaluating parent and teacher concerns related to listening difficulties. The questionnaire is a thirty-six item form that encompasses six different scales, including noise, quiet, ideal, multiple inputs, auditory memory/sequencing, and auditory attention span. There are as little as three and as many as eight items per scale. Parents and teachers may rate a child on a scale from -5 (cannot function at all) to +1 (less difficult) comparing him or her to same aged peers (Ferguson et al., 2011). Each scale is then summed and an average condition score is calculated. The summed total condition score for each of the six scales can be plotted on the graph to evaluate the child's rating compared to the normal range (Smoski et al., 1998).

The Children's Communication Checklist- Second Edition (CCC-2) is a seventy item questionnaire that is used to evaluate a child's social interaction and communication abilities. This questionnaire is divided into ten scales, which include: speech, syntax, semantics, coherence, inappropriate attention, stereotyped language, use of context, nonverbal communication, social relations, and interests. Parents are required to rank the frequency of their child's behaviors on a scale from 0 (less than once a week or never) to 3 (several times a day or always). Each scale is then added and transformed to a standardized score based on age (Ferguson et al., 2011).

Although questionnaires are commonly utilized to assess areas related to auditory processing abilities, they are poor predictors of APD status. Wilson et al. (2011) displayed a weak relationship between auditory processing questionnaire results and a diagnosis of APD. It was suggested that questionnaires should only be utilized to identify concerns related to APD, and not be employed to determine if a diagnostic APD evaluation is warranted.

Auditory Processing Behavioral Assessments

The traditional APD test battery encompasses a wide array of evaluations designed to assess various levels of the auditory processing system. Behavioral APD assessments are intended to evaluate each hemisphere of the brain, the corpus callosum, and the subcortical structures. These test results allow audiologists to determine the auditory strengths and weakness of each child in order to focus intervention approaches on the areas of auditory difficulties (Bellis & Ferre, 1999). The classifications of behavioral APD assessments and specific tests are outlined in Table 2, which is adapted from Dawes & Bishop (2009).

Table 2
List of Behavioral APD Classifications and Assessments

Classification of Behavioral APD Assessments	**Name of APD Assessments**
Dichotic Listening Assessments	• Dichotic Digits • Staggered Spondaic Words (SSW) • Competing Words • Competing Sentences
Temporal Processing Assessments	• Pitch Pattern Sequence (PPS) • Duration Pattern Sequence (DPS) • Gaps in Noise • Random Gap Detection Test • Auditory Fusion Test
Monaural-Low Redundancy	• Low-pass Filtered Speech • Time Compressed Speech • Time Compressed Speech with Reverberation • Speech in Noise Testing (Auditory Figure Ground Subtests) • Filtered Words
Binaural Interaction	• Spondee Binaural Fusion

Dichotic listening assessments are designed to assess the transmission of auditory information to each hemisphere of the brain via the corpus callosum (Bellis & Ferre, 1999). This is targeted by presenting a stimulus (spoken word or message) to both ears and requiring the patient to repeat back the information from one ear or both (Weihing et al., 2015). Since language processing occurs in Broca's area on the left side of the brain, any auditory information presented to the left ear needs to be sent from the right side of the brain via the corpus callosum to be decoded. A survey study completed by Emanuel (2002) found that the most common test of dichotic listening employed by practicing audiologists is the SSW, with competing words and competing sentences also being frequently administered.

Temporal processing assessments require the listener to differentiate patterns of auditory stimuli over a set period of time. Specifically, these tasks were designed to examine the processing of different frequencies, temporal ordering, and linguistic labeling (Bellis & Ferre, 1999). The pitch pattern sequence assessment requires the listener to utilize both processing of different frequencies and linguistic labeling. The listener hears three sounds in sequence and is obligated to indicate if each beep was 'high' or 'low.' These tasks focus on the rate at which an individual processes acoustic information accurately and are intended to establish if the auditory processing weakness is related to the right hemisphere of the brain or the left (Bellis & Ferre, 1999). Pitch pattern sequence is used the most often in clinical settings to assess temporal ordering, and the auditory fusion test is administered to determine the ability of a listener to detect gaps in noise (Emanuel, 2002).

Monaural low-redundancy tests are intended to determine how well a child can understand speech stimuli when it is degraded or distorted in some way. Alteration of the auditory stimuli is employed through the use of either a low-pass filter, background noise, time compression, or reverberation (Bellis & Ferre, 1999). The SCAN-C filtered words assessment and the three auditory figure ground subtests were reported as the most commonly used monaural low-redundancy tasks clinically (Emanuel, 2002).

To assess the listener's ability to combine auditory information presented to both ears, binaural interaction assessments are completed. The binaural spondee fusion assessment delivers different, but complimentary words to each ear (Bellis & Ferre, 1999). For example, "out" would be presented to the right ear, while "side" is presented to the left. The appropriate response to this test item would be "outside."

Figure 1 displays the sensitivity and false positive rate of a common behavioral assessment, SCAN-3C, utilized to assess the auditory processing abilities of children 5 to 12 years old. Selection of a criterion composite score that achieves a sensitivity of 90% results in an 80% false positive rate (1- specificity) in children that do not have APD. Similarly, the SCAN-3A, which is normed for individuals 13 to 50 years old, has a false positive rate of 49% when criterion score is selected to achieve sensitivity of 93%. This indicates that a high percentage of children and adults may be improperly diagnosed with APD due to the poor validity of these auditory processing behavioral assessments.

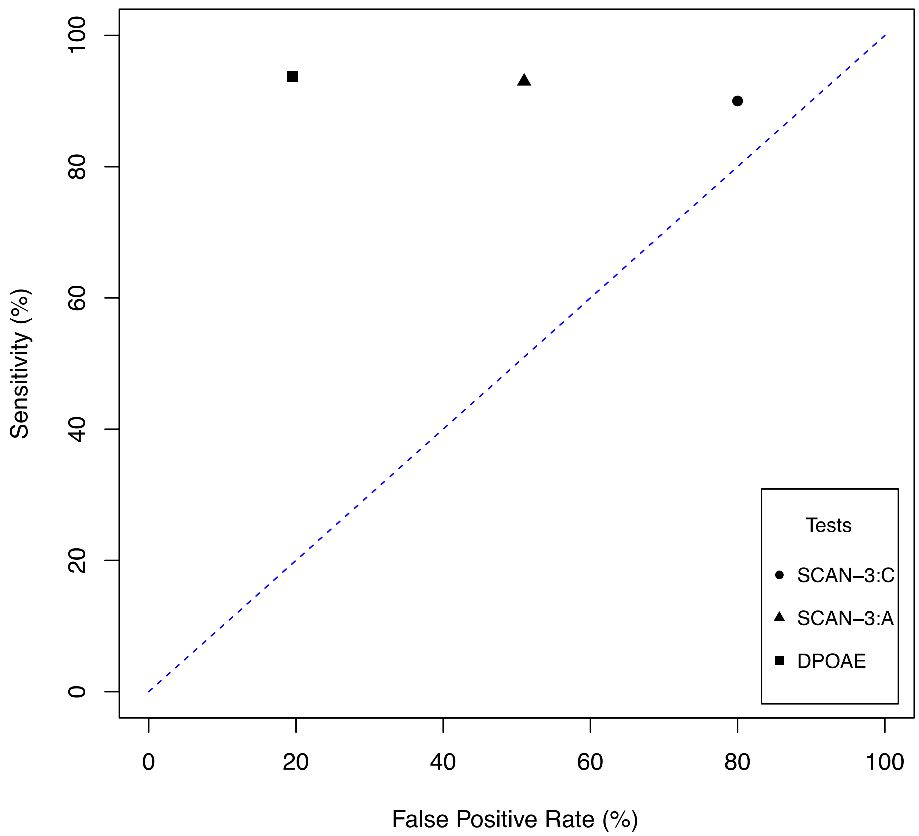

Figure 1. Sensitivity and false positive rate (1-specificity) of distortion product otoacoustic emissions (DPOAEs) hearing screenings, SCAN-3A and SCAN-3C (Kirby et al., 2011; Keith, 1995; Keith, 2000).

Electrophysiological Assessments

Recent research has focused on the utilization of electrophysiologic measures as an assessment tool for APD. Because electrophysiologic measures provide information regarding the processing of the sequence, timing, and neural location of auditory stimuli, they may be utilized as objective measures of the auditory processing system (Rocha-Muniz et al., 2014). Electrophysiological assessments are appealing to various healthcare professionals for the assessment and diagnosis of APD because they are less dependent on the attention, cognition, or language abilities of the child (Purdy et al., 2002).

Purdy et al. (2002) investigated auditory brainstem responses (ABR), middle latency response (MLR), P1-N1-P2, and P3 responses for a group of children with learning disabilities (LD) who were also suspected of having APD. Two significant differences were evident through the ABR recordings between the control group and the LD children with suspected APD. Both Wave V latency and Wave III-V interwave intervals were shorter for the group of LD children. In addition, the Na latency recorded during MLR was longer and the Nb amplitude was smaller for the LD children when compared to the control group. Cortical auditory evoked potentials (CAEP) revealed several significant differences between the two groups of children. These distinctions include shorter latencies for P1, longer latencies for P3, and smaller amplitudes for P3 for the LD group with standard and deviant stimuli. Furthermore, the LD children suspected of APD had smaller N1 amplitude and earlier P2 for standard stimuli, and earlier N1 and smaller P2-N2 for deviant stimuli (Purdy et al., 2002).

It was concluded that the electrophysiologic results provided sufficient evidence that the LD group of children had difficulties with auditory processing when combined with the data collected through teacher questionnaires, the SSW, and the SCAN competing words subtest. Nonetheless, the ABR recordings obtained through this study did not align with previous research. Previous research found abnormal morphology and absent peaks for individuals with suspected APD; however, the reason this study's recordings differed was not identified (Purdy et al, 2002). Therefore, the ABR findings should be interpreted with caution when diagnosing APD.

Song et al. (2006) examined recordings of click- and speech-evoked ABRs in children who have been diagnosed with a LD and a group of matched controls. Although this group of LD children were not suspected of having APD, abnormalities in the ABR recordings could indicate that this electrophysiological measure is capable of identifying breakdowns in the ascending auditory pathway in children with developmental deficits. Speech-evoked ABRs are said to provide insight into the processing of speech perception, neural encoding, synchrony, and central auditory processing abilities (Rocha-Muniz et al., 2014). Click-evoked ABR results revealed a delay in latencies and a decrease in amplitude when background noise was introduced. However, these effects of background noise on amplitude were noted in both groups of participants. The speech-evoked ABR showed an abnormal response to the stimulus /da/ for approximately 22% of participants, with the majority of these children (≈65%) being from the LD group. Abnormal responses consistently displayed a delay between Waves V and A (negative trough following wave V) with a reduced transition slope and a delayed Wave III latency. It should be noted that parental concerns of a learning problem were noted for the normal listening children who had abnormal responses to the speech-evoked ABR, but no formal diagnosis had been provided (Song et al., 2006)

Comparison of the click- and speech-evoked ABR recordings revealed a significant correlation between the click Wave V and the speech-evoked Wave V and A latencies (Song et al., 2006). No other significant correlations were prominent upon comparison. It was concluded through the analysis of this data that the processing of complex auditory stimuli, such as speech, is unique. Additionally, it was suggested that LDs do not interrupt the processing of click or speech stimuli at the level of the brainstem. However, it is recommended that both types of recordings are administered for comparison since a delayed speech-evoked ABR does not necessarily indicate a delayed click-evoked ABR. Although normal click evoked ABRs are indicative of the integrity of the ascending auditory pathway, speech-evoked ABRs may be used to assist in the diagnosis of auditory processing deficits in children because speech-evoked ABRs provide information about how speech syllables are encoded by the auditory system through the response of the brainstem (Song et al., 2006).

Assessing mismatch negativity (MMN) provides insight into the auditory cortex and the brain's ability to discriminate fine acoustic features of various auditory stimuli. Similar to the previously mentioned electrophysiological tasks, MMN does not require the attention of the listener, it is typical for his or her attention to be directed to another task. MMN in children was not addressed prior to the study completed by Kraus et al. (1992). This study examined MMN responses in school-aged children for speech stimuli that were perceived as the same phoneme. MMN was present in all children for all stimuli. It occurred at approximately 200 msec, while Wave N1 was recorded near 100 msec. Overall, the MMN responses obtained in school-aged children were similar to those of adults, suggesting that it may be utilized to assess the central auditory function of children. Since MMN is thought to derive from the auditory cortex, its use in assessing APD especially in children who are uncooperative or have poor cognition was recommended (Kraus et al., 1992).

Sharma et al. (2006) also investigated MMN to determine if more complex stimuli result in poorer recordings in children diagnosed with a reading disorder. Similar to the study by Song (2006), abnormalities of MMN recording in children with reading disorders provide evidence that developmental deficits may be assessed through electrophysiological assessment. However, contrary to the study completed by Kraus et al. (1992), MMN was not detected in all children. This was suggested to be a direct result of a poor signal-to-noise ratio or a consequence of the children not being able to distinguish the stimuli. Therefore, it was concluded that MMN is not a reliable tool to use in the assessment and diagnosis of APD in children. Moreover, no correlation between MMN and behavioral APD assessments was noted, further supporting that conclusion (Sharma et al., 2006).

Recommended Test Battery

The diagnosis of APD is complex since no standardized battery of subjective and objective assessments exists. Therefore, in 2000 James Jerger and Frank Musiek assembled a team of fourteen scientists and audiology clinicians to develop guidelines for the screening and diagnostic assessment of APD. No national audiology organization includes screening criteria for APD in its position statement; however, several checklists and questionnaires designed for this purposes are in circulation. It is crucial to understand that an auditory processing screening is not sufficient evidence to provide an APD diagnosis. Instead, the overall goal of a screening assessment is to be maximally sensitive to the disorder, which means a portion of the referral will be false positives due to the lower specificity. Three screening procedures were deemed to be effective: screening by questionnaire, screening by assessment; or screening utilizing both methods (Jerger & Musiek, 2000).

Screening questionnaires are deemed sufficient or insufficient based on psychometric properties and their pass/refer criteria. It is recommended that the following suspect behaviors related to APD be addressed via screening questionnaires: difficulty understanding speech in the presence of background noise; difficulty understanding speech that is distorted in some way;

difficulty following multi-step instructions; difficulty identifying and discriminating speech sounds; and inconsistent responses to auditory stimuli (Jerger & Musiek, 2000).

The criterion set for screening by assessment is fewer than that previously mentioned for questionnaires. It is recommended that an APD screening include a dichotic digits assessment and a gap-detection assessment. The dichotic digits assessment is utilized for screening because it diminishes the use of linguistic abilities. Therefore, if a child has below average speech and language skills they will minimally affect the outcome of the assessment. The gap detection test assesses temporal processing abilities, which is considered fundamental to the processing of speech information. These assessments are limited to individual six years and older; therefore, are not appropriate to use for the evaluation of children younger than six years (Jerger & Musiek, 2000).

To create a standardized diagnostic APD test battery is a difficult feat due to the lack of consensus among professionals. However, a minimal APD test battery was established including several behavioral and electrophysiological/electroacoustic assessments that were deemed necessary to obtain the minimal amount of information necessary to make a diagnosis. Behavioral measures include a comprehensive audiologic evaluation, a dichotic task, duration pattern sequence assessment, temporal gap detection, and a performance intensity function for word recognition test. Electrophysiological/electroacoustic measures include immittance audiometry, otoacoustic emissions, auditory brainstem response, and middle latency response (Jerger & Musiek, 2000).

Although this is the recommended minimal test battery, a survey by Emmanuel (2002) indicated that the majority of practicing audiologists do not perform all of these assessments with patients. According to the survey results, only approximately 50% of practicing audiologists used auditory brainstem response in the assessment of APD, and less than 35% incorporate any type of cortical related potential. However, high compliance was found for the behavioral APD measures.

Developmental Effects on APD Behavioral Assessments

Correctly identifying children who have APD is a difficult task, especially since there is a lack of 'gold standard' when it comes to its detection. Research supports the exclusion of other disorders/impairments prior to APD assessments, such as peripheral hearing loss, intellectual disability, traumatic brain injury, and emotional disorder (Jerger, 1998). However, there is no universally accepted test battery or cutoff score for abnormal behavioral APD assessment results (Shaikh et al., 2016).

Audiologists have the ability to select their own test battery since no standard test battery has been developed for diagnosis of APD. The Central Test Battery (CTB) developed by Katz in 1998 is most commonly utilized. The CTB incorporates the SSW, Phonemic Synthesis (PS), and Speech-in-Noise (SN) assessments. This test battery provides age-normative data for individuals five years of age and older, in addition to incorporating both quantitative and qualitative measures of assessment (Shaikh et al., 2016).

There is currently a lack of agreement in the audiology field regarding whether two standard deviations (SDs) below the mean on a normed test should be used as the cutoff score or whether it should be one SD below the mean to diagnose APD. Katz developed the CTB to incorporate both of these cutoff criterion, with one SD determining the age specific norms for children 5 to 11 years old and two SDs acting as the cutoff for individuals 12 years of age and older. Nonetheless, the American Academy of Audiology (AAA) and ASHA both recommend that two SDs be the cutoff score for abnormal for at least one ear on a minimum of two assessments, or three SDs in at least one ear on one assessment (Shaikh et al., 2016).

Shaikh et al. (2016) investigated how the cutoff score for abnormal affects the failure rate of children with suspected APD on behavioral assessments. Results revealed a higher failure rate for one SD on the SSW; yet, the right non-competing condition had the lowest failure rate and left competing had the highest failure rate for both conditions (one SD and two SD). These results indicate a right ear advantage, or a left ear weakness, for both failure rates. The quantitative PS assessment resulted in a failure rate of 51.5% in a population of children with no neurological deficits with one SD cutoff and 36.1% with a two SD cutoff. The scores obtained on the quantitative PS were better for both conditions than the qualitative scores. The SN test did not reveal any difference between ears; however, similar to the previous two assessments the one SD failure rate was higher for both the right (75.4%) and left (76.8%) ears than the two SD cutoff (approximately 50% for both ears) (Shaikh et al., 2016).

Overall, failure rates were higher with a one SD cutoff. Typically developing children were identified as having APD with a one SD cutoff in 86.6% of cases, while the percentage of typically developing children diagnosed with a two SD cutoff was 66.2%. Therefore, it was concluded that a two SD failure rate is more effective at excluding APD diagnosis and reducing the number of false positives. However, this is done at the expense of sensitivity, since children with suspected APD would receive more false negatives as well. The authors indicated that a two SD cutoff should be implemented with the use of the CTB for individuals of all ages and not just adults (Shaikh et al., 2016).

Jerger (1998) argued that two SDs, however, was too wide to efficiently identify children with APD. Instead, he maintained that the appropriate procedure for interpreting behavioral APD assessment results should be based upon the asymmetries in performance between the right and left ear input, the difference between monaural and binaural performance, and performance at different intensity levels. He argued that this was more effective in revealing auditory processing abnormalities than comparing performance on behavioral assessments to normative data because it allows the child to serve as his or her own control (Jerger, 1998).

Differential Diagnosis

Children who are referred for APD testing tend to have symptoms that overlap with a variety of other disorders including, but not limited to, attention deficit hyperactivity disorder, specific language impairment, dyslexia, and global cognitive deficits (Ferguson et al., 2011). In order to delineate APD from other disorder, a multidisciplinary approach is recommended to ensure accurate diagnoses. At minimum, a multidisciplinary team for APD should consist of an audiologist, speech-language pathologist, psychologists, classroom teacher, physician, and parents. However, it should be noted that assessments completed by other disciplines cannot be utilized as diagnostic tools for APD. Instead, the measures completed by speech-language pathologists and psychologists should be utilized to determine deficit specific intervention and management of the disorder (ASHA, 2005).

Because intervention approaches vary by disorder, an erroneous diagnosis of APD could prolong or exacerbate the difficulties experienced by the child. Therefore, differential diagnosis is crucial for ensuring appropriate treatment.

Attention Deficit Hyperactivity Disorder

It difficult to make a diagnosis of APD when the child displays characteristics associated with attention difficulties during behavioral assessments. Attention Deficit Hyperactivity Disorder (ADHD) is present in approximately 5% of school aged children, and is characterized by a persistent pattern of hyperactivity, inattention, and impulsivity (Lanzetta-Valdo et al., 2017). The association between ADHD and APD has been the focus of research studies for decades. Hypotheses have been formed proposing comorbidity between ADHD and APD. Other theories advocate that APD is a direct result of inattention and that APD and ADHD are a single developmental disorder (Chermak et al., 1999).

ADHD and APD have several overlapping clinical characteristics, which include academic difficulties, disorganization, and inability to stay on task. However, distinctions between the nature of the inattention between the two disorders have been made. Children with ADHD are characterized by consistent patterns of inattention, frequent and severe outbursts of hyperactivity and impulsivity, interrupting others when they are speaking, difficulty attending to detail, and inability to finish tasks. Characteristics directly associated with APD include difficulty hearing in background noise, difficulty following oral instruction, and poor auditory association skills (Chermak et al., 1999).

A recent study completed by Lanzetta-Valdo et al. (2017) examined the performance of children with ADHD on APD behavioral assessments with and without methylphenidate (MPH). MPH is the most common medical treatment for ADHD. Results showed that children with a diagnosis of ADHD performed poorly on all three behavioral APD assessments indicating weaknesses with binaural integration, temporal ordering, and auditory discrimination in noise. These children were then placed on MPH and retested utilizing the same behavioral auditory processing test battery. After six months of MPH treatment, the same children performed significantly better on all three of the APD behavioral assessments. However, it was not stated whether the results obtained after six months of MPH use were outside the normal range (Lanzetta-Valdo et al., 2017). An implication of these findings is that behavioral APD assessments could result in false positives for children with undiagnosed and/or unmedicated ADHD. It could be detrimental to a child if an erroneous APD diagnosis prevents the timely diagnosis and treatment of ADHD.

Tillery et al. (2000) also examined the effect of MPH on auditory performance; however, the participants in this study had been diagnosed with both APD and ADHD. This study did not reveal better performance on the APD assessments (SSW, phonemic synthesis, and speech-in-noise test) with the use of MPH. On the other hand, a significant improvement was found on the attention/impulsivity assessment (Auditory Continuous Performance Test) with the use of ADHD medication. Therefore, the MPH had a positive effect on attention, but did not reduce auditory dysfunction. It was suggested that these results indicate that APD and ADHD are independent disorder, but that they are comorbid in some children (Tillery et al., 2000).

Administering APD behavioral assessments to children with ADHD proves to be a difficult feat, especially when medication is not prescribed. The validity of these behavioral assessments must also be deliberated to ensure APD is not being misdiagnosed when the poor performance is directly correlated to ADHD. Contrary to Lanzetta-Valdo et al. (2017), Chermak et al. (1999) proposed that the likelihood of successfully administering behavioral assessments to a child with ADHD is near to impossible and that electrophysiological methods should be considered when possible.

Specific Language Impairment

Specific Language Impairment (SLI) is generally defined as “improper acquisition of speech in children without brain damage, hearing impairment, significant learning disorders, or deprived of social contact” (Wlodarczyd et al., 2014). Common difficulties presented in children with SLI, that are also seen in children diagnosed with APD, include difficulties with receptive and expressive language, reading, and spelling. The similarities between the two diagnoses generated a vast amount of research regarding the relationship between the two disorders. Several researchers suggest that APD may be the underlying cause of SLI in children (Sharma et al., 2009; Dawes et al., 2008; and Ferguson et al. 2010; in Miller & Wagstaff, 2012). Some propose that SLI is the underlying cause of APD (Banai et al, 2005; Basu et al, 2009; Bishop et al., 2005; Bishop & McArthur, 2005; McArthur et al., 2009; and McArthur & Bishop, 2005). Others argue that SLI is independent of APD (ASHA, 2005).

A study completed by Miller & Wagstaff (2012) assessed the performance of groups of children diagnosed with APD or SLI on four behavioral auditory processing tasks including, frequency (pitch) pattern test, duration pattern test, dichotic digits, and SSW. Results indicated that majority of children in both groups performed outside of normal limits on all four of the auditory processing assessments, which supports the notion that APD may be concomitant with other disorders such as SLI or that APD assessment cannot distinguish between the two disorders (Miller & Wagstaff, 2012).

Wlodarczyk et al. (2014) focused on the performance of children diagnosed with SLI on behavioral auditory processing assessments compared to same age peers with no speech-language impairments or academic difficulties. The five behavioral tests used for examination included the frequency (pitch) pattern test, duration pattern test, dichotic digits, gap detection test, and time-compressed sentences. Children with SLI performed significantly poorer on the temporal processing assessments, the dichotic listening task, and the monaural low-redundancy test. This indicates that children with SLI, similar to those diagnosed with APD, display difficulties with temporal integration and distorted speech signals. The gap detection assessment could not be completed by approximately 41% of participants in both the control group and SLI group; therefore, it was concluded that this test was not appropriate to assess the auditory processing abilities in children between the ages of 7 and 10 years old (Wlodarczyk et al., 2014).

Many children diagnosed with SLI have similar anomalies of higher auditory function (Wlodarczyk et al., 2014). Since SLI and APD do not have a standardized test battery for diagnosis, a wide array of other assessments, including those administered by speech-language pathologists, should be utilized to distinguish between the two diagnoses (Miller & Wagstaff, 2012).

Dyslexia

It has been estimated that approximately half of children diagnosed with APD fit the criteria for a diagnosis of SLI or dyslexia (Dawes & Bishop, 2010). Dyslexia is commonly described as "a disorder manifested by difficulties in learning to read and spell, despite adequate intelligence and conventional instruction" (Rosen & Manganari, 2001). Many children diagnosed with dyslexia have additional learning difficulties including, but not limited to, poor phonological processing and poor verbal working memory (Banai & Ahissar, 2006).

Farmer & Klein (1995) reviewed extensive literature to determine if research supports the hypothesis that a temporal processing deficit is the underlying cause of dyslexia. Dyslexic individuals performed outside of normal limits on tasks which required temporal or sequential processing; however, typically these same listeners performed well on assessments targeting detection or identification of a single stimulus. Additionally, research showed that dyslexic individuals performed poorly on any auditory or visual stimulus task which involved non-linguistic stimuli. There was not sufficient evidence in the literature to conclude that a temporal processing deficit is the underlying cause of dyslexia. Nonetheless, examination of the evidence revealed that dyslexia is not completely based on poor linguistic or phonemic abilities. Although there was an evident pattern of temporal processing deficits occurring in individuals with dyslexia, further research is warranted to determine the underlying cause of dyslexia (Farmer & Klein, 1995).

Heiervang et al. (2002) supported the conclusion made by Farmer & Klein (1995) that a temporal processing deficit may be present in individuals with dyslexia, but it is not the underlying cause. In addition, Heiervang et al. (2002) found that dyslexic children scored outside of normal limits on assessments which target the processing of rapid non-linguistic stimuli, and that the duration of said stimuli impacts the scores of both the dyslexic children and the control group.

A study completed by Dawes & Bishop (2010) examined the psychometric profile of children diagnosed with APD compared to those with a diagnosis of dyslexia. The standardized test battery included APD assessments, language, literacy, and non-verbal IQ measures, and parental questionnaires. Results indicated that children diagnosed with APD and dyslexia both performed outside of normal limits on the standardized auditory processing assessments, with the APD group of children tending to perform worse. However, the dyslexia group of children performed significantly more poorly than the APD group of children on the measure of literacy skills. It was determined that APD assessments are not capable of distinguishing the APD and dyslexic population (Dawes & Bishop, 2010).

Autism Spectrum Disorder

Autism Spectrum Disorder (ASD) is commonly defined as a heterogeneous behaviorally labeled disorder that is a spectrum of early onset neurodevelopmental disorders, which is characterized by limitations in social contact, communication skills, everyday functioning, atypical sensory processing, and repetitive patterns of behaviors and interests (Haesen et al., 2010; Kozou et al., 2017). ASD is the most severe neurodevelopmental disorder, and affects approximately one in every 68 children up to 8 years of age (CDC, 2014). Because many individuals with ASD experience language weaknesses, abnormal auditory processing abilities are thought to be a symptom of ASD. Previous research by Paul et al. (2007) and Alcantara et al. (2004) supported the notion that individuals with ASD have difficulties processing speech information, especially in the presence of background noise.

One structural abnormality that contributes to the poor processing of auditory information in individuals with ASD is the small size of their corpus callosum (Alexander et al., 2007; Stanfield et al., 2008; Keary et al., 2009). The corpus callosum is an important structure in the brain that allows for the inter-hemispheric transfer of auditory information. When completing a dichotic listening task individuals with ASD have not been found to exhibit the typical right ear advantage. Instead, individuals with ASD tend to prefer to listen to speech and musical stimuli with their left ear (Kozou et al., 2017).

Kozou et al. (2017) evaluated the performance of children with a diagnosis of ASD on the dichotic digits assessment, as well as several subtests of the SCAN3-C. All participants were between 7 and 12 years old. Results revealed four different performance patterns on the dichotic digits assessments: normal performance, poor performance in both ears, larger advantage in the right ear/left ear deficits, and larger advantage in the left ear/right ear deficits. Additionally, children with ASD displayed a wider range of scores on the SCAN3-C subtest than typically developing peers. Although some participants scored within normal limits on the three subtests of the SCAN3-C, overall, children with ASD performed more poorly than typically developing children on all three subtests. Performance on the SCAN3-C indicated that the auditory processing abilities of children with ASD vary significantly from person to person, and may even be typically developing (Kozou et al., 2017).

Individuals with ASD have been found to perform differently on auditory processing behavioral assessments related to pitch perception, auditory stimulus orientation, prosody, and auditory stream segregation (Papagiannopoulou, 2015). Heaton et al. (1998) found that individuals with ASD exhibited superior pitch perception, even without any musical training. Evidence suggested that individuals with ASD had the ability to more accurately identify and recall pure tones, even when a language impairment was present (Heaton et al. 1998; Heaton et al. 2008). Dawson et al. (1998) and Dawson et al. (2004) demonstrated that individuals with ASD failed to orient to auditory stimuli. It was suggested that this lack of ability to orient to auditory stimuli in individuals with ASD was associated to atypical language development, which is commonly seen in this population. Poor performance was also evident in prosody and auditory stream segregation (understanding speech in the presence of background noise) (Eigsti et al., 2012, O'Connor 2012, Anderson & Kraus, 2010).

General Cognitive Abilities

Auditory processing behavioral assessments should be designed to have the capability of determining the underlying cause of a listening concern. However, the ability of these assessments to distinguish APD from the disorders stated above and control for differences in cognitive ability on test performance is questionable (Rosen et al., 2010).

Rosen et al. (2010) examined whether poor performance on auditory processing behavioral assessments was directly correlated to APD or an underlying global cognitive deficit. The children who were suspected of having APD performed significantly worse on two out of the three cognitive assessments than the control group. Although no relationship was established between the degree auditory impairment and cognition, children in the suspected APD group performed below average on cognitive assessments. Therefore, cognitive abilities must be evaluated through a psychometric work-up prior to a diagnosis of APD (Rosen et al., 2010), which further supports a multi-disciplinary approach when assessing for APD.

Although the poor performance by the suspected APD group on the cognitive assessments was not directly linked to linguistic skills, this group also scored below average on standardized tests of reading, and their performance was significantly worse than the children in the control group (Rosen et al., 2010). In addition, understanding speech in the presence of background noise distinguished the suspected APD group of children from the control group (Rosen et al., 2010), indicating that this group of behavioral assessments is highly sensitive to auditory difficulties.

Moore et al. (2010) investigated if auditory processing abilities of children between 6 and 11 years old were related to the clinical presentation measures of cognition. Since APD is poorly understood, Moore et al. (2010) utilized the population approach for recruiting research participants. This approach provided the investigators with a high likelihood that a subset of the participants had APD. Five different auditory processing behavioral assessments were administered including: backward masking with 0-millisecond gaps, backward masking with 50-millisecond gap, simultaneous masking, simultaneous masking with spectral notch, and frequency discrimination. Standardized cognitive assessments were administered that focused on examining each participant's nonverbal reasoning, working memory, phonological processing and memory, and reading accuracy and fluency (Moore et al., 2010).

Data analysis revealed a moderate, but significant, correlation between the results of the cognitive assessments and the auditory processing test results. It was also concluded, however, that performance on derived tests of auditory processing (i.e. temporal and frequency resolution) were not directly associated to cognitive performance because participants who performed poorly on these auditory processing assessments did not perform any worse on the cognitive assessments than typically developing peers. The derived temporal processing measures were obtained by subtracting the or backwards masking with a 50-millisecond gap threshold from the backwards masking with a 0-millisecond gap threshold, while the derived frequency resolution measures were determined by subtracting the simultaneous masking with spectral notch threshold from the simultaneous masking threshold. Contrarily, the children who performed poorly on individual tests of auditory processing had significantly worse scores on the cognitive assessment when compared to those participants who performed within normal limits on the tests of auditory processing (Moore et al., 2010).

Overall, Moore et al. (2010) concluded that listening difficulties associated with APD were a direct result of impaired cognitive ability. Additionally, it was suggested that due to the results of this study, APD should be redefined as a cognitive disorder if no neurological lesion is identified because results indicated that poor performance on tests of auditory processing were influenced by the cognitive demands of the assessments rather than the sensory demands (Moore et al., 2010)

Discussion

There are concerns that professionals in different fields may be diagnosing children with different labels for the same group of symptoms. The need for a standardized test battery with scientific validity is necessary for the diagnosis of APD since current test batteries do not have the ability to distinguish APD from other developmental disorders. This is a difficult feat because the etiology of developmental APD remains unknown; however, it is the duty of an audiologist to delineate the cause of the listening problem in order to ensure a proper diagnosis.

In order to properly distinguish if a child has a deficit in auditory processing abilities, an audiologist must understand that different auditory discrimination abilities reach maturation at different ages across the first two decades of life. Therefore, a child may perform well on certain auditory processing assessments but not on others due to his or her developmental age as seen in the studies completed by Jensen & Neff (1993) and Moore et al. (2011). The literature also suggested that children may lack the ability to perform well on behavioral auditory processing assessments due to the cognitive load required for these tasks (i.e. working memory), and that performance may not be a true representation of his or her auditory processing abilities.

It became apparent throughout this literature review that different developmental disorders may result in abnormal performance on behavioral APD assessments, which again questions the validity of the APD test battery. The high false positive rates of both the SCAN-3C and the SCAN-3A (displayed in Figure 1) supports the argument that children with different developmental disorders, or no disorder at all, may be over-diagnosed with APD due to their poor performance on behavioral auditory processing assessments.

It was evident that both attention (Lanzetta-Valdo et al., 2017) and cognition (Rosen et al., 2010) have the potential to impact performance on APD assessments; therefore, both should be assessed prior to diagnosis. Due to the language load of many of the auditory processing behavioral assessments, a speech language assessment should also be administered to distinguish if the poor performance is truly due to auditory processing difficulties or if language abilities are compromised (Miller & Wagstaff, 2012). The need for further assessments in different professional fields prior to a diagnosis of APD further supports the need for a multi-disciplinary approach to differential diagnosis. Although the assessments completed by other disciplines cannot be used to “rule in” APD as a diagnosis, they can help differentiate and “rule out” other developmental disorders.

The diagnosis given to a child may be dependent upon which professional he or she is initially referred to. Since many symptoms overlap between the developmental disorders discussed in this literature review and that these disorders may also be comorbid, an improper diagnosis may be made if a multi-disciplinary approach is not utilized. The diagnosis given to a child impacts the services he or she will receive in an education setting; therefore, it is crucial that they receive an appropriate diagnosis. This may only be done if each child receives a full evaluation prior to any diagnosis.

The poor validity of behavioral APD assessments and the comorbidity of this disorder with other developmental conditions has many researchers trying to determine if electrophysiological assessments may be utilized for the differential diagnosis of APD. Thus far, results have been mixed, with some studies finding significant differences in some electrophysiological responses, and other no difference between those with suspected auditory processing difficulties and controls. Research to date has failed to establish a characteristic pattern of amplitude, latency, or morphology directly correlated to APD; therefore, there is continuous debate as to whether electrophysiological assessments are an efficient and accurate tool for the identification of APD in children. Several different electrophysiological measures have been recently examined; however, no auditory evoked potential has been identified that may accurately diagnose APD. Further research is needed due to the conflicting evidence currently available. Consequently, there is not enough data to support the utilization of electrophysiological assessments in the diagnosis of APD.

Conclusion

The evidence presented in this literature review supports the comorbidity of APD with an array of other developmental disorders, such as ADHD, SLI, dyslexia, and ASD. However, current test batteries designed to assess APD cannot alone distinguish between these disorders. There is a pressing need for the development of improved assessment methods that are sensitive to the diagnosis of APD without providing erroneous diagnoses of APD in children who have other disorders or are typically developing. A multidisciplinary approach is crucial for the assessment and intervention of APD in children to reduce the risk of misdiagnosis of APD in children with other developmental disorders.

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