

Viewpoint

An Objective Approach Toward Understanding Auditory Processing Disorder

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Purpose: In the field of audiology, auditory processing disorder (APD) continues to be a topic of ongoing debate for clinicians and scientists alike, both in terms of theory and clinical practice. In the current viewpoint, we first lay out the main issues that are central to the controversy surrounding APD, and then suggest a framework toward their resolution.

Method: The current viewpoint is informed by reviewing existing studies in the field of APD to better understand the issues contributing to the controversies in APD.

Results: We found that, within the current definition of APD, the two main issues that make the APD diagnosis

controversial are (a) comorbidity with other disorders and (b) the lack of domain specificity. These issues remain unresolved, especially with the use of the existing behavioral APD test batteries. In this viewpoint, we shed light on how they can be mitigated by implementing the administration of an objective, physiological test battery.

Conclusions: By administering an objective test battery, as proposed in this viewpoint, we believe that it will be possible to achieve a higher degree of specificity to the auditory domain that will not only contribute towards clinical practice but also contribute towards strengthening APD as a theoretical construct.

Auditory processing disorder (APD) is one of the most controversial topics that has intrigued clinicians and researchers in the field of audiology for decades. In the current viewpoint, we revisit some of the long-standing issues regarding what counts as APD, and how to effectively diagnose APD. A report from the consensus conference of 14 expert scientists working in the field of APD (Jerger & Musiek, 2000) suggested that “An APD may be broadly classified as a deficit in the processing of information that is specific to the auditory modality” (p. 468). However, Jerger and Musiek (2000) acknowledged the difficulty of determining domain specificity to the auditory modality. They identified three main factors that complicate the diagnosis of APD: (a) other types of disorders exhibiting similar symptoms (e.g., reading disability), (b) inability of the behavioral procedures in differentiating APD from other

disorders, and (c) confounding factors (e.g., lack of attention, lack of cooperation) that can influence the test results. Although these problems were identified at least 2 decades ago, little has been achieved towards finding solutions. APD within the current definition by the American Speech-Language-Hearing Association (ASHA, 2005a, Definition and Nature of APD, Paragraph 1) is considered as a deficit in one or more of the following skills: auditory discrimination; temporal processing including auditory pattern recognition, temporal integration, temporal ordering, and temporal masking; and binaural processing including dichotic listening, sound localization and lateralization, and auditory performance with competing or degraded acoustic signals. ASHA noted that APD is limited to deficits in the neural processing of auditory information in the central auditory nervous system and is not due to higher order processes such as language or cognition (ASHA, 2005b). However, the behavioral tests proposed by ASHA (2005b) to evaluate the skills mentioned above do not rule out the contributions of language and/or cognition, and are thus unable to circumvent the issues identified by Jerger and Musiek (2000). As a result, there are currently many divergent perspectives on the interpretation of APD (DeBonis & Moncrieff, 2008; de Wit et al., 2016; Friberg & McNamara, 2010; McFarland & Cacace, 2006, 2008; Moore, 2018). In the current viewpoint, we shed light on the two main issues

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of comorbidity and domain specificity that complicate the APD diagnosis within the current definition, and which ultimately question the validity of APD as a construct (Moore, 2018; Vermiglio, 2018). We then propose and describe a novel, objective test battery that aims to resolve these issues.

APD and Its Comorbidity With Other Disorders

Several studies (Dawes & Bishop, 2009, 2010; de Wit et al., 2016, 2018; Miller & Wagstaff, 2011; Sharma et al., 2009) have reported an overlap between the symptoms of APD and those of disorders of language (e.g., developmental language disorder [DLD], dyslexia), cognition (e.g., autism), and attention (e.g., attention-deficit/hyperactivity disorder). For example, children with APD and those with dyslexia have been found to have similar scores on IQ, language and literacy, and auditory processing abilities (Dawes & Bishop, 2010). Similarly, almost half of those diagnosed with APD may fit a diagnosis of DLD and/or dyslexia (Dawes & Bishop, 2010). Children with an APD diagnosis, at least within the current definition, usually score lower on language and communication scales, exhibit attention and memory problems, and achieve lower scores on IQ (de Wit et al., 2016). A recent review (de Wit et al., 2018) of APD studies suggests that there are minimal differences between children diagnosed with APD and those diagnosed with other developmental disorders. This supports the conclusion that APD, when diagnosed within the current framework, is difficult to separate from other, potentially comorbid disorders.

Lack of Domain/Modality Specificity

Another point of controversy is the specificity of APD and whether or not APD can be classified as a “domain specific” disorder of the auditory domain. Some reports suggest that APD can be designated as a distinct disorder if it is shown to be limited to the auditory domain (Cacace & McFarland, 2013; Jerger & Musiek, 2000; McFarland & Cacace, 2008). Others suggest that it is difficult to separate hearing or auditory processing from cognition and, as a result, it is inaccurate to discuss APD as a disorder limited to the auditory domain/modality (Dillon et al., 2014; Moore & Ferguson, 2014). In order to circumvent this issue, some have proposed conducting multimodal/multidomain testing to ensure that poor performance on APD tests is due to specific deficiencies in the processing of information in the auditory domain, without significant contribution from other domains/modalities. For example, in order to rule out contributions from the visual modality, visual analogs of auditory processing tests have been proposed (Cacace & McFarland, 2013). In fact, studies that have used the auditory and visual variants of the APD tests have found deficits in both auditory and visual modalities in individuals with APD, casting doubt on the specificity of APD (de Wit et al., 2016). However, multimodal testing has met with criticism due to the theoretical and practical difficulties posed

by the approach, mainly due to the subjectivity in testing across professions (de Wit et al., 2018; Moore, 2006).

We believe that the lack of domain specificity and the comorbidity between APD and other developmental disorders could at least partly be a result of the type of the testing material that is currently in use for diagnosing APD. Based on the characteristics of APD as defined by ASHA (2005a, 2005b) and the American Academy of Audiology (AAA, 2010), most of the currently available APD testing involves the domains of language (e.g., speech-in-noise), memory (e.g., duration pattern test, frequency pattern test), nonverbal IQ, and attention (e.g., most of the existing APD tests). We believe that a true comorbidity between APD and other disorders can only be confidently ascertained if the testing for APD excludes components from other domains. For example, an individual who exhibits APD on a test that is devoid of linguistic, attention, and memory demands, but still exhibits a language disorder (e.g., DLD), would be an example of comorbidity with DLD. However, with the currently available test batteries, it is difficult to ascertain whether the reduced scores on APD testing by individuals with other disorders (e.g., DLD) are due to the lack of domain specificity of the testing material itself, or due to a true comorbidity between the disorder in question and APD. This highlights the need that, as already recommended by ASHA (2005a, 2005b) and the consensus statement (Jerger & Musiek, 2000), APD as a construct should be evaluated within the auditory domain.

At this juncture, in order to test APD within the auditory domain only, we propose conducting auditory electrophysiology (e.g., auditory brainstem response (ABR), frequency following response [FFR]) and electroacoustic (e.g., otoacoustic emissions, immittance) testing protocols that require negligible participation from the participants. The idea of including auditory electrophysiology and electroacoustic testing for APD has been around for at least 2 decades, but has not gained enough traction. For example, ASHA (2005b, Central Auditory Processing, Paragraph 1) states that APD refers to “difficulties in the perceptual processing of auditory information in the central nervous system and the neurobiologic activity that underlies that processing and gives rise to the electrophysiologic auditory potentials.” In the consensus statement on APD (Jerger & Musiek, 2000), the scientists agreed that electrophysiological and electroacoustic tests are advantageous, since they were less influenced by extraneous variables; however, these tests were deemed too time consuming and expensive to administer (Moore, 2006). Furthermore, facilities for such testing were not widely available at that time (AAA, 2010; Jerger & Musiek, 2000), while electrophysiological and electroacoustic tests were even discouraged because of the lack of contemporary research supporting their value in testing for APD (Katz et al., 2002). Similarly, the AAA (2010) did not support these tests because no agreed-upon criteria and no accepted procedures for recording and analyzing cortical-auditory evoked potentials were available. Scalp-recorded auditory evoked potentials were suggested to be insufficiently reliable and domain specific, especially in the context

of long-latency cortical auditory evoked responses (Cacace & McFarland, 2013).

What Should “APD” and “APD Testing” Entail?

We propose that if we want to focus on the “auditory” aspect of “APD” as suggested in the previous reports and guidelines (AAA, 2010; ASHA, 2005b; Cacace & McFarland, 2008, 2013), investigating the lower, or basic sensory levels of auditory processing makes a strong case, since they are relatively independent of higher-order extraneous factors such as attention, memory, and linguistic abilities. Consider a continuum of sound processing that consists of an initial acoustic processing stage, which is then followed by a phonetic processing stage and finally by a language and cognition processing stage. Here, language and cognition processes are most affected by the extraneous factors of attention, memory, IQ, and language abilities (Klahr & Kotovsky, 2013; Kurland, 2011). Thus, we propose using stimuli for APD testing that address, at most, the first two stages of auditory processing, that is, acoustic and phonetic, but which exclude the language and cognition stage.

Electrophysiological and Electroacoustic Test Battery for APD

With the recent advances in technology, and in combination with more research in the area of objective auditory measurements, we believe that what seemed like a time-consuming, financially draining, and less reliable approach has now reached the stage where it can be a major contributor in current auditory testing paradigms. As more and more clinics and institutions include electrophysiological and electroacoustic testing, we believe that it is appropriate, if not imperative to develop an objective (electrophysiological and electroacoustic) test battery. It is worth noting that we agree with previous definitions of APD (ASHA, 2005a; AAA, 2010) that one of the prerequisites for an APD diagnosis is normal peripheral hearing sensitivity as recorded on routine audiometry. However, unlike the previous definitions, we do not restrict tests to detect deficits in the “central” auditory pathway, that is, beyond the auditory nerve. Instead, we propose that it is necessary to start at the periphery, since impaired hair cell functioning can degrade spectral and temporal tuning that is not detected by routine audiometry (Barbee et al., 2018; Guest et al., 2017, 2018; Oxenham & Bacon, 2003). Another example is the case of cochlear synaptopathy, where the ribbon synapses between the inner hair cells and type I auditory nerve fibers are damaged (Kujawa & Liberman, 2009), which leads to perceptual deficits in subsequent processing centers. Table 1 provides a list of anatomical sites starting from Outer Hair Cells (OHCs) up to the upper brainstem (inferior colliculi), as well as the efferent system from the olivocochlear bundle to the OHCs, and the tests that can evaluate the intactness of auditory processing in these sites. Administration of the whole site-based APD test battery might take around 30–40 min.

Table 1. Objective test battery for a site-based APD evaluation.

	Anatomical site	Test
1	Outer Hair Cells (OHCs)	Otoacoustic Emissions (OAE); Cochlear microphonics
2	Inner hair cells	Summating potential
3	Ribbon synapses	Wave I Auditory Brainstem Response (ABR)
4	Brainstem (cochlear nucleus, superior olivary colliculi, lateral lemniscus, inferior colliculi)	ABR waves II–V
5	Efferent system (olivocochlear bundle to OHCs)	Contralateral suppression of OAE
6	Low spontaneous rate auditory nerve fibers	Middle Ear Muscle Reflex (MEMR)

Note. APD = auditory processing disorder.

Along with such an anatomical site-based APD evaluation, we also propose a test battery for an auditory “processes”-based APD evaluation. We propose testing four basic auditory processes: auditory separation, localization, frequency resolution, and binaural interaction. They represent the most common auditory functions needed in everyday life that enable us to (a) perceive speech in the presence of background noise (e.g., in a cafeteria), (b) locate the sound source (e.g., while driving), (c) distinguish sound frequencies (e.g., for pitch perception), and (d) listen with both ears (e.g., for ease of listening). For testing auditory separation, which basically entails speech perception in noise, we propose using the FFR (Anderson & Kraus, 2010; Banai & Kraus, 2008; Kraus et al., 2017) with simple speech tokens (devoid of any linguistic load) in the presence of noise. An example of the speech stimuli would be the 40-ms /da/ stimulus from complex ABR (cABR) or Biological Marker for Auditory Processing (BioMARK; Anderson & Kraus, 2010) that contains just three vocal cycles beyond the consonant–vowel transition. For testing localization and frequency resolution, we propose the use of the newly introduced interaural phase difference following response as well as the frequency modulation following response (Parthasarathy et al., 2020). For testing the binaural auditory processes, we propose the use of the binaural interaction component (McPherson & Starr, 1993). Based on the behavioral manifestations exhibited by a patient who presents at an audiology clinic, a process-specific electrophysiological APD evaluation should be conducted (see Table 2), followed by the site-based APD test battery (see Table 1). For example, a person who presents with a complaint of poor speech perception in noisy conditions—which might suggest a deficit in the “auditory separation” process—will be given a cABR or FFR-in-noise evaluation, followed by a comprehensive site-based objective test battery (see Table 1) to determine the potential anatomical site of the deficit. For a person to be diagnosed with APD, they should report deficits in at least one of the basic auditory processes as well as exhibit below-normative performance on the corresponding electrophysiological test(s) (see Table 2). The site-based evaluation

Table 2. Objective test battery for a process-based APD evaluation.

	Auditory process	Behavioral manifestation of deficit	Test
1	Auditory separation	Difficulty in perception of speech in presence of noise.	FFR in noise, cABR or BioMARK in noise
2	Localization	Difficulty in being able to find the location of sound source.	Interaural phase difference following response
3	Frequency resolution	Difficulty differentiating pitches.	Frequency modulation following response
4	Binaural interaction	Difficulty in making sense of sounds with both ears but satisfactorily with either ear separately.	Binaural interaction component

Note. APD = auditory processing disorder; cABR = complex ABR; BioMARK = Biological Marker for Auditory Processing.

(see Table 1) in combination with the process-based evaluation will provide insights into the locus and the nature of the deficits in the auditory pathway.

Challenges and Future Directions

APD testing has had a long history of development and usage, which was inspired principally by known brain pathologies. For example, a frequency pattern test with a fair diagnostic accuracy (sensitivity = 83%; specificity = 88.2%) for cortical lesions (Musiek & Pinheiro, 1987) was proposed to be a part of the APD test battery (AAA, 2010). However, the interpretation of this test becomes problematic when a patient with another disorder (e.g., DLD) also performs poorly on the frequency pattern test (Miller & Wagstaff, 2011), since DLD has no known brain pathology. In other words, the results of the frequency pattern test could be affected by language domain processes, in which case they would not be specific to the auditory domain. The utility of such behavioral tests is therefore questionable. Instead, we propose that tracking down the anatomical (using site-based testing) and physiological (e.g., using process-based testing) deficits directly via the use of objective testing (electroacoustic and electrophysiological) is a more appropriate approach. We believe that, despite the availability of objective techniques in the field of audiology, APD testing has not fully realized its potential. Here, we propose that the time has come for electroacoustic and electrophysiological techniques to be used towards understanding deficits in auditory processing.

However, at this juncture, we must acknowledge that this does not come without challenges. First, instrumentation needs to be streamlined for the use of audiologists. This will entail developing and setting up user-friendly modules containing the process-based and site-based test batteries within the AEP systems popular among audiologists. This should be followed by establishing comprehensive age- and gender-based norms. Second, not all clinics and clinicians specialize in the area of APD and electrophysiology. Since using the proposed approach requires knowledge of both APD and electrophysiology, there is a growing need for awareness regarding the issue among the clinical audiologists; this can be achieved by conducting workshops/bootcamps at popular conferences (e.g., the annual ASHA convention) or separately, in order to provide “hands-on” experience with instrumentation and testing modules. Third, the issue

of limited insurance coverage for APD is long standing. As audiologists know, insurance companies may consider APD testing and treatment “*experimental and investigational because there is insufficient scientific evidence to support the validity of any diagnostic tests and the effectiveness of any treatment for APD*” (Aetna, 2020). Furthermore, APD is not recognized as a unique entity in the Diagnostic and Statistical Manual of Mental Disorders, 4th Edition, Text Revision (DSM-IV-TR; Segal, 2010). These issues can be mitigated by ascertaining the “auditory” locus of the disorder by modifying the APD testing to include objective measures (e.g., electroacoustic and electrophysiological) that are proven to test the basic auditory processes with little or no involvement of higher-level comorbid factors (e.g., language and cognition). The current proposed approach offers a starting point in this direction. While the tests in the site-based test battery (see Table 1) are relatively well known in the audiology practice, more clinical research is needed for the tests in the process-based test battery (see Table 2) before they can become an established part of APD testing routines.

Concluding Remarks

In the current viewpoint, we discussed the long-standing issues of comorbidity and domain specificity that continue to impede the understanding of APD. We believe that these issues have roots within the current construct definition of APD. We propose the use of an objective approach (electrophysiological and electroacoustic) to address the longstanding challenges of comorbidity and domain specificity, and in doing so, we try to provide a novel view of the APD construct as a whole. In addition to theoretical considerations, this viewpoint presents the very first steps towards a novel approach for the clinical practice of APD.

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