Auditory Processing Theories of Language Disorders: Past, Present, and Future

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Purpose: The purpose of this article is to provide information that will assist readers in understanding and interpreting research literature on the role of auditory processing in communication disorders.

Method: A narrative review was used to summarize and synthesize the literature on auditory processing deficits in children with auditory processing disorder (APD), specific language impairment (SLI), and dyslexia. The history of auditory processing theories of these 3 disorders is described, points of convergence and controversy within and among the different branches of research literature are considered, and the influence of research on practice is discussed. Theoretical and clinical contributions of neurophysiological methods are also reviewed, and suggested approaches for critical reading of the research literature are provided.

Conclusion: Research on the role of auditory processing in communication disorders springs from a variety of theoretical perspectives and assumptions, and this variety, combined with controversies over the interpretation of research results, makes it difficult to draw clinical implications from the literature. Neurophysiological research methods are a promising route to better understanding of auditory processing. Progress in theory development and its clinical application is most likely to be made when researchers from different disciplines and theoretical perspectives communicate clearly and combine the strengths of their approaches.

Key Words: language disorders, auditory processing, dyslexia (written comprehension), specific language impairment, electrophysiology

Most school-based speech-language pathologists (SLPs) are probably familiar with the term “auditory processing” and may have found that other professionals, such as audiologists, psychologists, and reading specialists, also use the term. At first glance, this situation looks good: Colleagues with different backgrounds share a vocabulary and, presumably, a theory. Stated very simply, that theory might be something like “auditory processing deficits cause language-related academic problems.” Intuitively, this seems like a reasonable approach. We learn our native language by listening to speech (unless we are exposed to a signed language). If the sounds of speech are not delivered to the language system accurately and quickly, then surely language ability will be compromised. However, despite decades of research, a complete theoretical account of how auditory perceptual deficits lead to impaired language has proven elusive. In the absence of such an account, auditory processing has become a buzzword that has almost as many meanings as there are people who use it. Therefore, use of the term may generate confusion rather than reduce it.

In this article, I briefly review the history of auditory processing theories of language-related learning difficulties. I believe one reason for the confusion surrounding the term auditory processing is that it has been studied by different groups of researchers with different goals, assumptions, and methods. With this background in mind, we can better understand points of convergence and controversy within and among the different branches of research literature and how research has influenced practice. The article will conclude with an examination of the theoretical and clinical contributions of neurophysiological methods, a discussion of future directions, and suggestions for informed reading of the literature.

Auditory Processing Deficits Are Implicated in Multiple Disorders

Auditory processing deficits have most often been invoked in theories about three disorders: auditory processing
disorder (APD),\textsuperscript{1} specific language impairment (SLI), and dyslexia. The presence of auditory processing deficits is the motivation for the diagnosis of APD. Children with APD demonstrate difficulties in one or more areas of perceptual processing of auditory information, such as sound localization and lateralization; auditory discrimination; auditory pattern recognition; temporal aspects of audition, including temporal integration, temporal discrimination (e.g., temporal gap detection), temporal ordering, and temporal masking; auditory performance in competing acoustic signals (including dichotic listening); and auditory performance with degraded acoustic signals. (American Speech-Language-Hearing Association [ASHA], 2005, p. 2)

Peripheral hearing impairment is usually an exclusionary criterion for APD. The ASHA definition does not specify exclusionary criteria, but it does state that it is inappropriate to apply the APD label to children with, for example, language impairment or learning disabilities “unless a comorbid deficit in the CNS [central auditory nervous system] can be demonstrated” (ASHA, 2005, p. 2).

It has been suggested for decades (see Rees, 1973; Rosen, 2003 for reviews) that auditory processing deficits underlie SLI. Children with SLI fail to learn language as quickly and accurately as their age-mates, but in the absence of hearing impairment, cognitive impairment, frank neurological disorder, or developmental disorders such as autism, and in the presence of language input that should be sufficient for normal learning (Bishop, 2006). There is also a long history of associations between dyslexia and auditory processing problems. Children with dyslexia fail to acquire fluent, accurate word-reading skills despite adequate instruction, and in the absence of cognitive impairment. The word-reading impairments are thought to result from impaired phonology (Lyon, Shaywitz, & Shaywitz, 2003).

For each of these three disorders, there is an associated body of research suggesting that observed problems with spoken and/or written language result from auditory processing deficits. However, despite some points of contact, these three branches of research literature have generally used different measures, and perhaps different conceptions, of what auditory processing is (Cacace & McFarland, 1998). Therefore, a comprehensive account of the role of auditory processing in these disorders is missing. The search for a single, comprehensive theory of auditory processing is closely tied to the following question: Are APD, SLI, and dyslexia distinct disorders (Dawes & Bishop, 2009; Kamhi, 2011)?

If SLI and dyslexia can be explained by the same auditory processing deficits that are found in APD, this would be evidence in favor of considering them a single disorder. If they can all be considered as one disorder, then the research literature associated with each could be synthesized, and such a synthesis might lead to advances in understanding the role of auditory processing deficits in that single disorder. However, it is by no means certain that APD, SLI, and dyslexia are underlyingly the same disorder. Some researchers have argued that SLI and dyslexia are different labels for the same disorder (Kamhi & Catts, 1986; Tallal, 1988, 2004); however, recent research (Bishop & Snowling, 2004; Catts, Adlof, Hogan, & Ellis Weismer, 2005) suggests that they are distinguishable. There have been a few systematic comparisons of APD with SLI and/or dyslexia (Dawes, Bishop, Sirimanna, & Bamiou, 2008; Ferguson, Hall, Riley, & Moore, 2011; Miller & Wagstaff, in press; Sharma, Purdy, & Kelly, 2009). These studies have consistently shown that children with APD have very similar profiles to children with language or reading impairments. ASHA’s technical report (2005) asserts that APD is distinct from language impairment, but research demonstrating how to differentially diagnose them is lacking (Dawes & Bishop, 2009; Kamhi, 2011).

With regard to SLI and dyslexia, a consensus has not yet been reached regarding the causal role of auditory processing deficits. I will describe some points of contention later in this article, but for now, it is enough to note that the debate continues (Dawes & Bishop, 2009; Kamhi, 2011). Importantly, the literature concerning these two disorders begins with observation of certain behavioral symptoms and searches for a mechanism to explain the symptoms. A problem with auditory processing is a candidate mechanism. For APD, however, the starting assumption is that some individuals have problems with auditory processing, and the question is how to assess those problems and determine their association with behavioral symptoms. This description of the difference in assumptions is necessarily somewhat oversimplified, but the overview in the following section will help to show how the difference has arisen.

**History of Auditory Processing Research**

There are several published reviews that trace the history of auditory processing as a construct and a topic of research (Jerger, 2009; Kamhi, 2011; Lahey, 1988; Leonard, 1998; McFarland & Cacace, 2009; Rees, 1973; Rosen, 2003). As one reads these reviews, along with the position statements of professional organizations (ASHA, 1996, 2005; Jerger & Musiek, 2000), it becomes clear that there are distinct strands of research that have developed largely independently of one another. Jerger (2009) identified three such strands: the audiological approach, the psychoeducational approach, and the language processing approach. The audiological approach, according to Jerger, originated with studies of adults with brain lesions. Tests that had been developed to assess central auditory processing abilities of these patients began to be used in the 1970s to assess...
children who, as described by Myklebust (1954) as early as the 1950s, had adequate peripheral auditory sensitivity but could not fully make use of the speech they heard (Jerger, 2009). The term central auditory processing disorder (CAPD), or APD, was used to describe children who performed poorly on such instruments.

Jerger’s (2009) description of the second strand of research, the psychoeducational approach, corresponds closely to the specific-disabilities orientation toward explanation of language disorders as described by Lahey (1988). Researchers in this orientation, often SLPs and psychologists, focus on rather narrowly circumscribed component abilities that are believed to be necessary for the production and comprehension of spoken language and/or literacy. The specific-disabilities approach is often found in the literature on dyslexia as well as the literature on SLI. Auditory perceptual skills, as Lahey noted, have been perennial favorites in the search for specific disabilities. The reasoning behind the orientation is that if specific disabilities contributing to language-related academic problems can be identified, they can also be remediated. Lahey provided a cogent critique of this approach. That critique exemplifies in many ways the language processing approach, Jerger’s third strand in the history of auditory processing research. The language processing approach emphasizes the interactive nature of speech and language processing, where knowledge of language and sensitivity to the context of its use have significant top–down effects on how the central nervous system (CNS) deals with an auditory signal.

This brief overview helps to explain why the research literature on APD, SLI, and dyslexia tend to remain distinct. APD has usually been studied using the audiological approach. Equipped with knowledge of CNS lesions and tests that are believed to assess their effects, researchers using this approach ask: What is the outcome for an individual with an APD? SLI and dyslexia have usually been studied using the specific-disabilities approach. Researchers who adopt this approach, equipped with knowledge of outcomes and tests to assess those outcomes, ask: Could an auditory processing deficit be the cause of this outcome? Here the focus tends to be on identifying a deficit through psycho-physical tasks, such as discrimination of tones or syllables, and linking that deficit to a distinctive and well-described outcome (e.g., a dyslexic profile). Research coming from the specific-disabilities perspective has often been critiqued by proponents of the language processing approach, who, equipped with an appreciation for the top–down influence of language knowledge, tend to emphasize the unique properties of speech and how speech may be processed differently from other auditory stimuli.

Controversies

There is no shortage of controversies in the research literature on auditory processing, and it is beyond the scope of this article to fully address these issues. I will, however, briefly discuss a cluster of issues that may help to illustrate why, despite all the research on auditory processing, a comprehensive theory remains hard to come by.

There is a central debate in the APD literature over the modality specificity of APD. Cacace and McFarland (1998, 2005) argued that APD should be defined as a deficit in the processing of auditory stimuli only. Therefore, assessment of processing in other modalities is required in order to rule out supramodal deficits such as memory, attention, or linguistic problems. Other researchers contend that the interactive nature of the CNS precludes such modality specificity (ASHA, 2005; Musiek, Bellis, & Chermak, 2005). Related to the modality specificity issue is a controversy regarding the use of linguistic material to assess APD, and auditory processing more generally in SLI and dyslexia. Moore (2006) argued that APD should be defined on the basis of processing of nonspeech sounds (see also Dawes & Bishop, 2009). With regard to dyslexia, Farmer and Klein (1995) argued from their review of the literature that individuals with dyslexia likely have a general temporal processing deficiency that encompasses not only nonlinguistic and linguistic auditory stimuli, but visual stimuli as well. In contrast, Mody (2003) summarized arguments that the evidence for nonlinguistic temporal processing problems is weak. According to Mody, some of the data presented as evidence of generalized deficits in rapid temporal processing can be interpreted as demonstrating phonological deficits. Furthermore, not all individuals with dyslexia have difficulty processing brief, rapid stimuli (e.g., Bishop, Adams, Nation, & Rosen, 2005).

Research on speech versus nonspeech deficits in children with SLI parallels that in children with dyslexia. For example, there is evidence that children with SLI have difficulty with frequency discrimination at the behavioral level (McArthur & Bishop, 2004). Furthermore, even some individuals with normal behavioral performance show abnormal cortical responses to tones (Bishop & McArthur, 2005). Children with SLI also have difficulty discriminating differences in amplitude envelope rise time (Corriveau, Pasquini, & Goswami, 2007). However, not all of the children in any particular sample performed below the level of their typically developing peers. In a study that examined both SLI and dyslexia, Fraser, Goswami, and Conti-Ramsden (2010) found rise time discrimination problems in children with dyslexia, with or without comorbid SLI, whereas children with only SLI did not perform significantly worse than typically developing age peers. Thus, it remains unclear whether deficient processing of nonspeech auditory stimuli is a consistent characteristic of either SLI or dyslexia.

Rosen (2003) emphasized that, even if some individuals with SLI and dyslexia have deficits in processing nonspeech stimuli, there is no viable theoretical account relating nonspeech to speech deficits. Leonard (1998) made a similar point, arguing that although children with SLI are repeatedly
deficits are associated with SLI and dyslexia, but do the deficits cause those disorders or are the auditory processing problems caused by the language and reading impairments in the disorders? Similarly, does APD result in deficits of language (or memory or attention), or can APD be explained as a consequence of such deficits?

There are reasons to think, as suggested in the language processing approach, that higher level constructs such as linguistic knowledge affect the processing of auditory input at an early stage. Banai and Kraus (2009) summarized evidence showing that auditory brainstem responses (ABRs) for speech can be changed by a lifetime of musical experience or by a few weeks of experience with a computer training program. They also described how ABRs are affected by what stimulus a participant chooses to attend to (Galbraith, Bhuta, Choate, Kitahara, & Mullen, 1998; Galbraith, Olman, & Huffman, 2003). In a study of children with speech sound disorders, Johnson, Pennington, Lee, and Boada (2009) found phonological awareness at age 5 to be a better predictor of backward masking performance (thought to index rapid temporal processing) at age 8 than age 5 backward masking performance predicted age 8 phonological awareness. Findings such as these suggest the presence of top–down influences on perception and call into question any model in which auditory processing causes language and reading problems.

There are further reasons to doubt that there is a direct link from rapid auditory temporal processing to language or reading. A study by Watson et al. (2003) with a community sample found that temporal speech processing measures were relatively poor predictors of reading achievement and overall academic performance in first and second grade. Moore, Ferguson, Edmondson-Jones, Ratib, and Riley (2010), also using a community sample of schoolchildren, found that auditory processing was a less effective predictor of communication and listening outcomes than measures of attention and cognition. Interventions designed to improve auditory processing through the use of modified speech have been found to be no more effective than other interventions (e.g., Gillam et al., 2008; see the Intervention section).

There is evidence, however, that favors a causal role for auditory processing in language and reading impairment. Much of this evidence comes from longitudinal studies of infants and young children. Infants with a family history of language impairment performed more poorly than peers without such a history on behavioral measures of rapid auditory processing at age 6–9 months, and their performance predicted language scores at 12 and 16 months (Choudhury, Leppänen, Leevers, & Benasich, 2007). Compared to typically developing peers, children with low word production at 12 and 24 months had, at age 5 months, shown reduced electrophysiological evidence of discriminating stress patterns based mainly on temporal cues (Weber, Hahne, Friedrich, & Friederici, 2005). These and other findings indicating that differences in auditory processing can be observed in young infants (e.g., Guttorm, Leppänen, Tolvanen, & Lytting, 2003) and are associated with later language development (e.g., Guttorm et al., 2005) suggest that auditory processing deficits exist before language begins to be used. Yet infants are in the process of learning language even before they are born; therefore, given the evidence for top–down effects on auditory responses (Banai & Kraus, 2009), it is possible that differences in infants’ auditory processing are the result, not the cause, of abnormal language processing. Furthermore, the speech versus nonspeech debate raises its head again even here. Molfese, Molfese, and Molfese (2007), in a review of studies from their own and other labs, suggested that infants’ event-related potential (ERP) responses to speech may be particularly predictive of language and reading outcomes.

Even these few examples pertaining to speech versus nonspeech processing, modality specificity, and direction of causal influence illustrate that the literature on auditory processing is rife with conflicting results and conflicting interpretations of results. Given this state of affairs, it is perhaps not surprising that a comprehensive theoretical account uniting research on APD, SLI, and dyslexia has proven elusive. Nonetheless, there are some points of convergence.

Convergence

The three strands of research identified by Jerger (2009)—the audiological, psychoeducational (or specific disabilities), and language processing approaches—are not without their similarities. For example, the traditional emphasis of the audiological approach on describing a profile of strengths and weaknesses in a number of component auditory processing abilities such as temporal processing, sound localization, auditory discrimination, and so on (ASHA, 2005) shares some of the philosophy of the specific-disabilities orientation (Kamhi, 2011). The audiological approach most clearly converges with the specific-disabilities approach when different auditory processing profiles are hypothesized to lead to distinct patterns of behavioral symptoms (Bellis, 2003; Katz, 1992). Also, in recent years, the audiological approach has incorporated knowledge about top–down influences of language knowledge and cognitive ability (Musiek & Chermak, 2007), showing some convergence with the language processing approach. In addition to these philosophical similarities, researchers from all three approaches have increasingly begun to turn to neurophysiological techniques such as
ERP and functional magnetic resonance imaging (fMRI) for better understanding of auditory processing.

**Neurophysiological Methods**

One reason for the controversies regarding the role of auditory processing in APD, SLI, and dyslexia is a reliance on behavioral measures. The behaviors that characterize these disorders are the result of multiple factors, from signal perception to interpretation of the signal (giving it meaning) to integrating the interpretation with existing knowledge and current context. When a behavior is observed—for example, poor discrimination of syllables—it is very difficult to determine where in the process failure occurred. Is there a general problem with signal perception or only with the perception of auditory input? Do problems arise before the signal is interpreted as linguistic, or afterward? How can we distinguish between perception and retention of a signal?

Given the current state of knowledge about the CNS, these questions are extremely difficult to answer; however, neurophysiological techniques may help provide answers (Dawes & Bishop, 2009). These techniques have some advantages over the behavioral methods that have been used in the audiological, specific-disabilities, and language processing approaches. Behavioral tests must often be sensitized, or made more difficult, so they will reveal weaknesses (Cacace & McFarland, 2005). For example, an auditory processing test might require the repetition of sentences presented in background noise. The overt response is influenced by the participant’s understanding of the instructions, perception and processing of the stimulus, attention, motivation, memory, and speech ability. In an ERP or fMRI study, no overt response is required (although an overt response may be used), and in some cases, the participant does not even need to be attending to the stimulus. Brain activity associated with simply perceiving the stimulus can be assessed. Brain activity associated with the other factors in the behavioral response may also be assessed if the researcher chooses.

Event-related potentials are obtained through electroencephalography (EEG), by measuring the electrical activity (or potential) of the brain that is time-locked to a stimulus event—hence, ERPs. ERPs are also called “evoked potentials,” and auditory evoked potentials have been used by hearing scientists for many years as a window into how the brain processes auditory input. The ABR can be measured within the first 10–15 ms following stimulus onset. The middle latency response, from approximately 12 ms to 50 ms poststimulus onset, is probably generated by the upper brainstem and primary auditory cortex and is followed by “later” cortical responses 50–250 ms after stimulus onset (Hall, 1992). Both ABRs and cortical responses have been used in investigations of auditory processing in children with APD, SLI, and dyslexia (e.g., Basu, Krishnan, & Weber-Fox, 2010; Bishop & McArthur, 2005; Jerger, Martin, & McColl, 2004; Jirsa, 1992; Jirsa & Clontz, 1990; Marler & Champlin, 2005; Martin, Jerger, & Mehta, 2007; McArthur, Atkinson, & Ellis, 2009; Sharma et al., 2006).

One major advantage of ERPs is their excellent temporal resolution, allowing researchers to track the brain’s response to stimuli almost millisecond by millisecond. It is very difficult to determine, however, where in the brain the responses are occurring. Although we categorize some auditory evoked potentials according to the location of their “generators,” such as the brainstem, this categorization is based on our knowledge of the anatomy and physiology of the CNS, not on any locational specificity of the EEG signal itself. In contrast, fMRI has excellent spatial resolution but relatively poor temporal resolution. It measures blood flow to areas of the brain; areas that get more blood are presumably more active. It takes several seconds for blood flow to change, however. Therefore, ERP and fMRI offer complementary data about brain activity.

It is important to understand that neither ERP nor fMRI techniques offer a perfectly transparent window into the workings of the brain. There are many steps of data processing and interpretation between the actual brain activity and the results of a neurophysiological study. Furthermore, the data are only as good as the design of the experiment that elicits them. Still, ERPs and fMRI do offer data about what the auditory nervous system is doing that cannot be obtained through behavioral methods. The following paragraphs summarize some illustrative findings using electrophysiological and MRI methods to investigate auditory processing.

Several studies have demonstrated that a substantial proportion of children with language and/or reading impairments have abnormal ABRs. These results have been obtained with different types of stimuli such as backward masked tones (Marler & Champlin, 2005), tonal sweeps and rapid clicks (Basu et al., 2010), and synthesized speech syllables (Banai, Nicol, Zecker, & Kraus, 2005; Johnson, Nicol, Zecker, & Kraus, 2007). A larger body of literature has found abnormal cortical responses in many children with language and/or reading impairments (see Banai & Kraus, 2007, for a review that includes findings for both subcortical and cortical responses). Bishop and McArthur (2005) investigated behavioral and ERP responses in a frequency discrimination task. Among their participants with SLI, ranging in age from 12 to 20 years, not all demonstrated difficulty with frequency discrimination. However, many of the participants had abnormal cortical responses, even in the presence of adequate behavioral frequency discrimination. Children with APD or suspected APD have been found to have abnormal cortical responses to speech or nonspeech stimuli (Jerger et al., 2002, 2004; Jirsa, 1992; Jirsa & Clontz, 1990; Martin et al., 2007).

Structural MRI studies, which examine brain morphology rather than brain activity, suggest that the brains of children with SLI differ from those of typically developing controls, with some areas being smaller and/or more symmetrical.
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of these interventions, therefore, can provide evidence for or against the theories that motivated the interventions. An excellent example is the computer-based training system Fast ForWord. Based on the work of Tallal and colleagues (Merzenich et al., 1996; Tallal et al., 1996), Fast ForWord uses modified speech in a series of computer games that react adaptively to the user’s performance, increasing or decreasing the difficulty level on the basis of prior responses. The modified speech is slowed, with selective amplification of rapid formant transitions (Nagarajan et al., 1998). If deficits in rapid auditory processing underlie language and reading problems, then the Fast ForWord intervention, targeting speed of processing, should ameliorate those problems.

A recent meta-analysis (Strong, Torgerson, Torgerson, & Hulme, 2011) identified six high-quality studies regarding the effectiveness of Fast ForWord. The authors concluded that there was no convincing evidence that Fast ForWord improved participants’ reading or language skills, whether compared to no-treatment controls or to controls receiving an active treatment. The participants in the reviewed studies were selected on the basis of language or reading impairment, and for one study, impairments in both. An illustrative example of the studies reviewed is a randomized, controlled clinical trial conducted by Gillam et al. (2008). The study compared Fast ForWord to another computer-based language intervention, to academic computer games without a language focus, and to intervention by an SLP. The results suggested that all interventions were effective in improving the children’s language performance and auditory processing (measured by a backward masking task), but that Fast ForWord was no more effective than the other treatments. The two language-focused computer interventions resulted in more improvement in phonological awareness than the other two treatments. There was no evidence, however, that intervention specifically targeted to auditory processing was more effective than other intensive interventions (Gillam et al., 2008).

Two recent systematic reviews examined studies regarding the effectiveness of auditory interventions, including but not limited to Fast ForWord. Fey et al. (2011) examined studies of auditory interventions for children with APD, language disorder, or both. Loo, Bamiou, Campbell, and Luxon (2010) reviewed studies of computer-based auditory interventions in which the children had language- or reading-related difficulties. The two reviews included many of the same studies, but each also included some unique studies, as the inclusion criteria were not the same. In both reviews, the studies reviewed varied in their quality, and quality was rated by the authors. Fey et al. (2011) concluded that weak evidence exists to suggest that auditory interventions can improve auditory functioning in children with APD, but there is little or no evidence that such interventions improve language outcomes. Similarly, there is some evidence that auditory

Intervention

Some hypotheses about auditory temporal processing have led directly to interventions. Data regarding the success
interventions improve auditory processing in children with language disorders, but the effects are not greater than control interventions, and the auditory interventions were not found to improve language outcomes in children with language disorders.

Loo et al. (2010) concluded that there is some evidence that computer-delivered auditory interventions improve auditory processing and phonological awareness in children with language- and/or reading-related learning problems. However, they found little evidence that such interventions were effective in improving language and reading outcomes. They also noted that two studies using paired audiovisual stimuli found promising results for improving reading skills.

An illustrative example of auditory intervention studies not involving Fast ForWord is Russo, Nicol, Zecker, Hayes, and Kraus (2005). These authors assessed the effect of using an auditory training computer program, Earobics (Cognitive Concepts, 1997), on brainstem and cortical responses and on behavioral responses in a rather broadly defined sample of children with language difficulties. Following intervention, the brainstem responses of the children more faithfully encoded timing characteristics of a synthetic speech syllable presented in background noise. These changes were associated with more mature cortical responding. Similar changes were not seen in a control group. Children in the intervention group showed improved behavioral performance on some tests of auditory language processing, but these changes were not associated with the changes in ABR. A listening comprehension test, which did not show a pretest–posttest difference, was associated with decreased variability of the brainstem response in noise. Thus, there is some evidence of improved auditory processing, but its relation to language performance is unclear.

An auditory perceptual training study was conducted by Moore, Rosenberg, and Coleman (2005) with typically developing children ages 8 to 10 years. The study investigated whether a phoneme discrimination computer game would result in increased phonological awareness and word discrimination. Both phonological awareness and word discrimination scores improved in the treatment group versus the no-treatment control group, although the evidence that phoneme discrimination itself improved was equivocal. Moore et al. suggested that the improvements in outcome measures were due to both perceptual learning and increased attention. As the authors noted, “perhaps perceptual learning is a type of improved attention” (Moore et al., p. 83). The hypothesis that gains in attention led to improved outcomes is consistent with a recent study from the same laboratory (Moore et al., 2010) in which a community-based sample completed auditory processing, speech recognition, language, cognitive, and attention measures. As described earlier, the results of the study suggested that attention and cognition were the best predictors of speech recognition, communication, and listening skills as rated by caregivers.

The role of musical training in auditory perceptual skill development is ripe for investigation. In a recent review, Chandrasekaran and Kraus (2010) argued, based on evidence that musicians exhibit superior speech processing compared to nonmusicians, that musical training is a promising method for improving speech perception in individuals who have difficulty excluding background noise, which, the authors suggested, is a common symptom in children with APD, SLI, and dyslexia. Listening to music (as opposed to being trained as a musician) has been used as a treatment approach for children with language, reading, and/or auditory processing disorders. The Listening Program (Advanced Brain Technologies, 2010), for example, uses a schedule of exposure to acoustically modified classical music. No published reports of effectiveness are available as yet.

The results of the intervention studies reviewed here suggest that auditory processing can be changed, even at the level of the brainstem. However, some important points can be drawn from these studies. One is that interventions not designed to affect auditory processing are equally as effective as an intervention that is intended to change auditory processing. Thus, we are left knowing no more than we did about a causal relationship between auditory processing and language. It is possible that other aspects of the interventions used, such as their intensive nature and requirements for focused attention, led to improved outcomes, when such improvements were found. Another lesson is that electrophysiological changes do not necessarily result in behavioral changes, at least not on the time scale of a few months. A corollary to this result is the finding by Bishop and McArthur (2005) that many youths with SLI had abnormal cortical responses to pure tones despite adequate behavioral frequency discrimination. The imperfect correlation between electrophysiology and behavior highlights the difficulty of establishing the direction of causality between auditory processing and language.

**Future Directions**

As noted at the outset of this article, there is an intuitive sense that accurate auditory perception is essential for normal language development. However, it is crucial to remember that speech perception does not proceed in an exclusively bottom–up manner. We might imagine a strictly bottom–up model in which sounds are converted to neural signals that are relayed from the periphery, through the auditory nerve and brainstem, to subcortical structures and finally the auditory cortex, with smaller units being combined into larger units somewhere along the way. But as Rees (1973) pointed out, speech perception requires phonological, semantic, syntactic, and contextual knowledge throughout the process, and acoustic units do not correspond in straightforward ways to linguistic units. The research available at that time was unable to single out any auditory skill or set of skills that was essential for language or reading development.
As Rosen (2003) noted 3 decades later, that situation has changed little.

Have those 30 years been wasted? Certainly not. We have learned a great deal about the brain in general and the central auditory nervous system in particular, and our knowledge grows daily. The technology available to study the auditory system in action is rapidly improving. Still, the task of understanding “auditory processing” is extremely challenging. The central auditory nervous system is a magnificently intricate set of structures that subserves, among other functions, the amazingly complex speech perception and language comprehension systems. Audition, speech perception, and language processing occur in the context of a lifetime of experience and knowledge about language. Even if that lifetime is the mere 3 or 4 years of a preschooler, an immense amount of experience is put into play in every encounter with speech. Thus, there is not going to be a simple story about how auditory perception and language interact. In order for the story to be told in all its complexity, researchers coming from audiological, psychoeducational, and specific-disabilities perspectives, as well as researchers taking a neuroscientific approach, must find a way to communicate so that shared perspectives, as well as researchers taking a neuroscientific approach, must find a way to communicate so that shared constructs, methods, and goals can be identified—as well as constructs, methods, and goals that are distinct to each perspective. To the extent that researchers and clinicians can communicate clearly about their theories, hypotheses, and findings, the full story of auditory perception and language can be discovered through a rich combination of approaches from the fields of audiology, speech-language pathology, education, psychology, and neuroscience.

There is still a long way to go in developing a comprehensive theory of auditory processing that will guide the practice of SLPs and audiologists, as well as teachers, psychologists, and other professionals. I am confident that such a theory can and will be constructed, but in the meantime, here are a few questions that readers can ask when evaluating information about auditory processing.

- What is the author’s perspective: audiological, psychoeducational, specific disabilities, neuroscience, or a combination? How does this perspective shape the research questions, methods, and interpretation?
- If the author is making recommendations for practice, what are they based on: the research literature, the author’s own data, the author’s clinical experience, or the opinion of experts in the field?
- What population is the author talking about: children with APD, SLI, dyslexia, or a broader category such as language-learning problems or learning disability? How confident are you that your client(s) is similar to the author’s population?

These questions do not provide a checklist for identifying “good” or “bad” research, but they should help clinicians in organizing and evaluating the sometimes confusing literature on auditory processing.

REFERENCES


