Improving neural response to sound improves reading

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Despite intense focus on improving reading scores, the most recently released National Assessment of Educational Progress reported that only one in three fourth grade students in the United States read at or above a proficient level, a change of only 5% since 1992 (1). In PNAS, Hornickel et al. (2) review the growing body of evidence that links reading failure to auditory processing disorders. They report that a group of dyslexic children who used an assistive listening FM system for one school year during classroom instruction significantly increased their phonological awareness ($P < 0.001$) and basic reading scores ($P = 0.006$). These data support an increasing number of studies that demonstrate that rapid and significant improvement in reading can result from auditory interventions. Their study also provides physiological data that supports the hypothesis that children with language learning impairments, including dyslexia, respond inconsistently to the rapidly changing spectrotemporal acoustic cues in speech and that this response becomes more consistent after auditory intervention.

Listening plays an essential role in learning throughout life, ranging from learning to talk and interact with family and peers, to learning in the classroom, to maintaining good interpersonal and professional relationships. The majority of formal education is delivered aurally and, as such, learning in the classroom depends on good listening skills. Learning to read proficiently is highly dependent on fine-grain acoustic processing (3). To break the code for reading a child must become "phonologically aware" that words can be broken down into smaller units of sounds (phonemes) and that it is these sounds that the letters represent. Given the centrality that good listening skills play throughout life, including learning how to read, it is surprising how little we know about the biological and environmental factors driving individual differences in auditory processing or how auditory processing mechanisms interact with other neural mechanisms (such as attention and memory) that are foundational skills for learning.

Listening is what we do with what we hear. In individuals with auditory processing disorder (APD) there is a mismatch between peripheral hearing (which is typically normal) and the ability to interpret, discriminate, and sequence sounds (4). Despite normal peripheral hearing, many children with a wide variety of developmental learning disabilities (including attention-deficit/hyperactivity disorder, autism spectrum disorder, specific language impairment, and dyslexia) have concomitant APD, and there is considerable debate as to how separable these diagnoses are (5).

Despite the relationship between individual differences in listening skills and learning skills and the importance of good listening skills in the classroom, there is very little focus by educators on either assessment or training of listening skills in typically developing children or remediation of APD in children with developmental learning disabilities. This is likely the result of ongoing debate both in the clinical as well as research literature pertaining to whether specific auditory processing skills play a significant role in developmental learning trajectories, especially reading, and if so, whether they are amenable to intervention and remediation (5, 6).

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Auditory Intervention Improves Reading

In PNAS, Hornickel et al. (2) report that children with dyslexia show inconsistent electrophysiological response to speech sounds at the level of the brainstem and that using a classroom assistive listening FM systems leads to significant improvement in the consistency of this neural response coupled with improvement in phonological awareness and reading skills. They assessed the impact of use of a classroom FM system for 1 y on auditory neurophysiology and reading skills in children with dyslexia and compared them with a matched group of children with dyslexia in the same schools who did not use the FM system. They found that (*i*) FM system use reduced the variability of subcortical responses to sound, (*ii*) this improvement was linked to concomitant increases in reading and phonological awareness, (*iii*) the degree of subcortical response variability before FM system use predicted gains in phonological awareness, and (*iv*) improvement in neural response consistency was specific to the response to the formant transitions (rapid spectrotemporal changes) within speech syllables that characterize consonants but not to the acoustically steady-state vowel. The matched control group of children with dyslexia attending the same schools who did not use the FM system did not show any of these effects. These results demonstrate that assistive listening devices improve the neurophysiological representation of speech, specifically the rapid spectrotemporal components that are most vulnerable to noise. This latter finding is particularly interesting because it is formant transitions within speech syllables that have been shown in both behavioral and physiological studies to be most impaired in children with language and reading disorders (3, 7).

These data support a growing body of research suggesting that there may be a developmental continuum beginning in infancy that links individual differences in rapid auditory processing to individual differences in language development and subsequently to reading and other literacy skills. Benasich and colleagues have conducted prospective, longitudinal studies of infants born into families with or without a family history of language learning impairments. Using both behavioral and electrophysiological methods, they found that individual differences in nonverbal rapid auditory processing thresholds (specifically spectrotemporal processing in the time window important for processing formant transitions in speech) prospectively predict rate of language development and disorders in toddlers (8) and subsequently reading development in early elementary school children (9). These results also are consistent with studies that have demonstrated improved attention, listening, and reading skills in children after a variety of auditory training approaches. These range from musical training (10, 11), to neuroplasticity-based

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auditory training designed explicitly to improve dynamic auditory processing and attention (12, 13), to the use of clear speech (14) or speech that has been computer modified to selectively enhance the amplitude and duration of the most rapidly changing acoustic components (such as formant transitions) within ongoing speech (15, 16).

Help Them Hear It!

Cross-linguistic studies have shown that children with dyslexia are universally impaired in acquiring phonological awareness skills (17). Children who have inconsistent physiological response to the rapidly changing acoustic waveform of speech will have great difficulty establishing consistent and reliable neural representations of phonemes. As a consequence, they will struggle with the phonological awareness skills they need to break the code for reading. Hornickel et al. (2) suggest that assistive listening devices and other forms of auditory training enhance the signal-to-noise ratio and, in turn, increase the consistency of neural responses to the acoustics of speech. In this way auditory interventions give dyslexic children an opportunity to receive a reliable acoustic signal from which they can learn how to listen and modulate their attention to focus on the speech signal at precisely the level they need to learn to read.

Given the positive results presented by Hornickel et al. (2), coupled with many years of similar studies showing the benefit of a variety of auditory interventions for typical as well as impaired readers, why do schools not offer all children the benefit of FM systems in their classrooms? We would not think of presenting lectures at professional meetings without the speaker using a microphone. Why do we deny students the same benefit in their daily learning environment? The reason, to a large extent, is historical. Schools focus on teaching academic content, not on enhancing basic sensory, perceptual, and cognitive skills that form the building blocks for leaning, per se. When a child first begins to struggle in school, it initially shows up as difficult learning how to read. Teachers assume that children come to school with the basic auditory, visual, language, and listening skills they need to learn. As such, when a child struggles to learn to read, intervention generally focuses on providing more time and individual attention focused on reading, specifically phonological awareness skills. However, for children who are unable to process the rapidly changing acoustic cues within speech, and as a result have not been able to establish reliable neural representations of the phonemes in the language they are trying to learn to read, no matter how much extra time or individual attention they are given they will not be able to become aware of phonemes their brain has failed to represented clearly and consistently. Just as the child who is struggling to learn how to read because of visual problems needs glasses before reading instruction can be successful, struggling students with auditory processing problems need their auditory problems remediated. The results from Hornickel et al.'s study (2) show the clear benefits of including auditory intervention for struggling readers. They point out that by enhancing signal perception children can become more actively engaged in and positively reinforced by listening. Learning to listen reduces the cognitive burden of attending to the signal. The more proficient children become in learning to listen, the more capacity they have for listening to learn.

Unfortunately, for the most part neither educational assessment nor intervention for reading failure is based on scientific advances in neuroplasticity or an understanding of the basic neural mechanisms underlying good listening skills. Although teachers certainly recognize the relationship between poor listening and attention skills in children and learning difficulties, they generally are not aware of recent research showing that these skills are significantly modifiable. There is an increasing need for translational research with implications for education. However, there is an even more pressing need to explore new ways of increasing the rate of bidirectional information flow between educators and scientists pertaining to the science of learning.

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