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Perceptual organization of speech signals by children with and without dyslexia

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ABSTRACT

Developmental dyslexia is a condition in which children encounter difficulty learning to read in spite of adequate instruction. Although considerable effort has been expended trying to identify the source of the problem, no single solution has been agreed upon. The current study explored a new hypothesis, that developmental dyslexia may be due to faulty perceptual organization of linguistically relevant sensory input. To test that idea, sentence-length speech signals were processed to create either sine-wave or noise-vocoded analogs. Seventy children between 8 and 11 years of age, with and without dyslexia participated. Children with dyslexia were selected to have phonological awareness deficits, although those without such deficits were retained in the study. The processed sentences were presented for recognition, and measures of reading, phonological awareness, and expressive vocabulary were collected. Results showed that children with dyslexia, regardless of phonological subtype, had poorer recognition scores than children without dyslexia for both kinds of degraded sentences. Older children with dyslexia recognized the sine-wave sentences better than younger children with dyslexia, but no such effect of age was found for the vocoded materials. Recognition scores were used as predictor variables in regression analyses with reading, phonological awareness, and vocabulary measures used as dependent variables. Scores for both sorts of sentence materials were strong predictors of performance on all three dependent measures when all children were included, but only performance for the sine-wave materials explained significant proportions of variance when only children with dyslexia were included. Finally, matching young, typical readers with older children with dyslexia on reading abilities did not mitigate the group difference in recognition of vocoded sentences. Conclusions were that children with dyslexia have difficulty organizing linguistically relevant sensory input, but learn to do so for the structure preserved by sine-wave signals before they do so for other sorts of signal structure. These perceptual organization deficits could account for difficulties acquiring refined linguistic representations, including those of a phonological nature, although ramifications are different across affected children.

1. Introduction

Developmental dyslexia is a relatively common disorder that can evoke a significant toll on affected individuals in terms of career, behavior, and social satisfaction (Chapman, Tunmer, & Allen, 2003; Snowling, Muter, & Carroll, 2007; Terras, Thompson, & Minnis, 2009). Nonetheless, the mechanism underlying this disorder has remained elusive to identification. At

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one time it was thought to arise from visual disturbances, specifically problems affiliated with the recognition of written symbols (e.g., Hinshelwood, 1900; Orton, 1937; Stephenson, 1907). In the 1970s, however, a major shift in paradigm occurred when I.Y. Liberman, Shankweiler, and their colleagues at Haskins Laboratories revealed that children with dyslexia are poor at recovering and manipulating individual phonemic segments in the speech signal (e.g., I.Y. Liberman, 1973; Shankweiler & Liberman, 1972; Shankweiler, Liberman, Mark, Fowler & Fischer, 1979). With that discovery, dyslexia changed from being within the purview of a visual disorder to being seen as a problem related to the processing of spoken language.

The work of I.Y. Liberman and others actually grew out of basic research on the mechanisms that underlie speech perception that was being done by A.M. Liberman and colleagues at the Haskins Laboratories. Around the mid-twentieth century, the common wisdom was that speech signals are comprised of isolable units, known as phonemes. Because most speakers of a language are able to separate the speech they hear into strings of these units, it was natural to conclude that phonemes are present in the signal in transparent and serial fashion. In turn, these phonemes serve as the building blocks of all other linguistic structure, such as words and sentences – according to the common wisdom. In his book recounting the history of Haskins Laboratories, A.M. Liberman (1996) explains that one of the first goals of laboratory staff was to develop a reading machine for the blind. Based on the common view, scientists thought it would be a fairly straightforward task to uncover the acoustic correlates of phonemic segments, and invent a device that would translate letters on a page into series of acoustic elements, each designed with those correlates set to specify the intended phoneme. But it soon became evident that the task would not be so simple. The speech spectrograph was the technological device that revealed what would become the largely intractable problems facing speech perception researchers. This tool allowed scientists for the first time to display speech signals on time x frequency plots. The two major challenges to the common view (that phonemes are represented serially in the speech signal) became immediately apparent, and sometime later were described by Pisoni (1985) as the problems of segmentation and acoustic invariance. Both problems are illustrated in Fig. 1, showing spectrograms of the word *bug* spoken by a man and a child. The problem of segmentation is exposed by the fact that it would be impossible to draw lines perpendicular to the time axis indicating where one phoneme ends and the next begins. Regarding the problem of acoustic invariance, these spectrograms illustrate how different the acoustic structure of this word is for the two speakers.

These problems led A.M. Liberman and colleagues to propose that speech is a code, rather than a cipher (A.M. Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967). In a cipher, there would be clear and unique acoustic correlates to each phoneme. The term *code*, on the other hand, specifies that there is considerable lack of correspondence between the units to be recovered (the phonemes in this case) and the way they are represented in the medium (the acoustic structure in this case). This lack of transparency means that listeners are required to perform some kind of perceptual feat to extricate the phonemes, a process that was termed *decoding*. That terminology was later extended to the process of reading, where the translation from orthographic symbols to phonemes is known as decoding, and the major chore facing children learning to read is described as *breaking the code* (e.g., Shaywitz, 2005).

1.1. Problems breaking the code define developmental dyslexia

Not long after the discovery by I.Y. Liberman and colleagues, research was undertaken to try to identify the source of the problems facing individuals with dyslexia. One of the first findings from that work was that individuals with dyslexia have

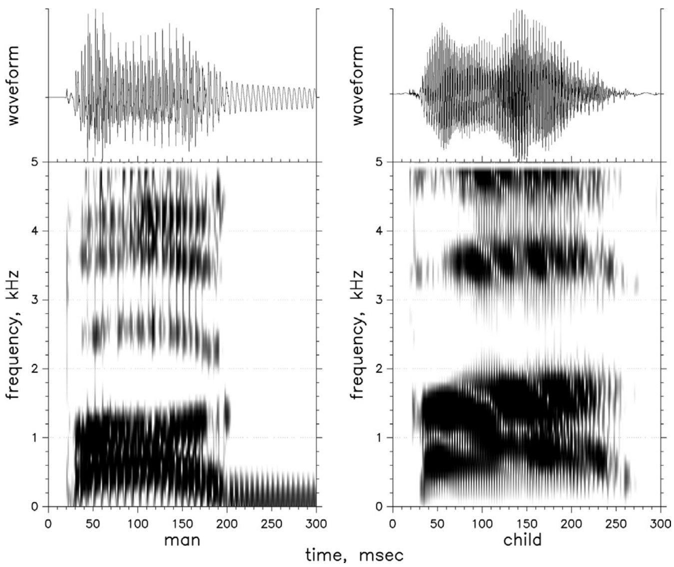

Fig. 1. Spectrograms of *bug* spoken by a man (left) and child (right).