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Auditory scene analysis in school-aged children with developmental language disorders

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ABSTRACT

Natural sound environments are dynamic, with overlapping acoustic input originating from simultaneously active sources. A key function of the auditory system is to integrate sensory inputs that belong together and segregate those that come from different sources. We hypothesized that this skill is impaired in individuals with phonological processing difficulties. There is considerable disagreement about whether phonological impairments observed in children with developmental language disorders can be attributed to specific linguistic deficits or to more general acoustic processing deficits. However, most tests of general auditory abilities have been conducted with a single set of sounds. We assessed the ability of school-aged children (7–15 years) to parse complex auditory non-speech input, and determined whether the presence of phonological processing impairments was associated with stream perception performance. A key finding was that children with language impairments did not show the same developmental trajectory for stream perception as typically developing children. In addition, children with language impairments required larger frequency separations between sounds to hear distinct streams compared to age-matched peers. Furthermore, phonological processing ability was a significant predictor of stream perception measures, but only in the older age groups. No such association was found in the youngest children. These results indicate that children with language impairments have difficulty parsing speech streams, or identifying individual sound events when there are competing sound sources. We conclude that language group differences may in part reflect fundamental maturational disparities in the analysis of complex auditory scenes.

1. Introduction

There is considerable controversy over the relationship between general auditory processing skills and language ability (Ramus et al., 2013). Developmental language disorders (DLDs), which include specific language impairment (SLI) and developmental dyslexia (DD), are defined by the absence of a clearly defined pathology (e.g., hearing loss or neurological disorders) in the face of an inability to use language with the same facility as age-matched peers. Many children with DLDs have persistent deficits in phonological processing (Briscoe et al., 2001). They have impaired ability to discriminate between speech sounds (Reed, 1989; Werker and Tees, 1987) and require larger spectral differences to differentiate phonemes than children with typical language development (TLD) (Elliot et al., 1989; Elliott and Hammer, 1988). Although ongoing research has failed to identify the etiologies of DLDs, it has spawned diverse hypotheses regarding the underlying causal factors. On one side of the continuing debate, DLDs are hypothesized to be due to a specific linguistic deficit of phonological processing, not generalizable to the acoustic elements of the speech sounds themselves (Bishop et al., 1999; Gatherole and Baddeley, 1993; Helzer et al., 1996; Mody et al., 1997; Nittrouer, 1999; Nittrouer et al., 2011; Ramus et al., 2003; Remez et al., 1994; Rosen, 2003; Rosen and Manganari, 2001; Schulte-Korne et al., 1999; Sharma et al., 2009; Snowling, 1998; Studdert-Kennedy, 2002).

On the other side, phonological processing deficits have been hypothesized to originate from a more general difficulty in perceiving acoustic information (Ahissar et al., 2000; Beattie and Manis, 2013; Benasich and Tallal, 2002; Benasich et al., 2002; Choudhury et al., 2007; Efron, 1963; Farmer and Klein, 1995; Hari and Renvall, 2001; Lubert, 1981; McAnally and Stein, 1996; McAnally and Stein, 1996; Nagarajan et al., 1999; Reed, 1989; Richardson et al., 2004; Tallal and Piercy, 1973a, 1973b; Tallal, 1980; Tallal et al., 1980, 1993, 1998; Wright et al., 2000; Wright et al., 1997). For example, it has been suggested that an inability to distinguish rapidly changing acoustic features at a normal rate impairs the ability to accurately represent the phonemic elements of the language, which in children with DLDs,

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may impede the normal development of spoken language (Stein and McAnally, 1995; Tallal and Piercy, 1973b). Further, individuals with language impairments often have 1) impaired ability to discriminate sound frequencies (Baldeweg et al., 1999; Hill et al., 2005; Mengler et al., 2005; McAnally and Stein, 1996; Nickisch and Massinger, 2009); 2) different auditory masking thresholds than controls (Montgomery et al., 2005; Hill et al., 2005); 3) poorer discrimination of sounds presented in rapid succession or briefly presented information (Ahissar et al., 2000; Benasich et al., 2002; Fazio, 1999; Tallal, 1976; Tallal and Piercy, 1973a; Tallal and Stark, 1981; Tallal et al., 1985, 1993; Wright et al., 1997); 4) difficulty with rise-time perception (Goswami et al., 2011); 5) difficulty with rhythm perception (Huss et al., 2011); 6) impaired ability to discriminate sequential sounds (Tallal and Piercy, 1973a); and, 7) poorer ability at reporting the order of sequential sounds (Tallal and Piercy, 1973b).

There has been considerable debate about this latter etiological hypothesis because general auditory processing deficits are not always found in children diagnosed with DLDs (Bishop et al., 1999; Helzer et al., 1996; Nittrouer et al., 2011). However, research continues to highlight difficulties of auditory perception in both SLI and DD (Catts, 1993; Catts et al., 2005; Stackhouse and Wells, 1997; Tallal, 2004; Bishop, 2007; Bishop and Snowling, 2004; Corriveau et al., 2007; Goulandris et al., 2000). The inability to empirically resolve the issue has hampered progress in understanding the role of auditory processing in observed phonological processing deficits of children with DLDs (Bailey and Snowling, 2002).

The current study approached the issue from a different perspective by exploring the relationship between phonological processing ability and auditory scene analysis in 7–15-year-old children with and without DLDs. Auditory scene analysis is a fundamental skill of the auditory system that facilitates the ability to perceive and identify sound events in the environment. It is the skill that allows us to select a voice in a crowded room or to listen to the melody of the flute in the orchestra. Auditory scene analysis is remarkable in that sound enters the ears as a mixture of all the sounds in the environment, from which mechanisms of the brain disentangle the mixture to integrate and segregate the input and provide neural representations that maintain the integrity of the distinct sources. If we were at a garden party, for example, we may hear the wind blowing, music playing, glasses clinking, and people who are talking. The different sources can be distinguished by multiple acoustic cues, such as the spatial location, the pitch, and the timbre (e.g., male vs. female voices). The multiple cues in the signal contribute to the identification of the individual streams (e.g., wind blowing), and strengthen the perception of stream segregation within the whole scene. What's interesting about understanding this skill in relationship to language impairments is the aspect of perceptual organization of sounds, when there are competing sound sources, which is common in everyday environments. The notion is that the ability to identify the order of within-stream events in complex environments is predicated on the sounds first being segregated (Sussman, 2005).

Additionally, there is evidence that speech perception requires fundamental sound processing mechanisms intrinsic to auditory scene analysis. Darwin (1981, 1984) demonstrated that only after partitioning sounds to streams were phonetic patterns heard. This indicates that phonological perception is dependent on the even more basic process of discriminating and segregating the acoustic signal into its constituent sound sources (Darwin, 2008). Thus, the ability to process the correct order of phonemes, a skill necessary to understand the speech stream, may be impaired by an inability to accurately segregate the acoustic signal into its constituent parts. Sussman (2005) found that auditory stream segregation processes precede within-stream event formation, which link or segregate successive within-stream elements together. This basic auditory processing mechanism is likely related to speech processing, providing additional support to this schema. Moreover, multiple reports have documented difficulties with stream segregation in adults with language impairments (Helenius et al., 1999; Petkov et al., 2005; Sutter et al., 2000). Although, there is no clear evidence that nonlinguistic auditory processing deficits cause language impairments, the presence of low level processing deficits in those with language impairments lends credibility to the hypothesis that accurate nonlinguistic auditory processing abilities are vital to typical speech development.

To assess auditory scene processing abilities, the frequency distance between two sets of sounds was used to either promote segregation (when the sounds were far apart in frequency) or promote integration (when near in frequency). Music provides an ‘everyday’ example in which frequency separation of tones serves as a cue for segregation. Composers have long known about this remarkable ability of the auditory system. The alternation of tones along the frequency dimension can promote the perception of one or more distinct streams or melodies, such that from one sound source, one timbre (e.g. a guitar), notes played sequentially across a range of frequencies result in the experience of multiple sound streams occurring simultaneously, and converging harmonically (e.g., listen to Francisco Tárrege's guitar piece *Recuerdos de la Alhambra*).

There were two main goals of the study. The first goal was to assess the ability of children to parse auditory input and perceive sound streams. This involved reporting how a mixture of sounds were perceived as one integrated or two segregated streams in one experiment, and selectively attending to one of the frequency streams to perform a simple sound discrimination task in the other experiment. Thus, Experiment 1 examined the global perception of the sounds, where Experiment 2 assessed the ability to detect a tone feature change occurring within a single stream. Here we aimed to gain a better understanding of whether the acuity for processing complex scenes in typical language development would be similar in children who have been identified with DLDs. We hypothesized that children with phonological processing deficits would require larger frequency separations to hear two streams or to detect deviant stimuli compared to children with TLD. The second goal was to determine whether the presence of phonological processing impairments would be predictive of stream segregation performance. Here, we evaluated the relationship of this fundamental but complex auditory scene processing skill to phonological processing ability, as measured on standardized tests of phonological (e.g., CTOPP). We hypothesized that phonological processing ability would predict stream segregation performance.

2. Methods

2.1. Participants

Seventy-eight children (39 females) ranging in age from 7 to 15 years ($M = 11/SD = 2$) were paid for their participation in the study. Participants were recruited by flyers posted in the immediate medical/research community and in local area schools. Children gave written assent and their accompanying parent gave written consent

Table 1
Participant information.

Typical language development				Developmental language disorder		
Age group	7–9 years	10–12 years	13–15 years	7–9 years	10–12 years	13–15 years
$n = 78$	9	16	14	9	15	15
M/F	2/7	5/11	6/8	4/5	12/3	10/5