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Electrophysiological correlates of rapid auditory and linguistic processing in adolescents with specific language impairment

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ABSTRACT

Brief tonal stimuli and spoken sentences were utilized to examine whether adolescents (aged 14;3–18;1) with specific language impairments (SLI) exhibit atypical neural activity for rapid auditory processing of non-linguistic stimuli and linguistic processing of verb-agreement and semantic constraints. Further, we examined whether the behavioral and electrophysiological indices for rapid auditory processing were correlated with those for linguistic processing. Fifteen adolescents with SLI and 15 adolescents with normal language met strict criteria for displaying consistent diagnoses from kindergarten through the eighth grade. The findings provide evidence that auditory processing for non-linguistic stimuli is atypical in a significant number of adolescents with SLI compared to peers with normal language and indicate that reduced efficiency in auditory processing in SLI is more vulnerable to rapid rates (200 ms ISI) of stimuli presentation (indexed by reduced accuracy, a tendency for longer RTs, reduced N100 over right anterior sites, and reduced amplitude P300). Many adolescents with SLI displayed reduced behavioral accuracy for detecting verb-agreement violations and semantic anomalies, along with less robust P600s elicited by verb-agreement violations. The results indicate that ERPs elicited by morphosyntactic aspects of language processing are atypical in many adolescents with SLI. Additionally, correlational analyses between behavioral and electrophysiological indices of processing non-linguistic stimuli and verb-agreement violations suggest that the integrity of neural functions for auditory processing may only account for a small proportion of the variance in morphosyntactic processing in some adolescents.

1. Introduction

Children with specific language impairment (SLI) exhibit significant difficulties in areas of language such as morphosyntax and lexical development (e.g., Leonard, 1998; McGregor, Newman, Reilly, & Capone, 2002). Although deficits in language are the primary and most obvious characteristics for many of these children, it is becoming increasingly clear that more subtle deficits in cognitive processes essential for language learning may contribute to these patterns of marked language difficulties. Several different cognitive processes have been shown to be atypical in children with SLI and it is possible that the cumulative effects of these fundamental weaknesses have a profound impact on these children's ability to acquire language in a typical manner. Earlier studies indicate that some of these primary cognitive processes may involve auditory processing, including rapid temporal processing of non-linguistic stimuli (e.g., Basu, Krishnan, & Weber-Fox, 2010; Benasich & Tallal, 2002; Friedrich, Weber, & Friederici, 2004; McArthur, Atkinson, & Ellis, 2009; McArthur & Bishop, 2005; Neville, Coffey, Holcomb, & Tallal, 1993; Tallal, 2000; Wible, Nicol, & Kraus, 2004, 2005), selective auditory attention (Stevens, Sanders, & Neville, 2006), speed of processing for non-linguistic as well as linguistic information (Miller, Kail, Leonard, & Tomblin, 2001; Miller, Leonard, & Finneran, 2008; Miller et al., 2006), and processing capacity/working memory (Ellis Weismer, Evans, & Hesketh, 1999; Ellis Weismer, Plante, Jones, & Tomblin, 2005; Leonard et al., 2007).

Much of the work characterizing SLI has been conducted with preschool and young school-age children (e.g., Leonard, 1998). However, studies indicate that SLI is often longstanding (e.g., Tomblin, Freese, & Records, 1992) and older children and adolescents with a history of SLI are at risk for reading disability (Catts, Bridges, Little, & Tomlin, 2008). Even though the overt symptoms of SLI change with age, some of the same details of language can persist as problems into adolescence and beyond. For example, many adolescents with SLI show an insensitivity to certain grammatical morpheme errors

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during sentence processing tasks (Leonard, Miller, & Finneran, 2009; Miller et al., 2008).

Given that auditory processing constitutes a fundamental ability, it would be natural to assume that deficits in auditory processing were responsible for the morphosyntactic deficits that are also observed in the SLI population. However, recent evidence from twin studies suggests that the relationship between auditory processing and language ability may be less direct. In one study, Bishop et al. (1999) administered a rapid auditory processing task employing non-linguistic stimuli as well as a nonword repetition task to monozygotic and same-sex dizygotic twins. Weaknesses on the nonword repetition task showed high estimates of group heritability. On the other hand, weaknesses in rapid auditory processing were more influenced by shared environment than by genetic factors. In a subsequent twin study, Bishop, Adams, and Norburby (2006) found that weaknesses in "grammatical computation" also had a genetic basis, yet this type of heritable ability was separable from ability on nonword repetition tasks. Central to the grammatical computation problem was a limitation in the use of verb-related grammatical forms such as third person singular *–s* and past tense *–ed*, and difficulty understanding the relations expressed in particular morphosyntactic constructions. Despite the distinct sources of these types of problems, Bishop and her colleagues found that many children exhibited deficits in more than one of these areas. These findings raise the possibility that weaknesses observed on measures of auditory processing and those seen on measures of grammatical ability are not causally related. Rather, any correlations observed between these different measures will be rather modest, and attributable to the comorbidity of these two types of weaknesses in the SLI population, one arising from a shared genetic source (grammatical computation deficit) and one showing low heritability (auditory processing deficit). We examine this issue in the present study.

The current study utilizes electrophysiological measures of both non-linguistic auditory processing and linguistic processing. Event-related brain potentials (ERPs) provide a functional measure of neural activity with very fine temporal resolution (Nunez, 1995) and allow the examination of specific operations of non-linguistic and linguistic processing (e.g., Friederici, 1997; Hagoort, Brown, & Groothusen, 1993; King & Kutas, 1995; Kutas & Hillyard, 1980; Mangun & Hillyard, 1991; Neville, Nicol, Barss, Forster, & Garrett, 1991; Osterhout & Holcomb, 1992; Polich & Kok, 1995; Weber-Fox, Hart, & Spruill, 2006). In this study, we focus on adolescents with SLI and their typically developing same-age peers. Although SLI is a longstanding problem, it is not known whether the conditions originally responsible for the language deficit are still present. For example, an early neuromaturational delay could lead to an initial period of slow language development such that by adolescence, age-level language ability has not yet been achieved. However, it is not clear if, at this point, neurological evidence of the language deficit still remains. Examination of the adolescents' underlying brain functions as reflected in ERPs can be extremely informative in this regard and therefore ideal for capturing group differences that may not be evident from behavioral measures alone. ERPs provide another level of analysis that may be more sensitive to differences in the processing abilities, and further, can shed light about underlying aspects of processing (e.g., post-lexical syntactic re-analysis, ease of lexical access). ERPs, combined with behavioral measures, are utilized in the current study to more closely examine neural functions underlying: (1) non-linguistic auditory processing in an odd-ball paradigm that elicits both early perceptual cortical potentials related to sensory processing (N100, P200) and later cognitive potentials indexing updates in working memory (N200, P300); (2) morphosyntactic processing, using verb-agreement violations in natural speech, that elicit a well-known late positivity (P600 or syntactic positive shift) thought to index recognition of a morphosyntactic violation and the listener's attempts to recover the meaning of a sentence (e.g., Osterhout & Holcomb, 1992; Osterhout & Mobley, 1995); and (3) lexical/semantic processing, utilizing unexpected verbs in natural speech, that elicit an N400 thought to index ease of lexical access and integration (e.g., Federmeier, Segal, Lombrozo, & Kutas, 2000; Kutas & Hillyard, 1980). Below we summarize findings from earlier electrophysiological studies of children with SLI.

1.1. Non-linguistic auditory processing and SLI

One of the first electrophysiological studies of brain activity in children with SLI employed both non-linguistic and linguistic stimuli (Neville et al., 1993). For the non-linguistic auditory processing condition, ERPs were elicited by brief tonal stimuli in children aged 8–10 years. ERPs elicited by brief tones with shorter interstimulus intervals (ISIs) resulted in reduced N100 amplitudes in the children with SLI who also performed poorly on a rapid auditory sequencing task. Further evidence that brain functions for non-linguistic auditory processing may be atypical for children with SLI was reported for subgroups of children with SLI who demonstrated atypical early cortical potentials (N1–P2–N2) elicited by tonal pairs (McArthur et al., 2009; McArthur & Bishop 2004, 2005). A study of cortical potentials in children with SLI aged 10–19 years and matched controls suggested that the neural responses of the group with SLI were less mature for tonal pairs presented with short ISIs (Bishop & McArthur, 2004). A recent study of auditory processing in children with SLI (aged 7–17) indicates that spectral information of consonant–vowel (CV) syllables is also processed less accurately by this population and further, that amplitudes of N2–N4 peaks for these stimuli correlated with the severity of language deficits (Čeponienė, Cummings, Wulfeck, Ballantyne, & Townsend, 2009).

Recent electrophysiological evidence indicates that differences in auditory processing in children with SLI are not limited to cortical regions. A recent study of children with and without SLI aged 4–10 years revealed atypical brainstem neural responses for temporal auditory processing for the children with SLI (Basu et al., 2010). Measures of the sustained frequency following response (FFR) elicited by fast tonal sweeps revealed degraded FFR phase-locked neural activity in seven of the 10 children with specific language impairment (SLI). In addition, the onset auditory brainstem responses (ABRs) of these children had longer latencies for waves II and V and an enhanced prolongation of wave III at higher click rates, indicating a greater susceptibility to neural adaptation (Basu et al., 2010). These results were consistent with findings of atypical brainstem and cortical auditory processes in children with more generally defined language impairment and language-based learning deficits (Wible et al., 2004, 2005). The findings from these electrophysiological studies indicate that neural functions for non-linguistic auditory processing may be less efficient in at least a subgroup of children with SLI.

Recent findings also suggest that auditory processing skills may be correlated with later language ability. In a behavioral study of infants that employed a head turn paradigm, Benasich and Tallal (2002) found that early deficits in discriminating rapid auditory cues are predictive of language delays at age 3 years. In addition, electrophysiological measures of auditory processing related to duration discrimination for syllables at 4 months of age were found to correlate with language impairments at age 4 years (Weber, Hahne, Friedrich, & Friederici, 2004). Thus, there are strong indications that fundamental auditory processing abilities may play a key role in later language ability and deficits in auditory processing may contribute to language impairments (Benasich & Tallal, 2002; Weber et al., 2004).