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Verbal and nonverbal semantic processing in children with developmental language impairment☆

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ABSTRACT

In an effort to clarify whether semantic integration is impaired in verbal and nonverbal auditory domains in children with developmental language impairment (a.k.a., LI and SLI), the present study obtained behavioral and neural responses to words and environmental sounds in children with language impairment and their typically developing age-matched controls (ages 7–15 years). Event-related brain potentials (ERPs) were recorded while children performed a forced-choice matching task on semantically matching and mismatching visual–auditory, picture–word and picture–environmental sound pairs. Behavioral accuracy and reaction time measures were similar for both groups of children, with environmental sounds eliciting more accurate responses than words. In picture–environmental sound trials, behavioral performance and the brain's response to semantic incongruency (i.e., the N400 effect) of the children with language impairment were comparable to those of their typically developing peers. However, in picture–word trials, children with LI tended to be less accurate than their controls and their N400 effect was significantly delayed in latency. Thus, the children with LI demonstrated a semantic integration deficit that was somewhat specific to the verbal domain. The particular finding of a delayed N400 effect is consistent with the storage deficit hypothesis of language impairment (Kail & Leonard, 1986) suggesting weakened and/or less efficient connections within the language networks of children with LI.

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1. Introduction

Developmental language impairment (LI), a.k.a. Specific Language Impairment (SLI), is characterized by language deficits with relative sparing of other cognitive domains (Bishop, 1997; Leonard, 1997). From the earliest stages of language development, children with LI appear to have lexical and semantic deficits and there is evidence suggesting that these deficits may become even more marked with age (e.g., Hayes, 1992; Stothard, Snowling, Bishop, Chipchase, & Kaplan, 1998). Children with LI produce first words at an older age (Trauner, Wulfeck, Tallal, & Hesselink, 1995) and they have smaller vocabularies (Bishop, 1997) than children with normal language development. In experimental word-learning contexts, children with LI learn fewer new words than typically developing children (e.g., Rice, Buhr, & Nemeth, 1990; Rice, Oetting, Marquis, Bode, & Pae, 1994). In naming tasks, they are often slower, and less accurate, than their typically developing peers (e.g., Katz, Curtiss, & Tallal, 1992; Lahey & Edwards, 1996; Leonard, Nippold, Kail, & Hale, 1983; Miller, Kail, Leonard, & Tomblin, 2001). Moreover, these children have difficulties in retrieving lexical items (see Messer & Dockrell, 2006 for a review), and their most frequent naming error type is semantic mislabeling (e.g., Lahey & Edwards, 1999; McGregor & Appel, 2002; McGregor, Newman, Reilly, & Capone, 2002).

Various hypotheses have been put forward to account for the semantic and lexical deficits in LI. Kail and Leonard (1986) proposed the *storage deficit hypothesis*, according to which naming (i.e., lexical) problems in children with LI are a byproduct of delayed language development. These authors proposed that the lexicons of children with LI resemble those of younger typically developing children in that only sparse information about lexical concepts has been mapped, and associations between related concepts are yet to be strengthened. Such a weakness of inter-connectedness of semantic representations is said to be apparent during word retrieval (e.g., McGregor & Appel, 2002; McGregor et al., 2002). Consistent with this idea, McGregor and Appel (2002) and McGregor et al. (2002) observed that for the items that children with SLI made naming errors on, they also drew with fewer features, provided less information for during definition tasks, and comprehended with less accuracy.

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While a lexical–semantic deficit in LI might be most apparent and best measurable in the language domain, it is possible that it extends to the nonverbal domain as well (e.g., Karmiloff-Smith, 1998). For example, one account of LI implicates problems with auditory perception at a preverbal level (e.g., Čeponienė, Cummings, Wulfeck, Ballantyne, & Townsend, 2009; Marler, Champlin, & Gillam, 2002; Tallal & Piercy, 1974, 1975; Tallal, Stark, & Mellits, 1985a,b). Evidence suggests that children with LI might have problems encoding and representing both verbal *and* complex nonverbal auditory information (Kraus et al., 1996; Uwer, Albrecht, & von Suchodoletz, 2002; McArthur & Bishop, 2005). It is presently under debate as to whether individuals with LI demonstrate a generalized auditory semantic processing deficit that spans both the verbal and nonverbal domains, or whether their semantic integration deficit is specific to the verbal domain.

One way to test whether or not semantic processing of verbal and nonverbal information follows the same path in typically developing children and those with LI is to compare behavioral and neural responses to spoken words with those elicited by environmental sounds. Speech and environmental sounds are two different types of auditory information that can serve the same purpose: They convey meaningful information involving people and environmental events. Thus, our perception and cognition of both types of auditory information may proceed in a similar fashion (for more a more detailed discussion see Cummings, Čeponienė, Dick, Saygin, & Townsend, 2008; Cummings et al., 2006). Consistent with this idea, recent behavioral evidence has suggested that word and sound processing change similarly during infancy (Cummings, Saygin, Bates, & Dick, 2009), typical development (Borovsky, Saygin, Cummings, & Dick, in preparation), aging (Dick et al., 2007; Saygin, Dick, & Bates, 2005), and in brain lesion patients (Saygin, Dick, Wilson, Dronkers, & Bates, 2003).

An unpublished behavioral study from our research group has compared how children with LI and their age-matched controls ($n = 28$ in each group, mean age = 12.3 years) process words and environmental sound (Borovsky et al., in preparation). In this study, children had to select one of two pictures that matched an auditory label—either a spoken word (noun + verb-ing, e.g., "piano playing") or an environmental sound (e.g., brief melody from a Bach fugue). Children with LI exhibited slower reaction times than their controls to both the word and environmental sound labels. Moreover, in the children with LI, robust correlations were found across reaction times in the two auditory domains. These results are consistent with the notion of sparse semantic representations and/or weak connections between semantic representations in children with LI in both the verbal and nonverbal domain (e.g., Kail & Leonard, 1986; Lahey & Edwards, 1996; Montgomery, 2002; Windsor & Hwang, 1999). Alternatively however, a more general, non-specific mechanism (e.g., motor, memory, attention, or cognitive slowness) might also account for such a uniform pattern.

Indeed, although overall word and meaningful nonlinguistic sound processing appear to yield similar behavioral indices, the neural processing routes involved in verbal vs. meaningful nonverbal processing are likely to be different. One measure that allows identification and assessment of distinct stages of neural processing is event-related brain potentials (ERPs) that reflect the precise timing of synchronous events in the neural encoding of stimuli. Therefore, they can reveal subtle differences in the processing of words and environmental sounds that may not be detected using behavioral measures. Specifically, all semantic stimuli (auditory or visual, orthographic or pictorial) elicit a N400 *peak* in the ERPs (e.g., Kutas & Federmeier, 2000; Kutas & Hillyard, 1980, 1983). The ERP region around the N400 peak (not just the peak itself) is enhanced in negative voltage when the stimulus does not match an expectancy set by a fore-going message. This enhancement, termed the N400 *effect*, is used to assess semantic integration across the semantic components of a message since its timing and magnitude correlate with the degree of semantic incongruency. ERP difference waves (i.e., semantic mismatch minus semantic match trials) are the standard way to evaluate the semantic mismatch N400 effect.

Using a cross-modal picture–sound match/mismatch paradigm, earlier we have compared the N400 effect elicited by words and environmental sounds in groups of healthy pre-adolescent, adolescent, and adult participants (Cummings et al., 2006, 2008). We observed that in college age adults, the N400 effect elicited by words peaked later than the N400 effect elicited by corresponding environmental sounds (Cummings et al., 2006). The latency differences between the verbal and nonverbal stimuli were explained by suggesting that words undergo an additional, lexical processing loop before their semantic nature can be accessed, whereas environmental sounds may directly activate the corresponding semantic representations, corresponding with an earlier peak latency of the N400 effect.

In a subsequent study of typically developing children (Cummings et al., 2008), we found no major maturational changes in the N400 effect between the pre-adolescent and adolescent children. However, as compared with adults, children demonstrated significant maturational changes including longer latencies and larger amplitudes of the N400 effect. Interestingly, these developmental differences were driven by stimulus type: The environmental sound N400 effect decreased in latency from adolescence to adulthood, while no age effects were observed in response to words. Thus, it appears that the semantic processing of single words is established by 7 years of age, but the processing efficiency of environmental sounds continues to improve into adulthood. This effect was explained by the predominance of verbal processing in everyday life, especially given that words are the substrates of thoughts; they are actively produced and listened to during interpersonal communication, as well as from various media sources. It was further suggested that because of the predominance of verbal input in the environment, early in development *both* verbal and nonverbal sounds might pass through the lexical loop. Once high-order and high-efficiency automatic subroutines come on-line, the need for the environmental sounds to pass through the lexical loop decreases, leading to reduced N400 latencies (Cummings et al., 2008).

While no electrophysiological (ERP) study has broached the verbal vs. nonverbal question in children with LI, one recent study with learning-disabled[2] and healthy adults ($n = 16$ in each group, ages 18–36 years) did address this issue. Plante, van Petten, & Senkfor (2000) presented their participants with visual–auditory word pairs (e.g., typed word "apple"–spoken word "orange") and picture–sound pairs (e.g., picture of a bird–sound of a birdsong). Both the typical and learning-disabled college students showed robust context N400 effects in response to the mismatching picture/sound pairs. However, the learning-disabled students exhibited a statistically smaller context N400 effect, as compared with that in their controls, in response to the *word* pairings. Thus, Plante et al. (2000) provided some evidence that college-aged adults with learning impairments are specifically impaired in the processing of verbal items. However, the verbal trials in their study consisted from a printed word paired with a spoken word, introducing a possible confound between lexical and orthographic processing.

[2] As stated by Plante et al. (2000), a learning disability diagnosis was defined as involving a deficit in one or more of the components of language, which negatively impacts academic performance including listening, speaking, reading, and writing. A designation of a learning disability is closely related to, and overlaps with, other diagnostic categories including developmental dyslexia and specific language impairment.