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Abnormal functioning of the left temporal lobe in language-impaired children

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ABSTRACT

Specific language impairment is associated with enduring problems in language-related functions. We followed the spatiotemporal course of cortical activation in SLI using magnetoencephalography. In the experiment, children with normal and impaired language development heard spoken real words and pseudowords presented only once or two times in a row. In typically developing children, the activation in the bilateral superior temporal cortices was attenuated to the second presentation of the same word. In SLI children, this repetition effect was nearly nonexistent in the left hemisphere. Furthermore, the activation was equally strong to words and pseudowords in SLI children whereas in the typically developing children the left hemisphere activation persisted longer for pseudowords than words. Our results indicate that the short-term maintenance of linguistic activation that underlies spoken word recognition is defective in SLI particularly in the left language-dominant hemisphere. The unusually rapid decay of speech-evoked activation can contribute to impaired vocabulary growth.

1. Introduction

Children with specific language impairment (SLI) fail to acquire age-appropriate language skills even though their development otherwise seems to be proceeding normally. Although the pattern of difficulties shows considerable variation between individuals, typically both language comprehension and production are affected (Bishop, 1997, 2006; Joanisse & Seidenberg, 1998). SLI children clearly deviate from the expected pattern of language development already around 2–3 years of age when most children show rapid progress in the mastery of receptive and expressive language skills. After initial diagnosis, children with SLI commonly receive years of speech therapy targeted on their special needs. During elementary school these children may study in special classes or need extra tutoring in mainstream classes (Stothard, Snowling, Bishop, Chipchase, & Kaplan, 1998). Difficulties are often relatively persistent, as young adults with a childhood history of language development continue to possess a limited vocabulary and weak verbal short-term memory (Helenius, Parviainen, Paetau, & Salmelin, 2009; Stothard et al., 1998; Tomblin, Freese, & Records, 1992; Whitehouse, Line, Watt, & Bishop, 2009). Word learning and verbal short-term memory abilities may further be related as it has been proposed that adequate temporary storage of phonological structures is an important prerequisite for learning new vocabulary (Adams & Gathercole, 2000; Baddeley, Gathercole, & Papagno, 1998; Gathercole & Baddeley, 1989, 1993).

Consistent with the evidence that temporary memory mechanisms have an important role in establishing lexical knowledge, behavioral studies (Gaskell & Dumay, 2003; Leach & Samuel, 2007; Storkel, Armbruster, & Hogan, 2006; Storkel & Hoover, 2010) and recent neurocomputational approaches (Davis & Gaskell, 2009) suggest that two distinct types of processes operate at different time scales during word learning. The rapid online processes take place while the words are perceived followed by more protracted processes operating over a period of hours or even days after the first hearing of the word. During the early phase of word acquisition, novel word has to be detected from the speech stream, and further, an initial representation of the novel word

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must be created. After these online operations, the novel word form must be integrated into the existing lexicon of established memory traces (Storkel & Hoover, 2010; Storkel et al., 2006). In a recent study by Bishop, Barry, and Hardiman (2012), children with SLI did poorly overall when asked to overtly repeat novel polysyllabic nonwords. When the same nonwords were presented for repetition several times in succession, the SLI children showed a trend for slower learning compared with typically developing children. Nonetheless, their level of learning was retained when tested after a delay of 1 h. Tentatively, these findings may be interpreted to suggest that particularly the online processes operating while perceiving and learning new words are affected in SLI children.

In the cortex, short-term memory mechanisms are associated with the phenomenon referred to as repetition suppression, i.e. the reduction of neuronal responses when the same stimulus is presented repeatedly (Desimone, 1996). Neurophysiological studies have shown reduced response amplitudes for recurring spoken words around 200–600 ms after the word onset (Bentin & Peled, 1990; Helenius et al., 2009; Marinkovic et al., 2003; Nagy & Rugg, 1989; Rugg, 1995). In this same time window, cortical responses also show sensitivity to lexical/semantic processes underlying word recognition, reflected as the so-called N400 event-related potential (ERP) and its neuromagnetic counterpart N400m (Bentin, McCarthy, & Wood, 1985; Helenius et al., 2002, 2009; Kutas & Hillyard, 1980; Rugg, 1985; for recent reviews, see, e.g., Kutas & Federmeier, 2011; Lau, Phillips, & Poeppel, 2008). The onset phase of the N400m response, between 200 and 400 ms in adults, has previously been suggested to reflect lexical activation (Helenius et al., 2002, 2009), i.e., activation of all possible word candidates that are recruited while listening to spoken input (Marslen-Wilson, 1987; Marslen-Wilson & Tyler, 1980). If the word is presented again after a short delay the effects of the earlier encounter still persist, leading to reduced activation of the neural population involved in word perception. This finding is in accordance with the notion that the neural network supporting speech processing is able to maintain the activation for some period of time (Cowan, 1988; MacDonald & Christiansen, 2002). ERP studies have reported repetition suppression for spoken words when the lag between the first and second presentation was 3–20 s (Minamoto, Tachibana, Sugita, & Okita, 2001).

The N400/N400m response can be evoked by all potentially meaningful word-like auditory stimuli such as pseudowords. The N400/N400m activation is longer-lasting and stronger to pseudowords than real words (Friedrich, Eulitz, & Lahiri, 2006; Helenius et al., 2009; O'Rourke & Holcomb, 2002). This has been interpreted to reflect an extended period of lexical recruitment for stimuli that have no match in the lexicon.

The effects of word repetition and lexicality (word vs. pseudoword) on speech-evoked N400m responses have been investigated in adults with a childhood diagnosis of language and reading impairments (Helenius et al., 2009). These magnetoencephalographic (MEG) recordings demonstrated a weak, bilateral repetition effect in adults with SLI. The lexicality effect in the left hemisphere was abnormally weak in SLI adults. Thus, the neural online processes involved in word recognition and short-term maintenance were defective in adults with a childhood history of language impairment.

Damage to the left hemisphere can cause substantial language problems. Normal development and functioning of the left hemisphere is likely to be critical also for language learning. The neural structures engaged in linguistic processing in language-impaired children are currently quite poorly characterized. The few fMRI studies conducted on SLI children and adolescents have reported reduced left lateralization in core language areas during complex comprehension and production tasks (Badcock, Bishop, Hardiman, Barry, & Watkins, 2012; de Guibert et al., 2011) or normal lateralization but hypoactivation in the left hemisphere in frontal, parietal or temporal areas (Ellis Weismer, Plante, Jones, & Tomblin, 2005; Hugdahl et al., 2004). Further, those children that had been late in using short spoken sentences in their communication (late talkers), have demonstrated significantly less activation in the left superior temporal gyrus than early talkers in tasks including speech and print (Preston et al., 2010). The mechanism by which these observed anomalies contribute to impaired word learning in language impaired individuals remains unknown.

Neurophysiological recordings have revealed profound developmental changes in the auditory cortical responses from childhood to adolescence (Albrecht, Suchodoletz, & Uwer, 2000; Bishop, Hardiman, Uwer, & von Suchodoletz, 2007; Holcomb, Coffey, & Neville, 1992; Takeshita et al., 2002). Generally, these studies have reported decreases in response latencies and emergence of earlier and more transient components with age. In a recent MEG study (Parviainen, Helenius, Poskiparta, Niemi, & Salmelin, 2011), the sequence of activation in the superior temporal cortex evoked by very simple verbal and non-verbal sounds was strikingly different between 7- to 8-year-old children and adults. In adults, the most prominent response elicited by simple tones is a transient activation peaking at around 100 ms (N100/N100m), whereas in children these same tones elicited a long-lasting response at around 250 ms. In the right hemisphere, the sequence in children additionally displayed an adult-like N100m response, suggesting that the right hemisphere matures faster than the left hemisphere.

Holcomb et al. (1992) tracked the developmental changes associated with the N400 response. Subjects aged 5–26 years listened to sentences that ended either with a highly expected or a semantically inappropriate word. The N400 response evoked by the inappropriate word displayed markedly reduced latency and decreased amplitude with age. Sabisch, Hahne, Glass, von Suchodoletz, and Friederici (2006) recorded ERP responses to correct sentences and semantically inappropriate sentences in 10-year-old SLI and control children. The control children showed an N400 amplitude difference to correct vs. inappropriate sentences, but in children with SLI no difference was detected. The interpretation was that SLI children have difficulties in processing words even when they are semantically primed. As the response to anomalous words was abnormally weak in the SLI children, this study remained uninformative on possible latency or amplitude differences of the N400 response between SLI and unimpaired children.

In the current MEG experiment, we conducted an in-depth analysis of the properties of the N400m response in normally developed children and in children with impaired language development. In particular, we aimed to clarify whether SLI is characterized by abnormal overall maturation of the N400m response or whether the language impairments are manifested in the functional properties of the N400m response. The functioning of the left and right temporal areas was probed by spoken real words and pseudowords (lexicality effect) presented only once or recurring immediately after the first presentation (repetition effect). In adults, the activation peaking at around 400 ms in the left and right superior temporal cortex is attenuated by stimulus recurrence and differentiates between words and pseudowords (Helenius et al., 2009). These responses and stimulus-induced modulations are also stronger in the left, language-dominant hemisphere than in the right hemisphere. Compared with adults we expect to see increased latency and amplitude of the N400m response in normally developed children as in previous ERP studies (Holcomb, Coffey, & Neville). If SLI is characterized by a developmental delay in the maturation of these responses, increase in the latency and amplitude of the N400m response should be even more pronounced in language-impaired than in control children. Furthermore, we predicted that the N400m response would be modulated by stimulus repetition and lexicality in normal children but in SLI children