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Neural competition as a developmental process: Early hemispheric specialization for word processing delays specialization for face processing

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ABSTRACT

Little is known about the impact of learning to read on early neural development for word processing and its collateral effects on neural development in non-word domains. Here, we examined the effect of early exposure to reading on neural responses to both word and face processing in preschool children with the use of the Event Related Potential (ERP) methodology. We specifically linked children's reading experience (indexed by their sight vocabulary) to two major neural markers: the amplitude differences between the left and right N170 on the bilateral posterior scalp sites and the hemispheric spectrum power differences in the γ band on the same scalp sites. The results showed that the left-lateralization of both the word N170 and the spectrum power in the γ band were significantly positively related to vocabulary. In contrast, vocabulary and the word left-lateralization both had a strong negative direct effect on the face right-lateralization. Also, vocabulary negatively correlated with the right-lateralized face spectrum power in the γ band even after the effects of age and the word spectrum power were partialled out. The present study provides direct evidence regarding the role of reading experience in the neural specialization of word and face processing above and beyond the effect of maturation. The present findings taken together suggest that the neural development of visual word processing competes with that of face processing before the process of neural specialization has been consolidated.

1. Introduction

Learning to read is an essential cultural experience for children. Evidence abounds that early exposure to reading has many positive effects (Olson, 1994; Whitehurst & Lonigan, 1998). Surprisingly, we have limited knowledge about its impact on early neural development for word processing (Ben-Shachar, Dougherty, Deutsch, & Wandell, 2011; Brem et al., 2010; Maurer, Brem, Bucher, & Brandeis, 2005; Maurer et al., 2006; Parviainen, Helenius, Poskiparta, Niemi, & Salmelin, 2006), and its collateral effects on neural development in non-word domains (Dehaene & Cohen, 2007; Dundas, Plaut, & Behrmann, 2012).

To bridge this gap, we specifically compared the impact of early reading experience on neural development of word and face processing in preschool children. One reason to do so is that among the many skills young children must acquire, the skills to read and process faces are amongst the most prominent. Deficiencies in either of these domains are associated with debilitating impairments (e.g., dyslexia, autism). Further, studies using electroencephalography (EEG) show that when seeing words and faces, children produce morphologically similar event-related potentials (ERPs); these similar responses also undergo a comparable developmental course until adolescence when neural responses to words and faces become differentiated (Brem et al., 2006, 2009; Itier & Taylor, 2004).

A growing number of neuroimaging studies with adults revealed that the left mid-fusiform region, which has been labeled as the Visual Word Form Area (VWFA) (Cohen et al., 2000, 2002; McCandliss, Cohen, & Dehaene, 2003), plays an important role in the processing of written words. Different from the left-lateral activation of written word processing, a right (sometimes bilateral) ventral occipito-temporal area, including parts of the middle fusiform gyrus, is more strongly activated by faces than other objects (Kanwisher, McDermott, & Chun, 1997; Puce, Allison, Asgari, Gore, & McCarthy, 1996; Tarkiainen, Cornelissen, & Salmelin, 2002). Perhaps related to these regions, many electrophysiological studies have identified a negative event-related

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potential component, known as N170. N170 can be readily recorded over the left posterior scalp sites when skilled readers are presented with visual words in different scripts. The N170 for alphabetic words at the posterior electrodes in the left hemisphere is greater for word processing than for processing of symbol strings or line-drawings of common objects (Bentin, Mouchetant-Rostaing, Giard Echallier, & Pernier, 1999; Mercure, Dick, Halit, Kaufman, & Johnson, 2008; Maurer et al., 2005; Rossion Joyce, Cottrell, & Tarr, 2003). The N170 response for Chinese characters was especially stronger than that of line-drawings in the left hemisphere (Cao, Li, Zhao, Lin, & Weng, 2011). Also, the real Chinese characters evoked greater N170 in the left posterior region than false-characters and stroke combination (Lin et al., 2011). A recent study revealed a more robust pattern of left-lateralization N170 for Chinese character: the left N170 but not the right N170 differentiated Chinese characters from control stimuli (Zhao et al., 2012). Thus, this left-lateralized N170 effect appears to be robust across different types of scripts and may reflect the specialized processing of words in skilled readers.

A similar N170 component has been found for face processing in adults as well. At about 170 ms post-stimulus presentation, negative event-related potentials are larger for faces than for many other categories of stimuli, especially in the right hemisphere (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Carmel & Bentin, 2002; Mercure et al., 2008). This ERP is highly sensitive to faces; even the simplest hint of a face, such as a face outline or even just a line-drawing of a single component (e.g. eyes), can readily elicit N170 to an extent similar to that elicited by a real, complete face image (Bentin et al., 1996; Henderson, McCulloch, & Herbert, 2003; Taylor, Itier, Allison, & Edmonds, 2001a).

Collectively, the results from neural imaging and EEG studies with adults suggest that different kinds of visual expertise may have differential neural bases in the left or right VOT. Word processing may be more localized in the left hemisphere, whereas face processing may be more localized in the right hemisphere. Presumably, this differential hemispheric specialization for faces and words is a consequence of the decade-long acquisition of face and word processing expertise during childhood.

Studies using electroencephalography (EEG) consistently show that the development of electrophysiological responses to word processing gradually emerges during childhood. Maurer and colleagues (Maurer et al., 2005) investigated the ERP responses to written German words in kindergarten children who had no reading experience (average age of 6.5 years). They found that the word–symbol difference of the N170 effect was absent in children with low letter knowledge but marginally significant in children with high letter knowledge (the N170 latency was between 164 ms and 269 ms). When the same group of children was in the 2nd grade (average age of 8.3 years), and had received formal reading training for one year, a larger N170 was observed for letter strings than symbol strings at both the group and individual levels, but this N170 effect was not yet left-lateralized (Maurer et al., 2006). Cao et al. (2011) found an increased and left-lateralized N170 response for Chinese words compared to line drawings among 7- to 13-year-old children. This N170 latency was found to decrease with age. For 7 year olds the latency was approximately 236 ms, whereas in 9 year olds it was approximately 228 ms. Additionally, Brem and colleagues found a left lateralized tuning effect of N170 for visual words, compared to symbols, in 10-year-old children. In addition to a similar decrease in latency, this effect also decreased in amplitude throughout adolescence and continued to decrease into adulthood (Brem et al., 2006, 2009). Thus, although the exact timing of left lateralization for visual word N170 appears to differ in different scripts, both studies in Chinese and non-Chinese children showed highly similar developmental pattern (Cao et al., 2011).

With regard to face processing, by 3 months of age, the N290, the component of similar morphology to the adult N170, showed adult-like patterns of enhanced amplitude to faces relative to visual noise images containing the amplitude spectra of a face (de Haan, Pascalis, & Johnson, 2002; Halit, Csibra, Volein, & Johnson, 2004). With increased age, this ERP component occurs earlier in latency and begins to resemble the adult N170 (e.g., right lateralized). For example, gray scale photographs of faces evoked N170 in 4- to 5-year-olds with a latency period lasting between 230 and 300 ms (Taylor, Edmonds, McCarthy, & Allison, 2001b). Schematic pictures of faces evoked N170 in 4-year-olds and 8- to 10-year olds with a latency period of about 240 ms, and about 220 ms respectively (Henderson et al., 2003). Nevertheless, the N170 response to faces in 14-year-olds still has a smaller amplitude and a longer latency period than that of adults, regardless of whether the stimuli are schematic faces or photographs (Itier & Taylor, 2004; Taylor, McCarthy, Saliba, & Degiovanni, 1999). The existing evidence taken together suggests that, like those associated with word processing, specific electrophysiological responses to faces emerge early but remain immature and continue to develop and become more adult-like throughout childhood.

As made clear by the above literature review, there exist considerable similarities as well as differences between the neurodevelopment of visual word processing and that of face processing. In particular, the neural markers (e.g., N170) for both word and face processing seem to develop in a similarly protracted time course. Further, the neural activities associated with word and face processing seem to be highly similar during the early stages of development, and then, with increased age, become differentiated in terms of lateralization. Word processing becomes increasingly left lateralized, whereas face processing tends to become more right lateralized, particularly in the ventral occipital–temporal cortex (VOT).

This early similarity and later differentiation may reflect interactions between the two developing neural systems as a result of learning to read. One possibility is that reading experience facilitates the development of both the word and face neural systems, leading to their eventual differentiation (*the facilitation hypothesis*). Alternatively, due to neural competition, reading experience may facilitate the development of the word system but concurrently delay that of the face system (*the competition hypothesis:* Dehaene & Cohen, 2007). Perhaps, similarities between children's neural responses to words and faces are simply coincidental. Thus, children's neural responses to faces should neither be related to reading experience or neural responses to words (*Null hypothesis*).

We directly tested the three possibilities in 5- and 6-year-olds prior to formal schooling through examining ERP responses to words and schematic faces. To disentangle the effect of age-related maturational factors and reading experience, we capitalized on the considerable variability in preschoolers' reading experience. Without formal schooling, some preschoolers merely know a handful of written words, whereas others have a large sight vocabulary (Whitehurst & Lonigan, 1998). We specifically linked children's reading experience (indexed by sight vocabulary, i.e. the words that appear frequently in most reading materials children encounter and could be recognized by children) to two major neural markers. The first was the amplitude differences between the left and right N170, a negative ERP obtained about 170 ms after the onset of word or face stimuli, located in the bilateral posterior scalp sites. Evidence shows that in the mature brain, the word N170 is more left-lateralized whereas the face N170 is more right-lateralized (Bentin et al., 1996; 1999; Cao