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Single and compound logographic Kanji words elicit distinct early neurophysiological responses: ERP evidence from fluent and naïve Kanji readers

Madison A. Niermeyer, Emily Miller, Yuko Tamaoki, Eve Wiggins, Courtney Stevens*

Willamette University, 900 State Street, Salem, OR, 97301, United States

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ABSTRACT

While the N170 to printed words in alphabetic scripts is consistently left-lateralized, the available evidence on logographic scripts is much less consistent. Here, we examined the extent to which use of single-character (e.g.,目) versus compound-character (e.g., 目玉) words in a logographic script could account for differences in the laterality of early neural responses in fluent readers. Participants included both fluent Kanji readers (n = 17) as well as naïve Kanji readers (n = 19), in order to separate out differences due to low-level physical differences between stimuli. While fluent Kanji readers showed a larger amplitude N170 overall relative to naïve readers, this expertise effect was bilateral, rather than left-lateralized as is common with alphabetic scripts. Trend-level differences in laterality were observed at the earlier P1 response, which has not been extensively examined in previous studies of logographic script reading, with naïve readers only tending to show right-lateralization across both single- and compound-character Kanji words. Both participant groups differentiated single and compound Kanji words, but contrary to predictions these effects were bilateral and evident during different stages of processing in each group. Among naïve readers, compound Kanji elicited a larger amplitude P1, suggesting influence on early perceptual processing, whereas among fluent readers, these differences were not apparent until the later N170. Taken together, findings from the present study indicate that low-level visual characteristics and perceptual expertise interact during the specialization of neural circuits for print, with implications for theories of lateralization of neural circuits for print.

1. Introduction

Previous event-related brain potential (ERP) studies indicate that fluent readers distinguish printed words in a known script from other visual stimuli within the first 200 msec of neural processing (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Kim, Yoon, & Park, 2004; Maurer, Brandeis, & McCandliss, 2005; Maurer, Zevin, & McCandliss, 2008; Wong, Gauthier, Woroch, DeBuse, & Curran, 2005). The most robust findings focus on the effects of orthographic status on the N170, a negative deflection in the ERP waveform over occipito-temporal sites peaking ~170 msec after stimulus presentation. Several studies report *absolute left-lateralization* of the N170 to printed words in known script, with a larger amplitude N170 over left-hemisphere compared to right-hemisphere electrode sites (e.g., Maurer et al., 2008; Proverbio, Cok, & Zani, 2002). Other studies report *relative left-lateralization* of the N170, with a larger amplitude response over left but not right hemisphere electrode sites when the N170 to printed words in a known script is compared to the response to low-level control stimuli, such as images, symbols, or false-font strings (e.g., Bentin et al.,

* Corresponding author.
E-mail address: cstevens@willamette.edu (C. Stevens).

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1999; Maurer et al., 2005). Together, these studies have contributed to the prevailing view that early neural processing of printed words is strongly left-lateralized (Carreiras, Armstrong, Perea, & Frost, 2014; Schlaggar & McCandliss, 2007).

While the reason for left-lateralization of early neural responses is unclear (Dien, 2010), the phonological mapping hypothesis (Maurer & McCandliss, 2007) proposes that left hemisphere specialization for reading reflects the automatic mapping of visual forms to left-lateralized spoken language systems. Under the phonological mapping hypothesis, a left-lateralized N170 would be expected cross-linguistically, as all printed scripts map symbols onto spoken words. In support of this, left-lateralization of the N170 has been documented across a large number of different scripts including English, French, German, and Korean (Bentin et al., 1999; Kim et al., 2004; Maurer et al., 2005). However, all of these scripts are classified as either alphabetic or syllabic, meaning they map symbols to individual speech sounds or syllables. In contrast, results from studies of logographic scripts including Chinese characters and Japanese Kanji, which can map visual symbols to units of meaning, generally with fewer clues to or less regular links from form to phonology, are less consistent. Whereas some previous studies of logographic scripts report left-lateralization of the N170 (Horie et al., 2012; Lin et al., 2011; Maurer et al., 2008; Wong et al., 2005; Zhang et al., 2011) others report bilateral N170 responses (Chen, Bukach, & Wong, 2013; Kim et al., 2004; Liu & Perfetti, 2003; Zhang et al., 2011) (see also Koyama, Kakigi, Hoshiyama, & Kitamura, 1998 for bilateral early magnetoencephalograhic responses). As well, while limited in its temporal precision, functional magnetic resonance imaging (fMRI) studies converge in suggesting the logographic script processing in occipitotemporal regions is bilateral, as opposed to left-lateralized as observed for alphabetic scripts (Nakamura, Oga, et al., 2005; Perfetti, Nelson, Liu, Fiez, & Tan, 2010; Tan, Laird, Li, & Fox, 2005).

Together, these findings suggest that early neural responses to logographic words are less consistently left-lateralized compared to alphabetic or syllabic scripts. Interestingly, there is direct evidence to support this hypothesis. For example, while Maurer et al. (2008) reported left-lateralization of the N170 to logographic words, this study also compared the *degree* of left-lateralization among different script types. Maurer and colleagues found that the degree of N170 left-lateralization for Japanese Kanji tended to be less robust than for syllabic Hiragana words. Similarly, Horie et al. (2012) included both Kanji and Kana words as stimuli. Although the authors did not directly compare the laterality of the N170 across stimulus type, examination of Table 1 suggests that the magnitude of left-lateralization is more than twice as large for Kana versus Kanji words (less than 1 μV for high and low frequency Kanji words, and greater than 2 μV for Kana words). However, the reason for this difference between script types is unclear.

One possibility is that the use of different types of logographic words across studies influences patterns of early lateralization. For example, in both Japanese Kanji and Chinese, words can be represented by single characters ("single character" words) or by two or more character compounds ("compound character" words). In Kanji, for example, the word for "eye" (目) is a single-character word, whereas the Kanji word for "eyeball" (目玉)/medama/, is a two-character compound, which is composed of the Kanji characters "目"/me/, meaning "eye," and also "玉"/tama/, meaning "round object" (Morton, Sasanuma, Patterson, & Sakuma, 1992). Both single and compound Kanji words are common in the Japanese writing system, with compound character words representing approximately 70% of words in most Kanji dictionaries (Kess & Miyamoto, 1999; Tamaoka & Hatsuzuka, 1998). Interestingly, while different ERP studies have generally used either single- or compound-logographic words as stimuli, to date no study has examined whether the neural responses to these types of words differ systematically.

However, single- and compound-character words likely place different demands on early neural processing. Beyond mere low-level differences in the physical stimulus of single and compound Kanji words (discussed below), fluent readers may approach single and compound character words differently. In particular, reading a compound character word may be more similar to reading a word in an alphabetic or syllabic script, as both involve sequential processing of different components of the word – separate characters in one case, and separate letters or letter combinations in the other. Although a simplification, it has been proposed that sequential processing and/or the analysis of higher spatial frequency information places greater demands on the left hemisphere, whereas holistic processing and/or the analysis of lower spatial frequency information places greater demands on the right hemisphere (e.g., Flevaris, Bentin, & Robertson, 2011, 2010; Evans, Shedden, Hevenor, & Hahn, 2000; Hsaio, Cipollini, & Cottrell, 2013; Lamb, Robertson, & Knight, 1990; Van Kleek, 1989). As well, single-character Kanji words often have less phonological determinism, meaning the same single Kanji words could be pronounced in many possible ways depending upon context. Although compound-character Kanji words may also have several possible phonological readings, the number of readings tends to be more constrained or even limited to a single reading. Thus, the processing demands of a script could drive early neural activity to be either left or right lateralized, depending upon the nature of the script, and, further, different types of words within a script might exhibit different patterns of cerebral lateralization.

Under this proposal, compound logographic words may be more likely to engage analysis of smaller sub-units within the word stimulus and/or engage obligatory or automatic phonological processing. This would lead to the prediction that in comparison to single character logographic words, compound character words would place greater demands on the left hemisphere, resulting in more consistent left-lateralized early neural responses for compound character words. This proposal fits well with existing behavioral evidence suggesting a left visual field (right hemisphere) advantage for processing single-character logographic words, and the reverse pattern for compound-character words (see Hatta, 1978; Kess & Miyamoto, 1999; Paradis, Hagiwara, & Hildebrandt, 1985). Previous behavioral studies also suggest that preferential engagement of the right hemisphere for character-based scripts may occur more commonly when task demands require physical matching or attention only to graphemic form, with left-hemisphere dominance becoming more likely when tasks require phonological or semantic processing (Hatta, 1979; Kess & Miyamoto, 1999). Indeed, it could be that single character Kanji, which often have many possible phonological readings, are more likely to engage visual processing strategies, whereas compound character Kanji words, which typically have few possible or only a single phonological reading, may be more likely to automatically engage left-hemisphere phonological systems (Hatta, 1978).

Interestingly, if the earlier ERP literature on logographic script processing is reinterpreted in light of these behavioral studies, a