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Top-down modulation of early print-tuned neural activity in reading

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ABSTRACT

Fast neural tuning to print has been found within the first 250 ms of stimulus processing across different writing systems, indicated by larger N1 negativity in the ERP to words (or characters) compared to control stimuli, such as symbols. However, whether print tuning effects can be modulated by task demands at early stages of visual word recognition is still under debate. To further explore this issue, an ERP study in Chinese was conducted. Familiar, high-frequency, left/right-structured Chinese characters and unfamiliar, stroke number-matched symbols (Korean characters) were used as stimulus conditions. While viewing the characters and symbols, 20 native Chinese speakers performed three tasks: delayed naming, repetition detection, and blue color detection. Results from occipito-temporal and whole map analyses suggest that the influence of task on print tuning changes throughout the N1. Accordingly in the N1 onset, a print tuning main effect was found, with a stronger N1 to words than symbols, irrespective of task. In the N1 offset, a print-by-task interaction reflected a more negative N1 to symbols than words in both delayed naming and color detection, but not in the repetition detection. After the N1 an N2 was observed with task and condition main effects at the whole map level. Taken together, the current study provides evidence that neural tuning to print is modulated by task demands already within the first 250 ms, suggesting that early visual-orthographic processing may be less automatic than it was thought, and the possible top-down modulation may be much faster than it was previously assumed.

1. Introduction

Fluent reading ability is based on the rapid recognition of visual words. As has been revealed by eye-tracking studies, the average fixation on a word lasts less than 250 ms and skilled readers are able to read 250 words per minute (Dimigen et al., 2011). Such a high reading speed requires fast and efficient neural brain processes that allow word recognition. Event-related potential (ERP) studies have consistently identified the N1 (or N170) component as a robust marker of visual word recognition. The N1 component occurs between around 120 and 280 ms after stimulus onset, with a negativity at occipito-temporal electrodes and a positivity at fronto-central electrodes. The peak occurs around 140–180 ms in adults (Eberhard-Moscicka et al., 2015; Maurer et al., 2005). Generally speaking, visual word recognition relies on two different kinds of information sources: (1) surface properties, such as word form; (2) lexico-semantic properties, such as word frequency (Hauk et al., 2006). Considering the above two rough types of information sources for visual word recognition, N1 sensitivity can be classified into two kinds: print tuning N1 and N1 sensitivity to lexical properties (Okumura et al., 2014).

1.1. N1 print tuning

N1 (or N170) print tuning is indicated by larger sensitivity to words/characters compared to control stimuli, such as symbol strings (Maurer et al., 2006). This N1 effect is considered as a neurophysiological marker for visual specialization for print, which could also be referred to as word form effect or coarse neural tuning for print (Brem et al., 2006; Maurer et al., 2006).

N1 print tuning has been reported for different writing systems, including Chinese (Xue et al., 2008; Zhao et al., 2012). It has been suggested that N1 print tuning may be more left-lateralized in alphabetic languages than in logographic languages, such as Chinese (Maurer et al., 2008; Yum et al., 2011). However, recent studies on print tuning in Chinese revealed mixed results. While some studies indeed found a right-lateralized or bilateral topography (Xue et al., 2008), other studies found a left-lateralized topography (Zhao et al., 2012). Moreover, left-lateralization of N1 print tuning in alphabetic languages was not always robust (Maurer et al., 2005). These results suggest that while N1 print tuning can be found across different writing systems, its lateralization may not be an as distinct characteristic of a particular writing system as previously thought.

Coarse neural tuning for print has been proposed to be an index of

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reading expertise, as revealed by cross-linguistic and developmental studies (Eberhard-Moscicka et al., 2015; Maurer et al., 2008; Wong et al., 2005). For instance, Japanese-English bilinguals showed a left-lateralized N1 increase to familiar Kana and Kanji words compared to native English monolinguals (Maurer et al., 2008). Developmentally, N1 sensitivity for print was absent in illiterate kindergarten children, but developed rapidly in school (Maurer et al., 2006), or even after a short reading training in kindergarten (Brem et al., 2010).

Despite the consensus that print tuning N1 reflects accumulated experience with familiar visual words, notably, most of these studies commonly used symbol strings as control stimuli that were not closely matched for low-level stimulus features with print (Brem et al., 2005; Maurer et al., 2006). Moreover, the few studies conducted using visually well-matched control stimuli (e.g., characters combined with strokes and false font strings) have yielded less robust results, especially in adults (Eulitz et al., 2000; Wong et al., 2005; Xue et al., 2008; Zhao et al., 2014). Similarly in Chinese, robust print tuning effect were found in studies using visually distinct control stimuli (Qin et al., 2016), but only small and less reliable effects were found with more closely matched control stimuli (Xue et al., 2008). With closely matched control stimuli, print tuning seems to be more prominent in the early part of the N1. In a recent study by Eberhard-Moscicka et al. (2016), fluent adult readers showed larger early N1 sensitivity to words than well-matched false font strings, while in the late part of N1 responses to false font seems to be larger than to words over the right hemisphere (Eberhard-Moscicka et al., 2016). Clearly, additional studies are required to investigate the print tuning effect when control stimuli were visually well-matched with print.

Several reasons for these mixed results of print tuning with more closely matched stimuli were proposed, including, but not limited to, developmental stage of reading, (Eberhard-Moscicka et al., 2015; Maurer et al., 2006), experimental parameters (e.g., writing systems and presentation duration) (Xue et al., 2008), as well as task demands which may introduce potential influence from phonological and/or lexical semantic processing (Yang et al., 2012). Among these, modulation of task demands on print tuning remains obscure, as mainly implicit word-processing tasks, such as repetition or color detection tasks, were used in previous studies (Appelbaum et al., 2009; Okumura et al., 2014). Thus, less clear is how print processing will be affected when performing explicit word-processing tasks. Nevertheless, the assumption of a potential important role of task demands in modulating surface word form processing is supported by literature about task effects on processing of lexical semantic properties.

1.2. N1 sensitivity to lexical properties and task modulation of processing lexico-semantic properties

Concerning lexical-semantic properties, word frequency is a well-known psycholinguistic variable, which is sensitive to earlier stages of lexical access (Hauk and Pulvermüller, 2004). A large number of studies have explored word frequency effects across different writing systems by employing different tasks (explicit: Hauk and Pulvermüller, 2004; Zhang and Wang, 2014; implicit: Grainger et al., 2012). In these studies, low frequency words consistently elicited larger N1 negativity compared to high frequency words, presumably reflecting the difficulty of which low frequency words access the corresponding lexical representations (Brysbaert et al., 2011). Robust findings of word frequency effects have led to a traditional view that earlier stages of lexical access are automatic and sensory-driven without modulation of tasks. However, over the last several decades, this traditional view has been criticized, as some studies showed that word frequency effects can be influenced by task demands (Chen et al., 2015; Strijkers et al., 2015). For instance, Strijkers et al. (2015) directly compared the brain's electrophysiological response to word frequency by employing two different tasks with the same stimuli. One was a semantic categorization task, which explicitly requires linguistic processing, the other one was a color detection task, where conscious linguistic processing is not necessary. Results showed that, robust word frequency effects occurred as early as 150 ms after stimulus onset in the semantic categorization task, but only later at around 220 ms in the color categorization task. These findings indicate that even the earlier stages of lexical access are affected by task requirements (Strijkers et al., 2015).

1.3. The present study

Given the convincing evidence that the early stage of access to lexico-semantic properties of a word is modulated by different task demands, it seems important to investigate whether the initial access to surface properties (e.g., word form) is also task-dependent. Moreover, considering the previously reported results that only the early part of the N1, but not the late part of the N1, was sensitive to the comparison between print and closely matched false font (Cohen et al., 2000), it seems also important to understand the onset and/or offset of the potential task modulations of surface print property processing under the context of well-manipulated control stimuli.

To our knowledge, only few fMRI studies to date have addressed these issues. For example, Yang et al. (2012) directly compared responses to stimuli that varied parametrically in their wordlikeness while performing an explicit lexical decision task and an implicit symbol detection task (Yang et al., 2012). The results showed that print tuning was only observed in the lexical decision task, but not in the symbol detection task, suggesting that task effects do influence coarse neural tuning for print. However, results from such fMRI studies were rather limited, as critical early orthographic processing could not be distinguished from late reentrant activation due to the low temporal resolution (Dale et al., 2000). Thus, time-sensitive techniques like EEG are crucial to precisely capture the temporal dynamic of task effects on coarse neural print tuning.

Combining the documented distinct word frequency effects between different tasks within 250 ms and converging evidence from fMRI studies about task effects on sensitivity to print, we assume that, task modulation on early print sensitivity may also occur within 250 ms.

In sum, the main goals of the present study were thus to explore: (1) whether early stages of print sensitivity processing can be modulated by task demands, and if so, (2) how these task effects would unfold within the early stages of print processing during word recognition. With respect to these two questions, the current ERP study compared the brain's responses to print in a task which involves explicit linguistic processing of stimuli, a task where no linguistic processing is required, and a task which requires participants to detect repeated stimuli from trial to trial. Moreover, to control well for low-level stimulus features, Korean characters were selected as contrast to Chinese characters, because both have rectangular shape and consist of strokes. Based on previous literature, we hypothesized that if task demands can modulate print tuning effects at early stages of visual word recognition, then we should find interactions of task and word-like sensitivity at earlier time segments within 250 ms.

2. Methods

2.1. Participants

Data from twenty right-handed, native Mandarin speakers (6 males, between 18 and 45 years old) are presented in this paper. All subjects had no reading disabilities and had normal or corrected-to-normal vision. Data from 4 additional subjects were excluded from the analysis due to low signal-to-noise ratios and from 2 additional subjects due to excessive eye blinks. Written consent forms were presented to participants before recording began. After the study, each participant received cash compensation.