On the Deployment of Spatial Attention to Parafoveal Chinese Characters: An Event-Related Potential Investigation

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Abstract

Using the event-related potential (ERP) technique and a visual search paradigm, the current study tested whether asymmetries in attention allocation policy between the two visual hemispheres may be the cause of previously reported asymmetries in reading parafoveal Chinese characters. Participants categorized eccentrically displayed color-defined items as Chinese character or non-character while ignoring contralaterally displayed distractor characters. The ERP time-locked to the onset of the array of characters showed an N2pc component. Critically, the N2pc was comparable in amplitude at left and right posterior electrode sites. These results suggest that attention is necessary for reading parafoveal Chinese characters. However, the absence of hemispheric asymmetries in attention deployment to left and right target characters suggests that differences in attention allocation policy between the two hemispheres are unlikely to be the root cause of overt performance asymmetries in reading parafoveal Chinese characters. The dynamics of spatial attention deployment in reading parafoveal Chinese characters are discussed.

Keywords**:** Chinese characters, Spatial attention, Parafoveal processing, Event-related potentials, N2pc.

1. Introduction

A well-established finding in the reading literature is that processing of English-like words displayed in the right visual field (RVF) is often faster and more accurate than processing of words displayed in the left visual field (LVF; e.g., Ellis, 2004; Nicholls & Wood, 1998; Siéroff & Riva, 2011). Two main accounts for this RVF advantage (RVFA) have been proposed (e.g., Siéroff, Dahman, & Fagard, 2012). One account revolves around the acquisition of specific scanning habits during the development of reading skills. In left-to-right scripts, such as the Latin alphabet, a word displayed in the RVF can be reached rapidly through left-to-right scan, while a slow right-to-left scan is required for a word displayed in the LVF (Bryden, 1961; Heron, 1957). This account has basically been abandoned following demonstrations of RVFA in right-to-left scripts, albeit of reduced magnitude compared with that found in left-to-right scripts. This has been shown to be the case for Arabic (Eviatar & Ibrahim, 2004), Hebrew (Babkoff & Faust, 1988), and Urdu (Adamson & Hellige, 2006). A different account posits that RVFA emerges from the structural asymmetry of neural structures involved in processing verbal items. This structural account hinges on the well-established direct connection between RVF stimuli and language-specific brain areas predominantly located in the left hemisphere (LH; e.g., Bradshaw, Nettleton, & Taylor, 1981; Hunter & Brysbaert, 2008; Kimura, 1966). According to this account, words displayed in the LVF must be transferred via the caudal portion of the corpus callosum to language-specific areas in the LH for dedicated processing. In support, Hunter and Brysbaert (2008) found that participants exhibiting a clear RVFA in picture-naming and word-naming tasks were left-cerebral dominant for language, whereas participants with no such advantage — or no LVFA — showed either bilateral activation, or were right-cerebral dominant for language.

The mechanism of RVFA for words is still under debate, and two popular interpretations posit that reading asymmetries, rather than a by-product of the neural organization of areas supporting the reading system, can be ascribed to inter-hemispheric asymmetries in the control of visual attention (Kinsbourne, 1970; Mondor & Bryden, 1992). The attentional bias account (Kinsbourne, 1970) posits that reading asymmetries can be ascribed to hemispheric asymmetries in the control of visual attention. Specifically, a linguistic task is held to engage preferentially the LH for attentional control. Consequently, more attentional resources are allocated to the RVF, resulting in faster and more efficient processing of words displayed in this visual hemifield. The attentional advantage account (Mondor & Bryden, 1992) posits instead that different word processing strategies exist in the RVF and LVF. The RVF advantage for words occurs because RVF words are processed in parallel (or “automatically”), requiring little or no attention, whereas LVF words require serial (or “attention demanding”) processing.

The role of attention in modulating the reading efficiency of parafoveal words is consensually supported by two classes of behavioral findings. In the spatial cueing paradigm and visual half-field presentation, a parafoveal word is preceded by a spatial cue that indicates the upcoming target’s location (i.e., a validly cued condition) or a non-target location (i.e., an invalidly cued condition). The cueing effect is defined as the difference between the validly and the invalidly cued conditions and is taken as an index of the influence of spatial attention on performance. Of import, cueing effects have been reported to be either smaller when the cue precedes words displayed in the RVF rather than the LVF (Ducrot & Grainger, 2007; Gatheron & Siéroff, 1999), or even reduced to nil in a subset of studies (Mondor & Bryden, 1992; Nicholls &Wood, 1998). In the visual word search paradigm, a simultaneous distractor is presented in the visual hemifield opposite to a target word. In these circumstances, the distractor have been shown to exert a generally larger interfering effect on recognizing words displayed in the LVF than in the RVF (Siéroff et al., 2012; Siéroff & Riva, 2011). Both the attentional bias and attentional advantage hypotheses can explain the smaller cueing and distractor interference effects on the RVF target than that on the LVF target, and the latter has recently been shown to provide a more convincing explanation of the reduction of cueing effects in the RVF (Luo, Proctor, Dell'Acqua, & Li, 2015).

The possible involvement of inter-hemispheric asymmetries in the deployment of spatial attention to eccentrically displayed words has also been explored using electroencephalography and the event-related potential (ERP) approach. Contrary to the hypothesis of an asymmetrical bias in the allocation of spatial attention determining a RVFA for visual words, no ERP studies have so far provided evidence for asymmetries in amplitude/latency of a component that is held to reflect the dynamics of spatial attention allocation to eccentric words, namely, N1 (e.g., Kornrumpf & Sommer, 2015). Cohen, Dehaene, et al. (2000) found that on the left inferior temporal electrode, where a slightly delayed N1 peaked, the relative voltage was more negative for RVF than LVF words and nonwords. In this study, a symmetrical ERP pattern was also reported for right inferior temporal electrodes. Similar results were reported by Ben Itzchak, Babkoff and Faust (2007).

This type of late-N1 ERP modulations in response to laterally displayed stimuli are akin to modulations reflected in a different ERP component with a slightly postponed time course, namely, N2pc, a consensual indicator of attentional selectivity (Luck & Hillyard 1994; Eimer, 1996). The N2pc — an increment in negativity recorded at occipito-parietal electrodes contralateral to target information relative to ipsilateral electrodes — onsets usually at about 170–180 ms post-stimulus, and peaks between 220 and 250 ms (e.g., Wascher, 2005; Woodman & Luck, 2003). The latency of N2pc depends on a number of factors, among which the relative saliency of target and/or distractors. Reducing distractor saliency or increasing target saliency is notoriously effective in making spatial attention shifts to a target stimulus more rapid. Rapid shifts of attention are usually associated with an anticipated onset of N2pc (Casiraghi, Fortier-Gauthier, Sessa, Dell'Acqua, & Jolicœur, 2013; Schneider, Beste, & Wascher, 2012; Wascher & Beste, 2010). N2pc has been hypothesized to reflect primarily the re-entrant influence of activity in frontal regions on early visual processing taking place in lateral portions of the intraparietal and intraoccipital sulci (IPS and IOS, respectively) and infero-temporal (IT) visual areas (e.g., Hopf et al., 2000; Scalf, Dux, & Marois, 2011).

Prior attempts at using N2pc to investigate the deployment of visual attention in reading have already provided some hints about the lack of asymmetries in deploying attention to either of two laterally displayed words. Dell'Acqua, Pesciarelli, Jolicœur, Eimer, and Peressotti (2007), for instance, displayed one green and one red string of letters, one to the left and one to the right of fixation, and instructed participants to attend to a target string defined by a pre-specified color, and ignore the other distractor word displayed in a different color for a delayed lexical decision task. The target string could be a word or a non-word.

When the target was a word, target/distractor pairs were semantically related on half of the trials and unrelated in the other trials. ERPs time-locked to the onset of the letter strings were characterized by an N2pc, whose amplitude did not differ significantly between left and right posterior electrodes. An asymmetric N2pc response was detected only when semantic effects were parametrically explored, in the form of an N2pc of reduced amplitude at left-sided electrodes when target and distractor pairs were semantically related vs. unrelated.

Here, we use a logic sharing a substantial analogy with that used by Dell'Acqua et al. (2007) to unveil possible asymmetries in attention allocation to either of two parafoveally displayed Chinese characters. Furthermore, based on prior demonstrations suggesting attention deployment may be influenced by the relationship between target/distractor pairs (Dell'Acqua et al., 2007), we systematically manipulated such relationship based on the following property of Chinese characters. Chinese characters are logograms composed of a varying number of strokes and always confined to a constant square-shaped area. The strokes can be arranged to form directly the simple characters, such as 大 (big) and 马 (horse). Contrary to simple characters, complex characters are composed of more than one orthographic component, called radicals that include one or more strokes. For example, 妈 (mother) is constructed from phonetic radical 马 (horse) and semantic radical 女 (female). In Chinese, words consist of one or more characters, but the majority of words are made up of two characters (e.g., Luo, Proctor, & Weng, 2015; Luo, Proctor, Weng, & Li, 2014). For example, the two-character word 特色 (Characteristic) is constructed by two character 特 (particular) and 色 (color).

Therefore, in the present design, two differently-colored Chinese-like characters were displayed laterally, one to the left and one to the right of central fixation. Subjects were instructed to covertly (i.e., while maintaining gaze at fixation) attend to a target character in a pre-specified color for a delayed "lexical" decision task (i.e., by answering via button press the question "Was the target character an existing Chinese character or a non-character?"). The distractor character, displayed in a different color from the target's, was always a true Chinese character. When target and distractor were both true Chinese characters, these characters could composed a word indicating a single concept (heretofore, *word* condition), or two different concepts (heretofore, *two-character* condition). At the most general level, finding an N2pc here would provide an unequivocal marker of the implication of spatial selective attention in the encoding of parafoveal Chinese logograms for a delayed lexical decision task. More critically, detecting direction and relative intensity of an inter-hemispheric N2pc amplitude/latency imbalance could help disentangle the two attentional accounts of RVFA succinctly mentioned in a foregoing section. The attentional bias account predicts that an N2pc should be detected only at LH posterior electrodes, as this account is clear in establishing that a linguistic task should engage only the LH for attentional control purposes. The opposite prediction can be made based on the attentional advantage account, which posits that the LH encodes characters automatically, with little or no attention requirements, whereas characters processed by the right hemisphere (RH) would be serial and attention demanding (Mondor & Bryden, 1992; Nicholls & Wood, 1998). Although of secondary interest for the present study, to our knowledge, this is the first exploration of whether spatial attention allocation to an eccentric Chinese character is modulated by the "lexical" relationship between the target and a distractor displayed symmetrically in the opposite hemifield. Although a similar attempt has already been undertaken by Dell'Acqua et al. (2007) by manipulating the semantic relationship between target/distractor pairs and finding a left lateralized effect of such manipulation on the N2pc — to remind, reduced N2pc when target/distractor pairs were semantically related vs. unrelated — here the manipulation exploits a peculiarity of pairs of Chinese logograms, which can compose a word indicating a single concept, or distinct concepts. The question at stake here is whether the N2pc to a target that can be "lexically" combined with a concomitant distractor to form a single concept would elicit a reduced N2pc (relative to when these two characters refer to distinct concepts), much like the N2pc described by Dell'Acqua et al. (2007) in response to words pairs sharing a conceptual/semantic relationship.

2. Methods

2.1. Subjects

Seventeen healthy volunteers (6 female; mean age 22 years) participated in this experiment. The participants were right-handed, native speakers of Chinese (Putonghua) with normal or corrected-to-normal vision. They all gave informed consent, were naïve as to the purpose of the study, and received compensation for their participation. One participant was rejected from analysis due to systematic eye movements toward the target (see below, *ERP data analysis*) and one because of high error rates in identifying the target (64% correct, the average from the other 16 participants being 88% ± 6%).

2.2. Stimuli

A total of 360 distractor-target pairs were used as stimuli in three conditions (120 pairs for each condition; see Table 1). In the *word condition*, the distractor and the target were two different Chinese characters that can compose a two-character word when reading from left to right in modern Chinese in China mainland. The mean frequency of these words was 54 (range from 30 to 90) per million. In the *two-character condition*, the distractor and target were two different Chinese characters not composing a word belonging to Chinese lexicon. Non-character targets were random compositions of a varying number of Chinese strokes equivalent, on average, to the number of strokes composing a true Chinese character. Each Chinese character or non-character was displayed only once throughout the experimental list of stimuli. The mean numbers of strokes were 8.3 and 8.4 for characters and non-characters, respectively. The average frequencies of the distractors were 712, 778, and 787 per million for in the word and two-character conditions, and when the target was a non-character, respectively. The average frequencies of the targets were 1128 and 998 per million for the word and two-character conditions, respectively. Frequency count is in terms of the *Modern Chinese Frequency Dictionary* (1986).

[Table 1, about here]

Each character displayed on a given trial was always of the same size, with a visual angle subtending $1.5° \times 1.5°$ at a viewing distance of approximately 58 cm. The pre-masks and post-masks were identical and were grey rectangles filled with a ‘cloud’ of black dots, each subtending 2.0 ° × 1.8 °. When displayed eccentrically on the screen, the center of each character or mask was 4.8 ° relative to the center of the screen.

2.3. Apparatus, procedure and design

The stimuli were presented on a 21-inch CRT monitor (resolution: 1024 × 768 pixels; refresh rate: 150 Hz) connected to a DELL PC, which controlled the presentation of stimuli, timing operations, and data collection by running E-Prime software (Schneider, Eschman, & Zuccolotto, 2002). Also, this computer was connected to a separate ERP host computer controlled by Net Station acquisition software.

[Figure 1, about here]

Figure 1 illustrates the temporal structure of each trial. Each trial began with a centrally presented fixation cross. Participants initiated the trial by pressing the spacebar on the computer keyboard. Following a spacebar press, a blank interval of 500 ms elapsed prior to the exposure of the two lateral pre-masks for 85 ms. The pre-masks were immediately replaced by the two characters that were exposed for 85 ms. A blank screen was then exposed for 51 ms, followed by the presentation of two post-masks for 85 ms. Pre- and post-masks were always identical on a given trial. The blank screen was presented to minimize the occurrence of integration between the target and the post-mask, which might have allowed subjects to recover the information relevant for the character decision task based on sensory/informational persistence (e.g., Coltheart, 1980), and reach an uninformative ceiling level of behavioral performance. After the offset of the post-masks, 1000 ms elapsed before a centrally displayed question mark prompting participants to enter a response. The two characters were always presented simultaneously with two different colors, one red and one green. Participants were instructed to pay attention to the character in a given color, with half of the participants attending to the red character and the other half to the green character, while ignoring the character of different color. With no speed pressure, participants pressed the “1” key of the numeric keypad to respond “Chinese character” or the “2” key to respond “non-character.” The responses were entered by using the right hand. Each participant performed one block of 20 practice trials, followed by two consecutive blocks of 180 experimental trials each. In each block, side of target presentation and target/distractor pair were fully crossed.

2.4. EEG recordings

EEG data were collected continuously with a 128-channel HydroCel Geodesic Sensor Net^{TM} (EGI net station, Electrical Geodesics Inc., Eugene, Oregon) with a 128 Ag/AgCl electrode array, which was connected to an AC-coupled, 128-channel, high-input impedance amplifier (300 MΩ, Net Amps^{TM}, Electrical Geodesics Inc., Eugene, USA). As illustrated in Figure 2, a vertex reference was used in the recording and COM was used as the ground electrode. Amplified analog voltages were high-pass filtered (0.1 Hz) and digitized at 500 Hz. Individual sensors were adjusted until impedance was below 50 kΩ. Blinks and eye movements were monitored based on the electro-oculogram (EOG) recorded at electrodes placed on the outer canthus and infraorbital ridge of each eye.

[Figure 2, about here]

2.5. ERP data analysis

EEG data were analyzed offline with Net Station Waveform Tools (Electrical Geodesics Inc., Eugene, USA). Amplified voltages originally referenced to vertex (Cz) were re-referenced offline to the average of all the electrodes, and a 0.3–40 Hz band-pass digital filter was applied. ERPs were averaged over -100–600 ms epochs time-locked to the characters' onset, considering EEG data in the -100–0 ms interval for baseline correction. ERPs were submitted to an artifact detection procedure to remove blinks (i.e., amplitude deflections greater than 70 μV in VEOG) and possible eye-movements away from fixation (i.e., amplitude deflections greater than 30 μV in HEOG). Segments containing blinks and/or eye movements, as well as epochs with more than 10 bad channels, were excluded from analysis.

To eliminate trials contaminated by possible eye movements towards the visual hemifield occupied by the target character, averaged contralateral-minus-ipsilateral HEOG waveforms to the target were inspected so as to reject trials associated with a deviation greater than 10 μV in a 0–700 ms post-characters time-window, indicating an eye movement greater or equal to 0.6 °towards the target. This application of this algorithm led to exclusion of 1 of the original 17 participants and of an average of 1.2% of epochs in the remnant dataset. The minimum number of artifact-free trials associated with a correct response for a participant to be included in the final sample was 28 in each cell of the experimental design (see below).

The average number of such trials across the six conditions was 38 (range 28–48).

As illustrated in Figure 2, ERP peak amplitudes and latencies were analyzed over two symmetrical channel subsets that were located in a occipito-parietal area near standard electrode sites (given in parenthesis) of the international 10/20 system, namely, P7 (58, 59, 64, 65) vs. P8 (96, 90, 91, 95). This choice was made based on a region-of-interest (ROI) approach that considered the most informative results described in Dell'Acqua et al. (2007; see also Predovan, Prime, Arguin, Gosselin, Dell'Acqua, & Jolicœur, 2009; Prime, Dell'Acqua, Arguin, Gosselin, & Jolicœur, 2011). The statistical analyses on average ERP amplitudes and latencies were performed in the standard time-window of the N2/N2pc component (200–330 ms), applying the Greenhouse-Geisser correction when appropriate.

3. Results

3.1. Behavior

Only trials on which target and distractor were both Chinese characters were included in the following analyses of variance (ANOVAs). Mean percent errors (Table 1) in the unspeeded lexical decision task were submitted to an ANOVA that considered target/distractor pair (word vs. two-character) and visual hemifield (heretofore VF: LVF vs. RVF) as within-subjects variables. The analysis showed no significant effects of VF or target/distractor pair, $F(1, 14) = 2.6$, $p > .13$, $\eta_p^2 = .156$; $F(1, 14) = 1.4$, $p > .25$, $\eta_p^2 = .092$, respectively. The interaction between target/distractor pair and VF was however significant, $F(1, 14) = 7.2$, $p < .02$, $\eta_p^2 = .339$. Separate analyses showed a reliable RVFA in the two-character condition, $F(1, 14) = 6.7$, $p < .03$, $\eta_p^2 = .323$, but not in the word condition, $F < 1$.

3.2. ERP amplitude and latency

The ERP results of greatest interest in the present investigation are graphically summarized in Figures 3 and 4. The ANOVA, including N2pc (contralateral vs. ipsilateral) and target/distractor pair (word vs. two-character) as within-subject variables, indicated a reliable main effect of N2pc, $F(1, 14) = 14.0$, $p < .01$, $\eta_p^2 = .500$. Neither the main effect of target/distractor pair nor the interaction between target/distractor pair and N2pc were significant, all *Fs* < 1. The ANOVA performed on the N2pc latency data, including N2pc and target/distractor pair as within-subject variables, showed no significant effects, all *Fs* < 1.

[Figure 3, about here]

The critical test checking for hemispheric asymmetries in N2pc amplitude was carried out by comparing absolute N2pc amplitude values calculated by subtracting, for each posterior electrode cluster, activity elicited by ipsilateral targets from activity elicited by contralateral targets. Thus, LH activity was calculated at the P7 cluster for RVF minus LVF targets and RH activity was calculated at the P8 cluster for LVF minus RVF targets. These values, graphically illustrated in Figure 4, were submitted to an ANOVA considering hemisphere (LH vs. RH) and target/distractor pair as within-subjects variables. The analysis showed no significant main effects or interaction between these factors, *Fs* < 1, indicating no significant inter-hemispheric asymmetries in N2pc amplitude. The ANOVA on the N2pc latency values, including hemisphere and target/distractor pair as within-subject variables, showed no significant effects, $Fs < 1$.

[Figure 4, about here]

4. Discussion

To summarize, we employed a variant of a search design in which pairs of horizontally aligned Chinese characters were displayed eccentrically and symmetrically relative to fixation, one of which had to be selected based on color for a delayed character/non-character decision. ERP responses to the pairs of Chinese characters were analyzed in search for signs of inter-hemispheric imbalance in the N2-range (i.e., N2pc), on the assumption that N2pc reflects the allocation of selective attention to the target character. The critical test was to compare N2pc responses recorded at left/right electrode sites to unveil potential asymmetries that were contrasted against predictions derived from two attention-based models of the well-established RVFA in word reading. A test of subordinate importance was to test the modulatory role of the “lexical” relationship between target and distractor Chinese characters, by comparing N2pc responses to targets that could indicate a single concept when combined with concomitantly displayed distractors, or concepts bearing no relationship with concepts indicated by distractors.

The present investigation produced three sets of empirical findings. At the behavioral level, a RVFA was detected on the accuracy in carrying out the delayed character/non-character decision on the target only in the two-character condition. No behavioral evidence of RVFA was observed in the word condition. At the ERP level, no significant inter-hemispheric difference in N2pc amplitude and latency was detected between parieto-occipital electrode sites (i.e., P7 vs. P8 clusters) contralateral to the visual hemifield occupied by the target. By eyeballing Figure 4, it appears as though the N2pc response was somewhat more substantial at LH vs. RH. Albeit not significant, this slight N2pc amplitude difference is however far from surprising, and consistent with recent MEG studies indicating that word-induced activation is often associated with a rapid surge of negative activity at left posterior recording sites peaking at about 200–250 ms, likely ensuing from activity in the left inferior Rolandic cortex (Marinkovic, Dhond, et al., 2003; Pammer, Hansen, et al., 2004). Lastly, amplitude and latency of the N2pc response were not influenced by the nature of the relationship between the characters, namely, N2pc of equal amplitude were detected when the target/distractor pair referred to a single concept or separate concepts.

As concerns the behavioral results, it must be pointed out that modern Chinese words might consist of one or more characters, but the majority of words are made up of two characters, which can be classified as simple and complex characters. Simple characters occupy about 5% of all characters and have holistic visual patterns that cannot be divided meaningfully into sublexical units, such as 大 (big) and 马 (horse). Complex characters, on the other hand, constitute about 95% of all characters and have two or more radicals. About 80% of complex characters are phonetic compounds, consisting of phonetic radicals that provide cues to the pronunciation of their host characters, and semantic radicals that usually imply the meaning of their host characters. For example, 妈 (mother) is constructed from a phonetic radical 马 (horse) and a semantic radical 女 (female). About 13% of complex characters are ideogrammic compounds constructed by combining two or three radicals' meanings, and these radicals are unrelated to the host character in pronunciation (e.g., Luo et al., 2015; Luo et al., 2014). For instance, combining 日 (sun) and 月 (moon), the two natural sources of light, makes 明 (bright). These features of Modern Chinese, in and of themselves, make it arduous to isolate parametrically (or control for) the impact of factors like familiarity, relative lexical frequency, and orthographic complexity on the behavioral results of tasks based on parafoveal reading (see Besner, Daniel, & Slade, 1982; and Fang, 1997, 2003, for a similar argument). Given however that the ERP results are a) demonstrably, a finer-grained characterization of the attentional processing subtended in reading parafoveal Chinese characters, and b) largely uninfluenced by the "lexical" relationship between target/distractor pairs, we feel dispensed from considering the pattern of behavioral results in point of RVFA as critical for a collective understanding of the outcome of present investigation.

The N2pc results are problematic for both the aforementioned accounts that generate predictions about the expected attentional modulations in the present task. The attentional bias account (Kinsbourne, 1970) ascribes neural structures of the left hemisphere (LH) to dedicate the role of controlling the entire chain of processing stages subtended in processing verbal material, including the control of spatial selective attention. This yielded to predict that an N2pc in response to verbal material displayed parafoveally should have been detected only at LH electrode sites. An N2pc response was in fact detected at the predicted LH location. However, in striking contrast with the above prediction, an N2pc of equivalent amplitude/latency was detected also at RH electrode sites, a result that cannot be reconciled with the attentional bias account. Note that the present N2pc results do not dispute the well-established LH dominance in language/verbal stimuli processing, which is supported by a flood of recent neuroimaging studies (e.g., Cohen et al., 2000). Rather, the present evidence of a RH-sided N2pc is at odds with the corollary of the attentional bias account that LH plays a dominant role in attention control based on the nature (verbal) of the visual stimuli employed in a given task. Furthermore, the symmetric N2pc response documented in the present context nicely dovetails with a recent functional magnetic resonance imaging (fMRI) investigation by Killebrew, Mruzek and Berryhill (2015), who displayed a visual array of stimuli scattered around fixation, and asked subjects to detect and memorize a differently-colored subset of a variable number (1 to 6) of them. Focusing on blood oxygenation level dependent (BOLD) activity of the intraparietal sulcus (IPS), a core hub of the fronto-parietal circuit underpinning the control of selective attention, these authors compared BOLD changes across two conditions, one in which the to-be-selected subset was composed of letters (surrounded by other letters) and another in which the to-be-selected subset was composed of tilted bars (surrounded by other tilted bars). Although IPS activity increased as the number of letters/bars in the subset was increased only up to about 3–4 stimuli, a prototypical response of IPS neurons (e.g., Todd & Marois, 2004; Vogel & Machizawa, 2004), it did so symmetrically — both when the memoranda were displayed in the LVF and RVF — showing thus a pattern of activity that was not modulated by the type of material subjects had to attend to and memorize. Critically, IPS neurons are held to be also involved in the generation of N2pc responses to eccentric visual stimuli (Dell'Acqua, Sessa, Toffanin, Luria, & Jolicœur, 2010), making thus a strong case against a hypothesis of material-driven inter-hemispheric asymmetry in the control of spatial selective attention.

The attentional advantage account (Mondor & Bryden, 1992) posits that different word processing subroutines are implemented by the LH and RH. Processing words by the LH is held to be automatic and require little or no attention, whereas processing words by the RH may be serial and require attention (Mondor & Bryden, 1992; Nicholls &Wood, 1998). This model is precise in defining the role of attention at the root of this functional asymmetry. Visual words displayed in the RVF would be coded as whole-word representations, whereas words displayed in the LVF would be coded as sequences of letters or letter-compounds, which are hypothesized to be assembled following serial attentional scanning. In support, recognizing long words has been shown to be less difficult in the RVF than LVF (Ellis, 2004; Siéroff et al., 2012). Moreover, word length effects in word recognition have been shown to be usually larger in the LVF than RVF (Auclair & Siéroff, 2002; Ellis, 2004; Lavidor & Ellis, 2002). In this framework, one obvious difference between English words and Chinese words is that strokes/radicals in Chinese words are arranged within a square-shaped area of constant extension, which is well within the perceptual span for efficient parafoveal sensory processing (Inhoff & Liu, 1998). The critical role of the different spatial organization of sublexical units between Chinese and alphabetic languages like English is substantiated by findings indicating that, differently than in the English-speaking population, Chinese patients affected by pure alexia never adopt a radical-by-radical (RBR) reading strategy. In addition, reading times in Chinese do not seem to correlate with the number of strokes/radicals (Chen et al., 2014; Shan, Zhu, Xu, Luo, & Weng, 2010; but see Yin & Butterworth, 1998). Collectively, these considerations yield to question the validity of the attentional advantage account for an interpretation of the present findings. To remind, based on this account, a RH-sided N2pc had to be expected since this model predicts that spatial attention had to be deployed to LVF words for serial scanning. The evidence briefly overviewed above suggests instead that serial attention scanning is unlikely to be involved in the encoding of Chinese characters. In addition, and more importantly, an N2pc was found in the present investigation in response to targets displayed both in the LVF and RVF, leading us to conclude that, much like the attentional bias account, even the attentional advantage account can hardly be reconciled with the present findings.

A last comment is in order with reference to the apparent discrepancy between the present findings indicating no role of the “lexical” relationship in modulating the N2pc amplitude *vis-a-vis* the N2pc attenuation in response to two semantically related words relative to two semantically unrelated words, reported by Dell’Acqua et al. (2007; see, for converging evidence, Stolz & McCann, 2000; Stolz & Stevanovski, 2004). There are two possible explanations of this inconsistency. One explanation, perhaps the more straightforward, is that the pair of Chinese words in the word condition of our design, where the attenuation of the N2pc was expected relative to the N2pc in the two-character condition based on Dell’Acqua’ et al. (2007) findings, separately referred to distinct concepts that shared no semantic/associative relationship. To exemplify, the character 特 (particular) and 色 (color) was a word pair included in the word condition list because they could be combined orthographically to form 特色 (characteristic). A second explanation for why we failed to find the expected “lexical” effect on N2pc amplitude is due to a difference in the choice of eccentricity between the stimuli used in the present and Dell’Acqua’s et al. (2007) studies.

Specifically, in Dell'Acqua et al. (2007), words' eccentricity was 2.8°, whereas the eccentricity of the stimuli used in the present investigation was 4.8°. Although this was a deliberate choice so as to match the eccentricity of the present stimuli with that used in the studies on the parafoveal word reading in Chinese examined in the Introduction, it is appropriate to consider that attentional benefits in cueing designs are generally found only beyond 3° of eccentricity (and improve up to 15°; e.g., Carrasco, Williams, & Yeshurun, 2002; Golla, Ignashchenkova, Haarmeier, & Their, 2004). In this optic, the present design could be easily refined by implementing a systematic and gradual variation of stimulus eccentricity to test whether the allocation of attentional resources to parafoveally displayed Chinese words may be ultimately permeable to combined "lexical" activation.

5. Conclusion

In conclusion, at test here was the hypothesis that a difference in attention deployment across the visual hemifield underlies the often found RVFA in reading parafoveally displayed visual words. We generated a set of predictions based on two models of RVFA, the attentional bias and advantage accounts, that emphasize the role of attention in causing the RVFA. By monitoring a ERP hallmark of attention deployment across LVF and RVF, the N2pc in response to parafoveally displayed Chinese characters, the present study showed an N2pc of equal amplitude when the to-be-selected target Chinese character was displayed in either LVF or RVF, suggesting that hemispheric asymmetries in reading parafoveal Chinese characters can hardly be ascribed to asymmetries in spatial selective attention allocation, as recently suggested by Luo et al. (2015).

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Tables

Table 1.

Percentage of errors in the character/non-character two-alternative forced task.

			Target visual field	
Condition	Distractor	Target	Left	Right
Word	特(particular)	色(color)	7. 8	7.6
Two-character	美(beauty)	任(any)	11.1	7.2

Note. The word 特色 is two-character word that means “characteristics” when reading from left to right in modern Chinese in China mainland.

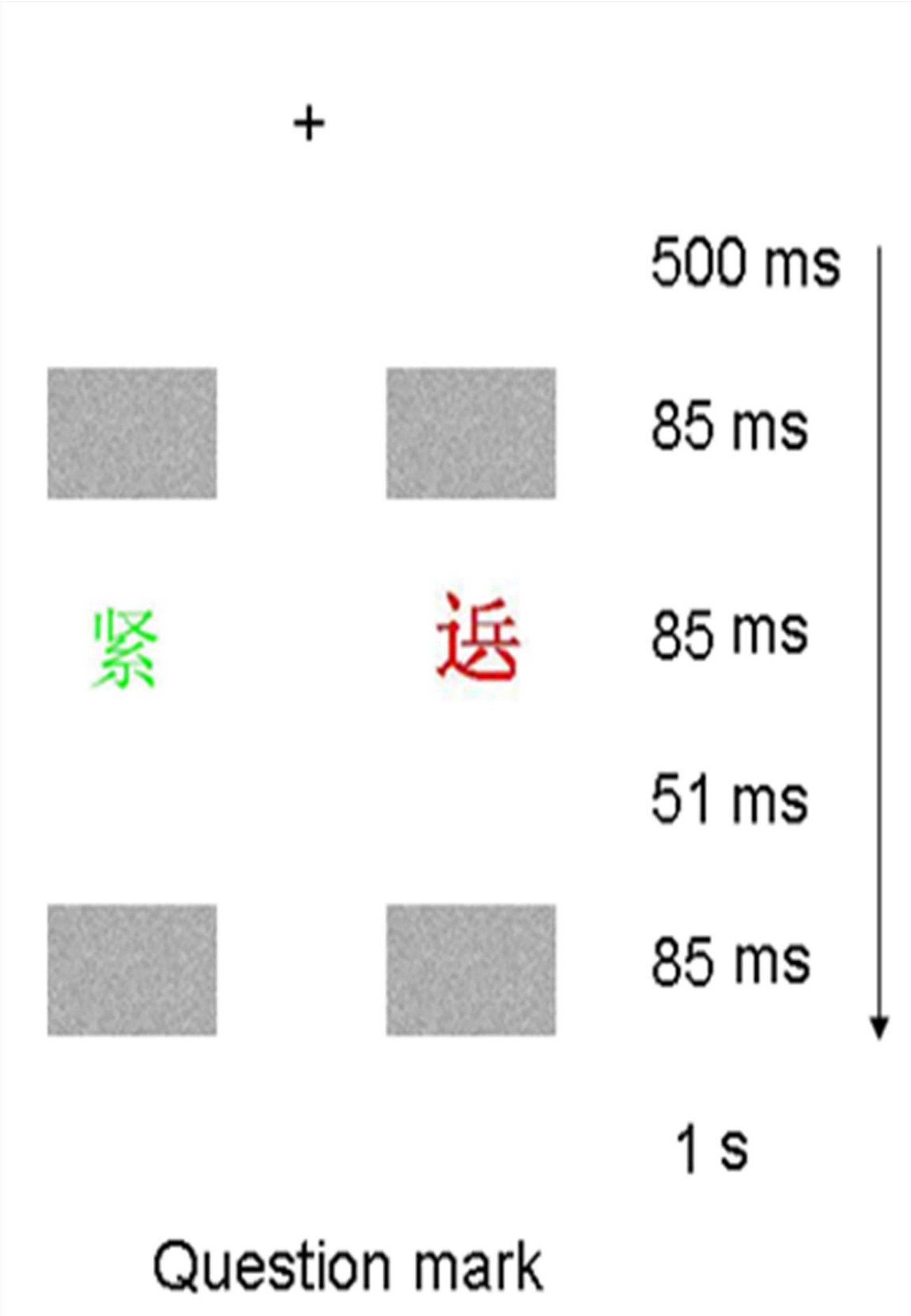
Figure captions

Figure 1. Schematic of the procedure. The left character is a Chinese character and the right character is a non-character, which was constructed from a radical 讠and a Chinese character 兵 by using TrueType software.

Figure 2. Geodesic sensor net layout. Electrode sites numbered along with the standard positions of the International 10/20 system. Black electrode clusters are regions that were considered in the ERP analyses. The two highlighted succinctly were located close to the standard electrode sites (given in parenthesis) of the International 10/20 system (Jasper, 1958): P7 (58, 59, 64, 65) vs. P8 (96, 90, 91, 95).

Figure 3. Grand average waveforms, contralateral and ipsilateral to the target, recorded at the P7-cluster (upper panel) and the P8-cluster (lower panel), as a function of target/distractor pair. The dashed-line box labeled N2pc provides an indication of the time-window considered in the N2pc analyses. LH = left hemisphere, RH = right hemisphere, LF = left visual hemifield, RF = right visual hemifield.

Figure 4. Grand average difference (contralateral minus ipsilateral) waveforms (i.e., absolute N2pc estimates) to the target character, recorded at P7-cluster (upper panel) and P8-cluster (lower panel), as a function of target/distractor pair. The dashed-line box labeled N2pc provides an indication of the time-window considered in the N2pc analyses.



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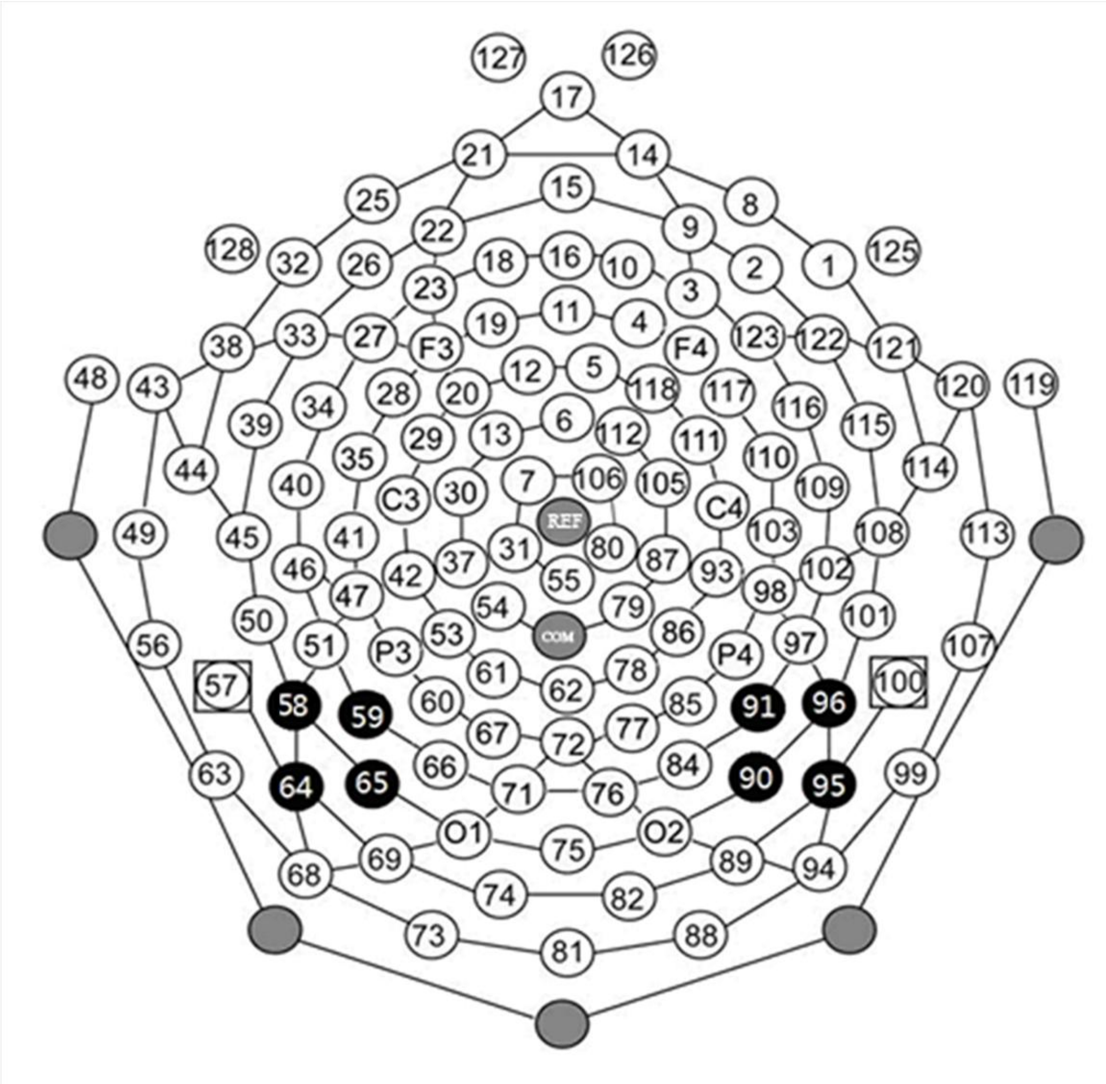
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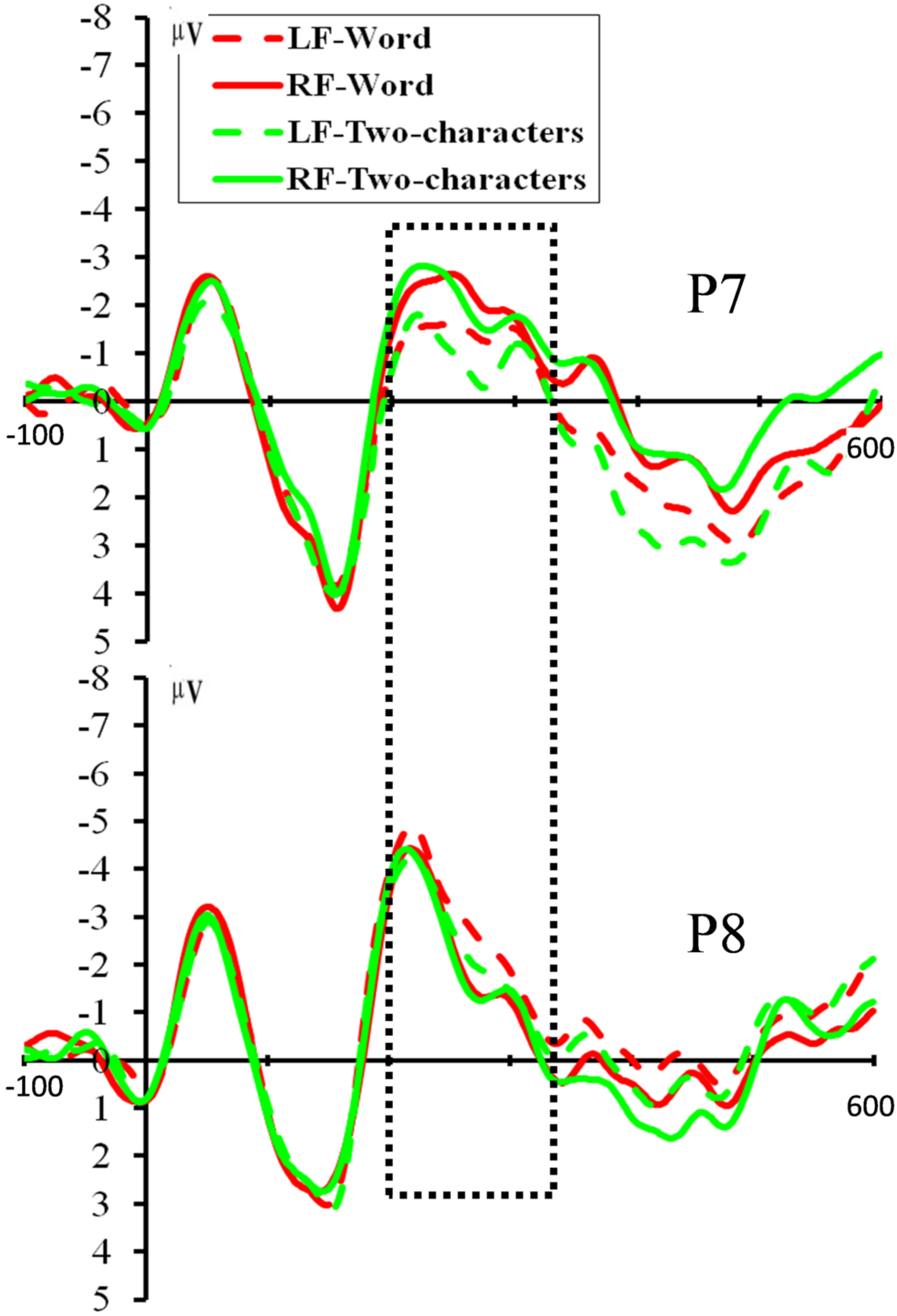

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LF-Two-characters
RF-Two-characters
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P8
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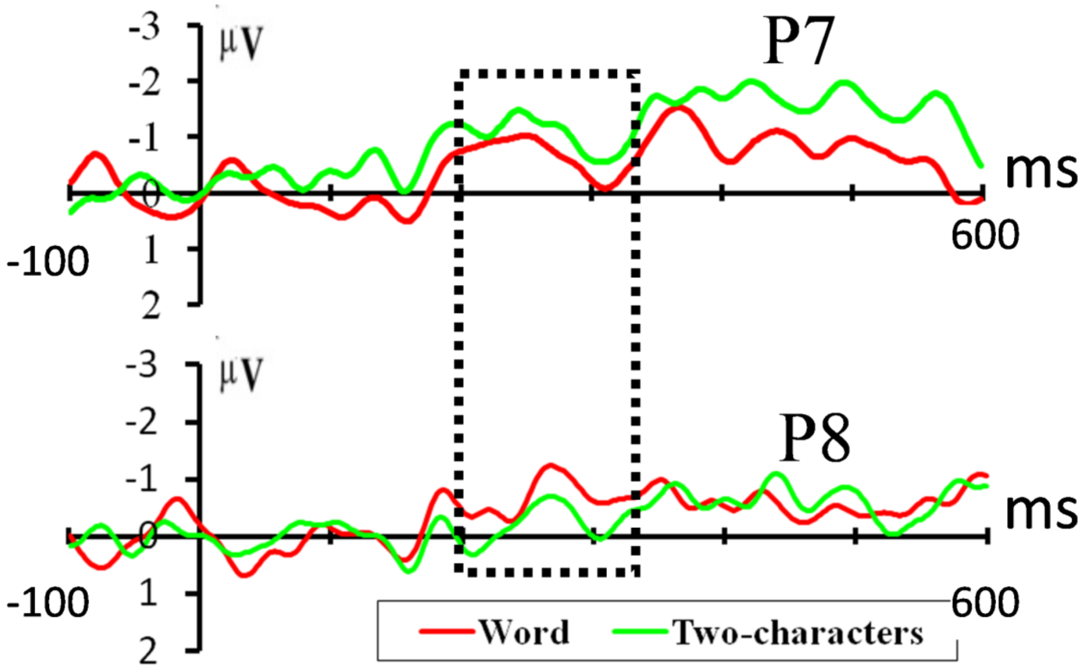
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Two-characters