

Consonantal overlap effects in a perceptual matching task

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Abstract

This study investigates the processing of letter position coding by exploring whether or not two explicitly presented words that share the same consonants, but that differ in their vowels, exert mutual interference more than two words that do not share their consonants. In an explicit perceptual matching task, word targets were preceded by a word reference that could share all the consonants either at the same position or in a different absolute position (while keeping their relative position intact) or preceded by an unrelated reference. Experiment 1 showed larger discrimination costs for pairs sharing the consonants at the same position than for pairs sharing their consonants in a different position. Experiment 2 investigated when and how the types of overlap influence word target processing by using event-related potential recordings. The ERP results showed a Relatedness effect only for targets that share the consonants at the same position from 120 ms to 600 ms post-target onset, whereas targets that share their consonants in different positions in the string produced null effects. Altogether, these data suggest that targets containing the same consonants included in the references in the same positions are processed as being highly similar to them, thus distorting target processing. Furthermore, these data suggest possible mechanisms of competition between lexical representations of the reference and target stimuli.

Keywords: visual word recognition; absolute position; relative position; consonantal overlap.

Introduction

Successful reading requires translating visual symbols into meaning. Decades of cognitive neuroscience research have highlighted that individual written words are recognized via their constituent letters (Grainger, 2008). Letter identity coding (determining what are the constituent letters) and letter position coding (determining the order of those letters) are two key aspects of visual word recognition, and efficient reading requires the association of letter identities with the corresponding positions within the printed words. Recent research has demonstrated the flexibility of the reading system in position coding (Garcia-Orza, Perea, & Muñoz, 2010; Gomez, Ratcliff & Perea, 2008; Humphreys, Evett, & Quinlan, 1990; Massol, Duñabeitia, Carreiras, & Grainger, 2013; Perea, Duñabeitia, & Carreiras, 2008; Perea & Lupker, 2003, 2004; Peressotti & Grainger, 1999; Schoonbaert & Grainger, 2004; see also van Assche & Grainger, 2006, for review of the arguments). The present investigation aims at examining the processing of letter position coding by exploring the extent to which two strings sharing their consonants activate each other, thus making it difficult to discriminate between them in a perceptual matching task. More specifically, the present study was designed to explore whether or not words sharing their consonants in the same position yield similar effects as pairs sharing their consonants in different positions (while keeping their relative-position intact).

To date, the majority of evidence regarding orthographic coding comes from studies using the masked priming paradigm, in which a briefly presented prime (usually presented for 50 ms) is followed by a target item (Forster & Davis, 1984). For instance, Peressotti and Grainger (1999) found that subset primes that share with the targets some letters that preserve their relative order

within the string (the so-called relative position priming effect; e.g., blcn-balcon [balcony in French]) led to facilitated priming effects as compared to unrelated primes (e.g., tpfv-balcon). Interestingly, when filler letters or characters are inserted into the prime stimulus (e.g., bslnrn-balcon) to provide absolute position information, the obtained priming effects are of the same magnitude as the relative position priming effects. Thus, primes composed of a subset of target word's letters facilitated the recognition of the word target under masked priming conditions (Grainger, Granier, Farioli, van Assche, & van Heuven, 2006; Humphreys et al., 1990; see also Carreiras, Duñabeitia & Molinaro, 2009, and Grainger & Holcomb, 2009, for similar results obtained with ERP recordings).

The results coming from these masked priming studies posed a challenge for visual word recognition models following slot-based representational schemes. Based on those and closely-related findings coming from transposed-letter manipulations (e.g., cholocate-chocolate; see Duñabeitia, Perea, & Carreiras, 2007; Kinoshita & Norris, 2009; Perea & Carreiras, 2006a, 2006b; Perea et al., 2008; Perea & Lupker, 2003, 2004; Schoonbaert & Grainger, 2004), a new set of models of orthographic coding has been developed in order to specify how visual information is transformed into an abstract code for letter information, allowing a certain degree of tolerance to variations in the precise position of the letters (SOLAR model, Davis, 2010; Overlap model, Gomez et al., 2008; Open-bigram model, Grainger & van Heuven, 2003; Norris & Kinoshita, 2012; SERIOL model, Whitney, 2001; Whitney & Cornelissen, 2008). Even if they all differ in terms of their detailed representations and processing assumptions, this new class of models accounts for an approximate and flexible coding for letter position and letter identity

information in the initial stages of visual word recognition. According to these models, letter identities are not rigidly allocated to a given position.

However, so far, most of the studies exploring orthographic overlap between two strings have used masked priming paradigms where nonword primes pre-activate targets' representations leading to facilitative effects. One clear limitation of these studies is the use of non-existing representations as (masked) primes, and so it is still unclear whether these effects may also be generalized to existing lexical representations (i.e., real words). Besides, the masked priming paradigm involves a very short time interval between prime and target stimuli paired with unconscious perception of the masked primes. This paradigm is considered as a powerful tool to investigate the earliest stages of visual word recognition (Forster & Davis, 1984; Grainger, 2008). This technique has been widely used in past years and provided further insights on processes occurring during word identification. As acknowledged by Forster and Davis (1984), this technique is most useful for investigating the earliest stages of processing by avoiding the establishment of an episodic component. At the same time, this paradigm does not allow for further exploring processes associated with explicit comparisons between stimuli given the pace of presentation. By increasing the presentation times and consequently allowing conscious perception of the stimuli, it may be possible to increase the effect sizes and the potential to observe differences between the two types of overlap (i.e., absolute position overlap vs. relative-position overlap). Therefore, the present study will explore the extent to which consonantal overlap effects visual word identification from a competition-based perspective (i.e., focusing on the competition between two strings with overlapping segments), asking participants to consciously identify whether two sequentially presented strings are the same or not. In the

present investigation we used the same-different perceptual matching task in which the first stimulus of the pairs will be presented for 300 ms, allowing conscious processing of this stimulus before target presentation, immediately followed by a second stimulus (the target), which was also presented for 300 ms. Participants were asked to judge whether or not the two stimuli were the same. Moreover, by comparing this manipulation with a same-different perceptual matching task (see Duñabeitia, Dimitropoulou, Grainger, Hernandez, & Carreiras, 2012), the present study aimed to provide critical information about orthographic coding and interconnectivities between orthographic prelexical and lexical levels of representation. Finding distinct patterns of effects for absolute position overlap and for relative-position overlap can be taken as evidence for modulation of orthographic coding by higher-level representations.

Numerous studies have reported significant priming effects only when primes and targets shared their consonants (e.g., *duvo-DIVA* [*diva* in French]) relative to a control condition (e.g., *rufo-DIVA*), whereas no significant priming effects were found for vowel-related priming (e.g., *rifa-DIVA*) (New, Araújo, & Nazzi, 2008; New & Nazzi, 2014; see also Duñabeitia & Carreiras, 2011; Carreiras & al., 2009). New and Nazzi (2014) highlighted that the different roles of consonants and vowels do not occur at the prelexical orthographic level, but rather that this difference could be due to how much lexical representations are activated by the prime and the target. Moreover, Duñabeitia and Carreiras (2011) developed the Lexical Constraint Hypothesis, according to which consonants carry more lexical information than vowels, because (with few exceptions) consonants are more numerous than vowels. Thus, it seems logical to assume that consonants will impose a higher lexical constraint as compared to vowels, whereas the number of active lexical candidates matching an only-vowel prime would be much higher than the

number of candidates matching an only-consonant subset prime. According to this Lexical Constraint Hypothesis and given the results reported in the literature showing a consonant-vowel asymmetry (Carreiras et al., 2009; Duñabeitia & Carreiras, 2011; New et al., 2008; New & Nazzi, 2014), we concentrated our efforts on exploring consonantal overlap between pairs of letter strings, leaving aside the vowel-relatedness effects.

In the present investigation, the use of a perceptual matching task allowed us to investigate how the consonant-relatedness effects can be modulated by the type of positional overlap, by asking participants to consciously identify whether two sequentially-presented strings are the same or not. In fact, it has been shown that this task is based on abstract letter identities and so it can reveal the nature of letter encoding at a prelexical level of processing (Angiolillo-Bent & Rips, 1982). The consonantal overlap between reference and target items was manipulated: two explicitly presented words share the same consonants either in the same position (e.g., ducha [shower] – dicho [proverb]) or in a different absolute position (while keeping their relative position intact) (e.g., nogal [walnut] – ingle [inner thigh]). This manipulation allows testing whether or not two explicitly presented words effectively activate each other more than word pairs that do not share their consonants (e.g., ducha- vello [fuzz], and nogal – mitra [miter]). Considering the evidence presented by Duñabeitia and Carreiras (2011) and by New et al. (2008), we predicted clear-cut effects for consonant-related pairs as compared to consonant-unrelated pairs, given the difficulty in recognizing differences between two words that have a high degree of orthographic similarity.

To sum up, the present investigation aims at exploring the effects between two words that share their consonants either in the same within-string position (absolute position) or in different positions (relative position). Experiment 1 was aimed at providing insight into these issues, whereas Experiment 2 aimed to investigate the time-course of orthographic processing and how it can be influenced by the strictly absolute position of the consonants using electrophysiological recordings (i.e., event-related potentials - ERPs).

Experiment 1: Behavioral Experiment

The goal of Experiment 1 was to explore how the position of the shared consonants modulates the effects of consonantal overlap. Participants were presented with pairs of 5-6 letter words, and they were asked to decide whether the two words were identical or different (see Proctor, 1981; Ratcliff, 1981). In the critical pairs of items (requiring a “different” response), the reference and the target could share all the consonants in the exact same position (i.e., absolute condition: ducha [shower] – dicho [proverb]) or in a different absolute position (i.e., relative condition: nogal [walnut] – ingle [inner thigh]) or could be unrelated (i.e., unrelated condition: ducha [shower] – vello [hair], nogal [walnut] – mitra [miter]). We expected that two letter strings sharing their consonants would exert mutual co-activation, leading to longer RTs in the related rather than unrelated conditions given the similarity between the consonant-related pairs (i.e., a discrimination cost). Following the results reported, among others, by Grainger et al. (2006), which demonstrated that primes preserving the relative- and the absolute-position letter information of the targets yield similar effects, we did not expect to find any modulation of the

discrimination cost depending on the position of the overlapping letters. Thus “ducha-dicho” and “nogal-ingle” should produce the same effects as compared to the control items “ducha-vello” and “nogal-mitra”.

Method

Participants

A total of 28 participants (14 women) with a mean age of 21 years ($SD = 2.71$) took part in the experiment. They were paid for their collaboration. All were native Spanish speakers, with no history of neurological or psychiatric impairment, and with normal or corrected-to-normal vision. Each participant signed an informed consent form before the experiment and was appropriately informed regarding the basic procedure of the experiment, according to the ethical commitments established by the Ethics Committee that approved the experiment.

Materials

The experiment included two different blocks of 180 pairs of words of 5-6 letters each. The first member of each pair was referred to as the reference and the second as the target.

In the two blocks, all 180 references and 180 targets were Spanish words. In the block created to explore absolute-position overlap, references could be followed i) by targets that were different than the references but that shared the same consonants in the exact same position in the string (45 trials; e.g., *ducha-dicho*), ii) by targets that were completely unrelated to the references (45 trials; e.g., *ducha-vello*), or iii) by targets that were the exact repetition of the references (90 trials; e.g., *ducha-ducha*). A parallel design was followed in the block created to explore relative-position overlap, with references that could be followed i) by targets that were different but that

shared the same consonants in different positions (45 trials; e.g., *nogal-ingle*), ii) by targets that were unrelated to the references (45 trials; e.g., *nogal-mitra*), or iii) by targets that were identical repetitions of the references (90 trials; e.g., *nogal-nogal*). To minimize potential confounds, the reference and target stimuli were carefully matched on a number of standard psycholinguistic variables (see Tables 1 and 2).

Hence, two different blocks of items were created in order to explore the two critical conditions, each of them including 90 pairs requiring a “same” response and 90 pairs requiring a “different” response (45 related pairs and 45 unrelated pairs): absolute-position pairs, relative position pairs. Two lists were created for each block following a counterbalanced design so that in each block each reference was presented twice, once requiring a “same” response and once requiring a “different” response. In each list and each block, unrelated reference-target pairs were formed by re-arranging the related reference-target pairs ensuring that there was minimal orthographic overlap between references and targets in the re-pairings. The unrelated references were less similar to the corresponding targets than the related references, with an average Orthographic Levenshtein Distance of 5.32 edits ($SD = .76$) for the Absolute Unrelated condition and of 2.33 edits ($SD = .50$) for the Absolute Related condition ($t(89) = -37.46, p < .001$), and an average of 4.94 edits ($SD = .83$) for the Relative Unrelated condition, as compared to the 3.51 edits ($SD = .55$) of the Relative Related condition ($t(89) = 17.44, p < .001$). The order of presentation of the blocks was randomized across participants and within each block, stimuli presentation order was also randomized.

<Tables 1 and 2>

Procedure

The presentation of the stimuli and recording of the responses was carried out using Presentation software. All stimuli were presented on a CRT monitor. Participants were informed that two strings of letters, one after the other, would be displayed. All stimuli were presented in white Courier New font (size 16) on a black background, with a viewing distance to the screen of 60 cm. Each trial began with a fixation stimulus (+) for 500 ms. Immediately after this, the reference stimulus was presented for 300 ms, and was horizontally centered and positioned 3 mm above the exact center of the screen. The reference was then replaced by the target stimulus that was horizontally centered and positioned 3 mm below the center of the screen. Target stimulus remained on the screen for 300 ms. The manipulation of the location of references and targets on the vertical axis was carried out in order to avoid physical overlap between the two strings. Once the target disappeared, there was an inter-stimulus interval that randomly varied between 900, 1000 and 1100 ms. The trial concluded with the presentation of an asterisk (*) for 500 ms. Participants were instructed to decide as rapidly and as accurately as possible whether or not the two strings were identical, as soon as the target stimulus was displayed on the screen. They responded “same” by pressing “L” and “different” by pressing “S” on the keyboard. Figure 1 summarizes the sequence of events on a trial. A short practice session was administered before the main experiment to familiarize participants with the procedure and the task.

<Figure 1>

Results

Statistical analyses were performed only on the “different” trials, since there was no experimental manipulation within the set of “same” trials. Incorrect responses and reaction times below and above 2.5 standard deviation from each participant’s mean were also excluded (2.81% of the data). Mean reaction times for correct responses and error rates are presented in Figure 2. Two separate analyses were performed to examine the effects of Relatedness for the Absolute conditions on the one hand (i.e., Absolute Related vs. Absolute Unrelated), and the effects of Relatedness for the Relative conditions on the other hand (i.e., Relative Related vs. Relative Unrelated). In both cases, pairwise comparisons were performed over participants and items on the reaction times and on the error rates. Furthermore, in the presence of significant Relatedness effects for both Absolute and Relative sets, a statistical comparison between the magnitudes of the effects was conducted.

<Figure 2>

Reaction time data

The analyses on RTs revealed a significant effect of Relatedness for the Absolute conditions, $t1(27) = 8.41, p < .001, t2(89) = 8.61, p < .001$, as well as for the Relative conditions, $t1(27) = 3.21, p = .003, t2(89) = 4.79, p < .001$, showing that unrelated pairs were responded to faster than Related pairs. In order to further explore potential differences in the magnitudes of the Relatedness effects obtained for both types of overlap (i.e., Absolute and Relative), the net effects were calculated by subtracting the RTs in the Related conditions minus the RTs in the Unrelated conditions, and contrasted. The two effects differed significantly ($t1(27) = 2.46, p = .020; t2(89) = 3.29, p = .001$). The Relatedness effect was larger for pairs that shared their

consonants in the same position (38ms) than for pairs that shared their consonants in a different position (20ms).

Error data

The analyses on error rates revealed a significant effect of Relatedness for the Absolute conditions, $t1(27) = 2.60, p = .015, t2(89) = 2.57, p = .012$, but the Relatedness effect was not significant for the Relative conditions, $t1(27) = 0.87, p > .1, t2(89) = 0.71, p > .1$. Therefore, the effect of Relatedness was present only for word targets preceded by a referent word that shared all the consonants in the same position, with more errors associated with targets following a consonant-related reference than for targets following an unrelated reference.

Discussion

Experiment 1 used an explicit perceptual matching task in order to investigate whether or not a word reference and a word target that share the same consonants in the same position or in a different position (while keeping their relative position intact) activate each other more than pairs that do not share their consonants. The results are clear-cut and demonstrated that when a reference and the subsequent target share a set of consonants, decisions in the same-different matching task are slower and less accurate as compared to decisions to pairs that did not have any letters in common. Moreover, the consonant-relatedness effects were stronger when the consonants were presented at the same position in the references and targets (e.g., *ducha-dicho*) than when the consonants were present in different positions (e.g., *nogal-ingle*) relative to the unrelated conditions. Thus, the present results extend previous findings highlighting that

consonant-relatedness effects can also be observed for consonantal relative position manipulation, as has been previously shown for absolute position (New et al., 2008). These results demonstrate that overlapping letter representations at an absolute-position level seem to be significantly more important for readers than those overlapping at the relative-position level.

Experiment 2: ERP Experiment

Experiment 2 combined the perceptual matching task with ERP recordings to provide observations on the time-course of orthographic processing underlying the effects observed in Experiment 1. In this experiment, word targets were preceded by a word reference that could share all the consonants at the same position (e.g., ducha-dicho) or in different positions (e.g., nogal-ingle) or have no letter in common (e.g., ducha-vello, nogal-mitra). Differences in electrophysiological measures of brain activity during absolute vs. unrelated conditions and relative vs. unrelated conditions will shed light of the underlying processes.

Related for the purpose of this experiment is the study from Duñabeitia et al. (2012), which combined the perceptual matching task with ERP recordings. The authors explored changes in character position (transpositions vs. replacements) in different types of strings. In their experiment, targets were preceded by a transposed-character reference or by a replaced-character reference and the stimulus pairs were either letter strings, digit strings or symbol strings. An early transposed-character similarity effect was reported mainly for letter strings in the 100-200 ms and in the 200 -325 ms time-windows, whereas a generalized transposed-character similarity effect was found in the following 350-500 ms epoch. This pattern of results strongly suggests

that letter strings are processed differently than other character strings and so provides evidence for a position coding mechanism specific to letter strings at the earliest epochs.

Considering, on the one hand, the results from Experiment 1 and, on the other hand, the results reported by Duñabeitia et al. (2012) at the electrophysiological level, we expected to find relatedness effects starting around 200 ms, that have been previously reported as being sensitive to variations between a memory residual (reference) and a mismatch template (target) (Näätänen, 1990). Consonant-related pairs were expected to produce less negative-going waveforms relative to consonant-unrelated pairs, because high similarity between two stimuli is associated with smaller negativities in this epoch (Comerchero & Polich, 1999; Squires, Hillyard, & Lindsay, 1973). Thus, assuming that reference-target pairs sharing their consonants will be perceived as highly similar by readers, we predicted differences starting to emerge around 200 ms post-target onset between pairs sharing all their consonants in the same position and pairs sharing all their consonants in different positions, given the difficulty in recognizing as different two strings that have a high degree of orthographic similarity.

Method

Participants

A total of 28 participants (12 women) with a mean age of 20.2 (SD = 2.06) years took part in the experiment. They were paid for their collaboration. They were all native Spanish speakers, with no history of neurological or psychiatric impairment, and with normal or corrected-to-normal vision. All participants were right-handed. They all signed informed consent forms before the experiment and were appropriately informed regarding the basic procedure of the experiment,

according to the ethical commitments established by the Ethics Committee that approved the experiment.

Materials

The exact same materials used in the absolute-position and relative-position word-word pairs tested in Experiment 1 were used in this experiment. Hence, the related pairs as well as the unrelated pairs were strictly identical to the ones previously described.

Procedure

The procedure for stimulus presentation was identical to that used in Experiment 1.

Electroencephalogram recording and analysis procedure

Participants were seated in a comfortable chair in a soundproof and dimly illuminated room. The electroencephalogram (EEG) was recorded continuously through a 32-channel Brain-Amp system from 27 Ag/AgCl electrodes mounted on an elastic cap (Easy Cap) that was positioned according to the 10-10 International system (Fp1/Fp2, F3/F4, F7/F8, FC1/FC2, FC5/FC6, C3/C4, T7/T8, CP1/CP2, CP5/CP6, P3/P4, P7/P8, O1/O2, Fz, Cz, Pz). The montage included 3 midline sites and 12 sites over each hemisphere. Four additional electrodes were used to monitor eye movements and blinking (two placed at lateral canthi and two below the eyes). An additional electrode placed over the left mastoid (A1) was used as the online reference and a final electrode was placed over the right mastoid (A2). For all scalp electrodes impedances were maintained below 5k Ω , and below 10k Ω for electrooculography (i.e., EOG electrodes). Continuous EEG was digitized at 250Hz and filtered offline (High-pass: 0.01Hz, 12 dB/octave; Low-pass: 30Hz,

48 dB/octave) using Brain Analyzer Software. All electrode sites were re-referenced offline to the average activity of the two mastoids. Each epoch was visually inspected to verify whether there were artifacts, and epochs with eye movements, blinking or electrical activities greater than $\pm 80\mu\text{V}$ were rejected. To maintain an acceptable signal-to-noise ratio, an a priori lower limit of 25 artifact-free trials per participant per condition was set. On this basis, five participants were excluded from further analysis.

ERPs were calculated by averaging the EEG time-locked from a point 300 ms pre-target onset up to 700 ms post-target onset. The 300 ms pre-target period was used as a baseline. We removed all the trials associated with incorrect responses (i.e., trials in which the target was incorrectly identified as being identical to the reference stimuli) (4.44% of trials). Moreover, only trials without muscle artifact or eye movement/blink activity were included in the averaging process (8.99% of trials eliminated). These resulted in a highly-similar rate of artifact-free segments across conditions (Absolute Related: 85.50%; Absolute Unrelated: 88.11%; Relative Related: 84.25%; Relative Unrelated: 88.40%). Only these artifact-free and error-free segments were averaged and analyzed.

Following visual inspection and based on the relevant literature (i.e., Duñabeitia et al., 2012), analyses on mean amplitudes were run on 3 time intervals: 120-200 ms, 200-300 ms and 350-600 ms. We employed an approach to data analysis in which the head is divided up into seven separate parasagittal columns along the antero-posterior axis of the head (see Figure 2). The electrode sites in each of three pairs of lateral columns and one midline column were analyzed in separate ANOVAs. Three of these analyses (column1, column 2, and column 3) involved the Relatedness factor (Related vs. Unrelated), the Hemisphere factor (Left vs. Right), and an

Electrode factor for each type of overlap (i.e., Absolute vs. Relative) separately. The fourth analysis involved midline electrode sites with the two levels of the Relatedness factor, and the three levels of the Electrode factor (electrodes Fz, Cz and Pz). We used the columnar approach for the analysis of the spatial component of the ERP data because it provides a thorough analysis of the entire head breaking the scalp up into regions (left and right, front and back), while at the same time allowing single or small clusters of sites to influence the analysis. This same approach has been successfully used in a number of previous studies (e.g., Holcomb & Grainger, 2006; Massol, Grainger, Dufau, & Holcomb, 2010; Massol, Midgley, Holcomb, & Grainger, 2011).

<Figure 3>

Results

Behavioral measures

The same analytical methods from Experiment 1 were employed. Incorrect responses and reaction times below and above 2.5 standard deviation from each participant's mean were excluded (2.85% of the data). Mean reaction times for correct responses and error rates are presented in Figure 4. Two separate analyses were performed to examine the effects of Relatedness (Related vs. Unrelated) in the Absolute conditions and in the Relative conditions separately. In both cases, pairwise comparisons were performed over participants and items on the reaction times and on the error rates.

<Figure 4>

The analyses on RTs revealed a significant effect of Relatedness for the Absolute conditions $t1(22) = 6.60, p < .001, t2(89) = 8.33, p < .001$, as well as for the Relative conditions, $t1(22) = 4.29, p < .001, t2(89) = 4.05, p < .001$, showing that Related conditions yielded longer RTs than Unrelated conditions. In order to further explore the difference in magnitudes of these Relatedness effects obtained for both types of overlap (i.e., Absolute vs. Relative), the net effects were calculated and contrasted. The results revealed that the two Relatedness effects were statistically different from each other (45 ms vs. 23 ms; $t1(22) = 2.58, p = .017 ; t2(89) = 2.75, p = .007$).

The analyses on error rates revealed no significant effect of Relatedness for the Absolute conditions, $t1(22) = 1.10, p > .1, t2(89) = 1.21, p > .1$, nor for the Relative conditions, $t1(22) = 0.59, p > .1, t2(89) = 1.02, p > .1$.

Electrophysiological measures

<Figures 5 and 6>

120-200 ms post-target onset

In this time-window, there was a significant effect of Relatedness for the Absolute conditions (Midline: $F(1,22) = 7.68, p = .011, \eta_p^2 = .259$; Column 1: $F(1,22) = 7.41, p = .012, \eta_p^2 = .252$; Column 2: $F(1,22) = 7.22, p = .013, \eta_p^2 = .247$; Column 3: $F(1,22) = 8.08, p = .007, \eta_p^2 = .286$). As can be seen in Figure 5, pairs sharing the consonants at the same position (i.e., Related pairs) were associated with less negative-going waveforms than Unrelated pairs. However, the effect of

Relatedness for pairs that shared their consonants in a different position was not significant at any of the electrode configurations (all $ps > .1$, see Figure 6) (Midline: $F(1,22) = 0.46$; Column 1: $F(1,22) = 0.11$; Column 2: $F(1,22) = 0.03$; Column 3: $F(1,22) < 0.01$). Furthermore, the effect of Relatedness did not interact with any of the electrode configurations (all $ps > .1$).

200-300 ms post-target onset

The main effect of Relatedness was significant for the Absolute conditions over Column 3; $F(1,22) = 4.35$, $p = .049$, $\eta_p^2 = .165$, but it was not significant for the Relative conditions (all $ps > .1$). Although the effect of Relatedness did not interact with any of the electrode configurations for the Relative conditions (all $ps > .1$), there was a significant interaction including the factors Relatedness and Hemisphere for the Absolute conditions over Columns 1, 2 and 3 (Column 1: $F(1,22) = 6.14$, $p = .021$, $\eta_p^2 = .218$; Column 2: $F(1,22) = 9.32$, $p = .006$, $\eta_p^2 = .298$; Column 3: $F(1,22) = 10.97$, $p = .003$, $\eta_p^2 = .329$), showing that the Relatedness effect was significant only over the right hemisphere (Column 1: $F(1,22) = 4.39$, $p = .048$, $\eta_p^2 = .167$; Column 2: $F(1,22) = 6.38$, $p = .019$, $\eta_p^2 = .225$; Column 3: $F(1,22) = 8.25$, $p = .009$, $\eta_p^2 = .273$). According to the analysis on the columns at the right hemisphere, targets preceded by a reference word that shared all consonants in the same positions were associated with less negative-going waveforms than targets preceded by an unrelated referent.

350-600 ms post-target onset

In this time-window, the main effect of Relatedness was significant for Absolute conditions over Midline, Column 1 and Column 2 (Midline: $F(1,22) = 15.50$, $p = .001$, $\eta_p^2 = .413$; Column 1: $F(1,22) = 12.71$, $p = .002$, $\eta_p^2 = .366$; Column 2: $F(1,22) = 6.76$, $p = .016$, $\eta_p^2 = .235$), showing

that targets preceded by a reference word that shared all the consonants in the same positions were associated with more positive-going waveforms than targets preceded by an unrelated referent. As for the Relative conditions, the main effect of Relatedness was not significant at any of the electrode configurations in this time-window (Midline: $F(1,22) = 0.91$; Column 1: $F(1,22) = 0.61$; Column 2: $F(1,22) = 0.69$; Column 3: $F(1,22) = 0.24$). The effect of Relatedness did not interact with any of the electrode configurations (all $ps > .1$) (see Figure 7).

<Figure 7>

Discussion

At the behavioral level, the results replicated the pattern of findings observed in Experiment 1. That is when a reference and the subsequent target share consonants, decisions in the same-different matching task are slower (i.e., a discrimination cost) compared to pairs of words that have no letters in common. Furthermore, the Relatedness effect was larger when the consonants were present in the same positions in the references and targets than when they were present in different positions in the strings (45 ms vs. 23 ms). At an electrophysiological level, significant Relatedness effects were found only when references and targets shared all their consonants in the same positions in the strings (e.g., *ducha-dicho*) in the three time-windows of interest, whereas targets sharing their consonants with the reference in different positions did not differ from targets that were orthographically unrelated to the reference (e.g., *nogal-ingle* vs. *nogal-mitra*). In other words, these results highlight that the type of positional overlap strongly modulates target processing starting at 120 ms post-target onset and lasting up to 600 ms. Besides, although the behavioral data revealed longer reaction times for targets sharing their

consonants with the reference in different positions (i.e., a significant Relatedness effect in the RTs for the items in the Relative set), the ERP data did not reveal any significant difference at any of the three time-windows between targets sharing consonants in different positions in the string and unrelated targets that did not have any letters in common with the reference.

According to the literature, the N1 component has been shown to reflect a benefit of correctly allocating attentional resources (Luck, 1995; Luck et al., 1994). A modulation of this component has mainly been reported when participants are asked to perform a discrimination task (Mangun & Hillyard, 1991). For instance, when participants are involved in a spatial cuing paradigm in which they are asked to discriminate between two alternative stimuli, Mangun and Hillyard reported a significant modulation of the N1 amplitude. Thus, the perceptual matching task combined with ERP recordings allows for highlighting early perceptual process involved during the discrimination between the reference and the target stimuli. Besides, Duñabeitia et al. (2012) used the perceptual matching task combined with ERP recordings to investigate transposed character effects in different types of strings (i.e., letters, digits, symbols). In the 100-200 ms time-window, they observed that targets deviating from the references by character transposition (i.e., related pairs) were associated with less negative-going waveforms than targets deviating from the references by character replacement (i.e., unrelated pairs). Furthermore, this Relatedness effect in the N1 time-window was mainly evident for letter strings as compared with both digit and symbol strings. This N1 effect strongly suggests that when two stimuli in the pair are perceived as highly similar, they are associated with a reduction of N1 amplitude relative to pairs of unrelated stimuli. Therefore, the present results are totally in line with the results provided by Duñabeitia et al. (2012). The unrelated targets represent clearly deviant stimuli from

the references, whereas the mismatch between references and targets sharing all their consonants in the same position is less obvious given the overlapping orthographic units, leading to the perceived greater similarity between these string pairs. The pattern of effects found in the 120-200 ms time-window reflects early stage of word processing in which information about visual features is mapped to abstract sub-lexical orthographic representations (see also Duñabeitia et al., 2012). According to the dual-route architecture for reading developed by Grainger and Ziegler (2011), the first stage of visual-word processing involves the coding of the information about the location of letter identities relative to the eye fixation. That is, at this level of letter detectors, the information about the position of the letters within a string in relation to the rest of the characters may not be encoded yet, given that the processes taking place at this stage are of visuo-orthographic nature (see also Grainger, Dufau, & Ziegler, 2016). In other words, these letter detectors indicate that a given letter identity is present in the stimulus at a particular position. That is letter detectors perform parallel letter processing with respect to eye fixation, but do not provide any information about the relative position of letters in the stimulus. The information about the location of letter identities generates then activity in the level of location invariant sub-lexical orthographic representations, in which the order of letters within a word will be inferred. Thus, the effect of Relatedness that was only present for the absolute-position overlap in the 120-200 ms could be explained by the fact that reference and target stimuli shared several visuo-orthographic features (i.e., the same characters) at the same location, yielding increased visual overlap as compared to reference-target pairs sharing consonants in different positions.

Furthermore, in the 200-300 ms time-window, less negative-going waveforms have been observed when references and targets share their consonants in the same position as compared to

references and targets that have no letter in common, whereas references and targets that share their consonants in different positions did not significantly differ from pairs of unrelated reference-target. Numerous studies that investigated processes involving in perception, attention and memory, have shown a negative-going component in the 150-300 ms time-window, the so-called N2 component. This N2 time-range has been well-studied and this component has been interpreted as a reflect of attentional shifts, maintenance of context information, detection of novelty among others (see Folstein & van Petten, 2008, for a review). Moreover, the N2 component is modulated according to the perceptual/visual overlap between two types of stimuli (Azizian, Freitas, Parvaz, & Squires, 2006). It should also be mentioned that different sub-components have been identified in this time-window (see Luck & Hillyard, 1994; Näätänen & Picton, 1986). For instance, Luck and Hillyard (1994) reported a dissociation between anterior and posterior N2 components. Whereas an anterior N2 has been related to detection of novelty, a posterior N2 has been associated with focusing of attention in visual search paradigm, among others. More relevant for the present investigation, Vogel and Machizawa (2004) observed a N2 component which has a more parietally scalp distribution in visual working memory tasks. The authors interpreted this component as a reflect of some aspects of working memory maintenance. Even though there are differences in scalp distribution across all these studies and the present results, it seems that the N2 component is modulated according to the visual overlap between target and reference stimuli.

Following this negative-going component, a positive-going component, generally referred to as P3, typically implies large parieto-central amplitudes, peaking between 300 and 400 ms after stimulus onset (Nieuwenhuis, de Geus, & Aston-Jones, 2011; Sutton, Braren, Zubin, & John,

1965). According to the account of Donchin and Coles (1988) that related P3 effects to “context updating” processes, the P3 component reflects a process in which the contents of working memory are updated upon the arrival of new information. Therefore, in the present study, targets whose consonants are in the same position as those of the reference words were processed as being highly similar to them, whereas targets whose consonants are in different positions than the reference words did not.

General Discussion

The present investigation aimed to provide new evidence regarding whether or not a word target that shares with a word reference all its consonants in the same position produces a different pattern compared to a word that shares with the word reference all its consonants but in a different absolute position.

Altogether, the present results demonstrated that when a reference and the subsequent target share all their consonants, decisions in the same-different matching task are slower and less accurate compared to pairs that did not have any letter in common (i.e., a discrimination cost). Consonant-related references interfered with target processing compared to unrelated pairs, with even stronger interference when the references and targets shared their consonants in an absolute position rather than a relative one. In other words, participants took more time to reject non-identical pairs that shared their consonants in an absolute position compared with pairs that shared their consonants in different positions. Thus, the present findings demonstrate that absolute-position overlap is much more difficult to overcome than relative-position overlap when

pairs of letter strings have to be compared. To our knowledge, this is the first demonstration of different effects of orthographic overlap between two explicitly presented items depending on the position of those consonants in the letter strings.

Up to now, the studies investigating relative vs. absolute position letter coding have mainly used the masked priming paradigm, in which a target word is typically preceded by a non-lexical masked prime. These studies have systematically reported an equivalent priming effect for prime-target pairs overlapping at a relative-position level (e.g., *arict-apricot*) and for those overlapping at an absolute-position level (e.g., *a-ric-t-apricot*) (Peressotti & Grainger, 1999; see also Grainger & Holcomb, 2009, for similar results obtained with ERPs), yielding the conclusion that letter position is not coded in an absolute-position manner, but rather at a more flexible position level. Although the masked priming paradigm is a powerful tool for investigating early stages of word processing, one limitation is that the primes are presented for such a brief period of time that participants are largely unaware of their nature, thus avoiding the establishment of an episodic component (Forster & Davis, 1984). Contrarily, increasing the processing time of the first letter string in the pair (i.e., the prime) allows activation and integration of higher abstract information regarding the first stimulus. By using the same-different perceptual matching task, the present results highlight that the relatively flexible nature of orthographic coding can be influenced by activation of competing lexical representation during target processing when both letter strings in the pair are explicitly presented (see also Burt, 2009; Massol, Molinaro, & Carreiras, 2015; Segui & Grainger, 1990, for comparisons between masked and unmasked priming paradigms). The present results provide new insights on the mechanisms involved in letter position encoding, revealing that these mechanisms are sensitive to the absolute position of the shared letters between the two strings (i.e., the reference and the target in same-different

matching tasks). In other words, overlapping letter representations at an absolute-position level interferes more than those overlapping at the relative-position level.

Some previous studies have reported early physical and/or orthographic effects arising between 100 and 200 ms post-stimulus onset. For instance, Duñabeitia et al. (2012), with the use of the perceptual matching task, found an early character transposition effect mainly for letter strings in the 100-200 ms time-window, anterior and centrally distributed, as compared to digit and symbol strings. Targets preceded by a transposed letter reference were associated with less negative-going waveforms than targets preceded by a replaced letter reference. The authors concluded that letter strings triggered a qualitatively distinct type of processing compared to other types of character strings (see also Carreiras, Quiñones, Hernández-Cabrera, & Duñabeitia, 2015) and interpreted this pattern of effects as reflecting the initial parallel mapping of visual features onto location-specific letter identities, as proposed by Grainger and Ziegler (2011; see also Grainger & van Heuven, 2003). Besides, in masked priming studies of word processing, it has been shown that the N/P150 component, which occurs in the 125-175 ms time-window, is sensitive to physical differences between primes and targets (Chauncey, Holcomb, & Grainger, 2008; Massol, Grainger, Midgley, & Holcomb, 2012; Petit, Midgley, Holcomb, & Grainger, 2006), but also sensitive to the degree of orthographic overlap between primes and targets (Carreiras, Perea, Vergara, & Pollatsek, 2009; Grainger, Kiyonaga, & Holcomb, 2006). While the scalp distribution of the N/P150 component is very focal – a more negative-going effect in the frontal electrode sites and a more positive-going effect in the occipital sites when the targets are the full repetition of the prime compared with unrelated primes, few studies have reported effects with a broader spatial distribution in the same time-window. For instance, Carreiras, Gillon-Dowens,

Vergara and Perea (2009) investigated the time-course of the processing of consonants and vowels in a delayed-letter paradigm. In this study, the critical conditions consisted of the simultaneous presentation of all letters of the letter strings, except that two non-adjacent internal letters (either two consonants or two vowels) were delayed for 50 ms. The authors found a difference in peak latency over anterior electrode sites, in the 120-170 ms time-window, such that the peak latency was larger in the vowel-delayed condition relatively to a baseline identity condition. In another study, Carreiras, Vergara and Perea (2009) reported an orthographic priming effect starting at 150 ms post-target onset, which was larger over the left hemisphere relative to the right. Similarly, Grainger et al. (2006) found a transposed-letter effect that was not restricted to the most posterior electrode sites, but rather had a broader distribution up to the median sites. Although the specific scalp topography seems to vary across studies, these previous data strongly support the hypothesis that components arising in this 120-200 ms time-window reflect an early perceptual process in which the mapping of visual features onto abstract orthographic representations has been initiated (see also Grainger & Ziegler, 2011).

In the two later time-windows, the present results revealed a relatedness effect that was only significant when the reference and target stimuli share all the consonants in the same position in the 200-300 ms and 350-600 ms time-windows. Smaller negativities for targets sharing the consonants with the reference in the same positions as compared to unrelated pairs. According to some previous research, the N2 component is typically elicited by a template (here, the target stimulus) that deviates from another that has been previously mentally stored (here, the reference stimulus) (e.g., Potts & Tucker, 2001). As previously mentioned in the discussion of Experiment 2, the N2 component is hypothesized to reflect the perceptual overlap between a reference and a

target stimulus (Azizian et al., 2006). Furthermore, the N2 component has also been associated with the degree of attention required for processing stimulus in the visual cortex (Suwazono, Machado, & Knight, 2000). During visual working memory tasks, a posterior N2 component has been related to working memory maintenance (Vogel & Machizawa, 2004). Hence, the N2 relatedness effect observed for Absolute conditions can be seen as a consequence of greater difficulty in processing, because participants perceived the consonant-related targets as being highly similar to the reference stimulus. In other words, unrelated reference-target pairs represent a larger mismatch than pairs of words sharing their consonants in the same positions.

Following this negative-going component, a positive-going component was observed. In the 350-600 ms, a consonant relatedness effect was found only when references and targets shared all the consonants in the same positions in the strings relative to unrelated pairs. According to Näätänen (1990), this P3 component can be taken as an index of match or mismatch of a given template (i.e., the target stimulus) as compared to a memory trace (i.e., the reference stimulus). Thus, consonant related targets would, to some extent, constitute a match to the memory trace created by the reference stimulus, whereas unrelated targets would notably deviate from this memory trace. In a similar vein, previous experiments have shown that the P3 amplitude is sensitive to the similarity between the reference and the target (see Comerchero & Polich, 1999). That is, the P3 amplitude is larger (i.e., more positive) when there is a match between the reference and target. Therefore, in the present study, the lesser positive-going waveforms for unrelated pairs could be interpreted as a consequence of the greater mismatch as compared to related pairs (Hoffman, 1990).

Besides, these results are also in line with the Lexical Constraint Hypothesis developed by Duñabeitia and Carreiras (2011). A given word does not activate only the lexical representation of the particular word but also that of orthographically similar words (see Coltheart, Davelaar, Jonasson, & Besner, 1977). According to Duñabeitia and Carreiras (2011), consonants impose strong lexical constraints, notably by imposing higher restriction in activation of lexical candidates. In the present experiment, it will be much more difficult to disentangle reference and target stimuli that shared some letters at the same positions relative to pairs of reference-target sharing letters in different positions. Indeed, similar lexical candidates will receive more activation from both reference and target stimuli when they share consonants at the same positions than when they share consonants in different positions. In other words, the number of activated lexical candidates will be smaller in the former case and so lexical competition operating between activated representations will consequently be associated with more difficulties for selecting the correct lexical representation. To some extent, it will be more difficult for the participant to respond that the reference and target stimuli are not the same when they share consonants in the same position as compared to when they share consonants in different positions. Therefore the N2/P3 effects observed in Experiment 2 can be a combination of a similarity effect between related references and targets in the Absolute set, and of a lexical competition effect for references and targets sharing all their consonants in the same positions.

Finally, one can consider that the masked priming paradigm and the explicit same-different judgment task might tap into different cognitive processing stages due to methodological differences such as the visibility of the items. Such an assumption is in line with evidence comparing masked and unmasked priming showing clear-cut differences in the observed effects.

It has been argued that both paradigms are mediated by common mechanisms and common representations but reflect different processes operating during target processing (Bowers, 2003; Burt, 2009). Moreover, according to a neuroimaging approach, consciously presented stimuli generate, in addition to bottom-up activity, reverberation of neural activity, which is mainly characterized by top-down amplification (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Haynes, Driver, & Rees, 2005; see also Kouider & Dehaene, 2007, for review). Hence, we argue that the effects reported here are mainly due to the visuo-orthographic overlap between the two related strings. Although these effects are mainly driven by the perceptual similarity between reference and target stimuli, it is still possible that high-order lexical competition between representations of the two words may also contribute to the observed effects.

Conclusions

In conclusion, the pattern of results observed in the present experiments highlight the importance of consonants in reading and demonstrates that two explicitly presented words containing the same consonants are processed as being highly similar to each other. These data revealed that overlapping letter representations at an absolute-position level are significantly more important for readers than those overlapping at the relative-position level.

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References

- Angiolillo-Bent, J. S., Rips, L. J. (1982). Order information in multiple-element comparison. *Journal of Experimental Psychology: Human Perception and Performance*, 8, 392-406. doi:10.1037/0096-1523.8.3.392
- Azizian, A., Freitas, A. L., Parvaz, M. A., & Squires, N. K. (2006). Beware misleading cues: perceptual similarity modulates the N2/P3 complex. *Psychophysiology*, 43(3), 253-260.
- Bowers, J. S. (2003). An abstractionist account of masked and Long-term priming. In S. Kinoshita and S. J. Lupker (Eds.), *Masked priming: State of the art* (pp. 97-120). Hove, UK: Psychology Press. doi: 10.4324/9780203502846
- Burt, J. S. (2009). Identifiable orthographically similar word primes interfere in visual word identification. *Journal of Memory and Language*, 61, 259 - 284. doi : 10.1016/j.jml.2009.06.003
- Carreiras, M., Duñabeitia, J. A., & Molinaro, N. (2009). Consonants and vowels contribute differently to visual word recognition: ERPs of relative position priming. *Cerebral Cortex*, 19, 2659 – 2670. doi:10.1093/cercor/bhp019
- Carreiras, M., Gillon-Dowens, M., Vergara, M. & Perea, M. (2009). Are vowels and consonants processed differently? ERP evidence with a delayed letter paradigm. *Journal of Cognitive Neuroscience*. 21, 275-288.
- Carreiras, M., Quiñones, I., Hernández-Cabrera, J.A., & Duñabeitia, J.A. (2015). Orthographic coding: Brain activation for letters, symbols and digits. *Cerebral Cortex*, 25(12), 4748-4760. doi: 10.1093/cercor/bhu163
- Carreiras, M., Perea, M., Vergara, M., & Pollatsek, A. (2009). The time course of orthography and phonology: ERP correlates of masked priming effects in Spanish. *Psychophysiology*,

- 46, 1113-1122. doi: 10.1111/j.1469-8986.2009.00844
- Carreiras, M., Vergara, M., & Perea, M. (2009). ERP correlates of transposed-letter priming effects: The role of vowels vs. consonants. *Psychophysiology*, *46*, 34-42.
- Chauncey, K., Holcomb, P. J., & Grainger, J. (2008). Effects of stimulus font and size on masked repetition priming: An ERP investigation. *Language and Cognitive Processes*, *2*, 183-200. doi: 10.1080/01690960701579839
- Coltheart, M., Davelaar, E., Jonasson, J. T., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), *Attention and performance IV* (pp. 535-555). Hillsdale, NJ: Erlbaum. DOI: 10.3758/bf03197471
- Comerchero, M. D., Polich, J. (1999). P3a and P3b from typical auditory and visual stimuli. *Clinical Neurophysiology*, *110*, 24-30. doi: 10.1016/s0168-5597(98)00033-1
- Davis, C. J. (2010). The spatial coding model of visual word identification. *Psychological Review*, *117*, 713-758. doi: 10.1037/a0019738
- Davis, C. J., & Perea, M. (2005). BuscaPalabras: A program for deriving orthographic and phonological neighborhood statistics and other psycholinguistic indices in Spanish. *Behavior Research Methods*, *37*, 665-671. DOI: 10.3758/bf03192738.
- Dehaene, S., Changeux, J. P., Naccache, L., Sackur, J., & Sergent, C. (2006). Conscious, preconscious, and subliminal processing: a testable taxonomy. *TICS*, *10*, 204–211. doi: 10.1016/j.tics.2006.03.007
- Donchin, E., Coles, M. G. H., (1988). Is the P300 component a manifestation of context updating? *Behavioral Brain Sciences*, *11*, 357–374. doi; 10.1017/s0140525x00058027
- Duñabeitia, J. A., & Carreiras, M. (2011). The relative position priming effect depends on whether letters are vowels or consonants. *Journal of Experimental Psychology: Learning*,

- Memory, and Cognition*, 37(5), 1143-1163. doi: 10.1037/a0023577
- Duñabeitia, J.A., Dimitropoulou, M., Grainger, J., Hernández, J.A., & Carreiras, M. (2012). Differential sensitivity of letters, numbers and symbols to character transpositions. *Journal of Cognitive Neuroscience*, 24(7), 1610-1624. doi: 10.1162/jocn_a_00180
- Duñabeitia, J. A., Perea, M., & Carreiras, M. (2007). Do transposed-letter similarity effects occur at a morpheme level? Evidence for morpho-orthographic decomposition. *Cognition*, 105(3), 691-703. doi:10.1016/j.cognition.2006.12.001
- Folstein, J. R., & van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology*, 45, 152-170. doi: 10.1111/j.1469-8986.2007.00602.x
- Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 10, 680-698. doi:10.1037/0278-7393.10.4.680
- García-Orza J, Perea M, Muñoz S (2010) Are transposition effects specific to letters? *Quarterly Journal of Experimental Psychology*, 63:1603-1618.
- Geisser, S., & Greenhouse, S. (1959). On methods in the analysis of profile data. *Psychometrika*, 24, 95-112. doi: 10.1007/bf02289823
- Gomez, P., Ratcliff, R., & Perea, M. (2008). The overlap model: A model of letter position coding. *Psychological Review*, 115, 577-601. doi:10.1037/a0012667
- Grainger, J. (2008). Cracking the orthographic code: An introduction. *Language and Cognitive Processes*, 23(1), 1-35. doi:10.1080/01690960701578013
- Grainger, J., Dufau, S., & Ziegler, J. C. (2016). A vision of reading. *Trends in Cognitive Sciences*, 20(3), 171-179. doi: 10.1016/j.tics.2015.12.008

- Grainger, J., Granier, J. P., Farioli, F., van Assche, E., & van Heuven, W. (2006). Letter position information and printed word perception: The relative-position priming constraint. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(4), 865-884. doi:10.1037/0096-1523.32.4.865
- Grainger, J., & Holcomb, P. J. (2009). An ERP investigation of orthographic priming with relative-position and absolute-position primes. *Brain Research*, *1270*, 45-53. doi: 10.1016/j.brainres.2009.02.080.
- Grainger, J., Kiyonaga, K., & Holcomb, P. J. (2006). The Time Course of Orthographic and Phonological Code Activation. *Psychological Sciences*, *17* (12), 1021-1026. doi : 10.1111/j.1467-9280.2006.01821.x
- Grainger, J. & van Heuven, W. (2003). Modeling Letter Position Coding in Printed Word Perception. In P. Bonin (Ed.), *The Mental lexicon*. New York : Nova Science Publishers (pp. 1-24). doi: 10.1037/0096-1523.32.4.865
- Grainger, J., & Ziegler, J. C. (2011). A dual-route approach to orthographic processing. *Frontiers in Psychology*. doi: 10.3389/fpsyg.2011.00054
- Haynes, J. D., Driver, J., & Rees, G. (2005). Visibility reflects dynamic changes of effective connectivity between V1 and fusiform cortex. *Neuron*, *46*, 811–821. doi : 10.1016/j.neuron.2005.05.012
- Hoffman, J. E. (1990). Event-related potentials and automatic and controlled processes. In Rohrbaugh JW, Parasurama R, Johnson R (Eds). *Event-related potentials: basic issues and implications*. Oxford University Press, New York, Oxford, pp. 145-157.
- Holcomb, P. J., & Grainger, J. (2006). On the time-course of visual word recognition: An ERP investigation using masked repetition priming. *Journal of Cognitive Neuroscience*, *18*

- (10), 1631-1643.
- Humphreys, G. W., Evett, L. J., & Quinlan, P. T. (1990). Orthographic processing in visual word identification. *Cognitive Psychology*, 22, 517-560. doi: 10.1016/0010-0285(90)90012-s
- Kinoshita, S., & Norris, D. (2009). Transposed-letter priming of pre-lexical orthographic representations. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 35, 1-18. doi: 10.1037/a0014277
- Kouider, S., & Dehaene, S. (2007). Levels of processing during non-conscious perception: a critical review. *Philosophical Transactions of the Royal Society of London B*, 362, 857-875. doi: 10.1098/rstb.2007.2093
- Luck, S.J. (1995). Multiple mechanisms of visual-spatial attention: Recent evidence from human electrophysiology. *Behavioural Brain Research*, 71, 113-123.
- Luck, S. J., & Hillyard, S. A. (1994). Electrophysiological correlates of feature analysis during visual search. *Psychophysiology*, 31, 291-308.
- Luck, S.J, Hillyard, S.A., Mouloua, M., Woldorff, M.G., Clark, V.P., & Hawkins, H.L. (1994). Effects of spatial cuing on luminance detectability: Psychophysical and electrophysiological evidence for early selection. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 887-904.
- Mangun, G.R., & Hillyard, S.A, (1991). Modulations of sensory-evoked brain potentials indicate changes in perceptual processing during visual-spatial priming. *Journal of Experimental Psychology: Human perception and performance*, 17(4), 1057-1074.
- Massol, S., Duñabeitia, J. A., Carreiras, M., & Grainger, J. (2013). Evidence for letter-specific position coding mechanisms. *PLoS ONE* 8(7): e68460.

doi:10.1371/journal.pone.0068460

Massol, S., Grainger, J., Dufau, S., Holcomb, P. (2010). Masked priming from Orthographic Neighbors: An ERP Investigation. *Journal of Experimental Psychology: Human, Perception and Performance*, 36(1), 162-174.

Massol, S., Grainger, J., Midgley, K. J., & Holcomb, P. J. (2012). Masked repetition priming of letter-in-string identification: An ERP investigation. *Brain Research*, 1472, 74-88.

doi:10.1016/j.brainres.2012.07.018

Massol, S., Midgley, K. J., Holcomb, P. J., Grainger, J. (2011). When less is more: Feedback, priming, and the pseudoword superiority effect. *Brain Research*, 1386, 153-164. doi: 10.1016/j.brainres.2012.07.018

Massol, S., Molinaro, N., & Carreiras, M. (2015). Lexical inhibition of neighbors during visual word recognition: an unmasked priming investigation. *Brain Research*, 1604, 35-51.

Näätänen, R., (1990). The role of attention in auditory information processing as revealed by event-related potentials and other brain measures of cognitive function. *Behavioral Brain Sciences*, 13, 201-288. doi: 10.1017/s0140525x00078407

Näätänen, R., & Picton, T. W. (1986). N2 and automatic versus controlled processes.

Electroencephalography & Clinical Neurophysiology, 38, 169-186.

New, B., Araújo, V., & Nazzi, T. (2008). Differential processing of consonants and vowels in lexical access through reading. *Psychological Science*, 19(12), 1223-1227. doi:

10.1111/j.1467-9280.2008.02228

New, B., & Nazzi, T. (2014). The time course of consonant and vowel processing during word recognition. *Language, Cognition and Neuroscience*, 29(2), 147-157. doi:

10.1080/01690965.2012.735678

Nieuwenhuis, S., de Geus, E.J., & Aston-Jones, G. (2011). The anatomical and functional relationship between the P3 and autonomic component of the orienting response.

Psychophysiology, 48(2), 162-175. doi: 10.1111/j.1469-8986.2010.01057.x

Norris, D., & Kinoshita, S. (2012). Reading through a noisy channel: Why there is nothing special about the perception of orthography. *Psychological Review*, 119, 517-545. doi:

10.1037/a0028450

Perea, M., & Carreiras, M. (2006a). Do transposed-letter similarity effects occur at a prelexical phonological level? *Quarterly Journal of Experimental Psychology*, 59, 1600-1613. doi:

10.1080/17470210500298880

Perea, M., & Carreiras, M. (2006b). Do transposed-letter similarity effects occur at a syllable level? *Experimental Psychology*, 53, 308-315. doi: 10.1027/1618-3169.53.4.308

Perea, M., Duñabeitia, J. A., & Carreiras, M. (2008). Transposed-letter priming effects for close vs. distant transpositions. *Experimental Psychology*, 55, 397-406. doi:

10.1027/1618-3169.55.6.384

Perea, M., & Lupker, S. J. (2003). Transposed-letter confusability effects in masked form priming. In S. Kinoshita and S. J. Lupker (Eds.), *Masked priming: State of the art* (pp.

97-120). Hove, UK: Psychology Press. doi: 10.4324/9780203502846

Perea, M., Lupker, S. J. (2004). Can CANISO activate CASINO? Transposed-letter similarity effects with nonadjacent letter positions. *Journal of Memory and Language*, 51, 231-246.

doi: 10.1016/j.jml.2004.05.005

Peressotti, F., & Grainger, J. (1999). The role of letter identity and letter position in orthographic priming. *Perception and Psychology*, 61, 691-706. doi:

10.3758/bf03205539

- Petit, J. P., Midgley, K. J., Holcomb, P. J., & Grainger, J. (2006). On the time-course of letter perception: A masked priming ERP investigation. *Psychonomic Bulletin and Review*, *13*(4), 674-681. doi: 10.3758/bf03193980
- Potts, G. F., & Tucker, D. M. (2001). Frontal evaluation and posterior representation in target detection. *Cognitive Brain Research*, *11*, 147-156.
- Proctor, R.W. (1981). A unified theory for matching-task phenomena. *Psychological Review*, *88*, 291-326. doi: 10.1037/0033-295x.88.4.291
- Behavioral and Brain Functions*, 4-27. doi: 10.1186/1744-9081-4-27
- Ratcliff, R. (1981). A theory of order relations in perceptual matching. *Psychological Review*, *88*, 552-572. doi: 10.1037/0033-295x.88.6.552
- Schoonbaert, S. & Grainger, J. (2004). Letter position coding in printed word perception: Effects of repeated and transposed letters. *Language and Cognitive Processes*, *19*, 333-367. doi: 10.1080/01690960344000198
- Segui, J., & Grainger, J. (1990). Priming word recognition with orthographic neighbors: Effects of relative prime-target frequency. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 65-76. doi: 10.1037/0096-1523.16.1.65
- Squires, K. C., Hillyard, S. A., & Lindsay, P. H. (1973). Cortical potentials evoked by feedback confirming and disconfirming an auditory discrimination. *Perception and Psychophysics*, *13*, 25-31. doi: 10.3758/bf03207230
- Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked-potential correlates of stimulus uncertainty. *Science*, *150*, 1187-1188. doi: 10.1126/science.150.3700.1187

- Suwazono, S., Machado, L., & Knight, R. T. (2000). Predictive value of novel stimuli modifies visual event-related potentials and behavior. *Clinical Neurophysiology*, *111*, 29-39.
- van Assche, E., & Grainger, J. (2006). A study of relative-position priming with superset primes. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *32*(2), 399-415. doi : 10.1037/0278-7393.32.2.399
- Van Veen, V. & Carter, C. S. (2002). The timing of action-monitoring processes in the anterior cingulate cortex. *Journal of Cognitive Neuroscience*, *14* (4), 593-602.
- Vogel, E. K., & Machizawa, M. G. (2004). Neural activity predicts individual differences in visual working memory capacity. *Nature*, *428*, 748–751.
- Whitney, C. (2001). How the brain encodes the order of letters in a printed word: The SERIOL model and selective literature review. *Psychonomic Bulletin and Review*, *8*, 221-243. doi:10.3758/BF03196158
- Whitney, C., & Cornelissen, P. L. (2008). SERIOL reading. *Special Issue of Language and Cognitive Processes*, *23*, 143-164. doi:10.1080/01690960701579771

Table 1

	Reference stimuli		Target stimuli		<i>p</i> values
	Average	<i>St. dev.</i>	Average	<i>St. dev.</i>	
Frequency	27.83	75.63	26.18	116.08	.875
Log Frequency	0.90	0.57	0.96	0.50	.323
Number of letters	5.49	0.50	5.49	0.50	1.00
Number of orthographic neighbors	2.73	2.50	2.86	2.51	.628
Sum log bigram frequency	11	1.74	11	1.84	.526
Mean log bigram frequency	2	0.30	2	0.32	.526

Table 1. Descriptive statistics for all reference and target stimuli (from B-Pal Database; Davis & Perea, 2005).

Table 2

	Absolute position		Relative position		P values
	Average	<i>St. dev.</i>	Average	<i>St. dev.</i>	
Frequency	23.86	<i>59.77</i>	28.49	<i>153.35</i>	.792
Log Frequency	0.98	<i>0.52</i>	0.93	<i>0.48</i>	.512
Number of letters	5.44	<i>0.49</i>	5.53	<i>0.50</i>	.230
Number of orthographic neighbors	3.14	<i>2.65</i>	2.56	<i>2.34</i>	.150
Sum log bigram frequency	11	<i>1.79</i>	11	<i>2.07</i>	.821
Mean log bigram frequency	2	<i>0.29</i>	2	<i>0.34</i>	.372

Table 2. Descriptive statistics for target stimuli (from B-Pal Database; Davis & Perea, 2005).

Figure captions

Figure 1. Schematic representation of an experimental trial.

Figure 2. Response time (in milliseconds, left panel) and percent error (right panel) to target words preceded either by a reference word that share all the consonants at the exact same positions or by a reference word that share all the consonants at different positions compared with unrelated references in Experiment 1.

Figure 3. Electrode montage and analysis columns used for ANOVAs.

Figure 4. Response time (in milliseconds, left panel) and percent error (right panel) to target words preceded either by a reference word that share all the consonants at the exact same positions or by a reference word that share all the consonants at different positions compared with unrelated references in Experiment 2.

Figure 5. Grand average ERPs corresponding to absolute conditions, over 17 representative electrode sites for the related condition (black lines) and the unrelated condition (red lines).

Figure 6. Grand average ERPs corresponding to relative conditions, over 17 representative electrode sites for the related condition (black lines) and the unrelated condition (red lines).

Figure 7. Voltage maps centered on the three epochs used in the statistical analyses. The maps represent voltage differences at each electrode site calculated by subtracting the voltage values in the related condition from the voltage values in the corresponding unrelated condition in Experiment 2.

Figure 1

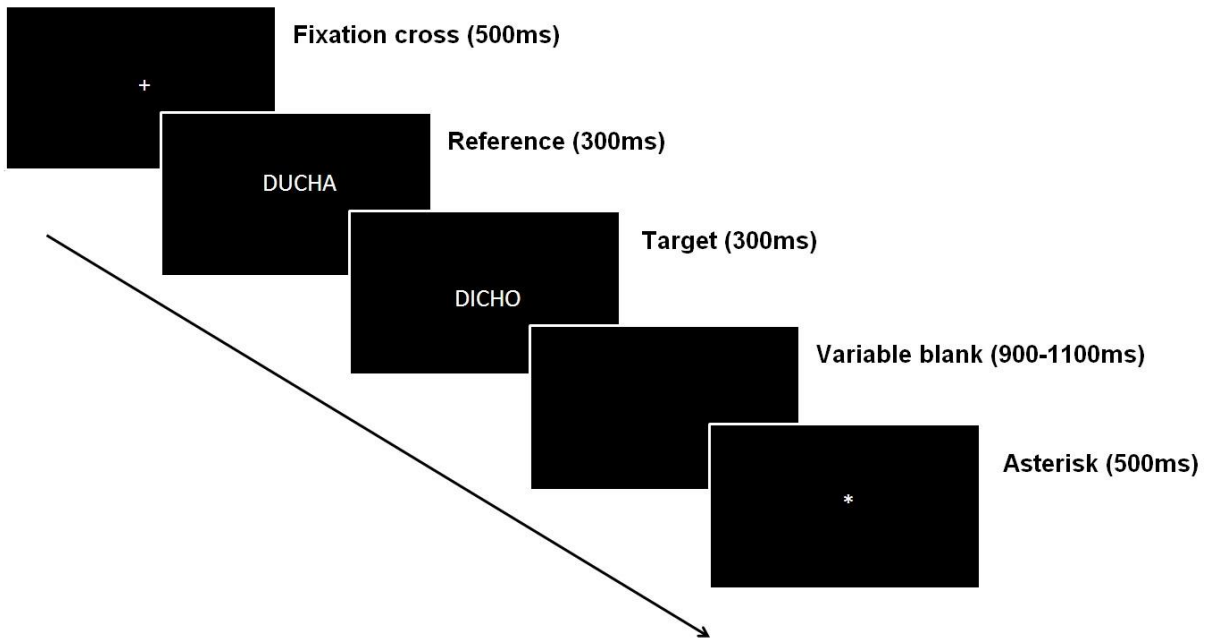
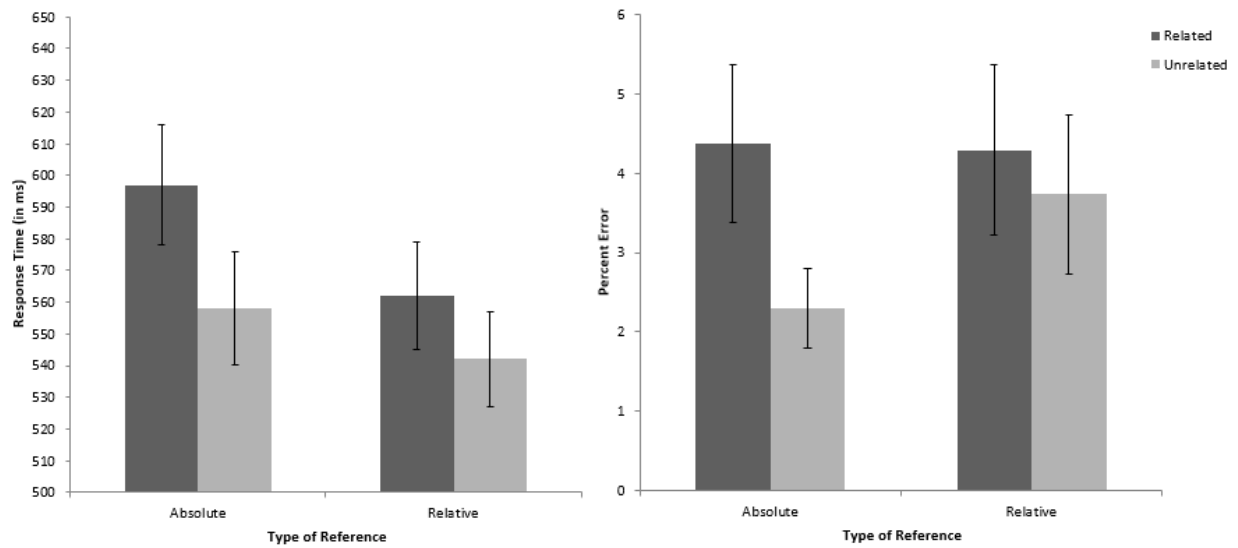


Figure 2



Note: Mean reaction times and percentage of errors for the “same” trials were 529 ms (4.28%) for targets.

Figure 3

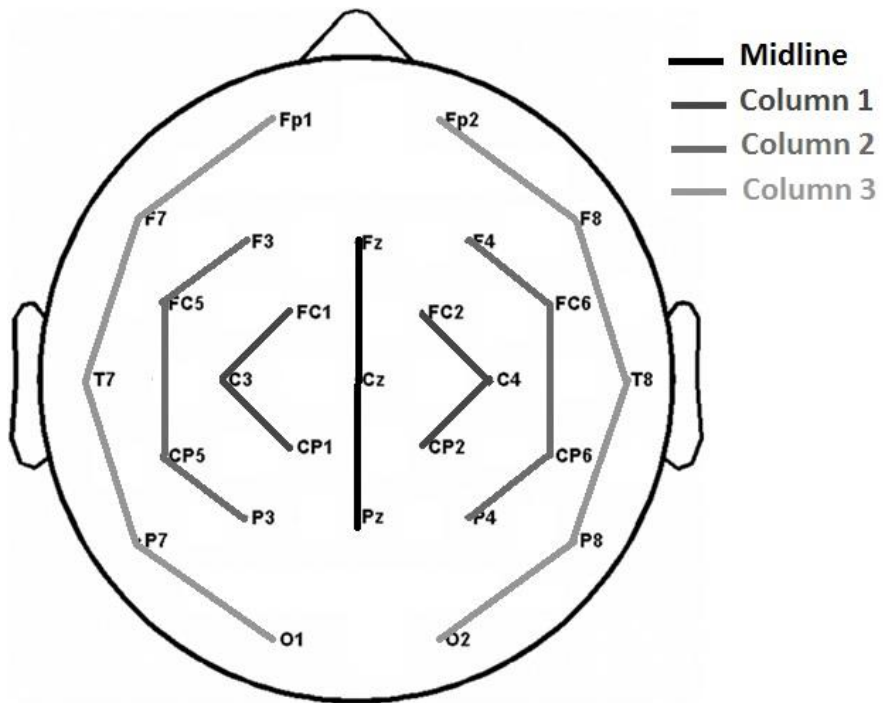
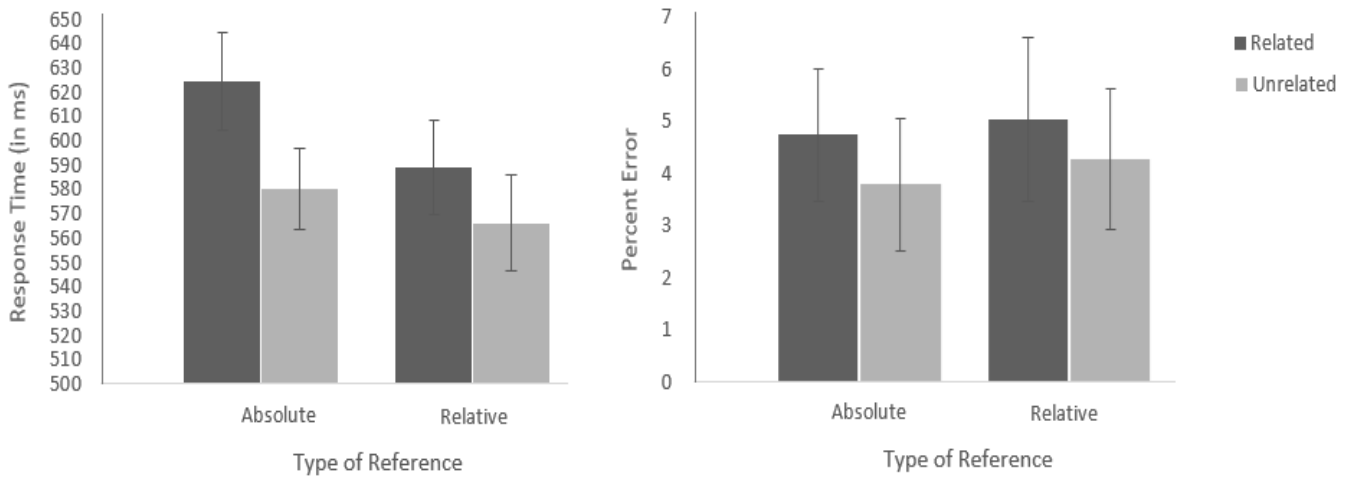


Figure 4



Note: Mean reaction times and percentage of errors for the “same” trials were 550 ms (6.67%) for targets.

Figure 5

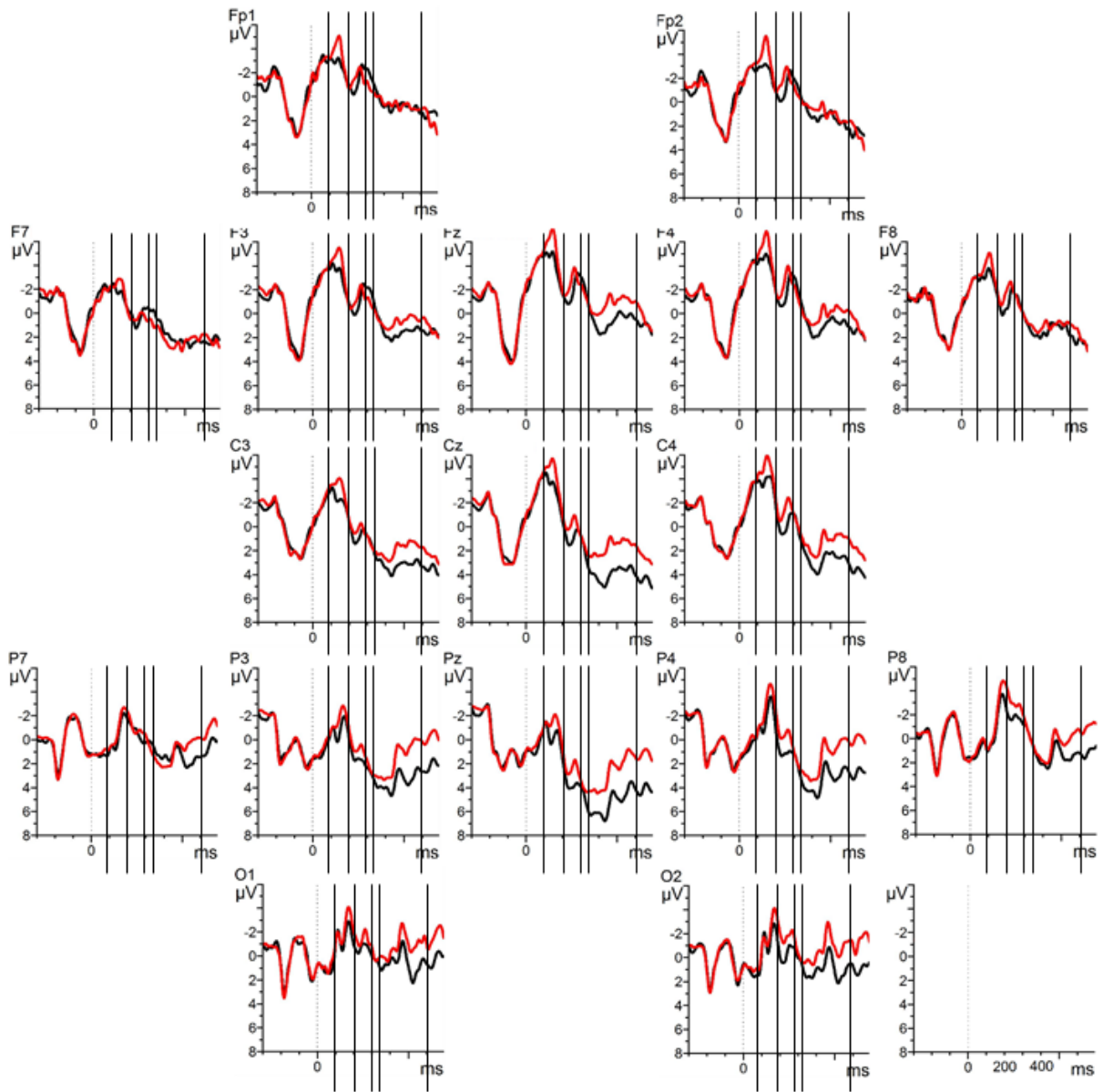


Figure 6

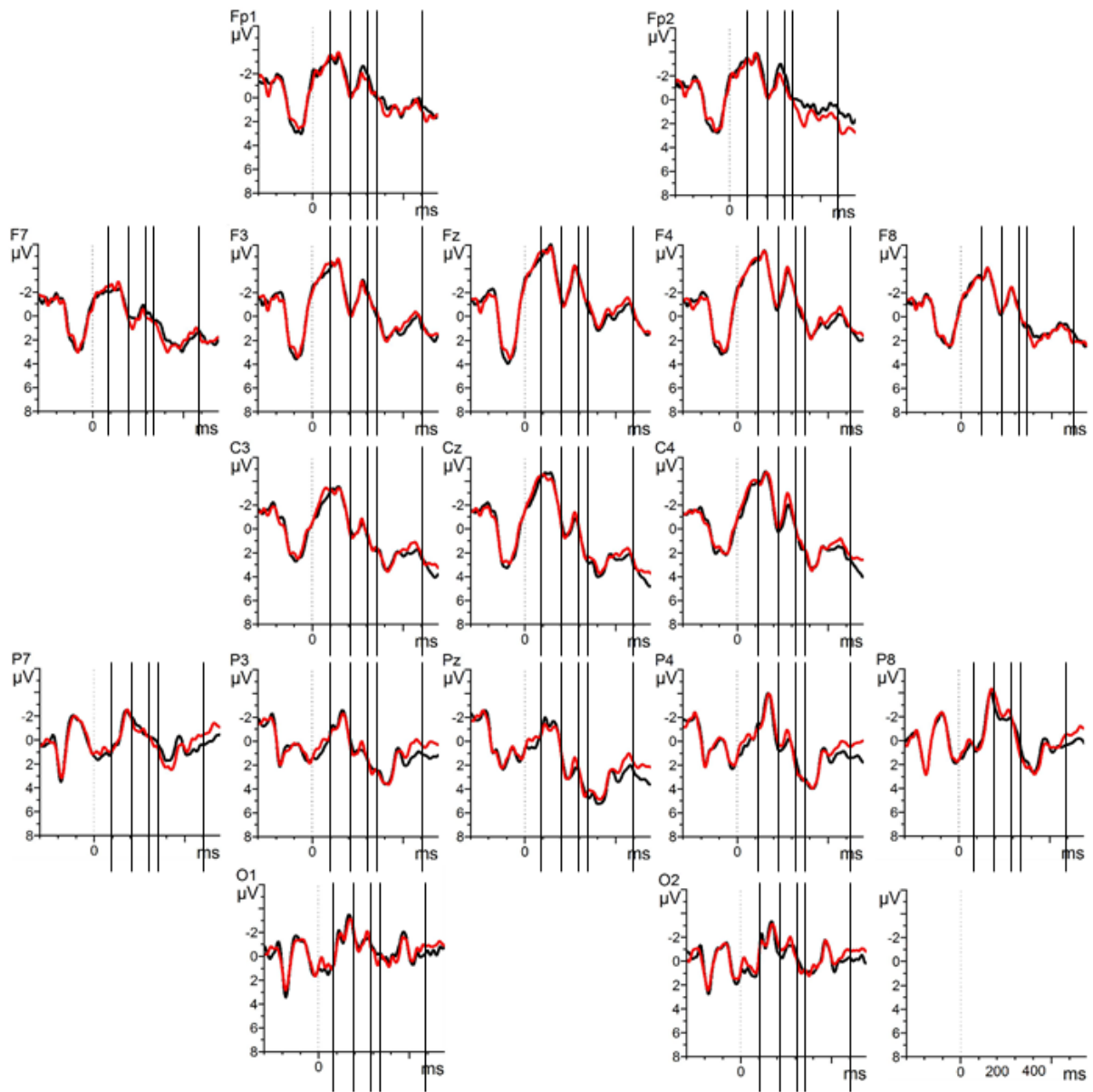


Figure 7

