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Title: N250 effects for letter transpositions depend on lexicality: *Casual* or *causal*?

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Running Head: Transposed-letter ERP masked priming effects

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Abstract

We examined the electrophysiological correlates of one of the most influential orthographic effects: The transposed-letter masked priming effect. Transposed-letter nonword-word pairs were included (*jugde-judge*), as well as transposed-letter word-word pairs (*casual-causal*) to investigate the influence of prime's lexicality in the transposed letter effect. The results showed that when compared against the substituted-letter control conditions (*jugde-judge* vs. *jupte-judge*), transposed-letter primes produced a lower negativity in the N250 component. In contrast, no differences were obtained between the two word-word priming conditions (*casual-causal* vs. *carnal-causal*). The influence of lexicality in the transposed-letter effect is discussed according to models of visual word recognition and previous evidence from ERPs.

Keywords: Visual Word Recognition; Letter Transpositions; N250; Orthographic

neighbors.

Introduction

In the process of visual word recognition readers extract information from the letters that constitute the string, identifying their identities and their position within the word [1]. This way, a reader distinguishes the correct lexical entry among visually similar candidates, inhibiting competing representations with overlapping letter identity and position information [2]. However, these neighboring orthographic competing words affect reader's performance. For instance, it has been shown that the larger the density of the word's orthographic neighborhood (e.g., *rat* or *car* as neighbors of *cat*) the faster and more accurately the word is read ([3] for review].

A remarkable part of the evidence concerning letter identification and ordering has been obtained from studies dealing with a well-known orthographic effect: The transposed-letter (TL) similarity effect. When a nonword is created by transposing two letters of a word (*jugde* from *judge*), this nonword is mistaken as the original word due to the perceptual similarity between the two strings [4,5]. Probably the most influential pieces of evidence have been obtained in masked priming experiments, showing that TL nonword primes produce form-priming effects relative to the appropriate orthographic control (*jugde-judge* vs. *jupte-judge* [6-8]). These results have been taken as evidence against models of word recognition that assume "position-specific" letter coding schemes [9], and have favored models that assume certain tolerance to position specificity [10-13].

Paradoxically, almost all the TL effects have been obtained in manipulations involving nonwords, not from real words. This is of special relevance, since a reader might tend to misread the nonword *jugde* as *judge*, but perceiving the word *trail* as *trial* might not be so common. Whilst the most stable lexical representation that could match the letter pattern in *jugde* and that could act as a strong attractor might be the word *judge*, the word *trail* has its own lexical representation and therefore this, and not *trial*, would be its most influential attractor. Despite the clear relevance of this issue for models, experiments dealing with transposed-letter word pairs are very scarce. Castles, Davis and Forster [14] reported a lexical decision experiment that explored masked TL priming effects for transposed-letter word pairs (*sign-sing*). They failed to find a TL priming effect relative to an orthographically unrelated condition (*clap-sing*). Duñabeitia, Perea and Carreiras [15] have also reported null TL word priming effects in a series of lexical decision masked priming experiments in which targets that were briefly preceded by TL prime words (*causal-casual*) were compared to double-letter substitution word primes (*carnal-casual*) and to totally unrelated word primes (*window-casual*) – note that the substituted-letter control condition is the most common baseline condition[1]. Thus, the behavioral evidence of TL masked priming effects with word primes points to a lack of facilitation on the target word recognition by the corresponding TL prime word, whilst the facilitative effect is constant when primes are TL nonwords[2]. The present study is aimed at exploring the influence of the lexical status of the primes in the TL priming effect by combining masked priming with event-related potential (ERP) recordings, with special attention to the early orthographic encoding stages of visual word recognition.

Preceding ERP evidence regarding the influence of masked TL primes on target words is very scarce, and importantly, restricted to nonword primes preceding word targets (TL word pairs have not been tested). Grainger, Kiyonaga and Holcomb [18] were the first to report the electrophysiological correlates for the TL priming effect for nonword primes, showing a clear posterior-oriented difference between TL pairs (*barin-brain*) as compared to double-letter substitution controls (*bosin-brain*). They found a more negative-going waveform between 150-250ms for substitution-letter nonword primes than for TL nonword primes. This component was characterized as a N250, which has been defined as a brain potential sensitive to form-level processing [18-20]. Holcomb and Grainger [19] showed that under masked priming conditions, the latency and amplitude of the N250 component reflected differences in form representations. They found larger (more negative) N250 for unrelated priming conditions (*porch-table*) than for full (*table-table*) and partial (*teble-table*) repetition conditions. Moreover, partial repetition conditions also showed larger negativity than full repetition priming conditions. They concluded that "*the more mismatching letters, the greater the amplitude*" of the N250 (p.1640). Carreiras, Vergara and Perea [21] also replicated this pattern of results in an ERP study that was devoted to explore the influence of the type of letter in the TL priming effects. Interestingly, among other effects, they also found a general TL priming effect that was mainly evident in the N250 time-window. Hence, at this point what seems clear is that the N250 component is sensitive to masked TL nonword-word priming, showing larger negativities for the double-letter substitution condition than for the TL condition. However, it is unclear whether this effect would hold for letter transpositions that result in the creation of a word (e.g., *trial-trail*). Unfortunately, due to clear linguistic restrictions (note that the presence of these type of word pairs is rare in most languages), such a manipulation has not been tested yet. Nonetheless, as argued before, there are reasons to think that the TL priming effect would result in different ERP effects depending on prime's lexicality.

According to previous behavioral data [14,15], the two members of a transposed-letter word pair exert scarce or null influence one onto the other, at least under masked priming conditions in the lexical decision task. Hence, it is unclear whether the N250 component, conceived as the clearest electrophysiological marker of the TL priming effect for nonword-word pairs, would be similarly modulated with a word-word manipulation. The idea that the N250 component is a marker of sub-lexical processing would predict that the TL priming effect should be highly similar for words and nonwords, since N250 would only reflect the processing of the relative positions of a word's constituent letters at a pure form level, with no influences of lexical or semantic factors [22]. Moreover, activation-based models of word identification predict that at early orthographic encoding stages, no differences should emerge for word and nonword TL primes with respect to their word targets, and that the null TL effect for word pairs would emerge as a consequence of later top-down effects from the lexical to the letter level, which would be stronger for words than for nonwords (consequently producing increased lateral inhibition within the lexical level). If this were the case and if the N250 reflects sub-lexical letter identification and parsing, no interaction between the TL priming effect and the lexicality of the prime would be expected. However, there is evidence showing that lexico-semantic factors have an impact in early ERP components in the masked priming paradigm. For instance, Morris, Frank, Grainger and Holcomb [23] found that semantic transparency of morphologically related words modulated the N250 component. In their study, pairs like *walker-walk* (with a transparent morphological relationship), *corner-corn* (with an opaque morphological relationship), and *brothel-broth* (with a form overlap) produced differential effects in the N250, and concluded that this component reflected an interface between sub-lexical (bottom-up) and lexico-semantic (top-down) representations, insofar it is sensitive to morphological decomposition processes and to semantic transparency, to some degree. Hence, it is possible at this stage that a factor such as prime lexicality might modulate the N250 TL effect. The present study is aimed at clarifying this issue, better defining this component.

In the present study Basque speakers were presented with visual target words that were briefly preceded by transposed-letter or substituted-letter word (e.g., *casual-causal* vs. *carnal-causal*) or nonword primes (e.g., *barin-brain* vs. *bosin-brain*). Basque is spoken by about 700.000 speakers in the Basque Country (South-West of France and North-East of Spain). The study was done in Basque because this language has a sufficient amount of TL word pairs.

Method

Participants. 23 native Basque speakers[3] (12 females; mean age: 20.09 years) with no history of neurological or psychiatric impairment took part in this experiment and were paid for their collaboration. All of them had normal or corrected-to-normal vision and were right-handed, as assessed with the Basque version of the Edinburgh Handedness Inventory. They all signed consent forms are were informed about the experimental procedure in advance. The ULL Ethical Committee formally approved the experiment.

Materials. A set of 84 Basque target words was selected for the word prime conditions (e.g., *pareta*, wall). These words were preceded by Basque prime words that were 1) their transposed-letter neighbor word (*partea-pareta;* a part-wall), or 2) a double-letter substitution word in which the two critical letters were substituted by other letters (*parada-pareta;* opportunity-wall). TL word primes and substituted-letter word primes were matched for frequency, length and orthographic neighbors (see Table 1). None of the word pairs were semantically or morphologically related. Another set of 84 different Basque target words was also selected for the nonword prime conditions (e.g., *artazi*, scissors). These words were matched to the previous set of target words in frequency, length and number of orthographic neighbors. These target words did not have any TL neighbors. The target words were preceded by nonword primes that were 1) the same as the target except for the transposition of two letters (*artzai-artazi*), or that were 2) the same as the target except for the substitution of the two letters involved in the transposition (*artrei-artazi*). A set of 24 names of professions was also included to make the semantic categorization possible (e.g., *maisu*, teacher). None of the prime or target words in the critical conditions referred to a profession. (Note that this same procedure was followed by Grainger et al. [18], who also presented the critical words for passive reading; Recent ERP evidence suggests that this task is also highly sensitive to low-level perceptual factors [19]). The 24 names of professions were presented twice, once as targets and once as primes (followed by unrelated targets), in order to control for prime visibility. Two lists of materials were constructed so that each critical target appeared once in each list, but each time in a different priming condition (transposed-letter or substituted-letter). 12 participants completed list 1 and 11 participants completed list 2.

-Table_1-

Procedure. Participants were individually tested in a well-lit soundproof room at the ELEBILAB laboratory (Vitoria-Gasteiz). The presentation of the stimuli was carried out using E-Prime. All stimuli were presented on a high-resolution monitor that was positioned at eye level 80-90cm in front of the participant. Each trial consisted in the presentation of a forward mask created by hash mark symbols for 500ms, followed by the displaying of the prime for 50ms, and immediately followed by the presentation of the target. Primes were presented in lowercase and targets in uppercase, in order to avoid direct physical overlap between primes and targets. Primes and targets were presented in 12pt. Courier New. Target items remained on the screen for 500ms. Inter-trial interval varied randomly between 700-900ms. Participants reported no awareness of the lowercase stimuli when asked after the experiment. All items were presented in a different random order for each participant. Participants performed a semantic categorization task: they were instructed to press the spacebar on the keyboard to indicate whether the letter string displayed referred to the name of a profession. Twenty warm-up trials, containing different stimuli from those used in the experimental trials, were provided at the beginning of the session. Participants were asked to avoid eye movements and blinks during the interval when the row of hash marks was not present.

EEG recording and analyses. Scalp voltages were collected from 58 Ag/AgCl electrodes which were mounted in an elastic cap (ElectroCap International, Eaton, USA, 10-10 system). The right mastoid earlobe was used as reference during acquisition at 512Hz of sampling rate. Eye movements and blinks were monitored with two further electrodes providing bipolar recordings of the horizontal and vertical electro-oculogram (EOG). Inter-electrode impedances were kept below 10KΩ. EEG was acquired with an analogue bandpass filter of 0.01-100Hz and re-filtered off-line with a 20Hz low-pass digital filter. The signal was then re-referenced to the linked mastoid activity. Epochs starting 200ms before and finishing 600ms after the target word presentation were selected for artifact rejection. Each epoch was in fact visually inspected in order to verify if there were artifacts and this operation resulted in the rejection of 5.5% of the epochs, without statistical difference in the number of rejections across conditions ($F(3,66)=1.242$, $p>0.1$). Baseline correction was performed based on the electrophysiological activity in the 100ms preceding the onset of the prime words as a reference signal value. Epochs were then averaged for each subject in the different conditions (Nonword Transposition, Nonword Substitution, Word Transposition, Word Substitution). Single-subject averages were then used to extract the grand-average to visually inspect the main effects comparing the four conditions.

Statistical analyses were run calculating the voltage activity in time windows of interest that corresponded to the N250 component (between 200-300ms) because this component was previously reported to be affected by transposed-letter manipulations in masked priming studies [18]. We run two distinct analyses on these data. The first was planned to verify the effects on the *midline*: a three-way ANOVA was run, with Electrode (four levels: Fz, Cz, Pz, Oz), Lexicality (two levels: Word and Nonword primes) and Condition (two levels: Transposition and Substitution) as factors. Possible *lateralized* effects were evaluated through an analysis on six groups of electrodes: Left Anterior group (average activity in F5,F3,F1,C5A,C3A,C1A), Right Anterior (F6,F4,F2,C6A,C4A,C2A), Left Central (C5,C3,C1,C1P,C3P,TCP1), Right Central (C6,C4,C2,C2P,C4P,TCP2), Left Posterior (P5,P3,P1,P1P,P3P,CB1) and Right Posterior (P6,P4,P2,P2P,P4P,CB2). The *lateralized* ANOVA included four factors: Longitude (three levels: Anterior, Central, Posterior), Hemisphere (two levels: Left, Right), Lexicality and Condition. Significant factors are reported only when they interact with the Lexicality and condition factors. Probability values are reported corrected with the Greenhouse-Geisser procedure [24].

In addition, we evaluated every possible ERP effect up to 600ms after target presentation through visual inspection and detailed t-tests by decomposing the whole epoch in twelve small time-windows of 50ms. Three groups of electrodes were selected for these analyses: Frontal (F3,Fz,F4), Central (C3,Cz,C4) and Parietal (P3,Pz,P4). For each group of electrodes t-tests were performed in each time-window, comparing the critical conditions (Transposed vs. Substitution) separately for the Word and Nonword manipulations.

Results

Behavioural results. Participants correctly categorized more than 97% of the profession names when these words were presented as targets. Contrarily, when they were presented as primes, less than 0.3% of the names were recognized.

-Figures_1_and_2-

EEG results.The visual inspection of the grand-average showed a larger negativity in the 200-300ms time window more evident in the posterior electrodes for the Nonword Substitution condition compared to the other conditions (see Figures 1 and 2). Statistics on the *midline* electrodes in this time window resulted in an interaction between Lexicality and Condition ($F(1,22)=9.02$, $p<0.01$). The main effects of Lexicality ($F(1,22)=2.91$, $p>0.1$) and Condition ($F(1,22)=1.28$, $p>0.1$) were not significant. The ANOVA on the *lateralized* groups showed a marginal main effect of Lexicality ($F(1,22)=3.14$, $p<0.1$) and the interaction between Lexicality and Condition ($F(1,22)=8.29$, $p<0.01$). The effect of Condition was not significant ($F(1,22)=1.56$, $p>0.1$).

Follow-up analyses were then planned to verify the source of the interaction between Lexicality and Condition. We thus compared the Transposition and Substitution conditions separately for Word and Nonword primes with the same ANOVA pattern used above. The *midline* analysis for the Nonword manipulation showed main effects of Electrode ($F(3,66)=19.88$, $p<0.001$) and, more critically, of Condition ($F(1,22)=10.62$, $p<0.01$). The *lateralized* analysis showed main effects of Longitude ($F(2,44)=24.24$, $p<0.001$), Hemisphere ($F(1,22)=13.22$, $p<0.001$) and Condition ($F(1,22)=9.36$, $p<0.01$). The Word manipulation in the *midline* analysis showed an effect of Electrode ($F(3,66)=19.88$, $p<0.001$), but no effect of Condition ($F(1,22)=2.35$, $p>0.1$). The *lateralized* analysis showed main effects of Longitude

(F(2,44)=23.09, p<0.001) and Hemisphere (F(1,22)=14.45, p<0.001), but no effect of Condition (F(1,22)=2.31, p>0.1).

A similar pattern was observed in the analyses on the 50ms time windows. Figure 3 reports t-values comparing Transposition and Substitution conditions separately for Word and Nonwords for each group of electrodes (Frontal, Central and Parietal) considered for these analyses. The horizontal bar represents the critical threshold of significance (t(22)=2.07, p=0.05). The only 50ms epochs where significant effects were found were the 200-250ms and 250-300ms time-windows, in which the three groups of electrodes showed differences for Transposition and Substitution conditions only with Nonword manipulations. In contrast, Word manipulations did not elicit any significant effect. Furthermore, Figure 3 also shows that no other effect in different time-windows was significant.

-Figure_3-

Discussion

The results of the present experiment were clear-cut: i) the transposed-letter N250 priming effect has been replicated with nonword-word pairs (the N250 was more negative-going for the substituted-letter condition than for the transposed-letter condition), ii) and no differences in the N250 component were observed between the transposed- and substituted-letter priming conditions when word-word pairs were used.

Studies that have explored the TL effect in masked priming [6-8] have consistently shown that a brief presentation of a nonword created by transposing two of the letters of a base word (*barin* from *brain*) facilitates the access to the base word more than a substituted-letter nonword (*bosin*; see [1] for review). However, empirical evidence regarding the TL masked priming effect has been almost exclusively obtained from studies testing nonword primes preceding word targets. In the absence of its own lexical representation, it is feasible to assume that the nonword *barin* would produce a high degree of activation on its most similar lexical match (the word *brain*), and consequently the pair *barin-brain* would produce effects that are very similar to the repetition priming effects (*brain-brain* [2,25]). However, for word-word TL pairs (*casual*/*causal*) null priming effects have been reported in lexical decision masked priming experiments [14,15]. In the case of TL word primes, "the prime is a perfect match with another word that is not the target", and no priming effect is expected ([14], p.353). In the present ERP study we have presented evidence in favor of this lack of co-activation of a TL word pair. Importantly, this finding was accompanied by a clear N250 TL masked priming effect for nonword-word pairs, replicating previous ERP evidence obtained by Grainger et al. [18].

The critical interaction between the N250 TL effect and prime's lexicality is at odds with a conception of the N250 component as a marker of form-level processing [18-20], which would predict the same results for word-word and nonword-word pairs. Holcomb and Grainger [19] proposed that the more mismatching letters between prime and target, the more negative the N250 would be, without any specific mention to the lexical status of the prime. Our results are difficult to accommodate within this view, since in both word-word and nonword-word conditions the amount of shared letters in the exact position was highly similar (60.2% and 59.8% respectively; $p>.75$). In contrast, our results fit the predictions of less restricted conceptions of the N250 that admit that this component is also sensitive to lexico-semantic properties of the primes [23]. Hence, the present results contribute to a better definition of the N250, a highly interesting component that seems to be especially suited for determining the cognitive processes underlying the masked priming paradigm.

The present results pose some problems for models of visual word recognition. For instance, the SOLAR and SERIOL models [10,11] predict clear effects of TL word pairs. According to SOLAR, “TL [transposed-letter] similarity ‘helps’ low frequency words and ‘hurts’ high frequency words” [10, p.319]. According to SERIOL, “having a transposed-letter neighbor can be inhibitory” [11, p.208]. As shown by the present experiment (and considering the preceding evidence from lexical decision masked priming experiments), none of these predictions are endorsed by empirical data. Hence, some parameter tweaking will be necessary in these models to account for the present findings, including early top-down inhibitory effects of candidate suppression within the lexical level (by lateral inhibition mechanisms) that reduce the impact of the initial facilitation due to the overlapping letters. In line with this proposal, the Overlap model [12] predicts that the spread of the encoded letter positions’ uncertainty for words is narrower and more precise than for nonwords, as a consequence of top-down influences from the lexical level.

Conclusion

In summary, the present experiment provides evidence for a clear dissociation between TL priming effects for word and nonword primes in the N250 component. Considering that the N250 masked priming TL effect disappears when primes are words, we propose that this orthographic priming effect is not totally blind to higher order lexico-semantic information, and that the N250 component does not exclusively reflect form-level processing.

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Table 1

Characteristics of the materials in the word-word and nonword-word trials used in the experiment. Mean frequency (in number of appearances per million words), length (in number of letters) and number of orthographic neighbors (N) are provided. Ranges are provided within parentheses.

	Frequency	Length	N
Word-Word trials			
Targets	18.81±37.90 (0.28-266.42)	5.20±1.15 (4-8)	8.95±6.63 (0-38)
Transposed-letter primes	198.32±394.54 (10.22-2403.35)	5.20±1.15 (4-8)	4.71±3.64 (0-17)
Substituted-letter primes	179.58±420.05 (0.28-2614.83)	5.20±1.15 (4-8)	4.82±4.22 (0-19)
Nonword-Word trials			
Targets	18.86±37.55 (0.28-260.63)	5.24±1.09 (4-8)	8.38±6.47 (0-35)
Transposed-letter primes	--	5.24±1.09 (4-8)	1.13±2.32 (0-16)
Substituted-letter primes	--	5.24±1.09 (4-8)	0.94±1.55 (0-6)

Note: None of the comparisons between the different values of each variable for the transposed and the substituted-letter primes resulted significant (all ps>.63). Similarly, targets in the word-word and nonword-word conditions did not significantly differ in any of the measures (all ps>.59).

Figure Captions

Figure 1. ERPs elicited by the target word in *Nonword-Word* priming conditions in nine representative electrodes. The dotted line refers to the double-letter substitution priming condition, and the solid line refers to the transposed-letter priming condition. Negative potentials are plotted upwards and each hash mask represents 100 ms.

Figure 2. ERPs elicited by the target word in *Word-Word* priming conditions in nine representative electrodes. The dotted line refers to the double-letter substitution priming condition, and the solid line refers to the transposed-letter priming condition. Negative potentials are plotted upwards and each hash mask represents 100 ms.

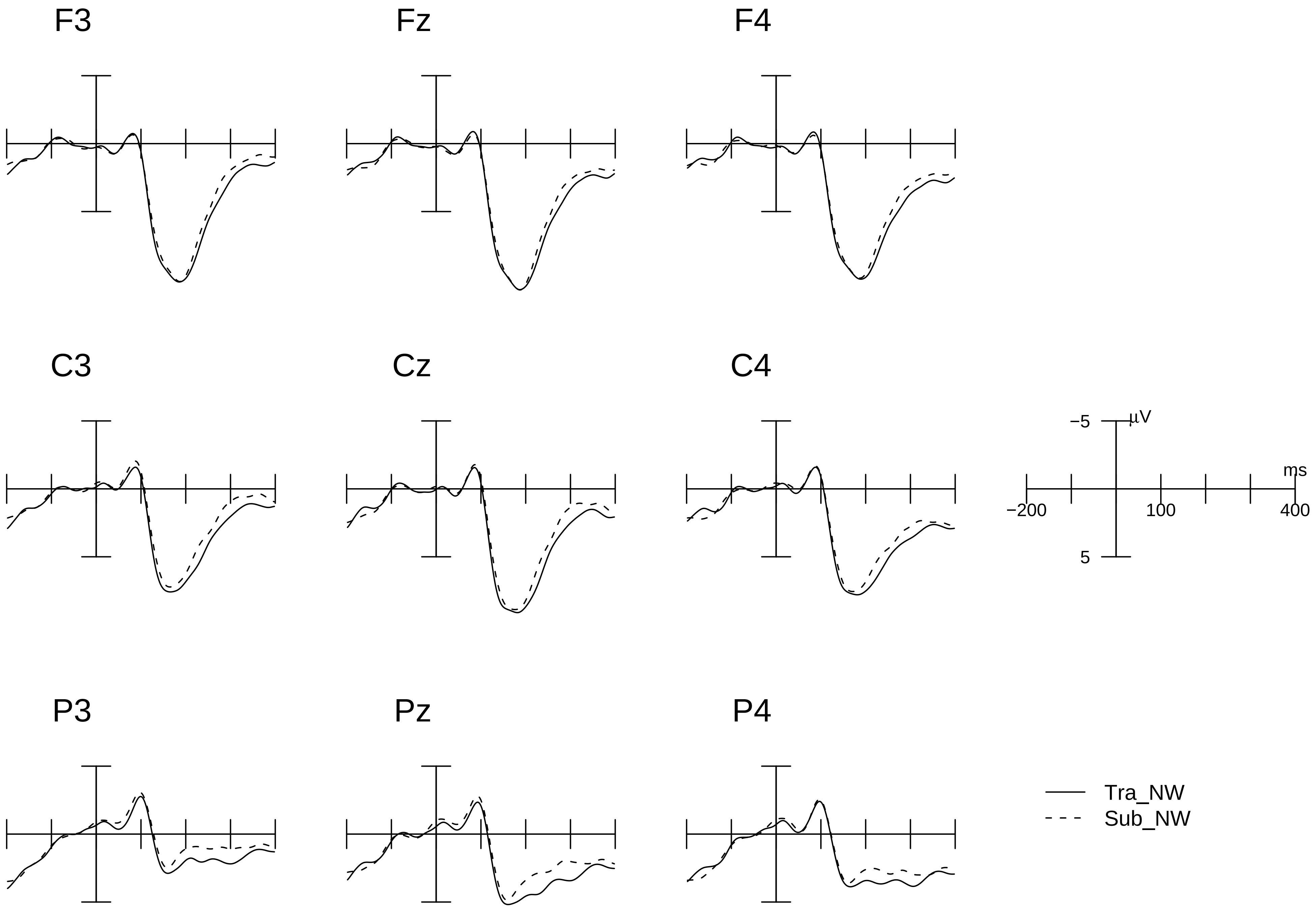
Figure 3. Graphical representation of the averaged t-test values of the Transposed-letter vs. Substituted-letter comparisons for Word and Nonword priming conditions in three regions: Frontal (average voltages of electrodes F3,Fz,F4), Central (C3,Cz,C4) and Parietal (P3,Pz,P4). The vertical axis shows the t values for the two-tailed t-tests, and the horizontal axis indicates the timing (in time bins of 50ms) up to 600ms. The solid line indicates the significance level (for $\alpha<0.05$, then $t(22)>2.07$).

Footnotes

Footnote 1. A broad assumption in the TL literature is that the best baseline for measuring the TL effect is a condition created by letter substitutions. Consider, for instance, the word *judge* and its TL prime *jugde*; According to recent visual word recognition models, the activation produced by a two-letter different control prime like *jupbe* would be different to the activation produced by an all-letter different control prime like *chair*. The Match Calculator software developed by Colin Davis (http://www.pc.rhul.ac.uk/staff/c.davis/Utilities/MatchCalc/index.htm), which provides similarity values among two strings based on models' predictions (where 0 indicates no match and 1 indicates a perfect match), shows that while the match between *judge* and *jupbe* is 0.33, 0.19 and 0.71 according to the SERIOL[11], OOB [13] and SOLAR[10] models respectively, the match between *judge* and *chair* is 0.00 in all cases. Therefore, considering preceding evidence that distinguishes between all-letter different and substituted-letter control primes [17], and the predictions for the models, we believe that the use of an all-letter different control is not appropriated for exploring the influence of a transposition that only involves a two-letter manipulation, since it might exaggerate the obtained differences between the control and orthographically related strings.

Footnote 2. It should be also mentioned that Andrews [16], in a masked priming naming study, obtained a different pattern of results. She presented participants with words (*salt*) that were preceded by word primes created by transposition (*slat*), by nonwords created by replacing one of the original letters by another (*saft*), or by unrelated word primes that overlapped with targets in the first letter (*spin*). Transposed-letter word primes inhibited the processing of targets compared to orthographically unrelated primes (i.e., *slat* inhibited the naming of *salt*). (Note, however, that the effect was not significant in the item analysis).

Footnote 3. The vast majority of Basque speakers in the Southern Basque Country are highly proficient Basque-Spanish bilinguals. However, this fact is not expected to influence the results in any sense, as far as none of the nonword prime strings in Basque was a real word in Spanish.



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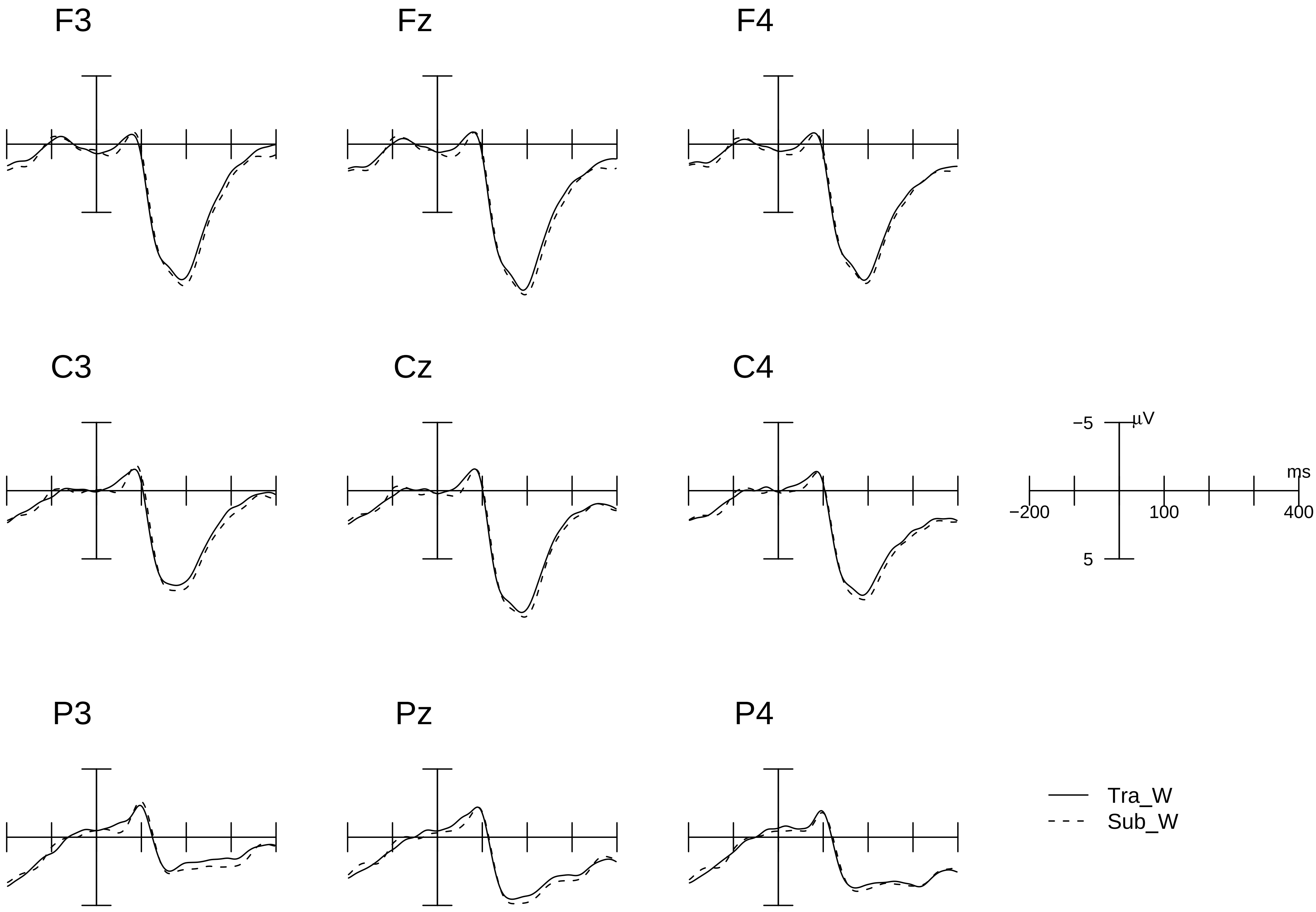
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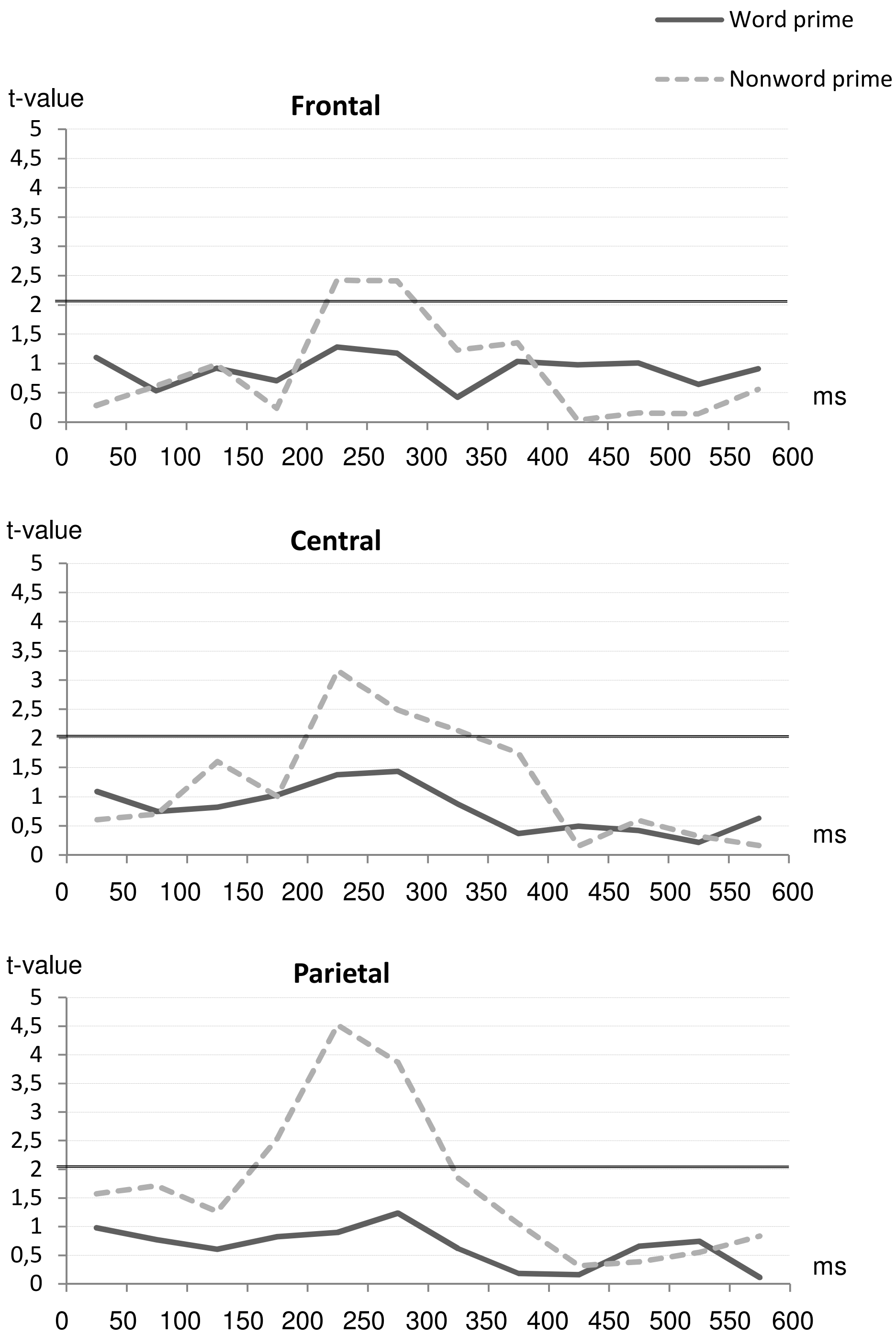
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