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The fox and the *cabra*: An ERP analysis of reading code switched nouns and verbs in bilingual short stories

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Abstract

Comprehending a language (or code) switch within a sentence context triggers 2 electrophysiological signatures: an early left anterior negativity post code switch onset – a LAN – followed by a Late Positive Component (LPC). Word class and word position modulate lexico-semantic processes in the monolingual brain, e.g., larger N400 amplitude for nouns than verbs and for earlier than later words in the sentence. Here we test whether the bilingual brain is affected by word class and word position when code switching, or if the cost of switching overrides these lexico-semantic and sentence context factors. Adult bilinguals read short stories in English containing 8 target words. Targets were nouns or verbs, occurred early or late in a story and were presented alternately in English (non-switch) or Spanish (switch) across different story versions. Overall, switched words elicited larger LAN and LPC amplitude than nonswitched words. The N400 amplitude was larger for nouns than verbs, more focal for switches than non-switches, and for early than late nouns but not for early than late verbs. Moreover, an early LPC effect was observed only for switched nouns, but not verbs. Together, this indicates that referential elements (nouns) may be harder to process and integrate than relational elements (verbs) in discourse, and when switched, nouns incur higher integration cost. Word position did not modulate the code switching effects, implying that switching between languages may invoke discourse independent processes.

Keywords

code switching; bilingualism; discourse processing; word class; LAN; LPC

1. Introduction

Bilingualism is a dynamic phenomenon that can affect language production and comprehension, as well as generate constructs not experienced by monolinguals. One

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experience unique to bilinguals is the ability to switch between languages during a conversation, referred to as code switching. Code switching is the integration of more than one language in a single communicative exchange (Heller, 1988). This subject has been studied from diverse perspectives (e.g. Bullock & Toribio, 2009; Gardner-Chloros, 2009). Some have focused on the cognitive and neural processes underlying code switching, especially with regard to the representation of two languages in bilingual memory and the bilingual brain (See for more information in Kutas, Moreno, & Wicha, 2009). The present study employs event-related potentials (ERPs) to examine the temporal dynamics of comprehending a language switch in short stories, with the goal of understanding the role of *word class* and *discourse context* (in terms of amount of preceding co-text) in bilingual comprehension of code switched words.

1.1 Code switching

The few ERP studies that have analyzed code switching in a sentence context have observed a code switching effect on the left anterior negativity (LAN) or N400 amplitude, where switched words elicited larger negative amplitude than non-switched words (Moreno, Federmeier, & Kutas, 2002; Proverbio, Leoni, & Zani, 2004; van Der Meij, Cuetos, Carreiras, & Barber, 2011).

Moreno, et al. (2002) observed a LAN – a negative-going ERP component over left anterior electrode sites – in English-Spanish bilinguals who read English sentences containing a Spanish word. The effect was attributed to increased working memory load arising from integrating the Spanish morphological cues into an English context. Similarly, van der Meij, et al. (2011) observed a LAN for Spanish-English bilinguals reading switched words in English sentences, but the effect was limited to higher proficiency bilinguals. The authors argued that this effect resulted from ‘the difficulty of integrating the different grammatical rules of both languages’ (p. 52). These arguments are consistent with the monolingual literature, where the LAN has been argued to reflect increased working-memory load (Kluender & Kutas, 1993). Others, however, have argued that the LAN is related to syntactic processes observed in word categorization and morphosynactic violations (Gunter, Friederici, & Schriefers, 2000; Neville, Nicol, Barss, Forster, & et al., 1991; Osterhout & Mobley, 1995).

In contrast, both high and low proficiency bilinguals in van der Meij, et al. (2011) showed an N400 effect at the switched word, which was argued to reflect ‘the activation costs of the specific lexical forms in the less active language’ (p. 52). The N400, which overlaps in time and polarity with the LAN, is a negative-going ERP component with peak latency around 400 ms (Kutas & Hillyard, 1984). It differs from the LAN based on its central-parietal distribution, and is thought to reflect access to meaningful information from memory (Kutas & Federmeier, 2000). The N400 amplitude is inversely related to the semantic fit of a word in preceding context, such that it decreases as the semantic fit of a word increases (van Petten, 1993; van Petten & Kutas, 1990, 1991). A N400 effect was also observed for switched words in Italian- English interpreters reading Italian and English sentences (Proverbio, et al., 2004). The position of the switch in these sentences was completely predictable, indicating that the N400 switching effect is not simply an effect of surprise. In addition, the switching direction modulated the amplitude of the N400: second-language English words embedded in Italian sentences elicited a larger N400 than first-language Italian words embedded in English sentences (c.f., switching from second language to first language can be more costly in single-word presentation paradigms in Meuter & Allport, 1999). The authors attributed this difference in the N400 effect based on the switching direction to greater difficulty of accessing conceptual knowledge when using a second, and later learned, language. Therefore, the N400 effect can result from processing a less active

lexical form (van der Miej, et al., 2011) or accessing meaning through a language that has weaker connections to conceptual knowledge (Proverbio, et al., 2004).

It is possible that code switching in sentences incurs a higher cognitive load at both syntactic and semantic level, given that a switch requires the application of different grammatical rules and integration of different semantic attributes. The presence of the LAN in high proficiency bilinguals could indicate that these bilinguals are more likely than low proficiency bilinguals to apply syntactic rules of the two languages in a mixed-language context (c.f. Osterhout et al., 2008). In addition, the N400 difference based on the switching direction may indicate that it is easier to integrate the lexico-semantic features of words from a stronger than a weaker language into the ongoing context.

The LAN/N400 is followed by a Late Positive Component (LPC), which is sometimes equated with the P600. The LPC is a large positive deflection with maximum amplitude over right posterior recording sites, beginning around 500 ms post-stimulus onset and lasting up to several hundred milliseconds. Both Moreno, et al. (2002) and van Der Meij, et al. (2011) observed an LPC for language switching, with larger amplitude to switched than non-switched words[1].

In Moreno, et al. (2002), the LPC was argued to reflect the processing cost of code switches in decision-making stages, which seems to refer to the increased cognitive load involved in processing an unexpected or improbable event (c.f. Kolk & Chwilla, 2007). Code switches are therefore treated more as a change in form than as a change in meaning (Moreno, et al., p. 204). LPC amplitude was negatively correlated with an individual’s vocabulary size in Spanish – a measure of proficiency, with increased Spanish vocabulary resulting in a smaller LPC. This finding is to a certain extent contrary to that of van Der Meij, et al. (2011), who observed a larger switching effect at the early phase of the LPC (450–650 ms) for high than low proficiency learners. The authors attributed this effect to more second language (L2) grammatical processing (the context language was the L2 of the bilinguals) by these learners, given that the LPC has been linked to repairing a syntactic anomaly (Hagoort, Brown, & Groothusen, 1993). This finding about two phases of the LPC was also consistent with those of the previous studies (Carreiras, Salillas, & Barber, 2004; Hagoort & Brown, 2000). The two accounts for the LPC by Moreno, et al. (2002) and van Der Meij, et al. (2011) need not be incompatible, because a syntactic anomaly is an unexpected event that needs further processing for integration. van Der Meij, et al. (2011) emphasized the linguistic processes for repair while Moreno, et al. (2002) stressed the general cognitive processes for comprehending an unexpected occurrence.

The LPC is only occasionally observed in studies using single-word code switching paradigms (Alvarez, Holcomb, & Grainger, 2003; Chauncey, Grainger, & Holcomb, 2008; Midgley, Holcomb, & Grainger, 2009; Phillips, Klein, Mercier, & de Boysson, 2006), indicating that this code switching LPC may be specific to sentence-level integration. Whereas, the LAN/N400 effect appears to index local integration, e.g., morphological cues, word form, and grammatical rules, the LPC may index global integration, e.g., integrating a switch with the greater discourse context. In the same vein, Salmon and Pratt (2002) observed in monolinguals N400/LPC effects for semantic incongruities in both sentence and discourse contexts. This suggests that there may be at least two levels of semantic processing: an earlier lexico-semantic stage and later integration of a word into the larger context. A more frontal LPC has also been linked to discourse-level complexity, e.g., the number of referents in the discourse (Kaan & Swaab, 2003). Therefore, the LPC can be

[1]Proverbio et al. (2004) did not report statistical analyses for the LPC time window.

considered a step in processing where all information, syntactic and semantic, is assessed for attaining the best interpretation.

1.2 Word class and code switching

The first goal of the current study was to compare the brain responses to comprehending switched nouns and verbs in discourse. There has been no systematic analysis of the effect of word class on processing a code switch using ERPs. The current study would determine whether the effect of code switching is modulated by word class. That is, is comprehension of a language switch differentially affected by word class, or is the process of extracting the essential semantic and grammatical information from a switch the same regardless of word class?

In the monolingual literature accumulating evidence has shown that nouns and verbs are processed differently, and therefore they are likely to tap into different cognitive and neural processes (Caramazza & Hillis, 1991; Federmeier, Segal, Lombrozo, & Kutas, 2000). This difference has been argued to arise from cerebral sensitivity to grammatical class processing or to semantic features associated with a word class (Pulvermüller, Lutzenberger, & Preissl, 1999; Shapiro & Caramazza, 2003). In ERP studies, nouns have been observed to elicit a larger N400 than verbs over central parietal electrode sites even in contexts where the word class of the upcoming word is very predictable (but also see Brown, Hagoort, & ter Keurs, 1999). In Federmeier, et al. (2000) and Lee and Federmeier (2006), nouns like *beer* in the context of ‘the beer’ generated a larger negativity than verbs like *eat* in the context of ‘to eat’ at 250–400 ms. The larger N400 effect of nouns over verbs was argued to be caused by a higher predictability of the semantic information of verbs over nouns and as a result an easier integration of verbs over nouns (Federmeier, et al., 2000, p. 2564). Additional evidence from both Federmeier, et al. (2000) and Lee and Federmeier (2006) showed that the N400 word class effect was present even for the class ambiguous words, e.g., *vote* in the contexts of ‘the vote’ and ‘to vote.’ This excludes the possibility that the word class effect is a purely lexical effect.

However, sociolinguistic evidence suggests that switched nouns can be easier to process than switched verbs. In natural conversation, nouns are switched more often than verbs (Muysken, 2000; Poplack, 1980). In Berk-Seligson’s (1986) code switching data from 87 Spanish/Hebrew bilinguals, single nouns comprised 40% of all switches whereas single verbs accounted for only 0.1%. There can be several reasons for why verbs are less subject to switching. Depending on language typology, verbs may have more complex and variable inflectional morphology in some languages than others (e.g., Spanish versus English respectively) to reflect grammatical categories like tense and modality. There are also language-specific features such as clitics and compound verbs (e.g., *take off, make up*), which may not be easily transferrable to another language. Nouns, on the other hand, generally have less variable word forms. In morphologically inflected languages like Spanish, the determiner carries most of the grammatical features (e.g., number, gender, case) for the noun, and in fact, determiners tend to be preserved in the matrix language with a language switch only at the noun (Dussias, 2001; Myers-Scotton, 1993). Consequently when switching between two languages, nouns are better candidates than verbs to preserve the *Equivalence of Structure Constraint*, or the law-abiding aspect of code switching in which switches tend to preserve the syntactic rules of either language (Pfaff, 1979; Poplack, 1980). Moreover, the referents of some types of nouns are more concrete and tangible than those of verbs, and therefore nouns are more stable in translation between languages (Gentner, 1981, 1982, 2006). Overall, nouns may be grammatically and conceptually more appropriate for switching than verbs, potentially making a switched noun easier to process than a switched

verb. Consequently, the N400 effect for switched nouns may be smaller than that for switched verbs.

In brief, nouns and verbs elicit different ERP effects, namely, larger N400 amplitude for nouns than verbs, suggesting that nouns may be harder to process than verbs. However, nouns are more likely to be switched in natural discourse than verbs. Therefore, verbs may cause a greater cost when switched than nouns. Here, we compared the effect of code switching (switch versus no switch) of nouns and verbs to determine which word class is more challenging to process when switched, and at what stage in processing.

1.3 Word position and code switching

The second goal of the current study was to investigate the effect of context, defined as the amount of preceding story, on comprehending a code switch. Moreno et al. (2002) have found a larger LAN code switching effect in regular contexts than in idiomatic contexts (e.g., *Out of sight, out of mente*.). The context effect likely arises from the integration of the new with the background information. In order to comprehend linguistic input, the brain relates the ongoing text to real world knowledge and to the preceding discourse (Federmeier, Kluender, & Kutas, 2003). The increased contextual information can facilitate lexical ambiguity resolution and the prediction of upcoming words (Federmeier, 2007; Kambe, Rayner, & Duffy, 2001). Consequently, the N400 amplitude decreases for sensible words as a sentence progresses – indexing facilitated integration (van Petten & Kutas, 1990, 1991). This facilitated integration resulting from greater context may also apply to code switched words. A word and its switched equivalent are different in form, but carry similar semantic information. By inference, one might speculate that semantic integration should be facilitated as context builds, even for a switched word. As a result, a switch that appears later in discourse may have a smaller N400 than a switch that appears earlier. However, greater context could have the exact opposite effect. The more time a bilingual spends in a single language the more active that language becomes (Grosjean, 2001). Therefore, a switch can become harder to integrate into the base language as the context develops. In this case, the N400 for a switch may be larger than a non-switch as the discourse context builds. Thus, whether an increased amount of discourse facilitates or hampers the processing of switches hinges on the treatment of these switches by a bilingual.

1.4 Specific aims

We investigated the interplay of code switching (non-switched word vs. switched word), word class (nouns vs. verbs), and word position (early vs. late) in comprehending bilingual short stories adapted from Aesop’s Fables. In the following example, switched words are in bold and English control words are underlined. In a second version of each story, the bold words would be English control words and the underlined words would be switched to Spanish.

> The wind and the **sol** were <u>disputing</u> which was the stronger. Suddenly they **miraron** a <u>traveler</u> coming down the street, and the sun said: "I see a way to decide our dispute. Whichever of us can cause that traveler to take off his cloak shall be regarded as the stronger. You begin." So the sun retired behind a cloud, and the **viento** began to <u>blow</u> as hard as it could upon the traveler. But the harder he blew the more closely did the traveler wrap his cloak round him, till at last the wind had to give in despair. Then the sun came out and shone in all his glory upon the traveler, who soon found it too hot to **caminar** with his <u>cloak</u> on.

Each story contained 8 target words that were presented in the same language as the story (English) or replaced by the translation equivalent in Spanish. The language switch could occur on either a noun or a verb, and either early or late in the story. We measured the ERPs

from the onset of each target word while fluent adult Spanish-English bilinguals read the stories for comprehension.

The findings will fill a gap in bilingual research by focusing on the electrophysiological signatures for comprehending a code switch in discourse, adding to what is known about single word processing and sentence comprehension. Previous studies have shown that switched words in a sentence context elicit a larger LAN/N400 and LPC over same-language words, nouns evoke a larger N400 than verbs, and early words in a sentence context produce a larger N400 than late words. The key questions here are whether switching enhances or reduces the effect of word class, and whether the amount of preceding context (early versus late in a story) affects comprehending a code switch in real time reading.

2. Results

Overall, the ERPs to each target word were characterized by early sensory components – N1, P2 over frontal sites and P1, N1, P2 over posterior sites – followed by a slower negative component and a late positive component (LPC), Figure 2. The LPC has the visual evoked potential for the next word superimposed, creating a triphasic wave between 500–700 ms post-stimulus onset. Omnibus ANOVAs with 2 levels of Code Switching (non-switch vs. switch) × 2 levels of Word Class (noun vs. verb) × 2 levels of Word Position (early vs. late) × 26 electrodes were performed on mean amplitude in two latency bands: 350–450 ms (negativity) and 500–900 ms (LPC) post-stimulus onset. We analyzed the LPCa (500–600 ms) window separately for the code switching effect, given that van Der Meij, et al. (2011) found a distributional difference in the early but not the later phase of the LPC (see the discussion in Section 1.1), and visual inspection of the waveforms suggested two LPC phases for our data.

To localize these effects across the scalp, a second ANOVA included 2 levels of Hemisphere (right vs. left) × 2 levels of Laterality (medial vs. lateral) × 4 levels of Anteriority (Prefrontal, Frontal, Centro-Temporal, Occipital). Effects for repeated measures with greater than one degree of freedom are reported with uncorrected degrees of freedom after Greenhouse-Geisser correction.

2.1 Negativity (350–450 ms)

There were no main effects of Code switching ($F_{1,23}$ = 0.167, p = .686), Word Class ($F_{1,23}$ = 2.393, p = .136) or Word Position ($F_{1,23}$ = 2.232, p = .149). Interactions between Code Switching and Electrode ($F_{25,575}$ = 3.425, p = .026), shown in Figure 1, and Code switching, Word Class and Electrode ($F_{25,575}$ = 2.950, p = .032), shown in Figure 3 were significant. In addition, interactions between Word Class and Electrode ($F_{25,575}$ = 3.151, p = .019), and Word Class and Word Position ($F_{1,23}$ = 4.737, p = .040) were also significant, Figure 2. Although the negativity appeared to be larger for early than late words (Figure 2, right), this effect failed to reach significance even at the 8 medial central electrodes where it was largest in amplitude (p = .068).

Code Switching × Electrode—The ROI analysis revealed that switches elicited a larger negativity than non-switches primarily over left-lateral fronto-central electrodes (Code switching × Hemisphere: $F_{1,23}$ = 11.711, p = .002; Code switching × Hemisphere × Laterality: $F_{1,23}$ = 8.519, p = .008; Code switching × Laterality × Anteriority: $F_{3,69}$ = 4.608, p = .011) (see Figure 1).

Word Class × Electrode—The ROI analysis revealed that nouns evoked a larger negativity than verbs primarily over centro-parietal electrode sites, with a right hemisphere

bias (Word Class × Hemisphere × Laterality × Anterority: $F_{3,69} = 3.615$, $p = .024$) (see Figure 1, bottom, and Figure 2, left).

Code Switching × Word Class × Electrode—The Word Class effect (nouns minus verbs) was the same for switched and non-switched words at posterior sties. However, over prefrontal and frontal electrodes larger negative amplitude was observed for non-switched nouns than nonswitched verbs (Code switching × Word Class × Anteriority: $F_{3,69} = 4.109$, $p = .041$), but switched nouns and verbs did not differ reliably (see Figure 3).

Word Position × Word Class—Independent paired-samples t-tests revealed that early nouns elicited larger negative amplitude than all other words (late nouns, early verbs, and late verbs) (*p*s < .05) (see Figure 4). Late nouns and verbs, and early and late verbs were not statistically different from each other. The lack of a 3-way interaction with code switching indicated that this word position effect on nouns, but not verbs, held true for both non-switched and switched words. We confirmed this with post hoc t-tests (switched noun: early > late, $p = .021$; non-switched nouns: early > late, $p = .011$; switched verbs: early = late, $p = .622$; non-switched verbs: early = late, $p = .278$).

2.2 LPC (500–900 ms)

There was a main effect of Code Switching ($F_{1,23} = 11.795$, $p = .002$), and an interaction of Code Switching by Electrode ($F_{25,575} = 11.174$, $p < .001$), Figure 1. Switched words evoked a larger positivity than non-switched words, with maximum amplitude over right-medial posterior electrodes (Code Switching × Hemisphere: $F_{1,23} = 6.241$, $p = .020$; Code Switching × Laterality: $F_{1,23} = 10.286$, $p = .004$; Code Switching × Hemisphere × Laterality: $F_{1,23} = 6.787$, $p = .016$; Code Switching × Anteriority: $F_{3,69} = 15.478$, $p < .001$; Code Switching × Laterality × Anteriority: $F_{3,69} = 7.289$, $p = .003$).

There was no interaction between Code Switching and Word Class ($F_{1,23} = 0.028$, $p = .869$) or Word Position ($F_{1,23} = 0.410$, $p = .528$). However, an ANOVA excluding Word Position was conducted to capture effects visible in the LPCa (500–600 ms). An interaction between Code Switching and Word Class ($F_{1,23} = 5.434$, $p = .029$) revealed larger LPCa amplitude for switched than non-switched nouns ($p = .009$), and no difference between switched and non-switched verbs ($p = .389$) (see Figure 5). This interaction was present across the scalp (Code Switching × Word Class × Electrode: $F_{25,575} = 0.608$, $p = .671$).

Word Class did not reach significance as a main effect ($F_{1,23} = 0.534$, $p = .472$); an interaction between Word Class and Electrode ($F_{25,575} = 2.748$, $p = .040$) was due to spurious differences across single electrodes (Figure 2 left side). Word Position did not reach significance as a main effect ($F_{1,23} = 0.064$, $p = .803$), but the interactions between Word Class and Word Position ($F_{1,23} = 7.415$, $p = .012$) and Word Class, Word Position and Electrode ($F_{25,575} = 3.235$, $p = .018$) did. Over prefrontal electrodes, early nouns elicited a larger sustained negativity than late nouns, which is consistent with the negativity observed in the earlier 350–450 ms time window at other electrode sites ($p = .004$, Figure 4 column 3) (Word Class × Word Position × Laterality × Anteriority: $F_{3,69} = 3.480$, $p = .035$). When looking at the effect of word class, late nouns elicited larger positive amplitude than late verbs ($p = .007$, Figure 4 column 2). However, we interpret this latter interaction with caution since it shows a reversal in polarity from frontal electrodes, where late nouns were marginally more negative than late verbs. When the prefrontal electrodes were removed from the analysis, this interaction no longer reached significance ($p = .056$), indicating that the effect is coming primarily from prefrontal sites.

2.3 Individual Differences

In order to assess whether or not the brain responses to code switching could be predicted by individual differences, Pearson's correlations were performed for the code switching effects (switch minus non-switch) on the negativity (350–450 ms) and LPC (500–900 ms) with several participant variables. The analyses were performed on ROIs where each effect was maximal: negativity – 4 left lateral electrodes, and LPC – the average across all channels. The independent variables were 1) the age of acquiring (AOA) L2 English (M = 6.6 years), 2) the difference between the English and Spanish BNT scores (Mean English BNTs minus Mean Spanish BNTs = −0.5), 3) the difference between the English and Spanish VFT scores (Mean English VFTs minus Mean Spanish VFTs = −0.5), and 4) the percent of English (52%) and Spanish (48%) use. None of these factors turned out to be predictors for any of the ERP code switching effects (ps > .207). Thus, we found no evidence that the individual traits of these balanced bilinguals modulated the ERP code switching effects.

3. Discussion

The current study set out to investigate the interplay between code switching, word class, and word position in discourse reading comprehension. Our findings on the one hand replicate the primary findings from sentence comprehension studies with regard to the LAN/N400 and LPC time windows, and on the other hand qualify what factors modulate these ERP results. Consistent with findings from previous studies, we found that switched words evoked larger negative amplitude than non-switched words over left-lateral frontal-central sites between 350–450 ms post stimulus onset, followed by a widely distributed positivity with maximum amplitude over right posterior electrodes. These findings are largely consistent with Moreno, et al. (2002), and likely reflect a LAN followed by a LPC. Moreno et al. observed earlier and smaller LPC amplitude to code switches for participants with greater proficiency in Spanish, the language of the switches in their sentences. Our population was equivalently proficient in their 2 languages, and therefore proficiency did not modulate the ERP effects. Age of acquisition (AOA) and frequency of language use were more variable in our population than language proficiency (ranging from 0–15 AOA and 10 to 90% use), but also did not modulate the ERP effects. We interpret these findings with caution with regard to the debate on AOA effects, given that this was not an a priori design of the study. We were more concerned with equating proficiency to avoid confounds from the switching direction given that switches were always presented in the subjects' first language.

As discussed in Section 1.1, the LAN has been associated with syntactic processing or increased working memory load. A switched word may carry language-specific morphosyntactic features that require additional processing effort. Or, it may increase the working memory load, as suggested by Moreno, et al. (2002), requiring morphosyntactic or semantic integration into the base language. We cannot determine based on our data which of these is the more accurate explanation. What we can conclude is that this LAN-like effect is a robust response for code switched words both in sentence and in larger discourse contexts. Moreover, our findings suggest that this left anterior negativity may be independent of the N400 response, which overlaps in time and polarity, based on how word class and word position modulate activity in this time window.

Again similar to Moreno, et al. (2002), code switched words also elicited a significant modulation of the late positive component, or LPC. The early phase of this code switching LPC effect was modulated by word class, indicating that although the LPC appears to be a robust code switching effect in sentence and discourse contexts, the LPCa may be specific to switched nouns. It has been argued that the LPC reflects a general stage of reprocessing and integration after an unexpected lexical item (Kolk & Chwilla, 2007). Thus, our results may

reflect on the one hand an increased reprocessing cost for all switches, but on the other hand, switched nouns but not switched verbs incur a higher cost at the early phase of reprocessing and integration.

A potential caveat for our findings relates to the switching direction between languages. Proverbio, et al. (2004) found that switching a single word in a sentence context is more costly, as measured by the N400 effect, when switching from L1 (first language) to L2 (second language) than vice-versa. We did not observe a modulation of the N400 with code switching; we only observed the LAN code switching effect. Moreover, in order to make the experiment length feasible, we only studied switching in one direction, from English to Spanish, which for our population was from L2 to L1. It remains to be seen if switches from L1 to L2 could cause more processing difficulty, and an N400 effect, as observed by Proverbio, et al. (2004). Nevertheless, our participants were balanced bilinguals, making language dominance an unlikely cause of the observed results, and reducing the likelihood that the factor of switching direction will change the findings for this population.

In the following, we focus the discussion on the unique contributions of our findings to the code switching literature.

3.1 Word Class effects

Our findings were consistent with studies that show a processing difference between nouns and verbs. Results of prior ERP and neuroimaging studies have indicated that noun and verb processing may draw on different neural resources (e.g., Federmeier, et al., 2000; Shapiro et al., 2005). However, these studies used isolated words or short phrases that could potentially draw a participant’s attention to the word class distinction. The present study investigated word class processing in a discourse context, where no particular task was imposed on the readers apart from reading for comprehension. We found a word class effect across languages in mixed-language texts, as both switched and non-switched nouns elicited a larger medial-central negativity than switched and non-switched verbs. This effect was not due to word frequency difference between the nouns and verbs, as discussed in Section 4.2. Thus, this finding suggests that words of different grammatical class tap into different cognitive and neural processes even in natural reading and even in bilingual texts.

Although both switched and non-switched words elicited a larger N400 for nouns than verbs over medial-central electrodes, the word class effect elicited an additional frontally distributed negativity only for the non-switched words (Figure 3). One possible explanation for this distributional difference may be the processing limitations during real time comprehension. Concreteness modulates the amplitude and distribution of the N400 effect, with a more frontal distribution for more concrete than abstract words (Ganis, Kutas, & Sereno, 1996; Lee & Federmeier, 2008). The addition of a switch may cause a processing limitation that could force the bilingual brain to extract essential morphosyntactic and semantic information of the switched word. In turn, more subtle semantic nuances, such as concreteness may be lost, which could explain the lack of a frontally distributed negativity for switched words. This finding indicates that code switching can disrupt the parsing routine in the way that the core features of a word are extracted for integration, but the subtlety is neglected so that neural resources can be preserved for fast and successful processing.

Word class also modulated the effect of code switching at a later stage of processing, namely the LPCa: 500–600 ms. The LPCa has a fairly even scalp distribution and has been associated in prior research with detection and diagnosis of structural errors (Kaan, Harris, Gibson, & Holcomb, 2000). In the present study, switched nouns elicited a larger positivity than non-switched nouns, but switched and non-switched verbs were not reliably different.

This suggests that switched nouns may be construed as a structural error that is more difficult than switched verbs. This finding seems counterintuitive, given that 1) nouns are more frequently switched than verbs, 2) some types of nouns especially concrete nouns have similar object concepts cross-linguistically and therefore have less variability in translation (Prior, Kroll, & MacWhinney, 2013; van Hell & De Groot, 1998), and 3) verbs can have more complex and variable inflectional morphology across languages (see Section 1.2). Based on these factors, switched verbs should in principle cause greater disruption in comprehension than switched nouns.

There is however some suggestion in the literature that verbs may be processed by common neural substrates in the bilingual brain, contrary to nouns (Perani et al., 1999). In turn, it may be easier to switch between languages for verbs if the necessary neural substrates are already engaged. Another possible account for the word class LPCa effect is that nouns are referring expressions while verbs are relational expressions (Gentner, 2006; Langacker, 2013). In story reading, once the relations among the referents are established, the linguistic information of verbs is unlikely to be retained, but nouns are referents that may reappear later in a story and thus, need to be kept active in memory. As a result, the lexical form of nouns is probably retained longer than verbs. In the current study, a switched noun represents a deviation (like an error), in terms of the physical form and semantic attributes, from the nouns encountered previously. Detecting and integrating these deviant words could potentially increase the processing cost. Data from Burkhardt (2006) have shown that the coreferential property of a noun phrase modulates both the N400 and P600 (a similar component to the LPC): the harder it is to integrate a noun, the larger the amplitude of the N400 and P600. Similarly, switched nouns in our study produced a larger LPCa than non-switched nouns, whereas verbs showed no difference. Together, these studies suggest that the referential property of a word can affect the integration cost for a particular word (c.f. Nieuwland & van Berkum, 2008). The next section will discuss more about the effect of coreferentality in reading comprehension.

In brief, the present study shows that the word class effect occurs in bilingual texts. Lee and Federmeier (2006) argued that word class effects may be driven by a combination of semantic and grammatical information processing (p. 199). By inference, code switching can open up another avenue to examine the interplay of semantic and grammatical processes.

3.2 Word position effects

N400 amplitude decreases for each word as a sentence progresses, such that words that occur earlier produce a larger negative deflection than words than occur later (van Petten, 1993; van Petten & Kutas, 1990, 1991). However, this reduction in N400 amplitude within a sentence does not occur when the sentence is embedded in a larger text (van Petten, 1995). In the present study, we presented switched words across short stories to see if the amount of preceding context modulates the effect of code switching. We compared target words early and late in the stories, and found no reliable effects of word position, as a main effect or in interaction with code switching. This was true for both switched and non-switched words, indicating that comprehending code switched words was not hindered or helped any more by the additional preceding context than comprehending non-switched words.

The literature suggests that processing a switch could be easier, assuming access to meaning is facilitated by additional context, or harder, if additional time in the matrix language puts the bilingual brain in a monolingual mode. Our findings supported neither. Instead, we observed equivalent code switch effects (non-switch minus switch) for both earlier and later words in the stories at both the N400 and the LPC time windows[2]. In conjunction with isolated word processing studies mentioned Section 1.1 (Alvarez, et al., 2003; Chauncey, et

al., 2008; Midgley, et al., 2009; Phillips, et al., 2006), our findings imply that the code switch LPC is related to sentence-level integration of the code switched word. The next step will be to determine if code switch comprehension is affected by word position in a single sentence. Based on our and van Petten's (van Petten, 1993; van Petten & Kutas, 1990, 1991) findings we predict that switches earlier in a sentence should be harder to process, and therefore elicit larger N400 amplitude, than switches later in that same sentence.

Independent of code switching, the only effect of word position was observed in the N400 time window in interaction with word class. Here, early nouns were more negative across the scalp than late nouns, whereas early verbs did not differ from late verbs. A similar difference was observed over prefrontal electrodes as a sustained negativity across the N400-LPC window. A sustained frontal negativity has been linked to a higher working memory load (King & Kutas, 1995). As mentioned in Section 3.1, nouns are coreferring expressions that need to be maintained in a discourse. An early noun can therefore cause a higher memory load than a late noun. Together, these findings suggest that nouns that appear earlier in the discourse require more neural resources to process than nouns that appear later in the discourse, whereas verbs are processed the same regardless of their position in the context.

Anderson and Holcomb (2005) compared the processing of antecedents (nouns first presented), repeated nouns, and synonyms in short discourses. Synonyms elicited a larger N400 than repeated nouns, but a smaller N400 than antecedents. This finding suggests that semantic access is harder for the first appearance of a noun, and easier when it reappears later. Synonyms fall in between, because even when a synonym appears for the first time, it can be related to a previous noun conceptually. Similarly, data from Burkhardt (2006) showed that both the N400 and P600 were affected by the coreferential property of a noun phrase: a new noun phrase in the discourse produced larger N400 and P600 effects compared to a previously introduced noun phrase. A bridged or inferred noun phrase (e.g., 'the composer' is inferred by the word 'concert' introduced earlier in the discourse) generated smaller N400 amplitude than a new noun phrase (with similar P600 amplitude). All of this suggests that a new noun is harder to retrieve from memory and also harder to integrate at the discourse level. Concordantly, in the current study early nouns produced a larger N400 and a sustained frontal negativity compared to late nouns. In contrast, verbs were not affected by word position. Thus, it appears that early nouns create greater processing costs both from a linguistic perspective – present new information, little lexical association with other words – and from a memory perspective – need to be held in the working memory.

4. Materials and methods

4.1 Participants

All participants were tested on the University of Texas at San Antonio campus, which has a large Spanish-English bilingual population among which code-switching behavior is not uncommon[3]. Twenty-eight consenting, healthy, right-handed balanced Spanish-English bilinguals participated in the experiment for monetary compensation; 4 were eliminated due

[2]Each story had 4 code switched words, which could potentially have allowed participants to prepare for upcoming switches. However, the location of each switch in a given sentence was unpredictable and different across stories, and the structure of each sentence varied, making it unlikely that participants could predict when a switch would occur. Future research could determine if other factors, such as the probability of a switch (many switches or few switches in a story) or the position of a single switch in the context (early or late) qualify our findings.

[3]We did not collect data on code-switching habits for this population sample. However, we know from our study that code switching frequency and the reasons for code switching vary in the local population (Blackburn & Wicha, submitted). We expect that the random sample of this test population is representative of this broad spectrum.

to excessive EEG artifacts or errors in the comprehension questions. The remaining 24 participants (ages 19–33 years, $M = 22.2$; 16 female) were native Spanish speakers, who had been first exposed to English at different ages (range: 0–15 years; $M = 6.6$). All had corrected or corrected-to-normal vision and reported no cognitive impairments. Before the ERP study, all participants completed the letter section of the Verbal Fluency Test (VFT) (Benton, Hamsher, & Sivan, 1994), and the Boston Naming Test (BNT) (Kaplan, Goodglass, & Weintraub, 1983) for evaluation of their vocabulary capacity in both languages. VFT scores across the sample were on average 11.6 (2.8 s.d.) words in English and 12.1 (3.0 s.d.) in Spanish. BNT scores across the sample were on average 44.2 (6.6 s.d.) out of 60 pictures named correctly in English and 44.7 (5.2 s.d.) in Spanish. Paired-samples t-tests revealed no reliable differences between the two languages in the participants' VFT or BNT scores (**VFT**: $t_{1,23} = 1.175$, $p = .252$; **BNT**: $t_{1,23} = .335$, $p = .740$), reflecting that the sample population was balanced in proficiency between English and Spanish.

4.2 Stimuli

The experimental materials included 20 short stories in English from Aesop's Fables (Ashliman & Vernon Jones, 2003). These stories provided well-written and brief (approximately 4 sentences in length) passages that were easy to read and comprehend. Each story had 8 target words, 4 verbs and 4 nouns (see example in Section 1.4). Each word appeared once in English and once as the translation equivalent in Spanish across 2 different versions of the story, such that every story version had a total of 4 switched words (2 nouns and 2 verbs). Each story version had the switches in the sequence of either VNVN or NVNV, wherein the switched verb and noun in each position across the two versions were as close to each other as possible. This controlled for the amount of context preceding each verb/noun pair across the discourse. To study the word position effect on code switching, the first two switched words were categorized as 'early switches,' and the last two were 'late switches.' Spanish words were presented with appropriate accents, and agreement and tense inflections.

Each participant read 20 stories, one version for each story. In total, each list contained 160 switched Spanish words (41 early nouns, 39 early verbs[4], 40 late nouns, 40 late verbs) and 160 English control words. We obtained the number of occurrences per million words for the actual form of the target words (e.g, *passed*) from Davis (M. Davis, 2002-, 2008-) for English and Spanish[5]. An analysis of variance was performed with Frequency as the dependent variable, and Language, Word Class, and Word Position as independent variables. A main effect of Language revealed that English words were more frequent than their Spanish equivalents ($F_{1,312} = 7.053$, $p = .008$). Overall, nouns were not different in frequency than verbs (Word Class, $F_{1,312} = 0.915$, $p = .339$) and early words were not different in frequency than late words ($F_{1,312} = 0.099$, $p = .753$). Since Spanish verbs tend to have more forms per lexeme than English verbs, we also checked the lexeme frequency for all the targets (i.e., including all the variants of 'pass,' e.g., *passed, passing*, and etc.). There was no Language effect ($F_{1,312} = 1.091$, $p = .297$) or Language × Word Class interaction ($F_{1,312} = 1.055$, $p = .305$).

We also measured the length of the critical words. Spanish words (Mean = 6.3) contained more letters than English words (Mean = 5.5) ($F_{1,312} = 17.213$, $p < .001$), and verbs (Mean

[4]Due to a technical error, one story had 2 early nouns instead of one early noun and one early verb. All but two (*pie* and *meter*) words were not cognates or interlingual homographs. Because the target words were not individually coded, we were not able to remove the two homographs.

[5]We obtained the word frequency based on the 1900s materials in Davis's Spanish database (about 20 million words), and all the words (1990-) in Davis's American English database (about 450 million words).

= 6.4) were longer than nouns (Mean = 5.4) ($F_{1,312}$ = 28.780, p < .001). There were no other effects.

Imageability ratings were also obtained as a measure of concreteness, from Davis and Perea (2005) for Spanish and from Davis (2005) for English. Nearly 1/3 of the stimuli (23 Spanish words and 29 English words) were not in the databases. Of those words in the databases, nouns were more imageable than verbs in both languages ($F_{1,267}$ = 122.164, p < .001), as is typical (Gentner, 1981). Comparing imageability across English and Spanish was not possible since the databases used different measures.

4.3 Procedure

Participants were seated in a sound attenuating and electrically shielded recording chamber, 3 feet from a color computer monitor. The stimuli were presented one word at a time (250–325 ms on, 175–221 ms off – duration correlated positively with word length) in the center of the monitor. Each sentence in a story began with a fixation marker ("+"), and ended with a blank screen that lasted for 1000 ms. Participants were asked to read for comprehension. They were also instructed to avoid blinking during a sentence and instead to blink between sentences. At the end of each story, they were required to answer a yes/no comprehension question by pressing two buttons on the keyboard with their right hand. No feedback was given on response accuracy, and no additional task was imposed. The mean accuracy rate on the comprehension questions was 91%, confirming attentive reading. We entered all the target words into data analysis, including those in stories with errors in comprehension questions because the comprehension questions were used only to encourage attentive reading but not to exclude particular trials.

4.4 EEG parameters

ERPSYSTEM software (developed by P. J. Holcomb; http://neurocoglaboratory.org/ERPSystem.htm) was used to simultaneously present visual stimuli to the participant and record the EEG activity. Continuous scalp EEG was acquired using a geodesic array of 26 electrodes embedded in a custom electrode cap (see Figure 2, line intersections represent electrode). Six free electrodes were used to record blinks (below the eye), horizontal eye movements (outer canthi), and left and right mastoid processes as reference. EEG data was amplified with analog differential bioamplifiers (SA Instrumentation, Co., San Diego, CA) using a band pass set from 0.01 (RC; −6 dB/oct) to 100 Hz (Butterworth; −12 dB/oct) and sampled at a rate of 250 Hz. Data was referenced online to the left mastoid and re-referenced offline to the algebraic sum of left and right mastoids. Electrode impedances were maintained below 5kΩ. A digital band-pass filter from 0.1–30Hz (3^{rd} order Butterworth) was applied to ERP data prior to analysis[6]. Trials with artifacts due to blinks, eye movement and excessive muscular activity were removed before data analysis, resulting in approximately 11% data loss. Data was analyzed relative to a 100 ms pre-stimulus baseline.

5. Conclusion

The current study investigated the interplay of code switching, word class and word position in processing written discourse. Balanced Spanish-English bilinguals read short English stories, each with a set of nouns and verbs switched into Spanish across the story. We replicated 2 previous findings. First, switched words elicit a larger left-lateral negativity

[6]The digital band pass filter was used to make the data comparable to prior studies (e.g., Moreno et al., 2002). Using visual inspection of the pre and post filtered data, we verified that the 0.1 high pass filter did not cause distortion in the time domain (VanRullen, 2011; Widmann & Schröger, 2012).

(LAN) than the non-switched words, and a larger LPC with a posterior maximum. Second, nouns produce a larger N400 than verbs. We also observed several new findings:

1. Code switching reduces the N400 word class effect over prefrontal scalp sites, possibly because the abruptness of switching results in shallow processing of lexical characteristics, such as concreteness.
2. Switched nouns produce a larger positivity than non-switched nouns in the LPCa latency (500–600 ms), but the switching effect was absent for verbs. This indicates that switched nouns are harder to integrate, possibly because of their referential properties.
3. Early nouns evoke a larger N400 and a larger sustained negativity at prefrontal sites than late nouns. This indicates that early referents may be harder to retrieve from memory and may incur a higher working memory load, because they present new information and need to be maintained in memory during discourse.
4. Code switching had the same effect regardless of when in the discourse it occurred. This suggests that switching, unlike word class, may not affect processing at the discourse level.

In brief, we show that the effect of code switching can vary based on the type of word switched (noun or verb), but it does not seem to be affected by where in discourse a switch occurs (in terms of the amount of preceding context). This study adds to the short list of publications addressing the electrophysiological basis of switching between languages, especially with regard to discourse processing and word class effects on comprehending a switched word.

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Highlights

- Adult bilinguals read short stories with occasional code-switched nouns and verbs
- Event-related potentials show that code switching increases LAN and LPC amplitude
- Switched nouns, not verbs, elicit larger LPCa amplitude
- Amount of preceding discourse did not modulate the code switch comprehension cost
- Referential phrases (nouns) may be harder to integrate into local and sentence context

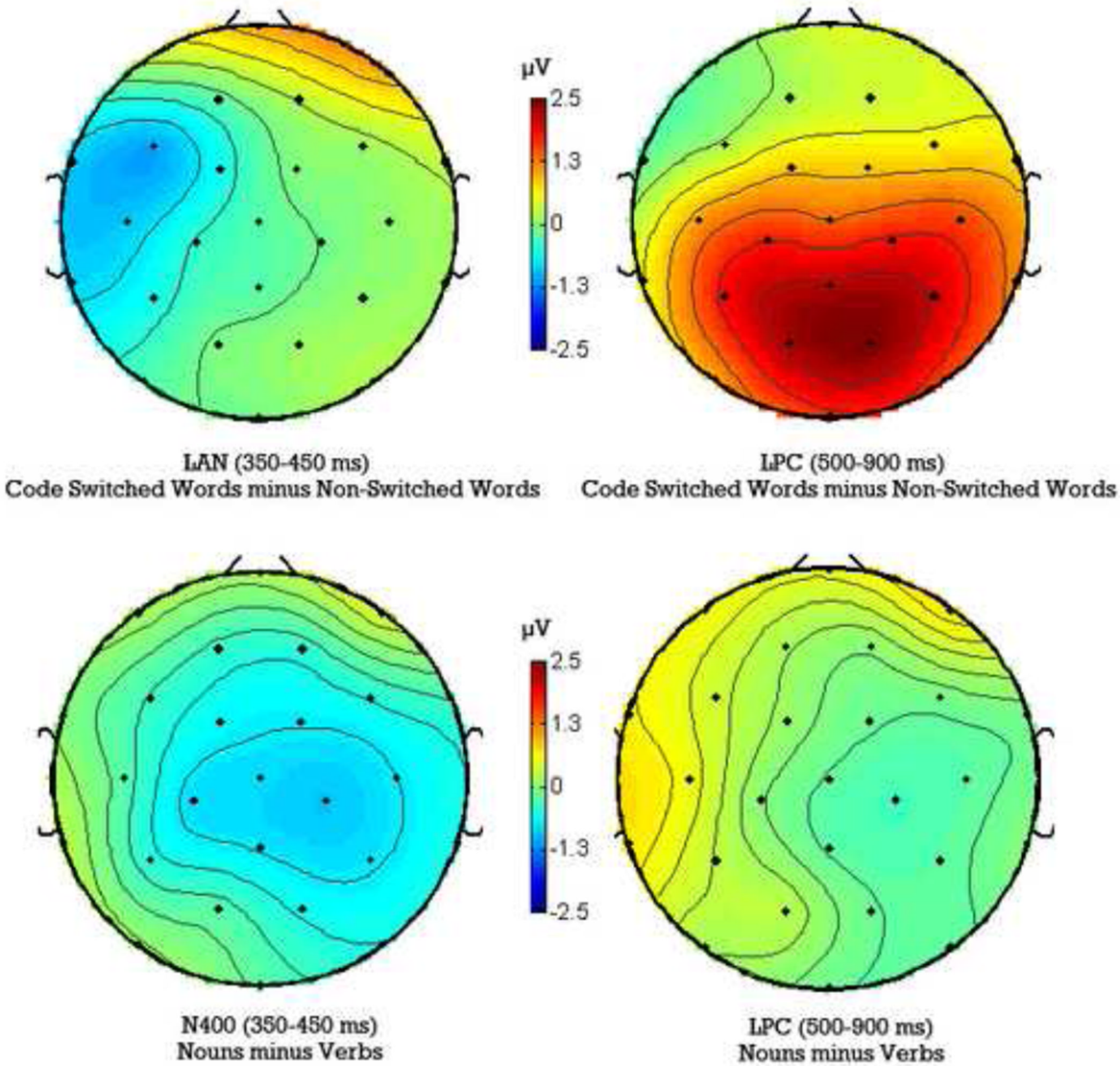

Figure 1.
Isovoltage scalp distributions for the effects of code switching (top row: code switched minus non-switched words) and the effects of word class (bottom row: nouns minus verbs) in the negativity (left column: 350–450 ms post-stimulus onset) and LPC (right column: 500–900 ms post-stimulus onset) time windows.

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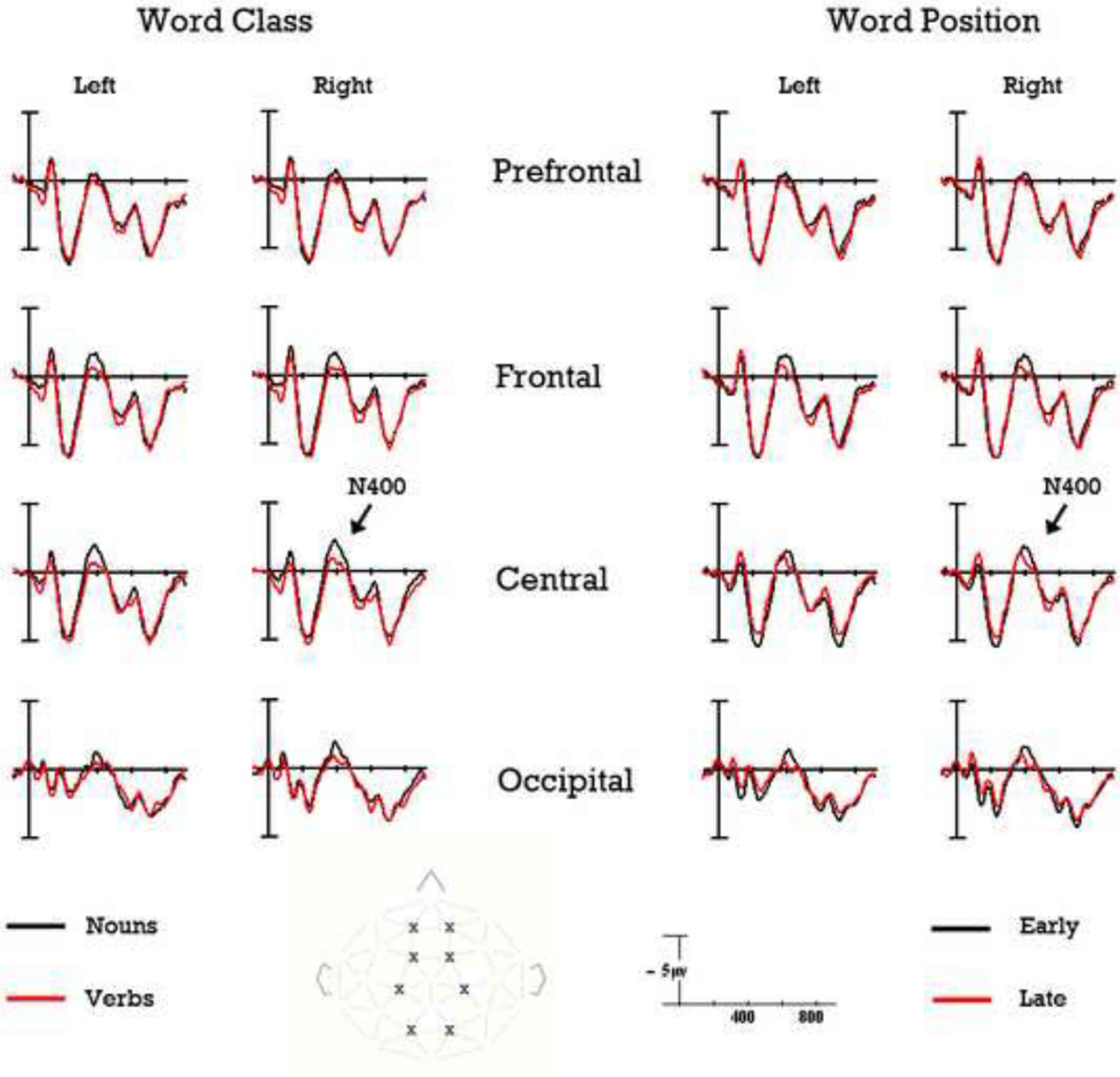

Figure 2.
Grand average ERPs from 8 representative electrodes Word Class (left) and Word Position (right). All electrodes are in medial positions. Negative amplitude in microvolts is plotted up on the y-axis; time is on the x-axis in milliseconds. Electrode positions, marked with an X, are shown on bird's-eye view of the head at the bottom of the figure.

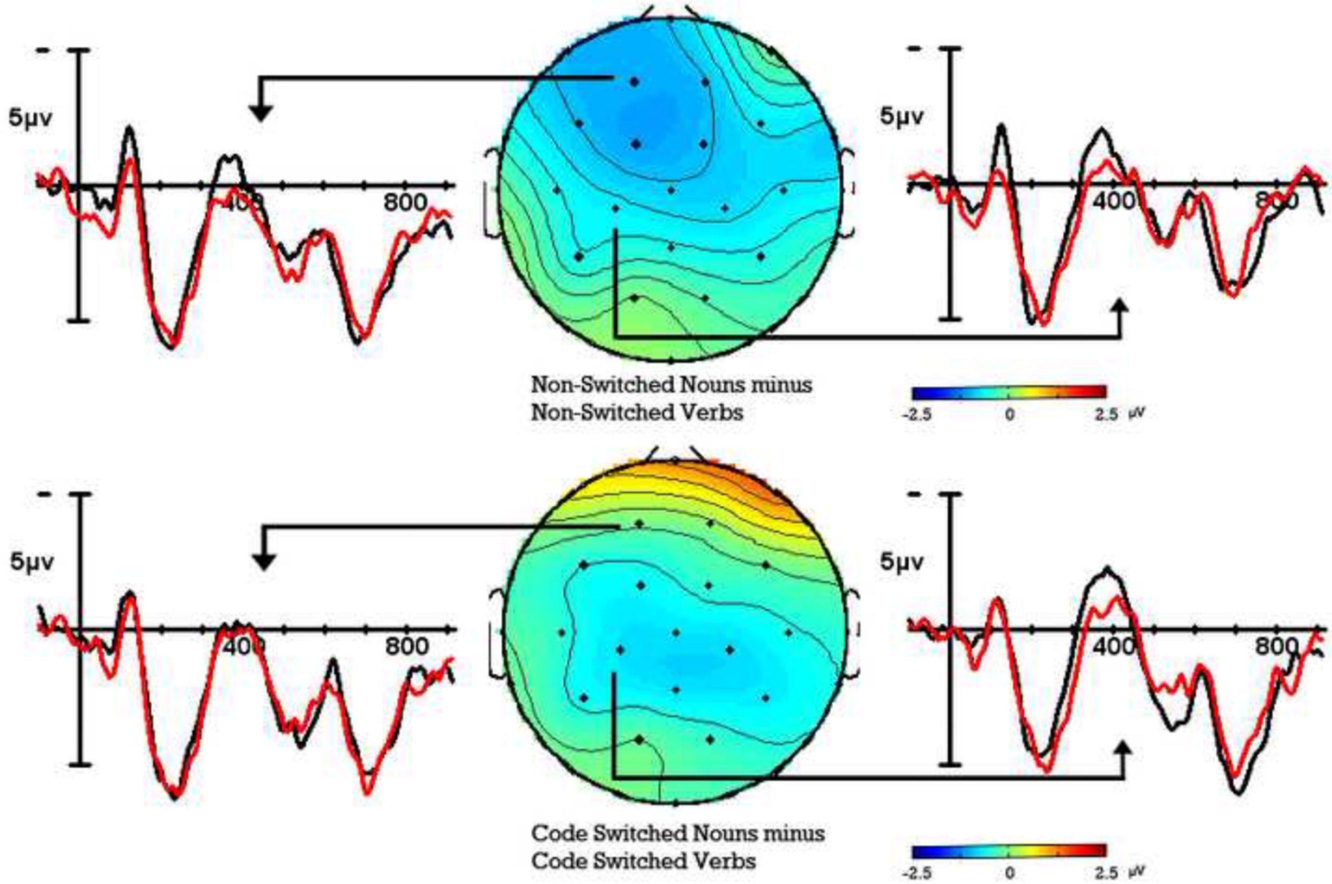

Figure 3.
The N400 effect (350–450 ms) for Code Switching by Word Class. Isovoltage scalp distributions for the effect of Word Class (nouns minus verbs) for non-switched (top) and switched (bottom) words, with 1 left medial prefrontal electrode and 1 left medial central electrode highlighted. Non-switched word class effect show a more frontally distributed N400 effect than switched word class effect; the N400 word class effect at medial central electrodes was not different between switched and non-switched words.

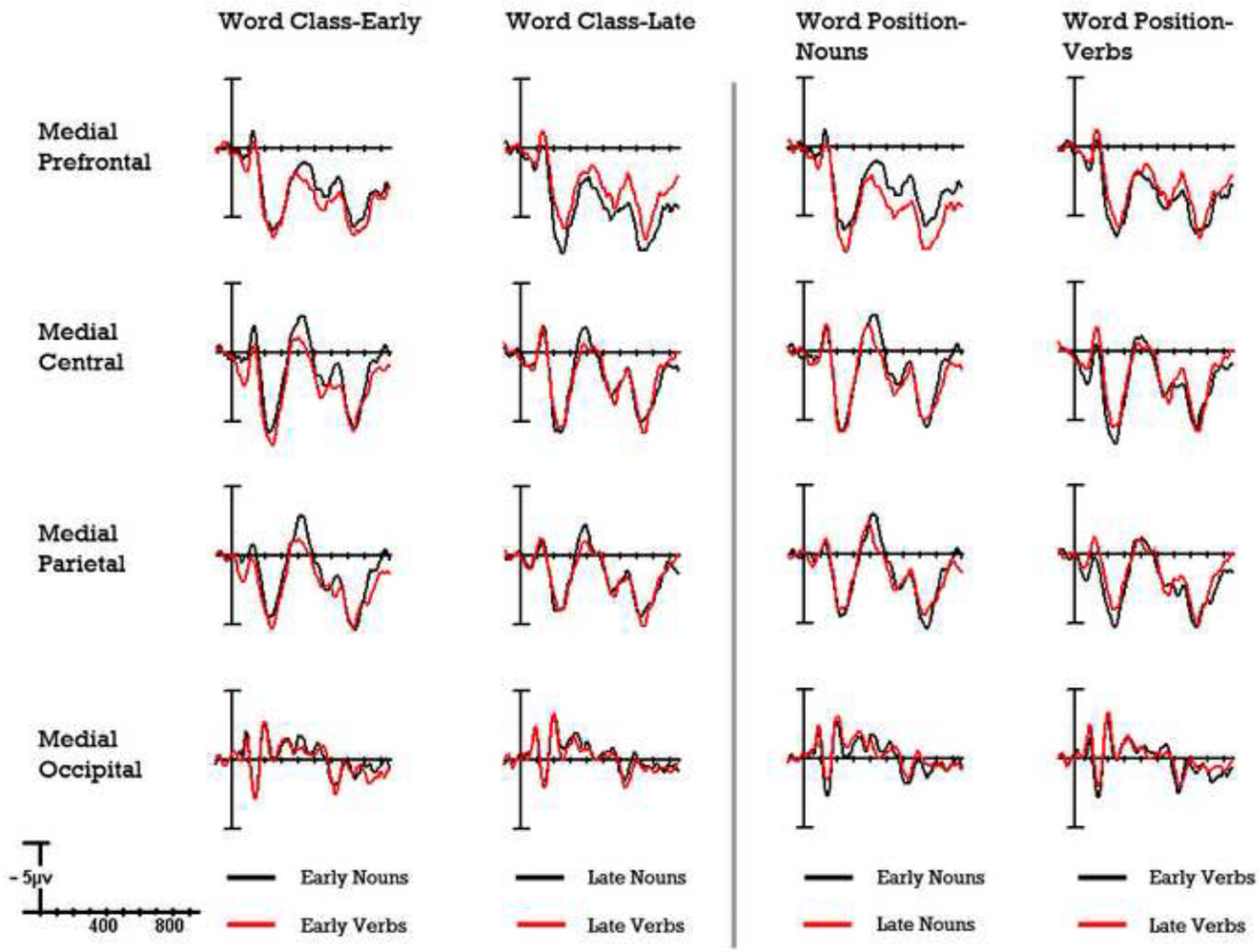

Figure 4.

Grand average ERPs for Word Class by Word Position shown at 8 representative electrodes (see Figure 2 for scalp positions). The left panel shows the word class effect plotted for early and late verbs separately. The right panel shows the same data plotted as word position effect for nouns and verbs separately.

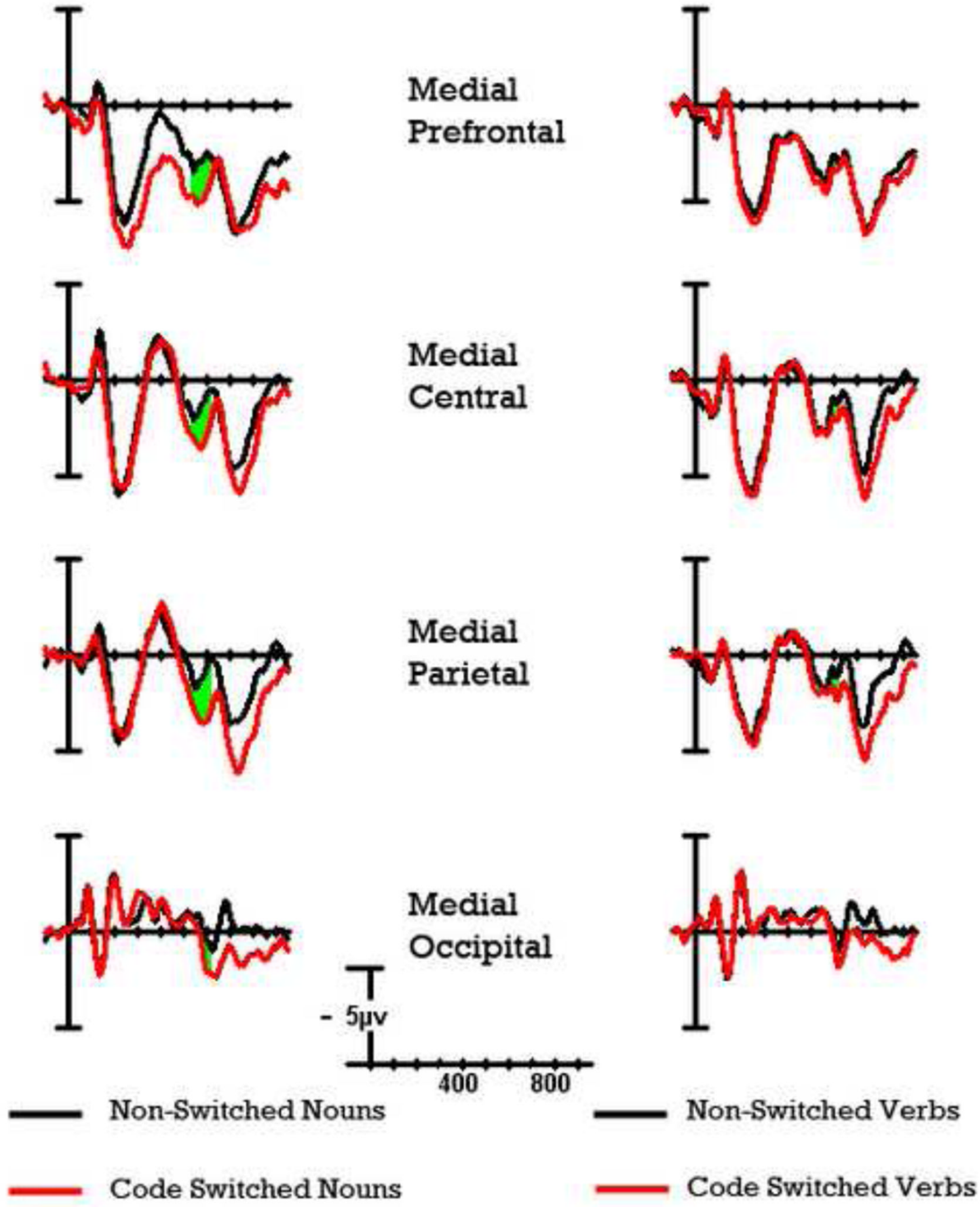

Figure 5.
Grand averaged ERPs for the 4-midline electrodes showing the effect of code switching for nouns (left) and verbs (right). The LPCa region is highlighted.