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Electrophysiological correlates of language switching in second language learners

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Abstract

This study analyzed the electrophysiological correlates of language switching in second language learners. Participants were native Spanish speakers classified in two groups according to English proficiency (high and low). Event-related potentials (ERPs) were recorded while they read English sentences, half of which contained an adjective in Spanish in the middle of the sentence. The ERP results show the time-course of language switch processing for both groups: an initial detection of the switch driven by language-specific orthography (left-occipital N250) followed by costs at the level of the lexico-semantic system (N400), and finally a late updating or reanalysis process (LPC). In the high proficiency group, effects in the N400 time window extended to left anterior electrodes and were followed by larger LPC amplitudes at posterior sites. These differences suggest that proficiency modulates the different processes triggered by language switches.

Descriptors: ERP, Bilingualism, Code-switching, Second language learning

The need to learn a new language after childhood has increased in recent years, due to the growing possibilities of travel and work in other countries. Therefore, studying how new languages are acquired and how they interact in the brain has become an important topic with social implications. In this investigation, we use online recordings to measure electrical brain activity when adult language learners read in their new language and, more specifically, we explore what happens when they encounter a switch between languages.

Second Language Acquisition

Most psycholinguistic models of bilingualism are models of second language processing without a developmental component (e.g., Dijkstra & Van Heuven, 1998, 2002). One exception is the Revised Hierarchical Model (RHM) of Kroll and Stewart (1994), which offers an explanation for the changes produced by second language acquisition. The RHM assumes an independent separate lexicon for each language and an integrated shared semantic/conceptual system. The model also proposes that the link between the first language (L1) and conceptual knowledge is very strong, whereas the link between the lexicon of the second language (L2) and the semantic/conceptual system changes during the process of second language acquisition. In an early stage of learning, there will be strong links from the L2 lexicon to L1 and weak links between the L2 lexicon and the semantic/conceptual system, with a tendency to access the meaning of words in L2 via the equivalent in their L1 (lexical mediation). With increasing competence in L2, the links from the L2 lexicon to conceptual knowledge become stronger, and learners will be capable of directly accessing the meaning of words in L2 and depend less on the link between the two lexicons (conceptual mediation). The predictions of the RHM have been tested using behavioral measures (reviewed in Kroll & Tokowicz, 2005), and in some electrophysiological studies (e.g., Midgley, Holcomb, & Grainger, 2009a; Rodríguez-Fornells, de Diego Balaguer, & Münte, 2006). Although more evidence is clearly needed (Brysbaert & Duyck, in press), the RHM could be an appropriate framework to interpret online measures of brain activity in second language learners.

Event-related potentials (ERPs) have been a very useful tool to track the changes that take place in the brain when people are

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learning a second language. One productive line of research has looked at changes in brain electrical activity during the learning of artificial languages (Bahlmann, Gunter, & Friederici; 2006; Friederici, Steinhauer, & Pfeifer, 2002). Other experiments have studied the impact of semantic or syntactic violations in second language learners during reading, either in longitudinal studies (Osterhout, McLaughlin, Pitkänen, Frenck-Mestre & Molinaro, 2006), or by comparing different groups with different levels of proficiency in their L2 (see review in van Hell & Tokowicz, 2010). In the present experiment, we studied the learning development in two groups of learners with different L2 proficiency, by analyzing the ERP correlates of language switching.

ERP Associated with Language Switching

In balanced bilingual populations, the substitution of an element (e.g., a word, phrase, or sentence) from one language with another from a different language is a common phenomenon, and is usually known as *code switching*. Language substitutions also happen in verbal exchanges between language learners, but probably for different reasons. Learners can use the L1 when they do not know the equivalent form in their L2. Switching between languages can be understood more as a compensatory strategy in the early stages of learning a second language, whereas for more balanced bilinguals switching may be associated with high competence. For this reason, we prefer to use the more general term of *language switching* instead of *code switching* when we refer to language learners who have not achieved a high level of proficiency in their L2 and do not use their second language in everyday life.

Moreno, Federmeier, and Kutas (2002) carried out an ERP study with bilinguals who were proficient both in English and in Spanish. They compared switches between languages to within-language, lexical switches in English sentences, which could end with the expected English word, its Spanish translation (code switch), or an English synonym (lexical switch). Lexical switches enhanced the N400 response (250–450 ms) maximum at right parietal sites, whereas code switches produced an increased negativity over left frontal sites (LAN), which was followed by a large posterior positivity (late positive complex or LPC) in the 450–850 ms time window. The N400 has been described as an index of the difficulty of meaning activation/integration processes in sentences; the more predictable a word, the smaller the N400 elicited (Kutas & Federmeier, 2000; Kutas & Hillyard, 1980; Molinaro, Conrad, Barber, & Carreiras, 2010). In contrast, LAN effects have been linked to working memory load and syntactic integration processing (Barber & Carreiras, 2005; Friederici, Pfeifer, & Hahne, 1993; Kluender & Kutas, 1993). The authors suggested that, for these bilinguals, the costs of switching between languages might be associated with decision-related processes more than lexico-semantic processing. Proverbio, Leoni, and Zani (2004) performed a similar study with native Italian simultaneous interpreters who had to read sentences for comprehension in Italian and in English with an English or Italian ending. In contrast to the previous study, they reported an N400 effect in response to code switching from L1 to L2 but not from L2 to L1. The authors claim that this asymmetric effect reflects difficulty in the semantic integration when an L2 word is encountered, because their participants acquired L2 after the consolidation of the conceptual system. Therefore, code switching in balanced bilinguals has resulted in ERP amplitude differences in the N400 time window, but, depending on the specific topographical distribution of the effect, they have been sometimes attributed to lexico-semantic processing and sometimes not.

According to the RHM, at early stages of second language acquisition, the link between L1 and L2 at the lexical level is stronger than at later stages, in which the L2 has established links with the conceptual system. Attending to this premise, we predict N400 effects associated with language switching in second language learners, which would indicate increased costs at the lexical level. Moreno et al. (2002) carried out a preliminary evaluation of the impact of proficiency on the ERP correlates of code-switching. They reported a regression analysis on ERP measures and participant scores in the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983) performed in English and Spanish. They found that increased Spanish vocabulary was predictive of both smaller mean amplitudes and earlier peak latencies of the LPC responses to code switches. However, it is important to note that the group of participants included both English and Spanish dominant bilinguals, therefore this data refers to proficiency in the switched language with respect to the base language, but not to the balance between L1 and L2. The present study has been designed to further explore the impact of L2 proficiency on the electrophysiological correlates of language switching, comparing two homogenous groups of Spanish speakers (L1) with different levels of proficiency in English (L2).

Early Orthographic Effects During Language Switching

Language switching in reading could also affect lower level processing related to the orthographic characteristic of each language, and that processing will also be examined in the present study. A relevant topic in second language processing is cross-language competition during word recognition. In addition to the described effects related to the ongoing integration of the switched words in the sentence context, some models propose that language selection of the input benefits from other sources of information, including the different orthographies of the languages (Dijkstra & Van Heuven, 2002). Detection of a language switch could take place at an early orthographic stage of word recognition that precedes meaning activation. Surprisingly, behavioral evidence has failed to support the role of orthography in language selection (e.g., Thomas & Allport, 2000). However, the time resolution of the ERP technique allows us to better test this prediction, looking at early effects associated with language switching. As we describe below, there are several ERP effects in the published literature that could index early detection of a change in orthographic form when a language switch is encountered.

Many prior studies have reported early ERP effects before the range of the N400 component, usually related to orthographic and phonological processing (see review in Barber & Kutas, 2007). These include effects of letter transposition (Carreiras, Vergara, & Perea, 2009), effects of consonants and vowels when manipulated selectively (Carreiras, Duñabeitia, & Molinaro, 2009; Carreiras, Gillon-Dowens, Vergara, & Perea, 2009) and effects of phonological syllable frequency (Barber, Vergara, & Carreiras, 2004; Carreiras, Vergara, & Barber, 2005). Several studies have shown that the visual N1 component, peaking around 170 ms after word onset, is modulated at left occipital electrodes by orthographic variables (Maurer, Brandeis, & McCandliss, 2005). These so-called N170 effects associated with word reading have been linked to activity in the occipital temporal fusiform gyrus of the left hemisphere (Glezer, Jiang, & Riesenhuber, 2009; McCandliss, Cohen, & Dehaene, 2003; Price and Devlin, 2003). At a slightly later latency, a negativity peaking at 250 ms with a central distribution (N250) has been observed in masking priming paradigms, and has also been claimed to reflect the mapping of sublexical information (e.g., ordered letter combinations) onto whole-word orthographic representations (Holcomb & Grainger, 2006). Interestingly, this N250 was found in response to language changes in two masked priming experiments when L2 words were preceded by unrelated L1 words (Chauncey, Grainger, & Holcomb, 2008), or by their L1 equivalent, but the time-course of this translation effect was somewhat later—peaking at 300 ms (Midgley, Holcomb, & Grainger, 2009b). In the ERP studies of code switching reviewed above, Moreno et al. (2002) did not report differences before the N400 time window in response to code switching, but Proverbio et al. (2004) described a modulation of the N1 component at left anterior electrodes. In the ERP studies of code switching in sentences reviewed above, neither Moreno et al. (2002) nor Proverbio et al. (2004) reported main effects of code switching before the N400 time window. However, Proverbio et al. (2004) described an interaction of semantic incongruence, code switching, and switching direction between 130 and 200 ms at some frontal electrodes, for which code switching from L2 to L1 produced amplitudes that are more negative and only with semantically incongruent words. In our study, the activation of the orthographic and phonological L1 and L2 patterns should be less balanced in second language learners as compared to bilinguals fluent in both languages, and this circumstance should enhance orthographic effects in response to language switching either in the N170 or in the N250 components.

The Present Experiment

Proficiency is a critical variable in the study of second language processing and one that has not been consistently controlled or manipulated in previous ERP studies of bilingualism in general (Kotz, 2008), and language switching in particular (van Hell & Witteman, 2009). The main goal of the present study is to investigate how proficiency in a second language affects the ERP correlates of language switches when second language learners switch from English (L2) to Spanish (L1). Following the RHM model, we hypothesize that, in contrast to the case of balanced bilinguals, switching across languages for second language learners can be understood more as lexical switching, because the connections between L1 and L2 words are still very strong, while connections between L2 lexical items and the conceptual system are still weak. Therefore, in contrast to Moreno et al. (2002), we predict an N400 effect in response to the code switches, and, in contrast with Proverbio et al. (2004), we expect to find this effect even when learners have to switch from their L2 to their L1. Moreover, if second language learners behave differently from balanced bilinguals in response to code switching, we can expect that the level of proficiency in L2 will modulate these differences. Therefore, we are also interested in the ERP changes that take place when competence in the second language increases.

We tested two different groups of learners with different levels of English (L2) proficiency living within a monolingual Spanish environment. They were all Spanish speakers attending English courses, but since in Spain books, films, and other productions are usually translated, dubbed, or voiced over in Spanish, they had little exposure to English via television or other means. Therefore, our participants do not use English in their daily life and are very far from the competence level of balanced bilinguals (those with similar skills in L1 and L2). The difference between the two groups was limited to L2 proficiency, and there were no significant differences in environmental exposure to English or in language learning methods. All of the participants share a similar socio-linguistic background. Comparing language-switching processing in these two groups, which differ only in their amount of training, will give us some insights about the development of second language processing.

Method

Participants

To select high and low proficiency second language learners, we recruited 58 potential participants from three different language schools in Tenerife and administered an English aptitude test. The test, from the modern languages school of the University of La Laguna, Spain, contains 60 multiple-choice questions on vocabulary and grammar and yields a proficiency level of 1 to 4. Table 1 shows examples of the test questions. According to the standards of the *Common European Framework of Reference for Languages* published by the Council of Europe (2001), the international equivalent of these levels is as follows: Level 1 = A1 (Breakthrough); Level 2 = A2 (Waystage) and B1 (Threshold); Level 3 = B2 (Vantage); Level 4 = C1 (Effective Operational Proficiency) and C2 (Mastery). It is important to note, however, that the label "Mastery" is not intended to imply native-speaker or near native-speaker competence. Individuals scoring Level 2 and Level 4 were recruited to form the low and high proficiency groups, respectively.

The 36 (22 male and 14 female) participants were aged 19 to 39 (mean age 27.4 years) and were all Spanish native speakers living in Spain. The participants were attending year-long English courses at the language schools when tested, and can therefore be considered active second language learners of English. Although they reported a mean age of acquisition (AoA) of 8.5 years at school, note that this average AoA could be misleading because it refers to the first classroom instruction in the Spanish education system, which usually involves a very superficial contact with the language. Most important for this study was their level of processing a written text in English. Therefore, we focused on reading skills and interpretation of written English and, after the objective English test, we administered a self-rating of English ability (LEAP-Q by Blumenfeld & Kaushanskaya, 2007). Self-reports were on a scale of 1 to 10, where 1 was almost none and 10 like a native speaker. Table 2 shows the ratings of each group on these tests. After the experiment, the experimenter had a brief chat in English with the subjects asking them about their difficulties during the experiment and their experience

Table 1. *Examples of the Questions Used to Assign Participants to the Two Groups*

Selection Items of Proficiency Pre-test of English as L2	Choices
Some people . . . Scotland speak a different language called Gaelic.	on-in-at
Would it . . . you if we came on Thursday?	agree-suit-like-fit
A building which was many . . . high was first called a skyscraper in the United States at the end of the 19th century.	stages-steps-storeys-levels
I find the times of English meals very strange—I'm not used . . . dinner at 6 pm.	to have-to having-having-have

Table 2. *Characteristics of the Participants Assigned to the Two Groups, Regarding Their Level of English*

		Low proficiency		High proficiency		*T*-test (*p*)
Men:Women		12:6		10:8		–
Age in years	(sd)	27.3	(5.3)	27.5	(4.9)	Ns
AoA in years	(sd)	8.2	(2.7)	8.7	(3.4)	Ns
English pre-test	(1–4)	2	4	–		
Self-rated speaking*	(sd)	5.3	(1.6)	7.5	(1.3)	> .01
Self-rated hearing*	(sd)	5.9	(1.6)	7.7	(1.5)	> .01
Self-rated reading*	(sd)	6.8	(1.7)	8.6	(1.3)	> .01

Note: Self-reports were on a scale of 1 to 10, where 1 was almost none and 10 was like a native speaker. AoA, age of acquisition; Ns, not significant.

with foreign languages. None of the participants reported frequent language switches in their everyday life, they only reported occasional language switches, especially in situations of explicit language learning. The participants also found it easier to read than to listen to or produce English, see Table 2.

All participants had normal or corrected-to-normal eyesight and no neurological history, and were right-handed as assessed by a Spanish version of the Edinburgh inventory (Oldfield, 1971).

Stimuli

Stimuli were 160 English sentences of 9 to 12 words. All had a similar structure, namely, compound sentences that included a subordinate clause, starting with a noun phrase followed by either a participle phrase after the noun, or a clause introduced by a relative pronoun such as "that" or "which" (e.g., "The house that we rented was furnished and felt cozy"). Each sentence contained an adjective that could occur in English (*no switch* condition, 80 sentences) or in Spanish (*switch* condition, 80 sentences, e.g., "The house that we rented was amueblada and felt cozy"). The adjectives always referred to the first noun of the sentence and were semantically congruent with the rest of the sentence. Typical word order is not identical in Spanish and English, so that the word order used here was grammatically correct in both languages, although not always the most frequently used one. Adjectives with a similar orthographic or phonological form between languages (i.e., false friends, cognates, or homophones) were not included. Average frequency of the Spanish adjectives was 22 per million with an average word length of 7 letters and 2 orthographic neighbors, reported with *BuscaPalabras* (Davis & Perea, 2005). The English adjectives had a length of 4–10 letters, an average frequency of 64.95 (SD = 136.17) per million, and an average of 2 orthographic neighbors according to the Celex lexical database (Baayen, Piepenbrock, & Van Rijn, 1993). However, these numbers must be interpreted with care since we cannot assume a high correlation with the frequency of use in the classroom environment. For this reason, all the sentences were checked by teachers of the language schools to make sure the participants were familiar with the vocabulary. The sentences were counterbalanced, so each adjective appeared in both conditions, thus creating two different lists.

Procedure

During online recording, each participant was seated in a sound-proof, electrically shielded room at the University of La Laguna approximately 80 cm from a CRT computer. Sentences were presented one word at a time in a grey-green lower case font against a black background via Presentation software (Version 0.70, http://www.neurobs.com). Prior to each sentence, there was a centered "+" sign for 1000 ms and then a blank screen for 500 ms. Each word was visible for 300 ms with a blank screen of 200 ms between words. To create an onset asynchrony between sentences, a blank screen appeared after each sentence with a variable duration of 500–1000 ms. Participants were instructed to read for comprehension, to blink only when there were no words on the screen, to relax their muscles, and to move as little as possible. There were two breaks during the experiment. After the experiment in L2 reported here, the participants were engaged in an unrelated 10-min-long experiment in Spanish. Therefore, the total length of the experiment was 2 h including electrode set up.

The session started with a short practice in the presence of the researcher. At the end of each sentence, the participant either pressed a button to continue or, for a third of the sentences, answered a yes/no comprehension question (e.g., "Did I rent a flat?" after "The house that we rented was furnished and felt cozy"). The questions were included to ensure that participants were reading the sentences for comprehension and were about the verb, the noun, or the adjective (one-quarter of the questions focused on the adjective). One third of the sentences were followed by a comprehension question, and half of the questions appeared after a sentence with a language switch and half after a sentence without a language switch. For the odd-numbered participants, the right hand was used to signal the "Yes" response and the left hand to the "No" response, and for the even-numbered participants, the order was reversed.

EEG Recording and ERP Analyses

The electroencephalogram (EEG) was recorded with 27 Ag/AgCl electrodes embedded in an elastic cap (Easycap, www.easycap.de) referenced to the left mastoid. Figure 1 shows a schematic representation of the electrode arrangement. Two pairs of electrodes above and below the right eye and on the outer canthi of

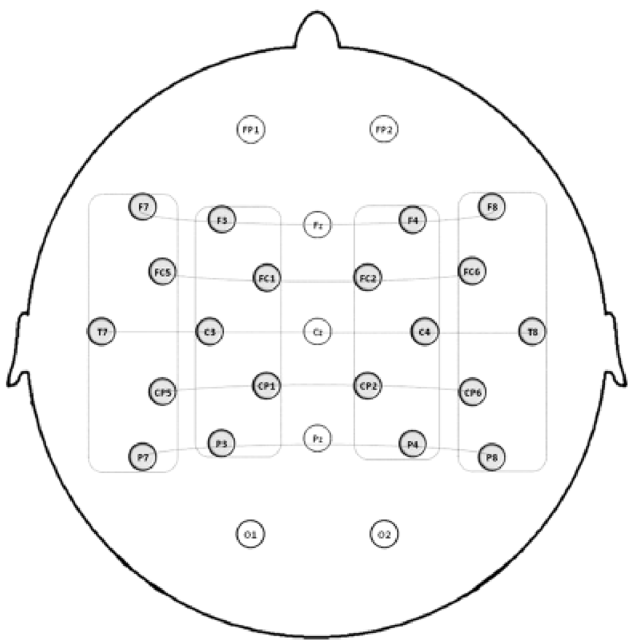

Figure 1. Schematic flat representation of the 27 electrode positions from which EEG activity was recorded. The electrodes analyzed in the ANOVAs are marked.

each eye registered vertical and horizontal eye movements (EOG). All electrical activity was recorded and amplified with a bandwidth of 0.01–100 Hz and a sampling rate of 500 Hz using battery-powered amplifiers (Brain Products, www.brainproducts.com). Impedance was equal to or less than 5 kΩ for all electrode sites except for the four eye channels, which were kept below 10 kΩ. EEG was stored and ERPs were later analyzed using BrainVision Analyzer 2.0 software (Brain Products). The offline filtering of the recordings consisted of a low cutoff filter of 0.1 Hz and a high cutoff of 30 Hz. Data was re-referenced to the algebraic mean of the right and the left mastoids. Blinks were corrected in the recording of only two participants that presented an excessive number of ocular artifacts following the procedure proposed by Gratton, Coles, and Donchin (1983). Artifacts were removed semi-automatically, with rejection values adjusted for each participant. This resulted in the exclusion of approximately 7% of the trials, which were evenly distributed across experimental conditions. The data were segmented relative to reference marker positions, 100 ms before and 1000 ms after onset of the adjective. Baseline correction was performed using the average EEG activity in the 100 ms preceding word onset.

Mean amplitudes were obtained for different time windows selected after visual inspection of the grand average waveforms: 200–300, 300–450, 450–650, and 650–850 ms. Since in the 200–300 ms time-window there can be effects with different polarity that overlap with the onset of later effects, prefrontal (Fp1, Fp2, F3, and F4) and parieto-occipital (P7, P8, O1, and O2) electrodes were analyzed separately. Mean voltage amplitudes relative to the start of the critical adjective were subjected to an omnibus analysis of variance (ANOVA) with Proficiency (low, high) as a between-group factor, Switch (switch, no switch) as a within-subject factor, and two topographical factors: Hemisphere (left, right), and Anterior Posterior (AP) (more anterior, more posterior).

For the analyses of the other time windows (300–450, 450–650 and 650–850), we organized the data from 20 electrodes (F3, Fc1, C3, Cp1, P3, F7, Fc5, T7, Cp5, P7, F4, Fc2, C4, Cp2, P4, F8, FC6, T8, Cp6, P8) into a grid-like scheme (see Figure 1) via three topographic factors of Hemisphere, Distance to midline (DM) (one position from midline, two positions from midline), and an AP factor with five levels (frontal, frontal-central, central, central-parietal, parietal). Repeated measures ANOVAs included a Bonferroni correction to control for type I error in multiple comparisons and all p values, mean squared error (*MSE*), and partial eta squared (η_p^2) are reported corresponding to Greenhouse-Geisser. When violating the sphericity assumption, we report the Greenhouse Geisser-epsilon (ε) to correct for the degrees of freedom. To show the relation of a switch to English and its distribution by group, we include a polynomial contrast for the only factor with five levels, AP. The reported main effects or interactions are limited to those related to the experimental condition Switch. For all statistical analyses, we used the program R (http://www.r-project.org).

Results

ERPs time-locked to the onset presentation of the critical word are shown in Figure 2, after averaging the data of all the participants for the two experimental conditions (language switching versus non-language switching), plotted in four representative electrodes. Figures 3 and 4 show the same grand averages in a larger set of electrodes and separately for the low and high English proficiency groups.

At posterior sites, the P1 and N1 components, which have been associated with the processing of visual stimuli, are clearly visible. Consistent with previous reports on the perception of linguistic stimuli, N1 amplitude is asymmetric across lateral sites, larger over the left than the right hemisphere. Relative to non-language switches, language switches elicited an early negativity between 200 ms and 300 ms after word onset with a left occipito-temporal distribution (labeled as *LO-N250* hereafter). In addition, starting also at 200 ms and lasting until the end of the analyzed segment, a prefrontal positivity (Fp1 and Fp2) distinguished language switches from no-language switches. After 300 ms post-target word presentation, a centro-parietal negativity, with a duration of 150 ms and peaking around 400 ms, shows

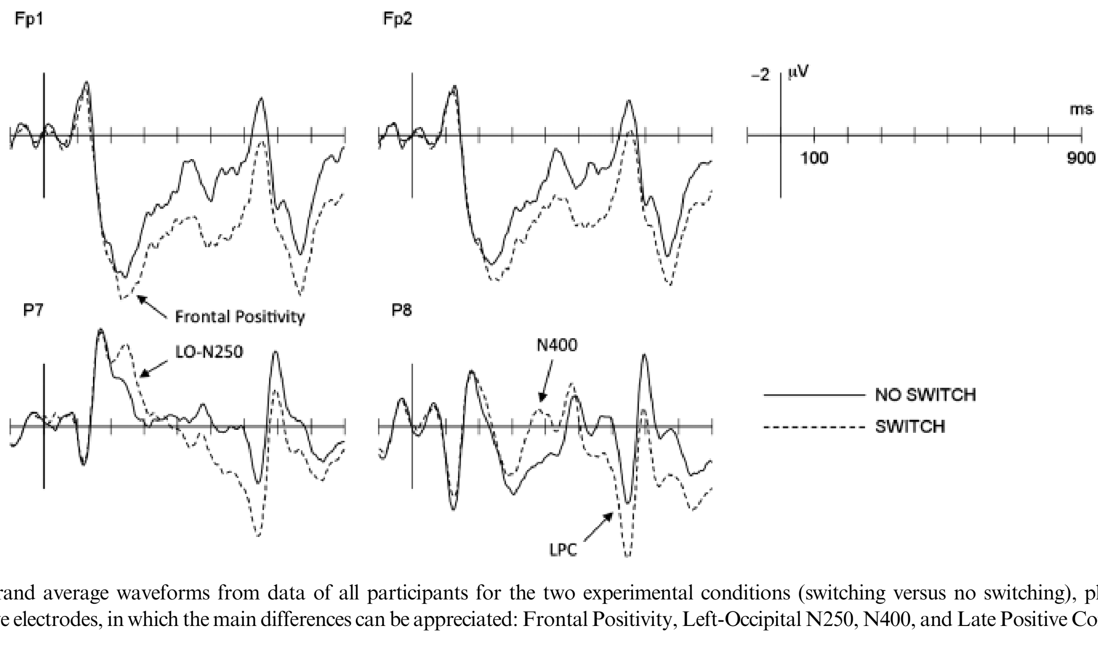

Figure 2. Grand average waveforms from data of all participants for the two experimental conditions (switching versus no switching), plotted in four representative electrodes, in which the main differences can be appreciated: Frontal Positivity, Left-Occipital N250, N400, and Late Positive Complex (LPC).

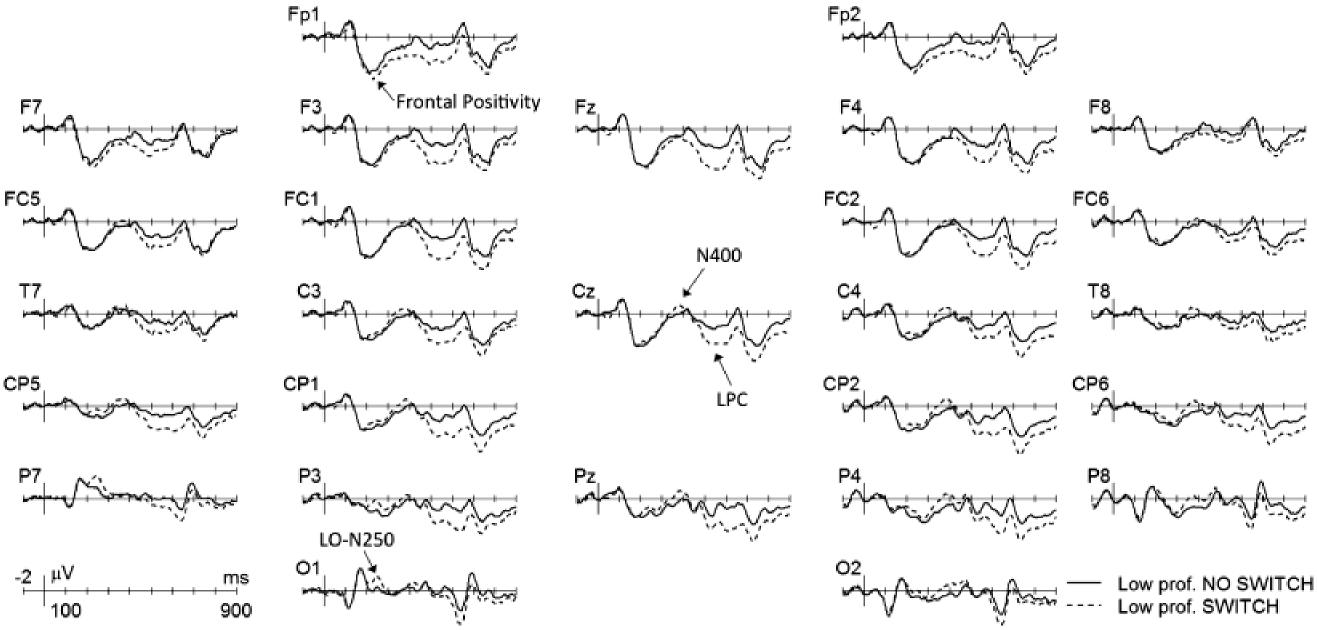

Figure 3. Grand average waveforms of the two conditions (switching versus no switching) for the Low proficiency group.

more negative values for the language switch than the no-language switch condition. This negativity is followed by a positivity for language switches relative to no-language switches starting at 450 ms after critical word onset, with a duration of around 400 ms. Figure 5 shows the topographical distribution of these effects over the scalp, after subtracting ERP activity elicited by the correct sentences from that of the language-switching sentences. As mentioned above, differences between 200 and 300 ms after word onset are focal and localized in the left occipital-temporal electrodes. A second negativity between 300 and 450 ms shows a broader distribution maximum at parietal sites of the right hemisphere for the low proficiency group (upper panel), whereas for the high proficiency group this effect is also maximum at the right-parietal sites but additionally visible at left-anterior sites (lower panel). Thus, the effect shows the typical N400 distribution in both groups, but additionally the distribution of the high proficiency group N400 extends to left frontal areas. The late positivity (between 450 and 850 ms), which is identified as an LPC, is divided in two different time windows. The first time window (between 450 and 640 ms) shows the early LPC with a broad anterior-posterior distribution, but maximum at the frontal sites for the low proficiency group, and at the posterior sites for the high proficiency group. The LPC continued in the second time window but now localized only over the posterior area in

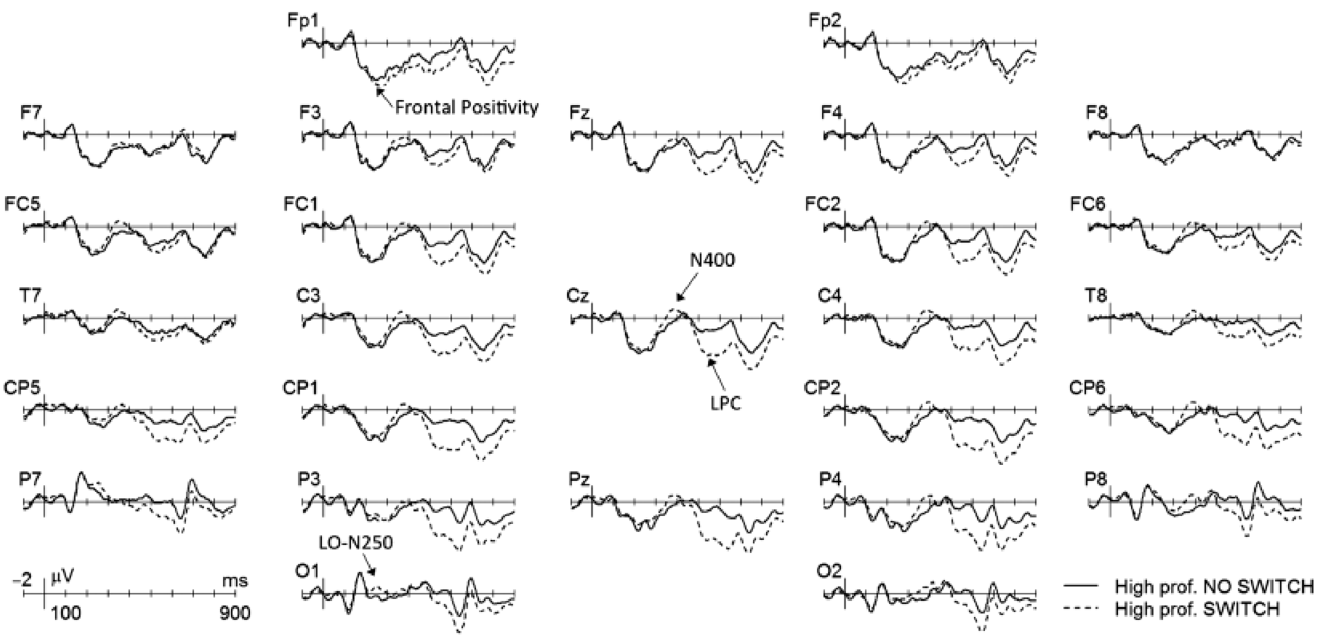

Figure 4. Grand average waveforms of the two conditions (switching versus no switching) for the High proficiency group.

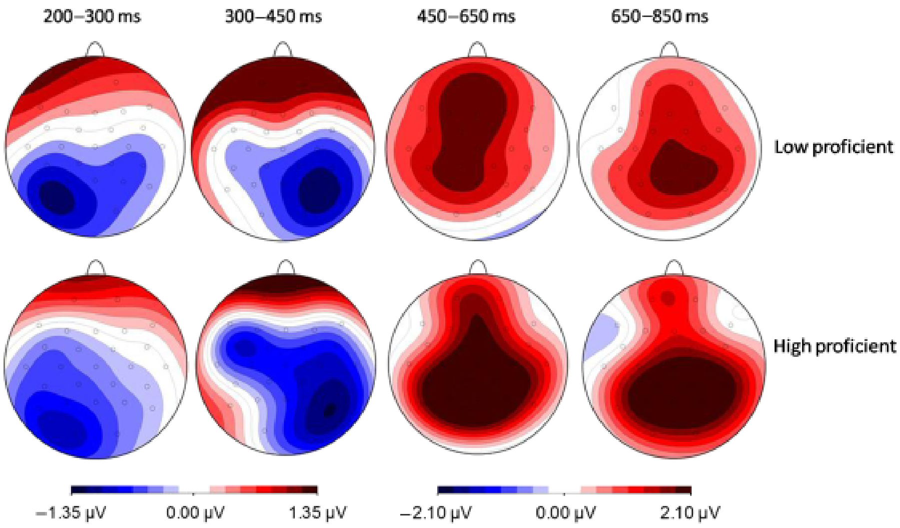

Figure 5. Topographical distribution of the language-switching effects by group (high and low proficiency) in the four analyzed temporal windows: 200–300, 300–450, 450–650 and 650–850 ms. Voltage maps were obtained for the averaged values of difference waves (switching minus no switching).

both groups. The difference waveforms in Figure 6 show that the changes in scalp distribution are due to the main differences between the effects in both groups: a) at frontal sites in the N400 time window (high proficient group producing a larger negativity than the low proficient group), and b) in the posterior sites in the first phase of the LPC (high proficient group producing a larger positivity than the low proficient group). Below, these observations about the various latency windows are tested to confirm their statistical significance.

Time Window Between 200 and 300 ms

The ANOVA (Proficiency × Switch × Hemisphere × AP) on the mean amplitudes of four occipito-parietal electrodes (O1, O2, P7, and P8) resulted in a main effect of Switch (F(1,34) = 23.23; $p < .001$; $MSE = 37.22$; $\eta_p^2 = 0.41$), an interaction between Switch and Hemisphere (F(1,34) = 11.51; $p < .01$; $MSE = 5.37$; $\eta_p^2 = 0.25$). This pattern of interaction confirms the specific topographic distribution of the effect, which is maximum at the left occipito-parietal electrodes. The frontal positivity for language switches, visible in the prefrontal electrodes, was analyzed with a similar ANOVA (Proficiency × Switch × Hemisphere × AP) including four frontal and prefrontal electrodes (Fp1, Fp2, F3, and F4). This ANOVA resulted in a two-way interaction between Switch and AP (F(1,34) = 12.71; $p < .01$; $MSE = 6.01$; $\eta_p^2 = 0.27$). The absence of interactions with the factor Proficiency in this time window shows that code switching affected ERPs independently of the level of L2 proficiency.

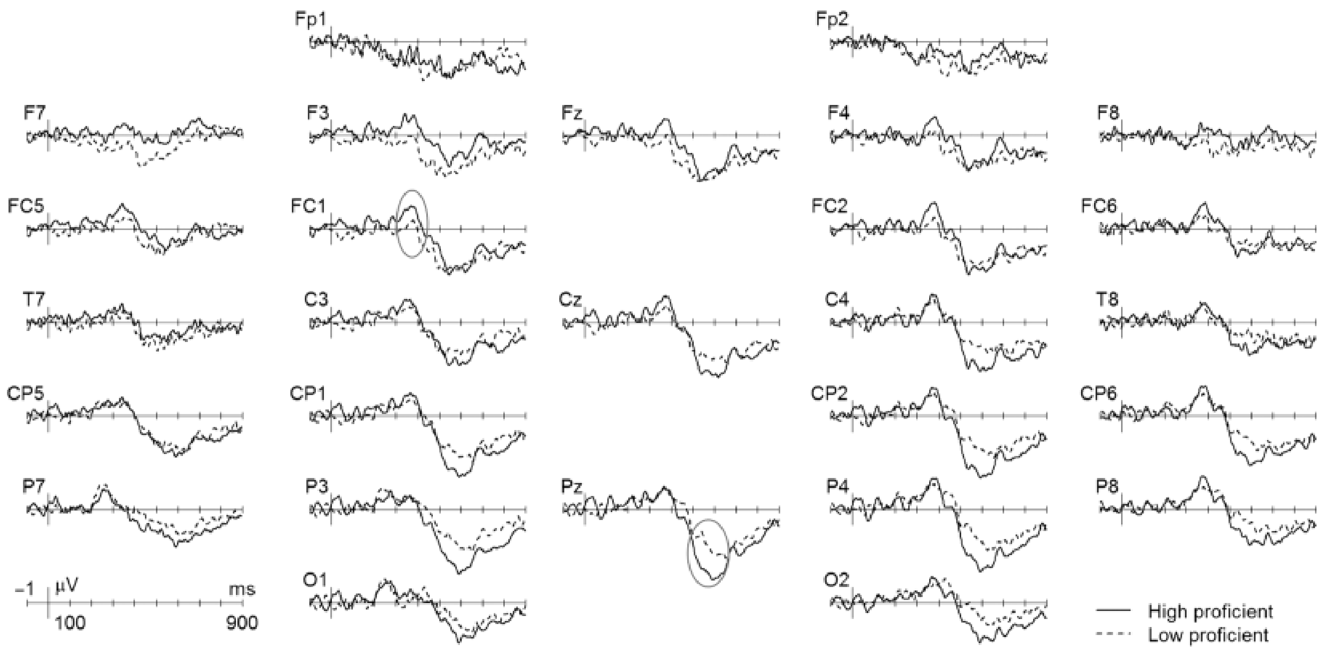

Figure 6. Difference waveforms of the High proficiency group versus the Low proficiency group, obtained by subtracting the no switch condition from the switch condition.

Time Window Between 300 and 450 ms

The ANOVA (Proficiency × Switch × Hemisphere × AP × DM) showed a main effect of Switch ($F(1,34) = 5.50$; $p < .05$; $MSE = 62.03$; $\eta_p^2 = 0.14$), interaction effects of Switch with Hemisphere ($F(1,34) = 6.34$; $p < .05$; $MSE = 15.79$; $\eta_p^2 = 0.16$) Switch with AP ($F(4,136) = 9.81$; $p < .001$; $\varepsilon = 0.35$; $MSE = 23.20$; $\eta_p^2 = 0.22$). There are also three-way interactions of Switch with Hemisphere with AP ($F(8,272) = 16.90$; $p < .001$; $\varepsilon = 0.48$ $MSE = 6.32$; $\eta_p^2 = 0.33$), and Proficiency with Switch with AP ($F(8,272) = 5.60$; $p < .05$; $\varepsilon = 0.35$; $MSE = 13.24$; $\eta_p^2 = 0.14$). A test for linear trends (using polynomial contrasts) reveals a significant linear trend for the interaction between Proficiency, Switch, and AP ($F(1,34) = 6.38$; $p < .05$; $MSE = 17.57$; $\eta_p^2 = 0.16$). This last interaction reflects the fact that the Switch effect was nearly the same at anterior as posterior electrodes for the more proficient group, whereas the low proficient group showed a similar negativity only at posterior electrodes. See Table 3 for mean amplitudes of the Switch effect in the two groups, separately for six of the electrodes included in the analyses. In summary, both groups show differences between conditions in the N400 time window, but with the typical right posterior distribution for the low proficiency group, and a more widespread distribution for the high proficiency group. Note that the frontal positivity starting after 200 ms post-target word presentation remains also visible in this time window in frontal electrodes for the low proficiency group only. This positivity probably overlaps with the frontal negativity in the case of the high proficiency group.

Time Window Between 450–650 ms

The analyses of the amplitude means in this time window by ANOVA (Proficiency × Switch × Hemisphere × AP × DM) showed a main effect of Switch ($F(1,34) = 35.37$; $p < .001$; $MSE = 793.02$; $\eta_p^2 = 0.51$), interaction effects of Switch with AP ($F(4,136) = 4.27$; $p < .05$; $\varepsilon = 0.35$; $MSE = 20.01$; $\eta_p^2 = 0.11$), and Switch with DM ($F(1,34) = 27.29$; $p < .001$; $MSE = 66.87$; $\eta_p^2 = 0.45$). There are also three-way interactions of Switch with Hemisphere and AP ($F(4,136) = 3.65$; $p < .05$; $\varepsilon = 0.61$ $MSE = 1.05$; $\eta_p^2 = 0.02$), and Switch with AP and DM ($F(4,136) = 4.68$; $p < .01$; $\varepsilon = 0.66$; $MSE = 1.45$; $\eta_p^2 = 0.12$), as well as the four- way interaction of Switch with Hemisphere with AP with DM ($F(4,136) = 7.11$; $p < .001$; $\varepsilon = 0.75$; $MSE = 3.55$; $\eta_p^2 = 0.17$). These interactions of the factor Switch with the topographical factors are consistent with the larger amplitudes of the LPC at posterior electrodes, over the midline, and, in this time window, slightly lateralized to the left. Importantly, there was also a three-way interaction of Proficiency with Switch with AP ($F(4,136) = 5.18$; $p < .05$; $\varepsilon = 0.13$; $MSE = 24.25$; $\eta_p^2 = 0.26$). Polynomial contrasts showed a significant linear relation between Proficiency, AP, and Switch ($F(1,34) = 6.10$; $p < .05$; $MSE = 32.85$; $\eta_p^2 = 0.15$). This three-way interaction is explained by between-group differences in the size of the switch effect at posterior sites. Although both groups show the LPC both at anterior as at posterior sites, the high proficient group shows a larger LPC only at the posterior areas. See Table 3 for mean differences of both groups separately.

Table 3. *Mean Differences (Switch Versus No Switch) for the Two Groups in Six Electrodes (FC1, FC2, C3, C4, CP1, CP2) in the Time Window of the N400 and the LPC*

Time window	300–450 ms		450–650 ms	
Proficiency	Low	High	Low	High
FC1	0.23	− 0.69	2.26	2.00
FC2	0.01	− 0.74	1.84	1.91
C3	− 0.41	− 0.70	1.65	2.02
C4	− 0.84	− 0.84	1.10	2.04
CP1	− 0.56	− 0.68	1.92	2.76
CP2	− 0.91	− 0.89	1.46	2.66

Time Window Between 650–850 ms

The ANOVA (Proficiency × Switch × Hemisphere × AP × DM) in this time window showed a main effect for Switch ($F(1,34) = 38.37$; $p < .001$; $MSE = 550.36$; $\eta_p^2 = 0.53$), and the interaction effects of Switch with Hemisphere ($F(1,34) = 9.77$; $p < .01$; $MSE = 20.58$; $\eta_p^2 = 0.22$), Switch with AP ($F(4,136) = 12.22$; $p < .001$; $\varepsilon = 0.34$; $MSE = 61.88$; $\eta_p^2 = 0.26$), and Switch with DM ($F(1,34) = 24.14$; $p < .001$; $MSE = 55.31$; $\eta_p^2 = 0.42$). Additionally, two triple interactions were revealed: Switch with Hemisphere with DM ($F(1,34) = 9.38$; $p < .01$; $MSE = 3.22$; $\eta_p^2 = 0.22$) and Switch with AP with DM ($F(4,136) = 3.32$; $p < .05$; $\varepsilon = 0.60$; $MSE = 1.31$; $\eta_p^2 = 0.09$). Linear contrasts reveal that code switching elicited a large positivity in this time window in comparison with no switches. These effects support the parietal distribution of the effect, which was larger around the midline and slightly lateralized to the right hemisphere. There is no interaction with the factor Proficiency, confirming the same magnitude and topographical distribution of this effect for both groups.

Discussion

This study investigated the processing of mixed language sentences in order to study ERP correlates of language switching in second language learners reading for comprehension. ERPs were obtained from Spanish speakers reading English sentences, half of which contained an adjective in Spanish in the middle of the sentences. We also explored the influence of second language learner proficiency on processing language switching, by including two groups: high and low level of English (L2). The language switch manipulation resulted in a pattern of sequential effects in the different time windows analyzed. In the time window of 200 to 300 ms after target word onset, switching to Spanish elicited an early negativity with a left occipital distribution in comparison with the English adjectives. Also starting at 200 ms, a long-lasting prefrontal positivity distinguished switches from the single-language sentences. In the 300–450 ms time window, language switching yielded an N400 effect with a broad distribution but maximum at right centro-parietal scalp. Finally, between 450 and 850 ms, the code language condition showed a large positive waveform widely distributed and visible at almost all scalp sites. There were also group differences in the scalp distribution of some of the language-switching effects that depended on L2 proficiency. The participants in the high level group generated a left anterior negativity in addition to the N400 effect, and larger LPC amplitudes than the low proficient group only in the posterior areas.

The first early negativity in response to language switching is visible between 200 and 300 ms, and one remarkable characteristic of this effect is that it is visible only at the left occipito-temporal electrodes. This focal scalp distribution is similar to that of the N170 response to words described in previous studies, which usually overlaps with and contributes to the visual N1 component (Maurer et al., 2005). Proverbio et al. (2004) reported ERP differences in the time range of the N1 component when code switching involved semantically incongruent words, but at frontal rather than posterior electrodes and only when switching from L1 to L2. In our data, the N1 component peaks at 170 ms and shows the classic leftward asymmetry attributed to orthographic processing (Nobre & McCarthy, 1994; Schendan, Giorgio, & Kutas, 1998). However, as language-switching effects do not start until 30 ms later and peak at 250 ms (see Figure 2), it is reasonable to speculate that this effect could reflect the activity of the same generator as the N170, and the delay in its onset would reflect subsequent processing after the initial low-level orthographic processing, i.e., the detection or switching to different patterns of orthographic regularities associated with a particular language (Dijkstra & Van Heuven, 1998, 2002). In this regard, it should be noted that N170 effects are typically obtained in word list experiments, whereas in the present study words were embedded in sentence contexts. N250 effects with a central scalp distribution have also been associated with orthographic processing (Holcomb & Grainger, 2006), but it is difficult to establish a functional relationship with the earlier N170 because this component has only been obtained with masked priming paradigms. In summary, our LO-N250 shows a similar latency as the central N250 obtained in masked priming paradigms, and shares its left occipital scalp distribution with the N170 effects reported with single word reading. Both N170 and N250 effects have been attributed to initial orthographic processing. Therefore, the left-occipital N250 described in the present study could reflect the detection or activation of a different set of orthographic/phonological rules, when changing from one language to another. This N250 takes place before the activation/integration of word meaning, which is consistent with the fact that the left-occipital N250 was independent of the later N400 effect and the level of proficiency of the participants.

Simultaneous with the onset of the left-occipital N250 (around 200 ms), a positivity in response to language switching starts at the prefrontal electrodes (see Figure 2). The reverse polarity and common onset of the anterior and posterior differences could suggest that both effects are the reflection of a single dipole. However, while the posterior effect lasts for 200 ms and its distribution is asymmetric across hemispheres, the frontal one is not lateralized and persists for several hundreds of milliseconds. This discrepancy could be due to an overlap with other effects, or alternatively it could mean that they are originated by different neural generators, and therefore associated with different cognitive operations. For example, frontal positivities have been reported in other language-switching studies, and have been linked to the executive control system (Rodríguez-Fornells et al., 2006). However, a more plausible explanation is that this positivity is the early onset of the LPC, with its maximum amplitude peaking in the late time windows.

The characteristics of the second negativity in response to language switching fit with a modulation of the classical N400 component. Semantically unexpected or difficult-to-integrate words in a given semantic context modulate this negativity between roughly 200 to 500 ms after target word onset with a right parietal distribution (Kutas & Federmeier, 2000). In the present experiment, meanings associated with the switched words should be as easy to integrate in the context as meanings of the non-switched words, because they are mostly the same. The N400 component is also sensitive to bottom-up processes of word recognition, and correlates with the costs of meaning activation (Barber & Kutas, 2007). For example, it is known that, without other constraints, lexical frequency inversely correlates with the N400 amplitude; the higher the frequency, the smaller the N400 (Barber et al., 2004; Van Petten & Kutas, 1990). Importantly, our results cannot be explained considering the frequency of use of the target words because participants switched from their L2 (less frequent words) to their L1 (with a higher subjective frequency). Proverbio et al. (2004) proposed that age of acquisition of L2 words, and not proficiency, was the key factor to explain their N400 effect when switching from L1 to L2, but again this explanation cannot be applied to our switching effects in the opposite direction. The most plausible account of the current result is that the N400 reflects the activation costs of the specific lexical forms in the less active language. This idea is consistent with models of bilingual processing that include separate lexicons with different levels of activation depending on the language in use, at least at some stages of second language learning. Converging evidence supporting the existence of separate lexicons with different access mechanisms in second language learners comes from a recent ERP study that reported larger N400 amplitudes for L1 words than L2 words in a block design without language switching (Midgley et al., 2009a). According to the RHM, in the first steps of second language acquisition, the lexicon of L2 does not have a direct link to the concept level and is therefore heavily dependent on the L1 lexicon. The link from L2 words to L1 words would be strong, facilitating the switching between languages at the lexical level, which is consistent with the N400 effect found in our study.

Negativities in this same time window but with left frontal distributions (LAN) have been linked to working memory load and syntactic parsing operations (Barber & Carreiras, 2005; Friederici et al., 1993; Kluender & Kutas, 1993). Moreno et al. (2002) reported a left anterior negativity but not an N400 effect in response to code switching with balanced bilinguals. They interpreted this negativity as unrelated to semantic processing, but merely reflecting a working memory load due to the integration of a Spanish word into an English context. The left frontal negativity found only for the high proficiency group in our study is consistent with the report of such negativity in balanced bilinguals. In other words, language-switching processing in our group of high proficient learners seems to be closer to that of the balanced bilinguals. This negativity, if related with the syntactic LAN effects, would reveal a higher influence of the L2 grammar in the integration of the switched words, and could reflect the difficulty of integrating the different grammatical rules of both languages.

Language switches also elicited a late positivity (LPC) peaking around 600 ms post word onset. This late positivity was also found in the study of Moreno et al. (2002) with a posterior distribution and was sensitive to the vocabulary level in the switched language independently of the dominant language of the participants. In our data, the LPC is observed both at anterior and at posterior sites, and proficiency in L2 modulated it at posterior sites. The LPC is usually interpreted as a late appearance of the P300 component, which increases in response to unexpected events or features that are relevant for categorization of the stimuli (Donchin, 1981; Polich, 2007; Verleger, 1988). This ERP component has been proposed to reflect brain activity related to the updating of mental representations, but it is composed of subcomponents that can be elicited separately by specific stimulus and task conditions. The P3a and "novelty P300" usually show a central/frontal distribution and have been linked to attentional processes triggered by the detection of unexpected stimuli. The parietal P3b is more sensitive to the relevance of the stimulus for the task, and has been related to context updating operations and subsequent memory storage (Polich, 2007). This model is consistent with the fact that in our data the frontal positivity starts at frontal sites as soon as the first orthographic mismatch is detected, and becomes maximum by the time that all lexical, semantic, and syntactic information is available. Additionally, while both groups showed similar effects at frontal areas, the magnitude of the posterior effect was larger when proficiency in L2 increased. This interaction between anterior and posterior positivities and the level of L2 proficiency suggests that our participants perceived language switches as rare or unexpected events in a similar way independently of their level of proficiency, but updating and integration processes differed depending on the level of competence in the second language.

A different but not totally incompatible view might present this late positivity as being a syntactic P600, because the relation of the P600 and the LPC is still a matter of debate (Coulson, King, & Kutas, 1998; Osterhout & Hagoort, 1999). The LPC found in our study resembles the P600 that previous literature has described in response to syntactic violations or non-preferred syntactic structures (Barber & Carreiras, 2005; Barber, Salillas, & Carreiras, 2004; Carreiras, Salillas, & Barber, 2004). Two different time-phases of the P600 have also been proposed with different sensitivity to experimental manipulations: a P600a with a broad anterior-posterior distribution over the midline, followed by the P600b with a right posterior distribution (Barber & Carreiras, 2005). In a similar way, P600 effects have also been reported with frontal or posterior distributions depending on experimental manipulations, but the exact cognitive meaning of these changes in the topographical distribution of the effect is still unclear (Filik, Sanford, & Leuthold, 2008; Kaan & Swaab, 2003). The enhancement of the late positivity at posterior sites in the high proficiency group, preceded by a left anterior negativity in the same group, can be interpreted as a LAN-P600 pattern. In a recent study, highly proficient late bilinguals showed similar LAN-P600 effects in response to syntactic agreement violations as native speakers, but the size of the P600 effect was larger for those agreement rules shared by L1 and L2 than those which were exclusive to L2 (Gillon-Dowens, Vergara, Barber, & Carreiras, 2009). Although the sentences in the present study did not contain syntactic violations per se, language switching could induce an interaction between incompatible grammatical rules in the two languages (e.g., gender agreement rules), leading to similar integration and reanalysis processes as those resulting from syntactic operations. Therefore, the effect of L2 proficiency found in the present study could indicate a greater implication of the L2 grammar in the processing of language switching in this group of learners as compared with those with lower levels of L2 competence.

To sum up, in contrast to data that suggest that language-switching costs take place only at a decision-related stage (e.g., Moreno et al., 2002; Thomas & Allport, 2000), the present results show that, at least at some stages of second language learning, language switching during sentence reading affects several levels of processing, including early orthographic/phonological processing and lexico-semantic processing. In addition, the present results show that integration processes change with the amount of training and the level of competence in the second language, probably because L2 grammar begins to play a role.

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