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MAARTJE VAN DEL MEIJ

Correlatos electofisiológicos del code-switching en españoles aprendiendo inglés

Directores
MANUEL CARREIRAS VALIÑA
FERNANDO CUETOS VEGA
HORACIO A. BARBER FRIEND

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UNIVERSIDAD DE LA LAGUNA

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"A scientist in his laboratory is not a mere technician: he is also a child confronting natural phenomena that impress him as though they were fairy tales."

-Marie Curie-

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1. GENERAL INTRODUCTION

Bilingualism in general is a social reality in a lot of communities; let alone in Europe more than one language coincides in several countries. For example in Belgium and Luxembourg there are at least three official languages (Dutch/Luxembourgish, German and French) and in Spain in several regions coexists more than one language (Spanish and Catalan, Galician or Basque). There is a tendency of social local politics and educators to increase the integration in the communities respecting their linguistic identity. The phenomenon bilingualism raises important questions on how bilinguals do process language, like for example how two different languages are represented in the brain, what impacts directly on such important issues such as brain plasticity. Also, the better is understood how two languages are organised, distributed and used, improves knowledge of language processing in general. Therefore, studying how different languages coexist in the brain has become an important topic in psycholinguistic and cognitive neuroscience with social implications.

In addition the use of more than one language is not limited to learning two languages simultaneously from birth, neither are the two of them used in an equivalent way. Many studies have been focussing on monolinguals versus highly proficient balanced bilinguals, but they are just two extremes of a continuum. More frequently are the cases of one language being more dominant than the other. A good example of this happening is when the second language is still developing, like in the case of 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 and the European Union that facilitated free movement of their citizens. The late second language learners is an interesting group to study, because it is getting more and more common to learn a language at school at the age of 7 or even later as an adult, and also because the study of second language learners can provide information on how the process of language acquisition in general develops. For example whether characteristics of the first language transfer to the second language and if this is the case, which characteristics and how does is happen, or how and on what level the two languages function independently on the long term. To put it briefly: whether or not the process of second language acquisition follows a similar pattern as first language learning.

In this research we will focus on late learners of a second language: people who started learning a second language after their infancy. It is important to emphasize that there are many factors that can determine second language learning; amongst them are motivation, linguistic and cultural context and the second language exposure and use in daily life. The participants in this study were learning a second language (English) in their own country (Spain) in a community that is profoundly monolingual Spanish (Canary Islands). Thus they were not being exposed to their second language (apart from their classes and self-chosen books, films, series and music. Although this may seem a very specific situation, it is quite frequently the case and additionally it permitted us to study the phenomenon of second language acquisition in a well-controlled environment in which the majority of the participants in the experiments received identical instructions and have a similar use of their second language.

Bilingualism results in people having to change languages all the time in many places, due to the daily use of multiple languages in public areas in different communities or by social groups. Whether we are producing or receiving two languages or managing a switch from one to the other, it involves highly skilled cognitive control. Code-switching is a process that permits us to analyse a specific aspect of bilingualism, namely the executive control that permits simultaneously fluid use of two languages and control to keep the languages separated to avoid interference. This controlling process has to develop during language learning, and thus far it has received little attention in psycholinguistic research. In this study we focussed on language switching in groups of people that were still in the process of second language learning. Briefly, we analyze how the participants switch from one language to the other when the languages are not balanced in proficiency; one is more dominant than the other. Therefore the direction of the switch (from the dominant to the non-dominant language or from the non-dominant to the dominant language) received special attention.

In the present research; The first experiment focussed on "simple" processes as visual word recognition and meaning activation costs by looking at language switches in word pairs in both directions, from the dominant language Spanish to the non dominant language English and vice versa, comparing them with word pairs completely in the dominant or non-dominant language. The participants, although being late second language learners, were all high proficient in reading in their second language but not as fluent as bilinguals, according to the English test results. The task they had to perform was, reading for comprehension and to decide for each word pair, whether the adjective and the noun were presented in the same language or not. This gave us the opportunity to present equal numbers of switched and non-switched word pairs in all possible combinations. The second and third experiments were focussing on the same process of language switching but in a more natural situation of sentence reading. In the second experiment we investigated switches from a dominant language sentence context to a word in a non-dominant language, thus from Spanish to English. The switches were unexpectedly in the beginning or in the middle of the sentence, which would tell us more about the relation of switching costs and previous sentence context. Using more natural reading allowed us to study more complex processes, like meaning integration and syntax processing. The third and final experiment contained sentences in the second non-dominant language and a switch to the dominant language, with a similar sentence structure as the sentences used in the second experiment. And apart from a different switch direction we preformed this experiment with two groups of participants with different levels of second language proficiency, allowing us to measure the switching costs in respect to the level of second language learning. Thus studying switches in different directions, in different context and with different proficiencies.

To study the costs of processing a controlled, task-induced language switch in an experimental setting when adult second language learners read for comprehension in their dominant language Spanish or non-dominant language English, we used a particular method of cognitive neuroscience, namely the recording of Event-Related Brain Potentials (ERPs). ERPs reflect regularities in electrical brain activity time-locked to an external event and are obtained from a recording of voltage variations over time (Electroencephalogram or EEG). The advantage of using ERPs is that this method has a fine temporal resolution and thus makes a very useful tool to investigate how cognitive processes unfold over time.

Before describing the different experiments in detail, we will first start with a theoretical background on language switching and second we will describe the different ERP components found in psycholinguistics studies in general and more detailed the ERP effects related to language switching and bilingual studies.

2. THEORETICAL BACKGROUND

2.1. Code-switching

2.1.1. Definition of Code-switching

The term language switching is used by Van Hell and Witteman (2009) to describe all kinds of switching between languages as well in production as in comprehension, varying from single items like words and numbers to words embedded in phrases in a meaningful context. The latter type of language switching is also called Code-switching (hereafter CS). CS is defined differently by linguistic, psychological and social scientists but in this dissertation we will follow the definition of Van Hell and Witteman (2009) adding to this that CS is used by fluent, stable as well as becoming or "un-becoming" bilinguals and thus their languages are undergoing a restructure or change (Bolonyai, 2009).

2.1.2. Code-switching research: Behavioural studies

According to Poulisse (1999) CS is triggered by psycholinguistic factors like online lexical retrieval, fluency problems and gaps of knowledge. When bilingual speakers want to express, process or comprehend a message they need to be able to select words from the intended language and to control for intrusion of the non-intended language. Language switching in speech production usually results in measurable costs (e.g., Campbell, 2005; Costa & Santesteban, 2004; Costa, Santesteban & Ivanova, 2006; Kolers, 1966; Li, 1996; MacNamara, Krauthammer & Bolgar 1968; Meuter & Allport 1999; Philipp, Gade & Koch, 2007; Soares & Grosjean 1984). However these switching costs were not always the same in both directions. Meuter and Allport (1999) found asymmetrical switching cost in a behavioural experiment with bilinguals using a number-naming paradigm. The participants had to name a number presented on a screen in their dominant or non-dominant language depending on the colour of the background. The switches occurred infrequently, unexpectedly and were in both directions, resulting in four different types of language pairs (dominant with dominant language pair, dominant with non-dominant language pair, non-dominant with dominant language pair and non-dominant with non-dominant language pair). The response latencies for both types of switch trials were slower than for the non-switch trials. More interestingly apart from reporting higher costs for the switch trials, there were asymmetrical costs depending on the direction of the switch. It took the participants longer to switch from their non-dominant to their dominant language than vice versa, which was called the asymmetrical switching costs effect. The authors related these results to the difference in strength of the two languages of these bilinguals. It took the participants longer to switch from naming in the non-dominant language to the dominant language, because to do the naming in the non-dominant language they had to actively inhibit the stronger dominant language. Thus, when switching to naming in the dominant language, there was a persisting effect of involuntary inhibition of the dominant language visible in the processing of the next trial. This top-down control of language selection is explained in the Inhibitory Control (IC) model (Green, 1986, 1993, 1998). This model included different language task schemes that "reactively" inhibited language tags at the lemma-level to exclude competitors from the non-intended language for production. To investigate the factor of proficiency on switching costs in word production, Costa and Santesteban (2004) performed a series of experiments comparing the switching performance of highly proficiency Spanish-Catalan bilinguals to Catalan learners with a Spanish native language and Spanish learners with Korean native language in a behavioural experiment using a picture-naming paradigm. Participants had to name a picture appearing on the screen in Spanish or Catalan depending on the colour of the stimuli. Similar to the results of Meuter and Allport (1999), the switching costs for both groups of learners were larger when the participants switched to the dominant language. However as predicted, the group of highly proficiency bilingual speakers showed symmetrical costs in both switch directions. Additionally the switching performance of highly proficiency bilingual speakers was tested in a third non-dominant language and surprisingly; again the switching costs were symmetrical. The authors proposed that the asymmetrical switching costs effect for the learners was due to the inhibition of the non-relevant language. Though, the lack of similar asymmetry for switching to the dominant first language coming from the non-dominant third language in fluent (early) bilinguals suggested facilitation to processing language switching (Costa & Santesteban, 2004). They suggested a heightened selection threshold for the dominant language that is strategically applied to bias selection in favour of the non-dominant language. More studies that reported the asymmetrical switching cost effect when switching in the direction of the dominant language (Campbell, 2005; Costa, Santesteban & Ivanova, 2006; Finkbeiner, Almeida, Janssen & Caramazza, 2006; Meuter & Allport, 1999;

Philipp, Gade & Koch, 2007). Although, some researchers suggested the effect was due to a difference in language activation instead of a difference in language inhibition (Costa & Caramazza 1999; Costa et al., 2006; Finkbeiner et al., 2006; La Heij, 2005).

Additional insight in the mechanisms of lexical selection and cognitive control of languages comes from studies investigating how bilinguals process switching between languages during language comprehension. Grainger and Beauvillain (1987) looked at the effect of language in a lexical decision task with bilinguals. Participants had to decide whether a letter string was a word or a non-word in which the language affiliation of the stimuli was not important for the required response. They reported slower reaction times to words in one language when the previous trial had been in a different language, compared to preceding within-language stimuli. Additionally, switching costs were found to be larger for targets in the second language (L2) when compared to targets in the first language (L1).

There is still a debate on how the lexicon of multilingual speakers is organized. In previous studies bilinguals were thought to have two separate lexicons that could be switched on and off by using a selective lexical access mechanism (e.g. MacNamara & Kushnir, 1971; Scarborough, Gerard, & Cortese, 1984). However it was discovered that there is always some interference between languages (e.g. review papers: Beauvillain, 1992; Brysbaert, 1998; Grainger, 1993; Kroll & Dijkstra, 2002; Kroll & de Groot, 1997; Smith, 1997; Van Heuven, Dijkstra, & Grainger, 1998). Bijeljac-Babic et al. (Bijeljac-Babic, Biardeau, and Grainger, 1997) investigated the inhibitory effect of cross-language orthographic neighbour primes in word recognition in French-English bilinguals. It took the participants longer to read the French word "*miel*" (honey) when it was preceded by the English primes "mile" or "meet". Interestingly, beginning bilinguals showed a smaller but still significant effect and French monolinguals showed no effect for English primes. Similar results were reported by Dutch-English bilinguals, and although they were performing a lexical decision task in their non-dominant language (English) only, it took them longer to decide on letter strings to be English words when these had a lot of *orthographic neighbours* (words with the same length but one letter different) in their dominant language Dutch (Van Heuven et al., 1998). Also in a go-no-go paradigm Dutch-English bilinguals found it more difficult to decide on whether *homographs* (words with the same spelling but a different meaning per language) were correct English words in comparison with non-homographs (Dijkstra, Timmermans & Schriefers, 2000). Dijkstra et al. (2000) repeated the go-no-go-paradigm in the dominant language Dutch. And again, even in their dominant language, it cost the participants in general longer to recognize a homograph as a correct word, and especially when the word had a higher frequency in the non-dominant language English (e.g. *room*, meaning cream in Dutch). Additionally a study with Dutch-English-French trilinguals of Van Hell and Dijkstra (2002) looked at the processing of *cognates* (words that are translated equivalent and have a large orthographic and phonological overlap between languages) like for example *bakker-baker*. Participants had to perform a lexical decision task in their dominant language Dutch. And although non-cognates were matched on frequency, orthographic neighbours and word length, the participants responded significantly faster on cognates. Concerning the term *bilinguals* in the previous studies, it is important to mention that the bilinguals were not equally proficient in both languages. Although the Dutch native speakers had a high proficiency in their non-dominant language English they were late second language learners (at the age of ten in a school setting) and were not as proficient as native English speakers. Thus these studies show an interaction between the dominant and non-dominant languages of bilinguals and late second language learners in visual word recognition. According to Dijkstra (2009) many studies suggested that word recognition in one language is affected by competing words in another language (e.g. Dijkstra, De Bruijn, Schriefers, & Ten Brinke, 2000; Dijkstra & Van Heuven, 1998, Van Heuven, Dijkstra, & Grainger, 1998). For this reason the mental lexicon of multiple language speakers is believed to be language-nonspecific (e.g. Brysbaert & Dijkstra, 2006; Brysbaert, Van Dyck, & Van de Poel, 1999; Dijkstra, Timmermans & Schriefers, 2000) and language selection in word retrieval takes place on the level of lexical access with inhibition of the competing overlapping word candidates of different languages (Grainger, 1993; Van Heuven et al., 1998).

To interpret bilingual orthographic word recognition Dijkstra and Van Heuven developed the Bilingual Interactive Activation model (BIA) with one shared lexicon and active excitatory or inhibitory language nodes at the word level (Dijkstra & Van Heuven, 1998; Van Heuven et al., 1998). In 2002 there came an extension of this model, namely the BIA+ model, with language nodes but now unable to inhibit words from other languages since they propose that language selection of the input can also benefit from other sources of information thus now additionally the model includes orthographic, phonological and semantic nodes (Dijkstra & Van Heuven, 2002). However, 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). Although the RHM proposes two separate lexicons and many studies are pointing in the direction of one shared lexicon. The BIA+ model can mimic second language acquisition by changing the frequencies of the nodes in the BIA+ model for different languages. The predictions of the RHM have been tested using behavioural measures (reviewed in Kroll & Tokowicz, 2005), and in some electrophysiological studies (e.g. Rodríguez-Fornells, De Diego Balaguer & Münte, 2006; Midgley, Holcomb & Grainger, 2009a). Although more evidence is clearly needed (Brysbaert & Duyck, 2010), the RHM could be an appropriate framework to interpret online measures of brain activity in second language learners.

2.2. ERPs and Code-switching

2.2.1. Main language related ERPs

The technique of Event Related Potentials (ERPs) is a good tool to study language processing since it shows regularities in electrical brain activity in response to an external event (e.g. Kutas, Van Petten & Kluender, 2006; Luck, 2005). An ERP is an average of the voltage changes of the EEG time locked to a stimulus, for example a word visually or auditory presented. Thus this technique allows amongst others to study word recognition and other language related cognitive processes unfolding over time. The characteristics of an ERP signal of word and stimuli processing in general are a series of positive and negative peaks. Some peaks are called components since they are related with specific cognitive processes depending on the task and type of stimuli. Now follows a summary of the most important ERP components related to language processing.

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 & Devlin, 2003). At a slightly later latency, a negativity peaking at 250 ms with a central distribution (N250) has been observed in masked priming paradigms, and has been claimed to reflect the mapping of sublexical information (e.g. ordered letter combinations) onto whole-word orthographic representations (Holcomb & Grainger, 2006). There is also a component called N2 appearing in roughly the same time-window as the N250 with a frontal-central distribution, related with cognitive control (Folstein & Van Petten 2008). Gajewski et al. (Gajewski, Stoerig, & Falkenstein, 2008) associated this component with the process of response selection and the anterior cingulate cortex (ACC). The ACC has been linked previously to response conflict monitoring (Botvinick, Cohen, & Carter, 2004; Van Veen & Carter, 2002) and response selection (e.g., Roelofs, van Turennout, & Coles 2006; Turken & Swick 1999). Another important component in visual word recognition is the N400, a large negative waveform with a central-parietal distribution. This component was first discovered with semantic incongruent sentences (Kutas & Hillyard 1980) and has been linked to reflect activation level of a word in memory (Van Petten & Kutas, 1987), and related to expectability and semantic memory retrieval (Kutas & Federmeier 2000; Kutas et al., 2006; Molinaro, Conrad, Barber & Carreiras 2010; Van Petten, Coulson, Rubin, Plante, & Parks, 1999). The N400 effect is not only visible in large structures but also when semantic and syntactic constraints were minimal for example at the beginnings of sentences (Van Petten & Kutas, 1990) or in word lists (Rugg, 1990). Studies with visual single word presentation have shown a correlation between the amplitude of this component and the meaning activation costs (Barber and Kutas, 2007). A component reported in the same time window as the N400, is the Left Anterior Negativity (LAN) with a left anterior distribution and is believed to be associated with the processing/detection of syntactic anomalies (Barber & Carreiras, 2005; Friederici, Hahne, & Mecklinger, 1996; Neville, Nicol, Barss, Forster & Garrett, 1991; Osterhout & Holcomb, 1992, 1993). In 1983 Kutas and Hillyard reported a frontal negativity between 300 and 400 ms as a response on syntactically anomalous words in an English prose passage (e.g., "As a turtle grows its shell *grow* too"), which they related to the working memory. Other studies, in which participants had to read for comprehension, have reported sustained anterior negativities with grammatically correct sentences that required a high working memory load (Kluender & Kutas, 1993; Streb, Rösler & Hennighausen, 1999). As we move further in time after word onset, we encounter upon the P600, a positive peak with a large duration starting around 500 ms. It is proposed that the P600 could index two functionally different processing stages (Barber & Carreiras, 2005; Carreiras, Salillas, & Barber, 2004; Hagoort & Brown, 2000; Kaan & Swaab, 2003). The first stage (500-750 ms) could be related with integration difficulties in relation with previous linguistic context (Kaan, Harris, Gibson & Holcomb, 2000) and is widely distributed including the frontal electrodes. The second stage (750-900ms) is linked with reanalysis/repair processes (Barber & Carreiras, 2005; Carreiras et al. 2004) and has a more posterior distribution. Although there is a strong relation between the P600 component and grammatical anomalies in sentences it cannot only be associated with syntactic processing difficulties (see for a review Bornkessel-Schlesewsky and Schlesewsky, 2008; Kuperberg, 2007). It should be noted that similar positivities have been related to more general cognitive processes that are not necessarily language specific, so some authors prefer the less specific term of Late Positive Complex (LPC). For example, the LPC has been related to executive control (Kolk & Chwilla, 2007), or memory retrieval (Paller & Kutas, 1992). Additionally, the LPC has been related with the P3 component that is associated with important, unexpected, infrequent stimuli in a sequence (Coulson, King & Kutas, 1998; Donchin & Coles, 1988; Verleger, 1988).

2.2.2. ERPs effects of Code-switching

There are not so many studies that combined language switching and ERPs. Jackson et al. (Jackson, Swainson, Cunnington & Jackson, 2001) did a digit naming study with single items with participants who were native Spanish speakers who reached a moderately proficiency in a second language that was either French, German, Spanish, Mandarin, or Urdu, and of which the majority had started learning relatively late (age 13-18). The participants had to name a digit in their first or second language, depending on the colour it was presented in, after the trial had disappeared from the screen. The language sequence and thus the language switches were predictable in this delayed digit-naming task. There were two consecutive trials in each language and a language switch on every second trial (a variation of the alternating runs paradigm; Rogers & Monsell, 1995). The results were similar to previous production studies (Campbell, 2005; Costa et al., 2006; Finkbeiner, et al., 2006; Meuter & Allport, 1999; Philipp et al., 2007) with larger reaction times for digits in a switch condition than in a non-switch trial. And there was a higher switching cost to switch from the non-dominant to the dominant language. The ERPs though only showed an early negativity on left-frontal and -central sites for switching from the non-dominant to the dominant language, starting at 320 ms after stimulus presentation. This N320 component was interpreted as a frontal N2, which is related with the suppression of the non-required trial in a Go-No-Go paradigm (Konishi, Nakajima, Uchida, Kikyo, Kameyama & Miyashita, 1999). Jackson et al. (2001) associated the N2 with the suppression of the dominant language to be able to perform the digit naming in the non-dominant language, in line with the IC model of Green (1998). Later studies though demonstrated that the N2 is more related with response conflict monitoring and less with inhibition (Folstein & Van Petten, 2008; Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003). Kutas et al. (Kutas, Moreno & Wicha, 2009) suggested that the N320 component might have reflected a greater need for resources to suppress an active dominant language in order to produce a word in the non-dominant language. Additionally in a later time window (385-700ms) Jackson et al. (2001) reported an enhanced P3/LPC for switched trials in both directions in comparison with non-switched trials, related with the executive control of response selection (Liotti, Woldorff, Perez, & Mayberg, 2000) or decision-related processes. The P3 amplitude is sensitive to an alternation effect: smaller P3s are associated with stimuli that continue an alternation sequence, and larger P3s are associated with those that discontinue a sequence (e.g. Jentzsch & Sommer, 2001; Johnson & Donchin, 1980). The

LPC in this case can be related with the preparation and monitoring of the less frequent switch versus the more frequent non-switch trials, since it is a predictable sequence and therefore visible in both directions, which is in line with the inverse relationship between P3 and stimulus probability.

Another language switching production study with single items was that of Christoffels et al. (Christoffels, Firk & Schiller, 2007). They had native German speakers, which were moderately fluent speakers of Dutch perform a picture-naming task. Again the colour of the picture indicated the language the participants had to respond in and the switches were unpredictable. The pictures represented cognates, for example the picture of an apple (*appel* in Dutch and *apfel* in German) and non-cognates, the picture of a plate (*bord* in Dutch and *teller* in German). The behavioural data yielded the typical switching cost pattern with longer naming latencies for switch than for non-switch trials indifferent of the switching direction though, and reported no differences between cognate and non-cognate picture naming. The results further showed that especially naming latencies in the dominant language were slowed down and that ERPs in the time window of the N2 were modulated. Surprisingly, they found more negative amplitudes to the non-switch than the switch trials as opposed to the study of Jackson et al. (2001). Christoffels et al. (2007) explained the differences in terms of the unpredictability of the language switch in their study compared to the study of Jackson et al. (2001). They concluded their data favoured a reduction of the level of activation of the dominant language to facilitate language production in the non-dominant-language (Costa & Santesteban, 2004; Meuter, 2005). Importantly the study also failed to show the cognate-effect; bilinguals produce and recognize cognates faster than non-cognates (Costa, Caramazza & Sebastián-Gallés, 2000; Dijkstra, Grainger & Van Heuven, 1999; Schelletter 2002).

Jackson et al. (Jackson, Swainson, Mullin, Cunnington & Jackson, 2004) performed an ERP study to look at the role of language suppression in receiving a language switch. Bilingual participants were presented a number sequence that alternated between their two languages and they had to decide whether a number was odd or even regardless of its language. This time there was no enhanced N320, nor an LPC for switched trials, suggesting the dominant language was not suppressed. This finding suggested a difference in language switching processing between comprehension and production, particularly in mixed language tasks where both languages have to be active. The results were thought to index the absence of a language-specific lexical selection mechanism in comprehension of language switches and suggest that the switching costs may arise from outside the bilingual lexico-semantic system.

Among the ERP studies on CS during language comprehension there can be made a distinction between those with single words and those on sentence reading. Alvarez et al. (Alvarez, Holcomb & Grainger, 2003) Chauncey et al. (Chauncey, Grainger & Holcomb, 2008) and Midgley et al. (Midgley, Holcomb, & Grainger, 2009b) studied CS of single words presented visually. Alvarez et al. (2003) focused on the organization of the dominant and non-dominant languages in starting late second language learners. They studied switching costs using a semantic categorization task in native speakers of English who were beginning learners of Spanish. Participants rated their proficiency in their second language (L2) substantially lower than their first language (L1). The focus of the researchers was on ERP word repetition effects, having the knowledge that many previous studies have shown a reduction of the N400 amplitude upon word repetition (Rugg, 1990). They recorded ERP responses to single English and Spanish words preceded by a same-language word (f.e. in L1: *dog*-dog and L2: *perro*-perro) or its translation (f.e. in L1 *perro*-dog or in L2 *arm*-brazo). Participants had to press a button when the word referred to a body part (approximately 10% of the words) irrespective of the language (go/no-go semantic categorization task). The amplitude of the N400 was modulated by repetition: smaller N400 amplitude for within language repetition in comparison with translation. And the repetition effect on the N400 amplitude was not the same for both directions: larger N400 amplitude for translation from L1 to L2, and a difference in latency, earlier for switches to L1 than to L2. When looking at a language effect for presenting words for the first time in L1 or L2, they found in the N400 time window (300-500 ms) that L2 words tended to produce more negative-going ERPs than words in L1, with a left-anterior distribution. These findings supported an asymmetry in lexical connections between L1 and L2 in beginning learners as presented in the RHM of second language acquisition of Kroll and Stewart (1994). If proficiency would increase, the differences in the N400 amplitude should diminish. Additionally to the translation and the repetition effect, Alvarez et al. (2003) reported language-switching effects visible in the N400 component in L1-L2 switch direction only. Though after 500 ms a negativity was reported for switches in both directions which was interpreted as evidence for a general language-switch effect with a delay in the L2–L1 direction. The authors suggested these findings to support inhibitory control over lexical activation as proposed in the BIA model (Van Heuven et al., 1998).

The ERP study of Chauncey et al. (2008) consisted of two experiments using a priming paradigm with masked primes (duration of 50 ms in Experiment 1 and 100 ms in Experiment 2) to investigate CS processing in French-English bilinguals. Participants executed a go/no-go semantic categorization task for the two different language blocks. The target words were either following a prime that was an unrelated word in the same or in the other language. They reported a N400 effect in the 375-550 ms time window for L1 target words when preceded by L2 primes in comparison with L1 primes. And they also recorded a N250 effect for L2 target words following an L1 prime in comparison with an L2 prime. The longer presentation times in experiment 2 increased the N250 and the N400 effect. The researchers suggested that during word recognition bilinguals compute automatically the language the word belongs to, which is an important element of the BIA model (Grainger & Dijkstra, 1992; Van Heuven et al. 1998).

In the CS study of Midgley et al. (2009b), the participants were moderately proficient in their non-dominant language and had to perform a go/no-go semantic categorization task. They reported a N250 in response to language changes in two masked priming experiments when words in the non-dominant language were preceded by unrelated words in the dominant language, or by their equivalent in the dominant language, but the time-course of this translation effect was somewhat later (peaking at 300 ms) than the N250 effect reported in previous studies of masked priming with native speakers (Holcomb & Grainger, 2006). Apart from the N250 there were language-switching effects in both switch directions visible in a modulation of the N400 component, with subtle topographic differences for the two switch directions. Since these switching effects were due to masked primes and the participants were unaware of the language switches, these results support the idea that the information about the language of a word is automatically computed during the visual word recognition process, and therefore they are consistent with the original BIA model (Grainger & Dijkstra, 1992; Van Heuven et al., 1998). Alternatively, Green's (1998) IC model and the BIA+ model (Dijkstra & Van Heuven, 2002) propose that executive control plays a central role in generating language switching effects. However, in the Midgley et al. (2009) study no additional effects were observed with supraliminal prime presentations (experiment 2). Therefore, their results support an automatic top-down modulation of activation of lexical representations as a function of language. Prime words automatically would activate the corresponding language node, and processing costs following a language switch would be the result of the top-down inhibition from the inappropriate language node towards the lexical representations of the language of the target words (van Heuven et al., 1998).

Anyhow, it is worth mentioning that when the results of this type of studies are compared, special attention should be paid to the L2 proficiency of the participants. For example, the beginning bilinguals in the study of Alvarez et al. (2003) reported low reading skills in L2 (6.1 ± 1.71 on a scale of 10), which seemed to be similar or a slightly higher in average than those of the participants of Chauncey et al. (2008) (3.7 ± 0.99 on a scale of 7), while the participants in Migdley et al. (2009b) showed the highest rates of L2 reading skills (4.9 ± 0.1 on a scale of 7).

Studies with online registrations of CS in sentence comprehension are also very scarce. 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; those 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 (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 et al., 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 et al. (Proverbio, Leoni & 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 a N400 effect in response to CS 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, CS 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.

In summary, there are not many ERP experiments that studied CS during language comprehension and the results that have been reported so far are mixed. The present dissertation aims to shed light on this issue by investigating CS at the word and at the sentence level. We will come back to their implications and the main inconsistencies between them when introducing each experiment and in the general discussion. In the following pages we will describe three experiments investigating CS between Spanish and English.

3. EXPERIMENTS

The present Ph.D. dissertation consists of three experiments in which we have studied CS in word pairs (Experiment 1) and CS in a task approaching more natural reading with sentences containing switches from L1 to L2 (Experiment 2) and switches from L2 to L1 (Experiment 3) and finally we compared how two groups of participants with different proficiencies process switches (Experiment 3). The main goal of these experiments is to look at the ERP effects of CS during reading, paying special attention to the direction of the CS (L1-L2 versus L2-L1), and trying to differentiate ERP language-related effects (e.g. N170, N250, LAN, N400 or P600) from those related to more general cognitive processes, like executive control (e.g. frontal positivities, N2 or LPC). This way we expect to contribute to shed light on the nature of the costs associated to CS executive

3.1. Experiment 1: Code-switching in word pairs

3.1.1. Introduction

Experiment 1 investigated CS in word pairs because it is the simpler situation that a bilingual or second language learner can face: just isolated words. In addition, the use of word pairs will allow us to establish a baseline with a tighter control over many variables such as word length, frequency and orthographic neighbours in each language simultaneously, as well as for how the word would be translated in L1 or in L2, this to avoid including words with multiple translations. The use of word pairs also gave us the opportunity to manipulate and investigate in a straightforward manner the direction of the switch, from L1 to L2 and vice versa. This way it was possible to isolate switch processing and its costs without the influence of integration in a broader context.

As we reviewed above, the behavioural CS study of Meuter and Allport (1999) reported the asymmetrical switching costs effect, which refers to longer reaction times when processing switches from the non-dominant language to the dominant language. In a ERP study, Alvarez et al. (2003) described for within language repetition a smaller N400 amplitude in comparison with translation and a difference in latency of the N400, that started earlier for switches to L1 than to L2. Using the masked priming technique, Chauncey et al. (2008) accounted for a N250 effect for L2 target words when following an L1 prime and a N400 effect in the 375-550 ms time window for L1 target words when preceded by L2 primes. Finally in a similar study, Midgley et al. (2009b) reported a N250 in response to language changes in two masked priming experiments when L2 words were preceded by unrelated L1 words and a delayed N250 (peaking at 300 ms) when they followed a translation in L1. Moreover, language-switching effects in both directions showed a modulation of the N400 component, with subtle topographic differences depending on the direction. Thus the majority of the studies reported the asymmetrical switching costs and showed a modulation of the N400 component and an effect in the N250 time window as a result of CS processing. Although it is difficult to compare the different studies it is interesting to note that Chauncey et al. (2009) claimed that the N400 effect in the switch direction of the dominant language is in line with the previous findings of Allport et al. (1999). And the delay of the N250 component (Midgley et al., 2009b) and the delay of the N400 component were both when switching from a word in L2 to its translation in L1 (Alvarez et al., 2003).

Although these studies give us very relevant insights about the processes of language switching in absence of a broader semantic or syntactic context, all of them looked at the effects of translation priming presenting pairs of nouns. Because the present study was designed as starting point to further understand the processes of CS in natural language comprehension, it used a quite different approach. Word pairs were composed by a combination of a function word (determiner) with a noun, thus creating noun phrases. Both the determiner (the articles "the" in English and "el" or "la" in Spanish[1] and the nouns were presented in the L1 or in the L2 form, and within pairs the language of the two words could be the same or not, therefore resulting in four different combinations:

L1-L1 (la rana)

L2-L2 (the frog)

L1-L2 (la frog)

[1] In Spanish the article "the" has also grammatical gender information associate to it, because they are involved in gender and number agreement relationships with other elements of the noun phrase as nouns or adjectives. For this reason there are two forms marking the masculine ("el") or feminine ("la") gender.

L2-L1 (the rana)

Function words lack specific semantic meaning but they can modify the meaning of other words and require agreement with the subsequent nouns in number and gender, and obviously also in the used language. This way, with determiner-noun word pairs presented sequentially, the determiner can work as a cue of the language of the incoming noun. The language of the determiner has to be fully activated in order to perform the subsequent integration operations. The violation of this kind of language expectations will result in a CS in absence of semantic relationships between the words. Therefore it is important to bear in mind that the expected effects would be more directly related to the CS processes than to the processes of facilitation across lexical items studied in previously published translation priming experiments. However, as in some previous studies, we also used mixed language items lists in which we manipulated the reading direction, which allowed us to compare word reading in L1 and L2 with and without CS.

Therefore, the main goals of the present study can be summarized as follows:

- To investigate if there would be an effect of the function words "the" versus "el/la" that could be linked with language detection or/and language activation processes. Effects at this point could be related with anticipatory strategies and executive control.
- To investigate if late second language learners despite their high proficiency in L2 do process nouns distinctively in their L2 compared to their L1. Specifically we will compare the N400 component amplitudes of the L1 and L2 nouns.
- To investigate the effects of CS with special attention to the switching direction, comparing the switching effects from L1 to L2 with those from L2 to L1.

3.1.2. Method

3.1.2.1. Participants

The participants were highly proficiency late second language learners. To select high proficiency second language learners, we recruited 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, contained 60 multiple-choice questions on vocabulary and grammar and yields a proficiency level of 1 to 3. Table 1 shows examples of the test questions. And 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 4 were recruited and resulted in 20 high proficiency second language learners.

Table 1. *Examples of the questions used to assess second language proficiency.*

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 6pm.	to have-to having-having-have

The 20 (4 male and 16 female) participants were aged 20 to 40 (mean age 25.9 years; SD 7.3) and were all Spanish native speakers living in Spain. The participants were attending yearlong 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 8.8 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 average ratings of the participants on these tests. After the experiment, the researcher had a brief chat in English with the participants, asking them to provide feedback about how they felt during the experiment and their experience with foreign languages. In relation to the experience with CS, the participants recognized not being used to switch between languages if not in a classroom setting. And finally all participants were controlled for normal or corrected-to-normal eyesight and not having a neurological or psychiatric history, all were right-handed as assessed by a Spanish version of the Edinburgh inventory (Oldfield, 1971).

Table 2. *Characteristics of the participants of experiment 1*

	Proficiency L2
Men: Women	4: 16
Age in years	25.9 (SD 7.3)
AoA in years	8.8 (SD 3.5)
English Pre-test	4 (Range 1-4)
Self-rated Speaking*	7.6 (SD 1.3)
Self-rated Hearing*	8.2 (SD 1.0)
Self-rated Reading*	8.3 (SD 1.3)

(SD) standard deviation, * self rate scale from 1 very low to 10 very high proficiency

3.1.2.2. Stimuli

Stimuli were 240 word pairs starting with an article and followed by a noun. Half of the word pairs started in L1 (Spanish) and the other 120 word pairs started in L2 (English). Fifty percent of all these word pairs continued with a Spanish noun ("*la rana*, *the rana*") or an

English noun (*"la frog", "the frog")*. Thus resulting in four different conditions; 60 word pairs completely in L1, 60 word pairs with a switch from L1 to L2, 60 word pairs completely in L2 and 60 word pairs with a switch from L2 to L1. All nouns were counterbalanced within language and appeared in both conditions (switch, no switch), thus creating **four** different lists. The lexical frequency, word length and orthographic neighbourhood size are derived from CELEX (Baayen, Piepenbrock & Van Rijn, 1993) using the program N-Watch (Davis, 2005) for the English words and from LEXESP database (Sebastián, Martí, Carreiras, & Cuetos, 2000) for the Spanish words with the program BuscaPalabras (Davis & Perea, 2005) see Table 3 and Appendix 5.1.1 There are some small differences between the two languages; the English words for example reported a higher frequency. However, since English is the L2 and not the L1, the differences between word frequency, word length and the number of orthographic neighbours is relative: For the participating Spanish native speakers, the Spanish norms are adequate, but the English words probably have a lower frequency of use than the predicted in the normative values. In a similar way, the L2 vocabulary is probably smaller than that of the average English native speaker, which implies fewer orthographic neighbours for a given word. When selecting the words we paid attention to familiarity by using the books used in classroom setting of the English school in La Laguna and translation effects, thus avoiding words with more than one translation or interpretation. We have had all words checked by native Spanish and native English speakers.

Table 3. *Characteristics of the items in both languages*

Stimuli (ENG/ESP)	Word Frequency (CELEX/LEXESP)	Word length (CELEX/LEXESP)	Orthographic Neighbourhood (CELEX/LEXESP)
Noun L1	35.9 (SD 47.8)	5.6 (SD 1.2)	3.7 (SD 4.7)
Noun L2	64.7 (SD 105)	5.2 (SD 1.2)	4.6 (SD 4.7)

3.1.2.3. Procedure

During online recording, each participant was seated in a soundproof electrically shielded room at the University of La Laguna approximately 80 cm from a CRT computer. Word pairs were presented one word at a time in a grey-white lower case font against a black background via Presentation® software (Version 0.70; www.neurobs.com). Prior to each word pair there was a centred "+" sign for 2000 ms and then a blank screen for 300 ms. The article was visible for 200 ms. This relative short presentation is on purpose since the articles are two to three letter function words, which need shorter reading time than the following nouns. This way the presentation of the noun phrase approaches more natural reading. Then there was a blank of 200 ms then the noun for 350 ms and another blank for 350 ms then a question mark with a duration of 1000 ms. The participant had to answer yes when article and noun were in the same language and no when they weren't. 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. To avoid interference of the possible side effect of cyclic artefacts during data recording, we created a variable inter-trial interval presenting a variable blank between 200 to 700 ms after each trial. 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. And the session started with a short practice in presence of the researcher.

3.1.2.4. EEG recording and ERP analyses

The electroencephalogram 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 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 kept equal to or less than 5 k**Ω** for all electrode sites except for the four eye channels, which were kept below 10 k**Ω**. EEG was stored and ERPs were later analyzed using BrainVision Analyzer 2.0 software (Brain Products: www.brainproducts.com). The offline filtering of the recordings consisted of a low cut-off filter of 0.1 Hz and a high cut-off 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 artefacts following the procedure proposed by Gratton et al. (Gratton, Coles, & Donchin, 1983). Artefacts were removed semi-automatically, with rejection values adjusted for each participant. After filtering we selected only the correct responses to include in the ERP analyses before continuing with segmentation. This resulted in the exclusion of approximately 10% on average of the trials, which were evenly distributed across experimental conditions with a minimum of 34 trials per condition.

Different segmentations were performed in order to look at the effect triggered by the articles and the nouns separately. For the articles the segments started at -100 ms and stopped at 800 ms of the article onset. The data were segmented relative to reference marker positions; also for the nouns the segments started 100 ms before the onset of the noun until 800 ms after onset of the noun. This way we could investigate the effect of language for both word types. For the analyses of the article we performed a baseline correction using the average EEG activity in the 100 ms preceding article onset (hence -500 to -400 ms of noun onset, we choose to separately repeat the analysis for the nouns with a new baseline correction of the average EEG activity in the 100 ms preceding the noun itself, thereby comparing word pairs in an ANOVA including the factor SWITCH *(No switch, Switch)* and three topographical factors, which are explained in detail below.

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 (HEMI) with the levels left and right, DISTANCE TO MIDLINE (DM) with two levels (one position from midline, two positions from midline), and an ANTERIOR-POSTERIOR (AP) factor with five levels (frontal, frontal-central, central, central-parietal, parietal) to show the relation of a language switch effect and its distribution. When running the ANOVA with these topographical factors and the experimental condition, in case of violating the sphericity assumption we reported Mauchly´s test statistic (W) and the Greenhouse Geisser-epsilon (GGε) to correct for the degrees of freedom. The reported main effects or interactions are limited to those related to the experimental condition SWITCH (Switch, No switch). All output is reported with the numerator (nDf) and the denominator (dDf) of Degrees of Freedom, the F-value, the p-value, the Sum of Squares (SS) and the Sum of Squares Error (SSE). Selection of the time windows was done after visual inspection of the grand average waveforms and point-by-point statistical analyses. The start of an effect was set apart from noise when for a duration of at least 20 points in time the main factors showed a significant effect coinciding with visual inspection of the graphs. For all statistical analyses, we used the program R (http://www.r-project.org). Therefore the reported analyses are summarized as followed:

ARTICLE (L1 vs. L2): For the analyses of the article; Mean voltage amplitudes relative to the start of the article were subjected to an omnibus analysis of variance (ANOVA) with ARTICLE (el, the) as a within-subject factor, and the three topographical factors: HEMI, AP and DM. Mean amplitudes were obtained for a large time window of 100 to 500 ms after article onset.

SWITCH L1→L2: Mean amplitudes were obtained for the following time windows 150-300 and 450-525 ms, was and they were analysed with an ANOVA with SWITCH as a within-subject factor, and the three topographical factors: HEMI, AP and DM.

SWITCH L2→L1: Mean amplitudes were obtained for the time windows 150-300, 300-450, 450-525 ms and the data was subjected to the same ANOVA as in switch L1→L2.

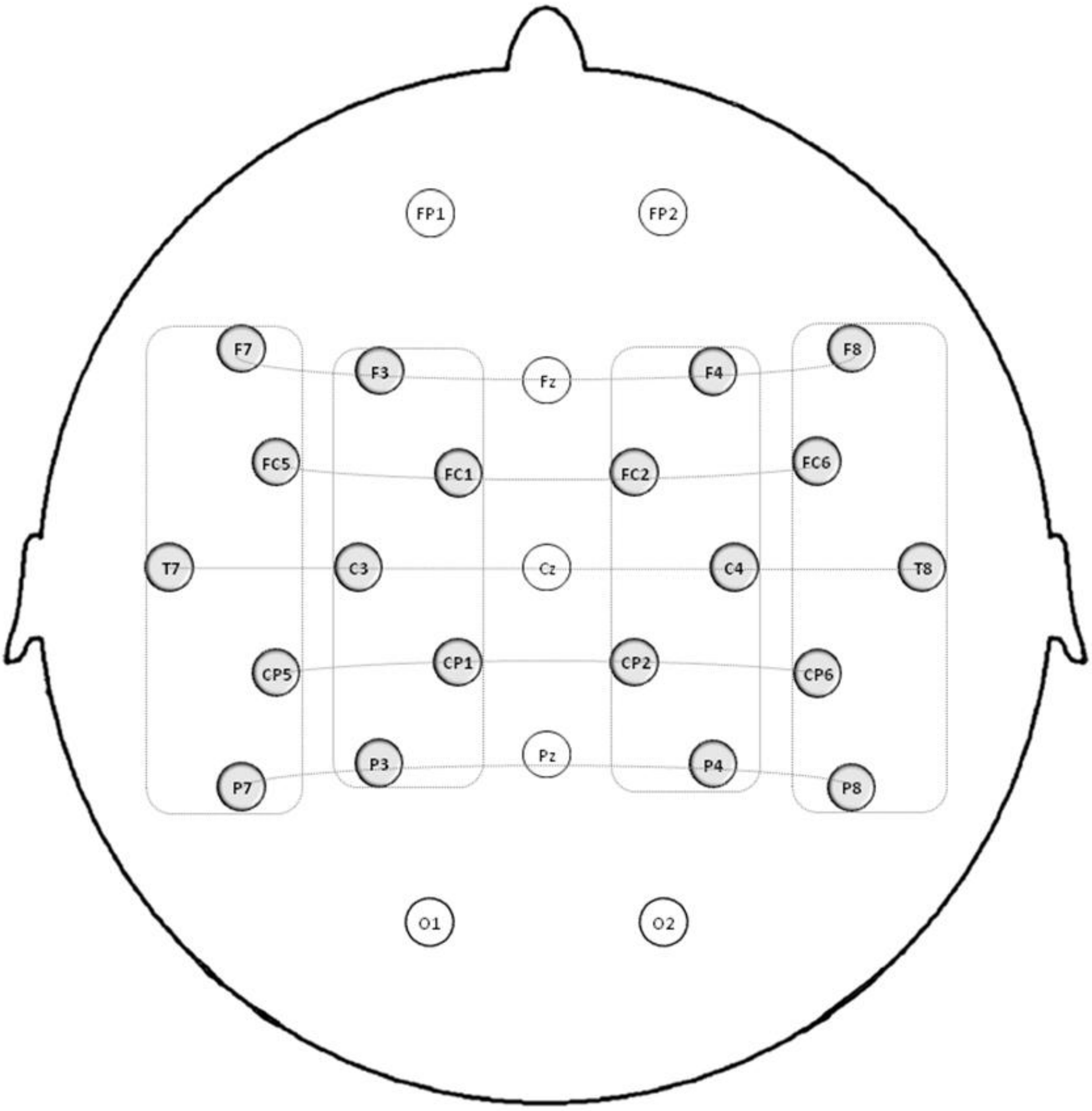

Figure 1. Schematic flat representation of the 27 electrode positions from which EEG activity was recorded. The electrodes analyzed in the ANOVAs are marked.

3.1.3 Results

Figure 2 plots grand average waveforms of ERPs time-locked to the presentation of the articles in Spanish (L1) or in English (L2). Visual inspection indicates clearly that Spanish and English articles started differentiating as early as after 100 ms post-article onset presentation. L2 articles showed more positive-going ERPs in comparison with L1 articles. The effect lasted around 450 ms (between 100 and 550 ms after stimuli onset), and as showed in Figure 3 has a widespread distribution, which is maximum at frontal sites.

Considering the long lasting effects of the article language, different ERPs were calculated time locked to the nouns presentation. Figure 4 shows the grand averages to nouns in the two non-switching conditions (the four conditions presented all together in a representative electrode can be found in Appendix 5.3.1). Although comparison of these waves could be questionable especially at early latencies due to observed differences in the time window in which base line correction was performed, it is worth to highlight that no differences are visible in the range of the N400 component between L1 and L2 nouns when noun phrases were presented in only one language. In any case, in order to avoid potential distortion of the CS effects due to the pre-stimulus activity, further comparison and analysis were made separately between conditions with the same article (L1-L1 vs L1-L2, and L2-L2 vs L2-L1). Figure 5 shows the grand averages of the condition of non-switching in Spanish (L1-L1) and the switching from Spanish to English (L1-L2). At the P2 component (150-300 ms) amplitude differences can be appreciated with ERPs to the switching condition being more positive than those of the non-switching condition. This effect almost reverses at the time-window of the N400 component (300-450 ms), where small differences in the opposite direction can be observed in a few central-parietal electrodes. Finally, after 450 ms ERPs to the switching condition become again more positive than those of the non-switching condition. Figure 6 plots the grand averages of the non-switching condition in English (L2-L2) and the switching condition from English to Spanish (L2-L1). This comparison reveals a slightly different picture; a long lasting negativity for the switching condition that starts at the P2 component is maximum at the peak of the N400 component and continues after 450 ms. The scalp distribution of these differences is represented in Figure 7 in different topographic maps obtained from the different waves at the three critical time windows. The positivity resulting in the L1→L2 CS shows a fronto-central distribution over the scalp in the P2 time window (150-300 ms), and more central-parietal distribution in the late time window (450-525 ms). The negativity of the L2→L1 CS show the typical central-parietal distribution of the N400 component, slightly lateralized to the right side especially at the time window were this component is larger (300-450 ms).

The statistical analyses supporting these observations for each of the three selected time windows are described below. Separate analyses were performed for the article comparison, and the two switching directions.

In the following figures the two switch effects and the topographical maps of effects reported in the three time windows are visible plotted in respectively sixteen electrodes.

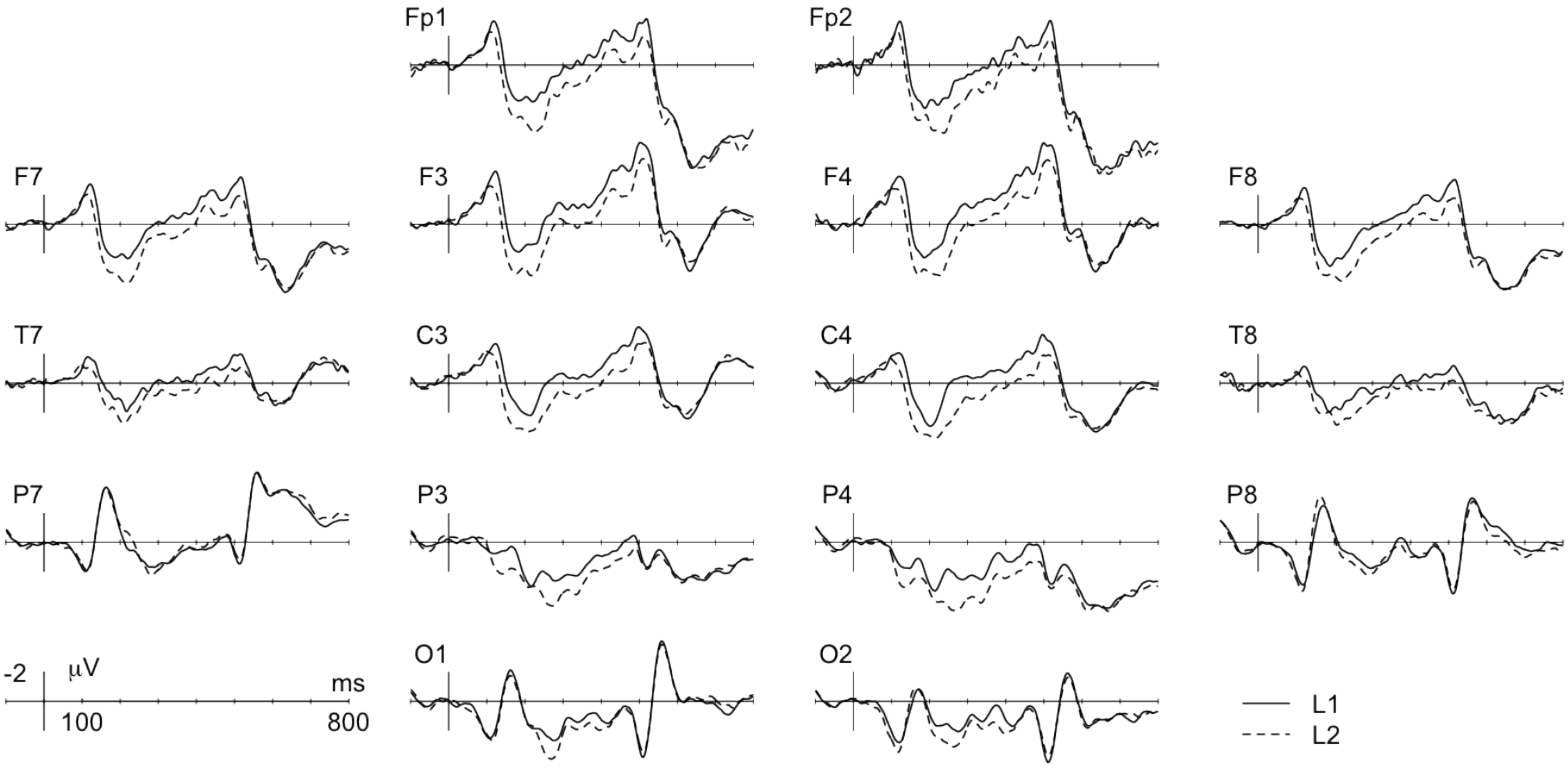

Figure 2. Grand average waveforms from data of all participants for the two articles (L1 or L2) preceding the noun, plotted in sixteen representative electrodes.

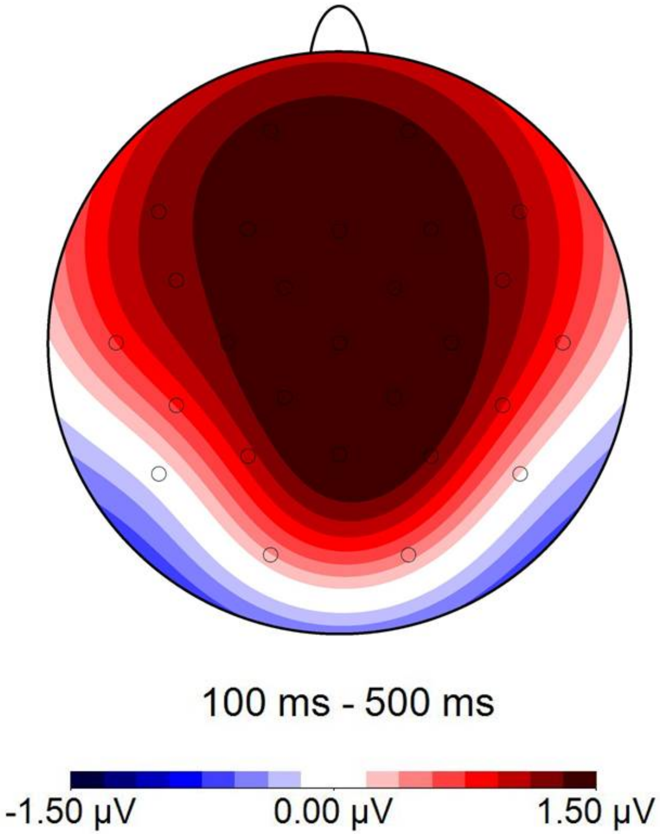

Figure 3. Topographical distribution of the language effects on function word processing in L1 and L2 in the analysed temporal window: 100-500 ms. Voltage maps were obtained for the averaged values of difference waves (L2 minus L1).

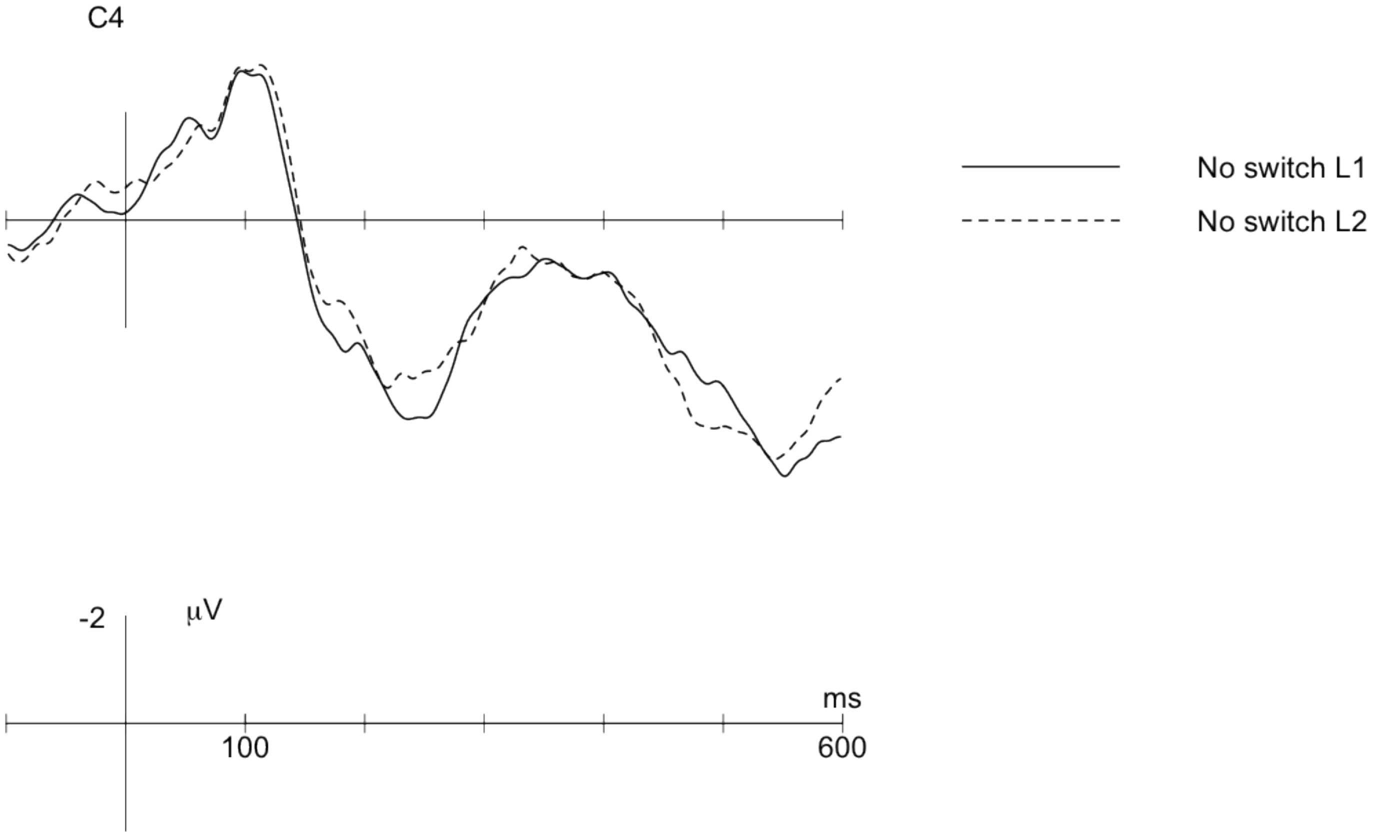

Figure 4. Grand average waveforms from data of all participants for the word pairs in L1 and L2 plotted in electrode CZ, only printed are the No switch conditions: the black line indicates L1 (la rana) and the dotted line L2 (the frog). Appreciate there are no differences in the N400 as a result of language use.

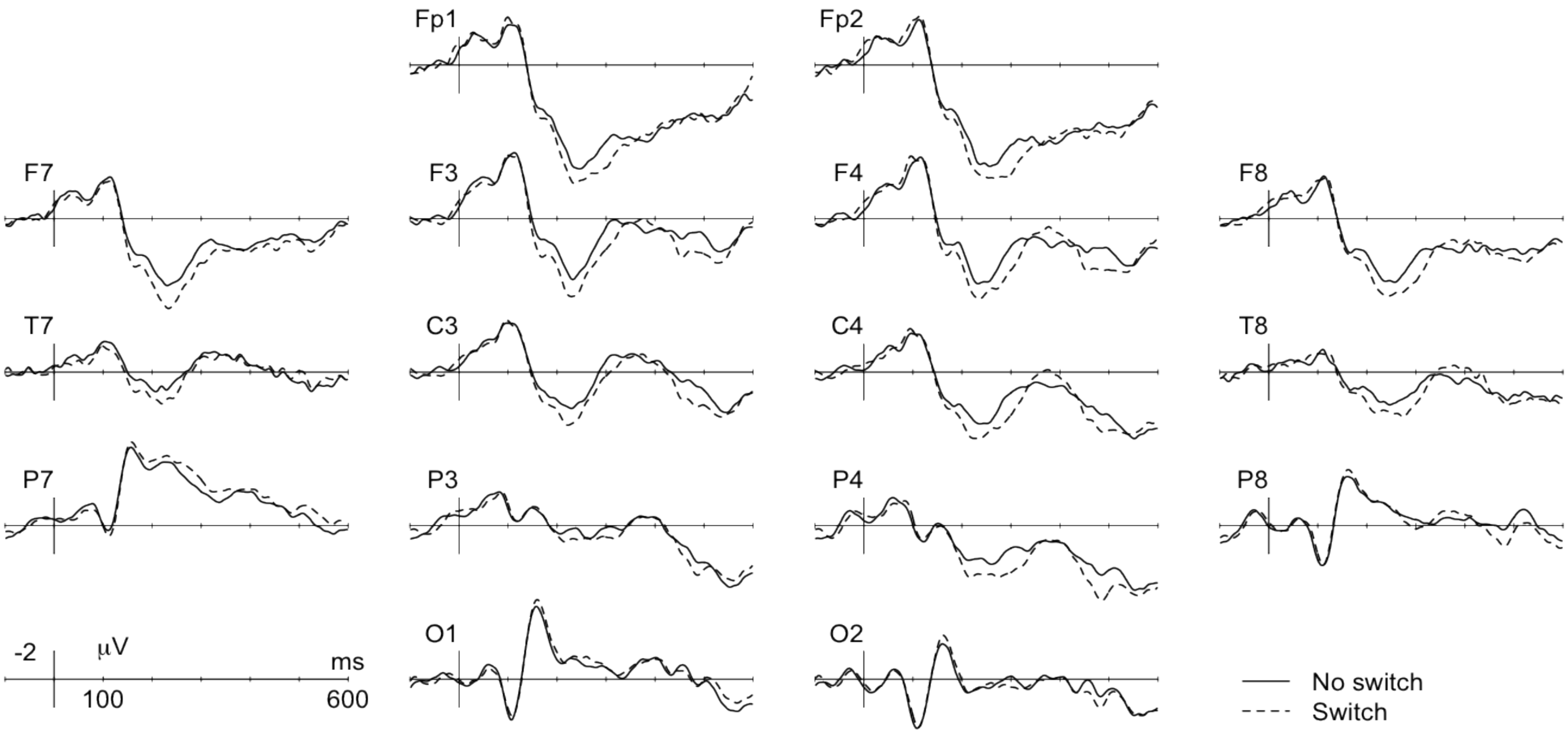

Figure 5. Grand average waveforms from data of all participants for Switch L1→L2 (No switch: *la rana,* Switch: *la frog*) plotted in sixteen representative electrodes, in which the main differences can be appreciated: long-lasting negativity.

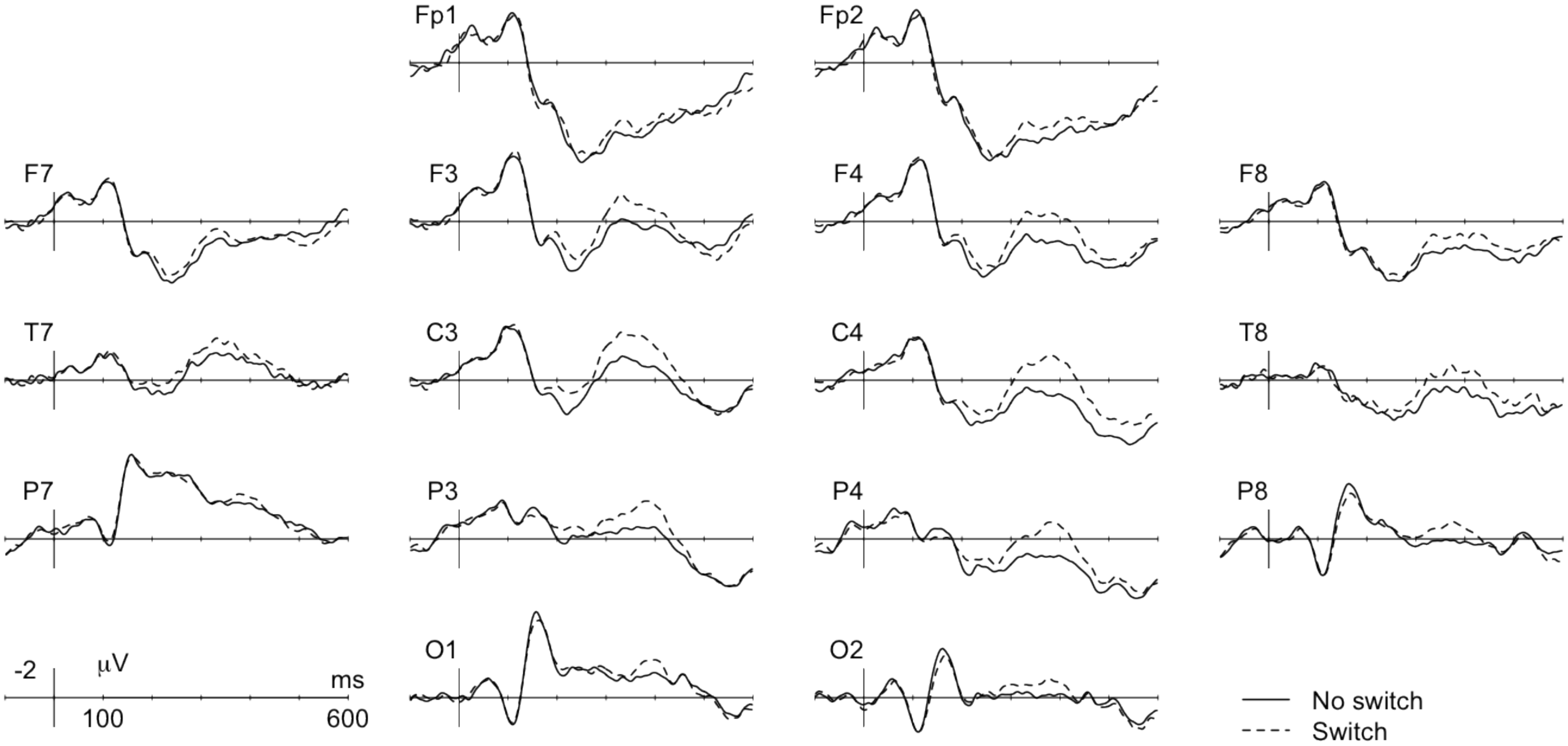

Figure 6. Grand average waveforms from data of all participants for Switch L2→L1 (No switch: *the frog,* Switch: *the rana*) plotted in sixteen representative electrodes, in which the main differences can be appreciated: long-lasting negativity.

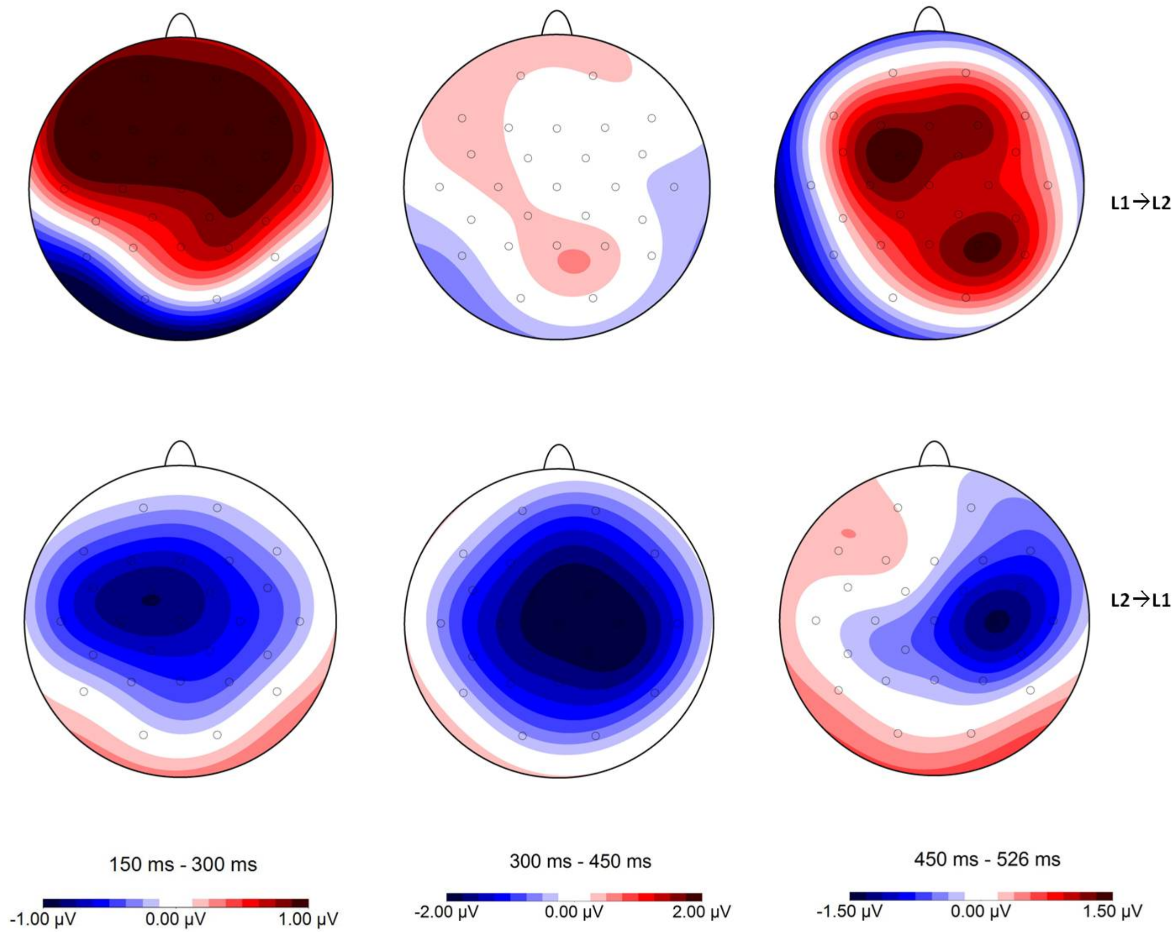

Figure 7. Topographical distribution of the language switching effects in L1→L2 (above) and L2→L1 (below) in the three analysed temporal windows: 150-300, 300-450 and 450-525 ms. Voltage maps were obtained for the averaged values of difference waves (switching minus no switching).

ARTICLE (L1 vs. L2)

Time window between 100 and 500 ms

The ANOVA (ARTICLE x HEMI x AP x DM) in this time window showed a main effect for ARTICLE ($F(1,19)= 30.08$; $p<0.001$), and the interaction effects of: ARTICLE with AP ($F(4,76)= 9.83$; $p<0.001$), and ARTICLE with DM ($F(1,19)= 23.13$; $p<0.001$) and a three-way interaction of ARTICLE with AP with DM ($F(4,76)= 21.45$; $p<0.001$). Post-hoc tests (see Appendix 5.2.1) revealed that and an English article elicited a large positivity in this time window in comparison with a Spanish article. The effect was very constant and although widespread in this time window, the interaction effects support the frontal-central distribution of the effect, which was larger around the midline and slightly less when the distance to the midline grew larger (see Figures 2 and 3). In Appendix 5.2.1 a complete overview of all statistical analyses and post-hoc test is reported in detail.

NOUNS: SWITCH L1→L2

Time window between 150 and 300 ms

The ANOVA (SWITCH x HEMI x AP x DM) in the time window of 150 to 300 ms after word onset showed a main effect for SWITCH ($F(1,19)=10.44$; $p<0.01$). It also showed a two-way interaction effect of SWITCH with AP ($F(4,76)=9.44$; $p<0.001$; $W=0.07$, $GG\varepsilon=0.43$), and three-way interaction effects of SWITCH with DM with AP ($F(4,76)=6.35$; $p<0.01$; $W=0.16$, $GG\varepsilon=0.50$) and SWITCH with HEMI with AP ($F(4,76)=5.24$; $p<0.05$; $W=0.06$, $GG\varepsilon=0.40$). Post-hoc tests revealed that a large ongoing positivity starting in this time window as a result of a switch from Spanish (L1) to English (L2) with a left frontal distribution.

Time window between 300 and 450 ms

The ANOVA (SWITCH x HEMI x AP x DM) in this time window showed an interaction effects of SWITCH with HEMI and AP ($F(4,76)= 4.77$; $p<0.05$; $W=0.12$, $GG\varepsilon=0.50$) and

SWITCH with DM with AP ($F(4,76)=7.00$; $p<0.001$; ($W=0.44$, $GG\varepsilon=0.69$). However Post-hoc tests (Appendix 5.2.1) did not confirm an effect for SWITCH in these interactions.

Time window between 450 and 525 ms

The differences in this time window were supported by an ANOVA (SWITCH x HEMI x AP x DM) showing a main effect for SWITCH ($F(1,19)=5.03$; $p<0.05$), and the interaction of SWITCH with DM ($F(1,19)=7.97$; $p<0.05$) and three-way interactions of SWITCH with HEMI with DM ($F(1,19)=6.33$; $p<0.05$) and SWITCH with HEMI with AP($F(4,76)=8.10$; $p<0.001$) for the second three-way interaction Mauchly's test indicated that the assumption of sphericity had been violated($W=0.06$, $p<0.01$). Therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($GG\varepsilon=0.39$). Additionally an interaction of the four factors SWITCH with DM with AP with HEMI was significant ($F(4,76)=3.65$; $p<0.01$) for which Mauchly´s test indicated violation of sphericity (W)=0.20, $p<0.001$) and Greenhouse-Geisser correction ($GG\varepsilon=0.39$). Post-hoc tests (Appendix 5.2.1) revealed that the positivity as a result of the switch from a Spanish article to an English noun, in comparison with a Spanish noun, starting in the previous window continued in this later time window. The effect had a central distribution extending to the left and right hemisphere and the frontal and parietal areas, hence the interactions with the distribution factors.

NOUNS: SWITCH L2→L1

Time window between 150 and 300 ms

In this time window an ANOVA (SWITCH x HEMI x AP x DM) showed a main effect for SWITCH ($F(1,19)=6.62$; $p<0.05$). Negativity as a result of a language switch from an English article to a Spanish noun confirmed a large ongoing negativity starting in this time window, with a widespread distribution.

Time window between 300 and 450 ms

The negativity of the N2 continued in this time window changing into an N400 effect, the ANOVA (SWITCH x HEMI x AP x DM) showed a main effect for SWITCH ($F(1,19)=18.18$; $p<0.001$), a two-way interaction of HEMI and SWITCH ($F(1,19)=4.93$; $p<0.05$) and the interaction of SWITCH with DM ($F(1,19)=9.63$; $p<0.01$).

Time window between 450 and 525 ms

The N400 continues with a slightly different distribution visible in the ANOVA (SWITCH x HEMI x AP x DM) showing interactions of HEMI and SWITCH ($F(1,19)=10.11$; $p<0.01$) and SWITCH with DM and AP ($F(4,76)=4.11$; $p<0.05$; $W=0.20$, $GG\varepsilon=0.58$). The effect had a widespread distribution. Although visually the centre of the effect seemed to change in time from left central anterior to right central parietal and then to right anterior. The effect is large and visible in nearly all electrodes.

3.1.4. Discussion

In the present experiment we studied CS effects in word pairs composed by an article and a noun forming minimal noun phrases. Articles and nouns were visually and serially presented in the L1 (Spanish) or the L2 (English) of the participants, either matching in language or containing a switch. This design allowed us to study CS in absence of semantic integration processes, and with minimal syntactic complexity. Additionally the design allowed us to investigate the effect of switching direction in the same set of stimuli and within participants in the same experimental session. ERP analyses revealed multiple effects related to the used language (L1 vs. L2; in articles and nouns) and associated with language switching (L1 → L2 vs. L2 → L1).

Results showed that the processing of the articles differed as a result of the language they were presented in, and that this difference started very early in time. ERP waves of articles in

Spanish (L1) were different from those presented in English (L2) as early as 100 ms after their onset presentation, the L2 articles showed more positive amplitudes than the articles in L1. This effect lasted around 450 ms (between 100 and 550 ms after stimuli onset), and although widespread around the scalp it was larger at frontal than posterior electrodes. Although not many studies have looked at the ERPs associated to function word processing, some authors proposed that these words could be playing a critical role predicting the syntactic and semantic characteristics of the incoming words. For example, the N400-700 effect appears as a frontal ramp-like increasing negativity starting 400 ms after the presentation of a function word and lasting until the presentation of the following content word (Van Petten & Kutas, 1991). This effect has been interpreted as part of the expectancy-related ERP components (CNV-like components, Kutas et al., 2006): after the lexical recognition of the function word, the cognitive system awaits for the presentation of the relative content word in order to assign it a role in the sentence context (Molinaro et al., 2008; Van Petten & Kutas, 1991). The differences found in the present experiment fit very well with the general interpretation of the N400-700. In this case the articles would be used as cues to predict the language of the incoming nouns. This could be important to maintain the language coherence of the noun phrases (in spontaneous language Code-switching rarely happens within noun phrases), especially because the task that the participants had to perform was to decide whether articles and nouns belonged to the same language. In addition, in the case of Spanish articles some characteristics of the articles (i.e. gender and number) are also used in the agreement processing of nouns. The early onset of the effect is probably due to the frequency of these words and the fact that in the experiment only three words ("el", "la" and "the") were presented in the first position of the word pairs, so their recognition could be made very quickly (right after the basic perceptual processes took place). Finally, since the SOA between article and noun was 400 ms, the offset of the function word effect around 550 ms coincided with the beginning of the recognition processes of the subsequent noun. Therefore the differences found between the L1 and L2 articles can be linked to expectancy or readiness processes triggered by the articles, which would pre-activate or de-activate a specific language. These preparatory strategies are consistent with the IC and the BIA+ models (Green, 1998; Dijkstra & Van Heuven, 2002), which propose that executive control plays a central role in language selection.

ERPs time-locked to the noun presentation in the non-switching condition were equivalent for the entirely English and the entirely Spanish noun phrases ("the frog" and "la rana"). This is an interesting result because previous studies have found differences in the N400 window for L1 and L2 words. For example, studies that have examined the N400 in bilinguals using the classical semantic violation paradigm, have reported a significant delay in its peak latency for L2 relative to L1 (Ardal, Donald, Meuter, Muldrew & Luce, 1990; Hahne, 2001; Moreno & Kutas, 2005; Weber-Fox & Neville, 1996), or changes in its scalp distribution (Proverbio, Cok & Zani, 2002). Also in a study with single word presentation Alvarez et al. (2003) found larger N400 amplitudes for L2 nouns than L1 nouns, but that effect was mostly due to the switching language costs in an experiment in which participants were showed lists of mixed L1 and L2 words. In our data, N400 effects of L1 and L2 did not differ from each other in peak latency, scalp distribution or amplitude. This is consistent with our interpretation of the language pre-activation by the article. Therefore, it seems that once the specific language has been activated, there are no additional costs in the meaning retrieval associated to the language dominance.

More central for the main goal of this experiment were the CS effects in the trials composed by language mixed word pairs. The most striking result was that within-noun phrase CS resulted in differences with opposite polarity depending on the switching directing. Especially in the P2 time window, switching from L1 to L2 resulted in more positive amplitudes than the non-switching condition, whereas switching from L2 to L1 resulted in more negative amplitudes than the non-switching conditions. In addition, in the N400 time window, when for switching from L1 to L2 no significant differences were reported, switching from L2 to L1 resulted in a significant N400 effect. Therefore, independently of the specific onset and duration of the effects, it is clear that CS from L1→L2 was mainly associated to a positive effect, whereas the CS of L2→L1 resulted in a clear N400 effect.

The functional interpretation of the L1→L2 CS effect could reflect an increase of atentional recourses when switching to the less dominant/used language. In this sense this effect could be related to the kind of effects known as P3 family components. The P300 component increases in response to unexpected events or features that are relevant for categorization of the stimuli (Donchin, 1981; Polich, 2007; Verleger, 1988). Since, according to the "context updating" theory (Donchin, 1981; Donchin & Coles, 1988, 1998) a language switch would predict a larger P300 amplitude. This is because a language switch requires the participation of cognitive control for updating the contents of working memory, the participation of attention, and the decision to change the language in the present context of the performance. It is important to remind that the task that the participants had to perform was to detect the language mismatches, so language switches themselves were relevant for the task independently of the switching direction. However, it could be the case that for non-balanced bilinguals switching from L1 to L2 is a more unexpected or disrupting event than switching from their L2 to their dominant and more frequently used L1.

Previous reports on language switching with single word presentation have reported contradictory results in relation to the interaction of N400 switching effect and the switching direction. Alvarez et al. found N400 switching effects only in the L1→L2 direction, whereas in masked priming experiments Chauncey et al. (2008) reported N400 effects only from L2 to L1, and Migdley et al. (2009b) reported N400 modulations for both switching directions (see also Duñabeitia, Dimitropoulou, Uribe-Etxebarria, Laka & Carreiras, 2010). Although, the different experimental designs and tasks that were used prevent a direct comparison with those previous ERP studies, our results are more in line with the asymmetric effect reported by Chauncey et al. that it CS N400 effect only for the L2→L1 direction. This asymmetry is also consistent with the previous results reported in behavioural language production experiments (Campbell, 2005; Costa et al., 2006; Finkbeiner, et al., 2006; Meuter & Allport, 1999; Philipp et al., 2007), in which larger reaction times were found for digits in switch trials compared with non-switch trials. These asymmetric costs have been interpreted as a consequence of the greater inhibition that is required over the dominant language when activating the non-dominant language (Meuter & Allport, 1999). Therefore in our results, the N400 L2→L1 switching effect would be an index of the additional costs of activating meanings in the L1 lexicon after the inhibition triggered by a L2 preceding article.

When analysing effects in adjacent time windows, it is important to pay special attention to the possible spatial and temporal overlapping of the effects. The positivity starting at the P2 time window could reduce a potential later N400 effect. Actually a small difference that was not statistically significant can be observed also for the L1→L2 switches in several central-parietal electrodes at the peak of the N400. In similar way the negativity observed in the P2 component for the L2→L1 switches, could be alternatively interpreted as the early onset of the subsequent N400 effect. Also consistent with the possible temporal overlapping of effects with different polarity is the late positivity that was visible after the N400 component in the L1→L2 switches (in the L2→L1 CS only the continuation of the N400 was observed). This could be the continuation of the initial positivity or could be identified as a LPC. However the fact, that the late positivity showed a more posterior distribution than the early positivity, could indicate that they are associated to different but probably related cognitive processes. Actually the LPC has also been related to the P3 components. One tentative interpretation is that whereas the early more frontal positivity could be related to the P3a subcomponent and detection and updating processes, the late and more posterior positivity would be closer to the P3b and P600 effects, which have been associated to integration and reanalysis processes.

In summary, in this experiment with minimal noun phrases we found different ERP effects related to the processing of both articles and nouns. Different activity associated to L1 and L2 articles was interpreted as the effect of preparatory strategies and executive operations that would lead to the modulation of activation levels of the L1 and L2 languages (e.g. lexicons, orthographic and phonological systems, and grammatical rules). Effects in the subsequent nouns were consistent with this idea. When the language of the nouns fulfilled the expectancies (i.e. non-switching conditions), no differences were found between L1 and L2 word processing. However, different effects were reported for the switching conditions depending on switching direction. L1→L2 CS recruited more atentional recourses, whereas L2→L1 switching resulted in more lexical retrieval costs, due to a larger previous inhibition of the dominant language. To further investigate these ERP effects and to test these interpretations, in the two next experiments, the CS processing was studied in a more natural context of sentence reading.

3.2 EXPERIMENT 2: SENTENCES: FROM L1 TO L2

3.2.1. Introduction

Experiment 1 resulted in several ERP effects triggered by code switches that took place within minimal noun phrases. In order to explore CS in a more natural reading situation, Experiment 2 studied the effects of similar code switches but now embedded in sentences. Using similar word pair phrases inserted in sentences allowed us to compare the same manipulation in a different experimental context. This way, we could test if the reported effects in Experiment 1 were specific of the used task and experimental design, or if they could be observed in a more natural reading task as well. It is plausible that the same manipulation engage additional cognitive operations when the syntactic and semantic context increases, as in the case of sentence versus word pair processing.

As described in the general introduction, to our knowledge only two ERP studies have investigated CS processing during sentence comprehension. 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 lexical switches within language 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 (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 et al. (Proverbio, Leoni & 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 CS from L1 to L2 but not from L2 to L1. The authors claimed 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, CS in balanced bilinguals resulted in ERP amplitude differences in the N400 time window, but depending on the specific topographical distribution of the effect, they were sometimes attributed to lexico-semantic processing and sometimes not.

The two mentioned studies used the same type of participants, which were balanced bilinguals (those with similar skills in L1 and L2). Even in the case of Proverbio et al. (2004), where the participants could clearly identify their L1, they were also highly proficient in L2, and used both languages frequently. This was definitely not the case of the participants in our Experiment 1, whom although rated as high proficiency late second language learners, did show a strong difference in the use and proficiency of L2 compared to L1. In the present experiment we tested an equivalent group of learners, so the results could differ from those of the previous studies with CS in sentences. According to the RHM (Kroll & Stewart, 1994), 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 expected quantitatively or even qualitatively different effects associated with CS in second language learners in comparison with balanced bilinguals. These differences could be especially evident in relation to the switching direction effects. We assume that direction effects are due to the general dominance of one of the languages in relation to the other. Therefore, with a larger asymmetry between languages, the stronger will be the switching direction effects. This is especially relevant because in our Experiment 1 with noun phrases, the N400 switching effects were evident only for switches from L2 to L1, whereas Proverbio et al. (2004) reported the N400 effect only for switches from L1 to L2 during sentence reading. Therefore using a group of second language learners (like in Experiment 1) and presenting switches in sentences (as in Proverbio et al.), we expected to contribute to the interpretation of these apparently contradictory results.

The present study focused on switches from L1 to L2 during sentence reading. Participants were native Spanish speakers with a high English proficiency (but always considerable lower than their L1). They were presented sentences in Spanish that contained a language switch in the beginning, middle or end of the sentence. These switches consisted in a single noun or adjective that was presented in English, and across sentences could happen at different positions of the sentence (making switches less predictable). There were two main positions in which the experimental manipulation took place: in nouns at the very beginning of the sentence or in adjectives at the middle of the sentence (apart from other positions as filler trials). For example, in the sentence "El gato estaba gordo y roncaba feliz" (*The cat was fat and snored happily*), the switch could happen at the noun "gato" (cat) or at the adjective "gordo" (fat). This allowed an adequate comparison between the effects obtained with noun phrases presented in isolation (Experiment 1) to effects of similar noun phrases located at the beginning of sentences (Experiment 2) and finally, within sentence comparison, to effects of verb phrases in a larger sentence context (Experiment 2). This was very similar to the method used by Barber and Carreiras (2005) for their study of ERP effects associated to morphosyntactic violations. They showed common effects for these three manipulations, but also qualitative differences between isolated noun phrases and noun phrases inserted in sentences, as well as quantitative differences between the two sentence positions. In a similar way, we expect to obtain information about the effect of semantic integration and syntactic complexity on CS effects. Additionally, we expect to replicate the positivities found in Experiment 1 when switching from L1 to L2. In this case the LPC possibly will increase due to the fact that CS during sentence processing could involve more integration difficulties as well as more reanalysis operations.

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.

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 (see General Introduction above). Some 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). Furthermore, at a slightly later latency, a negativity peaking at 250 ms with a central distribution (N250) has been observed in masked priming paradigms, and has 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 in sentences reviewed above, neither Moreno et al. (2002) nor Proverbio et al. (2004) reported main effects of CS before the N400 time window. However, Proverbio et al. (2004) described an interaction of semantic incongruence, CS and switching direction between 130 and 200 ms at some frontal electrodes; for which CS from L2 to L1 produced amplitudes that were more negative and only for 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 who are fluent in both languages, and as a result we expected enhanced orthographic effects in response to language switching either in the N170 or in the N250 components. In Experiment 1, the CS effects started as early as 100-150 ms after stimuli onset, meaning that language detection started very early in the visual word recognition process, actually in the same temporal range in which orthographic processing takes place. The word pair manipulation produced very large and very widely over the scalp distributed effects, probably because the task that the participants had to perform was directly related to CS, and the response had to be made right after reading the noun. It is possible that the large CS effects overrode orthographic effects that are usually smaller in magnitude. Therefore, in this second experiment, in which CS took place in words that are not directly related to the task resolution, we will pay additional attention to potential early ERP effects that could be linked to early orthographic ERP effects.

In summary, the main goals of this experiment were:

- To describe ERP effects of CS from L1 to L2 in a situation of sentence reading, and in non-balanced bilinguals (i.e. second language learners).

- To test if N400 effects reported by Proverbio et al. (2004) when switching from L1 to L2 in sentences could be replicated or if the lack of these effects reported in the Experiment 1 (with isolated noun phrases) is confirmed.

- To replicate the positivities found in Experiment 1, paying special attention to the LPC in a context where more integration costs and reanalyses processes are expected.

- To investigate the effect of context and integration processes in CS, by comparing the results of experiment 1 with CS in two different sentence positions.

- Finally, to describe potential early ERP effects associated to orthographic processing that could link this early stage of word processing with the language detection and selection processes.

3.2.2. Method

3.2.2.1. Participants

To select high proficiency second language learners, we used the same procedure as in experiment 1; we recruited 23 participants from different language schools in Tenerife and administered an English aptitude test to control for their level of English. Individuals who scored level 4 (High Proficiency) were recruited to participate in this study. Other than the objective English test of the language school of the University of La Laguna they had to fill in the subjective foreign language test LEAP-Q (Blumenfeld, & Kaushanskaya, 2007). Table 4 shows the average ratings of the participants on the subjective and objective assessments. The characteristics of these contributors were similar to the participants of experiment 1 in proficiency level and background, since they were all Spanish native speakers living in Tenerife in a Spanish monolingual environment; they sometimes used English at work or at the University, but they were not used to CS in their daily life. All participants were active second language learners of English and reported to find it easier to read than to listen to or to produce English. Also the other tests and questionnaires were equally to those of experiment 1. Thus only right-handed people with no neurological history were invited.

Two of the participants had to be excluded due to bad recording of the ERP data. The remaining 21 (17 female and 4 female) participants were aged 20 to 40 (mean age 25.1 years). Similar to the procedure used in experiment 1, the experimenter informed after the experiment how the participant had perceived the task and whether there were any difficulties in understanding words in L2. All participants commented that they had no problem with understanding neither the task nor the sentences.

Table 4. *Characteristics of the participants of experiment 2*

	Proficiency L2
Men: Women	4: 17
Age in years	25.1 (SD 6.8)
AoA in years	8.7 (SD 3.2)
English Pre-test†	4 (Range 1-4)
Self-rated Speaking*	7.6 (SD 1.3)
Self-rated Hearing*	8.2 (SD 1.1)
Self-rated Reading*	8.3 (SD 1.2)

*Self-reports were on a scale of 1 to 10, where 1 was almost none and 10 like a native speaker

†According to the standards of the Common European Framework of Reference for Languages published by the Council of Europe (2001): Level 1 = A1 (Breakthrough); Level 2 = A2 (Waystage) and B1 (Threshold); Level 3 = B2 (Vantage); Level 4 = C1 (Effective Operational Proficiency)

3.2.2.2. Stimuli

Stimuli were 160 Spanish sentences of 6 to 10 words. All had a similar structure, namely a noun phrase with a simple subject (e.g. "El gato estaba gordo y roncaba feliz."- "*The cat was fat and snored happily*"). This structure may not be the most frequently used one, but it is a correct syntactic structure in both languages, which was important, since typical word order is not identical in Spanish and English. The second word of half the sentences was a Spanish noun (*No switch, Position 1*) and in the other fifty percent of the sentences an English noun (*Switch, Position 1*) like for example, "El *cat* estaba gordo y roncaba feliz." Of the 80 sentences with a noun in Spanish, 40 sentences contained a switch to English in the adjective, which was the fourth word of the sentence (*Switch, Position 2*) (e.g. "El gato estaba *fat* y roncaba feliz.") and the remaining 40 sentences contained an adjective in Spanish (*No switch, Position 2*) but a switch to English in the seventh word of the sentence e.g. "El gato estaba gordo y roncaba *happily*." (*Filler switch*). Thus all sentences had a switch to L2 but in different positions; in the beginning (Position 1), in the middle (Position 2) or in the end (Filler) of the sentence. All switches were semantically congruent with the rest of the sentence. Switches with a similar orthographic or phonological form between languages (i.e. false friends, cognates or homophones) were not included in the switches that were analyzed, in the filler switches it was not controlled for. The sentences were counterbalanced, so each noun and adjective appeared in all conditions, thus creating four different lists. In this experiment we controlled for the language differences of grammatical features like frequency, orthography and number of orthographic neighbours by presenting the words in L1 and its unique translation in L2 for as well the nouns as the adjectives. As in experiment 1 the lexical frequency, word length and orthographic neighbourhood size were selected from CELEX (Baayen, Piepenbrock & Van Rijn, 1993) with N-Watch (Davis, 2005) for the L2 words and from LEXESP (Sebastián, Martí, Carreiras, & Cuetos, 2000) for the L1 words with BuscaPalabras (Davis & Perea, 2005) see Table 5 and Appendix 5.1.2. The items of both languages were as much as possible matched on all these characteristics. Although the lexical frequency was slightly higher for items in L2 as was the case in the word pairs experiment, this frequency is relative since words in L1 will have had more exposure and were perceived as more frequent by our participants.

Table 5. *Characteristics of the items in both languages*

Stimuli (ENG/ESP)	Frequency (CELEX/LEXESP)	Wordlength (CELEX/LEXESP)	Neighbourhood (CELEX/LEXESP)
Noun L1	90.0 (SD 164.2)	5.8 (SD 1.6)*	3.7 (SD 4.8)*
Translation Noun (L2)	99.7 (SD 127.7)	5.3 (SD 1.7)*	4.8 (SD 5.1)*
Adjective L1	20.9 (SD 39.2)*	7.2 (SD 2.0)*	2.9 (SD 3.9)
Translation Adjective (L2)	75.8 (SD 144.1)*	6.3 (SD 2.2)*	3.3 (SD 4.5)

* Significant $p < 0.05$ between languages

3.2.2.3. Procedure

The recording procedure was exactly the same as in Experiment 1. The participants were seated comfortably in a soundproof electrically-shielded room with approximately 80 cm distance from a CRT computer. The 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, 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. Also this time we created an onset asynchrony between sentences with a blank screen appearing 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. The total length of the experiment was two hours including electrode set up. The session started with a short practice in 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., "¿El gato estaba flaco?" – "*Was the cat thin?*" after "El gato estaba gordo y roncaba feliz." – *"The cat was fat and snored happily"*). 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 in the beginning and half after a sentence with a language switch on the fourth or seventh position in the sentence. 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. After the experiment the participants had to fill in some questions about the experiment, how they felt (comfortable, sleepy etc.) and whether they had understood the task and the sentences and what they thought the experiment was all about. This way we could check for bad recordings and if people had paid attention.

3.2.2.4. EEG recording and ERP analyses

The electroencephalogram was also recorded as described in Experiment 1, with 27 electrodes referenced to the left mastoid and with two pairs of electrodes to register vertical and horizontal eye movements (EOG). The battery-powered amplifiers were the same as the ones used in the previous experiment. All electrical activity was recorded and amplified with a bandwidth of 0.01–100 Hz and a sampling rate of 500 Hz. All electrode sites reported an impedance that was equal to or less than 5 k**Ω**, except for the four eye channels, those were kept below 10 k**Ω**. The offline analyses of the recorded and stored EEG data were done with BrainVision Analyzer 2.0 software (Brain Products: www.brainproducts.com). Which consisted in the offline filtering of the recordings with a low cutoff filter of 0.1 Hz and a high cutoff of 30 Hz. Data was re-referenced to the algebraic mean of two mastoid electrodes. Only in two participants it was necessary to correct for the effects of unwanted ocular movements following the procedure proposed by Gratton et al. (Gratton, Coles, & Donchin, 1983). Artefact rejection was adjusted to each participant individually and resulted in the exclusion of approximately 7% of all trials evenly distributed across experimental conditions. The data were segmented relative to reference marker positions, 100 ms before and 900 ms after presentation onset of the target nouns (first position), and -100 to 900 ms after target adjectives onset (second position). Baseline correction was performed using the average EEG activity in the 100 ms preceding noun/adjective onset.

Mean amplitudes were obtained for different time windows selected after visual inspection in combination with point-by-point statistical tests: an ANOVA checked every 2 ms on significant differences of CS, which helped to determine statistically when an effect started. This resulted in the following time windows: 200-300, 300-450, 450-600 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, parieto-occipital (P7, P8, O1 and O2) electrodes were analyzed separately. Mean voltage amplitudes relative to the start of the critical words were subjected to an omnibus analysis of variance (ANOVA) with SWITCH (Switch, No switch) and POSITION (Position 1, Position 2) as within-subject factors, and two topographical factors: Hemisphere (HEMI: left, right), and Anterior Posterior (AP: more anterior, more posterior).

For the further analyses of the first time window (200-300) and all analyses of other time windows (300-450, 450-600 and 600-750) 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 (as in Experiment 1.) via adding the three topographic factors Hemisphere (HEMI; left, right), Distance to midline (DM: distance 1, distance 2) and Anterior-Posterior (AP: frontal, frontal-central, central, central-parietal, parietal) factors. We performed Univariate Repeated-Measures ANOVA Assuming Sphericity (SWITCH x POSITION x HEMI x DM x AP) and adding Mauchly sphericity test (W) for each interaction with the factor AP that had more than two levels. In the latter case we reported the Greenhouse Geisser-epsilon (GGε) to correct for the degrees of freedom and the new probability. To show the relation of CS and the distribution of the effect we included post-hoc tests of all significant interactions of the three topographical factors with the experimental condition SWITCH, reported with Hochberg´s p, which was selected for its reduction of the false discovery rate (FDR). All results can be found in Annex 5.2.2. For all statistical analyses, we used the program R (http://www.r-project.org).

3.2.3. Results

The ERP data for switches in position 1 and 2 are plotted together in Figure 8. This figure shows a subset of representative electrodes, but a larger number of electrodes can be found in the Appendix 5.3.2. Visual inspection of the grand average waveforms of ERPs time-locked to the presentation of the switches in the two positions indicated two simultaneous effects for CS starting as early as 200 ms after word onset. Relative to no switches, CS elicited a negativity between 200 ms and 300 ms after word onset with a left occipito-temporal distribution (labelled as *LO-N250* hereafter). In addition, a long-lasting fronto-central positivity also beginning at 200 ms and lasting until the end of the analyzed segment, distinguished CS from No-switch trials. The positivity (between 200 and 850 ms) showed different topographical distributions through time. Between 200 and 450 ms the effect showed a frontal distribution, then it shifted towards a broad central distribution (450-600 ms), and in later latencies it is localized over the posterior area. The scalp distributions of the differences between conditions are represented in 2-D topographic maps of Figure 9. Figure 10 shows the overlapping of the difference waveforms representing the size of the differences between conditions for each sentence position separately (1^{st} vs. 2^{nd} position). Although CS in both positions independently of the word-type showed the same effects, visual inspection indicates larger differences in the late latencies of the positivity for the switch appearing later in the sentence (2^{nd} position). The statistical analyses supporting these observations for each of the four selected time windows are described below[2].

[2] Complementary statistics can be found in Appendix 5.2.2

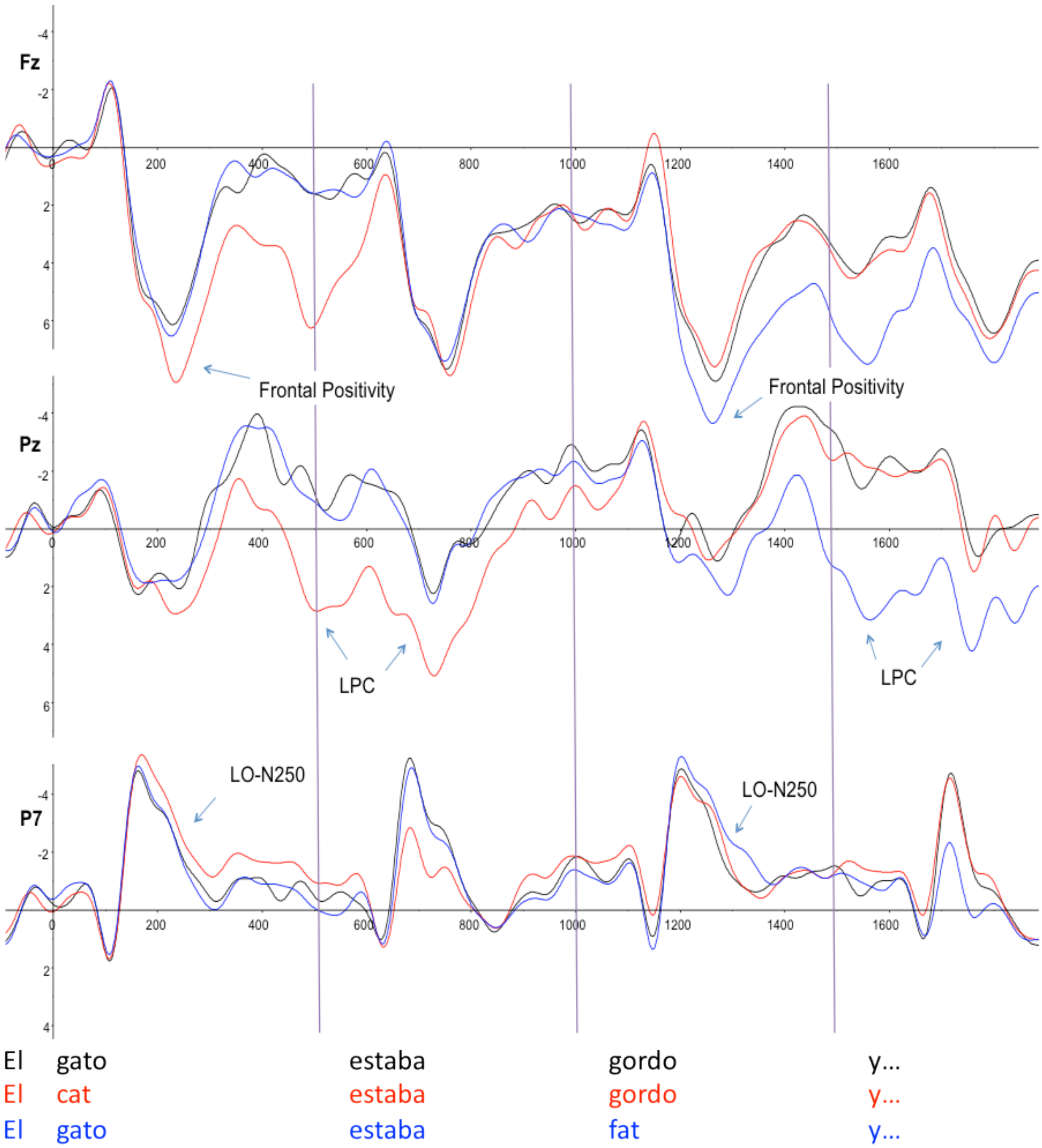

Figure 8. Grand average waveforms from data of all participants for all sentences plotted in the three midline electrodes; the black line indicates No switch, the red line CS in position 1 and the blue line CS in position 2. Appreciate the similar effects of CS independent of word type or presence in time.

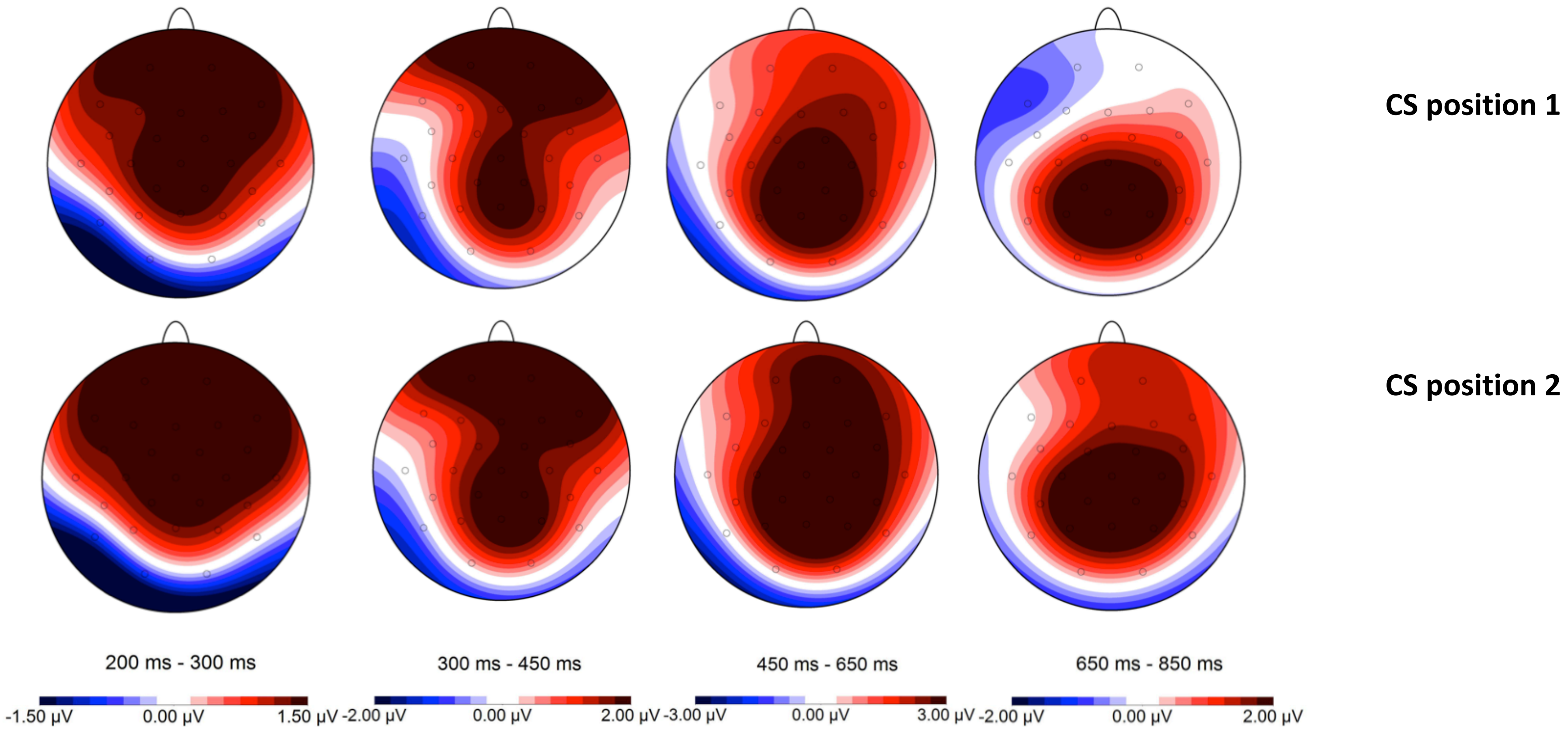

Figure 9. Topographical distribution of the CS effects for each position (2nd word upper row and 4th word lower row) in the four analysed temporal windows: 200-300, 300-450, 450-650 and 650-850 ms. Voltage maps were obtained for the averaged values of difference waves (Switch minus No switch).

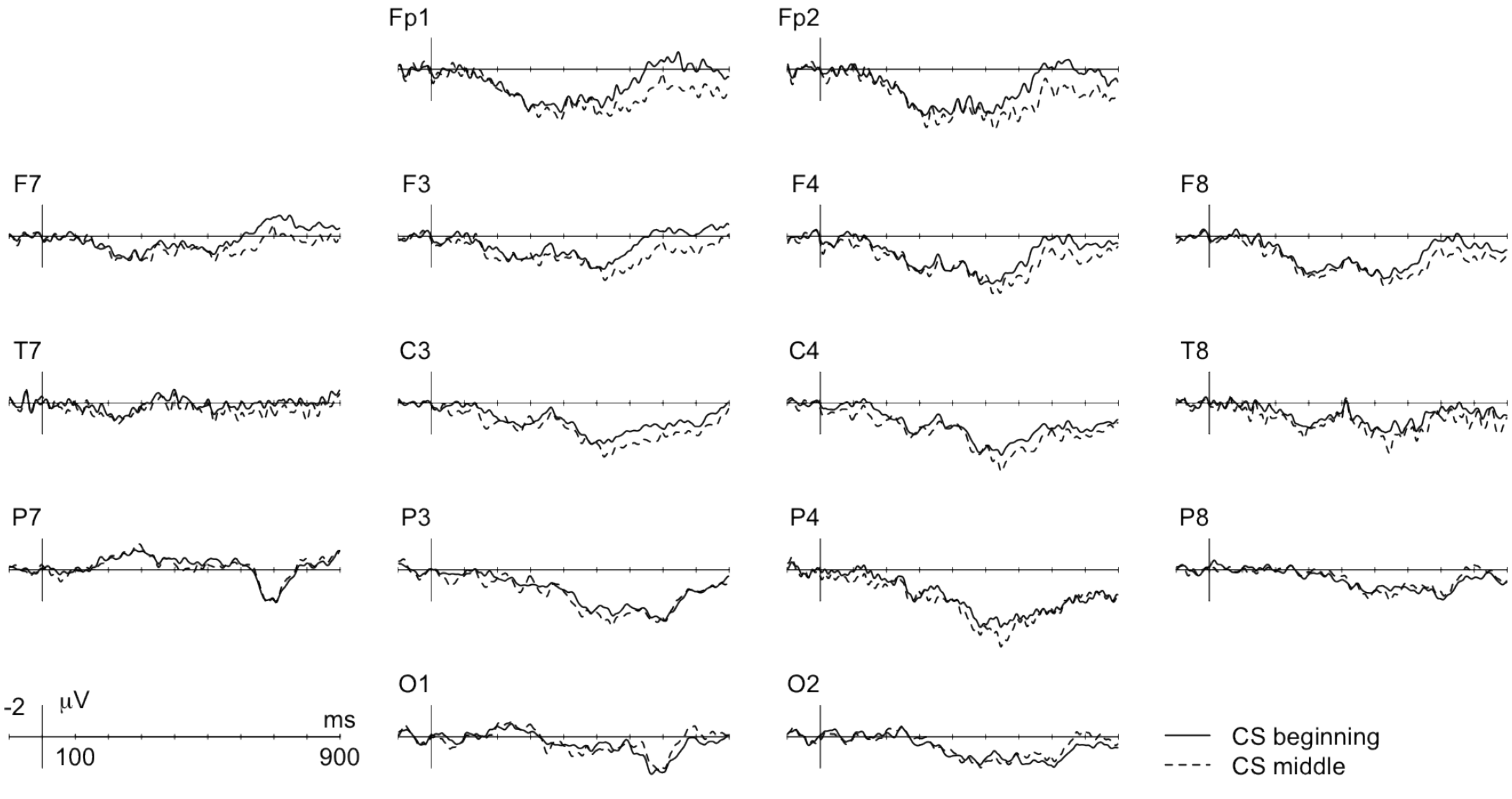

Figure 10. Grand average difference waveforms from data of all participants for the experimental conditions in the two different positions (CS beginning versus CS middle) plotted in sixteen representative electrodes. The difference waveforms were calculated by subtracting the No switch from the Switch condition.

Time window between 200 and 300 ms

Statistical analyses, ANOVA (SWITCH x POSITION x AP x HEMI x DM) confirmed the start of the positivity with a main effect for SWITCH ($F(1,20)=11.25$; $p<0.01$), two-way interactions SWITCH and HEMI ($F(1,20)=6.58$; $p<0.05$), SWITCH and DM ($F(1,20)=9.23$; $p<0.01$) and SWITCH with AP ($F(4,80)=14.78$; $p<0.001$; W=0.38, GGε=0.40). In addition there were three-way interactions of SWITCH, HEMI and DM ($F(4,80)=9.25$; $p<0.01$), SWITCH, HEMI and AP ($F(4,80)=6.98$; $p<0.01$; W=0.11, GGε=0.49) and of SWITCH, DM and AP ($F(4,80)=14.29$; $p<0.001$; W=0.24, GGε=0.61) and an interaction of SWITCH, POSITION, AP and DM ($F(4,80)=5.61$; $p<0.01$; W=0.37, GGε=0.71). Post-hoc tests of these interactions showed that the positivity had a broad frontal central distribution for CS in both positions, though the three-way interactions also showed in the left parietal level a change in direction although not significant, it probably indicated an overlap of positivity with the LO-N250 effect. In order to disentangle the four-way interaction including Switch, Position, DM and HEMI, we looked at the three-way interaction of SWITCH with AP and DM separately for each POSITION (Appendix 5.3.2). There was only a difference in the level "parietal" of the factor AP: on the parietal sites that were closest to the midline, CS was visible as positivity, whereas on the parietal sites furthest away from the midline, CS resulted in negativity (LO-N250). Both effects resulted significant for CS position 1 and almost for CS in position 2. The other sites (frontal to central-parietal) of the factor AP interacting with both levels of the midline showed a significant effect of CS in both sentence positions, resulting in a large positivity.

A closer look at the LO-N250 effect taking only four parietal-occipital electrodes (P7, P8, O1 & O2) in a different ANOVA (SWITCH, POSITION, HEMI, AP) resulted in a main effect of SWITCH ($F(1,20)=6.71$; $p<0.05$) an interaction of SWITCH with HEMI ($F(1,20)=18.45$; $p<0.001$) and a triple interaction of SWITCH, HEMI and AP ($F(1,20)=9.28$; $p<0.01$). The results confirmed a modulation of the LO-N250 as a result of CS in this time window with a parietal-occipital distribution with no interaction of sentence Position.

Time window between 300 and 450 ms

The early frontal positivity of CS that started at 200 ms continued in this time window as confirmed in an ANOVA (SWITCH x POSITION x HEMI x AP x DM) that showed a main effect for SWITCH ($F(1,20)=12.85$; $p<0.01$), a two-way interaction of HEMI and SWITCH ($F(1,20)=12.46$; $p<0.01$) an interaction of SWITCH with DM ($F(1,20)=15.61$;$P<0.001$), and an interaction of SWITCH and AP ($F(4,80)=5.80$; $p<0.05$; $W=0.02$, $GG\varepsilon=0.40$). Though it seems that in this time window additionally another more central-parietal distributed positivity started for CS, which was confirmed by interactions of SWITCH, HEMI with DM ($F(1,20)=12.56$; $p<0.01$) and SWITCH, HEMI with AP ($F(4,80)=3.36$; $p<0.05$; $W=0.10$, $GG\varepsilon=0.47$) and SWITCH, DM with AP ($F(4,80)=31.15$; $p<0.001$; $W=0.44$, $GG\varepsilon=0.55$). The statistics suggested an effect with a right-parietal centre (starting late positivity) and an effect with a right–frontal centre (continuing early positivity). There was no report of a significant interaction with the factor POSITION, thus the CS effects were the same in both sentence positions.

Time window between 450 and 650 ms

The ANOVA (SWITCH x POSITION x HEMI x AP x DM) of the data in this time window reported a main effect for SWITCH ($F(1,20)=18.29$; $p<0.001$) and an interaction of SWITCH and POSITION ($F(1,20)=6.78$; $p<0.05$). The effects of CS in this time window differed as a result of their position in the sentence. This was illustrated by the post-hoc tests and although in both positions there was a CS effect, the average effect of Switch had larger amplitudes and was more significant for position 2. Furthermore there were interactions of HEMISPERE and SWITCH ($F(1,20)=14.16$; $p<0.01$) and SWITCH and AP ($F(4,80)=4.16$; $p<0.05$; $W=0.03$, $GG\varepsilon=0.49$). And finally there were three-way interactions of the experimental condition with the topographical factors namely, SWITCH with DM and AP ($F(4,80)=24.94$; $p<0.001$; $W=0.20$, $GG\varepsilon=0.58$) and SWITCH with HEMI and DM ($F(1,20)=13.09$; $p<0.01$). All these interactions indicated a widespread positivity in this time window visible in all electrode sites apart from the some electrodes situated most left lateral. The effect showed significantly larger amplitudes for CS in position 2.

Time window between 650 and 850 ms

The ANOVA in this time window resulted in a main effect of SWITCH ($F(1,20)=5.56$; $p<0.05$), an interaction of SWITCH with POSITION ($F(1,20)=7.14$; $p<0.05$) and a triple interaction of SWITCH, POSITION and AP ($F(4,80)=7.85$; $p<0.001$; $W=0.03$, $GG\varepsilon=0.41$). These interactions indicated a difference for CS in the beginning of a sentence in comparison with CS later in the sentence: CS in position 1 did not reach significance in the two-way interaction of SWITCH and POSITION. However the triple interaction illustrated that CS in position 1 did generate an effect in this time window but only for the central-parietal and parietal sites, whereas the effect for CS in position 2 showed a larger distribution extending from the frontal-central sites to the parietal sites.

There were also some interactions of SWITCH only with the topographical factors namely: two-way interactions of SWITCH with DM ($F(1,20)=4.94$; $p<0.05$) and SWITCH with AP ($F(4,80)=9.87$; $p<0.001$; $W=0.03$, $GG\varepsilon=0.44$) and three-way interactions of SWITCH, HEMI and DM ($F(4,80)=4.63$; $p<0.05$), SWITCH with HEMI and AP ($F(4,80)=4.75$; $p<0.05$; $W=0.13$, $GG\varepsilon=0.48$) and SWITCH with DM and AP ($F(4,80)=11.37$; $p<0.001$; $W=0.41$, $GG\varepsilon=0.73$). These interactions confirmed a general distribution for CS with a right central parietal focus and decreasing on the lateral sites. The interaction effect of SWITCH with POSITION in the electrodes mentioned above can now be explained since these sites form the border of the effect of CS in position 1, whereas the widely distributed effect of CS in position 2 is still significant in the more peripheral electrode sites.

3.2.4. Discussion

This experiment looked at the processing of mixed language sentences, studying the ERP correlates of CS in second language learners reading for comprehension. Event-related potentials were obtained from Spanish speakers reading Spanish sentences that contained a noun or an adjective in English in the beginning or in the middle of the sentences respectively. The language switch manipulation resulted in a pattern of sequential effects analyzed in the different time windows. In the time window of 200 to 300 ms after target word onset, switching to L2 elicited an early negativity with a left occipital distribution in comparison with a continuation in L1. Also starting at 200 ms was a positivity maximum at frontal sites that distinguished switches from non-switches. This difference continued in the following analyzed time windows becoming larger at posterior sites in the late time windows (i.e. 450-650 and 650-850 ms). When comparing CS effects at the two different positions of the sentence, the results showed equivalent effects in the early time windows (200-300 and 300-450 ms), but larger effects for CS in the second position as compared to the first position in the late time windows (450-650 and 650-850 ms). Both the change in the scalp distribution and the different sensitivity to the sentence position support the distinction of this long lasting difference in two different effects, that is probably related to different cognitive operations.

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, Brandeis & McCandliss, 2005). Proverbio et al. (2004) reported ERP differences in the time range of the N1 component when L1→L2 CS involved semantically incongruent words, but at frontal rather than posterior electrodes. 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 did not start until 30 ms later and was maximum at 250 ms, 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 could indicate subsequent processing after the initial low-level orthographic processing, i.e., the detection or switching to different patterns of orthographic regularities associated to 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 (Duñabeitia et al., 2010; Holcomb & Grainger, 2006), but it is difficult to establish a functional relationship with the earlier N170, because the 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.

Simultaneous with the onset of the LO-N250 (around 200 ms), a positivity in response to language switching started at the frontal electrodes. 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 lasted only for 200 ms, the frontal positivity persisted for several hundreds of milliseconds. This difference in duration suggested that different neural generators originate them, and therefore these effects will be associated with different cognitive operations. As in the word pair experiment, the CS effect that started at the frontal electrodes was a long lasting effect, and at later latencies it showed a widespread distribution that was largest at the posterior sites. This late part of the effect fits with the LPC reported in the study of Moreno et al. (2002). 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 started at frontal sites as soon as the first orthographic mismatch was detected, and became maximum by the time that all lexical, semantic and syntactic information was available. 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 and has been related to integration and reanalysis processes (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 (Filjck, Sanford & Leuthold, 2008; Kaan & Swaab, 2003).

The ERP effects of CS were the same for the two sentence positions; in the noun at the beginning of the sentence and in the adjective at the middle position. However, while the LO-N250 and the fronto-central positivity showed an equivalent size, the effect of the LPC was larger in the second position than in the first one. It is important to mention that the differences between the two sentence positions were not restricted to the amount of previous context, because the target words at the two positions differed also in grammatical class or relative lexical frequency across languages. Although these other variables should affect mainly to the amplitude of the N400 component, we cannot completely dismiss their contribution to the sentence position effect. However, this difference is consistent with the interpretation of the LPC as a correlate of integration or reanalysis processes; the longer the previous context is, the more complex the reanalysis will be when the parser encounters a difficulty. A similar result was found in the study of Barber and Carreiras (2005) in which morphosyntactic violations were presented in the same two positions in Spanish sentences with the same syntactic structure. ERP effects were equivalent in the LAN and first phase of the P600, but were larger in the second position than in the first position during the second phase of the P600. The authors proposed that the second phase of the P600 was sensitive to reanalysis processes and the complexity of those processes increase with the amount of sentential context. However, it is important to note that statistical analyses and visual inspections of difference waves (see Figure 10) revealed that differences between sentence positions in the late time windows are restricted to the more frontal sites, so we cannot totally dismiss a contribution of the earlier fronto-central positivity to this effect.

One remarkable result in the present experiment was the lack of N400 effects in response to CS. This is consistent with the results of Experiment 1, where L1→ L2 switches in word pairs did not result in significant differences in the N400 time window. However the result contradicted the N400 effect reported by Proverbio et al. (2004) with more balanced bilinguals. However, there are several differences between both experiments that prevent a direct comparison. Between others, it is worth to mention that Proverbio et al. presented the code switches always in the last word of the sentences, which could have made them very predictable. Although it is not pertinent to try to explain absence of the N400 effect in our experiment, we can speculate that, as in Experiment 1, small N400 effects could have been overlapped by the observed large effects with the opposite polarity in the same time range and space. In any case, attending to the results with word pairs we still can predict a clear N400 effect with CS in the opposite direction, from L2 to L1.

In summary, three different effects were found in response to L1→L2 switches in sentences: a) the LO-N250 that we have linked to orthographic processing, b) a fronto-central positivity related to the detection of an unexpected event, and c) a LPC associated to reanalysis processes, which is larger at the middle position of the sentence. Although the LO-N250 was not observed in Experiment 1 with word pairs, the other two positivities mimic those found in that experiment for the L1→L2 switches. In the next experiment we will look at L2→L1 CS during sentence reading.

3.3. EXPERIMENT 3: SENTENCES: FROM L2 TO L1

3.3.1. Introduction

In the two previous experiments we have reported a series of ERP effects associated to CS, both in word pairs and in sentences. While in Experiment 1 we manipulated CS in both directions in respect to the dominant language, in Experiment 2 we only looked at switches from L1 to L2. When switching from L1 to L2, both experiments revealed an early positivity that started primarily at frontal sites and developed to more posterior areas at later latencies (LPC). We interpreted these positivities as belonging to the P3 group of components, and therefore reflecting updating and reanalysis of cognitive operations. If this interpretation is correct, we predict similar effects when switching in sentences from L2 to L1, but perhaps with different magnitude or latency. In a similar way, in the previous experiment with sentences we found an early effect at left occipital electrodes (LO-N250), which was interpreted as reflecting the impact of CS at the level of orthographic processing. Again and consistently with this interpretation we predict to find a qualitatively similar effect when switching from L2 to L1, because the detection of specific orthographic regularities or the costs of switching between orthographic systems should take place in both directions. Experiment 3 was planned to explore these predictions and to test other possible differences due to the switching direction, more concretely those related to a potential N400 effect.

In Experiment 1 with word pairs we found a N400 effect only for switches from L2 to L1. Moreover, in Experiment 2, we could not replicate the N400 effect reported by Proverbio et al. (2004) for CS from L1 to L2 in sentences. Taken together these two results, it is still an open question if the N400 effect will be visible when switching from L2 to L1 during sentence reading. N400 effect in response to CS can be interpreted to reflect an increase of activation at the lexical-semantic system, or as an increase of recourses during the meaning activation processes. As explained in Experiment 1, a N400 effect only in the L2→L1 direction would support the existence of an inhibition mechanism acting on one language when using the other, as well as the greater difficulty to inhibit L1 versus the L2 (Meuter & Allport, 1999). As we will explain below, this type of effects will be strongly determined by the level of L2 proficiency, and the asymmetry between L1 and L2 in competence and frequency of use. Proficiency therefore 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 of CS in particular (van Hell & Witteman, 2009). Therefore, in this new experiment, we were also interested in the ERP changes that take place when competence in the second language increases.

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. Moreover, if second language learners behave differently from balanced bilinguals in response to CS, we can expect that the level of proficiency in L2 will modulate these differences. ERPs have been a very useful tool to track the changes that take place in the brain when people are 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). 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). We tested two different groups of learners 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. 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 CS 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.

The RHM (Kroll & Stewart, 1994) briefly described in the section 2.1.2, is of particular interest in relation with our study with late second language learners. The model presents independent word form representations for the dominant language and the non-dominant language, and a shared conceptual level. Thus the first stage of language learning accounts for translation from non-dominant words to dominant words, to access the common concepts for both languages, and a stronger activation of concepts for the dominant language than for the non-dominant language. In the later stage of language learning the link between the non-dominant language word forms and the conceptual level gets stronger. Following the RHM, 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 a N400 effect in response to the code switches, which would indicate increased costs at the lexical level. Furthermore, and in contrast with Proverbio et al. (2004), we expect to find this effect when learners have to switch from their L2 to their L1.

To sum up, in the present study we will investigate the ERP correlates of language switches when second language learners switch from their L2 (English) to their L1 (Spanish).

Sentences like "The house that we rented was furnished and felt cosy" were presented in English to the Spanish native speaker participants, and the CS manipulation was made at the adjective located right after the verb, which was presented either in English ("furnished") in the non CS condition, or in Spanish ("amueblado") in the CS condition. As no qualitative differences were found between sentence positions in the Experiment 2, in this experiment we focused on the adjective manipulation at the middle of the sentence. Moreover, we enlarged the sentence context adding several words before the verb in order to ensure the complexity of the semantic and syntactic integration processes. The concrete aims of the experiment are listed below:

- To replicate the effects reported in the experiment 2 when switching from L1 to L2, namely the LO-N250 effect, the frontal positivity and the LPC.

- To test if the N400 effect can be observed in the L2→L1 CS as was the case with the isolated noun phrases in Experiment 1.

- To study the impact of learning development on CS by comparing two groups of learners with different L2 proficiency.

3.3.2. Method

3.3.2.1. Participants

To select high and low proficiency second language learners, we recruited 58 potential participants from three different language schools in Tenerife and administered the English aptitude test from the modern languages school of the University of La Laguna, which is described in Experiment 1. For the low proficiency group we invited the people that scored Level 2 = A2 (Waystage) and for the high proficiency group those who reached Level 4 = C1 (Effective Operational Proficiency) and C2 (Mastery). It is important to emphasize once more that the label "Mastery" is not intended to imply native-speaker or near native-speaker competence. In Table 6 are described the characteristics of each group. In the end we had recruited 18 participants for each group, the other potential candidates were discarded due to insufficient scores or were left-handed or had a neurological history.

Table 6. ***Experiment 3; 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	27.3 (SD 5.3)	27.5 (SD 3.9)	Ns
AoA in years	8.2 (SD 2.7)	8.7 (SD 3.4)	Ns
English Pre-test†	2	4	-
Self-rated Speaking‡	5.3 (SD 1.6)	7.5 (1.3)	*
Self-rated Hearing‡	5.9 (SD 1.6)	7.7 (1.5)	*
Self-rated Reading‡	6.8 (SD 1.7)	8.6 (1.3	*

‡ Self-reports were on a scale of 1 to 10, where 1 was almost none and 10 like a native speaker

† According to the standards of the Common European Framework of Reference for Languages published by the Council of Europe (2001): Level 1 = A1 (Breakthrough); Level 2 = A2 (Waystage) and B1 (Threshold); Level 3 = B2 (Vantage); Level 4 = C1 (Effective Operational Proficiency)

*Significant between groups with $p<0.01$

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. As in Experiment 1 and 2 all participants were attending year-long English courses at the language schools when tested, and could therefore be considered active second language learners of English. To obtain subjective information after the objective language test we administered a self-rating of English ability (LEAP-Q by Blumenfeld, & Kaushanskaya, 2007), which was also used in the previous experiments, this resulted in significant differences between the two groups on their ratings of reading, hearing and speaking of L2. Additionally, after the experiment, the researcher had a brief chat in English with the subjects to inquire after the experiment and their experience with foreign languages once more. 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 6. 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).

3.3.2.2. 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 cosy"). 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 cosy"). 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. All sentences were semantically correct but we avoided high cloze probability words since this variable has an effect on the N400 component. Average frequency of the Spanish adjectives was 22 per million with an average word length of 7 letters and 2 orthographic neighbours, reported with *BuscaPalabras* (Davis and Perea, 2005). The English adjectives had a length of 4-10 letters, an average frequency of 63.95 (sd=136.17) per million and an average of 2 orthographic neighbours according to the Celex lexical database (Baayen, Piepenbrock and 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.

3.3.2.3. Procedure

The study was recorded in the same laboratory described in Experiment 1 and 2. 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, 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 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 ten-minute-long experiment in Spanish. Therefore, the total length of the experiment was two hours including electrode set up.

The session started with a short practice in 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 cosy"). 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 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.

3.3.2.4. EEG recording and ERP analyses

The online recording of the electroencephalogram was proceeded exactly the same as in Experiment 1 and 2 and the offline recording as well apart from the blink reduction that was only necessary for two participants that presented an excessive number of ocular artifacts following the procedure proposed by Gratton et al. (Gratton, Coles, & Donchin, 1983). Artifacts were removed semi-automatically, with rejection values adjusted for each participant that resulted in the exclusion of only 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.

The statistical analyses were the same as in Experiment 1 and 2. Mean amplitudes were obtained for the 200-300, 300-450, 450-650, and 650- 850 ms time windows, which were selected after visual inspection of the grand average waveforms and statistical analysis of the segments. In the 200-300 ms time-window there could be effects with different polarity that overlap with the onset of later effects, therefore 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 (HEMI: left, right), and Anterior Posterior (AP: more anterior, more posterior).

The analyses of the other time windows (300-450, 450-650 and 650-850) were exactly the same as in Experiment 2: we organized the data into a grid-like scheme via three topographical factors and submitted the data to a repeated measures ANOVA (SWITCH, PROFICIENCY, HEMI, AP and DM). When violating the sphericity assumption we report the test statistic of Mauchly´s Sphericity (W) and the Greenhouse Geisser-epsilon (GGε) to correct for the degrees of freedom. The reported main effects or interactions were limited to those related to the experimental condition Switch[3]. For all statistical analyses, we used the program R (http://www.r-project.org).

3.3.3. Results

Event-related potentials time-locked to the onset presentation of the critical word are shown in Figure 11, after averaging the data of all the participants for the two experimental conditions (Switch, No switch), plotted in four representative electrodes. Figures 12 and 13 show the same grand averages in a larger set of electrodes and separately for the low and high English proficiency groups.

[3] See Appendix 5.2.3 for a complete overview of all statistical analyses and post-hoc test of the interactions with the factor SWITCH.

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, the 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 (LO-N250). 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 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 14 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 both groups. The difference waveforms in Figure 15 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 proficiency 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.

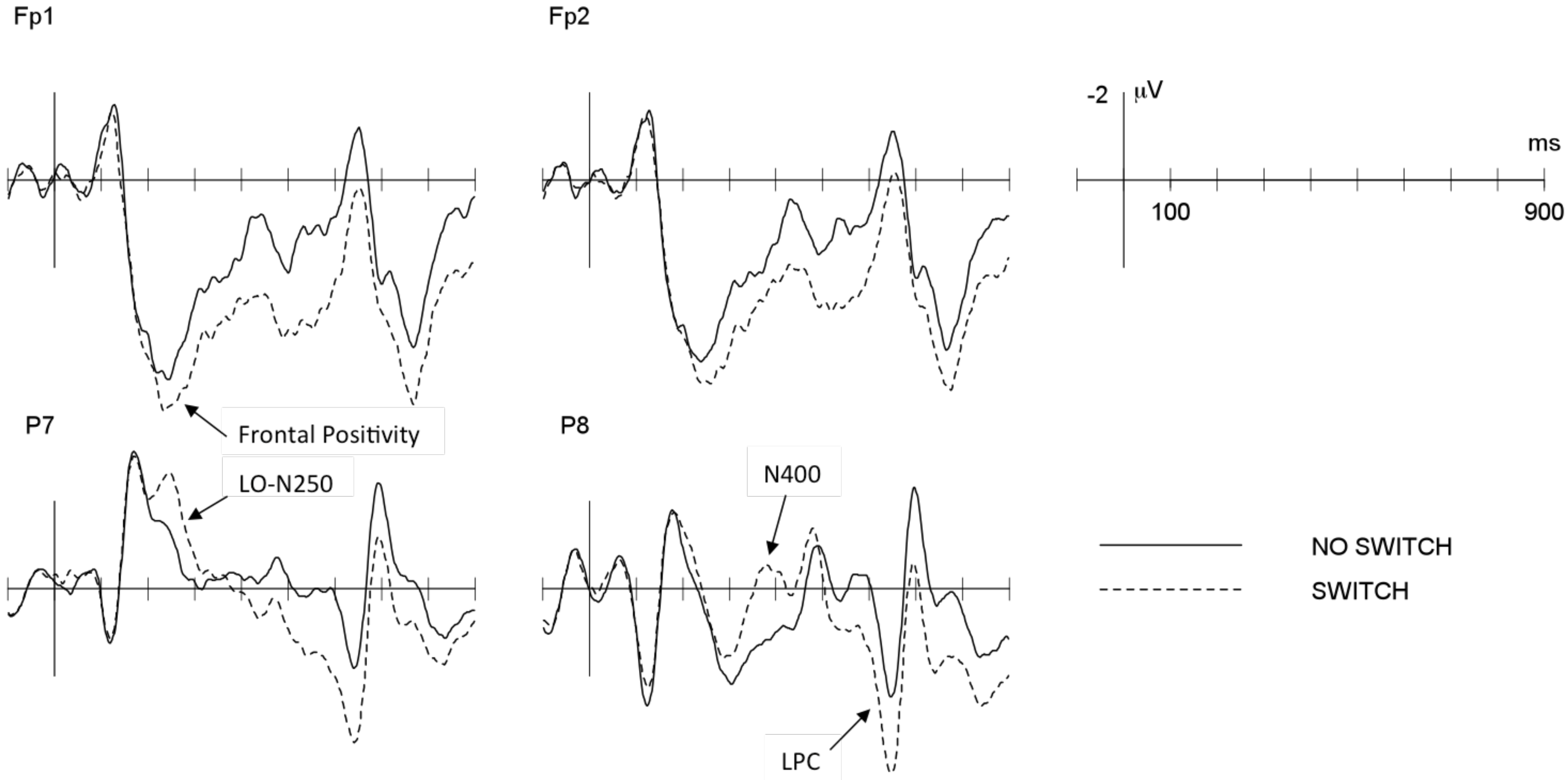

Figure 11. Grand average waveforms from data of all participants for the two experimental conditions (switching versus no switching), plotted in four representative electrodes, in which the main differences can be appreciated: Frontal Positivity, Left Occipital -N250, N400 and Late Positive Complex (LPC).

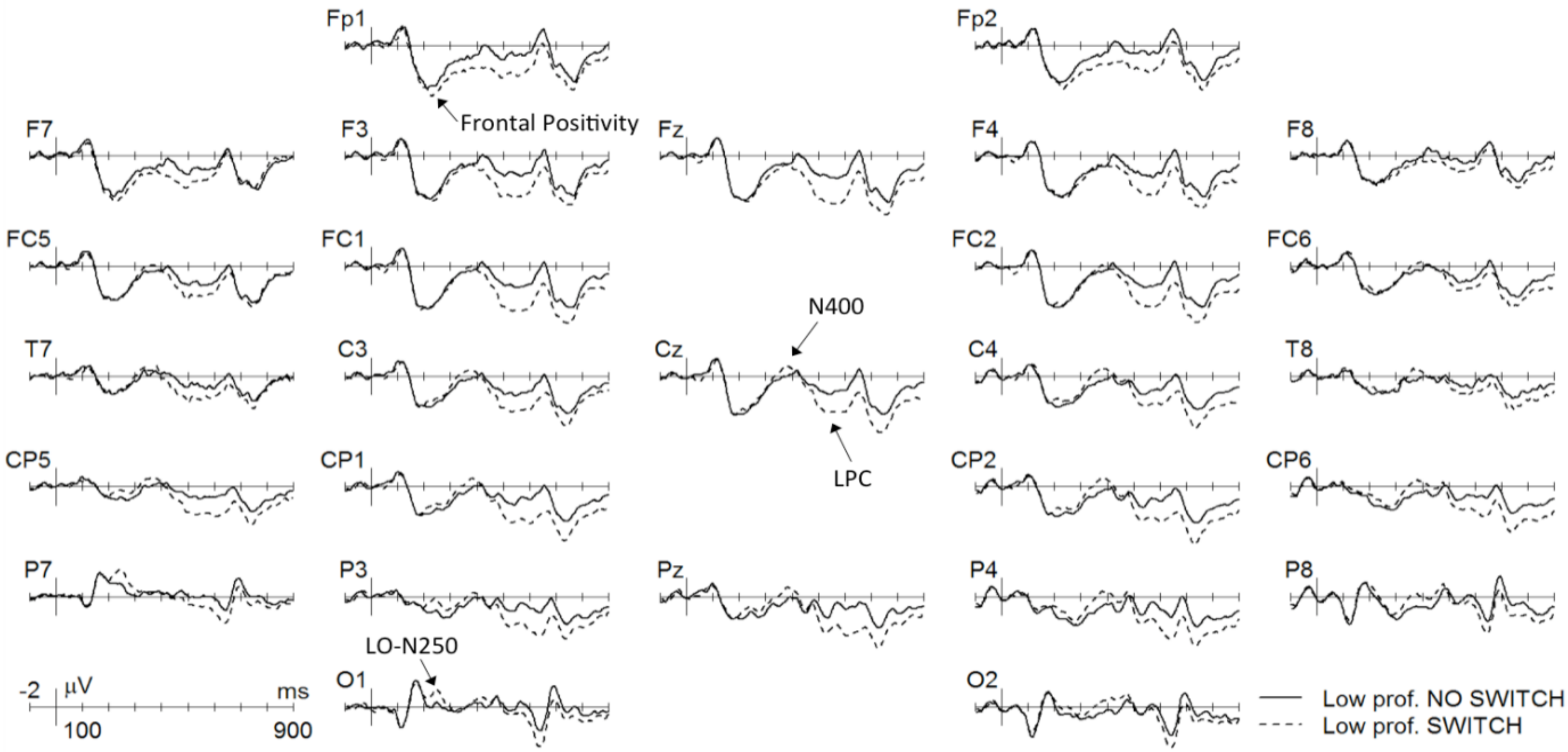

Figure 12. Grand average waveforms of the two conditions (switching versus no switching) for the Low proficiency group.

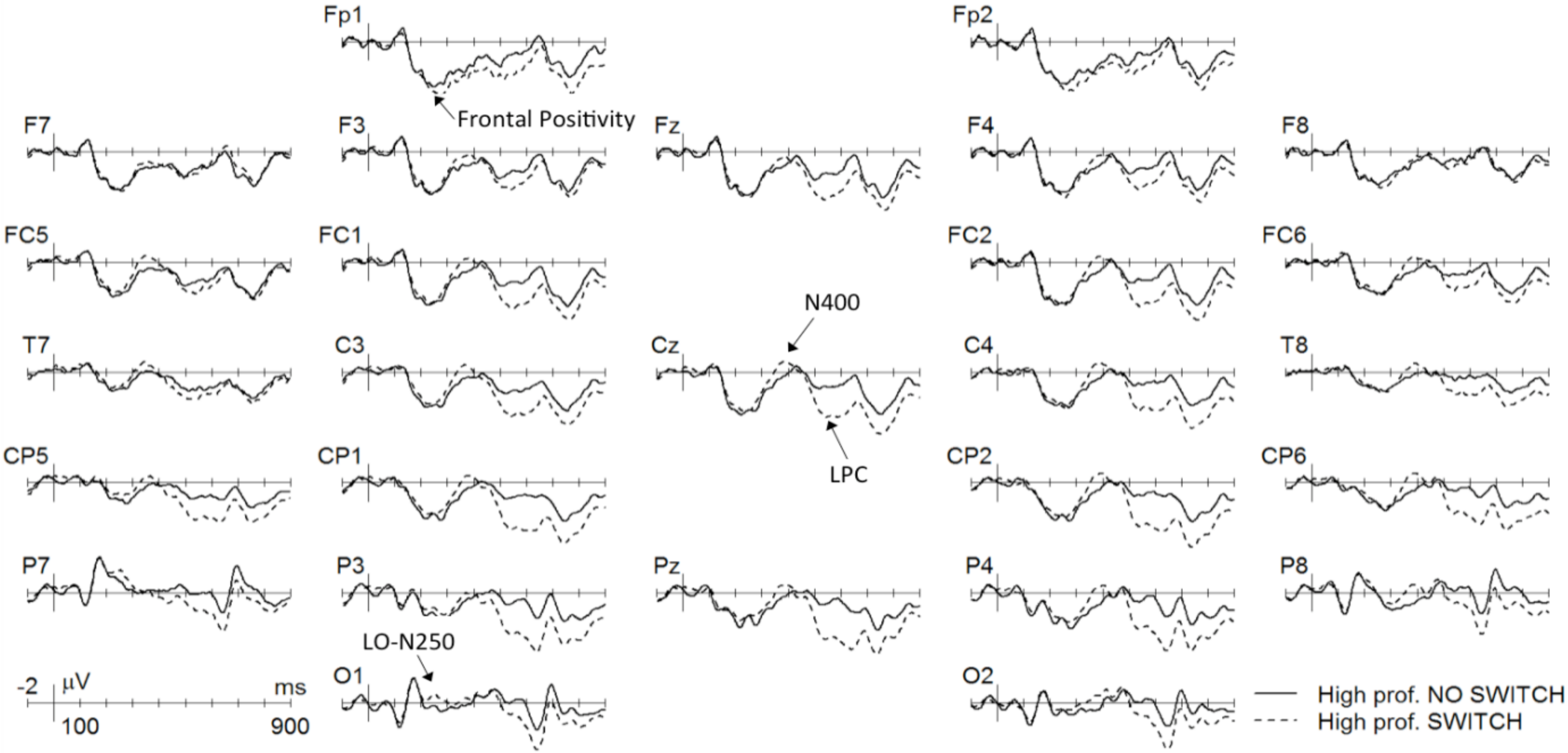

Figure 13. Grand average waveforms of the two conditions (switching versus no switching) for the High proficiency group.

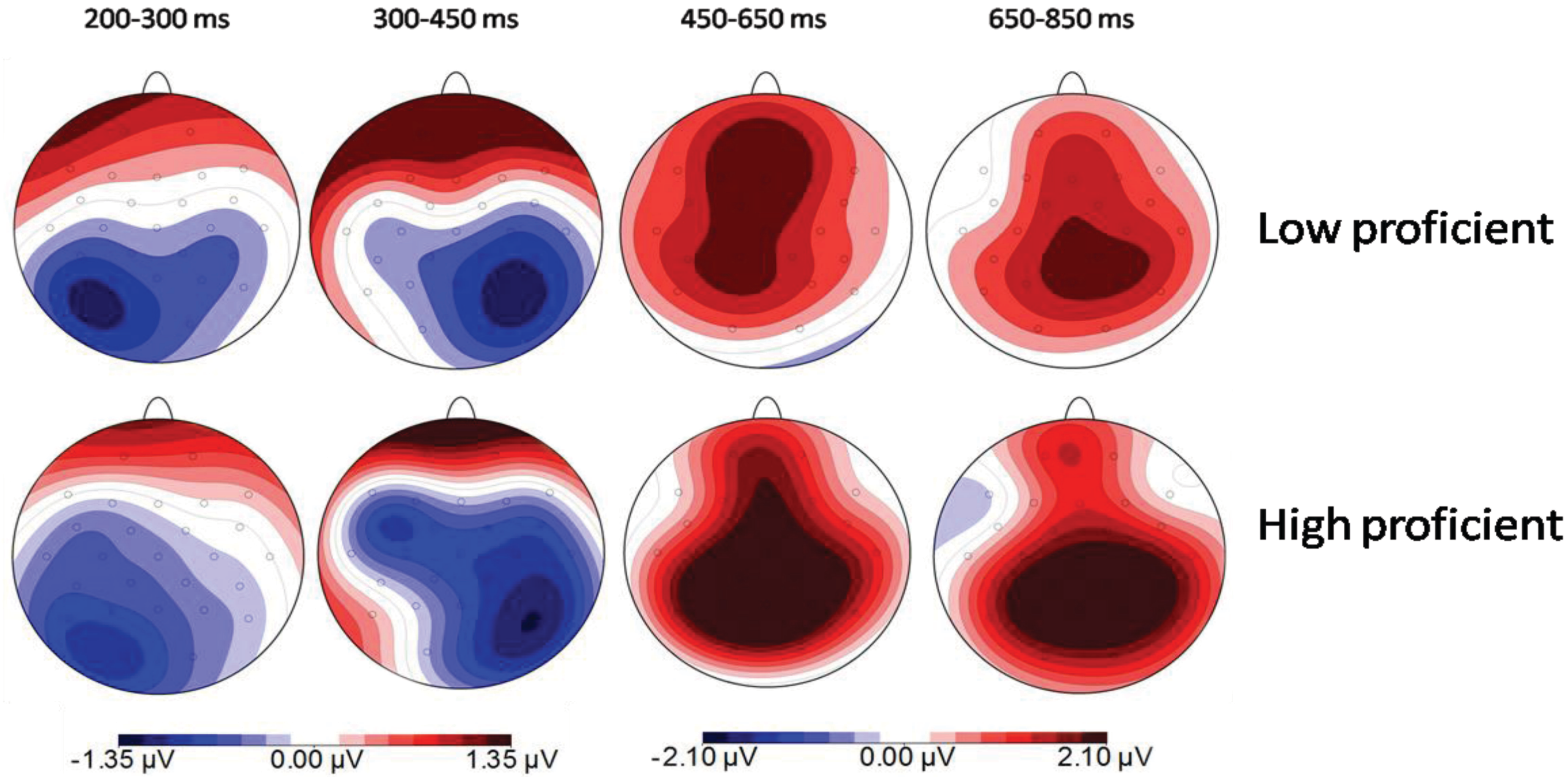

Figure 14. Topographical distribution of the language switching effects by group (high and low proficiency) in the four analysed temporal windows: 200-300, 300-450, 450-650 and 650-850 ms. Voltage maps were obtained for the averaged values of difference waves (switching minus no switching).

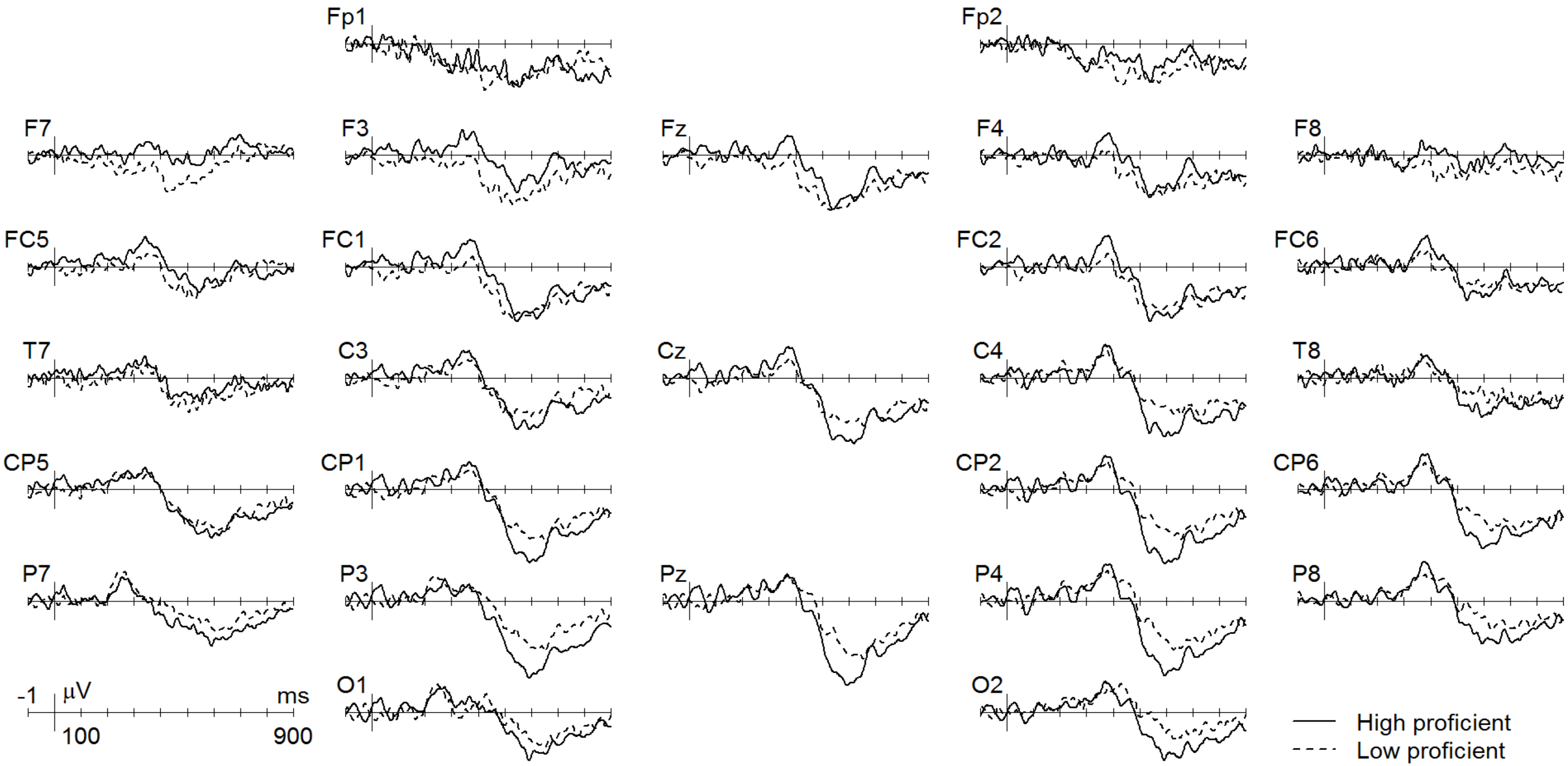

Figure 15. Difference waveforms of the High proficiency group versus the Low proficiency group; obtained by subtracting the no switch condition from the switch condition.

Time window between 200 and 300 ms

The ANOVA (PROFICIENCY x SWITCH x HEMISPHERE x AP) on the mean amplitudes of four occipito-parietal electrodes (O1, O2, P7, and P8) resulted in a main effect of SWITCH ($F(1,34)=23.9$; $p<0.001$), an interaction between SWITCH and HEMISPHERE ($F(1,34)=11.72$; $p<0.01$). 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 X SWITCH X HEMISPHERE X AP) including four frontal and prefrontal electrodes (Fp1, Fp2, F3 and F4). This ANOVA resulted in a two-way interaction between SWITCH and AP ($F(1,34)=16.04$; $p<0.001$). The absence of interactions with the factor PROFICIENCY in this time window shows that CS affected ERPs independently of the level of L2 proficiency.

Time window between 300 and 450 ms

The ANOVA (PROFICIENCY x SWITCH x HEMISPHERE x AP x DM) showed a main effect of SWITCH ($F(1,34)=7.60$; $p<0.01$), interaction effects of SWITCH with HEMISPHERE ($F(1,34)=11.2$; $p<0.01$) SWITCH with AP ($F(4,136)=8.64$; $p<0.001$; $W=0.02$, $GG\varepsilon=0.35$). There are also three-way interactions of SWITCH with HEMI with AP ($F(4,136)=19.57$; $p<0.001$; $W=0.09$, $GG\varepsilon=0.47$), and PROFICIENCY with SWITCH with AP ($F(4,136)=3.05$; $p< 0.05$; $W=0.02$, $GG\varepsilon=0.35$). Post-hoc test showed that the CS 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 Appendix 5.2.3). See Table 7 for mean amplitudes of the CS 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 x SWITCH x HEMI x AP x DM) showed a main effect of SWITCH ($F(1,34)=33.3$; $p<0.001$), interaction effects of SWITCH with AP ($F(4,136)=3.8$; $p<0.05$; W=0.01, GGε=0.34), SWITCH with HEMI ($F(1,34)=3.9$; $p<0.05$) and SWITCH with DM ($F(1,34)=26.4$; $p<0.001$). There are also three-way interactions of SWITCH with HEMI and AP ($F(4,136)=3.65$; $p<0.01$; W=0.19, GGε=0.58), and SWITCH with AP and DM ($F(4,136)=3.9$; $p<0.01$; W=0.38, GGε=0.66). 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 were also three-way interactions of PROFICIENCY with SWITCH with AP ($F(4,136)=3.5$; $p<0.05$; W=0.01, GGε=0.34) and PROFICIENCY with SWITCH with HEMI ($F(1,34)=3.9$; $p<0.05$). Post-hoc test showed a difference in the distribution of the LPC for the High and Low proficiency groups (see Appendix 5.2.3). It 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 7 for mean differences of both groups separately.

Table 7. ***Mean difference in microvolt (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 x SWITCH x HEMI x AP x DM) in this time window showed a main effect for SWITCH ($F(1,34)=36.95$; $p<0.001$), and the interaction effects of: SWITCH with HEMI ($F(1,34)=7.61$; $p<0.01$), SWITCH with AP ($F(4,136)=10.83$; $p<0.001$; $W=0.01$, $GG\varepsilon=0.34$), and SWITCH with DM ($F(1,34)=22.76$; $p<0.001$). Additionally, two triple interactions were revealed: SWITCH with HEMI with DM ($F(1,34)=7.28$; $p<0.01$) and SWITCH with AP with DM ($F(4,136)=3.05$; $p<0.05$; $W=0.28$, $GG\varepsilon=0.59$). Post-hoc tests reveal that CS 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.

3.3.4. Discussion

In this experiment we investigated CS from L2 to L1 during sentence reading. Event-related potentials 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 a LO-N250 effect. Also starting at 200 ms, a prefrontal positivity distinguished switches from the non-switches. 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 CS 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 LO-N250 reported in Experiment 2 with L1→L2 switches, was also observed in the present experiment with switches in the opposite direction. In both experiments the effect showed the same characteristics in onset, scalp distribution and duration. Therefore the neural computations that trigger this effect seem to be independent of CS direction. This fact is still consistent with our claim that the LO-N250 reflects either the detection of language specific orthographic regularities or the costs of switching between orthographic systems. Moreover, the LO-N250 would take place before the activation/integration of word meaning, which is consistent with the fact that it was independent of the later N400 effect and the level of proficiency of the participants. Also as in the L1→L2 CS of Experiment 2, around 200 ms after stimulus onset, and simultaneously to the onset of the LO-N250, a positivity in response to language switching started at the prefrontal electrodes and continued until the end of the analyzed segment. In experiment 2, this positivity was visible also at some central electrodes, but in this experiment that distribution was probably modulated due to overlap of other effects with the opposite polarity. Therefore, the results confirmed that this frontal positivity is also independent of CS direction.

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 300 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, Vergara & Carreiras, 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, Holcomb & Grainger, 2009a).

Negativities in this same time window but with left frontal distributions (LAN) have been linked to working memory load and syntactic parsing operations (Kluender & Kutas, 1993; Friederici, et al. 1993; Barber & Carreiras, 2005). Moreno et al. (2002) reported a left anterior negativity but not a N400 effect in response to CS 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.

As in Experiment 2, CS 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. 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 processes differed depending on the level of competence in the second language.

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, 2010). 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.

Proficiency effects aside, the results of the present experiment (L2→L1 CS effects) replicated the results of the previous experiment (L1→L2 CS effects): a LO-N250 effect, a long lasting frontal positivity and a LPC. Additionally, in the present experiment, a N400 effect was found for L2→L1 CS, a result that was not observed for the L1→L2 CS in sentences. This effect therefore depended on CS direction and we interpreted it as a consequence of the lexical activation costs derived from the inhibition of the non-used language, inhibition that would be larger for the dominant than the non-dominant language. Therefore, these results of the sentence experiment is highly consistent with that of the word pairs experiment; CS effects resulted in a N400 effect only when switching from L2 to L1, both in sentences and in minimal phrases.

3.4. GENERAL DISCUSSION

In three different ERP experiments we studied the electrophysiological correlates of CS; In an experiment with word pairs composing minimal noun phrases in which CS was studied in both directions, and in two sentence experiments in which we looked at the two switching directions separately. In addition, in the sentence experiments we also studied the influence of two important variables for this topic; the amount of sentential context and the L2 proficiency level of the participants. The results of the three experiments showed a coherent picture of the different ERP effects that allowed us to track the time course of the cognitive operations triggered by CS.

First of all, two types of positivities were defined in the three experiments. Although these two positivities showed some degree of temporal overlapping, they were distinguished attending to their scalp distribution and sensitivity to some experimental variables. The initial phase of this positivity showed a fronto-central distribution, whereas the second phase is larger at posterior areas. In Experiment 1, these positivities were not visible in the L2→L1 switching direction, maybe due to the overlapping with a larger effect with the opposite polarity. In Experiment 2, the positivity at late latencies was affected by the position in the sentence in which the CS took place. And finally, in Experiment 3, the level of L2 proficiency of the participants modulated the last segment of the positivity at posterior areas. We have associated these two positivities with the group of components or subcomponents related to the P3 component. The fronto-central positivity could be related with the detection of unexpected or infrequent events and the atentional resources recruited for the processing of the novel event and the subsequent context updating. This context updating in the working memory would modulate the LPC, and could involve integration and reanalysis operations (as described for the P600 effects). It is important to note, that the peak of the P3 component is delayed several hundred of milliseconds in language processing experiments (Kutas, McCarthy & Donchin, 1977). In our data, the fronto-central positivity starts very early, as soon as the orthographic information is available. However, the updating or integration/reanalysis processes associated to the LPC cannot start until much of the semantic and syntactic information is available. One important characteristic of this interpretation is that the cognitive processes associated to these positivities are not language specific and would be more related with general functions of the executive system. We will discuss below the theoretical implication of this claim, but at this point is worth mentioning a different line of research that has also described ERP effects of language switching associated to executive control. In several studies Fornells and colleagues (see review in Rodriguez-Fornells, 2006) have reported fronto-central negativities associated to cognitive control and inhibitory effects in bilinguals. For example, they reported a fronto-central negativity related to cross-language interference effects in Go/no-Go experiments (Rodriguez-Fornells, 2002), which was interpreted as a N2 component, a non-language specific component linked to response inhibition (Folstein & Van Petten, 2008). Moreover, they also reported a long-lasting midfrontal component after 400 ms that they claim to reflect the amount of cognitive control required to process a specific task in one language (Rodriguez-Fornells, 2006). Although the experimental design and tasks of those studies are not directly comparable with those used in the present study, it is an open question if the ERP effects of both lines of research, even showing different polarity, could be the manifestation of similar cognitive operations and share common neural sources.

The two sentence experiments (experiments 2 and 3) show a LO-N250 in response to CS, and this effect was independent of reading direction. Attending to its latency (before the lexico-semantic processes that modulate the N400) and characteristic scalp distribution, we have proposed that LO-N250 reflects either the detection of language specific orthographic regularities or the costs of switching between orthographic systems. Therefore this effect would support those models in which language selection can benefit from lower level characteristics of the input like orthographies regularities (Dijkstra & Van Heuven, 2002). This interpretation conveys that CS costs occur also at early stages of the visual word recognition process.

Our results have shown also a N400 effect in response to CS. This effect could be critical in our groups of non-balanced bilinguals because according to the RHM (Kroll & de Groot, 1997; Kroll & Stewart, 1994), 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 depending 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. The N400 effect was observed only when switching from L2 to L1 but not in the opposite direction, and this was true for word pairs (Experiment 1) and sentences (experiment 3). We interpreted the CS N400 effect as reflecting the activation costs of 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. These models argue for the existence of some kind of top-down or more local inhibitory mechanisms that enable the deactivation or partial suppression of the language not in use (Dijkstra & van Heuven, 1998, 2002; Green, 1986, 1998). Behavioral research has suggested that access to the non-dominant language representations requires greater inhibition of the dominant language, than the inverse situation (e.g. Meuter & Allport, 1999). This difference in the amount of inhibition to suppress one or the other language, would explain our direction effect in the N400 component. The N400 would be larger after L2→L1 switches because the L1 would be more inhibited and consequently the meaning activation would be more costly.

In addition to the N400 effect, the group with higher proficiency in L2 also showed a LAN effect. The same effect was also reported in the study of Moreno et al. (2002) with balanced bilinguals (but in this latter case without the N400 effect). Considering that the LAN has been usually linked to syntactic processing, our LAN effect could reflect the higher level of automatization of some integration processes when proficiency increases. In any case, the modulation of the distribution of the negativities and the subsequent positivities confirm the importance of proficiency in the study of bilingualism in general and CS in particular.

To sum up, we can conclude from our three ERP experiments that CS affect at different levels and at several steps during the time course of the comprehension process. Effects started very early after the presentation of the target when the first decoding operations start, and continue until late latencies in which meaning integration and global interpretation take place. Some theoretical models stress the role of the general executive system in the interpretation of the costs derived from CS (Macnamara & Kushnir, 1971;

Bialystok, 2001). On the other hand, other models have proposed language specific mechanisms that would determine cross-language selection and CS effects (Dijkstra & van Heuven, 1998, 2002; Green, 1986, 1998). Our results showed ERP effects associated to general cognitive control operations, like atentional or inhibition processes (fronto-central positivity and LPC). However, and in contrast to data that suggest that CS costs take place only at a decision-related stage (e.g., Thomas & Allport, 2000; Moreno et al., 2002), the present results show that, at least at some stages of second language learning, language switching during sentence reading affects several levels of linguistic processing, including early orthographic/phonological processing and lexico-semantic processing (LO-N250 and N400). Finally, the interaction of the CS N400 effect and the switching direction is consistent with those models that propose inhibition mechanisms in the selection of the intended language, and the need of greater inhibition for the dominant than for the non-dominant language (Green, 1998).

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5. APPENDIXES

5.1. Stimuli

5.1.1. Experiment 1

angle	lamp	soul	heart	wave
brain	life	tooth	miracle	wood
cotton	rule	wine	nerve	brother
elbow	shadow	allergy	poison	father
garden	shower	bell	roof	bishop
hammer	spaceship	cage	shoulder	jogger
heaven	whale	cloud	soap	nephew
nurse	ankle	curve	sport	cousin
mirror	mother	frog	travel	dressing
result	bridge	head	year	couch
shark	farmer	jewel	bay	coffee
smell	soldier	letter	blood	cowboy
sock	crab	page	capacity	nest
suit	fear	sauce	cross	friend
wind	garlic	sheet	drug	king
address	hate	snake	grave	aunt
beard	kiss	star	hour	girl
butter	month	wisdom	lettuce	dancer
carpet	oven	bone	reason	sister
crown	daughter	cork	seed	niece
flag	river	drawing	jungle	guide
happiness	shoe	fork	shop	nun
island	smoke	glove	song	grape

praise
dawn
queen
shape

abeja
aldea
brisa
carga
crema
chispa
hormiga
medida
naranja
onda
pera
pulsera
receta
sala
vaca
estornudo
litro
peinado
fármaco
pedazo
puño
tesoro
casco

ahorro
hierro
abrigo
tiro
consejo
patio
peso
aceituna
boca
broma
cera
cuenta
feria
judía
mejilla
nevera
paloma
plaza
queja
regla
siesta
vista
alfabeto
muslo
trapo
caldo
velo
rasgo

pulso
mérito
tejido
acento
estadio
trato
mito
aumento
conjunto
acera
botella
invasión
caña
compra
cueva
flauta
manta
obra
pantalla
prensa
rebaja
rosa
tapa
zona
adorno
trigo
trono
lavabo

tronco
vicio
embarazo
pago
trozo
saco
desnudo
voto
polvo
tono
siglo
altavoz
delfín
almacén
pensión
alacrán
arroz
cisne
paraguas
pastel
caracol
reloj
norte
cine
corriente
mente
pared
raíz

fiebre
oración
unidad
carne
mitad
cárcel
fuente
nave
miel
mosca

5.1.2. Experiment 2

El cheese estaba rico pero olía mal.

El background es rojo con letras verdes.

El desire era obvio para mis amigos.

El market es barato y tiene de todo.

El closet está polvoriento y nos hace toser.

El egg estaba grasiento y demasiado salado.

El price era elevado y exagerado.

El government era justo y ecuánime.

El bird era molesto pero estaba protegido.

El tree estaba frondoso y tenía fruta.

El day era perfecto para una excursión.

El castle estaba oscuro y les dio miedo.

El summer fue caluroso y lo pasamos bien.

El love era idílico y perdido en el tiempo.

El place es sofisticado y hay que reservar.

El sound es lejano pero se está acercando.

El turkey está tierno y relleno con almendras.

El increase fue significativo pero insuficiente.

El finger estaba hinchado y necesitaba cuidados.

El pocket estaba roto y perdí el móvil.

El game será tenso hasta el último momento.

El arm está herido y me duele.

El hair era rizado y teñido de rubio.

El book es grueso y me aburrió.

El lake estuvo helado durante todo el invierno.

El winter fue frío y había nevado.

El field estaba inundado por la riada.

El flight estaba repleto de turistas Británicos.

El job era diplomático y requería tacto.

El message era largo y sin sentido.

El end era estúpido e inesperado.

El circus era gracioso y tenía muchos acróbatas.

El sky estaba claro y azul hasta el horizonte.

El mouse era minúsculo y se escapó.

El topic estaba prohibido por lo que era atractivo.

El necklace era único y muy caro.

El train era lento y provocó retrasos.

El cigarette era fino y con sabor mentolado.

El dream era absurdo y me dejó temblando.

El hole era profundo y estaba lleno de agua.

La chain era metálica pero no aguantó el peso.

La answer fue satisfactoria y rápida.

La light llegó inesperada y nos sorprendió.

La stone era dura y hubo que trocearla.

La shirt está vieja y manchada.

La fall fue dramática pero no produjo heridas.

La live era tediosa aunque muy saludable.

La rain era continua y nos refugiamos.

La window estaba empañada por la humedad.

La date fue desastrosa y terminó temprano.

La voice era aguda y me molestaba.

La scarf es abrigada y luce elegante.

La milk estaba cortada y con grumos.

La sheep era negra y con mucha lana.

La sculpture era fea y sin sentido.

La city era cálida y tenía historia.

La key estaba gastada y no abrió la puerta.

La movie era mala pero bastante entretenida.

La cherry estaba madura y perfecta para cocinarla.

La table fue decorada por un artista.

La mountain era empinada y muy peligrosa.

La blouse estaba manchada y necesitaba lavarse.

La flower estaba marchita después de la sequía.

La tray era antigua y una pieza de coleccionista.

La moon estaba llena y celebramos una fiesta.

La wheel estaba inflada y no estaba pinchada.

La street está desierta cuando llueve.

La picture fue seria y todos salieron rígidos.

La candle era cuadrada y ligeramente perfumada.

La garbage estaba podrida y el olor era repugnante.

La apple está jugosa y sabe bien.

La race fu0e fantástica pero muy complicada.

La chair es cómoda y con una textura suave.

La capacity es limitada pero adecuada por ahora.

La branch era peligrosa y la podaron.

La sword estaba afilada y era mortal.

La food era vegetariana y baja en calorías.

La beach estaba arenosa y encontré muchos cangrejos.

La butterfly estaba moribunda y aleteando.

La laugh era histérica y sonaba falsa.

La chaqueta era leather como era la moda.

La boda fue beneficial para la familia Borgia.

La almohada era thin y me gustó.

La bebida era alcoholic y con mucho sabor.

La atmósfera era overwhelming y casi me desmayo.

La cerveza estaba foamy y sabía bien.

La ayuda fue fruitful porque han trabajado mucho.

La taza es delicate y no quiero romperla.

La amistad era genuine y la apreció sinceramente.

La entrada era small y ligeramente claustrofóbica.

La batalla fue short pero muy sangrienta.

La caja está flat porque la escachamos.

La compañía fue malicious y me arruinó.

La cortina era transparent y hecha a mano.

La fábrica estaba closed por razones de salud.

La casa estaba furnished y era acogedora.

La cuchara era silver pero no era de plata.

La clase era boring y nos dormimos.

La falda era posh y elegante.

La iglesia es silent y está poco concurrida.

El fuego fue destructive y difícil de apagar.

El loro es rude y muy escandaloso.

El curso era intense pero nos encantó.

El palacio es beautiful y tiene muchos visitantes.

El salto fue daring y resultó espectacular.

El nombre es exclusive y diferente.

El diseño es discrete y con detalles sutiles.

El vestido es expensive y de buena calidad.

El coche era fast pero consume demasiado.

El papel está torn y no sirve para pintar.

El bicho estaba adapted a este clima.

El sol estaba hidden tras las nubes.

El lápiz estaba blunt pero todavía servía.

El tigre estaba angry y enseñaba los dientes.

El gato estaba fat y roncaba feliz.

El enemigo era spiteful y todos lo temían.

El razonamiento fue suggestive pero equivocado.

El conejo era white y con manchas negras.

El viaje fue incredible de principio a fin.

El clima era sunny y muy agradable.

La tierra estaba contaminada y no it pudo usar.

La perla fue robada porque era famous.

La puerta estaba pintada con flores.

La nariz estaba morada porque le hit.

La hoja estaba seca y muerta since tiempo.

La granja era productiva y natural.

La concha era rosada y brillante.

La esperanza era pequeña pero nos encouraged.

La bicicleta está oxidada pero funciona well.

La maleta era rígida y de colour azul.

La roca era rugosa y tenía fungus.

La cama estaba rota desde ayer.

La gota estaba líquida pero se dried rápidamente.

La noche fue romántica e inolvidable.

La peluca era rubia y lacia.

La costa era linda y estaba nearby.

La burbuja fue pinchada con una needle.

La cebolla es sana y el garlic también.

La toalla era sedosa y muy soft.

La pastilla era segura y muy popular.

El osito estaba usado y le missed un ojo.

El juguete era nuevo y tuvo success.

El hielo está derretido y puede break.

El desayuno era delicioso pero no very abundante.

El cuchillo estaba sucio y tuve it fregarlo.

El perro es cariñoso y muy obedient.

El ritmo era contagioso y muy lively.

El mono era curioso y estaba alert.

El zumo era ácido y le added azúcar.

El grito fue doloroso y expresaba my sentimientos.

El mar estaba tranquilo y gris that tarde.

El globo estaba rodeado de jóvenes.

El imán era colorido y me liked.

El bolígrafo es amarillo con adornos childish.

El caballo estaba suelto en el field.

El colchón estaba preparado para su visit.

El anillo era dorado con brillantes.

El cristal estaba estallado por un side.

El sobre estaba vacío y faltaba money.

El ejemplo es clásico y me helps a entenderlo.

5.1.3. Experiment 3

The shirt you wear daily is *old* and needs cleaning.

This voice I can hear is *high-pitched* and bothers me greatly.

The scarf I prefer wearing is *warm* and looks elegant.

The life we live here is *active* and very healthy.

The milk that I drank was *sour* with some lumps.

The sheep that was lost was *black* and very sweet.

The faith that I have is *absolute* and comforts me.

The look they gave me was *filthy* so I turned away.

The sculpture I looked at was *ugly* and defied meaning.

The city I love most is *lively* and historically important.

The key you gave me was *worn* and didn't open the door.

The novel currently on sale is *bad* but entertaining enough.

The cherry that I picked was *ripe* and perfect for baking.

The table, we sat at was *decorated* by an artist.

The mountain that they climbed was *steep* and extremely dangerous.

The hotel we stayed in was *basic* but very pleasant.

The blouse I lent you was *stained* and needs washing.

The flower that I picked was *shrivelled* after a day.

The tray that was priced was *antique* and a collector's item.

The moon we saw yesterday was *full* and we had a party.

The wish that I made was *obvious* to my friends.

The market where we shop is *cheap* and has everything.

The wardrobe we never use is *dusty* and makes us cough.

The egg that I ate was *greasy* and too salty.

The price that we paid was *costly* and incorrect.

The government in office there was *lenient* and just.

The bird I heard singing was *annoying* and, unfortunately, protected.

The tree that grows here is *leafy* and bears fruit.

The day that we chose was *perfect* for the trip.

The castle they went into was *dark* and it frightened them.

The object I found here was *round* and looked familiar.

The moment that we shared was *perfect* but lost forever.

The restaurant where we dined is *exclusive*, and we had to reserve.

The sound you can hear is *distant* but coming closer.

The turkey we ate yesterday was *tender* and sweetened with almonds.

The love I longed for was *precious* but impossible.

The eclipse that we saw was *unheard-of* in this region.

The finger that I hurt was *swollen* and needed care.

The secret that was unravelled was *intriguing* but also dangerous.

The match I saw yesterday was *tense* until the last moment.

The school that was criticised was *private* and used selection criteria.

The banana I ate yesterday was *tasty* and soft.

The basket that I carried was *charming* and was handmade.

The part we need urgently is *hollow* but strong enough.

The outfit I wore then was *unsuitable* for the occasion.

The intervention that was planned was *necessary* but constantly delayed.

The shell that we found was *salty* from the ocean.

The purse I lost there was *gold* with a clip.

The puppy we gently stroked was *playful* but rather nervous.

The visit they promised me was *quick* but very pleasant.

The diet which we tried was *horrible* but successful.

A short exercise session is as *effective* as a long workout.

The news that we received was *discouraging* and worried me.

The doll that we saw was *pretty*, with cute clothes.

The pole that was used was *long* but easy to carry.

The reaction you gave me was *startling* and not what I expected.

The grass that was planted was *healthy* and started growing.

The command they gave them was *confusing* and barely audible.

The lock that we opened was *creaky* and needed oiling.

The disco that opened recently is *modern* and already popular.

The stone I stepped upon was *hard* and hurt me.

The circle that I drew was *neat* and showed skill.

The chicken that we ate was *spiced* with curry sauce.

The apartment we moved into was *clean* with high ceilings.

The date that was arranged was *disastrous* and finished early.

The background used the most is *violet* with green letters.

The increase that was given was *significant* but not sufficient.

The pocket of my trousers was *perforated* and my mobile fell through.

The job that I had involved *diplomacy* and required tact.

The examination that we underwent was *invasive* but done with care.

The fall of the Berlin wall was *foreseen* and celebrated nationwide.

The faculty we studied at is *conservative* and only open to men.

The cheese we were eating was *tasteless* and rubbery.

The material we sell best is *printed* and of high quality.

The sun we were watching was *sinking* below the horizon.

The path we walked down was *overgrown* and endless.

The field we walked trough was *damp* because of the rain.

The lounge we were shown was *mucky* and caused consternation.

My favourite swimming shorts are too *small* but have an awesome design.

The place they gave us is *bright* and cheerful in style.

The wheel that we inspected was *inflada* and showed no punctures.

This street we walked today was *desierta* when it rained.

The photo taken, made everyone look *seria* and they seemed stiff.

The candle I blew out was *cuadrada* and lightly scented.

The bag used for shopping is *mona* and easy to carry.

An apple that grows naturally is *jugosa* and tastes better.

The career I have now is *fantástico* but very complex.

The chair I sit on is *cómoda* and has a soft texture.

The capacity that is available is *limitada* but adequate for now.

The branch we hung on was *peligrosa* and started breaking.

The sword he polished carefully was *afilada* and therefore dangerous.

The radio I listen to is *típica* of the sixties.

The beach we went to was *arenosa* and covered with little crabs.

The butterfly that was caught was *moribunda* and withering.

The laughter that we heard was *histérica* and sounded false.

The jacket I was wearing was *ajustada* and very trendy.

The conversation they had together was *beneficiosa* for their cooperation.

The pillow I slept on was *ligera* but I like that.

That drink you gave me was *alcohólica* and nicely flavoured.

The atmosphere that surrounded us was *arrolladora* and I nearly fainted.

The arm I use most is *herido* and hurts me.

1The hair I picked up was *rizado* and not mine.

The book we study from is *grueso* and annoys me.

The ministry where we worked was *tedioso* but very busy.

The lake we looked for was *helado* so we went home.

The winter we spent there was *frío,* wet and snowy.

The disk that was recovered was *torcido* but still useful.

The flight that was delayed was *repleto* with British tourists.

The tea that was served was *flojo* and had no taste.

The message we had missed was largo and didn't make sense.

The end that I wrote was estúpido and irrelevant.

The circus that we visited was *gracioso* with lots of acrobats.

The crime that they committed was *horrendo* according to the prosecutor.

The mouse, which you killed was *minísculo* and had babies.

The topic we spoke about was *prohibido* and therefore intriguing.

The necklace they gave me was *único* and very pricey.

The train we took today was *lento* and caused delays.

The cigar that smelled sweet was *fino* and cost more.

The dream that I had was *loco* and left me trembling.

The hole that was dug was *profundo* and filled with water.

The beer we are drinking is *espumosa* and tastes good.

The aid that was provided was *fructífera* because they worked hard.

The cup that I broke was *delicada* and belonged to my grandmother.

The friendship that we shared was *genuina* and I cherished it.

The entrance we went through was *estrecha* and slightly claustrophobic.

The crowd that surrounded us was *exaltada* and demanded justice.

The democracy we have here is *falsa* and represses us.

The struggle I went through was *dura* but worth it.

The box you're looking for is *plana* because we squashed it.

The company that didn't pay was *maliciosa* and left me bankrupt.

The association we belong to is *insólita* but quite popular.

The idea that we had, was *encantadora* but difficult to implement.

The factory where we work was *clausurada* for health reasons.

The house I looked at was *amueblada* and felt cosy.

The spoon that we used was *plateada* and very valuable.

The class we attended yesterday was *aburrida* so we fell asleep.

The skirt I was wearing was *pija* and very elegant.

The division they were in was *competitiva* and they had to win.

The agency that we hired was *cumplidora* and worked efficiently.

This brand I always buy is *conocida* and very reliable.

The judgement that was reached was *merecido* and pleased the audience.

The parrot that talks loudly is *grosero* and looks goofy.

The course that we took was *intensivo* but we loved it.

The palace that was redecorated is *hermoso* and has many visitors.

The jump they made there was *osado* and looked spectacular.

The calendar they gave us was *exclusivo* and quite unusual.

The design I really love is *discreto* with subtle details.

The dress I bought there was *barato* but of good quality.

This car that I drove was *rápido* but still safe.

The paper used for wrapping was *rasgado* and didn't cover the parcel.

The bug I just squashed seemed *pequeño* but is dangerous.

The lighthouse we visited yesterday is *conocido* for its view.

The pencil I wrote with was *despuntado* but still useful.

The tiger that was captured was *enfedado* and paced up and down.

The cat I looked after was *gordo* and snored happily.

The enemy I fear most is *malvado* and incredibly mean.

The reasoning that was used was *sugestivo* and misleading.

The rabbit I was watching was *peludo* and looked sweet.

The journey that we made was *maravilloso* from beginning to end.

The weather we hoped for was *seco* and sunny.

5.2. ADDITONAL STATISTICAL RESULTS

Abbreviations:
SS: Sum of Squares
SSE: Error Sum of Squares
nDF: numerator Degrees of Freedom
dDF: denomenator Degrees of Freedom,
W: test value Mauchly
GGε: Greenhouse Geisser epsilon

5.2.1. EXPERIMENT 1

ARTICLE: THE – EL

Time window 100-500

ARTICLE x CHANNEL

ChannelEffect	nDF	dDF	F>=4		p<=0.05
Fz	Article	1	19	33.15	0.00002
Cz	Article	1	19	33.05	0.00002
Pz	Article	1	19	22.78	0.0001
FC2	Article	1	19	23.22	0.00009
CP2	Article	1	19	26.06	0.00006
Fp2	Article	1	19	32.63	0.00002
F4	Article	1	19	23.25	0.0001
C4	Article	1	19	18.59	0.0004
P4	Article	1	19	16.48	0.0007
FC6	Article	1	19	20.38	0.0002
CP6	Article	1	19	11.04	0.004
F8	Article	1	19	22.05	0.0002
T8	Article	1	19	15.76	0.0008
FC1	Article	1	19	27.94	0.00004
CP1	Article	1	19	29.19	0.00003
Fp1	Article	1	19	40.82	0.00000
F3	Article	1	19	37.63	0.00001
C3	Article	1	19	27.13	0.00005
P3	Article	1	19	12.08	0.003
FC5	Article	1	19	33.47	0.00001
CP5	Article	1	19	18.33	0.0004
F7	Article	1	19	35.16	0.00001
T7	Article	1	19	32,00	0.00002

ANOVA (ARTICLE: HEMI: DML: AP)

Univariate Type III Repeated-Measures ANOVA Assuming Sphericity

Efecto	**SS**	**SSE**	**nDf**	**dDf**	**F**	**Pr(>F)**
Article	209.18	132.14	1	19	30.08	2.7e-05 ***
Article:DM	17.66	13.91	1	19	23.13	9.7e-05 ***
Article:AP	20.97	40.54	4	76	9.83	1.8e-06 ***
Article:HEMI:AP	0.72	3.30	4	76	3.20	0.02 *
Article:DM:AP	6.18	5.47	4	76	21.45	7.1e-12 ***

Mauchly Tests for Sphericity and Greenhouse-Geisser Correction

	W	**P-VALUE**	**GGε**	**PR(>F[GG])**
Article:AP	0.01	0.000000	0.34	0.002 **
Article:HEMI:AP	0.04	0.000000	0.41	0.06 .
Article:DM:AP	0.14	0.00009	0.48	9.0e-07 ***

Signif. codes: '***' <0.001 '**'< 0.01 '*' <0.05 '.' <0.1

MAIN EFFECT ARTICLE

AVERAGE ARTICLE	**μV**
el	-0.2
the	0.8

TWO WAY INTERACTION

ARTICLE: AP
AVERAGE EFFECT ARTICLE IN EACH LEVEL OF ANTERIORITY

	FRONTAL	**FRONTAL.C**	**CENTRAL**	**CENTRAL.P**	**PARIETAL**
el	-0.9	-1.2	-0.2	0.4	1.0
the	0.4	0.1	0.8	1.5	1.4

AP	**EFFECT**	**T**	**DF**	**P**	**P.HOCHBERG**
FRONTAL	article	-6.09	19	1e-05	5e-05 ***
FRONTAL.C	article	-5.48	19	3e-05	9e-05 ***
CENTRAL	article	-5.73	19	2e-05	8e-05 ***
CENTRAL.P	article	-5.02	19	8e-05	0.0002 ***
PARIETAL	article	-1.95	19	0.07	0.07 .

ARTICLE: DM
AVERAGE ARTICLE IN EACH LEVEL OF DISTANCE TO MIDLINE

	Distance 1	**Distance 2**
el	-0.4	0.0
the	0.9	0.8

DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
DIST. 1	article	-5.44	19	3e-05 ***
DIST. 2	article	-5.42	19	3e-05 ***

THREE WAY INTERACTION

ARTICLE: DM: AP

Average effect of Article in each level of Anteriority with Distance to Midline

		FRONTAL	FRONTAL.C	CENTRAL	CENTRAL.P	PARIETAL
DISTANCE 1	el	-1.5	-1.9	-0.5	0.3	1.5
DISTANCE 2	el	-0.3	-0.5	0.0	0.5	0.5
DISTANCE 1	the	0.0	-0.5	0.8	1.7	2.5
DISTANCE 2	the	0.9	0.7	0.8	1.3	0.3

AP: DM	EFFECT	T	DF	P.HOCHBERG
FRONTAL DISTANCE 1	article	-5.76	19	2e-05 ***
FRONTAL DISTANCE 2	article	-6.12	19	2e-05 ***
FRONTAL.C DISTANCE 1	article	-5.2	19	5e-05 ***
FRONTAL.C DISTANCE 2	article	-5.8	19	2e-05 ***
CENTRAL DISTANCE 1	article	-5.03	19	7e-05 ***
CENTRAL DISTANCE 2	article	-6.75	19	0.000 ***
CENTRAL.P DISTANCE 1	article	-5.35	19	8e-05 ***
CENTRAL.P DISTANCE 2	article	-3.32	19	0.0004 ***

Signif. codes: ‘***’ <0.001 ‘**’< 0.01 ‘*’ <0.05 ‘.’ <0.1

SWITCH 1: L1→ L2

Time window 150-300

SWITCH x CHANNEL

Channel	Effect	nDf	dDf	F>=4	p<=0.05
Fz	Switch	1	19	9.56	0.006
Cz	Switch	1	19	6.09	0.02
FC2	Switch	1	19	8.26	0.01
Fp2	Switch	1	19	8.00	0.01
F4	Switch	1	19	9.89	0.005
C4	Switch	1	19	7.65	0.01
P4	Switch	1	19	5.82	0.03
FC6	Switch	1	19	9.29	0.007
CP6	Switch	1	19	5.09	0.04
F8	Switch	1	19	7.10	0.02
T8	Switch	1	19	9.43	0.006
FC1	Switch	1	19	11.65	0.003
Fp1	Switch	1	19	9.33	0.007
F3	Switch	1	19	15.16	0.001
C3	Switch	1	19	8.10	0.01
FC5	Switch	1	19	20.40	0.0002
F7	Switch	1	19	21.93	0.0002
T7	Switch	1	19	15.04	0.001
P7	Switch	1	19	5.62	0.03

ANOVA (SWITCH: HEMI: DM: AP)

Univariate Type III Repeated-Measures ANOVA Assuming Sphericity

	SS	SSE	nDf	dDf	F	Pr(>F)
Switch	120.86	219.88	1	19	10.44	0.004 **
Switch:AP	25.82	51.94	4	76	9.44	3.0 e-06 ***
Switch:HEMI:AP	4.89	17.70	4	76	5.24	0.0009 ***
Switch:DM:AP	4.47	13.38	4	76	6.35	0.0002 ***

Mauchly Tests for Sphericity and Greenhouse-Geisser Correction

	W	P-VALUE	GGε	PR(>F[GG])
Switch:AP	0.07	6.4e-07	0.43	0.001 **
Switch:HEMI:AP	0.06	1.6e-07	0.40	0.02 *
Switch:DM:AP	0.16	2.1e-04	0.50	0.004 **

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

MAIN EFFECT SWITCH

Average Switch μV	
No switch	1.5
Switch	2.3

TWO WAY INTERACTION

SWITCH: AP

Average Switch in each level of Anteriority

	FRONTAL	FRONTAL.C	CENTRAL	CENTRAL.P	PARIETAL
No switch	3.1	2.5	1.6	1.3	-1.0
Switch	4.3	3.6	2.4	2.0	-0.8

AP	EFFECT	T	DF	P.HOCHBERG
FRONTAL	switch	-4.45	19	0.001 **
FRONTAL.C	switch	-3.75	19	0.004 **
CENTRAL	switch	-3.80	19	0.004 **
CENTRAL.P	switch	-2.05	19	0.11
PARIETAL	switch	-0.68	19	0.51

Signif. codes: '***' <0.001 '**'< 0.01 '*' <0.05 '.' <0.1

THREE WAY INTERACTION

SWITCH: HEMI: AP

Average effect Switch in each level of Hemisphere with Anteriority

	FRONTAL	FRONTAL.C	CENTRAL	CENTRAL.P	PARIETAL
LEFT no switch	3.0	2.1	1.0	0.8	-2.0
RIGHT no switch	3.2	2.8	2.1	1.9	0.0
LEFT switch	4.3	3.3	1.8	1.3	-2.1
RIGHT switch	4.2	3.9	3.0	2.6	0.5

HEMI: AP	EFFECT	T	DF	P.HOCHBERG
FRONTAL LEFT HEMI	switch	-4.38	19	0.0006 ***

FRONTAL RIGHT HEMI	switch	-3.29	19	0.004 **
FRONTAL.C LEFT HEMI	switch	-4.1	19	0.001 **
FRONTAL.C RIGHT HEMI	switch	-3.1	19	0.006 **
CENTRAL LEFT HEMI	switch	-3.7	19	0.003 **
CENTRAL RIGHT HEMI	switch	-3.1	19	0.006 **
CENTRAL.P LEFT HEMI	switch	-1.7	19	0.11
CENTRAL.P RIGHT HEMI	switch	-2.2	19	0.08 .
PARIETAL LEFT HEMI	switch	0.4	19	0.68
PARIETAL RIGHT HEMI	switch	-1.5	19	0.28

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: DM: AP
Average effect Switch in each level of Anteriority with Distance to Midline

	FRONTAL	FRONTAL.C	CENTRAL	CENTRAL.P	PARIETAL
DIST. 1 no switch	2.8	2.7	2.1	2.3	1.0
DIST. 2 no switch	3.4	2.3	1.1	0.4	-3.0
DIST. 1 switch	4.0	3.8	3.0	3.0	1.6
DIST. 2 switch	4.5	3.3	1.8	0.9	-3.2

AP: DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
FRONTAL DISTANCE 1	switch	-3.7	19	0.001 **
FRONTAL DISTANCE 2	switch	-5.0	19	0.0002 ***
FRONTAL.C DISTANCE 1	switch	-3.2	19	0.005 **
FRONTAL.C DISTANCE 2	switch	-4.1	19	0.001 **
CENTRAL DISTANCE 1	switch	-3.0	19	0.008 **
CENTRAL DISTANCE 2	switch	-3.3	19	0.0007 ***
CENTRAL.P DISTANCE 1	switch	-1.9	19	0.07 .
CENTRAL.P DISTANCE 2	switch	-2.1	19	0.07 .
PARIETAL DISTANCE 1	switch	-1.9	19	0.16
PARIETAL DISTANCE 2	switch	1.3	19	0.21

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

Time window 300-450

ANOVA (SWITCH: HEMI: DM: AP)

Univariate Type III Repeated-Measures ANOVA Assuming Sphericity

	SS	**SSE**	**nDf**	**dDf**	**F**	**Pr(>F)**
Switch:HEMI:AP	4.46	17.77	4	76	4.77	0.002 **
Switch:DM:AP	3.33	9.05	4	76	7.00	7.6-e05 ***

Mauchly Tests for Sphericity and Greenhouse-Geisser Correction

	W	**P-VALUE**	**GGε**	**PR(>F[GG])**
Switch:HEMI:AP	0.12	0.00004	0.50	0.01 *
Switch:DM:AP	0.44	0.11	0.69	0.0007 ***

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

No significant effects for SWITCH in the three-way interactions

Time window 450-525

SWITCH × CHANNEL

Channel	Effect	nDf	dDf	F>=4	p<=0.05
F4	Switch	1	19	3.53	0.05
P4	Switch	1	19	13.28	0.001
CP6	Switch	1	19	6.27	0.02
P8	Switch	1	19	6.07	0.02
FC1	Switch	1	19	5.56	0.03
C3	Switch	1	19	6.07	0.02

ANOVA (SWITCH: HEMI: DM: AP)

Univariate Type III Repeated-Measures ANOVA Assuming Sphericity

	SS	SSE	nDf	dDf	F	Pr(>F)
Switch	103.4	393.5	1	19	5.03	0.04 *
Switch:DM	20.2	48.1	1	19	7.97	0.01 *
Switch:HEMI:DM	2.6	7.8	1	19	6.33	0.02 *
Switch:HEMI:AP	11.3	26.5	4	76	8.10	1.7 4e-05 ***
Switch:HEMI:DM:AP	2.3	11.8	4	76	3.65	0.009 **

Mauchly Tests for Sphericity and Greenhouse-Geisser Correction

	W	P-VALUE	GGε	PR(>F[GG])
Switch:HEMI:AP	0.06	2.2 e-07 0.39	0.003 **	
Switch:HEMI:DM:AP	0.20	0.0009	0.65	0.02 *

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

MAIN EFFECT SWITCH

Average Switch	µV
No switch	1.8
Switch	2.5

TWO WAY INTERACTION

SWITCH: DM
Average effect Switch in each level of Distance to Midline

	DISTANCE 1	DISTANCE 2
No switch	2.5	1.0

Switch	3.5	1.4		
DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
DISTANCE 1	switch	-2.5	19	0.04 *
DISTANCE 2	switch	-1.7	19	0.11

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

THREE WAY INTERACTION

SWITCH: HEMI: AP
Average effect Switch in each level of Hemisphere with Anteriority

	FRONTAL	**FRONTAL.C**	**CENTRAL**	**CENTRAL.P**	**PARIETAL**
LEFT no switch	1.3	1.2	0.9	2.0	0.7
RIGHT no switch	2.3	2.4	2.3	2.9	1.4
LEFT switch	2.2	2.3	1.2	2.5	0.8
RIGHT switch	3.1	3.3	2.9	3.9	2.5

HEMI: AP	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
FRONTAL LEFT HEMI	switch	-1.4	19	0.17
FRONTAL RIGHT HEMI	switch	-1.6	19	0.17
FRONTAL.C LEFT HEMI	switch	-2.2	19	0.09 .
FRONTAL.C RIGHT HEMI	switch	-1.8	19	0.09 .
CENTRAL LEFT HEMI	switch	-1.0	19	0.32
CENTRAL RIGHT HEMI	switch	-1.7	19	0.22
CENTRAL.P LEFT HEMI	switch	-1.3	19	0.19
CENTRAL.P RIGHT HEMI	switch	-2.2	19	0.09 .
PARIETAL LEFT HEMI	switch	- 0.07	19	0.95
PARIETAL RIGHT HEMI	switch	-3.3	19	0.008 **

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH 2: L2→L1

Time window 150-300

SWITCH x CHANNEL

Channel	**Effect**	**nDF**	**dDF**	**F>=4**	**p<=0.05**
Fz	Switch	1	19	4.39	0.05
Cz	Switch	1	19	5.57	0.03
FC2	Switch	1	19	6.24	0.02
C4	Switch	1	19	5.21	0.03
FC6	Switch	1	19	7.48	0.01
T8	Switch	1	19	5.19	0.03
FC1	Switch	1	19	6.34	0.02
CP1	Switch	1	19	4.21	0.05
C3	Switch	1	19	7.95	0.01
FC5	Switch	1	19	10.43	0.004

T7	Switch	1	19	11.81	0.003

ANOVA (SWITCH: HEMISPHERE: DM: AP)

Univariate Type III Repeated-Measures ANOVA Assuming Sphericity

Effect	SS	SSE	nDF	dDF	F	Pr(>F)
Switch	49.25	141.35	1	19	6.62	0.02 *

Signif. codes: '***'<0.001 '**' <0.01 '*'<0.05 '.'<0.1

MAIN EFFECT SWITCH

Average Switch µV	
No switch	1.2
Switch	0.7

Time window 300-450

SWITCH x CHANNEL

Channel	Effect	nDF	dDF	F>=4	p<=0.05
Fz	Switch	1	19	14.61	0.001
Cz	Switch	1	19	13.59	0.002
Pz	Switch	1	19	9.27	0.007
FC2	Switch	1	19	16.92	0.0006
CP2	Switch	1	19	13.77	0.001
Fp2	Switch	1	19	4.93	0.04
F4	Switch	1	19	15.94	0.0008
C4	Switch	1	19	17.94	0.0005
P4	Switch	1	19	12.85	0.002
FC6	Switch	1	19	23.17	0.0001
CP6	Switch	1	19	19.42	0.0003
F8	Switch	1	19	10.70	0.004
T8	Switch	1	19	24.57	0.00009
P8	Switch	1	19	6.14	0.02
FC1	Switch	1	19	14.73	0.001
CP1	Switch	1	19	13.53	0.002
F3	Switch	1	19	7.47	0.01
C3	Switch	1	19	13.85	0.001
P3	Switch	1	19	8.78	0.008
FC5	Switch	1	19	7.50	0.01
CP5	Switch	1	19	6.63	0.02

ANOVA (SWITCH: HEMISPHERE: DM: AP)

Univariate Type III Repeated-Measures ANOVA Assuming Sphericity

Effect	**SS**	**SSE**	**nDF**	**dDF**	**F**	**Pr(>F)**
Switch	340.59	355.99	1	19	18.18	0.0004 ***
Switch:HEMI	11.73	45.24	1	19	4.93	0.04 *
Switch:DM	26.91	53.70	1	19	9.52	0.006 **
Switch:AP	12.48	114.85	4	76	2.07	0.09 .

Mauchly Tests for Sphericity and Greenhouse-Geisser Correction

	W	**P-VALUE**	**GGε**	**PR(>F[GG])**
Switch:AP	0.03	0.00	0.41	0.15

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

MAIN EFFECT SWITCH

Average Switch μV

No switch	0.3
Switch	-1.0

TWO WAY INTERACTION

SWITCH: HEMI
Average effect Switch in each level of Hemisphere

	LEFT	**RIGHT**
No switch	-0.5	1.1
Switch	-1.6	-0.4

HEMI	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
LEFT	switch	3.3	19	0.004 **
RIGHT	switch	4.7	19	0.0003 ***

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: DM
Average effect Switch for each level of Distance to Midline

	DISTANCE 1	**DISTANCE 2**
No switch	0.5	0.1
Switch	-1.2	-0.8

DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
DISTANCE 1	switch	4.08	19	0.0006 ***
DISTANCE 2	switch	4.30	19	0.0006 ***

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

5.2.2 EXPERIMENT 2

Time window 200-300

SWITCH X CHANNEL

Channel	**Effect**	**nDf**	**dDf**	**F>=4**	**p<=0.05**
Fz	Switch	1	60	12.61	0.0008
Cz	Switch	1	60	13.55	0.0005
Pz	Switch	1	60	9.64	0.003
FC2	Switch	1	60	13.38	0.0005
CP2	Switch	1	60	12.68	0.0007
Fp2	Switch	1	60	16.05	0.0002
F4	Switch	1	60	17.05	0.0001
C4	Switch	1	60	14.19	0.0004
P4	Switch	1	60	10.18	0.002
FC6	Switch	1	60	23.98	0.00001
CP6	Switch	1	60	11.98	0.001
F8	Switch	1	60	28.91	0.00000
T8	Switch	1	60	21.71	0.00002
FC1	Switch	1	60	11.45	0.001
CP1	Switch	1	60	12.21	0.0009
Fp1	Switch	1	60	14.36	0.0004
F3	Switch	1	60	12.86	0.0007
C3	Switch	1	60	13.68	0.0005
O1	Switch	1	60	6.58	0.01
FC5	Switch	1	60	12.29	0.0009
F7	Switch	1	60	14.69	0.0003
T7	Switch	1	60	9.56	0.003
P7	Switch	1	60	20.82	0.00003

ANOVA (SWITCH: POSITION: HEMI: DM: AP)

Univariate Type III Repeated-Measures ANOVA Assuming Sphericity

Effect	**SS**	**SSE**	**nDF**	**dDF**	**F**	**Pr(>F)**
Switch	458.0	1	814.4	20	11.25	0.003 **
Switch:HEMI	17.6	1	53.4	20	6.58	0.02 *
Switch:DM	32.0	1	69.4	20	9.23	0.006 **
Switch:AP	90.9	4	123.0	80	14.78	4.4e-09 ***
Switch:HEMI:DM	3.5	1	7.6	20	9.25	0.006 **
Switch:HEMI:AP	3.9	4	11.2	80	6.98	7.2e-05 ***
Switch:DM:AP	18.6	4	14.8	80	25.2	1.7e-13 ***
Switch:POSITION:DM:AP	2.1	4	7.4	80	5.61	0.0005 ***
Switch:HEMI:DM:AP	1.1	4	7.5	80	2.82	0.03 *

Mauchly Tests for Sphericity and Greenhouse-Geisser Correction

	W	**P-VALUE**	**GGε**	**PR(>F[GG])**
Switch:AP	0.38	0.0001	0.40	7.8e-05 ***

Switch:HEMI:AP	0.11	0.000009	0.49	0.003 **
Switch:DM:AP	0.24	0.002	0.61	4.8e-09 ***
Switch:POSITION:DM:AP	0.37	0.03	0.71	0.002 **
Switch:HEMI:DM:AP	0.31	0.01	0.65	0.06 .

Signif. codes: '***'<0.001 '**'<0.01 '*'<0.05 '.'<0.1

MAIN EFFECT SWITCH

Average Switch µV	
No switch	2.9
Switch	4.0

TWO WAY INTERACTION

SWITCH: DM
Average effect Switch in each level of Distance to Midline

	DISTANCE 1	**DISTANCE 2**
No switch	3.6	2.2
Switch	5.0	3.0

DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**	
DISTANCE 1	switch	-3.4	20	0.003	0.004 **
DISTANCE 2	switch	-3.2	20	0.004	0.004 **

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: HEMI
Average effect Switch in each level of Hemisphere

	LEFT	**RIGHT**
No switch	2.7	3.2
Switch	3.6	4.4

HEMI	**EFFECT**	**T**	**DF**	**P.HOCHBERG**	
LEFT	Switch	-2.8	20	0.01	0.01 *
RIGHT	Switch	-3.7	20	0.001	0.003 **

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: AP
Average effect Switch in each level of Anteriority

	FRONTAL	**FRONTAL.C**	**CENTRAL**	**CENTRAL.P**	**PARIETAL**
No switch	4.3	3.9	2.6	2.6	1.2
Switch	5.7	5.3	3.8	3.6	1.4

AP	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
FRONTAL	switch	-4.0	20	0.004 **
FRONTAL.C	switch	-3.5	20	0.006 **

CENTRAL	switch	-3.7	20	0.005 **
CENTRAL.P	switch	-3.1	20	0.01 *
PARIETAL	switch	-0.7	20	0.49

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

THREE WAY INTERACTION

SWITCH: HEMI: DM
Average effect Switch in each level of Distance to Midline

	LEFT HEMI	**RIGHT HEMI**
DIST. 1 No switch	3.5	3.8
DIST.2 No switch	2.0	2.5
DIST. 1 switch	4.7	5.2
DIST. 2 switch	2.4	3.6

DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
LEFT DISTANCE 1	switch	-3.1	20	0.005 **
LEFT DISTANCE 2	switch	-3.5	20	0.004 **
RIGHT DISTANCE 1	switch	-2.0	20	0.06 .
RIGHT DISTANCE 2	switch	-3.8	20	0.002 **

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: HEMI: AP
Average effect Switch in each level of Hemisphere with Anteriority

	FRONTAL	**FRONTAL.C**	**CENTRAL**	**CENTRAL.P**	**PARIETAL**
LEFT no switch	4.3	3.8	2.4	2.3	0.7
RIGHT no switch	4.2	4.0	2.8	2.9	1.8
LEFT switch	5.6	5.1	3.4	3.2	0.4
RIGHT switch	5.9	5.6	4.1	4.1	2.4

HEMI x AP	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
FRONTAL LEFT HEMI	switch	-3.4	20	0.003 **
FRONTAL RIGHT HEMI	switch	-4.4	20	6e-04 ***
FRONTAL.C LEFT HEMI	switch	-3.1	20	0.005 **
FRONTAL.C RIGHT HEMI	switch	-3.8	20	0.002 **
CENTRAL LEFT HEMI	switch	-3.4	20	0.003 **
CENTRAL RIGHT HEMI	switch	-3.8	20	0.002 **
CENTRAL.P LEFT HEMI	switch	-2.8	20	0.01 *
CENTRAL.P RIGHT HEMI	switch	-3.3	20	0.008 **
PARIETAL LEFT HEMI	switch	0.9	20	0.36
PARIETAL RIGHT HEMI	switch	-2.0	20	0.12

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: DM: AP					
Average effect Switch in each level of Distance to Midline with Anteriority					
	FRONTAL	**FRONTAL.C**	**CENTRAL**	**CENTRAL.P**	**PARIETAL**
DIST. 1no switch	4.6	4.4	3.5	3.2	2.5
DIST. 2no switch	3.9	3.5	1.7	2.0	-0.4
DIST. 1switch	6.1	5.9	4.9	4.5	3.3
DIST. 2 switch	5.4	4.7	2.6	2.8	-0.5

AP x DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
FRONTAL DISTANCE 1	switch	-3.5	20	0.002 **
FRONTAL DISTANCE 2	switch	-4.5	20	0.0004 ***
FRONTAL.C DISTANCE 1	switch	-3.2	20	0.004 *
FRONTAL.C DISTANCE 2	switch	-3.9	20	0.002 *
CENTRAL DISTANCE 1	switch	-3.4	20	0.002 *
CENTRAL DISTANCE 2	switch	-3.9	20	0.002 *
CENTRAL.P DISTANCE 1	switch	-3.3	20	0.006 **
CENTRAL.P DISTANCE 2	switch	-2.7	20	0.01 *
PARIETAL DISTANCE 1	switch	-2.5	20	0.02 *
PARIETAL DISTANCE 2	switch	2.8	20	0.02 *

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

FOUR WAY INTERACTION

SWITCH: DM: AP FOR EACH POSITION					
Average effect Switch in each level of Distance to Midline with Anteriority					
POSITION 1	**FRONTAL**	**FRONTAL.C**	**CENTRAL**	**CENTRAL.P**	**PARIETAL**
DIST. 1 no switch	4.8	4.4	3.5	2.8	2.0
DIST. 2 no switch	4.7	3.9	2.1	1.9	-0.6
DIST. 1 switch	6.4	6.0	4.8	4.1	2.8
DIST. 2 switch	5.9	5.0	2.7	2.5	-1.0
POSITION 2					
DIST. 1 no switch	4.3	4.5	3.6	3.6	3.0
DIST. 2 no switch	3.3	3.0	1.4	2.2	0.5
DIST. 1 switch	5.8	5.9	4.9	4.9	3.9
DIST. 2 switch	4.8	4.5	2.5	3.0	0.0

AP x DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
FRONTAL DIST. 1 POSITION 1	switch	-4.3	20	6e-04 ***
FRONTAL DIST. 1 POSIITON 2	switch	2.6	20	0.02 *
FRONTAL DIST. 2 POSITION 1	switch	-4.1	20	06e-04 ***
FRONTAL DIST. 2 POSITION 2	switch	4.0	20	0.001 **
FRONTAL.C DIST. 1 POSITION 1	switch	-4.2	20	0.0005 ***
FRONTAL.C DIST. 1 POSITION 2	switch	2.2	20	0.04 *
FRONTAL.C DIST. 2 POSITION 1	switch	-4.3	20	0.0005 ***
FRONTAL.C DIST. 2 POSITION 2	switch	3.3	20	0.007 **
CENTRAL DIST. 1 POSITION 1	switch	-4.3	20	0.0008 ***
CENTRAL DIST. 1 POSITION 2	switch	2.5	20	0.02 *
CENTRAL DIST. 2 POSITION 1	switch	-3.6	20	0.002 **
CENTRAL DIST. 2 POSITION 2	switch	3.6	20	0.003 **
CENTRAL.P DIST. 1 POSITION 1	switch	-4.3	20	0.0006 ***
CENTRAL.P DIST. 1 POSITION 2	switch	2.2	20	0.05 *

CENTRAL.P DIST. 2 POSITION 1	switch	-2.9	20	0.008 **
CENTRAL.P DIST. 2 POSITION 2	switch	2.2	20	0.05 *
PARIETAL DIST. 1 POSITION 1	switch	-3.0	20	0.01 *
PARIETAL DIST. 1 POSITION 2	switch	1.7	20	0.1
PARIETAL DIST. 2 POSITION 1	switch	2.8	20	0.01 *
PARIETAL DIST. 2 POSITION 2	switch	-2.2	20	0.02 *

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

Analysis parietal-occipital negativity

ANOVA (SWITCH: POSITION: HEMI: AP)

Univariate Type III Repeated-Measures ANOVA Assuming Sphericity

Effect	**SS**	**SSE**	**nDF**	**dDF**	**F**	**Pr(>F)**
Switch	17.9	53.18	1	20	6.71	0.02 *
Switch:HEMI	14.2	15.4	1	20	18.45	0.0004 ***
Switch:HEMI:AP	2.0	4.3	1	20	9.28	0.006 **

Signif. codes: '***'<0.001 '**'<0.01 '*'<0.05 '.'<0.1

MAIN EFFECT SWITCH

Average Switch µV	
No switch	0.4
Switch	-0.1

TWO WAY INTERACTION

SWITCH: HEMI

Average effect Switch in each level of Hemisphere

	LEFT	**RIGHT**
No switch	-0.1	0.8
Switch	-1.0	0.8

HEMI	**EFFECT**		**T**	**DF**	**P.HOCHBERG**
LEFT	4.4	20	0.01	0.0006 ***	
RIGHT	0.2	20	0.001	0.8	

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: HEMI: AP

Average effect Switch in each level of Hemisphere with Anteriority

		PARIETAL	**Occipital**

LEFT no switch	-0.8	0.6		
RIGHT no switch	0.7	1.0		
LEFT switch	-1.9	-0.1		
RIGHT switch	0.8	0.8		
HEMI x AP	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
PARIETAL LEFT HEMI	switch	4.8	20	2e-04 ***
PARIETAL RIGHT HEMI	switch	-0.3	20	0.76
OCCIPTIAL LEFT HEMI	switch	3.3	20	0.007 **
OCCIPITAL RIGHT HEMI	switch	0.9	20	0.4

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

Time window 300-450

SWITCH X CHANNEL

Channel	Effect	nDf	dDf	F>=4	p<=0.05
Fz	Switch	1	60	13.74	0.0005
Cz	Switch	1	60	16.81	0.0001
Pz	Switch	1	60	22.67	0.00001
FC2	Switch	1	60	16.21	0.0002
CP2	Switch	1	60	19.87	0.00004
Fp2	Switch	1	60	39.36	0.00000
F4	Switch	1	60	23.14	0.00001
C4	Switch	1	60	15.18	0.0003
P4	Switch	1	60	25.09	0.00001
O2	Switch	1	60	8.82	0.004
FC6	Switch	1	60	25.26	0.00
CP6	Switch	1	60	14.36	0.0004
F8	Switch	1	60	38.08	0.00
T8	Switch	1	60	15.05	0.0003
P8	Switch	1	60	4.80	0.03
FC1	Switch	1	60	8.61	0.005
CP1	Switch	1	60	15.35	0.0002
Fp1	Switch	1	60	29.54	0.00
F3	Switch	1	60	7.02	0.01
C3	Switch	1	60	7.20	0.009
P3	Switch	1	60	9.97	0.002
P7	Switch	1	60	11.51	0.001

ANOVA (SWITCH: POSITION: HEMI: DM: AP)

Univariate Type III Repeated-Measures ANOVA Assuming Sphericity

Effect	SS	SSE	nDF	dDF	F	Pr(>F)
Switch	400.4	623.0	1	20	12.85	0.002 **
Switch:HEMI	83.3	133.6	1	20	12.46	0.002 **
Switch:DM	69.3	88.8	1	20	15.61	0.0008 ***
Switch:AP	36.1	133.9	4	80	5.40	0.0007 ***

Switch:HEMI:DM	12.5	19.8	1	20	12.56	0.002 **
Switch:HEMI:AP	3.86	23.0	4	80	3.36	0.01 *
Switch:DM:AP	19.2	12.3	4	80	31.15	1.2e-15 ***
Switch:POSITION:DM:AP	2.5	17.1	4	80	2.88	0.03 *

Mauchly Tests for Sphericity and Greenhouse-Geisser Correction

	W	**P-VALUE**	**GGε**	**PR(>F[GG])**
Switch:AP	0.02	0.00	0.40	0.01 *
Switch:HEMI:AP	0.10	0.000003	0.47	0.05 *
Switch:DM:AP	0.44	0.09	0.73	5.4e-12 ***
Switch:POSITION:DM:AP	0.09	0.000001	0.55	0.06 .
Switch:HEMI:DM:AP	0.43	0.08	0.71	0.09 .

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

MAIN EFFECT SWITCH

Average Switch µV	
No switch	0.2
Switch	1.1

TWO WAY INTERACTION

SWITCH: DM
Average effect Switch in each level of Distance to Midline

	DISTANCE 1	**DISTANCE 2**
No switch	-0.1	0.4
Switch	1.3	1.0

DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
DISTANCE 1	switch	-3.8	20	0.002 **
DISTANCE 2	switch	-3.0	20	0.007 **

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: HEMI
Average effect Switch in each level of Hemisphere

	LEFT	**RIGHT**
No switch	0.4	-0.0
Switch	0.9	1.4

HEMI	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
LEFT	Switch	-1.7	20	0.1 .
RIGHT	Switch	-4.8	20	0.0002 ***

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: AP
Average effect Switch in each level of Anteriority

	FRONTAL	FRONTAL.C	CENTRAL	CENTRAL.P	PARIETAL
No switch	1.3	0.4	0.0	-0.5	-0.3
Switch	2.7	1.5	0.7	0.5	0.3

AP	EFFECT	T	DF	P.HOCHBERG
FRONTAL	switch	-4.2	20	0.002 **
FRONTAL.C	switch	-3.2	20	0.01 *
CENTRAL	switch	-2.8	20	0.02 *
CENTRAL.P	switch	-3.3	20	0.01 *
PARIETAL	switch	-2.6	20	0.02 *

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

THREE WAY INTERACTION

SWITCH: HEMI: DM
Average effect Switch in each level of Distance to Midline

	LEFT HEMI	RIGHT HEMI
DIST. 1 No switch	0.0	-0.2
DIST.2 No switch	0.7	0.1
DIST. 1 Switch	1.1	1.5
DIST. 2 Switch	0.7	1.3

DM	EFFECT	T	DF	P.HOCHBERG
LEFT DISTANCE 1	switch	-2.9	20	0.009 **
LEFT DISTANCE 2	switch	0.2	20	0.86 .
RIGHT DISTANCE 1	switch	-4.5	20	4e-04 ***
RIGHT DISTANCE 2	switch	-4.7	20	0.0002

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: HEMI: AP
Average effect Switch in each level of Hemisphere with Anteriority

	FRONTAL	FRONTAL.C	CENTRAL	CENTRAL.P	PARIETAL
LEFT no switch	1.6	0.6	0.2	-0.4	-0.2
RIGHT no switch	0.9	0.2	-0.3	-0.7	-0.3
LEFT switch	2.5	1.3	0.5	0.4	-0.1
RIGHT switch	2.8	1.8	0.8	0.7	0.8

HEMI x AP	EFFECT	T	DF	P.HOCHBERG
FRONTAL LEFT HEMI	switch	-2.3	20	0.03 *
FRONTAL RIGHT HEMI	switch	-5.4	20	6e-05 ***
FRONTAL.C LEFT HEMI	switch	-1.8	20	0.09 .
FRONTAL.C RIGHT HEMI	switch	-4.4	20	0.0006 ***
CENTRAL LEFT HEMI	switch	-0.9	20	0.38
CENTRAL RIGHT HEMI	switch	-3.8	20	0.002 **
CENTRAL.P LEFT HEMI	switch	-2.3	20	0.03 *
CENTRAL.P RIGHT HEMI	switch	-3.9	20	0.002 **
PARIETAL LEFT HEMI	switch	-0.4	20	0.72 .

PARIETAL RIGHT HEMI	switch	-4.1	20	0.001 **

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: DM: AP

Average effect Switch in each level of Distance to Midline with Anteriority

	FRONTAL	FRONTAL.C	CENTRAL	CENTRAL.P	PARIETAL
DIST. 1 no switch	1.1	0.2	-0.1	-0.9	-0.6
DIST. 2 no switch	1.5	0.6	0.1	-0.2	0.1
DIST. 1 switch	2.5	1.7	1.0	0.6	0.7
DIST. 2 switch	2.8	1.4	0.3	0.4	-0.1

AP x DM	EFFECT	T	DF	P.HOCHBERG
FRONTAL DISTANCE 1	switch	-3.7	20	0.001 **
FRONTAL DISTANCE 2	switch	-4.7	20	0.0003 ***
FRONTAL.C DISTANCE 1	switch	-3.3	20	0.006 **
FRONTAL.C DISTANCE 2	switch	-3.0	20	0.007 **
CENTRAL DISTANCE 1	switch	-3.1	20	0.01 *
CENTRAL DISTANCE 2	switch	-1.6	20	0.13
CENTRAL.P DISTANCE 1	switch	-3.7	20	0.003 **
CENTRAL.P DISTANCE 2	switch	-2.4	20	0.02 *
PARIETAL DISTANCE 1	switch	-4.1	20	0.001 **
PARIETAL DISTANCE 2	switch	0.9	20	0.37

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

Time window 450-650

SWITCH X CHANNEL

ChannelEffect	nDf	dDf	F>=4	p<=0.05	
Fz	Switch	1	60	20.78	0.00003
Cz	Switch	1	60	27.10	0.00
Pz	Switch	1	60	43.64	0.00000
FC2	Switch	1	60	28.11	0.00000
CP2	Switch	1	60	36.72	0.00000
Fp2	Switch	1	60	17.46	0.00010
F4	Switch	1	60	26.24	0.00000
C4	Switch	1	60	32.91	0.00000
P4	Switch	1	60	46.75	0.00000
O2	Switch	1	60	16.75	0.0001
FC6	Switch	1	60	44.88	0.00000
CP6	Switch	1	60	39.67	0.00000
F8	Switch	1	60	35.82	0.00000
T8	Switch	1	60	42.27	0.00000
P8	Switch	1	60	14.22	0.0004
FC1	Switch	1	60	20.07	0.00003
CP1	Switch	1	60	30.07	0.00
Fp1	Switch	1	60	9.62	0.003
F3	Switch	1	60	9.49	0.003

C3	Switch	1	60	23.71	0.00001
P3	Switch	1	60	30.01	0.00000
FC5	Switch	1	60	6.11	0.02
CP5	Switch	1	60	17.91	0.00008

ANOVA (SWITCH: POSITION: HEMI: DM: AP)

Univariate Type III Repeated-Measures ANOVA Assuming Sphericity

Effect	**SS**	**SSE**	**nDF**	**dDF**	**F**	**Pr(>F)**
Switch	1487.4	1626.8	1	20	18.29	0.0004 ***
Switch:POSITION	97.9	288.7	1	20	6.78	0.02 *
Switch:HEMI	108.3	153.0	1	20	14.16	0.001 **
Switch:DM	172.5	229.4	1	20	15.04	0.0009 ***
Switch:AP	38.2	183.4	4	80	4.16	0.004 **
Switch:HEMI:DM	18.0	27.5	1	20	13.09	0.002 **
Switch:HEMI:AP	4.2	28.0	4	80	3.00	0.02 *
Switch:DM:AP	42.1	33.7	4	80	24.94	2.0e-13 ***

Mauchly Tests for Sphericity and Greenhouse-Geisser Correction

	W	P-VALUE	GGε	PR(>F[GG])
Switch:AP	0.03	0.00	0.49	0.02 *
Switch:HEMI:AP	0.21	0.0007	0.56	0.05 .
Switch:DM:AP	0.12	0.00002	0.57	1.6e08 ***

Signif. codes: ‘***’ <0.001 ‘**’ <0.01 ‘*’ <0.05 ‘.’ <0.1

MAIN EFFECT SWITCH

Average Switch	**µV**
No switch	0.5
Switch	2.3

TWO WAY INTERACTION

SWITCH: POSITION

Average effect Switch in each level of sentence POSITION

	POSITION 1	**POSITION 2**
No switch	0.5	0.4
Switch	1.9	2.8

POSITION	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
POS.1	switch	-3.3	20	0.003 **
POS.2	switch	-4.5	20	0.0004 ***
No switch	position	0.2	20	0.9
Switch	position	-2.7	20	0.03 *

Signif. codes: ‘***’ <0.001 ‘**’ <0.01 ‘*’ <0.05 ‘.’ <0.1

SWITCH: DM
Average effect Switch in each level of Distance to Midline

	DISTANCE 1	**DISTANCE 2**
No switch	0.4	0.4
Switch	3.0	1.7

DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
DISTANCE 1	switch	-4.2	20	0.0004 ***
DISTANCE 2	switch	-4.2	20	0.0004 ***

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: HEMI
Average effect Switch in each level of Hemisphere

	LEFT	**RIGHT**
No switch	0.9	0.0
Switch	2.3	2.4

HEMI	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
LEFT	Switch	-3.1	20	0.005 **
RIGHT	Switch	-5.0	20	0.0001 ***

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: AP
Average effect Switch in each level of Anteriority

	FRONTAL	**FRONTAL.C**	**CENTRAL**	**CENTRAL.P**	**PARIETAL**
No switch	1.1	0.8	0.5	0.1	-0.2
Switch	2.7	2.9	2.2	2.5	1.4

AP	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
FRONTAL	switch	-3.5	20	0.002 **
FRONTAL.C	switch	-3.9	20	0.002 **
CENTRAL	switch	-4.2	20	0.001 **
CENTRAL.P	switch	-4.5	20	0.0008 ***
PARIETAL	switch	-4.5	20	0.0008 ***

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

THREE WAY INTERACTION

SWITCH: HEMI: DM
Average effect Switch in each level of Distance to Midline

	LEFT HEMI	**RIGHT HEMI**
DIST. 1 No switch	0.7	0.1
DIST.2 No switch	1.1	-0.1

DIST. 1 switch	2.9	3.0
DIST. 2 switch	1.6	1.9

DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
LEFT DISTANCE 1	switch	-3.7	20	0.002 **
LEFT DISTANCE 2	switch	-1.7	20	0.1
RIGHT DISTANCE 1	switch	-4.7	20	0.0003 ***
RIGHT DISTANCE 2	switch	-5.1	20	1e-04 ***

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: DM: AP

Average effect Switch in each level of Distance to Midline with Anteriority

	FRONTAL	**FRONTAL.C**	**CENTRAL**	**CENTRAL.P**	**PARIETAL**
DIST. 1 no switch	0.9	0.4	-0.1	0.0	-0.2
DIST. 2 no switch	0.8	0.5	0.1	0.2	-0.1
DIST. 1switch	3.4	2.8	1.0	3.0	2.6
DIST. 2 switch	2.4	1.5	0.3	2.0	0.3

AP x DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
FRONTAL DISTANCE 1	switch	-3.8	20	0.001 **
FRONTAL DISTANCE 2	switch	-4.0	20	0.001 ***
FRONTAL.C DISTANCE 1	switch	-4.1	20	0.001 **
FRONTAL.C DISTANCE 2	switch	-3.9	20	0.0071**
CENTRAL DISTANCE 1	switch	-4.1	20	0.001 **
CENTRAL DISTANCE 2	switch	-3.9	20	0.001 **
CENTRAL.P DISTANCE 1	switch	-4.4	20	0.0003 ***
CENTRAL.P DISTANCE 2	switch	-4.6	20	0.0003 ***
PARIETAL DISTANCE 1	switch	-5.1	20	1e-04 ***
PARIETAL DISTANCE 2	switch	-1.7	20	0.10 .

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

Time window 650-850

SWITCH X CHANNEL

Channel	**Effect**	**nDf**	**dDf**	**F>=4**	**p<=0.05**
Cz	Switch	1	60	7.26	0.009
Pz	Switch	1	60	17.97	0.00008
CP2	Switch	1	60	14.20	0.0004
C4	Switch	1	60	10.62	0.002
P4	Switch	1	60	19.54	0.00004
O2	Switch	1	60	5.49	0.02
FC6	Switch	1	60	7.62	0.008
CP6	Switch	1	60	13.60	0.0005
T8	Switch	1	60	5.62	0.02
P8	Switch	1	60	5.60	0.02
CP1	Switch	1	60	12.47	0.0008
C3	Switch	1	60	7.37	0.009

P3	Switch	1	60	18.89	0.00005
O1	Switch	1	60	4.75	0.03
CP5	Switch	1	60	10.45	0.002
Fz	Switch: POSITION	1	60	4.60	0.04
F4	Switch: POSITION	1	60	4.32	0.04
FC6	Switch: POSITION	1	60	5.20	0.03
F3	Switch: POSITION	1	60	4.70	0.03
C3	Switch: POSITION	1	60	4.72	0.03
FC5	Switch: POSITION	1	60	5.11	0.03
T7	Switch: POSITION	1	60	4.20	0.04

ANOVA (SWITCH: POSITION: HEMI: DM: AP)

Univariate Type III Repeated-Measures ANOVA Assuming Sphericity

Effect	**SS**	**SSE**	**nDF**	**dDF**	**F**	**Pr(>F)**
Switch	269.1	967.2	1	20	5.56	0.03 *
Switch:POSITION	128.5	359.7	1	20	7.14	0.01 *
Switch:DM	42.2	171.0	1	20	4.94	0.04 *
Switch:AP	91.2	184.7	4	80	9.87	1.5e-06 ***
Switch:HEMI:DM	3.6	15.5	1	20	4.63	0.04 *
Switch:POSITION:AP	27.6	70.2	4	80	7.85	2.2e-05 ***
Switch:HEMI:AP	6.2	27.2	4	80	4.57	0.002 **
Switch:DM:AP	14.1	24.8	4	80	11.37	2.3e-07 ***
Switch:HEMI:DM:AP	1.7	9.3	4	80	3.63	0.009 **

Mauchly Tests for Sphericity and Greenhouse-Geisser Correction

	W	P-VALUE	GGε	PR(>F[GG])
Switch:AP	0.03	0.00	0.44	0.0006 ***
Switch:POSITION:AP	0.03	0.00	0.41	0.003 **
Switch:HEMI:AP	0.13	0.00002 0.48	0.02 *	
Switch:DM:AP	0.41	0.06	0.73	7.0e-06 ***

Signif. codes: ‘***’ <0.001 ‘**’ <0.01 ‘*’ <0.05 ‘.’ <0.1

MAIN EFFECT SWITCH

Average Switch μV	
No switch	2.1
Switch	2.9

TWO WAY INTERACTION

SWITCH: POSITION

Average effect Switch in each level of sentence POSITION

	POSITION 1	**POSITION 2**
No switch	2.6	1.6
Switch	2.9	2.9

POSITION	**EFFECT**	**T**	**DF**	**P.HOCHBERG**

POS.1	switch	-0.7	20	0.50
POS.2	switch	-3.1	20	0.01 *

Signif. codes: ‘***’ <0.001 ‘**’ <0.01 ‘*’ <0.05 ‘.’ <0.1

SWITCH: DM
Average effect Switch in each level of Distance to Midline

	DISTANCE 1	**DISTANCE 2**
No switch	2.6	1.6
Switch	3.7	2.1

DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
DISTANCE 1	switch	4.3	20	0.0003 ***
DISTANCE 2	switch	5.2	20	8e-05 ***

Signif. codes: ‘***’ <0.001 ‘**’ <0.01 ‘*’ <0.05 ‘.’ <0.1

SWITCH: AP
Average effect Switch in each level of Anteriority

	FRONTAL	**FRONTAL.C**	**CENTRAL**	**CENTRAL.P**	**PARIETAL**
No switch	3.3	2.9	2.0	1.8	0.5
Switch	3.4	3.5	2.7	3.2	1.7

AP	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
FRONTAL	switch	-0.2	20	0.82
FRONTAL.C	switch	-1.5	20	0.3
CENTRAL	switch	-2.4	20	0.07 .
CENTRAL.P	switch	-3.0	20	0.03 *
PARIETAL	switch	-3.4	20	0.01 *

Signif. codes: ‘***’ <0.001 ‘**’ <0.01 ‘*’ <0.05 ‘.’ <0.1

THREE WAY INTERACTION

SWITCH: POSITION: AP
Average effect Switch in each level of Distance to Midline with Anteriority

	FRONTAL	**FRONTAL.C**	**CENTRAL**	**CENTRAL.P**	**PARIETAL**
POS. 1 no switch	5.0	4.2	2.5	1.7	-0.2
POS. 2 no switch	1.7	1.7	1.5	1.8	1.2
POS. 1 switch	4.3	3.9	2.6	2.6	0.9
POS. 2 switch	2.5	3.1	2.8	3.7	2.5

AP x DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
FRONTAL POSITION 1	switch	2.4	20	0.05 .
FRONTAL POSITION 2	switch	-1.9	20	0.07 .
FRONTAL.C POSITION 1	switch	-0.5	20	0.6
FRONTAL.C POSITION 2	switch	-2.7	20	0.03 *
CENTRAL POSITION 1	switch	-0.5	20	0.6
CENTRAL POSITION 2	switch	-3.3	20	0.007 **

CENTRAL.P POSITION 1	switch	-1.9	20	0.08 .
CENTRAL.P POSITION 2	switch	-3.3	20	0.007 **
PARIETAL POSITION 1	switch	-2.9	20	0.009 **
PARIETAL POSITION 2	switch	-3.1	20	0.009 **

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: HEMI: DM
Average effect Switch in each level of Distance to Midline

	LEFT HEMI	RIGHT HEMI
DIST. 1 No switch	2.7	2.5
DIST.2 No switch	1.8	1.4
DIST. 1 switch	3.7	3.8
DIST. 2switch	2.0	2.2

DM	EFFECT	T	DF	P.HOCHBERG
LEFT DISTANCE 1	switch	-2.0	20	0.05 .
LEFT DISTANCE 2	switch	-0.6	20	0.5
RIGHT DISTANCE 1	switch	-2.6	20	0.03 *
RIGHT DISTANCE 2	switch	-2.8	20	0.02 *

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: DM: AP
Average effect Switch in each level of Distance to Midline with Anteriority

	FRONTAL	FRONTAL.C	CENTRAL	CENTRAL.P	PARIETAL
DIST. 1 no switch	3.5	3.3	2.4	2.3	1.5
DIST. 2 no switch	3.2	2.6	1.5	1.3	-0.4
DIST. 1 switch	3.6	4.1	3.6	3.9	3.3
DIST. 2 switch	3.2	2.9	1.8	2.4	0.2

AP x DM	EFFECT	T	DF	P.HOCHBERG
FRONTAL DISTANCE 1	switch	-0.3	20	0.9
FRONTAL DISTANCE 2	switch	-0.1	20	0-9
FRONTAL.C DISTANCE 1	switch	-1.5	20	0.2
FRONTAL.C DISTANCE 2	switch	-1.3	20	0.2
CENTRAL DISTANCE 1	switch	-2.5	20	0.04 *
CENTRAL DISTANCE 2	switch	-1.7	20	0.1
CENTRAL.P DISTANCE 1	switch	-2.9	20	0.009 **
CENTRAL.P DISTANCE 2	switch	-3.2	20	0.009 **
PARIETAL DISTANCE 1	switch	-3.7	20	0.003 **
PARIETAL DISTANCE 2	switch	-2.5	20	0.02 *

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

5.2.3 Experiment 3

Time window 200-300

SWITCH x CHANNEL

Channel	Effect	nDf	dDf	F>=4	p<=0.05
Cz	Switch	1	34	4.71	0.04
Pz	Switch	1	34	12.07	0.001
CP2	Switch	1	34	8.24	0.007
Fp2	Switch	1	34	4.92	0.03
P4	Switch	1	34	12.53	0.001
O2	Switch	1	34	14.35	0.0006
CP6	Switch	1	34	7.48	0.01
P8	Switch	1	34	5.87	0.02
CP1	Switch	1	34	9.85	0.004
Fp1	Switch	1	34	5.51	0.02
C3	Switch	1	34	9.03	0.005
P3	Switch	1	34	15.89	0.0003
O1	Switch	1	34	30.74	0.000
CP5	Switch	1	34	15.81	0.0004
F7	Switch	1	34	4.45	0.04
P7	Switch	1	34	20.57	0.00007

Analysis frontal positivity

ANOVA (SWITCH: HEMI: AP)

Univariate Type II Repeated-Measures ANOVA Assuming Sphericity						
	SS	**SSE**	**nDf**	**dDf**	**F**	**Pr(>F)**
Switch:AP	7.3	15.5	1	34	16.0	0.0003 ***

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1						

TWO WAY INTERACTION

SWITCH: AP

Average effect Switch in each level of Anteriority		
	PREFRONTAL	**FRONTAL**
No switch	4.0	3.9
Switch	4.7	4.0

AP	EFFECT	T	DF	P.HOCHBERG
PREFRONTAL	switch	-2.4	35	0.047 *
FRONTAL	switch	-0.52	35	0.61

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1				

Analysis parietal-occipital negativity

ANOVA (SWITCH: HEMI: AP)

Univariate Type II Repeated-Measures ANOVA Assuming Sphericity

	SS	SSE	nDf	dDf	F	Pr(>F)
Switch	38.8	55.1	1	34	23.90	2.4e-05 ***
Switch:HEMI	5.5	15.9	1	34	11.72	0.002 **

Signif. codes: ‘***’ <0.001 ‘**’ <0.01 ‘*’ <0.05 ‘.’ <0.1

MAIN EFFECT SWITCH

Average Switch μV	
No switch	0.2
Switch	-0.6

TWO WAY INTERACTION

SWITCH: HEMI
Average effect Switch in each level of Hemisphere

	LEFT	RIGHT
No switch	-0.4	0.7
Switch	-1.4	0.3

HEMI	EFFECT	T	DF	P.HOCHBERG
LEFT	switch	5.3	35	2e-05***
RIGHT	switch	3.2	35	0.003

Signif. codes: ‘***’ <0.001 ‘**’ <0.01 ‘*’ <0.05 ‘.’ <0.1

Time window 300-450

SWITCH x CHANNEL

Channel	Effect	nDf	dDf	F>=4	p<=0.05
Cz	Switch	1	34	9.00	0.005
Pz	Switch	1	34	8.94	0.005
FC2	Switch	1	34	3.80	0.04
CP2	Switch	1	34	18.95	0.0001
Fp2	Switch	1	34	13.93	0.0005
C4	Switch	1	34	28.74	0.00001
P4	Switch	1	34	29.03	0.00001
O2	Switch	1	34	26.07	0.00001
FC6	Switch	1	34	18.17	0.0002
CP6	Switch	1	34	53.54	0.00
T8	Switch	1	34	23.52	0.00002
P8	Switch	1	34	40.65	0.00
CP1	Switch	1	34	5.68	0.02

Fp1	Switch	1	34	12.94	0.001
C3	Switch	1	34	5.17	0.03
FC5	Switch	1	34	3.76	0.04

ANOVA (SWITCH: HEMI: DM: AP)

Univariate Type II Repeated-Measures ANOVA Assuming Sphericity

	SS	SSE	nDf	dDf	F	Pr(>F)
Switch	85.7	383.6	1	34	7.6	0.009 **
Switch:HEMI	23.5	71.0	1	34	11.2	0.002 **
Switch:AP	25.6	100.7	4	136	8.64	3.1e-06 ***
Switch:HEMI:AP	13.3	23.8	4	136	19.57	9.7e-13 ***
Switch:HEMI:DM	1.9	7.2	1	34	9.05	0.005 **
Switch:DM:AP	3.9	16.8	4	136	7.95	8.7e-06 ***
Switch:DM:HEMI:AP	1.5	11.4	4	136	3.58	0.002 **
Switch:PROF:AP	12.0	100.7	4	136	3.05	0.004 **

Mauchly Tests for Sphericity and Greenhouse-Geisser Correction

	W	P-VALUE	GGε	PR(>F[GG])
Switch:AP	0.02	0.00	0.35	0.002016 **
Switch:HEMI:AP	0.09	0.00	0.47	3.4e-07 ***
Switch:DM:AP	0.38	0.0003	0.74	8.97e-05 ***
Switch:DM:HEMI:AP	0.40	0.0005	0.66	0.007 **
Switch:PROF:AP	0.02	0.00	0.35	0.04 *

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

MAIN EFFECT SWITCH

Average Switch	**µV**
No switch	0.8
Switch	0.3

TWO WAY INTERACTION

SWITCH: HEMI
Average effect Switch in each level of Hemisphere

	LEFT	RIGHT
No switch	0.6	0.9
Switch	0.4	0.2

HEMI	EFFECT	T	DF	P.HOCHBERG
LEFT	switch	1.0	35	0.31
RIGHT	switch	5.1	35	2e-05

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: AP

Average effect Switch in each level of Anteriority					
	FRONTAL	**FRONTAL.C**	**CENTRAL**	**CENTRAL.P**	**PARIETAL**
No switch	1.1	0.8	0.5	0.7	0.8
Switch	1.2	0.3	-0.1	0.0	0.2

AP	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
FRONTAL	switch	-0.1	35	0.90
FRONTAL.C	switch	2.6	35	0.03 *
CENTRAL	switch	3.8	35	0.002 **
CENTRAL.P	switch	3.6	35	0.004 **
PARIETAL	switch	2.7	35	0.03 *

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

THREE WAY INTERACTION

SWITCH: HEMI: AP

Average effect Switch in each level of Hemisphere with Anteriority					
	FRONTAL	**FRONTAL.C**	**CENTRAL**	**CENTRAL.P**	**PARIETAL**
LEFT no switch	1.3	0.8	0.3	0.5	0.4
RIGHT no switch	1.0	0.8	0.6	1.0	1.3
LEFT switch	1.3	0.3	0.0	0.1	0.4
RIGHT switch	1.0	0.2	-0.3	-0.1	0.1

HEMI: AP	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
FRONTAL LEFT HEMI	switch	-0.3	35	0.92
FRONTAL RIGHT HEMI	switch	0.1	35	0.92
FRONTAL.C LEFT HEMI	switch	1.8	35	0.09 .
FRONTAL.C RIGHT HEMI	switch	3.4	35	0.004 **
CENTRAL LEFT HEMI	switch	1.6	35	0.11
CENTRAL RIGHT HEMI	switch	6.0	35	0.00 ***
CENTRAL.P LEFT HEMI	switch	1.7	35	0.10
CENTRAL.P RIGHT HEMI	switch	5.9	35	0.00 ***
PARIETAL LEFT HEMI	switch	-0.01	35	0.99
PARIETAL RIGHT HEMI	switch	6.3	35	0.00 ***

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: DM: AP

Average effect Switch in each level of Distance to Midline with Anteriority					
	FRONTAL	**FRONTAL.C**	**CENTRAL**	**CENTRAL.P**	**PARIETAL**
DIST. 1 no switch	1.2	0.8	0.7	0.8	1.2
DIST. 1 switch	1.1	0.4	-0.1	0.0	0.4
DIST. 2 no switch	1.0	0.8	0.2	0.6	0.5
DIST. 2 switch	1.2	0.2	-0.2	0.0	0.1

AP: DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
FRONTAL DISTANCE 1	switch	0.5	35	0.60
FRONTAL DISTANCE 2	switch	-1.0	35	0.34
FRONTAL.C DISTANCE 1	switch	1.74	35	0.18
FRONTAL.C DISTANCE 2	switch	3.60	35	0.004 **

CENTRAL DISTANCE 1	switch	3.82	35	0.003 **
CENTRAL DISTANCE 2	switch	3.16	35	0.01 **
CENTRAL.P DISTANCE 1	switch	3.38	35	0.007 **
CENTRAL.P DISTANCE 2	switch	3.56	35	0.004 **
PARIETAL DISTANCE 1	switch	2.91	35	0.02 *
PARIETAL DISTANCE 2	switch	2.24	35	0.06 .

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: HEMI: DM

Average effect Switch in each level of Distance to Midline

		LEFT HEMI	RIGHT HEMI
DIST. 1	No switch	0.8	1.0
DIST. 2	No switch	0.5	0.8
DIST. 1	Switch	0.4	0.3
DIST. 2	Switch	0.4	0.1

DM	EFFECT	T	DF	P.HOCHBERG
LEFT DISTANCE 1	switch	1.6	35	0.13
LEFT DISTANCE 2	switch	0.3	35	0.77
RIGHT DISTANCE 1	switch	3.0	35	0.0006 ***
RIGHT DISTANCE 2	switch	6.1	35	0.00 ***

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: PROFICIENCY: AP

Average effect Switch in each level of Hemisphere with Anteriority

		FRONTAL	FRONTAL.C	CENTRAL	CENTRAL.P	PARIETAL
HIGH	no switch	1.5	1.0	0.6	0.9	0.9
HIGH	switch	1.1	0.3	0.0	0.2	0.4
LOW	no switch	0.8	0.6	0.3	0.6	0.8
LOW	switch	1.2	0.3	-0.3	-0.2	0.1

AP: PROFICIENCY	EFFECT	T	DF	P.HOCHBERG
FRONTAL HIGH proficiency	switch	1.9	17	0.15
FRONTAL LOW proficiency	switch	-1.3	17	0.22
FRONTAL.C HIGH proficiency	switch	3.4	17	0.007 **
FRONTAL.C LOW proficiency	switch	0.8	17	0.42
CENTRAL HIGH proficiency	switch	2.8	17	0.02 *
CENTRAL LOW proficiency	switch	2.6	17	0.02 *
CENTRAL.P HIGH proficiency	switch	2.2	17	0.04 *
CENTRAL.P LOW proficiency	switch	2.8	17	0.03 *
PARIETAL HIGHproficiency	switch	1.4	17	0.17
PARIETAL LOW proficiency	switch	2.5	17	0.05 *

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

Time window 450-650

SWITCH x CHANNEL

Channel	Effect	nDf	dDf	F>=4	p<=0.05
Cz	Switch	1	34	9.0	0.005
Pz	Switch	1	34	8.9	0.005
FC2	Switch	1	34	3.8	0.04
CP2	Switch	1	34	19.0	0.0001
Fp2	Switch	1	34	13.9	0.0005
C4	Switch	1	34	28.7	0.00001
P4	Switch	1	34	29.0	0.00001
O2	Switch	1	34	26.1	0.00001
FC6	Switch	1	34	18.2	0.0002
CP6	Switch	1	34	53.5	0.00
T8	Switch	1	34	23.5	0.00002
P8	Switch	1	34	40.7	0.00
CP1	Switch	1	34	5.7	0.02
Fp1	Switch	1	34	12.9	0.001
C3	Switch	1	34	5.2	0.03
FC5	Switch	1	34	3.8	0.04

ANOVA (SWITCH: HEMI: DM: AP)

Univariate Type II Repeated-Measures ANOVA Assuming Sphericity

	SS	SSE	nDf	dDf	F	Pr(>F)
Switch	755.0	770.7	1	34	33.3	1.7e-06***
Switch:HEMI	7.6	52.8	1	34	3.9	0.03 *
Switch:AP	32.0	223.1	4	136	3.8	0.001 **
Switch:DM	63.5	83.2	1	34	26.4	1.1e-05 ***
Switch:HEMI:AP	3.3	23.5	4	136	3.6	0.002 **
Switch:DM:AP	3.0	27.4	4	136	3.9	0.001 **
Switch:PROF:AP	29.7	223.1	4	136	3.5	0.002 **
Switch:PROF:HEMI	7.6	52.8	1	34	3.9	0.03 *

Mauchly Tests for Sphericity and Greenhouse-Geisser Correction

	W	P-VALUE	GGε	PR(>F[GG])
Switch:AP	0.01	0.00	0.34	0.02 *
Switch:HEMI:AP	0.19	0.00000002	0.58	0.01 **
Switch:DM:AP	0.38	0.0002	0.66	0.005 **
Switch:PROF:AP	0.01	0.00	0.34	0.03 *

Signif. codes: ‘***’ <0.001 ‘**’ <0.01 ‘*’ <0.05 ‘.’ <0.1

MAIN EFFECT SWITCH

Average Switch	μV
No switch	1.1
Switch	2.6

TWO WAY INTERACTION

SWITCH: HEMI
Average effect Switch in each level of Hemisphere

	LEFT	**RIGHT**
No switch	1.3	0.9
Switch	2.9	2.2

HEMI	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
LEFT	switch	-6.4	35	0.00
RIGHT	switch	-3.9	35	2e-05

Signif. codes: ‘***’ <0.001 ‘**’ <0.01 ‘*’ <0.05 ‘.’ <0.1

SWITCH: AP
Average effect Switch in each level of Anteriority

	FRONTAL	**FRONTAL.C**	**CENTRAL**	**CENTRAL.P**	**PARIETAL**
No switch	1.2	1.5	1.1	1.1	0.6
Switch	2.3	2.9	2.4	3.0	2.2

AP	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
FRONTAL	switch	-3.8	35	0.0006 ***
FRONTAL.C	switch	-3.7	35	8e-05 ***
CENTRAL	switch	-5.5	35	0.00 ***
CENTRAL.P	switch	-6.1	35	0.00 ***
PARIETAL	switch	-5.2	35	3e-05 ***

Signif. codes: ‘***’ <0.001 ‘**’ <0.01 ‘*’ <0.05 ‘.’ <0.1

SWITCH: DM
Average effect Switch in each level of Distance to Midline

	DISTANCE 1	**DISTANCE 2**
No switch	1.4	0.9
Switch	3.2	1.9

DM	**EFFECT**	**T**	**DF**	**P.HOCHBERG**
DISTANCE 1	switch	-5.9	35	0.00 ***
DISTANCE 2	switch	-5.3	35	1e-05 ***

Signif. codes: ‘***’ <0.001 ‘**’ <0.01 ‘*’ <0.05 ‘.’ <0.1

THREE WAY INTERACTION

SWITCH: HEMI: AP
Average effect Switch in each level of Hemisphere with Anteriority

	FRONTAL	**FRONTAL.C**	**CENTRAL**	**CENTRAL.P**	**PARIETAL**
LEFT no switch	1.5	1.7	1.4	1.3	0.7
RIGHT no switch	0.9	1.3	0.7	1.0	0.5
LEFT switch	2.6	3.2	2.9	3.4	2.6
RIGHT switch	1.9	2.6	2.0	2.7	1.8

HEMI: AP	EFFECT	T	DF	P.HOCHBERG
FRONTAL LEFT HEMI	switch	-3.5	35	0.001 **
FRONTAL RIGHT HEMI	switch	-3.6	35	0.001 **
FRONTAL.C LEFT HEMI	switch	-5.2	35	2e-05 ***
FRONTAL.C RIGHT HEMI	switch	-3.0	35	0.0003 ***
CENTRAL LEFT HEMI	switch	-5.9	35	0.00 ***
CENTRAL RIGHT HEMI	switch	-3.4	35	8e-05 ***
CENTRAL.P LEFT HEMI	switch	-6.7	35	0.00 ***
CENTRAL.P RIGHT HEMI	switch	-5.2	35	1e-05 ***
PARIETAL LEFT HEMI	switch	-5.9	35	0.00 ***
PARIETAL RIGHT HEMI	switch	-3.2	35	0.0002 ***

Signif. codes: ‘***’ <0.001 ‘**’ <0.01 ‘*’ <0.05 ‘.’ <0.1

SWITCH: DM: AP
Average effect Switch in each level of Distance to Midline with Anteriority

	FRONTAL	FRONTAL.C	CENTRAL	CENTRAL.P	PARIETAL
DIST. 1 no switch	1.6	1.7	1.3	1.2	1.0
DIST. 1 switch	3.1	3.6	3.0	3.4	3.1
DIST. 2 no switch	0.9	1.4	0.9	1.0	0.2
DIST. 2 switch	1.4	2.2	1.8	2.6	1.3

AP: DM	EFFECT	T	DF	P.HOCHBERG
FRONTAL DISTANCE 1	switch	-3.5	35	0.0002 ***
FRONTAL DISTANCE 2	switch	-2.2	35	0.03 *
FRONTAL.C DISTANCE 1	switch	-5.6	35	0.00 ***
FRONTAL.C DISTANCE 2	switch	-3.3	35	0.003 **
CENTRAL DISTANCE 1	switch	-5.4	35	2e-05 ***
CENTRAL DISTANCE 2	switch	-3.8	35	3e-05 ***
CENTRAL.P DISTANCE 1	switch	-6.0	35	0.00 ***
CENTRAL.P DISTANCE 2	switch	-5.8	35	0.00 ***
PARIETAL DISTANCE 1	switch	-5.5	35	0.00 ***
PARIETAL DISTANCE 2	switch	-3.5	35	7e-05 ***

Signif. codes: ‘***’ <0.001 ‘**’ <0.01 ‘*’ <0.05 ‘.’ <0.1

SWITCH: PROFICIENCY: AP
Average effect Switch in each level of Hemisphere with Proficiency

	FRONTAL	FRONTAL.C	CENTRAL	CENTRAL.P	PARIETAL
HIGH no switch	1.4	1.6	1.2	1.1	0.4
HIGH switch	2.2	3.0	2.7	3.4	2.5
LOW no switch	1.1	1.4	1.0	1.1	0.8
LOW switch	2.4	2.8	2.1	2.6	1.9

AP: PROF	EFFECT	T	DF	P.HOCHBERG
FRONTAL HIGH proficiency	switch	-1.8	17	0.08 .
FRONTAL LOW proficiency	switch	-3.6	17	0.005 **
FRONTAL.C HIGH proficiency	switch	-3.3	17	0.005 **
FRONTAL.C LOW proficiency	switch	-3.3	17	0.005 **
CENTRAL HIGH proficiency	switch	-3.4	17	0.0008 ***

CENTRAL LOW proficiency	switch	-3.3	17	0.004 **
CENTRAL.P HIGH proficiency	switch	-5.2	17	0.0001 ***
CENTRAL.P LOW proficiency	switch	-3.4	17	0.003 **
PARIETAL HIGHproficiency	switch	-5.1	17	2e-04 ***
PARIETAL LOW proficiency	switch	-2.5	17	0.02 *

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: PROFICIENCY: HEMI
Average effect Switch in each level of Hemisphere with Proficiency

		LEFT	RIGHT
HIGH	no switch	1.4	0.8
HIGH	switch	3.1	2.5
LOW	no switch	1.2	1.0
LOW	switch	2.8	1.9

	EFFECT	T	DF	P.HOCHBERG
Left Hemi HIGH proficiency	switch	-3.6	17	5e-04 ***
Left Hemi LOW proficiency	switch	-3.3	17	5e-04 ***
Right Hemi HIGH proficiency	switch	-3.1	17	0.001 **
Right Hemi LOW proficiency	switch	-2.8	17	0.01 *

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

Time window 650-850

SWITCH x CHANNEL

Channel	Effect	nDf	dDf	F>=4	p<=0.05
Fz	Switch	1	34	23.2	0.00003
Cz	Switch	1	34	31.4	0.00
Pz	Switch	1	34	23.8	0.00002
FC2	Switch	1	34	29.4	0.00
CP2	Switch	1	34	39.8	0.00
Fp2	Switch	1	34	9.5	0.004
F4	Switch	1	34	13.1	0.0009
C4	Switch	1	34	46.6	0.00
P4	Switch	1	34	36.0	0.00
O2	Switch	1	34	17.5	0.0002
FC6	Switch	1	34	9.6	0.004
CP6	Switch	1	34	51.1	0.00
T8	Switch	1	34	21.1	0.00006
P8	Switch	1	34	29.2	0.00001
FC1	Switch	1	34	26.3	0.00001
CP1	Switch	1	34	38.1	0.00000
Fp1	Switch	1	34	6.5	0.02
F3	Switch	1	34	7.2	0.01

C3	Switch	1	34	26.0	0.00001
P3	Switch	1	34	32.0	0.00
O1	Switch	1	34	13.9	0.0005
CP5	Switch	1	34	33.1	0.00
T7	Switch	1	34	6.1	0.02
P7	Switch	1	34	18.6	0.0001

ANOVA (SWITCH: HEMI: DM: AP)

Univariate Type II Repeated-Measures ANOVA Assuming Sphericity

	SS	SSE	nDf	dDf	F	Pr(>F)
Switch	526.3	483.32	1	34	36.95	6.8e-07 ***
Switch:HEMI	13.0	62.8	1	34	7.61	0.009 **
Switch:AP	73.9	235.0	4	136	10.83	1.2e-07 ***
Switch:DM	51.7	77.1	1	34	22.76	3.4e-05 ***
Switch:HEMI:DM	2.2	10.0	1	34	7.28	0.01 *
Switch:DM:AP	3.8	32.2	4	136	3.05	0.004 **

Mauchly Tests for Sphericity and Greenhouse-Geisser Correction

	W	P-VALUE	GGε	PR(>F[GG])
Switch:AP	0.01	0.00	0.34	0.0007 ***
Switch:DM:AP	0.28	0.000004	0.59	0.02 *

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

MAIN EFFECT SWITCH

Average Switch μV	
No switch	2.0
Switch	3.2

TWO WAY INTERACTION

SWITCH: HEMI
Average effect Switch in each level of Hemisphere

	LEFT	RIGHT
No switch	2.0	2.0
Switch	3.1	3.4

HEMI	EFFECT	T	DF	P.HOCHBERG
LEFT	switch	-5.3	35	1e-05
RIGHT	switch	-6.2	35	0.00

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: AP

Average effect Switch in each level of Anteriority

	FRONTAL	FRONTAL.C	CENTRAL	CENTRAL.P	PARIETAL
No switch	2.2	2.6	2.0	2.2	1.0
Switch	2.7	3.6	3.1	3.9	2.6

AP	EFFECT	T	DF	P.HOCHBERG
FRONTAL	switch	-2.1	35	0.05 *
FRONTAL.C	switch	-3.3	35	0.0003 ***
CENTRAL	switch	-6.0	35	0.00 ***
CENTRAL.P	switch	-7.0	35	0.00 ***
PARIETAL	switch	-5.7	35	0.00 ***

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: DM

Average effect Switch in each level of Distance to Midline

	DISTANCE 1	DISTANCE 2
No switch	2.5	1.4
Switch	3.1	2.3

DM	EFFECT	T	DF	P.HOCHBERG
DISTANCE 1	switch	-6.3	35	0.00
DISTANCE 2	switch	-5.1	35	1e-05

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

THREE WAY INTERACTION

SWITCH: DM: AP

Average effect Switch in each level of Distance to Midline with Anteriority

	FRONTAL	FRONTAL.C	CENTRAL	CENTRAL.P	PARIETAL
DIST. 1 no switch	2.6	2.9	2.4	2.6	2.1
DIST. 1 switch	3.6	3.4	3.9	3.6	3.1
DIST. 2 no switch	1.8	2.2	1.5	1.7	-0.1
DIST. 2 switch	1.8	2.8	2.3	3.3	1.1

AP: DM	EFFECT	T	DF	P.HOCHBERG
FRONTAL DISTANCE 1	switch	-3.4	35	0.003 **
FRONTAL DISTANCE 2	switch	-0.1	35	0.92
FRONTAL.C DISTANCE 1	switch	-5.5	35	0.00 ***
FRONTAL.C DISTANCE 2	switch	-2.3	35	0.03 *
CENTRAL DISTANCE 1	switch	-6.2	35	0.00 ***
CENTRAL DISTANCE 2	switch	-3.4	35	1e-04 ***
CENTRAL.P DISTANCE 1	switch	-6.3	35	0.00 ***
CENTRAL.P DISTANCE 2	switch	-7.3	35	0.00 ***
PARIETAL DISTANCE 1	switch	-5.9	35	0.00 ***
PARIETAL DISTANCE 2	switch	-5.2	35	1e-05 ***

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

SWITCH: HEMI: DM

Average effect Switch in each level of Distance to Midline

		LEFT HEMI	RIGHT HEMI
DIST. 1	No switch	2.5	2.5
DIST. 2	No switch	1.5	1.4
DIST. 1	Switch	3.0	3.2
DIST. 2	Switch	2.0	2.5

DM	EFFECT	T	DF	P.HOCHBERG
LEFT DISTANCE 1	switch	-5.9	35	0.00 ***
LEFT DISTANCE 2	switch	-3.4	35	0.002 **
RIGHT DISTANCE 1	switch	-6.4	35	0.00 ***
RIGHT DISTANCE 2	switch	-5.3	35	1e-05 ***

Signif. codes: '***' <0.001 '**' <0.01 '*' <0.05 '.' <0.1

5.3. ADDITIONAL FIGURES

5.3.1. EXPERIMENT 1

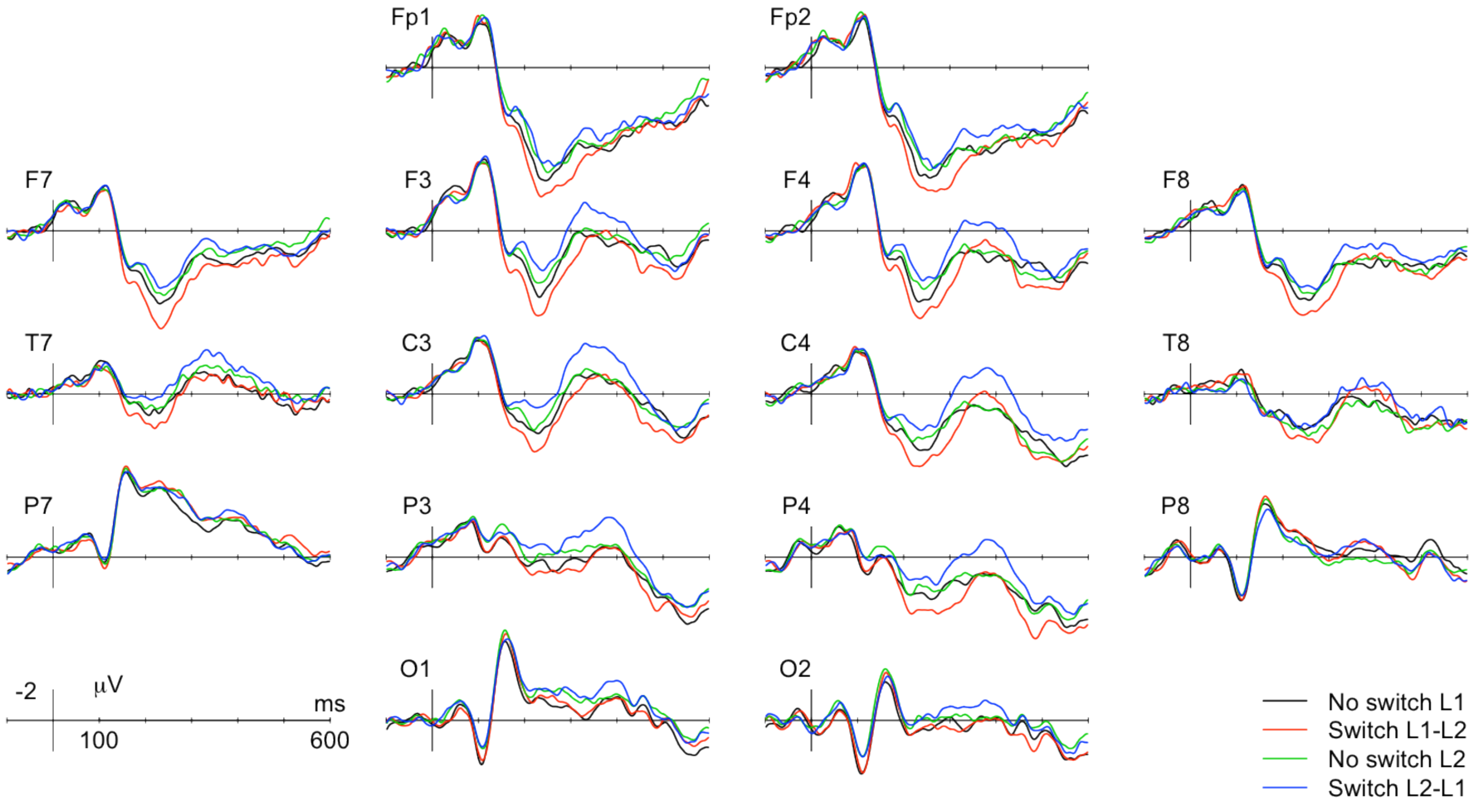

Figure A. Grand average waveforms from data of all participants for all word pairs plotted in 16 electrodes, in the No switch conditions the black line indicates L1 (la rana) and the green line L2 (the frog). In the Switch conditions there is the red line L1 to L2 (la frog) and the blue line L2 to L1 (the rana). Appreciate the differences in direction for the language switches.

5.3.2. EXPERIMENT 2

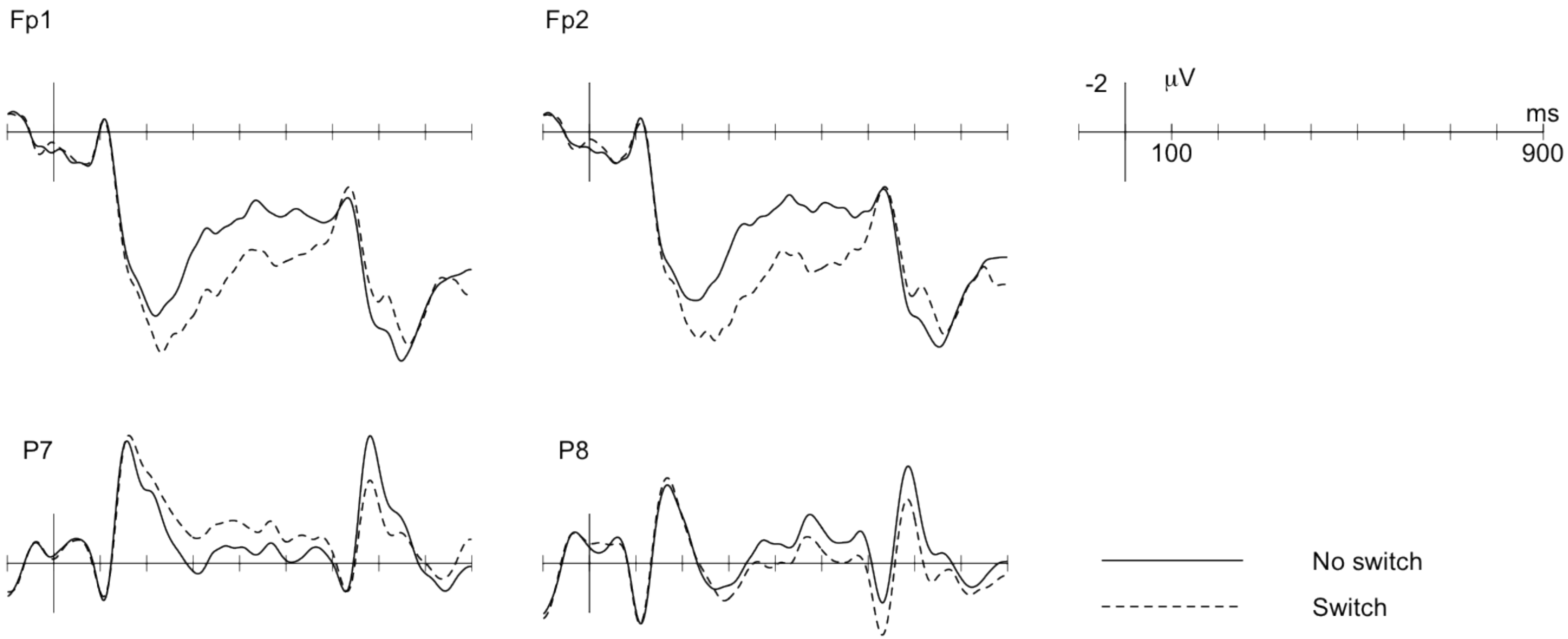

Figure B. Grand average waveforms from data of all participants for the two experimental conditions (switching versus no switching) in the beginning position of a Spanish sentence, plotted in four representative electrodes, in which the main differences can be appreciated: Frontal Positivity, Left Occipital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

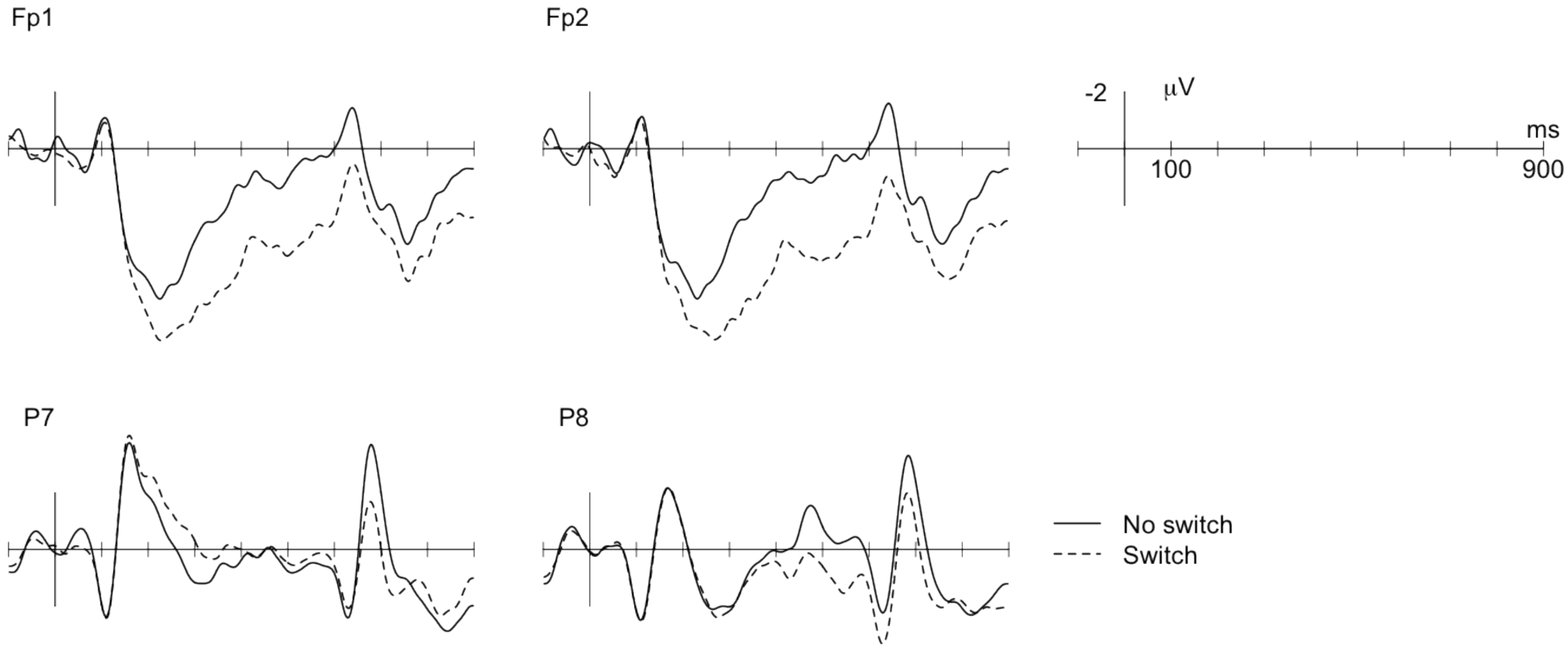

Figure C. Grand average waveforms from data of all participants for the two experimental conditions (switching versus no switching) in the middle position of a Spanish sentence, plotted in four representative electrodes, in which the main differences can be appreciated: Frontal Positivity, Left Occipital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

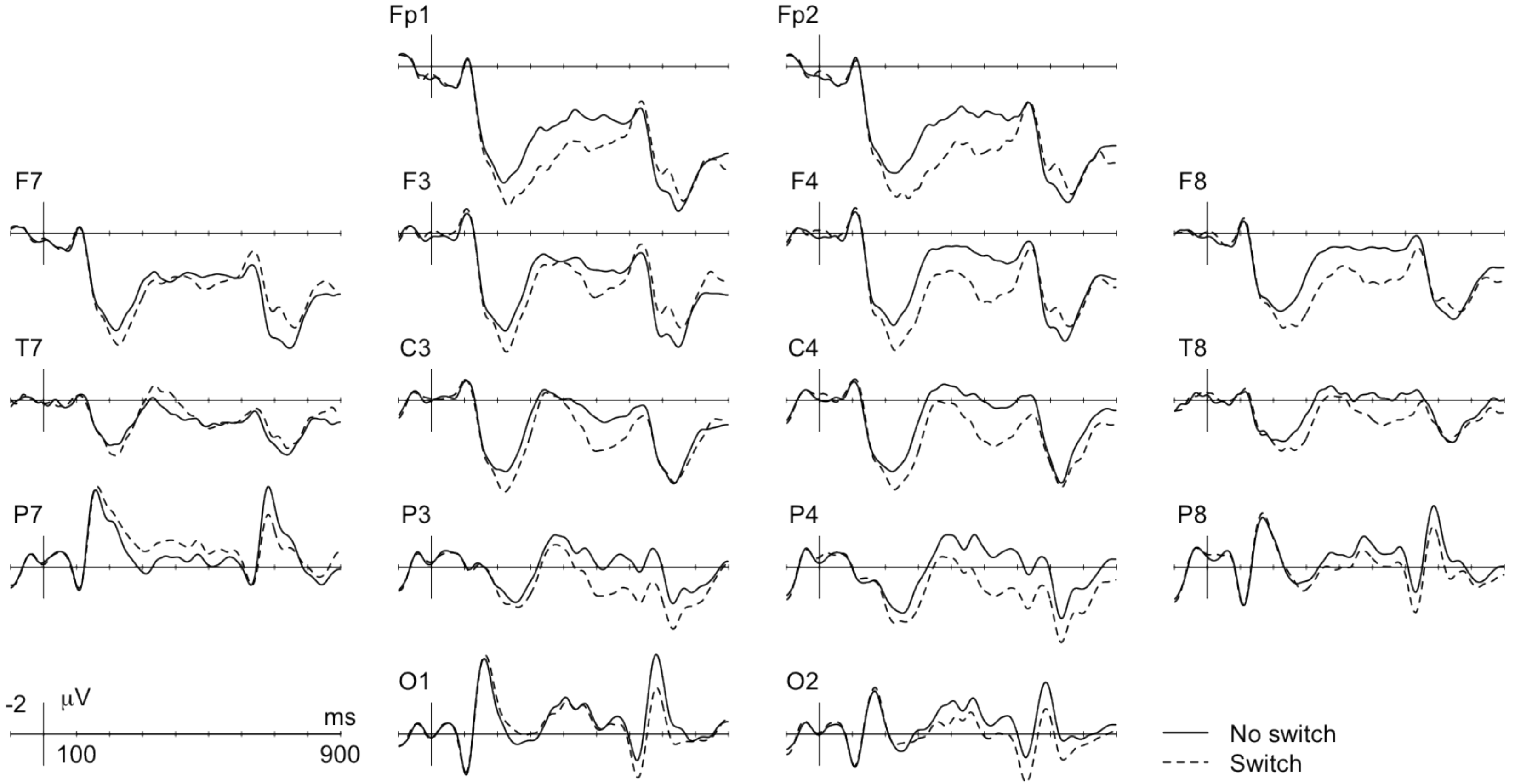

Figure D. Grand average waveforms from data of all participants for the two experimental conditions of the NOUN (No switch, Switch) in the first position of a Spanish sentence, plotted in sixteen representative electrodes, in which the main differences can be appreciated: Frontal Positivity, Left Occipital-N250, N400 and Late Positive Complex (LPC).

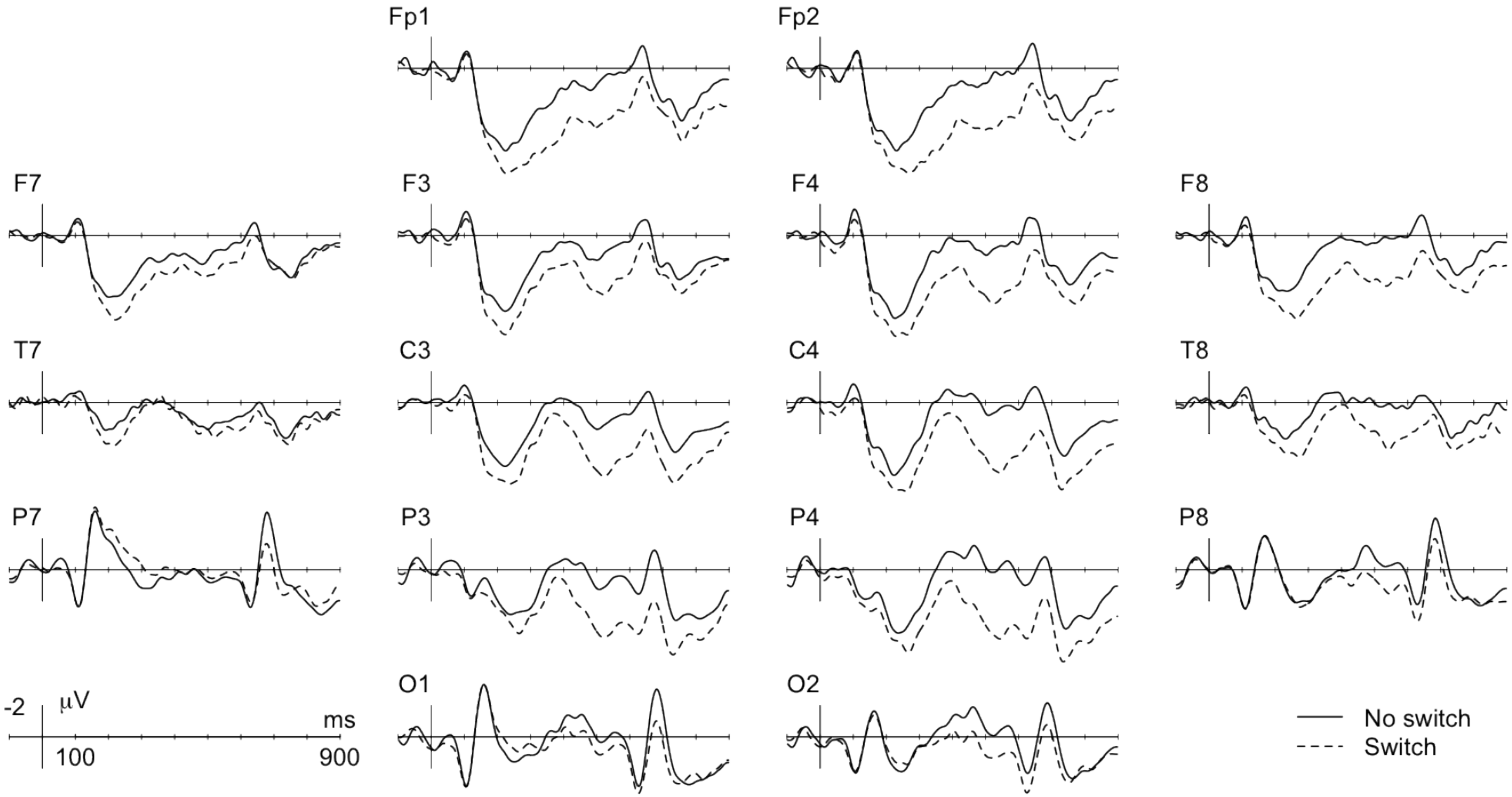

Figure E Grand average waveforms from data of all participants for the two experimental conditions of the ADJECTIVE (No switch, Switch) in the second position of a Spanish sentence, plotted in sixteen representative electrodes, in which the main differences can be appreciated: Frontal Positivity, Left Occipital -N250, N400 and Late Positive Complex (LPC).

5.4. RESUMEN EN ESPAÑOL

El bilingüismo es una realidad social en muchas comunidades, en Europa varios idiomas coinciden en un mismo país. Por ejemplo, en Bélgica y Luxemburgo, hay por lo menos tres idiomas oficiales (holandés / luxemburgués, alemán y francés) y en España en varias regiones coexisten más de un idioma (español y catalán, gallego o vasco). Hay una tendencia de la política social y educativa para aumentar la integración en las comunidades manteniendo el respeto de su identidad lingüística. El fenómeno del bilingüismo plantea importantes cuestiones sobre cómo los bilingües procesan el lenguaje, y cómo dos lenguas diferentes están representadas en el cerebro, que impacta directamente en cuestiones tan importantes como la plasticidad del cerebro. Además, el entendimiento de cómo dos lenguas se organizan, distribuyen y usan en el cerebro, mejora el conocimiento del procesamiento del lenguaje en general. Por lo tanto, el estudio de cómo coexisten diferentes lenguas en el cerebro se ha convertido en un tema importante en la neurociencia cognitiva y la psicolingüística con implicaciones sociales.

El uso de más de un idioma no se limita al aprendizaje de dos lenguas al mismo tiempo desde el nacimiento, ni suelen ser los dos utilizados en una manera equivalente. Muchos estudios se han centrado en los monolingües frentes a los bilingües equilibrados y muy competentes, pero estos son sólo dos extremos de un continuo. Más frecuentes son los casos en que una lengua es más dominante que la otra. Un buen ejemplo de que cuando esto ocurre, es cuando la segunda lengua está aún en desarrollo, como en el caso de cuando se aprende una segunda lengua. La necesidad de aprender un nuevo idioma después de la infancia ha aumentado en los últimos años, debido a las crecientes posibilidades de viajar y trabajar en otros países y a que la Unión Europea facilita la libre circulación de sus ciudadanos. Los alumnos tardíos que aprenden una segunda lengua es un grupo interesante para estudiar, porque es cada vez más y más común el que se aprenda un idioma en la escuela a la edad de siete años o incluso más tarde en la edad adulta, y también porque el estudio de los estudiantes de segunda lengua puede proporcionar información sobre cómo se desarrolla el proceso de adquisición del lenguaje. Por ejemplo, si las características de de la primera lengua se transfieren a la segunda lengua, y si este es el caso, qué características y cómo sucede, o cómo y en qué nivel las dos lenguas funcionan de manera independiente a largo plazo. En pocas palabras: si el proceso de adquisición de segundas lenguas sigue un patrón similar al de la primera lengua.

Esta investigación se centrará en los estudiantes tardíos de una segunda lengua: las personas que empezaron a aprender un segundo idioma después de su infancia. Es importante destacar que hay muchos factores que pueden determinar el aprendizaje de un segundo idioma, entre ellos están la motivación, el contexto lingüístico y cultural, la exposición a la segunda lengua y su uso en la vida cotidiana. Los participantes en este estudio hicieron el aprendizaje de un segundo idioma (Inglés) en su propio país (España) en una comunidad que es profundamente monolingüe del español (Islas Canarias). Por lo tanto no están expuestos a su segunda lengua (aparte de sus clases y algunos libros, películas, series o música. Aunque esto pueda parecer una situación muy específica, es muy frecuente y además nos permite estudiar el fenómeno de la adquisición del segundo idioma en un entorno bien controlado en el que la mayoría de los participantes en los experimentos ha recibido instrucciones idénticas y tienen un uso similar de su segunda lengua.

En ocasiones el bilingüismo tiene como consecuencia el que las personas tienen que cambiar de idioma con frecuencia, debido al uso diario de varios idiomas en las zonas públicas en las diferentes comunidades o grupos sociales. Ya sea que estén produciendo o que reciben dos idiomas, la gestión de un cambio de uno a otro requiere de un control cognitivo altamente cualificado. "Code-switching" (CS) es un proceso que nos permite analizar un aspecto específico del bilingüismo, es decir, el control ejecutivo que permite utilizar simultáneamente la fluidez de las dos lenguas y el control para mantener las lenguas separadas para evitar interferencias. Este proceso de control tiene que desarrollarse durante el aprendizaje de los idiomas, y hasta ahora ha recibido poca atención en la investigación psicolingüística. Este estudio se centró en el cambio de idioma en grupos de personas que todavía estan en el proceso de aprender su segundo idioma. En pocas palabras, se analiza cómo los participantes cambian de un idioma a otro cuando las lenguas no están equilibradas en su dominancia, una es más dominante que la otra. Por tanto, la dirección del cambio (de la dominante a la lengua no dominante o de la no dominante a la lengua dominante) recibió una atención especial.

En la presente investigación, el primer experimento se centró en procesos más "simples" como los procesos de reconocimiento visual de palabras y en los costes de activación tras un cambio de idioma en pares de palabras en ambas direcciones, desde la lengua dominante (español) al idioma no dominante (inglés), y viceversa, así como la comparación con pares de palabras por completo en el idioma dominante o no dominante. De acuerdo con los resultados de un examen de inglés, los participantes, a pesar de aprender su segundo idioma tarde, eran bastante competentes en la lectura en su segundo idioma, pero no tan fluido como los bilingües equilibrados. La tarea que tenían que realizar era la lectura para la comprensión y decidir, para cada par de palabras, si el adjetivo y el sustantivo se presentaron en la misma lengua o no. Esto nos dio la oportunidad de presentar igual número de pares de palabras con "Code-switch" y "No-Switch" en todas las combinaciones posibles. Los experimentos segundo y tercero se centraron en el mismo proceso de cambio de idioma, pero en una situación más natural de la lectura de frases. En el segundo experimento se investigó como se pasa desde un contexto de frase en el idioma dominante a una palabra en una lengua no dominante, por lo tanto del español al inglés. Los cambios fueron inesperadamente en el principio o en el medio de la oración, lo que nos dicen más sobre la relación de los costes del cambio y del contexto anterior de la frase. El uso de la lectura más natural nos permitió estudiar procesos más complejos, como los de integración y procesamiento de la sintaxis. El tercer experimento contiene frases en la segunda lengua no dominante y un cambio a la lengua dominante, con frases con una estructura similar a las utilizadas en el segundo experimento. Y aparte de una dirección de cambio diferente, realizamos el experimento con dos grupos de participantes con diferentes niveles de dominio del segundo idioma, lo que nos permitió medir los costes del cambio en relación con el nivel de aprendizaje de las segundas lenguas. Por lo tanto, se estudiaron los cambios de idiomas en diferentes direcciones, en diferentes contextos y con diferentes competencias.

El estudio de los costes de procesamiento de "Code-switch" se utilizó un método particular de la neurociencia cognitiva, la grabación de los Potenciales Cerebrales Relacionados con Eventos (ERPs). Los ERPs reflejan regularidades de la actividad eléctrica del cerebro a lo largo del tiempo en relación con un evento externo, y se obtienen a partir de un registro de variaciones de voltaje en el tiempo (electroencefalograma o EEG). La ventaja de utilizar la técnica de ERP es que este método tiene una resolución temporal muy buena y por lo tanto es una herramienta muy útil para investigar cómo se desarrollan los procesos cognitivos en el tiempo.

El presente tesis doctoral consiste en tres experimentos en los que hemos estudiado CS en pares de palabras (Experimento 1), y CS en una tarea más cercana a la lectura natural con oraciones que contenían cambios de L1 a L2 (Experimento 2), y cambios de L2 a L1 (Experimento 3). Finalmente se compararon cómo dos grupos de participantes con diferentes niveles de conocimiento de su segundo idioma procesaban el CS (experimento 3). El objetivo principal de estos experimentos es observar los efectos de ERP de CS durante la lectura, prestando especial atención a la dirección del CS (L1-L2 frente L2-L1), y tratando de diferenciar efectos ERP relacionados con el lenguaje (por ejemplo, N170, N250, LAN, N400 y P600), así como efectos ERP de los procesos cognitivos relacionados con el funcionamiento general del sistema ejecutivo de control (por ejemplo, positividades frontales, N2 o LPC). De esta manera esperamos contribuir al conocimiento de la naturaleza de los costes cognitivos asociados al CS.

5.5. CONCLUSIONES EN ESPAÑOL

En tres diferentes experimentos de ERPs se estudiaron los correlatos electrofisiológicos del CS; en un experimento con pares de palabras formados por pares de palabras (sintagmas mínimos), el CS se estudiadó en ambas direcciones, y en dos experimentos con frases en los que se estudió el CS en las dos direcciones por separado. Además, en los experimentos con frases también se estudió la influencia de dos variables importantes para este tema, la cantidad de contexto de la frase y el nivel de dominio de L2 de los participantes. Los resultados de los tres experimentos mostraron una imagen coherente de los diferentes efectos ERP que nos ha permitido seguir el curso temporal de las operaciones cognitivas provocadas por el CS.

En primer lugar, dos tipos de picos positivos se definieron en los tres experimentos. A pesar de que estos dos picos positivos mostraron un cierto grado de solapamiento temporal y espacial, se diferenciaron atendiendo a su distribución en el cuero cabelludo y a la sensibilidad a algunas variables experimentales. La fase inicial de esta positividad mostraró una distribución fronto-central, mientras que la segunda fase es mayor en las zonas posteriores. En el Experimento 1, estas positividades no eran visibles en la dirección de cambio de L2 a L1, tal vez debido a la superposición con un efecto mayor de polaridad opuesta. En el experimento 2, la positividad en las latencias finales se vio afectada por la posición en la frase en la que el CS se llevó a cabo. Por último, en el Experimento 3, el nivel de dominio de L2 de los participantes moduló el último segmento de la positividad en las zonas posteriores. Hemos asociado estos dos picos positivos con el grupo de subcomponentes relacionados con el componente P3. El efecto positivo fronto-central podría estar relacionado con la detección de acontecimientos inesperados o poco frecuentes, y con los recursos atencionales reclutados para el procesamiento del evento novedoso y la actualización del contexto posterior. Esta actualización en la memoria de corto plazo modularía el LPC, y podría incluir las operaciones de integración y re-análisis (tal como se describe para los efectos P600). Es importante señalar, que el pico de la componente P3 se retrasa varios cientos de milisegundos en experimentos del lenguaje. En nuestros datos, la positividad fronto-central comienza muy temprano, tan pronto como la información ortográfica está disponible. Sin embargo, la integración de la actualización y / o re-análisis de los procesos asociados a la LPC no puede comenzar hasta que gran parte de la información semántica y sintáctica esté disponible. Una característica importante de esta interpretación es que los procesos cognitivos asociados a estas positividades no son específicos del idioma y estarían más relacionados con las funciones generales del sistema ejecutivo. Vamos a discutir a continuación la implicación teórica de esta afirmación, pero en este punto vale la pena mencionar otra línea de investigación que también ha descrito efectos ERP de cambio de idioma asociados al control ejecutivo. En varios estudios de Fornells y colegas (ver revisión en Rodríguez-Fornells, 2006) han informado de negatividades fronto-centrales asociadas al control cognitivo y a los efectos inhibitorios de los bilingües. Por ejemplo, se describió una negatividad fronto-central relacionada con los efectos de interferencia entre lenguas en experimentos Go / No-Go (Rodríguez-Fornells, 2002), que fue interpretado como el componente N2, un componente específico del lenguaje vinculado a la inhibición de la respuesta (Folstein y Van Petten, 2008). Por otra parte, también describieron un componente medial-frontal de larga duración después de los 400 ms que propusieron refleja la cantidad de control cognitivo necesario para procesar una tarea específica en un idioma (Rodríguez-Fornells, 2006). Aunque el diseño experimental y las tareas de los estudios no son directamente comparables con las tareas utilizadas en nuestro estudio, queda abierta la pregunta de si los efectos ERP de las dos líneas de investigación, incluso mostrando una polaridad diferente, podrían ser la manifestación de operaciones cognitivas similares que comparten orígenes neuronales comunes.

Los dos experimentos de frases (experimentos 2 y 3) muestran un efecto LO-N250 en respuesta al CS, y este efecto fue independiente de la dirección de la lectura. Atendiendo a su latencia (antes de los procesos léxico-semánticos que modulan la N400) y la característica distribución en el cuero cabelludo, hemos propuesto que el efecto LO-N250 refleja bien la detección de las regularidades del lenguaje ortográfico específico, o bien los costes de cambiar entre los sistemas ortográficos. Por tanto, este efecto apoyaría aquellos modelos en los que la selección del idioma se pueden beneficiar de características de nivel inferior como las regularidades ortográficas (Dijkstra y Van Heuven, 2002). Esta interpretación conlleva que los costes de CS se producen también en las primeras etapas del proceso de reconocimiento visual de palabras.

Nuestros resultados han demostrado también un efecto N400 en respuesta al CS. Este efecto podría ser crítico en nuestros grupos de bilingües no equilibrados, porque de acuerdo con el modelo de HRM (Kroll y De Groot, 1997; Kroll y Stewart, 1994), en los primeros pasos de la adquisición de segundas lenguas, el léxico de la L2 no tiene relación directa con el nivel conceptual, por lo que dependen en gran medida del léxico de L1. El enlace de las palabras de L2 a L1 sería fuerte, lo que facilitaría el cambio entre las lenguas a nivel del léxico, lo cual es coherente con el efecto N400 que se encuentra en nuestro estudio. El efecto N400 se observó sólo cuando se cambiaba de L2 a L1, pero no en la dirección opuesta, y esto ocurrió con los pares de palabras (Experimento 1) y las frases (experimento 3). Hemos interpretado el efecto N400 de CS como el reflejo de los costes de la activación de determinadas formas léxicas en la lengua menos activa. Esta idea es coherente con los modelos de procesamiento bilingüe que incluyen léxicos separados con diferentes niveles de activación en función del idioma en uso. Estos modelos sostienen la existencia de algún tipo de mecanismos inhibitorios de arriba hacia abajo o mecanismos locales que permiten la desactivación parcial de la lengua que no está en uso (Dijkstra y van Heuven, 1998, 2002, Green, 1986, 1998). La investigación conductual ha sugerido que el acceso a las representaciones del lenguaje no dominante exige una mayor inhibición de la lengua dominante, que la situación inversa (Meuter y Allport, 1999). Esta diferencia en la cantidad de inhibición para suprimir uno u otro idioma, explicaría nuestra asimetría según la dirección del efecto N400. El N400 sería más grande después del cambio L2-L1 debido a que la L1 estaría más inhibida y en consecuencia la activación del significado sería más costosa.

Además del efecto N400, el grupo con mayor dominio de L2 también mostró un efecto LAN. El mismo efecto se encontró en el estudio de Moreno et al. (2002) con los bilingües equilibrados (pero en este último caso, sin el efecto N400). Teniendo en cuenta que la LAN ha sido vinculada con el procesamiento sintáctico, nuestro efecto LAN podría reflejar el mayor nivel de automatización de algunos procesos de integración que se incrementa con la competencia. En cualquier caso, la modulación de la distribución de las negatividades y de las positividades posteriores confirman la importancia de la competencia en el estudio del bilingüismo en general y, en particular, del CS.

En resumen, podemos concluir a partir de los tres experimentos de PREs que el CS afecta a distintos niveles y en varios pasos durante el curso temporal del proceso de comprensión. Los efectos comienzan muy pronto tras de la presentación de la palabra clave, cuando se han iniciado las operaciones de decodificación, y continúan hasta latencias tardías en las que la integración de los significados y la interpretación global debe llevarse a cabo. Algunos modelos teóricos destacan el papel del sistema ejecutivo general en la interpretación de los costes derivados del CS (Macnamara y Kushnir, 1971; Bialystok, 2001). Por otra parte, otros modelos han propuesto mecanismos específicos lingüísticos que determinan la selección entre lenguas para explicar los efectos de CS (Dijkstra y van

Heuven, 1998, 2002, Green, 1986, 1998). Nuestros resultados mostraron efectos de ERP asociados a las operaciones generales de control cognitivo, y a los procesos atencionales o de inhibición (positividad fronto-central y LPC). Sin embargo, y en contra de los datos que sugieren que los costes de CS tienen lugar sólo en una etapa de toma de decisiones (por ejemplo, Thomas y Allport, 2000; Moreno et al, 2002), nuestros resultados muestran que, al menos en algunas etapas de aprendizaje del segundo idioma, el cambio de idioma durante la lectura de frases afecta a varios niveles del procesamiento lingüístico, incluyendo el procesamiento ortográfico y/o fonológico y el procesamiento léxico-semántico (LO-N250 y N400). Por último, la interacción del efecto N400 de CS y la dirección de CS es consistente con los modelos que proponen mecanismos de inhibición en la selección de la lengua en uso, y la necesidad de una mayor inhibición de la lengua dominante que de la no dominante (Green, 1998).