Using Event-Related Potentials to Explore Sentential Code-Switching In English-French Bilinguals

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Abstract

Code-switching is known to incur a processing cost, yet little is known regarding what occurs after the code-switched word. The current study tested English (L1)-French (L2) unbalanced bilinguals in an Event-Related Potential (ERP) study in which they read sentences and performed a plausibility judgment. Sentences contained either no code-switches, one code-switch (i.e., switching into the second language), or two code-switches (i.e., switching into the second language and returning to the original language). A Late Positive Component was evoked to L2 items at the code-switched word and an N400 was evoked to all code-switched conditions at the sentence-final word. Results indicate that, for unbalanced bilinguals, it is harder to switch into L2 regardless of the type of code-switch encountered.

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Bilingual individuals, with two languages at their disposal, are able to choose which of their two languages in which to express an idea. In some cases, they may even switch back and forth between their two available languages; this phenomenon is known as code-switching. Although some studies examining the situations under which bilingual individuals code-switch (e.g Grosjean, 1988; Bentahalia & Davies, 1994; Heredia & Altarriba, 2001; Ramírez-Esparza, Gosling, Benet-Martínez, Potter, & Pennebaker, 2006) suggest that code-switching during spontaneous speech may seem effortless and is under voluntary control, it is clear that code-switching may have a cost to comprehenders asked to quickly switch between two languages. Specifically, in order for the conversation to succeed, the comprehender must be able to process these code-switches online as their occurrence is not predictable. Indeed, many studies have demonstrated that comprehenders incur a processing cost when they have to quickly switch between several languages (Grainger & Beauvillain, 1987; Thomas & Allport, 2000; Alvarez, Holcomb, & Grainger, 2003). The present study investigated the timing and duration of these switch costs.

Models of Bilingualism

Previous research has examined how languages are organized in bilingual memory, resulting in several models of bilingual mental lexicons. Although the current study does not test the predictions of these models, we will use them to discuss code-switching during sentence-level language comprehension. Below I will discuss several models: the Revised Hierarchical Model (Kroll & Stewart, 1994), the Bilingual

Interactive Activation model (Grainger & Dijkstra, 1992; Dijkstra & van Heuven, 1998), and the Bilingual Interactive Activation + model (Dijkstra & van Heuven, 2002).

The Revised Hierarchical Model (RHM) (Kroll & Stewart, 1994) depicts the bilingual memory organization of second language learners based on translation tasks (see Figure 1). In these tasks, participants are asked to either name the translation equivalent of a word that is presented, or to comprehend words that have been presented following their translation equivalent. There are bidirectional links both between the lexicons for L1 and L2 (lexical links) and between each lexicon and the conceptual representation (conceptual link). Critically, this model proposes these links to be asymmetric; the lexical link going from L2 to L1 is a stronger connection than the link between L1 and L2 because L2 learners learn the new L2 words in relation to their L1 counterparts. Moreover, the conceptual link from L1 is stronger than the link from L2 because L1 has a richer representation, noted by a larger lexicon than for L1. This stronger link is postulated because speakers have more experience with this language and thus have more opportunities to form connections between L1 words. Although, this model does not make specific predictions regarding code-switching, presumably, code-switching from L1 into L2 would occur via lexical links. That is, when working in L1 information flows easily from the L1 lexicon to the conceptual representation. When an L2 item is presented, that item would take longer to reach the conceptual store than it would to be translated into its L1 translation equivalent, which then could easily access its conceptual representation. Code-switching from L2 into L1 would therefore be easier because when working in L2, information is both translated into L1 and then connected to concepts and directly connected to concepts so when an L1 item is presented, it can easily access the conceptual representation. This model also does not posit any method of control for how this switching is accomplished.

Unlike the RHM, the Bilingual Interactive Activation (BIA) model (Grainger & Dijkstra, 1992; Dijkstra & van Heuven, 1998) posits an integrated lexicon of L1 and L2 words in its description of bilingual orthographic word recognition (see Figure 2). Information flows through the feature level, the letter level, the word level up to the language level. In order to differentiate between words of different languages, the words are connected to their respective language nodes. These language nodes, when activated by a word in their language, suppress the activation of all words of the other language thereby allowing a bilingual to successfully function in a monolingual setting. Code-switching, in this framework, would necessitate activating the code-switched language node, suppressing the original language node, lifting the inhibition on the word of the code-switched language, and suppressing the activation of the words of the original language. This model does not posit any advantage for L1 over L2, so it could be assumed that code-switching from L1 into L2 and from L2 into L1 would be equally difficult.

The BIA+ of Dijkstra and van Heuven (2002) aimed to expand and improve upon the existing BIA model by including phonological representations as well as a distinction between linguistic processes and control processes (see Figure 3). In the Identification system, which comprises the linguistic processes, phonological and orthographic information pass through sublexical and lexical processing before connecting to a shared semantic representation. The language nodes of the BIA are still present in the BIA+, but are separate from the semantic system and do not inhibit lower levels of processing. In the Task schema part of the model, bilingual control of language is governed by schema, which are created for every specific task (i.e., translating or code-switching). Code-switching would thus occur via an alteration of the task schema. When working in L1, the task schema would simply describe the linguistic processing of the L1 items. When an L2 word is then encountered, the schema is violated, forcing a new schema to be created that describes the linguistic processing of L2 items. As in the BIA, there are no differences in the BIA+ between size of representation or strength of links between L1 and L2, so code-switching in either direction should be equally difficult.

One striking feature of the BIA and BIA+ models is that they incorporate a lexicon that houses words of both languages. This allows for words of both languages to be activated when confronted with an input word, referred to as language nonselectivity. Language selectivity, on the other hand, claims that when a bilingual individual encounters a letter string (e.g. COIN, which means "coin" in English and "corner" in French), only words from one language are activated and able to influence lexical access of that letter string (Macnamara & Kushnir, 1972; Grainger & Beauvillain, 1987; Thomas & Allport, 2000).

As evidence for language nonselectivity, studies have found that when bilinguals work in one language, the other language may still influence processing of incoming words. For example, processing words with many orthographic neighbors in the not-in-use-language is slower (van Heuven, Dijkstra, & Grainger, 1998) and evokes a larger N400 amplitude (Midgley, Holcomb, van Heuven, & Grainger, 2008) relative to words with few orthographic neighbors in the not-in-use-language.

Evidence in favor of language selectivity stems from the observation that switching between a bilingual's two languages. Whether in reading time (Macnamara & Kushnir, 1972) or reaction time to a task in which participants had to judge the lexicality of a letter string (Grainger & Beauvillain, 1987; Thomas & Allport, 2000), studies have shown that switching between two languages takes significantly more time than remaining in one language. This indicates that both languages are not readily available for access.

Although code-switching costs, or costs that arise from switching between a bilingual's two languages, appear to contradict the claim of language nonselectivity, it must be noted that during these code-switches that the bilingual does recognize the code-switched word as a word from the other language and can access its semantics and relevant information. This ability to recognize a word in one language while working in a sentence of the other language provides support for the nonselective view. The switch cost arises, therefore, from the violation of the expectation that the upcoming word in a sentence will be in the same language as the previous word. This cost does not reveal an inability to access the meaning of a word in the other language, but reveals that it is anomalous within the context.

These models of bilingual memory organization for language provide a framework within which we can attempt to explain experimental findings.

Behavioral Studies of Bilingual Code-switching

Behaviorally, most studies examining code-switching have presented participants with a word in one language quickly followed by a word in the other language; this is known as the between-language priming technique. Results of these studies have revealed that code-switching is more difficult that non-switching. For example, Grainger and Beauvillain (1987) examined RTs to prime-target pairs within one language (e.g., base - table) relative to prime-target pairs between languages (e.g., base – trop) while participants judged the lexicalilty of a letter string (i.e., lexical decision task). Between-language pairs, which require code-switching, were significantly slower that within-language pairs, which did not require code-switching. These results indicate that code-switched pairs were harder to process. In addition, this switch cost is larger with longer durations of the prime word (Grainger & O'Regan, 1992).

Asymmetric switch costs are found when switching between languages in both directions (Jiang & Forster, 2001). Using translation priming (i.e., a word is followed by its translation equivalent in the other language) in Chinese-English bilinguals in a covert paradigm with a lexical decision task, priming was greater from L1 to L2 than from L2 to L1. Given the models previously discussed, these results suggest that, as in the RHM, L1 items have robust enough representations to allow priming to occur between L1 and L2 words whereas L2 items have not yet reached sufficient strength and thus do not rapidly activate semantic neighbors and translation equivalents.

Translation and semantic priming, or priming with semantically-related word pairs, across languages resulted in differential patterns of priming with and without a forward mask, which inhibits conscious processing (Basnight-Brown & Altarriba, 2007). Significant translation priming was found in both language directions, but semantic priming was found only from L2 to L1. Semantic priming effects, however, were eliminated when the prime was presented subliminally whereas translation priming effects remained. They concluded that the priming asymmetry, the finding that L2 words primed L1 words but L1 words did not prime L2 words, was due to language dominance as these bilinguals were L2 dominant. Thus, these results support Jiang and Forster (2001) where priming occurred only when the prime was of the dominant language. These results were replicated by Finkbeiner, Forster, Nicol, and Nakamura (2004) with a lexical decision task. However, using a semantic categorization task, in which participants had to decide if the target word belonged to a specific semantic category, priming from L1 to L2 words and L2 to L1 words was found, indicating that priming depends on the type of processing.

In a study that examined code-switching in trilinguals, Phillipp, Gade, and Koch (2007) found that regardless of in which language (L1, L2, or L3) the switch cost occurred, it was always greatest for the dominant rather than the non-dominant language, replicating previous results of asymmetric shift costs (Jiang & Forster, 2001; Basnight-Brown & Altarriba, 2007). When participants had to either switch back and forth between two languages (L1-L2-L1) or switch between all three languages (L1-L2-L3), a repetition cost was found for the conditions involving switching back into the original language (L1-L2-L1). This cost may be due to the inhibition of L1 as the participant must switch into L2, and then the presence of L1 again must overcome that inhibition. The dominant language was more strongly inhibited than the non-dominant language. However, other results suggest that this finding is not due only to inhibition of the dominant language, but also due to persisting activation of the original language (cf. Phillipp et al., 2007).

In all, these behavioral studies indicate that there are asymmetric switch costs (i.e. greater costs when switching from the dominant to the weak language than from the weak to the dominant language) but that these costs are affected by task and nature of the stimuli (Jiang & Forster, 2001; Finkbeiner, 2004; Basnight-Brown & Altarriba, 2007; Phillipp, Gade, & Koch, 2007). In order to examine a direct measure of neural activity associated with code-switching, some studies have employed event-related potentials (ERPs) (Moreno, Federmeier & Kutas, 2002; Proverbio, Leoni, & Zani, 2004; Jackson, Swainson, Mullin, Cunnington, & Jackson, 2004; Chauncey, Grainger, & Holcomb, 2008). The remainder of this section will focus on studies using ERPs.

Event-Related Potentials (ERPs)

ERPs offer an online measure of the brain activity associated with language comprehension without the need for an overt response. By recording the electrical activity of neurons, ERPs allow for fine-grained temporal resolution on the order of milliseconds. Moreover, by time-locking to a specific stimulus-onset, ERPs provide information about the cognitive processes associated with integrating a specific word into its preceding context. ERP components are systematic deflections of the waveform that have been shown to index specific cognitive processes. For the purposes of this paper, we will be concerned with two ERP components – the N400 and the Late Positivity Component (LPC).

The N400 is a negative-going ERP component occurring approximately between 300 and 500 ms. The N400 is thought to index the ease of semantically integrating a word into its preceding context (Kutas & Hillyard, 1980; Kutas & Hillyard, 1984). At the word-level, the N400 is smaller when words are semantically related to preceding words relative to unrelated to preceding words (Holcomb, 1993). This priming effect remains when participants make explicit judgments regarding the relatedness of prime-target pairs or when they simply probe for a certain semantic category among target words (Kreher, Holcomb, and Kuperberg, 2006). Importantly, the N400 is also modulated to words within sentences such that the N400 is larger when a word is semantically incongruous with its preceding context. For example, in the sentence, "She takes her coffee with milk and sugar/socks," the unexpected and anomalous word "socks" evokes an N400 component compared to the expected word "sugar". In addition to the expectedness of the word, the N400 can also be modulated by the sentence constraints and world knowledge (Federmeier & Kutas, 1999).

A later component, the late positive component (LPC), is evoked approximately 500 ms following word onset and continues for several hundred milliseconds. It is thought to reflect reanalysis and reprocessing of a stimulus. That is, if an anomalous item were presented, extra processing would be incurred to check the initial processing for possible mistakes. Specifically, the LPC has been associated with the cognitive control of task switching, or the changing of the goal of the task (e.g., switching from naming a number presented to judging if the number is odd or even) (Liotti, Woldorff, Perez III, & Mayberg, 2000). Trials involving a task switch incur a larger positivity than trials that do not require a task switch. Similarly, the LPC is modulated to code-switching such that code-switched trials evoke larger amplitude LPCs than non-switched trials (Jackson, Swainson, Cunnington, & Jackson, 2001). This effect is also observed when code-switching occurs within sentences (Moreno, Federmeier, & Kutas, 2002).

Event-Related Potentials and Bilingualism

A recent study investigated the neural indices of bilingual language processing (Midgley, Holcomb, & Grainger, 2009). In a group of second language learners, Midgley et al. found a larger amplitude N400s evoked L2 words compared to L1 words. However, and in a group of balanced bilinguals, they found similar ERPs to L1 and L2 items. This finding indicates that, in second language learners, L1 items have more robust representations, in that participants have more experience with L1 items and have likely made more connections among L1 items than L2 items in second language learners.

Other ERP studies have specifically investigated code-switching. Jackson, Swainson, Mullin, Cunnington, and Jackson (2004) tested the cost of code-switching with an ERP experiment with a parity judgment task, in which participants had to decide whether the presented number word was odd or even. Number words were presented as switch trials (following a word in the other language) or non-switch trials (following a word in the same language). Results demonstrated a language-specific code-switching effect. Specifically, in the N400 epoch, code-switch trials were more negative than non-switch trials, but this effect was only found for switching into L1. Interestingly, no LPC differences were observed, an effect that had been found in a production language switching task (Jackson, Swainson, Cunnington, & Jackson, 2001). However, Jackson et al. (2004) and Jackson et al. (2001) employed different tasks, which may account for these discrepant findings.

In an ERP study using the priming paradigm where participants were not consciously aware of the primes (i.e. masked priming), Chauncey, Grainger, and Holcomb (2008) investigated language switching with related and unrelated prime/target word pairs in second language learners. Asymmetrical switching effects were found wherein L1 targets elicited more negative N400 effects when preceded by L2 primes than when preceded by L1 primes. L2 targets, on the other hand elicited an ERP component associated with prelexical processing, the N250, where L1 primes were more negative than L2 primes. This study provided evidence that the effects of code-switching are automatic (i.e., without overt task switching) and fast-acting. However, a different ERP study of code-switching (Alvarez, Holcomb, & Grainger, 2003) that used overt priming, where participants were consciously aware of the primes, found a larger N400 effect when switching from L1 into L2, but not when switching from L2 into L1. Additionally, a larger LPC was evoked to between-language repetitions than within-language repetitions, indicating that code-switches are both unexpected items, illustrated by an N400 effect, and require additional reprocessing, illustrated by an LPC.

Finally, Litcofsky, Midgley, Holcomb, & Grainger (2009) investigated the effects of code-switching in a single-word presentation study with a lexical decision task in second language learners of French. Switching into L1 (e.g. plage-knife) was associated with a marginal N400 effect and a robust LPC effect compared to remaining in L1 (e.g. beach-knife). Interestingly, in contrast, there were no effects for switching into L2 (e.g., beach-couteau) compared to remaining in L2 (e.g., plage-couteau). Litcofsky et al. posit that working in L2 requires inhibition of the dominant L1, thus switching into L1 requires releasing that inhibition. In contrast, working in L1 does not require inhibition of the weaker L2, thus there is no inhibition to be released when switching into L2.

In sum, studies investigating code-switching with the ERP technique have found that code-switching (between-language repetitions) evoke a larger amplitude LPC than remaining in the same language (within-language repetitions) (Alvarez, Holcomb, & Grainger, 2003), and that code-switching is an automatic process (Chauncey, Grainger, &

Holcomb, 2008). Moreover, there exists asymmetry in the N400 effect regarding the direction of the code-switching. Priming studies have found an increased N400 when switching into L2 (Alvarez, Holcomb, & Grainger, 2003), but single-word presentation and parity judgments result in increased N400 when switching into L1 (Jackson, Swainson, Mullin, Cunnington, & Jackson, 2004; Litcofsky, Midgley, Holcomb, & Grainger, 2009). Interestingly, these ERP results are ambiguous with regards to the direction of code-switching that incurs increased switch costs whereas the behavioral results discussed above found increased switch costs when switching into L1 (Jiang & Forster, 2001; Basnight-Brown & Altarriba, 2007). It is possible that these discrepancies arise from differential processing demands of the tasks.

The studies reviewed above have examined code-switching at the single-word-level. However, code-switching, which occurs in conversation in real-life settings, is found within a larger context. Although most studies have examined word-level code-switching, several studies have examined processing of code-switched words within a larger sentence context (Moreno, Federmeier, & Kutas, 2002; Proverbio, Leoni, & Zani, 2004). Proverbio, Leoni, and Zani (2004) studied code-switching within highly proficient bilinguals (e.g., simultaneous interpreters). Participants read sentences which began in L1 or L2 and then either continued in the original language of the sentence or switched to the other language. Half of the sentences included an unexpected final word (semantic incongruence) and participants judged how well the sentence-final word fit with the rest of sentence. A larger amplitude N400 was evoked all code-switched words compared to non-switched words, and this effect was greater when switching from L1 into L2 than when switch from L2 into L1. Behaviorally, participants also had faster RTs to sentences going from L2 into L1 than L1 into L2, replicating the ERP data. However, it is important to note that participants were highly balanced bilinguals (i.e., equally proficient in L1 and L2) and sentences were blocked by type (i.e., in one block participants saw only sentences that contained code-switches and in another block only sentences without code-switches) so that the switch was entirely predictable. Thus, the results may be particular to highly balanced bilinguals and not be generalizable to second language learners. Moreover, it is possible that in a paradigm where the switches are unpredictable (i.e., not blocked by type), there will be greater effects of switching in the form of greater amplitude N400s, especially to the sentences switching from L1 into L2, because the L2 items would be more unexpected.

Finally, Moreno, Federmeier, and Kutas (2002) examined neural activity evoked to within-sentence lexical switches (e.g. "Each night the campers built a *blaze*."), language switches (e.g., "Each night the campers built a *fuego.*"), or no-switch sentences (e.g., "Each night the campers built a *fire*.") in balanced bilingual subjects. All sentences began in English (L1) and the sentence-final word was either an expected word, a lexical switch (an unexpected word), or a code-switch (the translation equivalent of the expected word). Results demonstrated that the lexical switches and code-switches elicited the same amplitude N400, but that the scalp distribution of the effects differed. Lexical switches evoked the classic N400 scalp distribution with maximal negativity in centroparietal sites, medial, and more right lateralized, while code-switches were most negative frontally and left lateralized[1]. In addition to the N400, code switches also evoked a larger amplitude LPC where the code-switch was more positive than the non-switch and more positive than lexical switches. These results indicate that the processing of code-switches within sentences is not merely the same as encountering an unexpected word. Specifically, the presence of an LPC in addition to the N400 effect indicates that code-switches evoke an additional reprocessing cost or involve an additional repair relative to unexpected words.

These few studies that have dealt with code-switching in sentences have all stopped at the code-switched word. Yet conversations do not stop as soon as a code-switched item is introduced. Thus, it is important to investigate the neural processing associated with words following a code-switched word. The current study examined within-sentence code-switches at and beyond a code-switched word. In order to examine whether additional code-switching costs are found beyond the code-switched word, the present study included sentences that had no, one, or two code-switches (see Table 1) . In the no code-switch condition, sentences were presented in all one language (i.e.., all in English or all in French) – e.g., "Let's have some cheese before our meal". In the one code-switch condition, only the mid-sentence noun and the remainder of the sentence was replaced with the French translation equivalent – e.g., "… fromage avant notre repas". In the two code-switch condition, a mid-sentence noun was replaced with a word in the other language. Thus, if a sentence began in English, the noun would be presented in French – e.g., "cheese" was replaced with French translation equivalent "fromage" and the remainder of the sentence would be in English.

We had several predictions. Firstly, we expected to replicate Midgley, Holcomb, and Grainger (2009) and find overall language effects where L1 items elicit a larger amplitude N400 than L2 items. Secondly, we aimed to replicate previous findings for the first code-switched word. That is, switch conditions (i.e., one-switch and two-switch conditions) should elicit greater amplitude N400s and larger LPCs than non-switch conditions indicating that code-switched words are more difficult to integrate into the preceding context than non code-switched words (Moreno et al., 2002).

We examined the sentence-final word to determine whether both, or only one of the presented languages was available to the reader, indicated by ease of processing. There were three possibilities concerning the ease of processing the words following the code-switched word. First, both languages could be equally available such that conditions remaining in the code-switched language (i.e., one-switch condition) and conditions switching back into the context language (i.e., two-switch condition) would elicit similar processing. If this were the case, we should find similar amplitude N400s and LPCs in the one and two code-switch condition at the sentence-final word and both conditions should show greater N400s and LPCs than the no code-switch condition. Second, switching back into the context language could be harder than remaining in the code-switched language indicating that there has been a switch into the code-switched language. If this were the case, we should find greater amplitude N400s and LPCs to the two code-switch condition compared to the one code-switch condition and both greater than the no code-switch condition. Finally, switching back into the context language could be easier than remaining in the code-switched language indicating that the code-switched word is just a temporary access into the other language. If this were the case, we should find greater amplitude N400s and LPCs to the one code-switch condition compared to the two code-switch condition and both greater than the no code-switch condition.

Method

Participants

Twelve undergraduates from Tufts University, aged 18 to 22 (mean age = 21.6, 9 female), participated in this experiment for cash. Written informed consent was obtained from all participants. All were right-handed, native speakers of English, with normal or corrected-to-normal vision, and no history of traumatic brain injury or psychiatric disorders. Participants were L2[2] French speakers who had learned French in a school setting and had spent an extended period of time immersed in French culture and language within the last two years (e.g., had studied abroad in France). There was no significant exposure to another language before the age of five. To ensure a sufficient level of French proficiency, participants completed a Language History Questionnaire in which they rated their French speaking, reading, and comprehension ability (see Table 2). Eight participants were enrolled in an upper-level French class at the time.

Design and Stimuli

Two-hundred and forty sentence scenarios were created. The English and French versions of each scenario were translation equivalents. Sentences began in either English or French and finished in one of three code-switch conditions: no code-switch, one code-switch, or two code-switches. Every scenario was rotated through all six conditions (see Table 1).

Each sentence began with 3-6 words that constituted the context. This context was followed by a noun, a preposition, one or two intervening words (articles), and a sentence-final noun. We analyzed two words in every sentence – the Critical Word (CW) and the Sentence-Final Word (SFW). The CW was the site of the first code-switch and immediately preceded the preposition. Following this code-switch, sentences either remained in the code-switched language (one code-switch condition) or switched back into the context language (two code-switch condition). In addition, one-third of the sentences included no code-switches (i.e., appeared all in English or all in French). The SFW was examined as the first content word following the second code-switch.

All CWs and SFWs were non-cognate, one-to-one translation equivalents. Non-cognates are words whose translation equivalents in each language do not share orthography or phonology; thus it is readily apparent to which language they belong. A one-to-one translation equivalent means that the two words refer to the same semantic item and only to that item in each language. Scenarios contained the same number of words in every condition (including numbers before and after the CW) and expressed the same semantic content in each condition. In order to ensure that all scenarios were highly natural-sounding, all French sentences were rated to be highly French-sounding ('4' or '5' on a 5-point scale) by a native-French speaker.

In addition, we included 60 filler scenarios to ensure that participants read all sentences for comprehension. Participants' task was to make a plausibility judgment on each sentence. Filler scenarios were constructed in the same pattern as the experimental stimuli, with the exception that the SFW was a semantically anomalous noun. To ensure a clear distinction between the plausible/experimental sentences and the implausible/filler sentences, ratings were collected from eight native-English speakers on the English sentences of each scenario. The ratings consisted of making a plausibility judgment on all 300 stimuli (experimental and filler were intermixed in one list). Raters were instructed to indicate whether or not the sentence was "possible in the real world". Those sentences that were not rated highly plausible (experimental sentences) nor highly implausible (filler sentences) (e.g., at least six out of the eight rated the sentences as plausible or implausible) were reconstructed.

All 300 scenarios were rotated through 6 lists using a Latin Square design such that each participant saw each scenario in only one condition, but all scenarios were seen en each condition across participants. In addition, sentences were blocked by the context language. Order of context language was counterbalanced such that half of the participants saw lists 1-6 with the English context block first and the other half of participants saw lists 1-6 with the French context block first.

Procedure

Participants were told that they would be reading sentences that first began in English (or French, depending on the block), but that they may notice some of the words within the sentences were in French (or English). Participants were instructed to read for comprehension and make a plausibility judgment on the semantic content of all sentences regardless of language

Trials began with the word “READY” or “PRÊT” (depending on the context language of the sentence) in the middle of the screen. At this time participants were able to blink and pressed a button to begin the trial. A fixation cross appeared on the screen for 550 ms followed by a 100 ms interstimulus interval (ISI) to orient the participant’s gaze to the center of the screen. The sentence was then presented in rapid serial visual presentation (RSVP). Each word was on the screen for 550 ms with an ISI of 100 ms, with the exception of the SFW, which was on the screen for 700 ms followed by an ISI of 500 ms. A question mark then appeared on the screen indicating that the participant should make their decision about the plausibility of the sentence by pushing either the "yes" or "no" button on a gamepad (see Figure 4). Participants were instructed to avoid blinking until the question mark appeared on the screen. There were nine breaks during the experiment to avoid participant fatigue. Four practice sentences beginning in English and four practice sentences beginning in French were presented prior to the experiment to familiarize the participant with the procedure and the task. Following the ERP recording, participants completed a post-translation test in which they translated all CWs they viewed in French (dependent upon list) from French to English (L1 → L2).

EEG Recording Procedure

Participants were seated in a comfortable chair about 76 cm from the computer in a sound-attenuated darkened room. An elastic cap (Electro-Cap International) with 29 active tin electrodes was placed on the participant's head. The electrodes were located in the standard International 10-20 system locations as well as at additional sites over the left and right hemispheres (see Figure 5).

Electrode locations consisted of five sites along the midline (FPz, Fz, Cz, Pz, Oz), three medial electrode sites over each hemisphere (FC1/FC2, C3/C4, CP1/CP2), four lateral electrodes over each hemisphere (F3/F4, FC5/ FC6, CP5/CP6, P3/P4), and five peripheral sites over each hemisphere (FP1/FP2, F7/F8, T3/ T4, T5/T6, O1/O2). In order to monitor vertical eye movements/blinks and horizontal eye movements, electrodes were placed below the left eye and lateral to the right eye respectively. Electrodes were referenced to the left mastoid and an electrode placed on the right mastoid monitored differential mastoid activity.

The electroencephalogram (EEG) was amplified by a SA Bioamplifier using a bandpass of 0.01 to 40 Hz and was continuously sampled at a rate of 200 Hz. Electrode impedances were kept below 10 kΩ for the eyes and below 5 kΩ at all other sites. For each participant, separate ERPs were averaged off-line at each electrode site for each experimental condition. Trials contaminated with eye artifact or amplifier blockage were not included.

Data Analysis

Analyses of CWs and SFWs were conducted on mean amplitude values with a baseline of 100 ms activity preceding word onset. Analyses were conducted at 300-500 ms and 500-700 ms following word onset. These time windows were chosen to correspond to the typical N400 time window and to the epoch of late positive components, respectively. Repeated measures analyses of variance (ANOVAs) were performed on the five midline sites and, to examine the scalp distribution of the effect, on a group of 18 non-midline sites. Language (English, French) and Switch Condition (CW – no-switch, switch; SFW – no code-switch, one code-switch, or two code-switches) were within-subjects factors in both ANOVAs. For the CW, Switch had only two levels because the one code-switch and two code-switch conditions were combined and compared with the no-switch condition. The midline ANOVA included a factor of site (FPz, Fz, Cz, Pz, Oz) to examine the Anterior-Posterior (AP) distribution of the effect. The non-midline ANOVA included factors of Hemisphere (Left, Right), AP distribution (anterior, central, posterior), and Column (medial, lateral, peripheral) to explore the scalp distribution of the effect (see Figure 5).

The analyses compared only conditions in which the target word was in the same language to control for lexical effects[3]. A Greenhouse-Geisser correction was applied to analyses with more than one degree of freedom in the numerator. We report original degrees of freedom with corrected *p* values. Significant interactions were examined further with simple effects tests and planned comparisons.

Results

Behavioral Results

Participants averaged 65% correct on the post-translation test indicating that they satisfactorily comprehended the stimuli.

ERP Results

Artifact contamination from eye movement or amplifier blocking led to the rejection of 12% of trials at the CW and 14% of trials at the SFW. A 2 (Language: English, French) by 2 (Switch: no code-switch, code-switch) repeated measures ANOVA for the CW and a 2 (Language: English, French) x 3 (Switch: no code-switch, one code-switch, two code-switch) repeated measures ANOVA for the SFW demonstrated that the number of trials rejected did not differ by condition (all *p*s > 0.11).

ERPs at the Critical Word

Figure 6a (ERP waves to L1 CWs) and Figure 6b (ERP waves to L2 CWs) show a negative component from 300-500 ms post-stimulus onset and a positive component from 500-700 ms post-stimulus onset.

N400 (300-500 ms). Overall, as expected, L1 critical words elicited a larger N400 amplitude than did L2 critical words, and this was verified by main effects of Language (midline: $F(1, 11) = 22.12$, $p < 0.01$; non-midline: $F(1, 11) = 14.51$, $p < 0.01$).

Despite there being no Language x Switch interactions (all *F*s < 1.83, all *p*s> 0.20), we examined L1 (English) and L2 (French) CWs separately since we had predicted different patterns of results for each language. There were no significant Switch effects for L1 CWs (all Fs < 2.24, all ps > 0.26). A different pattern of results emerged for L2 CWs. As observed in Figure 6b of L2 CWs, the non-switch condition (L2-L2) was more negative than the switch condition (L1-L2). This was confirmed by a Switch by Hemisphere by AP Distribution interaction ($F(2, 22) = 6.10$, $p < 0.01$), which we followed up with simple effects ANOVAs[4] . Visual inspection of the ERP waves indicated that this difference was maximal at right hemisphere anterior sites.

Late positivity (500-700 ms). There were no main effects of Language (midline: $F(1, 11) = 1.48$, $p > 0.10$; non-midline: $F(1, 11) = 2.32$, $p > 0.10$) nor of Switch (midline: $F(1, 11) = 0.07$, $p > 0.10$; non-midline: $F(1, 11) = 0.01$, $p > 0.10$). However, there was a Language by Switch by Column by Hemisphere interaction (midline: $F(4, 44) = 3.17$, $p = 0.07$; non-midline: $F(2, 22) = 4.28$, $p < 0.05$) and a Language by Switch by AP Distribution interaction at non-midline electrode sites ($F(2, 22) = 11.70$, $p < 0.01$).

To examine these interactions and to follow-up a priori predictions, we analyzed L1 and L2 CWs separately. For the L1 CWs, there were neither significant main effects of Switch (midline: $F(1, 11) = 0.51$, $p > 0.10$; non-midline, $F(1, 11) = 0.77$, $p > 0.10$) nor interactions with AP Distribution (all ps > 0.08) nor with Hemisphere (all ps > 0.16).

In contrast, as seen in Figure 6b, the L2 switch condition (L1-L2) was more positive than the L2 non-switch condition (L2-L2). This was confirmed by a Switch by Hemisphere by AP Distribution interaction, $F(2, 22) = 0.05$, $p < 0.05$. Subsequent simple effects ANOVAs indicated that there were a significant Switch by AP Distribution interactions in the right hemisphere ($F(2, 22) = 0.4.55$, $p = 0.05$) and left hemisphere ($F(2, 22) = 4.64$, $p < 0.05$). Although no significant effects of Switch were found at anterior, central, or posterior sites (all *p*s > 0.17), visual inspection indicated that the difference between the L2 switch condition and the L2 non-switch condition was greatest at posterior electrode sites.

ERPs at the Sentence Final Word

Figure 7a (ERP waves to L1 SFWs) and Figure 7b (ERP waves to L2 SFWs) show a negative component from 300-500 ms post-stimulus onset and a positive component from 500-700 ms post-stimulus onset.

N400 (300-500 ms). At the sentence-final word, there were main effects of Switch (midline, trend: $F(2, 22) = 3.58$, $p < 0.10$; non-midline: $F(2, 22) = 3.98$, $p < 0.05$) and, importantly, Switch interacted with Language, Column, and Hemisphere (non-midline: $F(4, 44) = 7.47$, $p < 0.001$), and with Language and AP Distribution, (non-midline: $F(4, 44) = 4.11$, $p < 0.05$).

In order to further explore these Switch x Language interactions, we examined L1 and L2 SFWs separately. As seen in Figure 7a showing L1 SFWs, the two code-switch condition (L1-L2-L1) was more negative than the one code-switch condition (L2-L1-L1), which was more negative than the no code-switch condition (L1-L1-L1). This was verified by main effects of Switch (midline, trend: F (2, 22) = 3.11, $p < 0.10$; non-midline: $F(2, 22) = 4.03$, $p < 0.05$) and interactions of Switch by AP Distribution (midline: $F(8, 88) = 3.82$, $p < 0.05$; non-midline, $F(4, 44) = 6.59$, $p < 0.01$). Subsequent simple effects tests were used to examine the scalp distribution of these effects and demonstrated that the difference between Switch conditions was maximal over anterior electrode sites (midline: FPz: $p < 0.01$; Fz: $p < 0.05$; Cz: $p < 0.10$; Pz: $p > 0.10$; Oz: $p > 0.10$; non-midline: anterior: $p < 0.05$; central: $p < 0.05$; posterior: $p > 0.10$).

As seen in Figure 7b the L2 SFWs elicited a different pattern of results than did the L1 SFWs. For the L2 SFWs, the one code-switch condition (L1-L2-L2) was more negative than the two code-switch condition (L2-L1-L2), which was more negative than the no code-switch condition (L2-L2-L2). Although there were no main effects of Switch (midline: $F(2, 22) = 1.86$, $p > 0.10$; non-midline: $F(2, 22) = 2.12$, $p > 0.10$), there was an interaction of Switch by Column by Hemisphere (non-midline: $F(4, 44) = 4.11$, $p < 0.05$)[5]. Visual inspection indicated that the difference between the three conditions was maximal at medial anterior sites.

Late positivity (500-700 ms). In the late time window, there was a marginal Language by Switch by AP Distribution interaction in the non-midline sites (midline: $F(8, 88) = 1.23$, $p > 0.10$; non-midline: $F(4, 44) = 2.60$, $p < 0.10$). In order to explore our a priori predictions that each language would elicit a different pattern of results and to further explore this marginal interaction, subsequent simple effects ANOVAs were conducted to examine if there were differences between L1 and L2 SFWs.

There were no significant effects for L1 SFWs (all *p*s > 0.15). In contrast, for L2 SFWs, there was an interaction of Switch by Column by AP Distribution (non-midline: $F(8, 88) = 3.17$, $p < 0.05$)[6]. Visual inspection indicated that the no code-switch condition (L2-L2-L2) was more positive than the two code-switch condition (L2-L1-L2), which was more positive than the one code-switch condition (L1-L2-L2). This difference appeared to be greatest at medial anterior sites.

ERPs to Semantically Incongruous Sentence-Final Words

Finally, in order to ensure that participants read all scenarios for comprehension, we examined the ERPs evoked to semantically incongruous SFWs (filler scenarios) relative to congruous SFWs (experimental scenarios). Figure 8 (ERP waves to Semantically Incongruous SFWs) shows a negative component from 300-500 ms post-stimulus onset and a prolonged negativity from 500-700 ms post-stimulus onset.

N400 (300-500 ms). Overall, semantically incongruous SFWs elicited larger amplitude N400s than did congruous SFWs as demonstrated by main effects of Anomaly (midline: $F(1, 11) = 9.07$, $p < 0.05$; non-midline: $F(1, 11) = 6.70$, $p < 0.05$). However, when L1 and L2 SFWs were examined separately, differences between the languages were observed. Specifically, as seen in Figure 8, whereas L1 incongruous SFWs evoked a larger negativity than congruous SFWs (main effect of Anomaly – midline: $F(1, 11) = 11.78$, $p < 0.01$, non-midline: $F(1, 11) = 8.37$, $p < 0.05$), there was no significant effect of Anomaly for L2 SFWs (midline: $F(1, 11) = 0.25$, $p > 0.10$; non-midline: $F(1, 11) = 0.03$, $p > 0.10$).

Late positivity (500-700 ms). There were no main effects of Anomaly (midline: $F(1, 11) = 0.00$, $p = 0.96$; non-midline: $F(1, 11) = 0.987$, $p = 0.34$) nor interactions with Anomaly (all Fs < 3.70 , all ps > 0.07). In addition when L1 and L2 SFWs were examined separately, there were no main effects of Anomaly or interactions with Anomaly for either L1 SFWs or L2 SFWs (all ps > 0.20).

Discussion

It is well established that the first code-switch incurs a processing cost as it is an unexpected occurrence (Jiang & Forster, 2001; Moreno, Federmeier & Kutas, 2002; Finkbeiner, 2004; Proverbio, Leoni, & Zani, 2004; Jackson, Swainson, Mullin, Cunnington, & Jackson, 2004; Basnight-Brown & Altarriba, 2007; Philipp, Gade, & Koch, 2007; Chauncey, Grainger, & Holcomb, 2008; Litcofsky, Midgley, Holcomb, &

Grainger 2009). However, it is less certain how the words are processed immediately following that code-switch. The current study examined what happened after this code-switch by visually presenting English-French bilinguals sentences that contained no code-switch, one code-switch, or two code-switches. By comparing the one code-switch condition to the two code-switch condition, we could identify whether the comprehender reacts to the first code-switch by anticipating the subsequent words to be in either language, in the first-presented language or in the second-presented language. We predicted one of three things to happen – 1) that both languages would be equally available and there would be no difference between switching back into the first-presented language and remaining in the second-presented language, 2) that the language of the code-switch would be more available than the original languages as comprehenders would expect the subsequent words to remain in that language, or 3) that the comprehender would treat the first code-switch as temporary and would thus expect the subsequent words to be in the original language. We first discuss results at the critical code-switched word and then turn to findings of the sentence-final word.

Finally, it is important to note that participants were reading for comprehension as typical N400 effects were evoked when comparing semantically incongruous sentence-final words to congruous sentence-final words. The N400 component is known to index semantic incongruity within sentences (Kutas & Hillyard, 1980). Semantically incongruent words are unexpected given the context of the sentence thus necessitating extra processing to integrate that word into the context. This finding of the expected N400 indicates that participants were attending to the stimuli, allowing us to relate our findings specifically to the code-switching in the sentences.

We found an overall effect of language such that L1 items evoked a larger amplitude N400 than L2 items at the critical word. This finding replicates previous research (Midgley, Holcomb, & Grainger, 2009) in that second language learners tend to have attenuated ERPs in their L2 compared to balanced bilinguals who show equal amplitude ERPs to L1 and L2 items. Despite the fact that N400s are generally larger for items hard to integrate or more unexpected, which would appear to be L2 items, Midgley et al. posit that language learners, who have not yet achieved fluency in their L2, have weaker representations of L2 items and fewer connections between L2 items than L1 items.

In addition, our results partially replicated the previous research on the first code-switched word in the sentence, the critical word. Previous studies have found an N400 to the code-switched word compared to the non-switched word when switching from L1 into L2 in sentences (Moreno, Federmeier, & Kutas, 2003). We found an N400 and an LPC to the switch condition compared to the non-switch condition when the code-switched word was in L2, but not in L1. This results differ from the behavioral and single-word ERP results that larger switch costs when switching into L1 (Jiang & Forster, 2001; Jackson, Mullin, Cunnington, & Jackson, 2004; Basnight-Brown & Altarriba, 2007; Litcofsky, Midgley, Holcomb, & Grainger, 2009). One potential reason for the discrepancy is that most previous studies have examined balanced or highly proficient bilinguals (Moreno et al., 2003). With this population, in order to successfully process words in L2, comprehenders must inhibit L1 words. When an L1 word is then encountered, it is then necessary to lift that inhibition when an L1 word is encountered, as described in the RHM (Kroll & Stewart, 1994) in that the lexicons compete for activation. However, in the current experiment, with proficient, but not balanced bilinguals, who have not yet formed symmetrical links between L1 and L2, it is not necessary to inhibit L1 words in order to successfully comprehend L2 code-switched words. Conversely, with this less proficient population, when working in L2, L1 is automatically activated via lexical links, therefore when an L1 code-switched word is encountered there is less difficulty to full access L1 and it is not difficult to suppress L2.

An additional or alternative reason for the discrepancy between studies is that the majority of previous studies were examining code-switching at the word-level whereas this study examines code-switching at the sentence-level. While at the word-level it is necessary to inhibit L1 words competing for selection during lexical access, at the sentence-level efforts are concentrated on integrating the incoming information into the preceding context. Thus, when working in L2, efforts are focused on fully comprehending the L2 information, which may depend on translating the L2 words into L1 in less proficient bilinguals. Whereas at the word-level, it is necessary to inhibit the L1 words in order to access L2 words, at the sentence-level, it may be necessary to activate L1 words in addition to L2 words. This online L2 to L1 translation may have been made possible by the long word presentation duration. Each word was presented for 550 ms with a 100 ms interstimulus interval, during which time it may have been possible to translate the L2 item into L1. In order to examine the influence of presentation rate, future studies should manipulate the duration of word presentation to find the minimum duration necessary to comprehend L2 words without having ample time to translate those words into L1.

Moreover, we did not find any LPC modulation at the critical word, inconsistent with previous findings (Moreno et al., 2002). While Moreno et al. found an increased LPC to code-switched words compared to non-switched words, they tested balanced bilinguals who had achieved "near-native fluency" in their L2. Proficiency is known to affect the quality of processing (Midgley, Holcomb, & Grainger, 2009). As discussed above, language learners, or less proficient bilinguals, tend to have weaker representations of their L2 and rely more heavily on the lexical links from the L2 lexicon to the L1 lexicon, as proposed by the RHM (Kroll & Stewart, 1994). Balanced bilinguals, on the other hand, have nearly equal representations of each language, possibly a shared lexicon, and can function in each language directly with the conceptual representations, as suggested by the BIA (Grainger & Dijkstra, 1992; Dijkstra & van Heuven, 1998) and BIA+ models (Dijkstra & van Heuven, 2002).

We next turn to our critical question of which language is available following the code-switched word. For all L1 sentence-final words regardless of context language of the sentence, we found the largest amplitude N400 evoked to the two code-switch condition, followed by a medium-sized N400 amplitude to the one code-switch condition, and the smallest amplitude N400 was evoked to the no code-switch condition. This pattern would suggest that it is harder to switch back into the context language after encountering a first code-switch than to simply remain in the code-switched language. The L2 SFWs showed a different pattern. The one code-switch condition elicited the greatest N400, followed by the two code-switch condition, and the no code-switch condition had the smallest N400. This result suggests that it is harder to remain in the code-switched language than revert back to the context language. These two patterns of result seem incompatible. The L1 code-switches seem to imply that a code-switch of one noun acts as an entire code-switch into the other language, while the L2 code-switches imply that the code-switch of one noun is only a "borrow" from the other language and that the base language of the sentence remains the original language.

These results, at first glance, may seem difficult to reconcile, but, a visual inspection of the one-code switch condition (e.g., My cousins have a *piscine derrière leur maison*) to the no code-switch condition (e.g., My cousins have a pool behind their house.) for both L1 and L2 and the two code-switch condition (e.g., My cousins have a *piscine* behind their house.) to the no code-switch condition (e.g., My cousins have a pool behind their house.) for both L1 and L2, suggests that all comparisons indicate that it is more difficult to switch into L2, regardless of context[7]. For both L1 and L2 sentence-final words, the one code-switch condition was more difficult relative to the no-switch condition, as demonstrated by a larger amplitude N400 to the switch condition. Based on visual inspection, the difference between the conditions was greater for the L2 SFWs. This means that it was more difficult to switch from L1 into L2 and remain in L2 than to switch from L2 into L1 and remain in L1. This is intuitive as it means that it is harder to work in L2 compared to L1, something assumed for unbalanced bilinguals. Moreover, this replicates the findings at the CW where it was harder to switch into L2 than to L1.

The two code-switch comparison allows for inferences to be made about the effect of borrowing a word from the other language. For both languages, the two code-switch condition was harder (indexed by a greater N400) than the no code-switch condition, however, this difference appears to be greater for the L1 SFWs (i.e., comparing a sentence all in L1 with a sentence in L1 with two code-switched word in L2) than for the L2 SFWs. These results suggest that, when working in an L2 sentence, these low proficient bilinguals are already activating and relying to some extent on the L1 translation of the sentence. Thus, when an L1 word is encountered, it does not require a lot of extra processing and is not entirely unexpected. On the other hand, when in an L1 sentence, the L2 of a language learner is not activated as it is not necessary for comprehension, but when an L2 word is encountered, it is necessary for much extra processing to access this weaker language and to inhibit the dominant L1. As discussed above, these findings demonstrate that it is harder to borrow a word from L2 than it is from L1.

Overall, these results seem to be consistent with the predictions of the RHM (Kroll & Stewart, 1994) in that asymmetric results were found. It seems that the present participants, while capable in their L2, relied quite heavily on the L2-L1 lexical links. Increasing the likelihood of relying on these links was the relatively long word duration employed in this study; specifically each word of the sentence was displayed onscreen for 550 ms with a 100 ms ISI. This is ample time for the participant to recognize the L2 word and translate the word into their L1. Such a long display was chosen to ensure that participants had sufficient time to recognize and process the L2 words as they are less familiar at encountering them. However, future studies should have shorter word presentations to prevent the time for translating to see if language learners still are able to comprehend L2 items. That is, if the presentation is shortened to not allow translation, are these learners able to rely on L2 processing alone? If not, this would provide more support for the RHM and the asymmetrical links where L2 relies heavily on L1. However, if language learners were able to successfully comprehend L2 items at a shorter display time, it would suggest that when pressed for time, learners are able to rely solely on L2 processing.

Importantly, while the present findings seem most consistent with the RHM (Kroll & Stewart, 1994), this evidence does not invalidate the BIA (Grainger & Dijkstra, 1992; Dijkstra & van Heuven, 1998) and BIA+ (Dijkstra & van Heuven, 2002) models are incorrect. As suggested by Midgley et al. (2009), it seems that the RHM most aptly describes the processing of L2 learners, while the BIA and BIA+ is more appropriate for balanced bilinguals. If this study were conducted with balanced bilinguals, we would expect to find a different pattern of results, wherein the switch costs were equal for both languages. This is because in balanced bilinguals both languages are represented fairly equally and one language does not rely on the other language for processing.

In addition, as discussed in the Introduction, switch costs do not pose a problem for the language nonselective argument as a code-switched word is an unexpected event and the fact that it can be recognized while in the context of a sentence in the other language gives support to the argument that both languages are available during lexical access. While it seems like the presence of switch costs would indicate that the participants were functioning in a monolingual mode and then had to switch into another monolingual mode (that of the code-switched language), it is highly improbably that these individuals were in a monolingual mode. That is because the participants were recruited because they were bilingual and were constantly reading sentences with code-switches. While the number of words in the context language was varied and a condition was included without code-switches in order to lessen the expectation of a specific code-switch, participants still knew that overall they would be encountering both L1 and L2 items. That the switch costs were found even though participants knew that code-switches would appear speaks to the ability for a few words in one language to create the expectation for the subsequent words to remain in that language.

While this study provides good evidence for what happens after the first code-switch in sentences, there are several limitations. First, although the present study examined code-switching during reading, in reality code-switching is mainly an oral phenomenon. Studies on the production of code-switches have focused on the inhibition of the non-target language and have found asymmetrical switch costs where switching into the dominant L1 is harder than switching into the weaker L2 (Meuter & Allport, 1999; Kroll, Bobb, Misra, & Guo, 2008; for a review of switching and neuroimaging, see Abutalebi & Green, 2008). Therefore, future studies should examine code-switching using aural presentation.

Future studies should also examine both early and late language learners. Participants in the present study were late bilinguals – all participants began learning L2 French after the age of 5 and most learned it in a school setting. Early bilinguals – those who learned both languages simultaneously from a young age – would presumably function under the guidelines of the BIA or BIA+. Like late, balanced bilinguals, early bilinguals should show switch costs because a code-switch still represents an unexpected event, even if the L2 items can be processed without extra effort.

Moreover, the present findings are based on results from 12 participants in the study. Aside from giving low power for statistical analyses, this means that there was high amounts of variation in the proficiency and language history of the participants. We believe that with more participants, we would find a similar, but stronger, pattern of results.

In addition to conducting this study with different populations of bilinguals, it would be interesting to manipulate the length of the first code-switch. As our analysis by visual inspection indicated, a simple one word borrowing from the other language behaves differently than a full code-switch into the other language. In comparing a code-switch of one word in the other language to a code-switch of multiple words – encompassing a noun phrase, a verb phrase, or an entire clause – we could determine if the nature of the code-switch affects the quality or magnitude of the switch cost. Moreover, it would be beneficial to investigate code-switching within discourse as conversations encompass a series of sentences. This would allow for a better approximation of real-world code-switching.

In sum, the present study is the first to examine the neural correlates of what occurs in a sentence following a code-switch. We demonstrated that whether the code-switched word is treated as a temporary borrowing or as a full code-switch into the other language, it is more difficult for second language learners to switch into their L2 compared to switching into their L1. These findings add to the growing literature that suggest that while code-switches frequently occur in conversation, they incur a cost associated with switching that can be modulated by the context and task of the switching, the direction of the switch, and the proficiency of the bilinguals.

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Footnotes

[1] While the authors describe this effect as an N400, given the scalp distribution of the effect, it could be considered a left anterior negativity (LAN), a component that has been associated with working memory demands (King & Kutas, 1995).

[2] One participant learned Turkish at home during elementary school before learning French in a school setting.

[3] We chose not to analyze the CW and SFW based on the context language of the sentence (cf. Moreno et al, 2002..) because it has been established that there exists language effects such that L1 items elicit greater amplitude waves compared to L2 items regardless of any lexical or frequency factor (Midgley, Holcomb, & Grainger, 2009), thus masking any effects due solely to code-switching.

[4] Simple effects ANOVAs revealed no significant Switch by AP Distribution interactions in either the right or left hemispheres (ps > 0.10).

[5] No significant effects were found in either the right or left hemispheres (all ps > .10).

[6] Follow-up tests revealed no significant effects at anterior, central, or posterior sites (all ps > 0.15).

[7] This approach maintains the control of lexical effects discussed earlier by comparing only conditions in which the target word was in the same language, but also takes into consideration the context of the overall sentence, which is more similar to the analysis of Moreno et al. (2002). Yet, since statistical analyses were not performed on these comparisons, these are currently speculative conclusions.

Table 1

Example scenario rotated through every condition.

L1-L1-L1	My cousins have a pool behind their house.
L1-L2-L1	My cousins have a piscine behind their house.
L1-L2-L2	My cousins have a piscine derrière leur maison.
L2-L2-L2	Mes cousins ont une piscine derrière leur maison.
L2-L1-L2	Mes cousins ont une pool derrière leur maison.
L2-L1-L1	Mes cousins ont une pool behind their house.

Table 2

Self-reported ratings of language abilities in L1 and L2.

	L1 English Mean (*sd*)	L2 French Mean (*sd*)
Reading	6.92 (*0.29*)	5.17 (*0.72*)
Speaking	7.00 (*0*)	4.92 (*0.67*)
Listening	7.00 (*0*)	5.00 (*0.74*)

Figure Captions

Figure 1. The Revised Hierarchical Model (RHM) of Kroll & Stewart (1994).

Figure 2. The Bilingual Interactive Activation model (BIA) of Dijkstra and van Heuven (1998).

Figure 3. The BIA+ model of Dijkstra and van Heuven (2002).

Figure 4. A typical experimental trial. The timings for each presentation are noted at left.

Figure 5. Electrode montage showing the locations of 29 scalp electrodes. The four lines indicate the four columns used for analysis (i.e., midline, medial, lateral, and peripheral).

Figure 6a. ERP waves to L1 CWs.

Figure 6b. ERPs to L2 CWs. On the left is a voltage map showing the scalp distribution of the effect. On the right are the ERP waves from three electrode sites.

Figure 7a. ERPs to L1 SFWs. In the middle are the ERP waves from three electrode sites. On either side are voltage maps showing the scalp distribution of the activation 350 ms post-stimulus onset.

Figure 7b. ERPs to L2 SFWs. In the middle are the ERP waves from three electrode sites. On either side are voltage maps showing the scalp distribution of the activation 350 ms post-stimulus onset.

Figure 8. ERP waves to L1 and L2 Semantically Incongruous Sentence-Final Words.

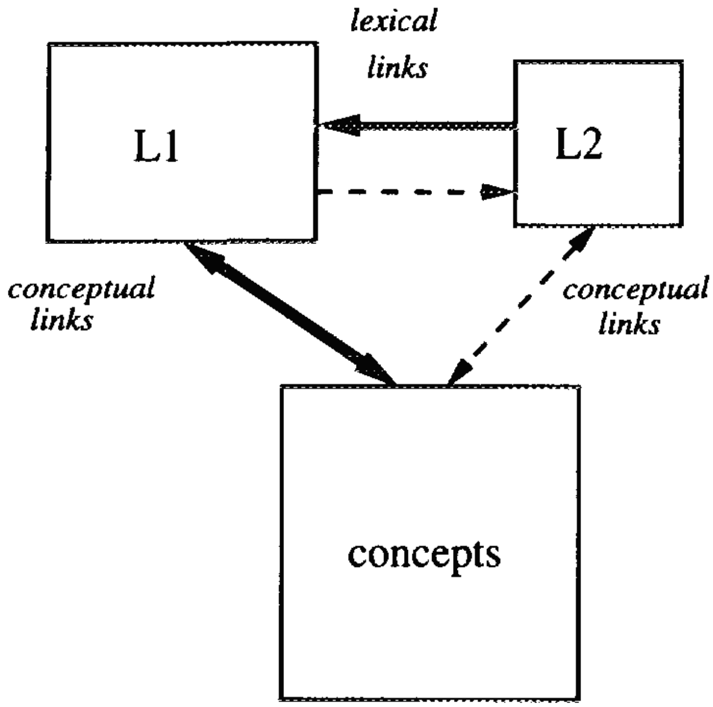

lexical
links
L1
L2
conceptual
links
conceptual
links
concepts

Figure 1.

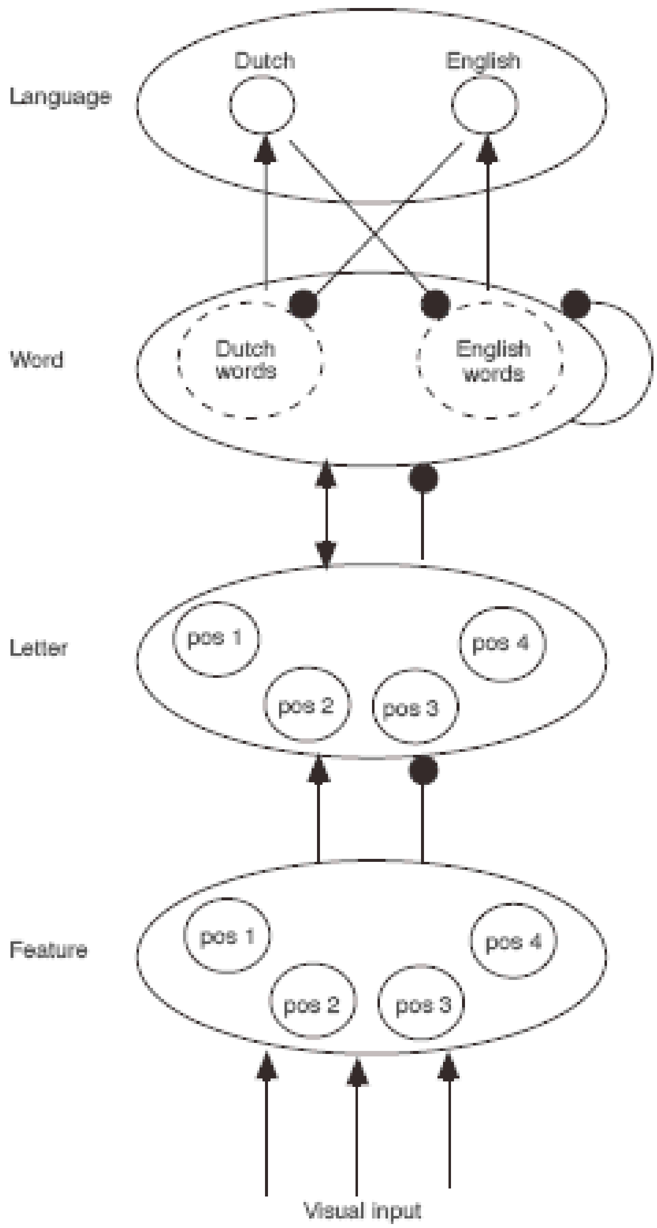

Language
Dutch
English
Word
Dutch
words
English
words
Letter
pos 1
pos 4
pos 2
pos 3
Feature
pos 1
pos 4
pos 2
pos 3
Visual input

Figure 2.

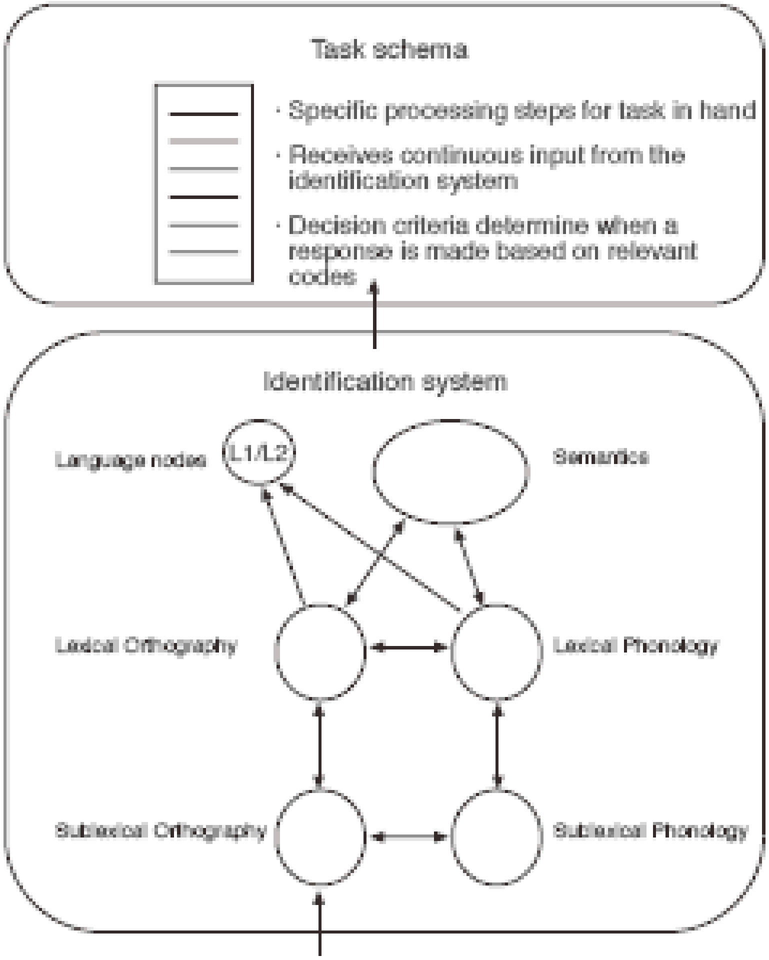

Task schema
· Specific processing steps for task in hand
· Receives continuous input from the identification system
· Decision criteria determine when a response is made based on relevant codes
Identification system
Language nodes
L1/L2
Semantics
Lexical Orthography
Lexical Phonology
Sublexical Orthography
Sublexical Phonology

Figure 3.

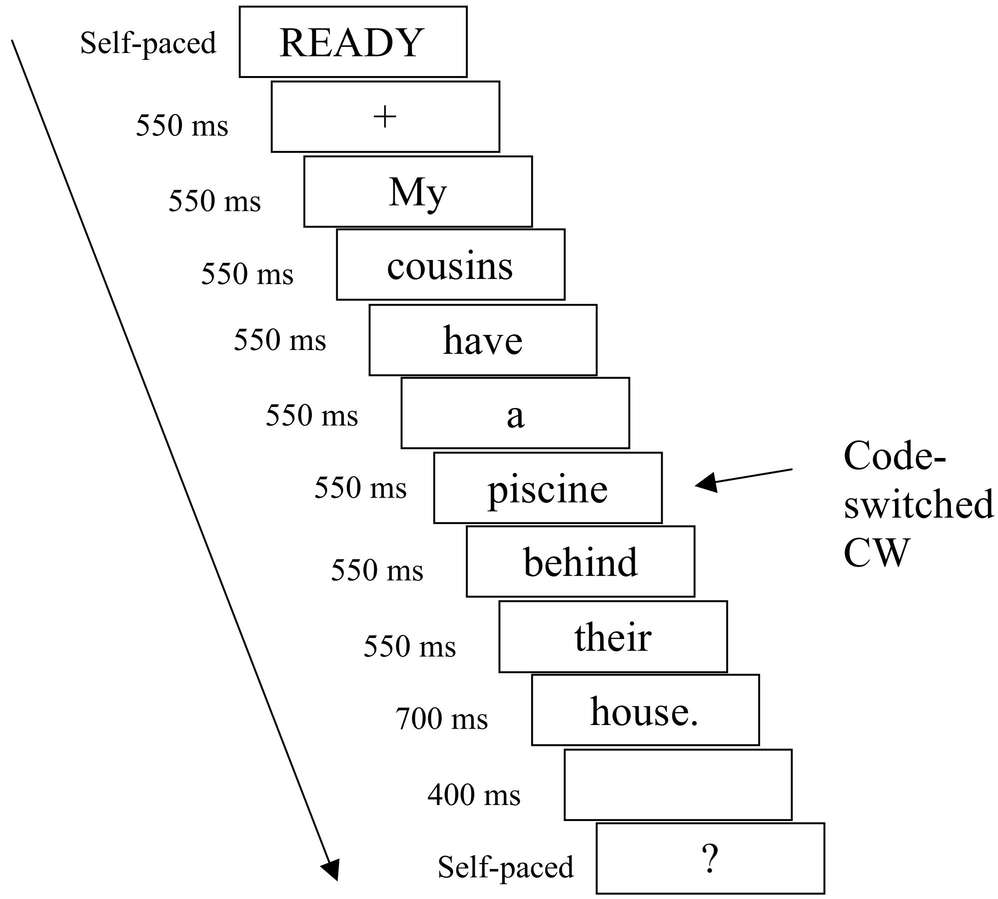

Self-paced
READY
550 ms
+
550 ms
My
550 ms
cousins
550 ms
have
550 ms
a
550 ms
piscine
Code-switched CW
550 ms
behind
550 ms
their
700 ms
house.
400 ms
Self-paced
?

Figure 4.

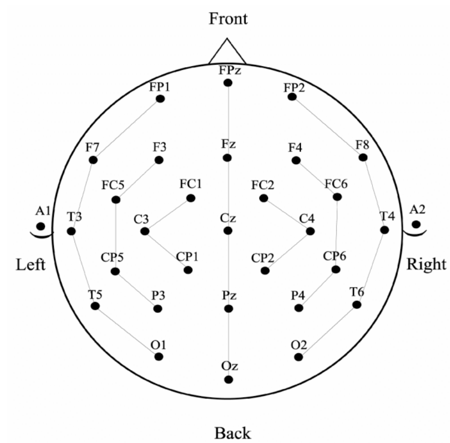

Front
FPz
FP1
FP2
F7
F3
Fz
F4
F8
FC5
FC1
FC2
FC6
A1
T3
C3
Cz
C4
T4
A2
Left
CP5
CP1
CP2
CP6
Right
T5
P3
Pz
P4
T6
O1
O2
Oz
Back

Figure 5.

L1 (English) Critical words

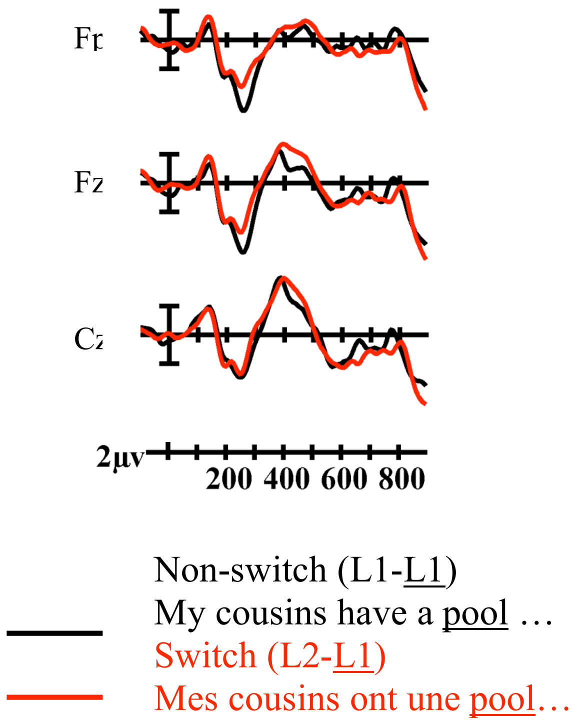
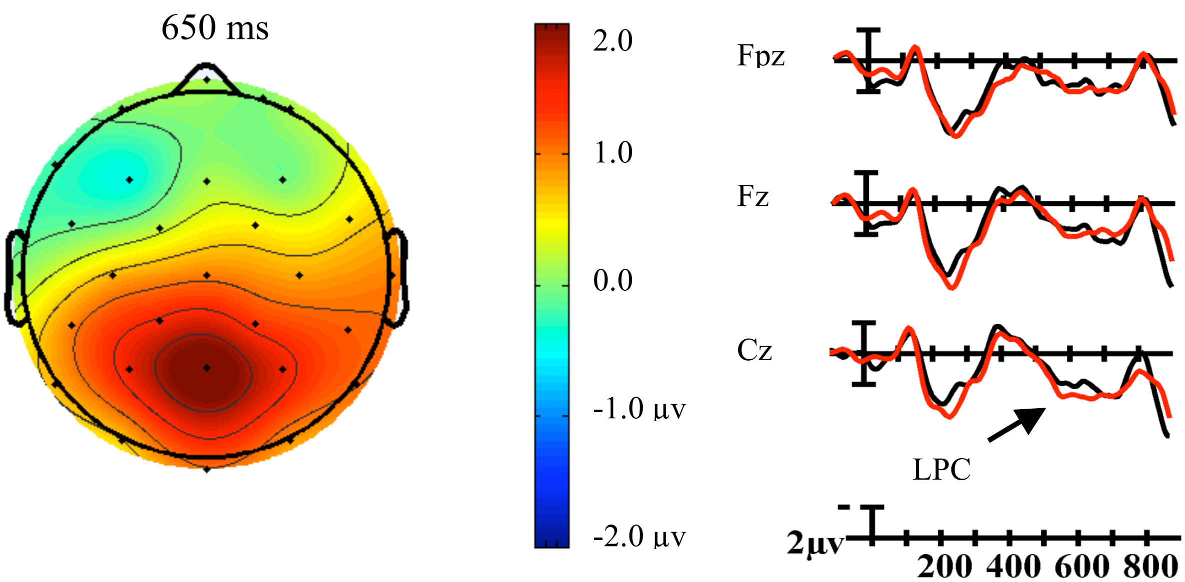


Figure 6a.

L2 (French) Critical Words



Non-switch (L2-L2)
Mes cousins ont une piscine …

Switch (L1-L2)
My cousins have a piscine…

Figure 6b.

L1 (English) Sentence-Final Words

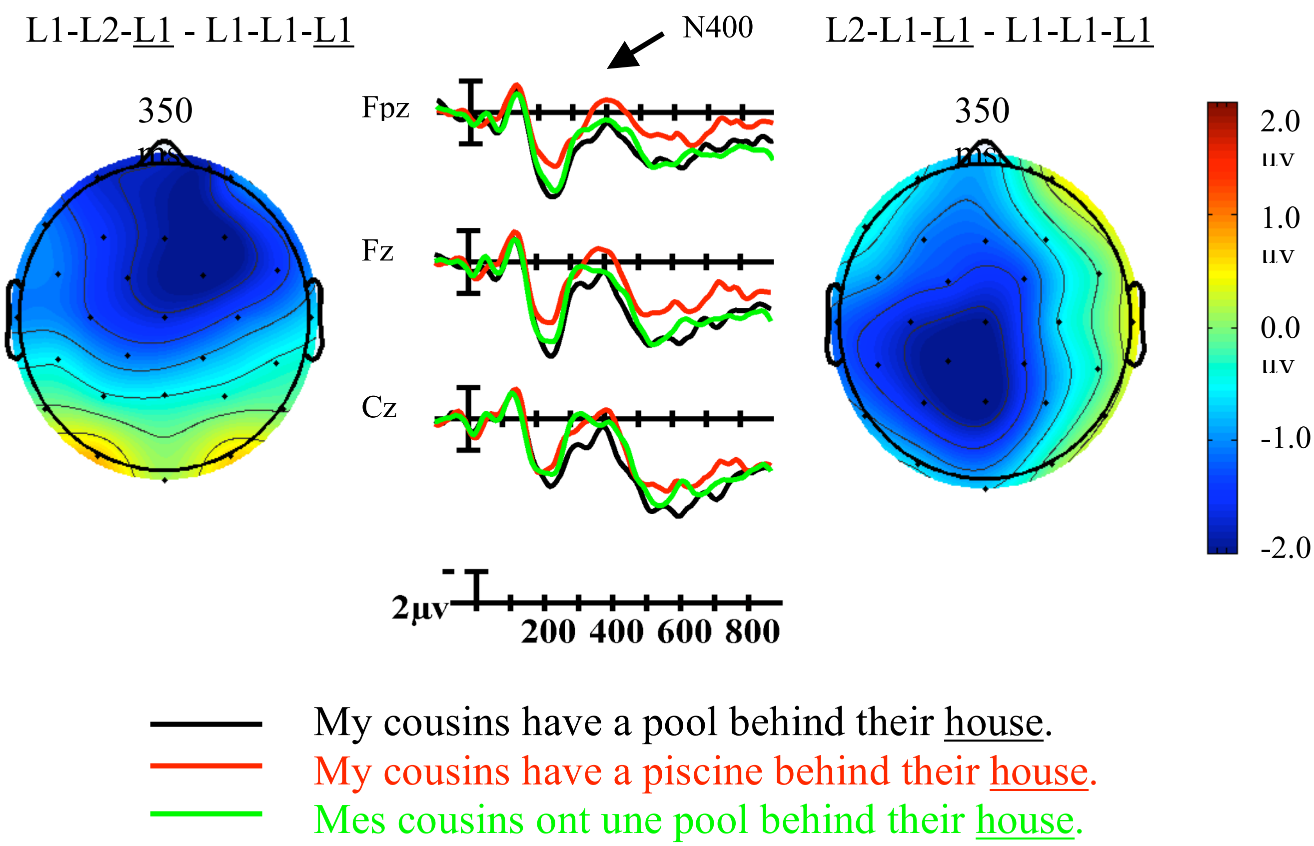


Figure 7a.

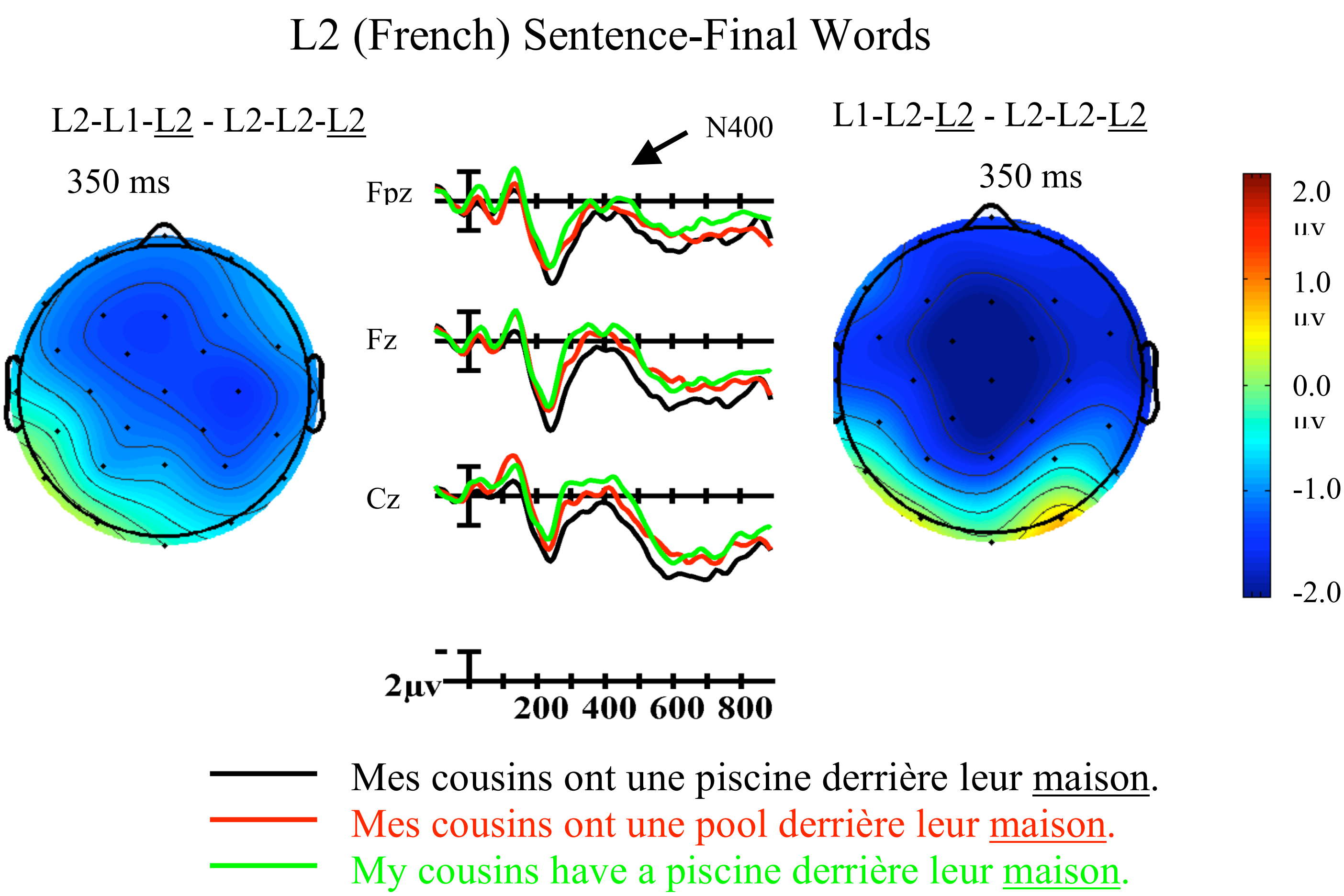
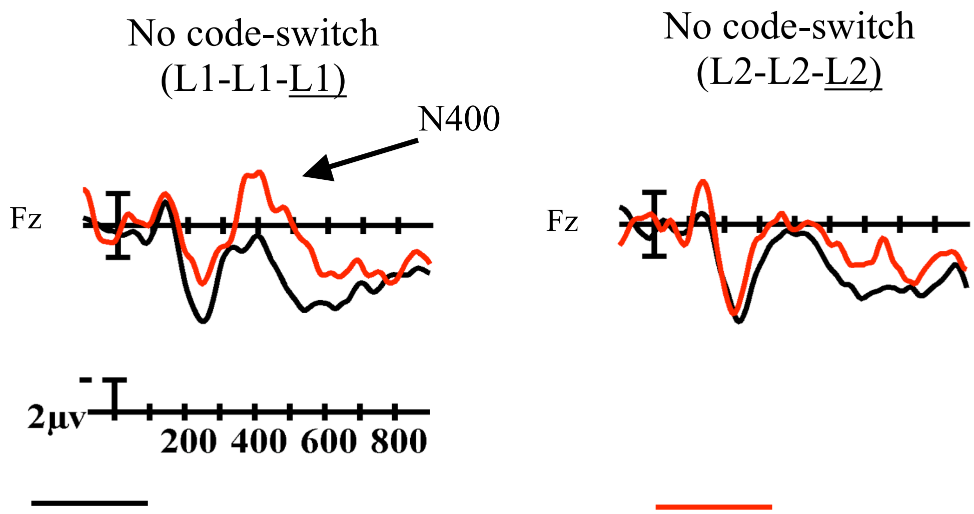

L2 (French) Sentence-Final Words
L2-L1-L2 - L2-L2-L2
350 ms
N400
Fpz
Fz
Cz
2µv
200 400 600 800
L1-L2-L2 - L2-L2-L2
350 ms
2.0 µv
1.0 µv
0.0 µv
-1.0
-2.0
Mes cousins ont une piscine derrière leur maison.
Mes cousins ont une pool derrière leur maison.
My cousins have a piscine derrière leur maison.

Figure 7b.

Incongruous SFWs



Congruous SFW - My cousins have a pool behind their house.

Incongruous SFW - The aquarium kept the whale during the candle.

Figure 8.