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Accessing word meaning in two languages: An event-related brain potential study of beginning bilinguals[☆]

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Abstract

Twenty-eight native-English speakers enrolled in beginning and intermediate university Spanish courses participated in a mixed language semantic categorization task in which critical words were presented in English (L1) and Spanish (L2) and repetitions of these words (within- and between-languages) were presented on subsequent trials (i.e., immediate repetition). Event-related potentials were recorded to all items allowing for comparisons of the N400 component to repetitions within- and between-languages as well as to words presented for the first time. Three important findings were observed in this sample of participants during relatively early stages of acquiring a second language. First, in the typical N400 window (300–500 ms), between-language repetition (translation) produced a smaller reduction in N400 amplitude than did within-language repetition. Second, the time-course of between-language repetition effects tended to be more extended in time and differed as a function of language with L2–L1 repetitions producing larger priming effects early (during the typical N400 window) and L1–L2 repetitions producing larger priming effects later (during windows after the typical N400). Third, a greater negativity in the ERP waveforms was observed when the word on the directly preceding trial was from the other language. Within the time frame of the N400, this language switch effect arose only when the target word was Spanish and the preceding word English (i.e., L1–L2). The results are discussed within the framework of current models of bilingual lexical processing.
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1. Introduction

How do speakers of more than one language represent and process the words in each language? Most current theories of bilingual lexical processing assume that the representation of words and concepts is divided into lexical and conceptual levels, one for word form representations and one for word meanings (e.g., Potter, So, Von Eckardt, & Feldman, 1984; Snodgrass, 1984). In this so-called hierarchical view, translation equivalents have separate word form representations at the lexical level, but at least partially shared semantic representations in a common semantic/conceptual system. According to one version of the hierarchical view, the word association model, words in the second language (L2) access concepts via lexical-level links with words in the first language (L1). In an alternative view, the concept mediation model, direct access to concepts is available to words in each language.

Potter et al. (1984) tested these rival hypotheses by comparing more and less fluent bilinguals in L1-to-L2 translation (e.g., see "house," say "casa") and picture naming in L2 (e.g., see a picture of a house, say "casa"). Because picture naming is thought to require retrieval of a picture's concept (Johnson, Paivio, & Clark, 1996; Potter & Faulconer, 1984) similarities in task performance would suggest that translation also requires conceptual processing, precisely what the concept mediation model predicts. In contrast, the word association model predicts that translation is faster than picture naming because it bypasses conceptual memory via lexical-level links between translation equivalents. Potter et al. (1984) found that translation and picture naming

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were performed in roughly the same amount of time regardless of bilinguals' L2 proficiency, suggesting that less and more fluent bilinguals could access concepts directly from L2 words.

Subsequent research has suggested that this might not be true for bilinguals in the early phase of L2 acquisition (the focus of this study), and that such bilinguals rely on word association with L1 to understand L2 words (e.g., Chen & Ng, 1989; Dufour, Kroll, & Sholl, 1996; Kroll & Curley, 1988; Talamas, Kroll, & Dufour, 1999). As a result, it has been proposed that beginning bilinguals access meaning for L2 words via lexical-level links with L1, and only after increased L2 proficiency do they shift to direct conceptual processing (Kroll, 1993).

In response to the evidence for a developmental shift from word association to concept mediation, Kroll and Stewart (1994) proposed a Revised Hierarchical Model (RHM). Because of the early reliance on the first language, lexical-level links are stronger from L2 to L1 than from L1 to L2, and as a result of the early grip on meaning, L1 words have a stronger connection to concepts than words in L2. It is also assumed that lexical-level links remain active after bilinguals establish direct links from L2 to conceptual memory, but the strength of these links vary with the relative dominance of each language.[1]

Because of the hypothesized asymmetric connections in bilingual memory, the RHM predicts that L1 words have privileged access to conceptual memory and L2 words privileged access to lexical representations in L1. Accordingly, backward translation (L2-to-L1) should be more likely to occur via lexical-level links, and forward translation (L1-to-L2) should be more likely to use the slower and indirect route via conceptual memory. Therefore, the revised model predicts an asymmetry in translation performance in which backward translation should be faster and less sensitive to semantic variables than forward translation. Kroll and Stewart (1994) tested these hypotheses by having bilinguals translate words that were presented in semantically blocked (e.g., arm, head, leg) and randomly mixed (e.g., shirt, sink, apple) lists. Because backward translation (L2-to-L1) was faster and more accurate than forward translation (L1-to-L2), and only the latter was influenced by the semantic context of the list, the results were interpreted as support for asymmetric connections. However, contradictory results were reported by De Groot and Poot (1997) who found that less fluent bilinguals were actually faster at forward than backward translation.

Furthermore, contrary to a strong version of the revised model, De Groot, Dannenberg, and Van Hell (1994) found that semantic variables (e.g., word concreteness, definition accuracy) were correlated with both forward and backward translation, albeit less in the latter. La Heij, Hooglander, Kerling, and van der Velden (1996) also examined the role of concept mediation in translation, but did so by manipulating the effect of non-verbal semantic context (e.g., a picture of a fork vs. a picture of a car) on a to-be-translated word (e.g., SPOON). At variance with the RHM, a semantically related context facilitated both L1-to-L2 and L2-to-L1 translation, and at times facilitation was even greater in backward than forward translation. Using a bilingual version of the Stroop color-word task, Altarriba and Mathis (1997) showed that novice bilinguals produce across-language Stroop effects after only one session of learning Spanish–English translation equivalents, demonstrating semantic interference and concept mediation in L2 at the earliest stages of learning a second language.

There is therefore some evidence that concept mediation operates in both forward and backward translation, even in bilinguals with a relatively low level of fluency in their second language. These studies argue against the asymmetry model of word translation and the idea that beginning learners of a second language are initially dependent on lexical connections to L1 before being able to directly access meaning representations from words in L2.

However, one problem with many of the above studies is that they focused primarily on word translation. If translation is the process under investigation, then this task is probably a good choice. However, if the goal of the research is to provide a better understanding of the underlying organization of lexical and semantic memory for words in a bilingual's two languages, then this task may be problematic. This is because overt translation while undoubtedly sensitive to memory processes, is also likely to involve additional strategic processes that occur during and after retrieval of information from lexical and semantic memory. These additional processes might then be expected to confound the contribution of lexical/semantic processes to the translation response. Therefore using measures such as reaction time and percent errors in a task such as this makes it difficult if not impossible to disentangle the factors of interest (see Kounios, 1996). Consequently, the present study sought to examine how beginning bilinguals access word meaning in L1 and L2 by tracking a neural substrate of single-word processing (the event-related brain potential (ERP) technique) in a task that did not require explicit translation. One distinct advantage of this approach over that used in the above studies is that it minimizes the influence of

[1] Even though more direct connections are presumably established between L2 and conceptual memory with increasing competence, work by Kroll and colleagues (e.g., Kroll & Sholl, 1992) suggests that even in relatively fluent users of L2 the existence of stronger L2 to L1 lexical links (established during L2 learning) can still be found. This evidence takes the form of relatively faster translation of L2 words to L1 than L1 words to L2.

extraneous task demands (e.g., Kounios & Holcomb, 1992).

1.1. Event-related potentials

Neural processing was monitored in this study by recording ERPs while subjects preformed a semantic word-detection task in L1 and L2. The N400 component, a negative-going wave peaking about 400 ms post-stimulus onset, was the primary dependent variable. The N400 has proven sensitive to semantic processing in numerous previous studies (e.g., Kutas & Hillyard, 1984, Kutas & Hillyard, 1980; Kounios & Holcomb, 1992, 1994). For example, the N400 has been shown to be sensitive to both the semantic content of individual words and to the context in which they appear (e.g., Holcomb, Kounios, Anderson, & West, 1999; Federmeier & Kutas, 1999)—its amplitude being larger for words with greater semantic content and for words in less constraining contexts. Numerous studies have also shown that words repeated within an experiment also elicit smaller N400s upon their second presentation than do words presented for the first time (e.g., Bentin & Peled, 1990; Besson & Kutas, 1993; Besson, Kutas, & Van Petten, 1992; Hamberger & Friedman, 1992; Karayanidis, Andrews, Ward, & Mc Conaghy, 1991; Rugg, 1985, 1987, 1990; Smith & Halgren, 1989; Smith & Halgren, 1989; see Rugg, 1995 for a review).[2] However, repetition effects on the ERP typically extend beyond the timeframe of the N400 and sometimes include an earlier phase between 200 and 300 ms as well as a later phase between 500 and 800 ms (see Rugg & Doyle, 1994). The earlier and later portions of the ERP repetition effect most likely reflect aspects of repetition beyond those associated with the semantic attributes indexed by the N400. For example, there is some evidence that the early phase may reflect repetition effects within a word form system, while the later phase might reflect repetition effects in an explicit recognition memory system (e.g., Doyle, Rugg, & Wells, 1996). The comparison of within-language and across-language (translation) repetition in the present study allowed a further analysis of form and semantic-level contributions to ERP repetition effects.

1.2. Present study

The major aim of the current study was to use ERP measures to examine the organization and processing of words in the first (L1) and second (L2) language of bilingual participants who were relatively early in their acquisition of L2 (i.e., substantially prior to L1–L2 parity). An immediate repetition priming paradigm (word x presented on trial n is repeated, or its translation presented, on trial $n+1$) was used to examine both within- and between-language repetition effects.[3] In order to ensure semantic processing of the word stimuli, a semantic categorization task was employed. In this task participants were presented with a continuous stream of words in English and Spanish, a proportion of which were within- and between-language repetitions of the previous word. Their task was to read each word and to press a button when they detected an occasional word (10% of trials) that referred to a part of the body in either language (e.g., "arm" or "brazo"). These body-part words were included to ensure that participants attended to and semantically analyzed all words in both languages. Critical items were Spanish and English nouns that did not refer to body parts and therefore did not require an overt response. Behavioral data were collected for the body-part words, but due to the small number of observations these were only used to calculate mean semantic categorization times and error rates in L1 and L2.

The comparison of within-language and between-language (translation) repetition effects on the N400 should inform us about the relative role of form and meaning overlap in generating these effects. The translation equivalents tested in the present study were all non-cognates with minimum orthographic and phonological overlap. Thus the size of across-language repetition effects on the N400 should help determine how much of the within-language effect is semantically driven. This general objective was examined within the framework of the RHM and concept mediation models of bilingual lexical processing (see above). Given the

[2] While no definitive explanation of the N400 exists, the bulk of the available evidence favors the view that the N400 reflects the comprehension systems attempt to integrate information into a semantic context (Brown & Hagoort, 1993; Halgren & Smith, 1987; Holcomb, 1993; Rugg, 1990). In this view, conditions that facilitate integration reduce N400 amplitude and conditions that make integration more difficult or effortful increase N400 amplitude. In terms of the integration hypothesis, ERPs to repeated words reflect the ease with which a word is integrated with its semantic context, in this case the context set up by the word itself. Note that this view of the N400 does not limit its occurrence to linguistic contexts. There is ample evidence that the process reflected by this ERP component is sensitive to semantic integration in other domains as well (e.g., objects, and faces—Bentin & McCarthy, 1994; McPherson & Holcomb, 1999).

[3] The choice of an immediate repetition priming paradigm (as opposed to delayed/lagged repetition) was made because immediate repetition is more commonly used in experiments examining word processing (as opposed to memory based effects that are seen in paradigms using delayed or "lagged" repetition). Moreover, lexically mediated priming does not appear to withstand priming intervals that span multiple words (Neely, 1991) and priming at longer lags is therefore more likely to reflect primarily episodic contributions to priming. Of course, immediate repetition is also sensitive to episodic factors (when primes are not masked as was the case in this study), but in this study most of the critical comparisons are made to items with similar episodic contributions.

particular bilingual population tested in the present study (native English speakers in introductory and intermediate college Spanish courses),[4] the RHM predicts that between-language repetition effects will vary as a function of language order (L1–L2 or L2–L1). Such translation effects on N400 amplitudes should be larger in the direction L2–L1 (backward translation), than L1–L2 (forward translation), given the asymmetric processing described in this model. This is because an L2 word should automatically activate the form representation of its L1 equivalent thus generating repetition effects that should be similar to within-language L1 repetition. According to the RHM, L1 words do not automatically activate the form representations of their L2 equivalents (or at least not as fast or as strongly as in the L2–L1 direction), but do activate a meaning representation shared by the L2 word. Thus, to the extent that both form and meaning overlap influence repetition effects, there should be a smaller or perhaps a later effect in this condition. On the other hand, the concept mediation model predicts that between-language repetition effects should not depend on language direction. Meaning representations are activated in the same way in L1 and L2. Forward and backward translation involves the same mechanisms in this model. According to the concept mediation model, the extent to which within- and between-language repetition effects differ should reflect the influence that form overlap has on these effects.

Turning to the predictions for within-language repetition effects, there should be a greater repetition effect in L2 than L1. This is because the bilingual participants tested in the present study had much less experience with L2 words than L1 words, which should make these words more difficult to process resulting in stronger benefits of repetition. This can be thought of as the bilingual variant of the repetition times frequency interaction reported in previous ERP studies (e.g., Rugg, 1990). Indeed, if L2 words behave like low-frequency L1 words (as in the Bilingual Interactive Activation model, Grainger, 1993; Van Heuven, Dijkstra, & Grainger, 1998), then we should observe larger N400 amplitudes in L2 words, and a stronger reduction of these amplitudes with repetition.

Finally, the mixed-language presentation conditions used in the present study allow us to examine whether a language switch produces an effect on ERPs. Behavioral measures have systematically shown a cost in processing following a language switch compared to when the directly preceding word is from the same language (Grainger & Beauvillain, 1987; Thomas & Allport, 2000). There are currently two interpretations of these switch costs in bilingual word recognition. According to one position, switch costs arise within the bilingual language processing system, as the result of inhibitory control over total lexical activation within each of the bilinguals languages (van Heuven et al., 1998). With regard to ERP effects this model predicts that N400s should be larger to words following a switch in language compared to words occurring after another word in the same language. Alternatively, switch costs could arise outside of the language processing system as a result of competition between stimulus–response task schemas set up for the particular task at hand (Green, 1998; Thomas & Allport, 2000). Given the semantic nature of the task used in the present study, and the fact that participants did not respond to critical items, the second explanation should predict that language switches would not influence ERP components known to be related to lexical processing.

2. Method

2.1. Participants

Twenty-eight undergraduate volunteers (14 men, 17–22 years of age, mean age 19) from Tufts University participated in the experiment for credit and/or cash. All were right-handed native speakers of English, with normal or corrected-to-normal visual acuity who were enrolled in beginning to intermediate courses in Spanish at the university (mean number of university courses in Spanish = 2.14, *SD* = 1.46). All significant prior exposure to Spanish was via the classroom setting.

Several approaches were taken to assure that all participants had sufficient knowledge of Spanish to perform the experimental tasks, but not enough to be considered competent/fluent users of the language. First, to evaluate their relative competence in L1 and L2 all participants completed a questionnaire rating their reading and speaking skills in English and Spanish (10 point scale). Every participant rated their reading, speaking, and auditory comprehension ability in L1 substantially higher than in L2 (see Table 1), although no participant rated their L2 reading skill (the most important L2 skill for this study) lower than 3.

Table 1
Mean (*SD*) self-ratings in L1 and L2

	English	Spanish
Reading ability	9.7 (0.72)	6.1 (1.71)
Speaking ability	9.9 (0.45)	5.7 (1.94)
Auditory comprehension	9.8 (0.65)	6.3 (1.92)

[4] Although many of the participants in this study took Spanish in high school before enrolling in university Spanish courses, as is typical of foreign language students in the United States, none had become fluent in Spanish. As discussed by De Groot and Kroll (1997) this is typically because of a lack of opportunities to speak Spanish outside of the classroom environment.

Second, each participants knowledge of Spanish and their relative facility with Spanish and English were also evaluated with more objective criteria. All participants were given an un-timed post-ERP session translation task to assess their knowledge of the Spanish stimulus words used in the ERP experiment. Performance on this task ranged from 42 to 93% correct with a mean of 69% (note that only words correctly translated were used in forming ERP averages for Spanish words). Reaction time and error rates to probe words in English and Spanish were also measured during the ERP session (see below). Participants responded more quickly to probe words in English (682 ms) than in Spanish (727 ms, main effect of Language: $F(1, 27) = 10.98$, $p < .003$), and were more accurate at identifying probes in English (93.3%) than in Spanish (74%; $F(1, 27) = 36.74$, $p < .001$).

2.2. Stimuli and procedure

Participants were tested in a sound attenuated room and seated in a comfortable chair approximately 57 in. in front of a monitor. The stimuli for the study consisted of non-cognate translation equivalents that were gathered from textbooks used in elementary and intermediate Spanish courses at the university. These words were evaluated by a group of native Spanish speakers including faculty from the Spanish department at Tufts as to their suitability for participants and to eliminate ambiguous translations. The stimuli consisted of concrete nouns between 3 and 10 letters in length with a mean word frequency in English of 80 occurrences per million (based on Kucera & Francis, 1967).

On each trial, participants were presented with a single word and had to decide if the item referred to a body part in either Spanish or English. If an item referred to a body part (probe—13% of trials) the participant had to press a button as quickly as possible. For all other items no overt response was required.

There were three types of experimental trials; trials where the item on the immediately preceding trial was the same word in the same language (within-language repetitions), trials where the item on the preceding trial referred to the same concept but was in the other language (between-language repetitions), and trials where the item on the preceding trial was a different word (first presentations). Within the two repetition conditions (within- and between-language), one half of the experimental trials involved English words and one half involved Spanish. Thus stimuli were defined by two within-subject variables, *repetition* (first presentations, within-language repeats and between-language repeats) and *language* (English or Spanish).

Each participant was presented with a total of 160 first presentation–repetition pairs, 40 pairs in each of the four repetition conditions. In within-language repetition conditions (i.e., English–English and Spanish–Spanish), a word was presented in the same language on both its first and repeated presentation (e.g., dog–dog, mesa–mesa). In between-language repetition conditions (i.e., English–Spanish and Spanish–English), the language was changed between presentations (e.g., dog–perro, mesa–table). In order to minimize expectations of first presentation–repetition pairs, 80 non-repeating filler words (40 non-repeating English and 40 non-repeating Spanish) were interspersed between critical trials.

First presentation–repetition pairs and non-repeating words were selected from six similarly constructed lists of 40 translation equivalents, and counterbalanced so that, across participants, each stimulus appeared once in each of the four repetition conditions and two non-repeating conditions. However, subjects were presented with only one experimental list therefore each stimulus was viewed in only one condition per list. The presentation and order of lists were counterbalanced across all participants. The same presentation of body-part words was used in each list.

Stimuli were displayed at the center of the monitor as white lower-case letters on a black background. Each trial consisted of a stimulus word presented for 400 ms, and was followed by the following sequence: an 800 ms blank screen interval, an asterisk for 1000 ms (signaling that it was permissible to blink or move one's eyes), and a final 500 ms blank screen interval. The stimulus word from the next trial immediately followed the 500 ms blank.[5]

Participants were instructed to immediately press a "yes" button on a response box resting in their lap whenever a body-part word appeared in either English or Spanish. The hand used for responding was counterbalanced across subjects. Otherwise, participants were asked not to move or blink except for when an asterisk appeared on the screen. The experiment was preceded by three sets of practice words (25 trials each) none of which appeared in the actual experiment. Altogether the experiment lasted about 40 min including brief breaks approximately every 90 stimuli. At the conclusion of the recording session participants were given a translation task involving all of the Spanish words that were presented during the experiment.

2.3. EEG recording procedure

The electroencephalogram (EEG) was recorded from 13 scalp locations using tin electrodes embedded in an

[5] After pilot work with the semantic categorization task we decided on an SOA of 2.7 s. There were two reason for this decision. First, intervals significantly shorter than 2.7 s frequently did not leave enough time for participants to processes the Spanish words and then get ready for the next trial. Second, shorter intervals do not leave a sufficient interval between trials to allow participants to blink.

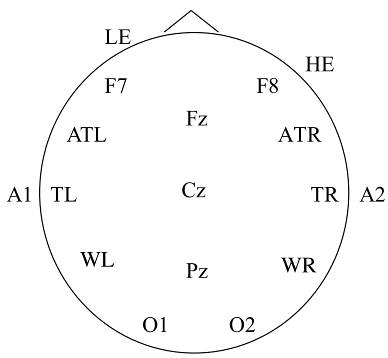

Fig. 1. Schematic diagram of electrode montage used in this study.

elastic cap (Electro-Cap International). These electrode sites, shown in Fig. 1, included seven standard locations from the International 10–20 system: left and right occipital (O1, O2), left and right frontal (F7, F8), and frontal (Fz), central (Cz), and parietal (Pz) midline sites. Six other locations were included: temporal–parietal left and right (WL, WR: 30% of the interaural distance lateral to a point 13% of the nasion–inion distance posterior to Cz), left and right temporal (TL, TR: 33% of the interaural distance lateral to Cz), and left and right anterior temporal (ATL, ATR: 50% of the distance between T3/4 and F7/8) sites. Blinks/eye movements were monitored with electrodes below the left eye (LE) and the outer canthus of the right eye (HE).

All electrodes were referenced to the left mastoid (A1); right mastoid (A2) activity was recorded on a separate channel and after data collection all scalp sites were re-referenced to an algebraic average of the two mastoids. Scalp and reference electrode impedances were kept below 5 kΩ, eye electrode impedances below 10 kΩ.

The EEG was processed through Grass Model 12 amplifiers at a bandpass of 0.01–30 Hz, digitized on-line at 200 Hz, and stored on a hard disk for later analysis. Trials contaminated by eye movement, muscle activity, or amplifier blocking were rejected prior to averaging. The number of trials rejected was very stable across conditions (9% for each of the six main conditions) and participants (ranging between 0 and 20%).

2.4. Data analysis

All ERPs were quantified by measuring the mean amplitude relative to the average of a 100 ms pre-stimulus baseline. Four latency windows were measured: 150–300, 300–500, 500–700, and 700–1000 ms. These epochs were chosen because they correspond to previous reports of early (pre-N400), middle (N400), and late (LPC) phases of the ERP repetition effect and because they should be sensitive to any temporal shifts in repetition due to L1 mediation. Separate omnibus repeated measures analyses of variance (ANOVAs) were used to analyze each window and to analyze midline and lateral scalp sites. In addition to the primary factors of interest (see below) midline ANOVAs included a factor of *electrode site* (Fz vs. Cz vs. Pz) and lateral ANOVAs factors of *electrode site* (frontal vs. anterior temporal vs. temporal vs. Wernicke's vs. occipital), and *hemisphere* (left vs. right). The Geisser–Greenhouse correction (Geisser & Greenhouse, 1959) was applied to repeated measures with more than one degree of freedom in the numerator. In all analyses, ERPs to Spanish words for which incorrect responses were given in the post-experimental Spanish translation task were omitted from the Spanish average ERPs.[6]

To examine the effects of repetition on within- and between-language word processing, ERPs were formed at each electrode site in six conditions: English first presentation words, Spanish first presentation words, English within-language repeated words, Spanish within-language repeated words, English between-language repeated words (i.e., ERPs were time locked to English words that followed a translation equivalent Spanish word), and Spanish between-language repeated words. Separate omnibus ANOVAs were performed on all four ERP mean amplitude measurement windows in a 3 by 2 design with repetition (first presentation vs. within-language repetition vs. between-language repetition) and language (English vs. Spanish) as the primary factors. Omnibus ANOVAs were followed-up with more specific analyses examining the effects of repetition. These analyses were performed on difference waves calculated by subtracting both within- and between-language repeated words from first presentation words in the same language. Difference waves offer the advantage of removing activity that the two conditions being subtracted from each other have in common, leaving only the activity that differentiates them. In the current study this was language specific activity (e.g., differences in orthography) which might otherwise compromise direct ERP comparisons between languages. Four separate waveforms were calculated: the English within-language repetition effect, the Spanish within-language repetition effect, English between-language repetition effect, and Spanish between-language repetition effect. The same three windows used to quantify the raw ERP waves were also used to measure the difference waves.

[6] Although this approach to data analysis (separate repeated measures ANOVAs on multiple ERP components and multiple scalp variables) is now the most conventional one used by ERP researchers, it should be kept in mind that it comes with a somewhat increased risk of type I errors due to the fact that adjacent ERP measurement windows result in correlated/non-independent data sets. However, given that all of the windows used here have been reported to produce ERP repetition effects in previous studies, we feel confident that none of the effects reported here are spurious.

In a second set of analyses, concentrating on differences in words encountered for the first time in the experiment (i.e., not repetitions), ERPs were formed based on the language of the word on the *preceding* trial. This resulted in four different conditions: English first presentation words preceded on the previous trial by an English word (English following English), English first presentation words preceded on the previous trial by a Spanish word (English following Spanish), Spanish first presentation words preceded on the previous trial by a Spanish word (Spanish following Spanish), and Spanish first presentation words preceded on the previous trial by an English word (Spanish following English). Separate 2 by 2 ANOVAs were used to contrast the two languages (English vs. Spanish) and two prior trial types (English vs. Spanish) for each of the later three latency windows (300–500, 500–700, and 700–1000 ms).

Two different strategies were used to keep comparable numbers of trials in all of the above conditions. In the analyses examining repetition effects, the two types of first presentation ERPs (English and Spanish) were formed from items where the word on the following trial was a within-language repetition (i.e., between-language first presentations were not included). This was deemed appropriate since participants had no way of knowing during the processing of first presentation words what type of item was going to occur on the next trial. Moreover, given the nature of the design (across subjects all words rotated through all conditions), the ERPs in the various first presentation conditions should have been comparable. However, in the analyses examining the effects of a prior word's language on first presentation processing, more first presentation trials were needed to examine the influence of the two languages. Therefore, both types of first presentation words (within and between) were included.

3. Results

3.1. Overview of ERPs

Grand mean ERPs averaged across all 28 participants are shown in Fig. 2 (English) and Fig. 3 (Spanish). In both figures, ERPs for first presentations are contrasted with ERPs for within- ("English Repetition" or "Spanish Repetition") and between-language repetitions ("Spanish Translation" or "English Translation"). In Fig. 4 are plotted the difference waves calculated by subtracting either within-language repeated word ERPs

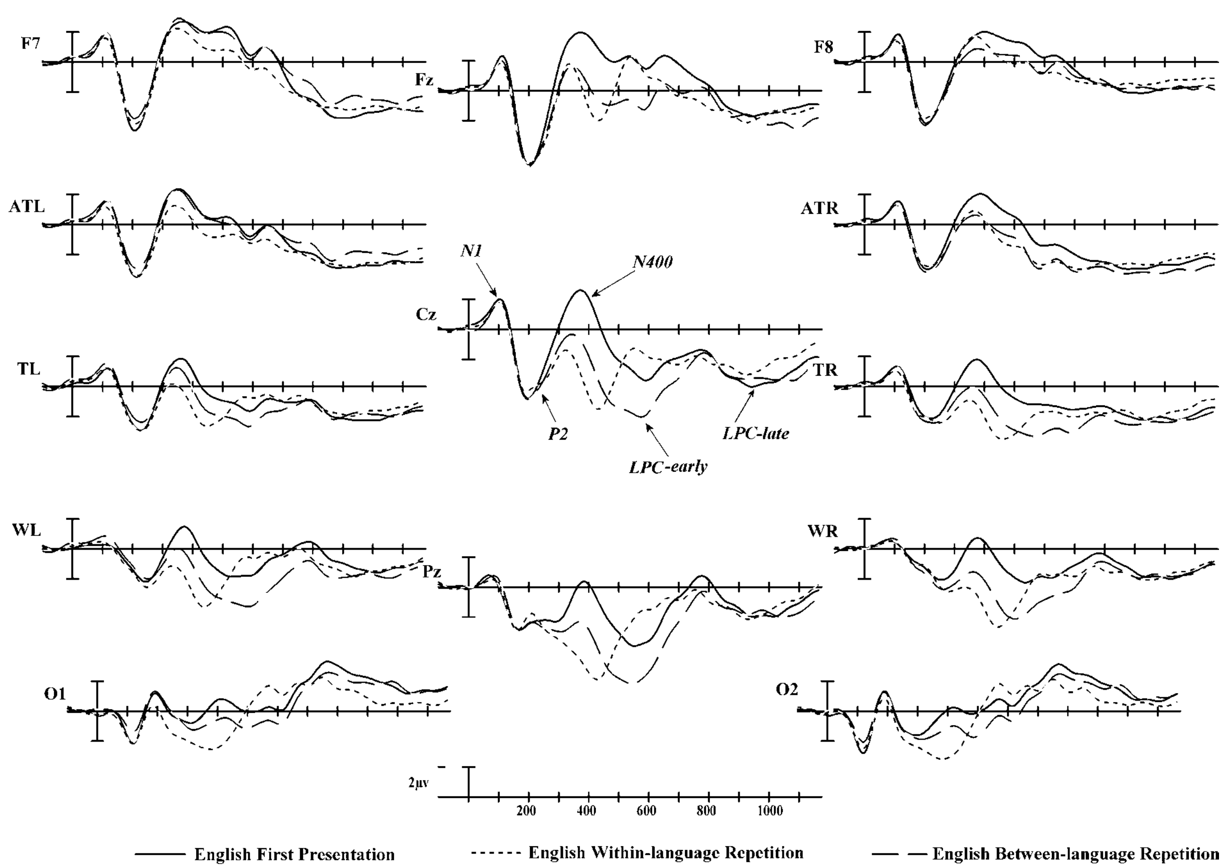

Fig. 2. ERPs to three English repetition conditions. In this and subsequent figures stimulus onset is the vertical calibration bar. Note that negative voltages are plotted in the upward direction.

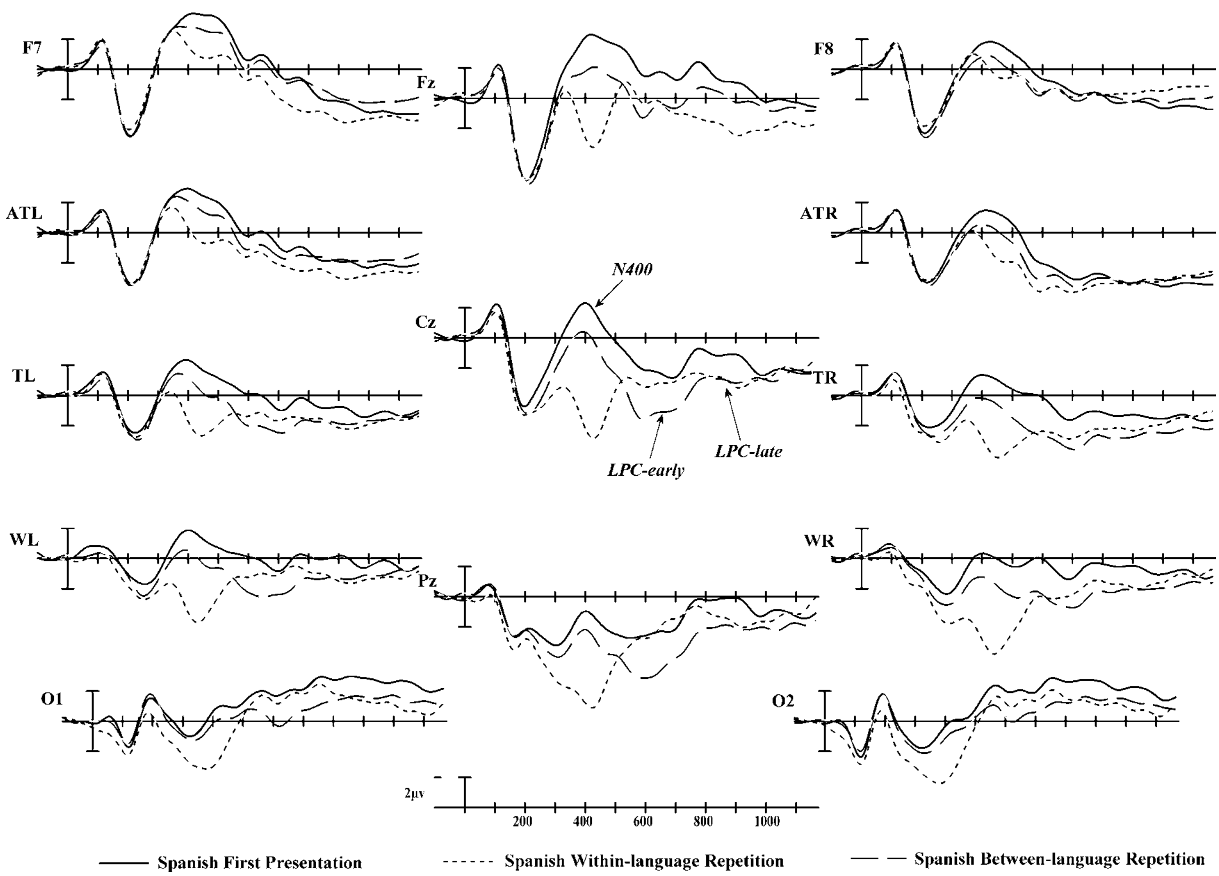

Fig. 3. ERPs to three Spanish repetition conditions.

from first presentation word ERPs and between-language repeated word ERPs from first presentation word ERPs. Finally, in Fig. 5 ERPs to first presentation Spanish and English words are plotted as a function of the language of the word from the previous trial.

The ERPs in Figs. 2, 3, and 5 reveal that several early components were elicited across languages and conditions, beginning with a broadly distributed negativity (N1) that peaked at approximately 100 ms at all but the most posterior sites (O1, O2). At these posterior sites there was an early positivity (P1) that peaked about 125 ms followed by an N1 with a peak around 200 ms. At most sites, the N1 was followed by a large positive-going wave (P2) that peaked around 200 ms. Close examination of these figures reveals that there were few if any effects of repetition or language on these early ERP components.

The P2 was followed by a broad negative-going wave peaking between 350 and 450 ms (N400). The N400 was widely distributed across the scalp but appeared somewhat larger (i.e., more negative-going) over the left than the right hemisphere, and over the front than the back of the head. Following the N400, there was a late positive complex (LPC) which, depending upon site and condition, peaked between 400 and 700 ms. The LPC tended to be more positive over the midline and more posterior sites (except O1 and O2). Examination of Figs. 2–5 suggests that both the N400 and LPC produced clear effects of language and repetition.

3.1.1. Repetition effects 150–300 ms

The omnibus ANOVA for the earliest epoch showed that there was a small difference between languages (midline: $F(1,\ 27) = 6.38, p < .018$) with Spanish words producing slightly larger P2 components than English words. There was also a significant difference between the three repetition conditions (main effect of repetition, lateral: $F(2,\ 54) = 4.10,\ p < .031$; midline: $F(2,\ 54) = 3.40,\ p < .05$) with first presentations producing the most negative-going ERPs, within-language repetitions producing the least negative-going ERPs and between-language ERPs falling in between (see Figs. 2 and 3). There were, however, no interactions between language and repetition in this epoch.

3.1.2. Repetition effects 300–500 ms

The omnibus ANOVA for the N400 epoch showed that there was no overall difference between languages, but that there was a significant difference between the three repetition conditions (main effect of repetition, lateral: $F(2,\ 54) = 43.06,\ p < .001$; midline: $F(2,\ 54) = 49.17,\ p < .001$) with first presentations producing the

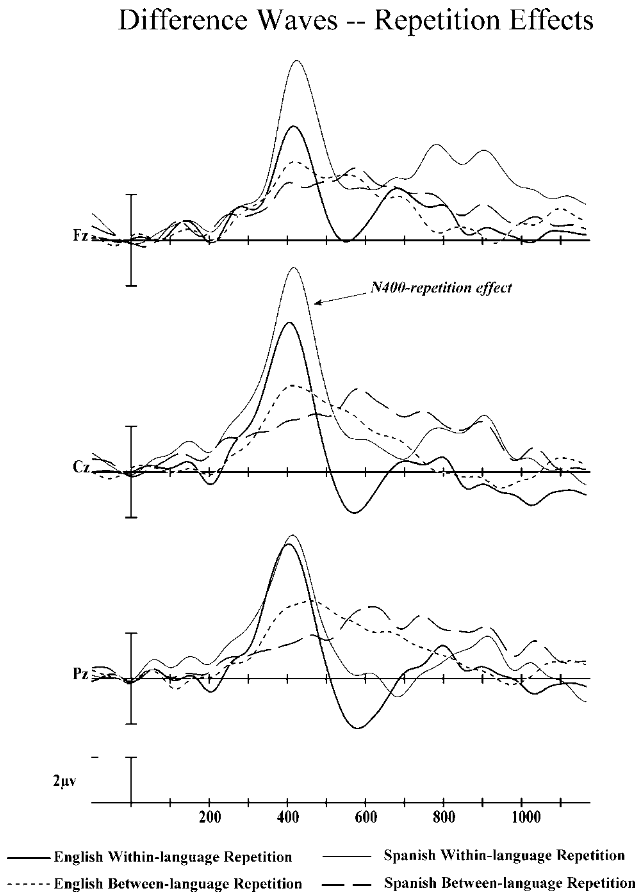

Fig. 4. ERP difference waves for within- and between-language comparisons.

most negative-going ERPs, within-language repetitions producing the least negative-going ERPs, and between-language ERPs falling in between (see Figs. 2 and 3). However, unlike the earlier epoch, the pattern of within- and between-language repetition differed for Spanish and English items as indicated by the Language × Repetition interaction (lateral: $F(2,\ 54) = 2.89$, $p < .066$; midline: $F(2,\ 54) = 5.67$, $p < .006$).

To better characterize the repetition by language interaction further comparisons in this epoch were made on difference waves (i.e., the within- language English repetition effect, the within-language Spanish repetition effect, the between-language English repetition effect, and the between-language Spanish repetition effect—see Fig. 4). In the difference wave analyses there was a main effect of repetition type (lateral: $F(1,\ 27) = 24.31$, $p < .001$; midline: $F(1,\ 27) = 20.82$, $p < .001$) with within-language repetition producing a larger N400 effect than between-language repetition. However, there was also a significant repetition type by language interaction (lateral: $F(1,\ 27) = 6.08$, $p < .02$ midline: $F(1,\ 27) = 12.33$, $p < .002$). Follow-up analyses revealed that the within-language Spanish repetition effect was larger than the English repetition effect, especially at more anterior sites (language × site interaction, lateral: $F(4,\ 108) = 3.35$, $p < .06$; midline: $F(2,\ 54) = 3.72$, $p < .048$), while the English between-language repetition effect (ERPs to English words preceded by unrelated Spanish words subtracted from ERPs to English words preceded by Spanish translation equivalents of the English words) was marginally larger than the between-language Spanish repetition effect (midline: $F(1,\ 27) = 3.14$, $p < .088$; note the difference between the dashed lines in Fig. 4).

3.1.3. Repetition effects 500–700 ms

As in the previous epoch the omnibus ANOVA showed that there were no overall differences between the languages, but that there were differences between the repetition conditions (main effect of repetition, lateral: $F(2,\ 54) = 11.77$, $p < .001$; midline: $F(2,\ 70) = 18.00$, $p < .001$). First presentations again produced the most negative-going ERPs, however, between-language repetitions now produced the most positive-going ERPs and within-language repetitions produced intermediate amplitudes. There was also a trend for repetition effects for the two languages to differ, especially at lateral sites going from the front to the back of the head (Language × Repetition × Electrode Site interaction, lateral: $F(8,\ 216) = 3.17$, $p < .022$).

The omnibus ANOVA was again followed-up with analyses of the differences waves to help better characterize the language by repetition interaction. In these analyses there were effects of repetition type, but these differed as a function of electrode site location (repetition type × electrode site interaction, lateral: $F(4,\ 108) = 11.20$, $p < .001$; midline: $F(1,\ 27) = 12.52$, $p < .001$). At posterior sites between-language repetitions produced larger negative difference waves than did within-language repetitions, while at more anterior sites the differences were either smaller (midline) or reversed (lateral). As in the previous epoch, there was also a tendency for the languages to differ as a function of repetition type (repetition type × language interaction; midline: $F(1,\ 27) = 3.54$, $p < .071$; repetition type × language × electrode site, lateral: $F(4,\ 108) = 3.86$, $p < .017$). Follow-up analyses revealed that this pattern was due primarily to Spanish repetitions producing more negative difference waves than English repetitions (main effect of language, lateral: $F(1,\ 27) = 4.70$, $p < .039$; midline: $F(1,\ 27) = 3.36$, $p < .078$). Unlike the 300–500 ms epoch, there were no differences between languages for between-language repetitions (Fs < 1), nor was there an asymmetry in repetition type between the languages (i.e., both produced between-language repetition effects that were larger than within-language repetition effects especially towards the back of the head).

3.1.4. Repetition effects 700–1000 ms

As in the previous three epochs the omnibus ANOVA showed that the three repetition conditions differed, but

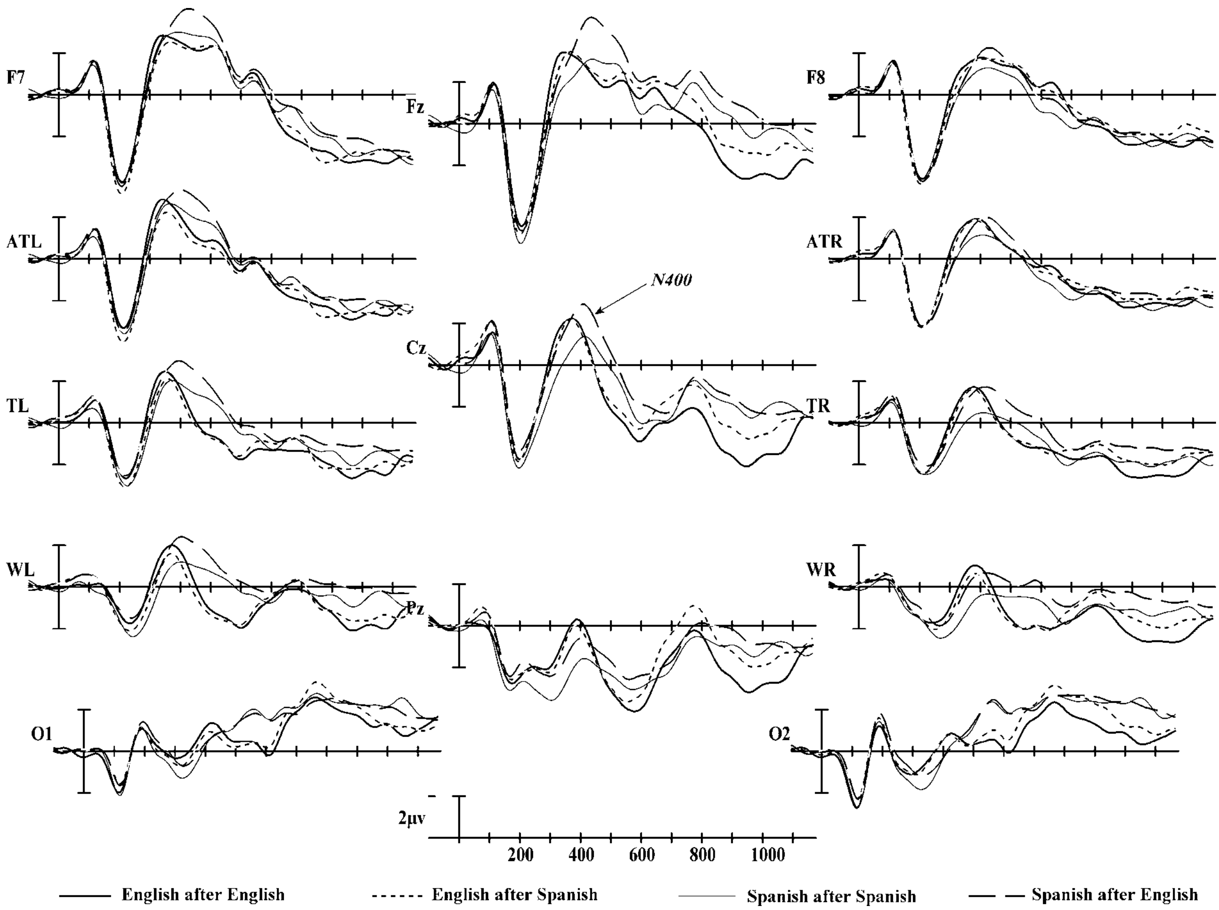

Fig. 5. ERPs to first presentations sorted by the language on the previous trial.

that the pattern of differences varied across the head (Repetition × Electrode Site, lateral: $F(8,\ 216) = 4.06$, $p < .009$; midline: $F(4,\ 108) = 7.16$, $p < .001$). Moreover, at midline sites this pattern differed as a function of language (Language × Repetition × Electrode Site interaction: $F(4,\ 108) = 6.16$, $p < .01$).

In the difference wave analyses there were effects of repetition type, but these differed as a function of electrode site location (repetition × hemisphere × electrode site, lateral: $F(4,\ 108) = 6.37$, $p < .004$; repetition × electrode site, midline: $F(2,\ 54) = 12.84$, $p < .001$). Also, repetition type differed as a function of language across the three midline sites (repetition type × language × electrode site interaction, midline: $F(2,\ 54) = 7.51$, $p < .006$). Follow up analyses on the difference waves revealed that there was a significant difference between Spanish within-language repetitions and Spanish between- language repetitions, with within-language producing the biggest negativity at the front of the head and between-language the biggest at the back (repetition type × electrode site interaction: $F(2,\ 54) = 16.98$, $p < .001$). However, the same contrast produced no differences for English words. A comparison of between- language repetition difference waves revealed a marginal difference between the languages (midline: $F(1,\ 27) = 3.16$, $p < .087$), and a significant effect at the Cz site ($F(1,\ 27) = 5.04$, $p < .033$). As can be seen in Fig. 4, this effect appears to be due to Spanish translations producing a larger negativity than English translations in this epoch.

3.2. Summary of ERP repetition results

Repetition effects started in the pre-N400 epoch (150–300 ms). Both English and Spanish words presented for the first time produced larger negativities than did the same words when repeated on the next trial (within-language repetition effect). Moreover, in the N400 window (300–500 ms) this effect was marginally larger for Spanish than English words. A similar ERP effect was obtained in both languages when first presentation words were compared to words that were translation equivalents of the preceding item (between-language effect), although this difference appeared to be smaller and more extended in time than the within-language repetition effect. Also, between 300–500 ms the between-language effect was marginally larger for L1 (English) than L2 (Spanish) translations. In the early phase of the

LPC (500–700 ms) Spanish words continued to show a robust within-language repetition effect. And while English words produced no clear within-language repetition effects, they did show, as did Spanish words, a clear between-language effect, although there were no differences between the languages in the size of this effect. Finally, in the latter phase of the LPC (700–1000 ms) only Spanish words revealed reliable within-language repetition effects. There was also evidence that the Spanish translation effect, which was marginally smaller than the English translation effect in the 300–500 ms epoch, was now larger than the English effect.

3.2.1. First presentation effects

In the 300–500 ms window Spanish words presented for the first time tended to produce more negative-going ERPs than comparable English words, especially over more anterior and left hemisphere sites (Language $\times$ Electrode Site $\times$ Hemisphere interaction, lateral: $F(4, 108) = 9.266$, $p < .001$; Language $\times$ Electrode Site interaction, midline: $F(2, 54) = 21.21$, $p < .001$). However, much of this difference was due to Spanish first presentation words that followed another Spanish word compared to Spanish words that followed a switch from English. The comparable switch from Spanish to English produced few if any differences in this epoch for English first presentation words compared to English words following other English words (see Fig. 5; Previous Word Type $\times$ Language interaction, lateral: $F(1, 27) = 9.04$, $p < .005$; midline, $F(1, 27) = 10.93$, $p < .002$).

In the 500–700 ms window Spanish first presentation words continued to produce more negative going ERPs than comparable English words, but now at more posterior lateral sites (Language $\times$ Electrode Site interaction, lateral: $F(4, 108) = 12.70$, $p < .001$). Spanish words that followed Spanish words also continued to produce more positive-going ERPs than Spanish first presentation words following English words. However, English first presentation words now produced a similar language switching trend, with English following English words producing more positive ERPs than English following Spanish words (main effect of Prior Word Type, lateral: $F(1, 27) = 4.43$, $p < .042$; midline: $F(1, 27) = 8.28$, $p < .007$—see Fig. 5).

Finally, in the 700–1000 ms window, Spanish first presentation words continued to produce more negative-going ERPs than English words, especially over more anterior sites along the midline (Language $\times$ Electrode Site interaction, midline: $F(2, 54) = 9.26$, $p < .002$). And first presentation words following a word in the same language tended to produce more positive-going ERPs than first presentation words following a word in the other language (main effect of Prior Word Type, midline: $F(1, 27) = 9.86$, $p < .003$), especially over the right hemisphere (Prior Word Type $\times$ Hemisphere interaction, lateral: $F(1, 27) = 4.29$, $p < .046$).

4. Discussion

The present results allowed us to examine processing differences in a dominant (L1) and subordinate (L2) language within a population of students at a relatively early stage of second language acquisition. ERP repetition effects were shown to depend on language dominance, and on whether or not the repetition occurred within or between languages (across non-cognate translation equivalents; i.e., words that share meaning while having minimal orthographic and phonological overlap). Furthermore, a new language switching effect was observed in the ERPs when participants moved from their dominant to their subordinate language.

As has been reported in previous studies (Rugg, 1987), the effects of repetition started relatively early in 150–300 ms window on the trailing edge of the P2 component, but prior to what is considered the traditional onset of the N400. However, while this early epoch differentiated the three repetition types (first, within- and between-language), they did not differ for the two languages. In the timeframe of the N400 component (300–500 ms), the effects of repetition continued, with within-language word repetitions producing a smaller amplitude N400 than between-language repetitions, and between-language repetitions producing a smaller N400 than words occurring for the first time in the experiment. Importantly, there were also differences in the effects of repetition for the two languages. The within-language N400 repetition effect (the ERP difference between first presentation words and their immediate repetition) was marginally stronger for Spanish words (L2) than for English words (L1) and the Spanish effect was also more extended in time than the English effect—lasting past 1000 ms at some sites (see Fig. 4). Between- language repetition effects revealed a somewhat different pattern. When a Spanish word preceded its English translation equivalent (i.e., L2–L1), the ERP effects of repetition on the English word tended to emerge during the N400 window (300–500 ms) and started to decline in the subsequent windows (500–700 and 700–1000 ms). However, when an English word preceded its Spanish translation equivalent (i.e., L1–L2) the effects of repetition on the Spanish word were smaller in the traditional N400 window and tended to grow in the latest measurement window (700–1000 ms—see Fig. 4). In other words, between- language repetition effects tended to have a later time-course in the L1–L2 direction than in the L2–L1 direction. These results speak to the general issue of how one can interpret ERP repetition effects, as well as to the question of how lexical and semantic representations are organized in bilingual memory at a relatively early stage in becoming bilingual.

4.1. Bilingual repetition effects

One interpretation of the current pattern of repetitions effects would appear to be most compatible with the concept mediation model. Recall that this model predicts symmetrical between-language repetition effects because between- language interactions, in either direction, occur at the conceptual/semantic level. In support of this model, the overall size of the between-language effects (i.e., across ERP epochs) were roughly equivalent for L1–L2 and L2–L1, although these effects were smaller than within-language repetition effects. To account for the different sizes of repetition effects it could be argued that there was greater trial-by-trial temporal variability in the time-course of priming effects in the between-language trials (perhaps due to language switching). For example, rather than producing a crisp N400 peak the between- language conditions produced a temporally smeared N400 spread across several epochs (the same could be said for the following LPC effect), thus reducing its amplitude in the traditional N400 window (300–500 ms). Accordingly, if we had been able to temporally align the priming effects, the overall amplitude differences between conditions might not have occurred.

One problem with the above account is that the pattern of temporal smearing differed for the two between-language priming effects. The L2–L1 condition tended to produce priming effects with an earlier time-course than the L1–L2 condition (see Fig. 4). This finding is inconsistent with a common conceptual locus for both types of between-language priming. An alternative and more straight forward interpretation of this pattern of results is one that is more consistent with the revised hierarchical model (RHM). According to the RHM, processing of a word in L2 activates its lexical representation first in the L2 lexicon, then its translation equivalent in the L1 lexicon, and finally the semantic representation in shared conceptual memory. In contrast, processing a word in L1 activates only the L1 lexical entry which then activates semantic representations. Consequently, in the current study when an L1 word followed an L2 translation equivalent, there was immediate overlap at both the lexical (form) and semantic (meaning) levels shortly after the onset of the L1 item. The immediacy of this form and meaning overlap resulted in relatively speedy priming effects as reflected by the larger priming in the N400 than later LPC windows. However, when an L2 word followed an L1 translation equivalent, the L2 word had to first activate its L2 lexical entry, and then activate its L1 equivalent (the first place where overlap/priming could occur). This additional operation tended to shift the bulk of the priming effect to a later epoch. This view suggests that the later priming effect seen for the L1–L2 condition is actually a delayed N400 effect.

Note that the earlier and larger L2–L2 within-language than L1–L2 between-language effects, as well as the larger L2–L2 than L1–L1 within-language effects also follow from the predictions of the RHM. First consider the L1–L2 vs. L2–L2 case. L2–L2 priming gets the benefit of form and meaning overlap at both the L2 and L1 lexical level, as well as at the level of meaning. L1–L2 priming, on the other hand, is missing the contribution of L2 lexical overlap and instead must wait until the L2 word activates its L1 lexical equivalent before it can commence. Likewise, L2–L2 within-language priming was larger than L1–L1 because the L1–L1 case is missing the second source of lexical priming available to L2 words.[7]

One problem with the above account of the ERP results is that it does not explain the difference in the size and temporal distribution of repetition effects observed across the L1–L1 and L2–L1 conditions. Since both conditions presumably involve lexical and semantic overlap with similar time-courses they should have produced similar priming effect profiles. However, this failure might be accommodated by assuming that on some L2 trials there is no access to the translation equivalent in L1 (i.e., a translation failure), and therefore no access to meaning. Alternatively, there may be contributions to within-language priming that are not available to the between-language conditions, and it may be these contributions that drove some of the within/between differences. At a purely descriptive level within-language repetitions involved complete overlap at the physical, word-form and meaning levels, while between-language repetition involved overlap only at the level of meaning and possibly, in some cases (according to the RHM), at the level of words-forms.

One issue that has not been mentioned is the influence of strategic and episodic memory effects on within- and between-language priming. In the current experiment the interval between stimuli was long enough (2.7 s) that the influence of such processes cannot be ruled out.

[7] The finding of larger repetition effects for L2 words would also seem to be consistent with a suggestion by Bentin and McCarthy (1994) who proposed that N400 immediate repetition effects are primarily due to the elimination of the N400 to the repeated items. In our case this would predict that after repetition L2 and L1 words should be about equal in amplitude (i.e., the N400 is driven to its floor in both cases), and therefore that L2/L1 repetition differences are due to larger N400s for L2 words at first presentation. L2 first presentation words did have a slightly larger N400 than L1 first presentation words, however, L2 repetitions also had slightly more positive ERPs. Therefore, the larger L2 repetition effect appears to have been due to a combination of factors. Another possible explanation for the larger within-language repetition effect for Spanish is that there was a larger change in participants decision confidence going from the first to the second presentation of Spanish words. Note however, that this explanation only works for the post-N400 epoch as previous studies have shown that decision/response related processes have minimal effects on the N400 (e.g., Kounios & Holcomb, 1992).

Moreover, the use of an immediate repetition paradigm (as opposed to a lag 2 or 3) might have further encouraged participants to engage in such strategies. For example, it is possible that at least some participants actively translated each word just prior to the next trial. Such a strategy could potentially inflate the between-language repetition effect. However, it seems unlikely that participants would have actively engaged in such a strategy in the current study as the nature of the task (semantic categorization) does not appear to offer any advantage for doing so. However, future studies should use either a shorter prime/target interval, or masked primes to eliminate the possibility of such strategic effects.

4.2. N400 repetition effects

If the reduction in N400 amplitude due to repetition is indeed caused both by shared form and meaning across repeated words, what is the mechanism underlying this effect? The present results point to the form–meaning interface as a likely locus. Word recognition involves the activation of the appropriate orthographic and phonological representations followed by the activation of semantic representations associated with these forms. Given potential ambiguities at either level (form or meaning), the resonant dynamics of the form–meaning interface allows the word recognition system to settle on a unique form–meaning combination for recognition. Here we hypothesize that the amplitude of the N400 is directly related to the difficulty in associating a specific meaning with a specific form. Word repetition can facilitate this process at two distinct levels: via repetition of the same word form, and via repetition of the same meaning.

This account of N400 repetition effects fits well with the pattern of form and repetition priming reported by Doyle et al. (1996). These authors observed similar patterns of reduced N400 amplitude for repeated (e.g., scandal–scandal) and form-related words (e.g., scan–scandal). The repetition effect became larger than the form-priming effect after approximately 350 ms of stimulus processing, suggesting the existence of an earlier form-related component, and a later semantic component. However, Doyle et al. excluded a semantic interpretation of the repetition effect given that they observed a similar pattern of form and repetition priming for non-word stimuli (e.g., bup–buple; buple–buple). Nevertheless, as recently argued by Holcomb, O'Rourke, and Grangier (2002), N400 effects observed with non-word stimuli can reflect meaning activation from form overlap with real words. The repetition effect observed with non-word stimuli could be due to improved orthographic information (via repetition) allowing a more effective blocking of form–meaning resonance (see Bentin & McCarthy, 1994, for a similar explanation). The lexical processor would continue to attempt to derive semantic information from a non-word stimulus until the degree of mismatch in bottom–up (form-driven) and top–down (meaning-driven) information blocks this processing.

One repetition finding that was not expected was the shift in the distribution of effects in the within-Spanish conditions to more anterior sites (see Fig. 4). Typically, N400 effects are distributed towards more posterior sites (as was the case for the within-English conditions). One, highly speculative and admittedly post-hoc explanation for this pattern is based on a similar distributional finding for concrete as opposed to abstract words in L1. Kounios and Holcomb (1994) demonstrated that concrete words generated larger frontal N400 repetition effects than did abstract words, while over the back of the head the two word types produced similar N400 responses. They proposed that the anterior concreteness effect reflected concrete words privileged accesses to imagistic representations, while the more posterior N400 repetition effects, which were comparable for abstract and concrete words, reflected equal access to linguistic representations. According to this view our larger anterior N400 effect for Spanish words reflects that our relatively new learners of Spanish relied more heavily on the concrete/imagistic representations associated with Spanish words in making their categorization decisions in Spanish.

4.3. Language switching effects

In the present study, the N400 amplitude to Spanish (L2) words was greater than to English (L1) words. However, this language effect was mostly due to an increase in the N400 amplitude to Spanish words when they followed English words (i.e., following a language switch). English words were less sensitive to language switches, at least within the time frame of the N400.

A comparable language-switching effect was first observed in behavioral data by Grainger and Beauvillain (1987) with English–French bilinguals. In a generalized lexical decision task (respond word to a stimulus that is a word in either English or French), they found that RTs to word stimuli were slowed when the immediately preceding word was from the other language. This language-switch cost in generalized lexical decision has been replicated by Thomas and Allport (2000), and is generally found to be equally strong in the direction L1–L2 and L2–L1. Contrary to these behavioral data, the language-switching effects in N400 amplitude observed in the present study were highly asymmetric and were only robust in L1–L2 switches. However, this asymmetry disappeared in later ERP components. After 500 ms, the fact that the word of the previous trial was from the other language provoked more negative-going ERPs in both L1 and L2. This result suggests that there is a general language-switch effect on ERPs that takes longer to develop in the L2–L1 direction. This effect could be related to the inhibitory control over lexical activation proposed in the Bilingual Interactive Activation model (van Heuven et al., 1998). According to this model, presentation of a word in one language leads to the global inhibition of all words in the other language. This inhibition will make it harder to process words following a language switch, as attested by the behavioral data (Grainger & Beauvillain, 1987; Thomas & Allport, 2000). The inhibition of word form representations will make it harder to recover the associated meaning, thus causing an increase in N400 amplitude.

The critical aspect of the present results is that a language-switch effect was observed in ERP measures when participants did not have to respond to critical word stimuli. This suggests that language switches are affecting processing related to the recovery of meaning from form, and are not the result of task-specific decision schemas that operate separately on each language (Green, 1998). Most important, these language switch effects should be clearly distinguished from switch costs that are observed when a given language *must* be selected in order to perform the task (e.g., Meuter & Allport, 1999). The latter type of switch cost is more intimately related to the general issue of executive control during task switching (Jackson, Swainson, Cunnington, & Jackson, 2001).

5. Conclusions

The present study documents three important findings observed in ERPs to isolated words during a semantic categorization task with English–Spanish bilinguals. First, within-language repetition effects were larger and more prolonged in L2 (Spanish) than L1 (English). Second, consistent with the RHM model of bilingual word processing, the time course of repetition effects between-languages was shifted later when the repeated (translated) word was in Spanish than in English. Third, a greater negativity in the ERP waveforms was observed when the word on the directly preceding trial was from the other language. Within the time frame of the N400, this language switch effect arose only when the target word was Spanish and the preceding word English although a later switch effect was present for both Spanish and English.

We are currently planning experiments that will examine repetition effects with cognate as well as non-cognate translation equivalents in English-French bilinguals (e.g., compare chaise–chair, with arbre–tree). If, as we hypothesize, the repetition effect in N400 amplitude is modulated by both form and meaning, then cognate translation equivalents should show a greater effect than non- cognates.

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