Language Effects in Second-Language Learners: A Longitudinal ERP Study

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Abstract

Are the mechanisms involved in word recognition in early L2 learners different from those of more proficient L2 users and how do these mechanisms evolve during learning? Our study sought to closely track language effects in beginning learners of an L2. In the present study both behavioral and ERP data were collected to investigate the changes over time of L2 processing in beginning learners. Monolingual L1 English-speakers enrolled in introductory Spanish at Tufts University were first trained on a list of 228 Spanish words and their English translations. These critical items were chosen from the vocabulary to be learned in their introductory Spanish class over the course of the semester. Behavioral data from this training session and the following experimental sessions showed expected learning effects. In the three subsequent experimental sessions the participants saw three lists – an English list, a Spanish list, and a mixed language list, performing a go/no-go lexical decision task. As observed in previous studies our results showed overall larger negativities in the N400 epoch to L1 items than to L2 items. The differences varied in that amplitudes in the traditional N400 epoch to L2 items became more negative over the course of the semester. These results suggest that L2 items become more connected in the mental lexicon rapidly in the earliest stages of learning a second language, emphasizing the plasticity of the mature brain.

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As technological advances continue to facilitate global communication, bilingualism is becoming increasingly more prevalent and even necessary in society. Already, it is estimated that up to half of the world's population is functionally bilingual at some level, and that approximately 55 million people in the United States alone are bilingual (Grosjean, 2010). The question of how the mature brain acquires a second language is becoming increasingly more relevant, not only to the scientific community but to our population as a whole.

Lenneberg (1967) proposed that language could only be acquired during a "critical period" that lasted throughout childhood up until about puberty. Though this hypothesis was originally intended to apply to the acquisition of the first language (L1), it has been tested as a hypothesis for second language (L2) acquisition as well. Johnson and Newport (1989) found that the earlier native Chinese- and Korean-speaking children moved to the United States and began learning English (L2), the greater the advantage they had in eventual mastery of English grammar. This effect was evident for children who arrived before puberty. However, for those who arrived after the proposed "critical period", achievement was significantly lower on grammatical tasks, and was unrelated to age of arrival (e.g., no difference between people who arrived at 17 years old or 40 years old).

However, due to the marvelous plasticity of the adult brain, it is still possible for adults to acquire a second language to a highly proficient degree. It has also been shown that elderly bilingual subjects outperformed elderly monolingual subjects on tasks requiring inhibitory control, an aspect of executive function (Bialystok, Martin, & Viswanathan, 2005). Bialystok et al. suggested that because these elderly bilinguals spent many years forced to manipulate and switch between two different languages, their cognitive system had gained an advantage in these types of executive function tasks.

Whether an adult must learn a second language for business purposes, to communicate with loved ones, or merely to survive in a new or changing society, becoming bilingual later in life is often a slow and taxing endeavor. How does this L2 acquisition process occur at the neurological level? Are the same mechanisms involved in both expert L1 and novice L2 word processing? Does the processing of L2 evolve with increased L2 proficiency? These are some of the questions motivating the current study, and while a single experiment cannot answer them all, it is imperative that we begin to understand the underlying cognitive mechanisms that promote bilingualism in the mature brain.

Bilingual Language Processing Models

Most language-processing findings would agree that words possess both lexical and semantic properties. However, how these properties are stored and processed in the bilingual brain remains a central question to bilingualism research. Some studies suggest that the two languages are stored in separate mental lexicons while others propose that they share an integrated mental lexicon for languages with shared alphabetic codes (for a review, see Kroll & Tokowicz, 2005). The models to be discussed here are the Revised Hierarchical Model (Kroll & Stewart 1994), the Bilingual Interactive Activation (BIA) Model (Dijkstra & Van Heuven 1998; Grainger & Dijsktra 1992), and the BIA+ Model (Dijsktra & Van Heuven 2002). Though the current study does not directly test any of these models, they provide a framework for the consideration of bilingual language processing in the present study.

Kroll and Stewart's (1994) Revised Hierarchical Model (RHM) attempts to describe the organization of language memory in mature early L2 learners (see Figure 1). The box and arrow model was created as a result of behavioral reaction-time data in tasks using category interference and word-naming. The RHM proposes that there are lexical and conceptual (semantic) links in bilingual memory, but that these links are asymmetric for the two languages involved. The lexical link from L2 to L1 is hypothesized to be stronger than the lexical link from L1 to L2 because L2 word forms are initially associated with L1 word forms rather than with concepts. The conceptual link between L1 and concept memory is proposed to be stronger than the link between L2 and the concept store. Kroll and Stewart (1994) also add that the L2 conceptual link increases in strength as the person becomes more proficient in L2, though the lexical links between L1 and L2 do not disappear. Under the RHM, in early language learners, L2 semantic processing must be mostly mediated by the L1 lexicon, whereas L1 words have direct access to conceptual memory.

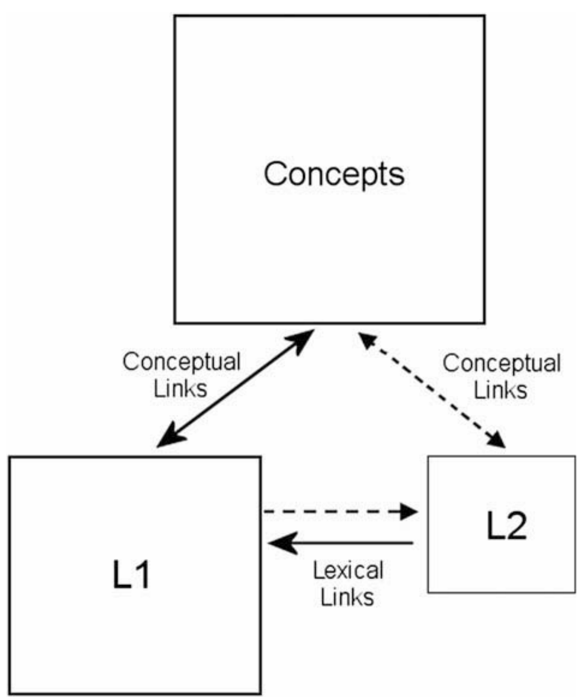

FIGURE 1. THE REVISED HIERARCHICAL MODEL (RHM) BY KROLL & STEWART (1994).

In contrast to the RHM, the BIA model (Dijsktra & Van Heuven, 1998; Grainger & Dijsktra 1992) proposed that in visual word recognition L1 and L2 share a nonselective integrated lexicon (see Figure 2). The BIA model posits that in bottom-up processing, a word stimulus is first processed at the feature level, next the letter level, then the word level, and finally at the level of language type. Once a language node is activated, it inhibits all words in the other language, enabling a bilingual to function in a monolingual context. Though this model does not make any direct hypotheses about language acquisition, it would be assumed under the BIA model that all new L2 words are integrated into the single non-selective mental lexicon.

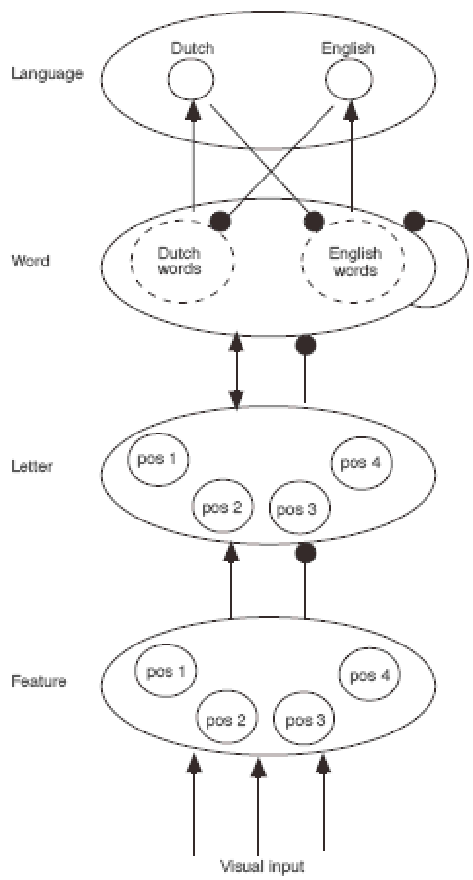

FIGURE 2. THE BILINGUAL INTERACTIVE ACTIVATION MODEL (BIA) OF DIJKSTRA AND VAN HEUVEN (1998).

The BIA+ model (Dijsktra & Van Heuven, 2002), a revision of the BIA model, offers a more thorough account of bilingual word processing, and differentiates between linguistic and non-linguistic context effects (see Figure 3). In addition to the orthographic pathway, the word identification system of the BIA+ model accounts for phonological representations in the integrated mental lexicon. According to the BIA+ model, an orthographic word undergoes both orthographic and phonological processing at the sub-lexical and lexical levels before accessing the semantic representation. The language nodes proposed in the BIA model are also modified for the BIA+ model. The role of the language nodes has been altered such that in the BIA+ model they only function as language tags that are based solely on lexical information, rather than being influenced by context. To account for the effect of non-linguistic context on bilingual word processing, the BIA+ model also posits a separate task/decision system that uses non-linguistic information (e.g., task demands, instructions) to moderate activation for items in the target or non-target languages. Again, though the BIA+ model makes no specific hypothesis about early L2 learning, as long as the L1 and L2 share scripts, they should be integrated into the same non-selective mental lexicon.

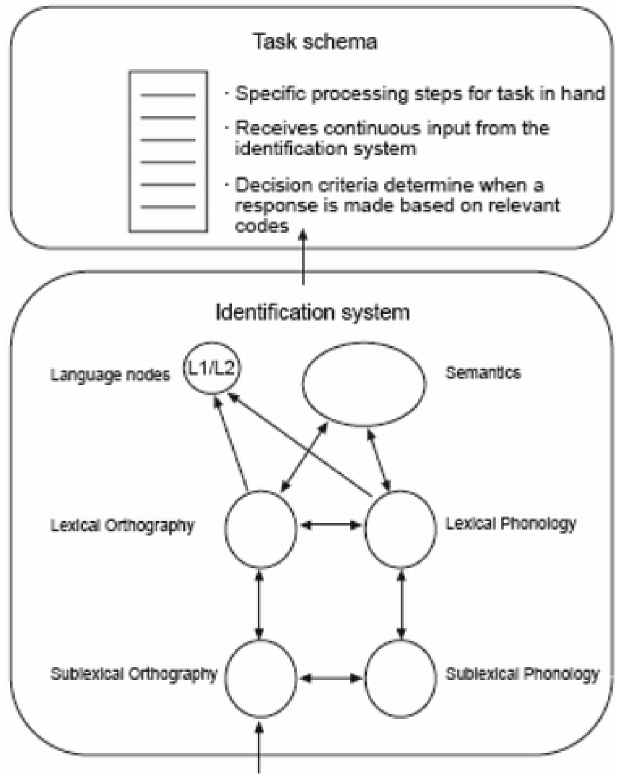

FIGURE 3. THE BIA+ MODEL OF DIJKSTRA AND VAN HEUVEN (2002).

Event-Related Potentials (ERPs)

Different experimental techniques have been used to study bilingual word processing depending on the empirical question. For example, Kroll and Stewart (1994) had participants respond by verbally naming pictures or translating visually presented orthographic words, and then measured accuracy and speed to detect differences between L1 and L2 processing. It was from these data that the RHM was formed (Kroll & Stewart, 1994). However, this behavioral data can only provide so much insight into the rapid process of word recognition.

The method used in the present study, the recording of the electroencephalogram (EEG), provides a continuous measurement of changes in electrical activity on the scalp which results from the firing of neurons in the brain. These electrophysiological voltage changes are detected using electrodes that are placed on the scalp, often embedded in a soft cap to hold them in place. While the raw EEG data can be informative about the general mental state of an individual (e.g., whether a person is asleep or mentally alert), it lacks the specificity necessary to isolate the sensory, perceptual and cognitive processes involved in complex mental tasks such as word comprehension. Event-related potentials (ERPs) are short segments of EEG recordings that are time-locked to the onset of a stimulus and averaged together by experimental condition. For example, an ERP would consist of EEG data recorded from 100ms before the visual word was presented, until 1000ms after the word stimulus. These ERPs are important to cognitive neuroscience and language processing in particular because they occur in real-time and can show changes in neurological activity at the millisecond level (Osterhout & Holcomb, 1995). Because of their excellent temporal resolution and sensitivity to tiny changes in neural activity, ERPs are becoming a more popular tool for studying language comprehension.

An ERP waveform has several *components* that have been shown to differ according to experimental condition and task manipulations in language processing. Several of these components have been shown to reflect underlying mechanisms involved in linguistic processing. The component of interest to the present study is the well-known N400 component, which is a negative-going wave that peaks approximately 400 ms after the onset of a visual word stimulus. Much research suggests that the N400 is sensitive to lexical and semantic processing (Kutas & Hillyard, 1980, 1984; Bentin, 1987; Kounios & Holcomb 1992, 1994; Osterhout & Holcomb, 1995). It was first shown that semantically inappropriate words in sentences (e.g. "He takes his coffee with milk and socks") produced a larger N400 than semantically appropriate words (Kutas & Hillyard, 1980). The N400 has also been shown to be sensitive to the ease of accessing semantic information about individual words from long-term lexical memory, where more readily available words (e.g., higher frequency or repeated words) elicit smaller N400 waves than words that are more difficult to retrieve (Kutas & Federmeier, 2000). The N400 component has also been shown to be sensitive to pseudowords, which are letter strings that are pronounceable in the language they are created from, but they have no meaning (e.g., FLARK is an English pseudoword). In a priming lexical decision task, Chwilla, Brown, & Hagoort (1995) observed that the N400 for the target words was largest when the target word was a pseudoword, intermediate for target words with unrelated primes, and the least negative N400 waveform was observed for target words preceded by a semantically related word. There is also evidence that the N400 effect can be seen as a result of lexical processing, such that words with more orthographic neighbors (words differing by just one letter when letter positions are conserved; Coltheart, Davelaar, Johnasson, & Besner, 1977) elicit a larger N400 than words with fewer orthographic neighbors (Holcomb, O'Rourke, & Grainger, 2002).

In a recent priming ERP study with a similar protocol to Chwilla et al. (1995), McLaughlin, Osterhout, and Kim (2004) found that even after only 14 hours of L2 instruction, L2 pseudoword targets elicited a larger N400 than semantically related or unrelated target words. At this early stage of learning, participants' accuracy in differentiating between pseudowords and real words was no different than the accuracy of the control subjects who were not learning the L2. However, the ERP data recorded during this experimental session showed that the brain was beginning to differentiate between pseudowords and real words in the L2. This study is an important testament to the sensitivity of ERPs, and proves them to be quite useful in studying changes in neurological activity that cannot yet be reported behaviorally by participants. Because of their sensitivity to lexical and semantic processing and fine temporal resolution, ERPs and particularly the N400 component are the best tools available for investigating word processing in early L2 learners.

ERPs and the Language Effect

Relatively few studies have directly compared the N400 component of L1 and L2 in early bilinguals. According to the BIA+ model, one could say that new L2 words might be processed similarly to low-frequency L1 words, which elicit a relatively greater N400 than high-frequency L1 words (Van Petten & Kutas, 1990). This is the reasoning that Alvarez, Holcomb, and Grainger (2003) used to predict that L2 words would elicit a larger N400 effect than L1 words in their repetition effects study. However, they found that L1 words produced a somewhat larger N400 than L2 words at posterior electrode sites. This finding was quite unexpected, and since then several studies have investigated this surprising effect of language at the N400.

In a 3-part ERP study, Midgley, Holcomb, and Grainger (2009) compared L1 and L2 processing in intermediate and proficient late bilinguals. The study repeated the same experimental design with three different groups of participants - English speakers with intermediate French, French speakers with intermediate English, and proficient French-English bilinguals. Participants performed a go/no-go semantic categorization where they passively read English and French translation equivalents for meaning on critical trials. Midgley et al. (2009) found that in intermediate second language learners, L1 items elicited a greater (more negative) N400 than L2 items at posterior electrode sites. Because this effect was replicated in both English-French and French-English intermediate second language learners, it cannot be due to specific characteristics of the languages, but rather it must be due to the difference in word processing between an L1 and an L2. In the third experiment, participants were native French speakers that were late learners of English, beginning acquisition at age 12, but considered themselves highly proficient in both French and English. Results showed that there was an interaction between language and scalp site at the N400, and upon visual inspection of their Figure 8 (see Figure 4) it can be assumed that this interaction is mostly due to the differences between L1 and L2 at anterior scalp sites. At electrode site Pz, it can be seen that there is very little difference between L1 and L2 in the N400 region. The results of the three experiments in this study confirm the finding that the L2 posterior N400 is attenuated relative to the L1 N400, and that this difference is mediated by L2 proficiency. Midgley et al. suggest that this observable difference between L1 and L2 could be due to the fact that L2 words have less dense orthographic neighborhoods. Orthographic neighborhood size has been shown to be

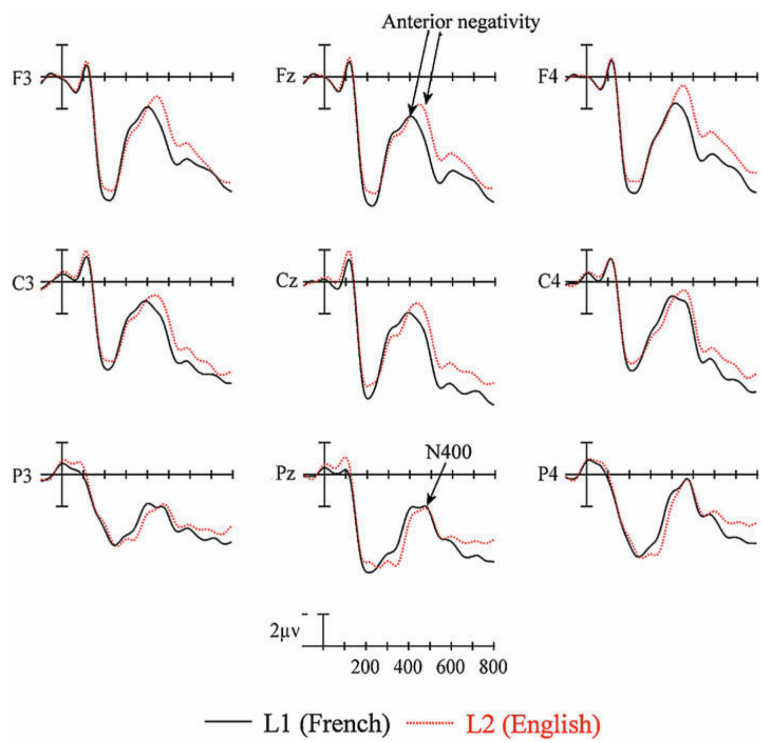

FIGURE 4. FIGURE 8 FROM MIDGLEY ET AL. (2009).

directly correlated with N400 amplitude, where words with smaller orthographic neighborhoods elicit smaller N400s (Holcomb, O'Rourke, & Grainger, 2002). The increased orthographic and semantic connectivity of L2 words in the lexicon could account for the higher N400 amplitude in proficient bilinguals as compared to intermediate bilinguals.

As mentioned previously, McLaughlin et al. (2004) also used ERP to investigate L2 acquisition. Their study focused on the earliest stages of L2 learning, and employed a lexical decision L2 semantic priming task where prime-target pairs were either semantically related, unrelated, or word-pseudoword pairs. Participants in the experimental condition of this study were university students who had never studied French prior to enrollment in an introductory French course at the outset of the study. The control group consisted of students who never had instruction or exposure to French. ERPs and behavioral data were collected for 3 sessions. McLaughlin et al. found that even in the first session, after an average of 14 hours of classroom instruction, learners' ERPs demonstrated learning in that pseudoword target items elicited a larger N400 than unrelated or related prime-target pairs, an effect that can also be seen in monolingual language processing (Chwilla et al., 1995). They also found that these priming effects became more pronounced across sessions (session 2 = 63 hours of instruction, session 3 = 138 hours), suggesting that the effects were a direct result of increasing L2 proficiency in these late learners. ERP data from the first session suggested significant cognitive learning had occurred before behavioral data showed any difference between the experimental group and the control group. Though there was no direct comparison to L1 processing, results from this study demonstrate that L2 acquisition in adult learners actually happens quite rapidly, and can be measured using the N400 component of ERPs.

Another study that addresses early L2 learning in university students was conducted by Stein, Dierks, Brandeis, Wirth, Strik, and Koenig (2006). Participants were English-speaking students in a German language-immersion exchange program in

Switzerland. Experimental sessions were conducted before German (L2) learning occurred, and then about 5 months later after intense L2 instruction. ERPs were collected to individual word items from English (L1), German (L2), and Romansh (an unknown language) on both days. Although Stein et al. did not report amplitude differences between L1 and L2 at the N400 during either session, they did find that the duration of the L2 N400 waveform was reduced on day 2. Using a source estimation method, Stein et al. suggested that their resulting topographical differences in the N400 time window were due to a shorter duration of activation of the left inferior frontal gyrus (IFG) to L2 words. Imaging studies have shown that the IFG is involved in retrieving information from semantic memory when retrieval is difficult (Fiez, 1997; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). From this data, it was concluded that shorter activation of the IFG on day 2 caused a shorter duration of the N400 waveform, which reflected L2 learning between day 1 and day 2 of the experiment. Stein et al. hypothesize that the earlier activation of the IFG on day 2 shows that with increasing L2 proficiency, L2 words are processed more quickly and with facilitated access to semantic information.

The present study

The study by Midgley et al. (2009) illustrated quite clearly the attenuation of the N400 in L2 compared to L1 and that this difference is smaller in more proficient bilinguals. McLaughlin et al. (2004) demonstrated the rapidity of early L2 acquisition, but did not directly compare processing of new L2 items to the processing of established L1 items in these early bilinguals. Therefore, the current study aimed to determine if the language effect described by Midgley et al. (2009) still applies at the earliest possible stage of L2 acquisition and to investigate whether the effect of language at the N400 decreases over a short learning period due to increased L2 proficiency. The present study also used both pure and mixed language lists. For advanced learners or proficient bilinguals pure lists may more accurately reflect their real-world language experience. However, for early L2 learners it could be more ecologically valid to process L1 and L2 items in a mixed list because early learners must often learn L2 while frequently using L1 as well. We also had some predictions about the effect of language-switching on bilingual word processing. We hypothesized that L1 switched items in the mixed list would elicit a larger N400 (Midgley, Holcomb, & Grainger, in preparation) and that for this reason there would be a slightly greater effect of language in the mixed lists.

The present study also aimed to investigate changes in the language effect over time. In order to longitudinally examine the language effect, the current study involved English-speakers enrolled in an introductory Spanish course at Tufts, ensuring that they would be naïve L2 learners. The stimuli for the experiment were taken from the course curriculum such that data would reflect learning due to formal classroom instruction. ERPs were collected from all participants periodically over the course of 5 months.

Previously described studies informed several predictions that we formed about the results of the current study. First, we predicted that we would replicate findings from Midgley et al. (2009), such that L1 items would elicit larger N400 waveforms than L2 words in all sessions. Because Midgley et al. (2009) compared intermediate and proficient bilinguals and showed that the language effect at the N400 was reduced in the more proficient bilinguals, we hypothesized that if Spanish proficiency increased across sessions, the language effect would then be attenuated across sessions. Additionally, we predicted that this mediation of the language effect would be evident even over the 5-month period of our study because of the rapidity and sensitivity with which ERPs evidenced L2 learning in the study by McLaughlin et al. (2004).

Method

Participants

Twelve Tufts University undergraduate students (7 female, mean age = 18, SD = 0.70) who were enrolled in Introductory Spanish were paid to participate. All were native English speakers, were right-handed, had normal or corrected-to-normal vision, and had no history of traumatic brain injury. English was reported to be the first language learned by all participants (L1), with no other languages learned before the age of 8. Prior to enrolling in Spanish I at Tufts, 9 of the participants had no formal exposure to Spanish (L2), and 3 participants had learned Spanish for 2 to 4 years in high school.

Participants reported their abilities to read, speak and comprehend English and Spanish (1 = unable; 7 = expert) as well as how frequently they read or communicated (spoke or wrote) in both languages (1 = rarely; 7= very frequently). All participants consistently rated their L1 language use and ability as significantly higher than in their L2 ($t(1,11)= 29.11$, $p < 0.001$) (See Table 1).

	L1 - English	L2 - Spanish
Language ability	6.88*(0.25)*	2.08*(0.48)*
Language use frequency	7.00*(0.00)*	1.52*(0.86)*

TABLE 1. MEAN (SD) OF SELF-REPORTED LANGUAGE ABILITY AND USE FREQUENCY IN ENGLISH (L1) AND SPANISH (L2).

Stimuli

The stimuli created for this study were 228 three- to seven-letter non-cognate morphemically simple Spanish words being taught in the Tufts Spanish I curriculum and their translations into English (see Appendix A for complete list of critical items). The average length of the English items was 4.79 letters (SD = 1.11) while the average length of the Spanish items was 5.36 (SD = 1.15). The average written CELEX log frequency of the English items was 2.19 (SD = 0.03) which is equivalent to 155 occurrences per million items.

The probe items consisted of 76 English pseudowords and 76 Spanish pseudowords (see Appendix B for complete list of pseudoword items). The pseudoword items were based on their respective original language and retained phonetic and orthographic properties of that language. The average length of the English pseudoword items was 4.87 letters (SD = 1.18) while the average length of the Spanish pseudoword items was 5.17 (SD = 1.22).

Each group of 228 English items and 228 Spanish items were divided into four sub-groups of 57 items each. These English and Spanish sub-groups were then combined to create 4 lists that all included an English block (57 English items, 19 English pseudoword items), a Spanish block (57 Spanish items, 19 Spanish pseudoword items), and a Mixed block (57 English items, 19 English pseudoword items, 57 Spanish items, 19 Spanish pseudoword items). The word items and pseudoword items were presented in a random order in each block. The lists were created from the subgroups such that if a participant saw ''apple'' in the English block they would not see ''manzana'' in the Spanish block or in the Mixed block, in order to avoid repetition of translation equivalents. These blocks were presented in a counterbalanced manner across participants, and the participants did not see the blocks in the same order from one session to the next.

Procedure

Training session

The first of 5 total sessions was a vocabulary training program where participants were exposed to and tested on all of the Spanish words that were used in the study. The training session took place in a room with 0-2 other participants present, each at his or her personal computer station. The participants worked silently and at their own pace. First, participants were given a pre-test where they were asked to provide the English translations for any of the 228 Spanish items they already knew. Next the participants performed a training task that used a quarter of the Spanish items. During the training task participants saw a fixation point followed by a single Spanish item followed by the simultaneous appearance of the same Spanish item on the right and its English translation equivalent on the left of the same screen (Figure 5a). The participants were allowed to study the translation screen as long as they felt they needed to remember the translation, and pressed a key on the keyboard to proceed to the next item.

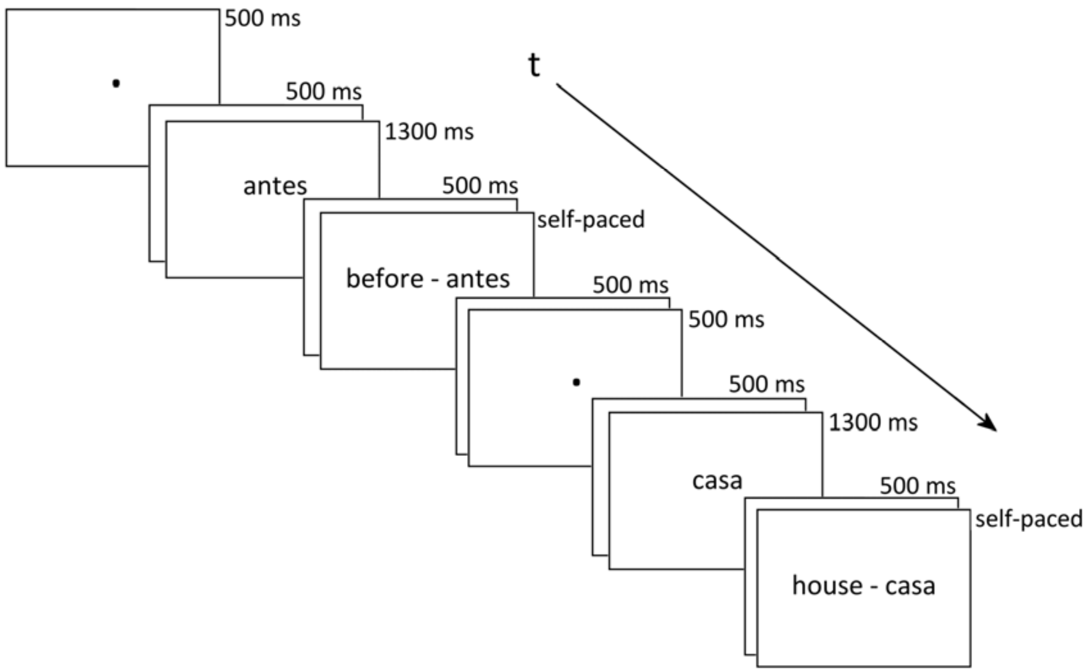

Figure 5a. A typical vocabulary training trial. The duration of each presentation is noted to the right.

After being trained on one section of the items, participants were tested on that same group of items in a different order. During testing, participants saw a fixation point, an English word, and then a screen with two Spanish words on it, one being the correct translation of the previous English word. To choose the correct Spanish translation, participants pressed the "1" on the keyboard if the correct translation was on the left, or a "0" on the keyboard if the correct item was on the right. The participants' time was not limited for this choice between the two Spanish items presented. After the participants chose between the two Spanish items, the correct Spanish translation appeared on the screen before the next English word was shown (Figure 5b).

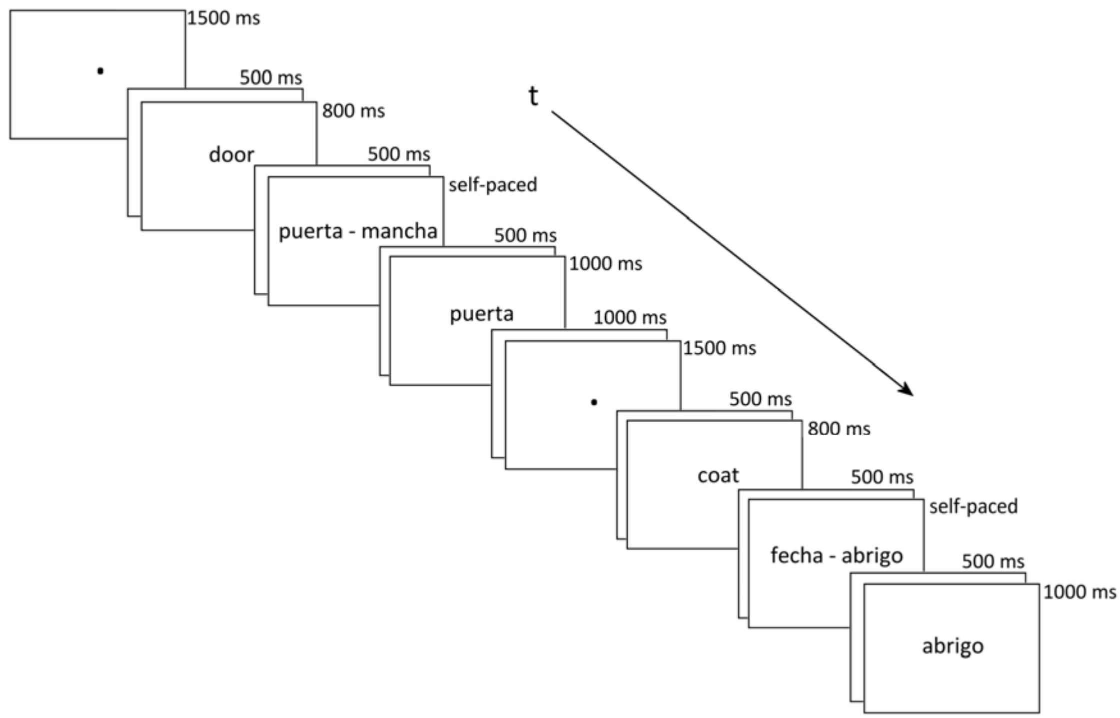

Figure 5b. A typical vocabulary testing trial. The duration of each presentation is noted to the right.

This training/testing pattern was performed four times during the training session so that all participants were exposed to all Spanish items used in the experiment. The training/testing lists were presented in a counterbalanced order across participants. At the end of the training session participants were administered a post-test which was identical to the pre-test to assess learning.

Experimental sessions

Four experimental sessions were conducted where the average number of days from the start of the semester for Session 1 was 34 days, for Session 2a was 56 days, for Session 2b was 86 days, and for Session 3 was 153 days. On all 4 experimental days, participants were seated in a comfortable chair approximately 1.5 meters away from a monitor. Stimuli appeared in white Verdana text centered on a black screen. The maximum height and width of the stimuli were such that no saccades would be required during reading of the single word stimuli. Each trial consisted of a fixation cross, a blank screen, an item, a blank screen, and then a symbol during which participants were allowed to blink followed by a blank screen (see Figure 5c for stimuli durations and example of trial). Other than during the blinking screen, participants were asked to remain still and relaxed for the purpose of collecting artifact-free data.

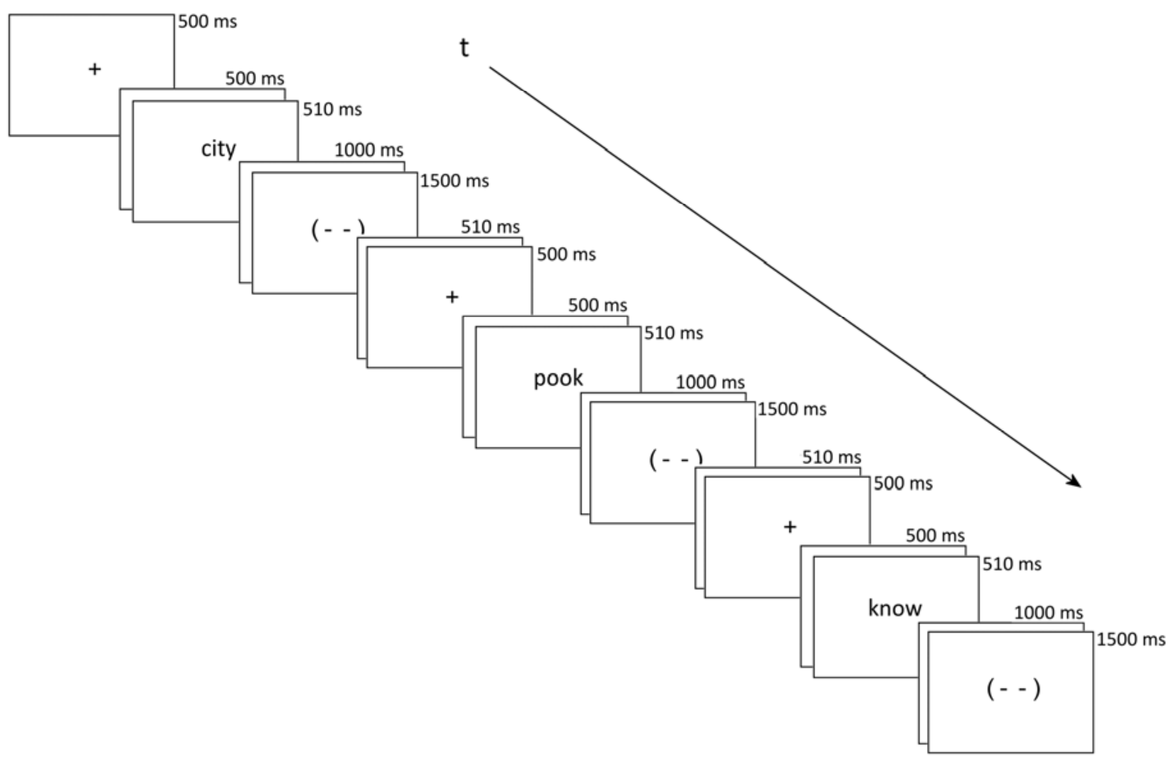

FIGURE 5C. A TYPICAL EXPERIMENTAL TRIAL. THE DURATION OF EACH PRESENTATION IS NOTED TO THE RIGHT.

The participants completed a go/no-go lexical decision task, in which they were asked to press one button on a game pad as quickly as possible whenever they detected a pseudoword. No response was required to critical items. Before the experimental lists, participants were shown a practice list to familiarize them with the task. After the experimental section, participants were asked to provide English translations of all 228 Spanish words used to create the items for the study in order to test for learning and comprehension.

Though 4 experimental sessions were conducted, only 3 of these sessions were used in the data analysis. Session 2a was omitted for several reasons. First, Sessions 2a and 2b were conducted an average of only 23 days apart, whereas when Session 2a is omitted, Sessions 1 and 2b are 53 days apart, and Sessions 2b and 3 are 67 days apart. The omission of Session 2a allows for more even intervals between experimental sessions. The other reason for omitting Session 2a from data analysis is because ERPs elicited by English items in the pure list in this session resulted in an unexpected and unusual resulting average waveform that stood out compared to ERPs to English items from the Session 2a mixed list and from all other lists in all other sessions. This difference cannot be explained by any logical conclusion. Therefore, to avoid extra noise in the data analysis, Session 2a was eliminated from all analyses. From this point on in the paper, Session 2b will simply be referred to as Session 2 to avoid confusion.

EEG recording procedure

During each experimental session participants were tested in a darkened sound attenuated room while seated in a comfortable chair. The electroencephalogram (EEG) was then recorded from 29 tin scalp electrodes which were embedded in an elastic cap (Electro-Cap International, see Figure 6). To monitor blinks and eye movements, additional free electrodes were attached below the left eye (LE) and to the right of the right eye (VE). All electrodes were referenced to an electrode placed on the left mastoid bone (A1), and continuous recording from an electrode on the right mastoid bone was used to monitor and account for differential mastoid activity. All 29 head electrode impedances were below 5kΩ, eye electrodes were below 10 kΩ, and mastoid electrodes were less than 2 kΩ. The EEG was amplified using an SA Bioamplifier at a bandpass of 0.01-40 Hz, and the EEG was measured at a rate of 200 Hz throughout the experiment.

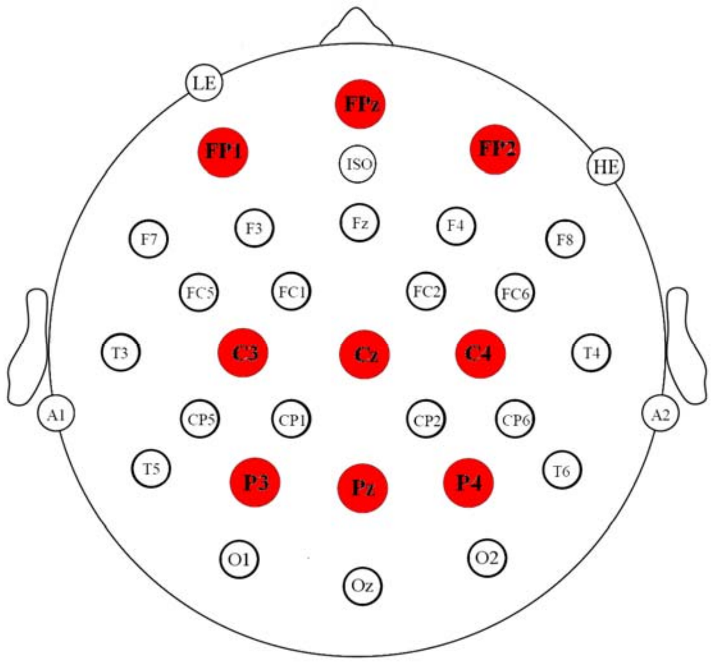

Figure 6. Electrode montage showing the locations of 29 scalp electrodes. The electrodes highlighted in red represent electrode sites used in data analysis (FP1, FPz, FP2, C3, Cz, C4, P3, Pz, P4).

Data analysis

The analysis of ERPs was conducted using an average of the mean amplitude values which were lowpass filtered at 15 Hz. A subset of 9 of the 29 scalp electrodes was chosen for analysis. Mean amplitude was measured in three epochs (200-400ms, 400-600ms, and 600-800ms) to best observe the activity before, during, and after the typical N400 waveform. Average waveforms were created for three levels of SESSION (Session 1, Session 2, and Session 3), two levels of LANGUAGE (L1 and L2), two levels of LISTTYPE (Pure and Mixed), and nine levels of DISTRIBUTION (all 9 electrodes recorded; see Fig 5). Repeated analyses of variance (ANOVAs) were performed separately on the data in each of these epochs. A Geisser and Greenhouse (1959) correction was applied to all repeated measures with more than one degree of freedom in the numerator. Language effects were further explored by session in a time-course analysis on 100ms-epochs. Voltage maps were also created to visually reflect these results.

Results

Behavioral Data

Participants scored an average of 40.8% (SD = 7.2%) on the pre-test administered before the training session and they scored a 71.9% (SD = 10.1%) on the post-test given immediately after the same training session. The post-test scores for experimental sessions 1, 2, and 3 were 62.8% (SD = 12.1%), 76.8% (SD = 9.7%), and 78.7% (SD = 9.3), respectively (see Table 2).

	Training Pre-test	Training Post-test	ERP 1 Post-test	ERP 2 Post-test	ERP 3 Post-test
Score	40.83*(7.2)*	71.93*(10.1)*	62.77*(12.1)*	76.83*(9.7)*	78.71*(9.3)*

TABLE2. MEAN(SD) PERCENTAGE OF CORRECTLY TRANSLATED SPANISH ITEMS IN LIST OF STIMULI.

Button-press responses to pseudoword items (see Table 3) indicated that participants were able to perform the experimental task in both their L1 and their L2. A reduction in the number of false alarms to real word items in the Spanish list and the mixed list over time also may reflect L2 learning.

	English List		Spanish List		Mixed List	
	BP	FA	BP	FA	BP	FA
Session 1	95.61 *(6.28)*	0.58 *(1.14)*	80.70 *(15.28)*	12.13 *(7.75)*	89.04 *(10.03)*	6.14 *(3.17)*
Session 2	98.25 *(4.67)*	0.58 *(0.86)*	75.88 *(19.75)*	2.92 *(2.63)*	90.79 *(4.42)*	1.83 *(1.47)*
Session 3	96.05 *(6.78)*	1.02 *(0.90)*	73.68 *(16.94)*	2.78 *(2.04)*	84.87 *(13.19*	2.12 *(1.15)*

TABLE 3. MEAN (SD) PERCENTAGE OF CORRECT BUTTON PRESSES (BP) TO PSEUDOWORD ITEMS AND PERCENTAGE OF FALSE ALARMS (FA) TO REAL WORD ITEMS BY LIST TYPE IN EACH SESSION.

Visual inspection of ERPs

Figure 7a shows 9 electrode sites where ERPs are time-locked to critical items. It is important to note that when ERPs are plotted on a time scale, they are always inverted such that negative voltage is plotted above the x-axis, which is why the typical N400 component is an upward peak. Early on in the waveforms, all 4 ERPs share a similar pattern of a slight peak in negativity at about 100ms, which is most prominent in the central and anterior electrodes. This negativity is then followed by a steep increase in positivity by all 4 waves around 150-200ms. At this time there is a clear divergence of the 4 waves. At posterior electrodes the differences in negativity begin around 250ms and peak at approximately 400ms (N400 component). These amplitude differences are due to attenuation of the ERP waves in L2 as compared to L1. This main effect of language can be observed in each session independently (Figure 7b). Even more specifically, the L2 Session 1 wave is the least negative and as the sessions progress, the resulting L2 wave shows increased negativity in the N400 region. This phenomenon can most easily be observed at electrode site Pz (Figure 7c).

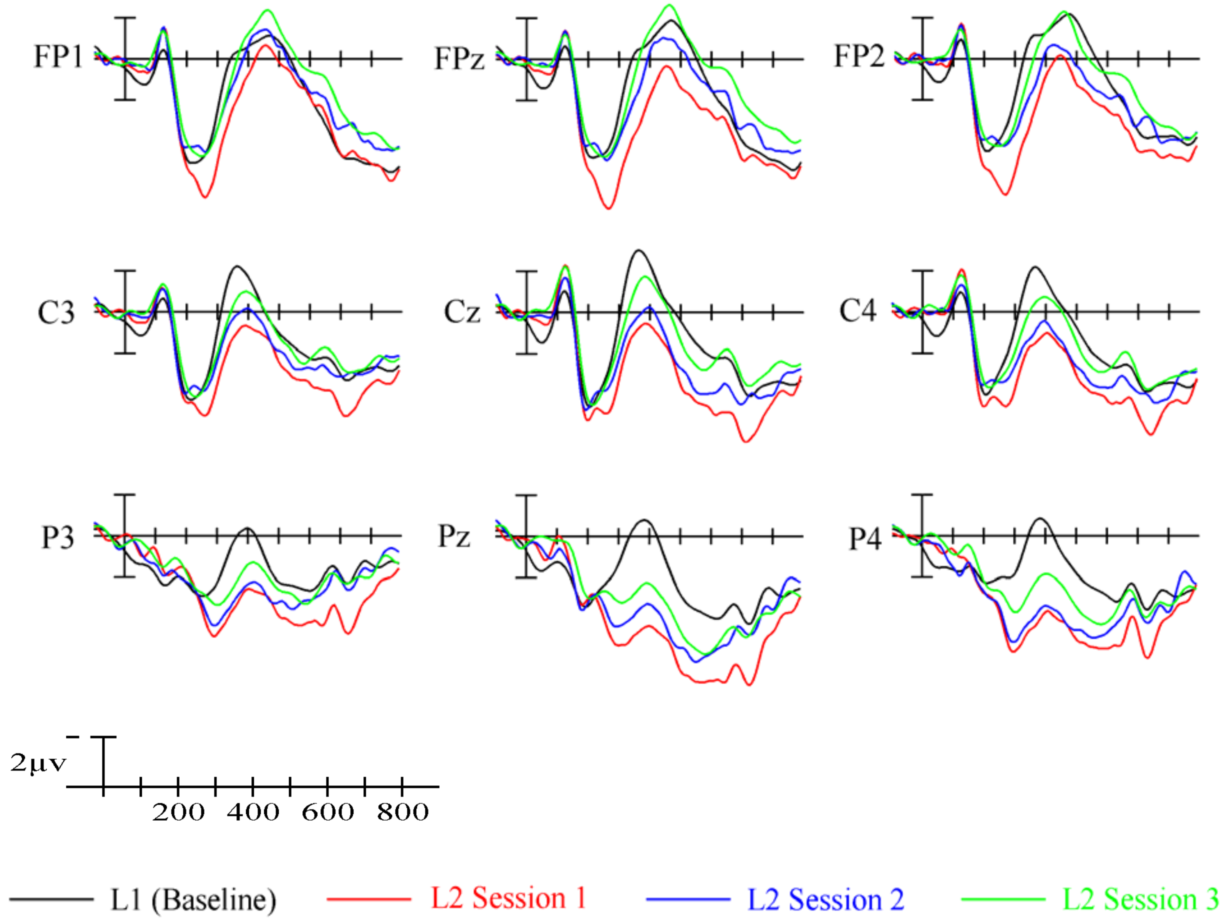

FIGURE 7A. ERPS TO L1 AND L2 ITEMS COMPARING ALL SESSIONS AT 9 ELECTRODES.

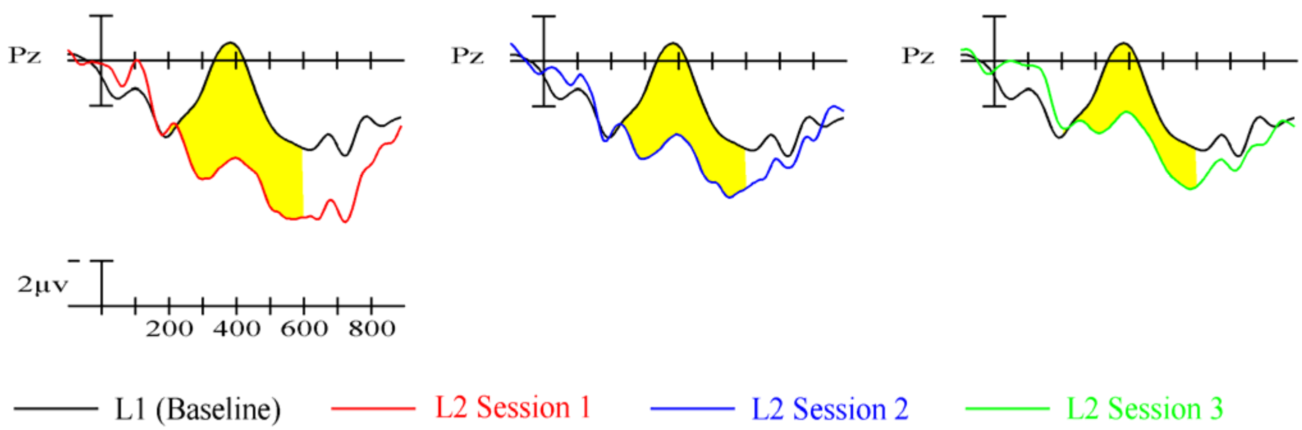

FIGURE 7B. ERPS FROM CENTRAL POSTERIOR ELECTRODE SITE(PZ) TO L1 AND L2 ITEMS BY SESSION.

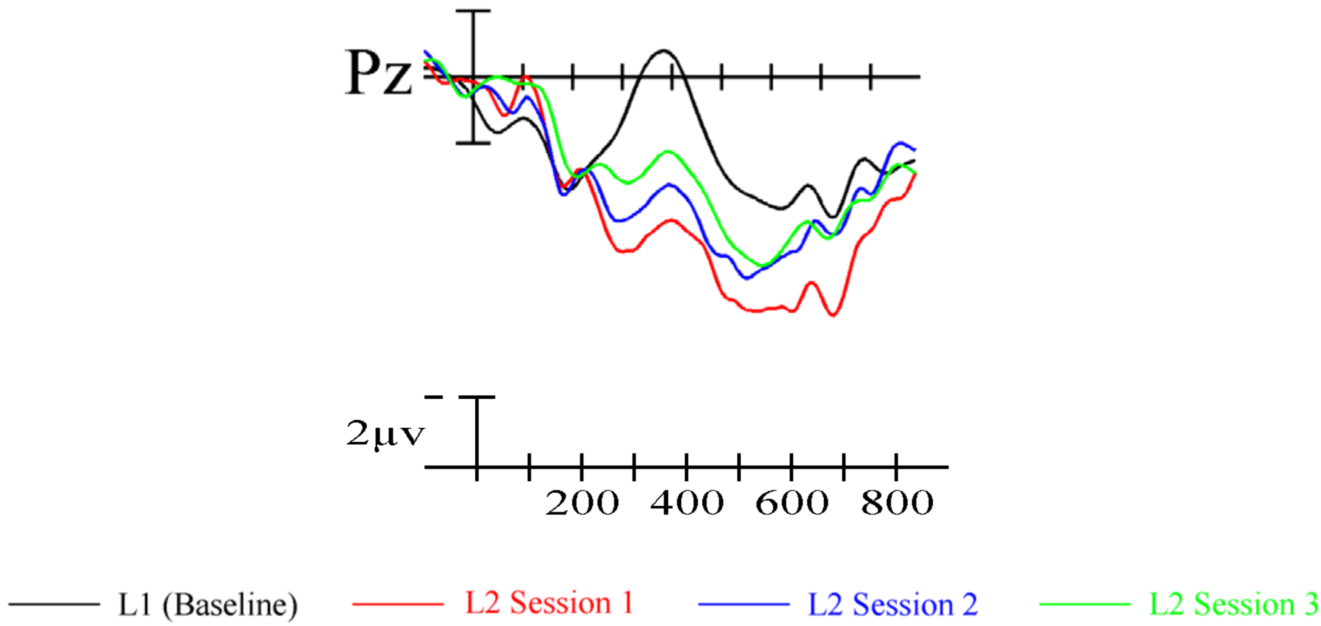

FIGURE 7C. ERPS TO L1 AND L2 ITEMS COMPARING ALL SESSIONS AT CENTRAL POSTERIOR ELECTRODE SITE (PZ).

A visual inspection of anterior electrodes in the 200-400ms epoch the L2 Session 1 wave has a more positive deflection than the L2 waves from Sessions 2 and 3, which appear to be similar in this early epoch. During the 400-600ms epoch L2 waves from all 3 sessions show the same progressive change in amplitude as they do in more posterior electrode sites in the same epoch.

Figure 8 shows voltage maps depicting the differences between L1 and L2 (L2 is subtracted from L1) for each session. It is clear that in Session 1 there is a robust and widespread difference between L1 and L2 starting at 350ms, which is depicted by the deep blue color covering the entire scalp. In Session 1 these differences become more localized to the central and posterior region of the scalp, but persist until the end of the recording epoch. The voltage maps at 450ms best visualize the language effect at the N400 component. As the sessions progress, this difference at 450ms remains robust but is more focused in the posterior area of the head. It can also be observed that while posterior differences between L1 and L2 persist for the entire recording epoch in Session 1, in Sessions 2 and 3 this posterior difference is attenuated earlier in the recording epoch.

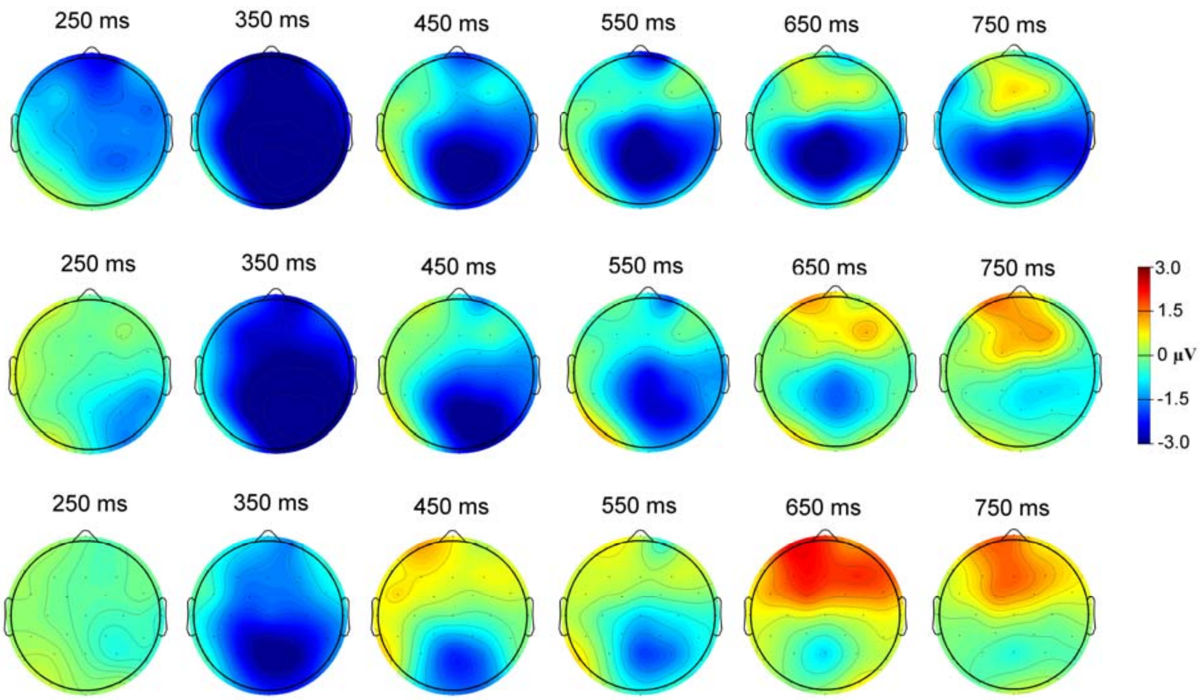

FIGURE 8. VOLTAGE MAPS FROM ALL SESSIONS (L1 – L2).

ERP Data Analysis

200-400 ms epoch

In this early epoch there was a main effect of LANGUAGE ($F(1,11) = 36.48$, $p < 0.001$) where L1 items were more negative-going than L2 items, as can be seen in Figures 8. These language differences were also mediated by scalp distribution (LANGUAGE x DISTRIBUTION, $F(8,88) = 3.69$, $p = 0.032$). There was no main effect of LISTTYPE and no interaction of LISTTYPE with LANGUAGE or SESSION. There was no main effect of SESSION and no interactions.

400-600 ms epoch

This is the epoch where language effects across sessions were observed. In the traditional N400 epoch there were differences between the two languages, (LANGUAGE, $F(1,11) = 4.99$, $p = 0.047$) which again differed according to scalp site (LANGUAGE x DISTRIBUTION, $F(8,88) = 4.81$, $p = 0.025$). A main effect of SESSION ($F(2,22) = 8.38$, $p = 0.005$) was also observed during this epoch. Interestingly, we also found an overall significant interaction between SESSION x LANGUAGE x DISTRIBUTION ($F(16,176) = 3.02$, $p = 0.040$). A visual inspection of the Pz electrode in Figure 7c shows that over time the amplitude of the L2 wave in the N400 region increases, becoming more negative with each session. Again, there was no main effect of LISTTYPE and no interactions.

600-800 ms epoch

In the later epoch we again observe robust language effects that were a function of scalp distribution (LANGUAGE x DISTRIBUTION, $F(8,88) = 9.91$, $p < 0.001$). This effect can be seen at posterior electrode sites in Figure 7a. As in earlier epochs, there was no main effect of LISTTYPE and no interactions.

Time-course analysis

A time-course analysis was performed to further investigate language effects in each session and differences in this effect between sessions (Table 4). The time-course analysis shows the robust, widely distributed language effect in Session 1, and little interaction between language and distribution. However, this language effect becomes more localized and posterior in later sessions, where there is more interaction between language and scalp distribution. This trend is also illustrated in the voltage maps (Figure 9).

	200-300	300-400	400-500	500-600	600-700	700-800

Session 1	Language effect	**	***	***	***	*	*
	Language effect x distribution				**	*	
Session 2	Language effect		***	**	**		
	Language effect x distribution		*	**	*		
Session 3	Language effect		***				
	Language effect x distribution		**	**	*	**	*

*** = p <0.01 ** = p <0.05 * = p <0.10

TABLE 4. TIME-COURSE ANALYSIS (100 MS INTERVALS) OF LANGUAGE EFFECT AND INTERACTION OF LANGUAGE EFFECT BY DISTRIBUTION.

Discussion

In previous research it has been shown that in mature L2 learners of an intermediate level, L2 items elicit an attenuated N400 component compared to L1 words (Midgley et al., 2009). There is also some evidence that the N400 component is sensitive to L2 lexicality judgments in the earliest stages of L2 acquisition (McLaughlin et al., 2004). The current study aimed to expand this body of research by investigating the language effect at the N400, comparing ERPs of L1 and L2 in early L2 learners. To attain the most realistic data possible, monolingual English-speaking students in an introductory Spanish course were studied in three sessions over the course of five months. In each session, ERPs were collected to L1 and L2 items passively read for meaning. Because the N400 component has been understood to reflect semantic processing of a word (Kutas & Hillyard, 1980, 1984), this was the component of most interest in this experiment. Based on previous studies, we predicted that the N400 to L2 items would have a reduced amplitude in comparison to L1 items. Additionally, we expected that this language effect would diminish across sessions as participants became more proficient in their L2.

We observed a significant effect of language in each session independently, particularly at posterior electrode sites, such that L2 words always elicited an attenuated N400 component compared to L1 words. This finding replicates the results from Midgley et al. (2009) acquired from intermediate L2 learners. The important difference here is that the present study focused on the earliest stage of L2 learning. Though Midgley et al. (2009) showed this language effect in intermediate learners, the question remained as to whether this language effect described all stages of L2 learning, or only emerged after people completed the earliest stages of L2 acquisition. When considering languages with similar alphabets (e.g., English and Spanish), it is plausible that L2 words would be processed similarly to L1 low-frequency words or pseudowords in the initial phase of L2 learning (eliciting a larger N400 than high-frequency L1 words; Kutas & Federmeier, 2000; Chwilla et al., 1995), and then with increasing proficiency begin to demonstrate the observed language effect. However, the results of the present study confirm that the language effect is found to be robust even after only 34 days of L2 learning.

Not only did we find an effect of language in each session, but we found that this effect diminished across sessions, such that the L2 N400 component continued to increase in amplitude from session 1 to session 2 and from session 2 to session 3. This effect suggests that the L2 N400 is mediated by language proficiency in language learners, especially when these results are considered in conjunction with the results from Midgley et al. (2009) who found a language effect in intermediate learners, but not in proficient bilinguals. This attenuation of the language effect that we observed also supports the findings by McLaughlin et al. (2004) which reported rapid changes in brain responses to L2 items after only 14 hours of instruction, and then continued differentiation of ERPs to L2 pseudowords and real words across several subsequent sessions. These findings, along with those of the present study suggest that there is significant neurological plasticity, even in the adult language system.

As an explanation for the attenuated L2 N400, or the language effect, Midgley et al. (2009) hypothesized that this difference between L1 and L2 processing was caused by differences in orthographic neighborhood size of the items in L1 compared to those in L2. It can be assumed that L1 items are much more richly interconnected in the lexicon than are L2 words, and in monolingual studies it has been shown that words with larger orthographic neighborhoods elicit higher-amplitude N400s (Holcomb et al., 2002). This evidence could explain why the L2 N400 amplitude increased over time. As participants become more proficient in their L2, the L2 words themselves would benefit from more overall connectivity – both orthographic and semantic – and would elicit greater N400s (Midgley et al., 2009; Kounios & Holcomb, 1994).

The original study design included two different types of lists – both mixed and pure language lists. We intended to investigate the effect of list type on the language effect in word processing in early language learners. From a study conducted by Midgley et al. (in preparation), we predicted that L1 switched items in the mixed list would elicit a larger N400 and that for this reason there would be a slightly greater effect of language in the mixed lists. In fact, we observed no significant interaction between language effect and list type. There could be several factors contributing to this lack of observable interaction. First, the present study might not have had sufficient statistical power, and it is possible that these variable switch effects might become significant with more subjects. Another possibility is that switch effects in the earliest stage of learning may not resemble the profile of switch effects in the intermediate learners studied by Midgley et al. (in preparation).

Though the present study provides solid evidence for the language effect on early L2 learning and the rapidity of L2 acquisition, the study has some limitations. First, the data in the current study were collected from only 12 participants. This low number of subjects allows for high amounts of variability in the subjects language history and ability, and as mentioned above could have resulted in lower statistical power. However, despite having few subjects, the results still reached significance, indicating that this effect of language at the N400 and its attenuation over time are quite robust phenomena.

Additionally, the present study only followed participants over 5 months of language learning, and already there were significant increases in N400 amplitude to L2 items. However, in the Midgley et al. (2009) study, intermediate learners still showed a significant language effect after an average of 5 years of learning French (L2). It would be quite illustrative for a future study to follow participants over several years to investigate the trajectory of this language effect. It is possible that the evolution of the language effect slows after an initial L2 learning phase and may only slowly increase during the intermediate learning phase.

Another finding worth further exploration was that we found no significant effect of language prior to 200 ms except in Session 3. Midgley et al. (2009) found an early main effect of language prior to 200 ms in their intermediate L2 learners but not in proficient bilinguals. Any effects in this early epoch are believed to be sensitive to orthographic manipulations of stimuli (Holcomb et al., 2002), which is why, unlike the N400 component, these effects may vary with type of language. Different languages vary by types of alphabets used, incorporation of different types of accents, word-length, bigram frequency, and by many other visual characteristics, and early effects may reflect these differences. It would be quite relevant for a future study to investigate the effect of type of language on these early components. For example, a study could compare native English-speakers learning different alphabetic languages (e.g., Spanish, Hebrew or Russian) whose words have varying bigram frequencies or different visual characteristics in comparison to English. It would also be interesting to categorize these languages by how orthographically shallow (high letter-to-sound correspondence) or deep (low letter-to-sound correspondence) they are, and compare ERPs with this difference as a factor. Spanish is a much more orthographically shallow language than English, and it would also be valuable to investigate these early language effects in Spanish-speakers in the earliest stage of learning English to see if there are significant differences before 200 ms and when these differences arise. Studies investigating early differences in ERP components in early language learners would serve to elaborate on the full time course of word processing to include pre-lexical orthographic processes, rather than just lexical and semantic processing at the N400.

The present study provides the first evidence of a language effect at the typical N400 component in the earliest stage of L2 learning in the adult brain. Our results also suggest that this language effect evolves quickly as a result of increasing L2 proficiency. We propose that this increase in N400 amplitude to L2 items is the result of increased L2 orthographic connectivity in the mental lexicon due to L2 learning. In addition to the few existing studies that have investigated L2 learning, the findings from the current study suggest that while learning a second language as an adult may seem difficult and slow, the brain's marvelous plasticity allows for a quite rapid integration of a second language into the mental lexicon.

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Appendix A

Critical Items: Spanish and English Translation Equivalents

abogado	lawyer
abrigo	coat
abrir	open
aceite	oil
adios	goodbye
afuera	outside
agua	water
ahora	now
ajo	garlic
alemán	german
algodón	cotton
allí	there
alto	tall
alumno	student
amigo	friend
ancho	wide
anillo	ring
año	year
antes	before
aquí	here
árbol	tree
arroz	rice
ayudar	help

bufanda	scarf
cabeza	head
cajero	cashier
cambiar	change
camisa	shirt
cansado	tired
cantar	sing
carne	meat
carta	letter
casa	house
casado	married
cebolla	onion
cena	dinner
cerca	near
cerveza	beer
chorizo	sausage
cierto	true
ciudad	city
coche	car
cocinar	cook
comer	eat
comida	food
comprar	buy

diente	tooth
dinero	money
donde	where
dormir	sleep
ducha	shower
dulce	sweet
durante	during
edad	age
ejemplo	example
empezar	begin
enero	january
enfermo	sick
enojado	angry
enseñar	teach
escoger	choose
escuela	school
esposa	wife
fácil	easy
falda	skirt
fecha	date
feliz	happy
feo	ugly
fiesta	party

hombre	man
hoy	today
huevo	egg
joven	young
jugo	juice
lana	wool
lápiz	pencil
lástima	pity
leche	milk
lechuga	lettuce
leer	read
lejos	far
libro	book
llamar	call
llegar	arrive
loco	crazy
lugar	place
madre	mother
malo	bad
mandar	send
manejar	drive
mano	hand
manzana	apple

azúcar	sugar
azul	blue
baile	dance
bajo	short
barato	cheap
barco	ship
bata	robe
beber	drink
bien	well
bistec	steak
blanco	white
boda	wedding
bolsa	bag
bonito	pretty
bueno	good

corbata	tie
corto	short
cosa	thing
creer	believe
cual	which
cuando	when
cuarto	room
cuchara	spoon
cuero	leather
cuerpo	body
dar	give
decir	say
delgado	thin
derecha	right
después	after

frijol	bean
frío	cold
fumar	smoke
ganga	bargain
gastar	spend
gordo	fat
gracias	thanks
gris	gray
guante	glove
hablar	speak
hambre	hunger
hasta	until
hermano	brother
hijo	son
hola	hello

martes	tuesday
menos	less
mercado	market
merecer	deserve
mes	month
mesa	table
moda	fashion
muerto	dead
mujer	woman
mundo	world
muy	very
nada	nothing
nadar	swim
naranja	orange
nieve	snow

noche	night
nunca	never
oferta	sale
oír	hear
otoño	autumn
padre	father
país	country
palabra	word
pardo	brown
pelo	hair
peor	worse
pequeño	small
pero	but
pesado	heavy
picante	spicy
playa	beach
postre	dessert
precio	price
primero	first
primo	cousin
pueblo	town
puerta	door
pupitre	desk
querer	want
querido	dear
queso	cheese
quien	who
regalo	gift

seda	silk
seguir	follow
segundo	second
semana	week
siempre	always
silla	chair
sobrino	nephew
sol	sun
sonido	sound
sucio	dirty
suerte	luck
tacón	heel
talla	size
tarjeta	card
taza	cup
tenedor	fork
tener	have
tienda	store
tío	uncle
todo	all
trabajo	work
traje	suit
triste	sad
uva	grape
venir	come
ver	see
verano	summer
verdad	truth

regla	ruler
reloj	clock
rey	king
rojo	red
ropa	clothes
roto	broken
rubio	blonde
saber	know
salir	leave
sed	thirst

verde	green
vestido	dress
viajar	travel
vida	life
viejo	old
viento	wind
vino	wine
vivir	live
volver	return
zapato	shoe

Appendix B

Probe Items: Spanish and English Pseudowords

Spanish Pseudowords			
fei	láriz	sener	sen
leor	tacór	hiso	opoño
brana	fanda	ensermo	frimo
poír	uca	langa	napanja
pilo	anullo	jes	dien
anchu	limro	parlo	ropo
prumo	alarno	rono	regundo
viabar	pual	canrado	sopido
mereler	beser	enad	esrosa
shuante	azútar	praje	dicero
nuerta	loso	granias	azun
colsa	vima	nerano	bucio
fasa	manrana	carsa	tol
padios	prierto	butanda	teo
vir	pelgado	eño	nandar
hampre	riento	areite	olgodón
dieste	ciutad	spieve	mado
samina	nasta	cadre	aproz
catisa	borito	ogua	dreer

English Pseudowords			
onien	lear	tummer	pring
theat	rity	bartain	fap
shance	cress	blothes	corton
demerve	frich	oal	fastion
hene	mollow	pess	sut
shoser	nale	shere	flace
fappy	unril	slock	benore
wome	heturn	stend	bolieve
glable	oten	wesk	mive
nuy	anter	shen	maney
pruth	saurage	bonth	sourd
tranel	fip	kroken	wice
swit	nuck	lired	rold
phord	kight	sint	stope
tean	blonte	lenter	coundry
sarty	pawyer	tize	pook
ald	ell	ean	nend
lort	pessert	sor	sesk
irrive	sall	mown	butumn