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Meaning first: A case for language-independent access to word meaning in the bilingual brain

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Abstract

This study aimed to determine how deeply a word is processed in the bilingual brain before the word's language membership plays a role in lexical selection. In two ERP experiments, balanced Spanish-English bilinguals read lists of words and pseudowords in Spanish and English, and performed in each language 1) a language-specific lexical decision task, e.g., respond to real words in Spanish, and 2) a language-specific category decision tasks, e.g., respond to Spanish words that refer to a person. In Experiment 1, infrequent words elicited larger negativity between 350–650 msec post-stimulus onset for both target and non-target languages. This indicates that language membership did not block lexical access of non-target words, contrary to previous findings. In Experiment 2, we measured the onset of the target-category P300 as a way of determining if words from the non-target language were temporarily treated as targets. When Spanish was the target language, the ERP waveforms diverged early based on semantic category (people versus non-people), indicating that non-target 'English people' words were briefly treated as potential targets. This finding indicates that meaning was accessed prior to using language membership for lexical selection. However, when English was the target language, the waveforms diverged first based on language (Spanish versus English) then semantic category. We argue that the order in which meaning or language membership are accessed may be based on the frequency of use of a bilingual's languages: the more frequently a language is used (English was more frequently used herein), the faster the words are identified as members of the language, and the greater interference it causes when it is not the target language. In brief, these findings make the case for a moment in processing when language membership matters less than meaning.

Keywords

Bilingual lexical access; event-related potentials; language membership; lexical access; semantic categorisation; world frequency

1. INTRODUCTION

A man living in Mexico City was at a full-service gas station with his family. When the Spanish-speaking station attendant walked up to the window and asked how much gas the man wanted, the man said he wanted a full tank plus an additive. The station attendant

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looked at him dumbfounded. The man repeated himself and said a bit more to clarify. The man finally realized why the attendant didn't respond when his children said, "Dad you are speaking in English". The man laughed in disbelief and then switched to Spanish. This anecdote from one of the authors is an example of a surprisingly common bilingual phenomenon; a moment when we seem to be unaware of the language we are using. In this study we aimed to determine if a similar moment is quantifiable during comprehension. To do this, we tested how deeply a word is processed in the bilingual brain before the word's language identity kicks in.

An issue of ongoing debate in bilingual word comprehension is whether lexical access occurs selectively in one language or not. By necessity, in order to access words selectively a bilingual must identify the language to which a word belongs (i.e., language membership), be it implicitly or explicitly. Language membership information can in theory be used to block the processing of non-target language words, including access to their semantic information, thus contributing to selective lexical access. Alternatively, language membership information may become available late in lexical processing, in which case it would not function as a filter for non-target words. The current study aims to determine at what stage in word processing language membership affects lexical access, or conversely, up to what stage language membership is ignored to allow for deeper word processing. We look at the automatic access of information during two comprehension tasks with mixed-language word lists, and record event-related potentials (ERPs) from proficient Spanish-English bilinguals. The continuous recording and temporal precision of ERPs allowed us to address two aims. First, we assessed whether balanced bilinguals use language membership to block processing of one language, as reflected by their sensitivity to the lexical frequency of words in the non-target language. Second, we employed a new paradigm to study the temporal dynamics of access to language membership information, and determine whether it is accessed before or after semantic information.

Early models of bilingual memory assume separate lexicons for the two languages (Kirsner, Smith, Lockhart, & King, 1984). Access to lexico-semantic information was thought to happen at a late processing stage, conditional on language selection at earlier stages, such that words of the context-irrelevant language did not reach the lexico-semantic level of processing. In support of this proposal, proficient bilinguals seemed able early on to discontinue processing of a written word in the task-irrelevant language (Gerard & Scarborough, 1989; Neumann, McCloskey, & Felio, 1999; Scarborough, Gerard, & Cortese, 1984). Later, Rodriguez-Fornells et al. (2002) provided the strongest evidence for language-specific word recognition, using ERPs and functional magnetic resonance imaging (fMRI) (though a subsequent production task showed strong cross-language interference, Rodriguez-Fornells et al., 2005). Spanish/Catalan bilinguals were required to make a manual response to words in a list in one language and not to pseudo-words and words in the other language. The N400 frequency effect, which is usually larger in amplitude for low-frequency than high-frequency words (Rugg, 1990), was observed for words in the target language (either Spanish or Catalan), but not for words in the non-target language. In addition, there was no evidence of preparation of a motor response for words in the non-target language (based on the absence of lateralized readiness potentials), suggesting that the bilinguals were able to suppress the task-irrelevant language. In a parallel fMRI experiment, bilinguals and Spanish monolinguals exhibited similar brain activation for non-target Catalan words and pseudo-words. However, compared to monolinguals, bilinguals had greater activation of the posterior inferior frontal area in response to target Spanish words, and greater activation of the planum temporale for all words. Both brain regions have been related to phonological processing. Direct access from orthography to the lexicon, presumably used by monolingual Spanish speakers, may produce response competition from the non-target words. Thus the differential activation was attributed to the bilinguals' use of

a “sublexical pathway, that is, activating only graphemic-phonological spelling rules of the Spanish language,” (p. 1028). The inhibition of the direct access route was implicated in greater activation in an anterior prefrontal region by bilinguals than monolinguals, in response to the non-target words. Thus bilinguals may use a lexical retrieval pathway different from that of monolinguals, and achieve selective lexical access by inhibiting direct access from orthography to the lexicon.

However, there is also strong evidence for implicit interference effects from the non-target language even when processing only the target language. This implies that both languages may be active during language comprehension, regardless of a word’s language membership. Evidence for non-selective lexical access has shown that interference arises at different levels of lexical access: semantic, lexical (homographs), and sublexical (neighborhood density), thereby implying bilinguals are not impervious to cross-language interference in visual word processing. At the semantic level, many studies have observed cross-language priming, for direct translations and semantically related words, often with more robust priming from the first language (L1) to the second (L2) than vice versa (see the summary by Altarriba & Basnight-Brown, 2007). Priming studies therefore seem to favor automatic processing of the meaning of words, which can facilitate the retrieval of semantically related words in both languages. At the lexical level, numerous studies have examined the effect of cognates (words that share both form and meaning across languages) and interlingual homographs (words that share a same form but not meaning across languages) on lexical decision (e.g., de Bruijn, Dijkstra, Chwilla, & Schriefers, 2001; de Groot, Delmaar, & Lupker, 2000; Dijkstra, Timmermans, & Schriefers, 2000; Duyck, Van Assche, Drieghe, & Hartsuiker, 2007; Kerkhofs, Dijkstra, Chwilla, & de Bruijn, 2006; van Hell & Dijkstra, 2002; von Studnitz & Green, 2002) and found that cognate and homograph recognition was often affected by their meaning and frequency in the non-target language. At the sublexical level, Holcomb, Grainger, & O’Rourke (2002) have shown that words with more orthographic neighbors (words of the same length that differ in only one letter) within the same language had a larger N400¹ than those with fewer neighbors. Across languages, a target-language word that has many neighbors in the non-target language was found to evoke larger N400s than words with few neighbors (Midgley, Holcomb, van Heuven, & Grainger, 2008). Results of all these studies suggest that bilinguals are not able to completely turn off the non-target language when processing a target language.

In sum, there is experimental evidence supporting both selective and non-selective lexical access. The current study investigates whether the availability of language membership can serve to block processing of words in the non-target language. Language membership information must exist in some form in bilingual memory. Otherwise, bilinguals would not be capable of speaking one language at a time and making language-specific lexical decisions. But then, how is language membership information represented in a bilingual brain? It may be that the bilingual lexicons are functionally separate, even if they can be activated in parallel (e.g., Kroll, van Hell, Tokowicz, & Green, 2010), or they may be overlapping and highly interconnected, requiring an explicit or implicit way of determining language membership. Distributed connectionist models, for example, do not generally assume two separate lexicons for a bilingual. Instead, words are identified as members of a language by their specific orthographic and phonological features, and also by the language context (Dijkstra & Snoeren, 2004; Thomas & van Heuven, 2005). In contrast, localist connectionist models, exemplified by the Bilingual Interactive Activation Plus (BIA+) model (Dijkstra & van Heuven, 2002), postulate a separate language node. In the BIA+ model, the language node is like a label attached to a word, and does not function as a filter

¹The N400 is an ERP component with a negative voltage deflection peaking around 400 msec post-stimulus onset, which is thought to reflect semantic processing (Kutas & Federmeier, 2011; Kutas & Hillyard, 1980).

that can block the non-target words. It is representational but not functional within the word identification system, and can minimally affect individual word activation (Figure 1) (van Heuven & Dijkstra, 2010). This assumption contrasts with an early version of the BIA model where language membership information can inhibit non-target language words (Dijkstra & van Heuven, 1998). Thus, language membership information may be realized as sublexical features, or as labels attached to words, or through co-activation of other words in a language context. The present study does not address directly the question of the form that language membership takes in bilingual memory. Instead, we assume that language membership information exists in some way and ask at what point in processing (when) does language membership information affect the course of lexical access?

1.1 Overview of the present study

We conducted 2 experiments with balanced Spanish-English bilinguals and measured ERPs to target and non-target language words in a mixed-language list. In Experiment 1, we measured ERPs from Spanish-English bilinguals while they made lexical decisions in one language (target) and were asked to ignore the other (non-target). We compared the brain's response to words of high and low lexical frequency in the non-target language, to determine if lexical access was blocked or not in this language. A similar paradigm was used by Rodriguez-Fornells et al. (2002), where they reported selective lexical access for words in the target language, as discussed before. The goal of Experiment 1 was to attempt to replicate these findings, and then further test in Experiment 2 processing of non-target words using a different task.

Experiment 2 employed a mixed-language word list similar to the one used in Experiment 1 to look into the possibility that language membership might play a role in restricting access to semantic information for the non-target language. In paradigms where one type of word requires a categorical response (e.g., respond when you see an animal word), the corresponding target-word ERPs are associated with response-related components, like the P300 (e.g., Polich, 2003). In Experiment 2, we took advantage of this response-related brain activity to determine at what point bilinguals classify non-targets as such. Participants were required to make language-specific semantic-category decisions, e.g., respond only to Spanish words that refer to a person. The waveform morphology of the target words (e.g., 'Spanish people' words) would then reflect the target identification process. If language membership information is accessed before semantic information, ERP responses to words of a language would be initially different from words of the other language, irrespective of semantic category. In contrast, if semantic information is accessed before language membership information, ERP responses to words of a semantic category would be initially different from words of the other category, irrespective of language. By examining the onset of the divergence of the ERPs to words of different languages and semantic categories, we can logically deduce at what point language membership information is accessed relative to semantic information.

1.2 General methods

Participants—All participants completed both experiments in one day. Twenty-four (14 women) healthy right-handed Spanish-English balanced bilinguals were paid to participate. They were 18 to 35 years old ($M = 23.4$, $SD = 4.4$), and residents of the state of Texas, USA. All of them reported Spanish as their L1. They were first exposed to English at different ages (range: 0–17 years), and had received on average 11 years of formal education in each language (Spanish range: 2–15 years; English range: 3–23 years). Data of additional three participants was excluded from analysis because of excessive response errors and ERP artifacts.

Before the ERP session, each participant completed a battery of Spanish and English language tests, which included four tests in each language from Woodcock (1991): Letter-Word Identification, Passage Comprehension, Word Attack, and Reading Vocabulary. These tests specifically evaluated reading skills, which were most relevant to the ERP tasks. Participants took about one hour to complete the language tests.

The raw score of each test was converted to a Relative Mastery Index (RMI), which indicates the mastery level of an examinee on the task relative to the age-equivalent norm group. The RMI can be interpreted as the chance of success on tasks similar to the ones an examinee undertakes. In Woodcock, the mean success rate of the norm group is 90% for all tasks. Thus, an examinee who obtains an index below 90 on a task indicates a below average ability relative to the norm group. But note that this index is normalized based on the test results of monolingual speakers in each language.

The mean English RMI of our participants was 81.4 (range: 60 to 97) and that of Spanish was 83.0 (range: 61 to 95). A paired-samples t-test showed a non-significant difference ($t_{23}=2.01$, $p=.600$) between the two indexes. According to the eleven levels (from 'Negligible' to 'Very Advanced') of Cognitive-Academic Language Proficiency (CALP) in Woodcock (1991), no participant differed for more than two levels in their Spanish and English ability.² Most participants fell between the level 'Limited' to 'Average' in the two languages.

Additionally, participants were asked to circle real words on a list of 15 low-frequency and 15 pseudo-words in each language. These words were not used in the ERP experiments. All participants acquired at least 25 correct answers (including correct identification and correct rejection) for each list.

Procedure—Visual stimuli were presented in the center of a 19-inch CRT monitor, at high contrast as white letters on a black background in the Verdana font (letter matrix = 40 pixels wide by 80 pixels). Each word was displayed for 600 msec, preceded by a cross (+) at the same location for 800 msec (with a 200 msec inter-stimulus interval) and followed by a blank screen for 1400–1600 msec. Participants were seated in a sound-insulated electrically shielded chamber, 19 inches away from the monitor. They were instructed to make responses by pressing a button on the keyboard.

Each experiment had two sessions, one in each language. The order of the language was randomly assigned. Each participant started with the lexical decision task (Experiment 1) in one language, either Spanish or English. She would then undertake the lexical semantic task (Experiment 2) in the same language as the previous session. After a 10-minute break, she would perform the same two tasks in the other language in the same order.

A practice session that contained 18 words prepared participants for the upcoming task. Each experimental session contained 486 randomized trials (480 experimental trials and 6 covert practice trials at the beginning of a session) and lasted approximately 25 minutes. Four rest breaks were interspersed throughout. Participants were instructed to respond when a target was identified, and no response was required for non-targets. No feedback was provided. Behavioral data in the form of accuracy and reaction time were collected along with the EEG recording.

²Seven participants were slightly more Spanish dominant, with Spanish one level above English; 10 scored at the same level in both languages; 7 were slightly more English dominant. Within the English dominant group, 2 participants performed two levels better in English than Spanish. We repeated analyses without these two individuals and found almost no differences in the pattern of the effects. The only difference was an earlier frequency effect for non target English words in Experiment 1: a main effect of Frequency occurred at 400–450 msec (c.f. Table 2).

Continuous electroencephalogram (EEG) was recorded from 32 tin electrodes, 26 embedded in a standard cap (Electro-Cap Inc., see Figure 2) in geodesic array, and 6 electrodes to record eye artifacts and mastoid process references; each referenced on-line to the left mastoid (e.g., Wicha, Moreno, & Kutas, 2004). Blinks and horizontal eye movements were monitored through a bipolar recording from electrodes placed on the outer canthi of each eye and under each eye. Electrode impedances were maintained below 5k Ω . The EEG was amplified with SAI analog bio-amplifiers with band pass set from 0.01 to 100 Hz, and sampled at 250 Hz. The output of the bio-amplifiers was fed into a 32 channel 12-bit analogue-to-digital converter. *ERPSYSTEM* software (developed by P. J. Holcomb) was used to simultaneously present visual stimuli to the participant, and deliver event and timing codes to the data acquisition PC with the onset of each word.

Trials with artifacts due to eye movements, excessive muscle activity or amplifier blocking were eliminated off-line before averaging. Approximately 14% of the total trials in the two experiments were rejected, with roughly equal loss of data across conditions. Furthermore, incorrect trials and trials with a delayed response (exceeding the 1400–1600 msec ISI) were excluded from the data analysis, which accounted for an additional 5% of data. Hence, 81% of total data was entered into the ERP analysis. Data was re-referenced to the algebraic sum of the left and right mastoids, and averaged for each experimental condition. A digital band-pass filter set from 0.1 to 30 Hz was used on all of the data prior to running analyses to reduce high frequency content irrelevant to the components of interest.

Analyses are reported time-locked to each word relative to a 100 msec pre-stimulus baseline. Characterization and differences in the early sensory components – N1, P1, N2, P2 – and the slower components – N400, LPC – was done by visual inspection and statistical analyses. Effects for repeated measures with greater than one degree of freedom are reported after Greenhouse-Geisser correction. Mean amplitude of averaged ERPs to a condition was subjected to global repeated-measures ANOVAs with the variables of interest by electrode for each time-window, selected based on visual inspection of the waveforms. Moving time-windows (e.g., 50-msec segments) were also used to identify the precise timing of an effect. A 5% significance level was maintained throughout these analyses.

2. EXPERIMENT 1

2.1 Stimuli

In this experiment, participants were required to make a language-specific lexical decision for a word, e.g., English real word. The experiment included two sessions, each with either Spanish or English as the target language. The stimuli in both sessions were identical. Each session contained 160 Spanish nouns, 160 English nouns, and 160 pseudo-words, half derived from words of each language. The frequency and other lexical information of the words were obtained from Davis and Perea (2005) (based on the LEXESP database) for Spanish, and from Davis (2005) (based on the CELEX database) for English. The real words were equally divided into high-frequency and low-frequency words; thus there were 80 high-frequency and 80 low-frequency English and Spanish words, respectively.

No cognates and near-cognates were used, so as to reduce the confusion of language membership of a word. Moreover, words were carefully selected to deter rejection based on simple orthographic strategies. Thus, no English words contained the letters *k* and *w*, which are not common in the Spanish language. Likewise, no accented words were used.

The appendix summarizes the lexical information of the words. In Experiment 1, the frequency per million of words, Log 10 frequency, and familiarity rating³ were significantly different ($p < .001$) in independent-samples t-tests between the high-frequency and low-

frequency words in a language. But the number of syllables, summed log bigram frequency, number of letters, number of orthographic neighbors, and number of phonological neighbors were not significantly different ($ps > .30$). Overall, the high-frequency and low-frequency words differed in frequency and the related familiarity, but were matched on a number of other lexical features. Therefore, any difference observed in their EEG responses was likely due to frequency and/or familiarity.

The English pseudo-words used in this study were obtained from The English Lexicon Project (Balota et al., 2007). We created the Spanish pseudo-words by changing one to two letters of real words. The number of syllables, summed log bigram frequency, number of letters, and number of orthographic neighbors of the pseudo-words were matched to the real words.

2.2 Results

Behavioral Findings—Table 1 shows the accuracy rates and reaction times of the English and Spanish words in Experiment 1. Responses were considered incorrect if they occurred after the 1400–1600 msec ISI from stimulus offset. Repeated-measures ANOVAs yielded no main effect of Language (Target accuracy: $F_{1,23}=2.658$, $p=.117$; Reaction time: $F_{1,23}=2.147$, $p=.156$), but a main effect of Frequency in both target accuracy rates ($F_{1,23}=71.217$, $p<.001$) and reaction times ($F_{1,23}=125.833$, $p<.001$). High-frequency words were responded to faster and more accurately than low-frequency words. A significant interaction of Language and Frequency was found for both target accuracy rates ($F_{1,23}=5.339$, $p=.030$) and reaction times ($F_{1,23}=23.041$, $p<.001$). Planned comparisons suggested a significant main effect of Frequency, the effect being larger for Spanish than English, but no main effect of Language for target accuracy rates. As for reaction times, the main effect of Frequency was modulated by Language: Spanish low-frequency words were responded to significantly slower than English low-frequency words ($F_{1,23}=5.313$, $p=.031$). These results have two implications. First, the frequency manipulation was valid, given that significant main effects of Frequency were found for both languages. Participants were significantly faster and more accurate at identifying the high-frequency words than the low-frequency words in both languages. Second, they performed slightly better in English than Spanish in this speeded word recognition task, as revealed in the faster reaction time for the low-frequency English words. This may reflect their enhanced efficiency in processing English words than Spanish words in a time-pressured setting. The significance of this will be elucidated later.

Table 1 also shows the response bias measure ‘criterion location’ (c) (Macmillan & Creelman, 2005) of each task. A positive c value indicates a conservative approach to the task and a negative c value indicates a liberal approach⁴. As for this study, a conservative bias would increase the chance of rejecting a real word, while a liberal bias would increase the chance of accepting a pseudo-word. This bias could create an illusion of a higher target accuracy rate for a language if participants were, for some reason, more liberal towards words from one language.

ANOVAs of c values with Experiment (Experiment 1 vs. 2) and Language as factors indicated only a significant main effect of Experiment ($F_{1,23}=330.809$, $p<.001$), but not Language ($F_{1,23}=.349$, $p=.561$), and no interaction ($F_{1,23}=4.253$, $p=.051$)⁵. Participants were

³Not all the words used in this study have a familiarity rating in the databases. The familiarity figures in the tables were derived from words with a rating, consisting of 84% of all stimuli.

⁴The values of c were obtained from averaging the z -score of the Hit rate of the targets and the z -score of the False Alarm rate of the pseudo-words that were derived from words of the language same as the targets. In order to successfully transform a raw score to a z -score, neither the Hit nor False Alarm rate can be 1 (i.e., correct identification of all target words) or 0 (i.e., correct rejection of all pseudo-words). Should that happen, the raw score would be adjusted one downward or upward, i.e., one mistake would be assumed.

more liberal in performing the lexical decision task (Experiment 1) than the language-specific category decision task (Experiment 2), but they showed little difference in their strategy used in identifying targets in the two languages. Thus, it can be concluded that a liberal response bias could not explain the higher accuracy rates of English than Spanish in both experiments.

Electrophysiological Findings—The critical comparisons were between the ERP responses to high-frequency and low-frequency words. Four sets of data in this experiment permitted this comparison: Spanish words as the target, English words as the target, Spanish words as the non-target, and English words as the non-target. Figure 3 plots ERPs of four representative electrodes in medial positions for the data sets. A transient difference in amplitude between high-frequency and low-frequency words appeared around 200 msec, and a distinct difference 400–650 msec. To elucidate the timing of any significant effects, we performed statistical comparisons of the ERPs of the high-frequency and low-frequency words every 50 msec from 200 to 650 msec.

Table 2 summarizes the repeated-measures ANOVA results of the frequency effect for the four data sets in Experiment 1. Main effects of Frequency were found in a brief early as well as a prolonged later time-window. In the latency of 250–300 msec, low-frequency words elicited a larger negative amplitude than high-frequency words for both target ($F_{1,23}=5.454$, $p=.029$) and non-target ($F_{1,23}=4.789$, $p=.039$) English words. In a later time window 350–650 msec, there were main effects of Frequency and Frequency x Electrode interactions for the Spanish and English target words and for the Spanish non-target words. As for the English non-target words, there were not main effects of Frequency, as shown in Table 2, but significant Frequency x Electrode interactions. Figure 3 highlights the time window when the effects were found for each type of stimuli. Figure 4 shows the scalp distribution of group ERP average difference (low-frequency words minus high-frequency words) during the time window when the effect was significant. The enhanced negativity for the low-frequency words was maximal in the posterior medial locations, with a slight left-hemisphere dominance. The overall results suggested that the bilinguals were sensitive to both target and non-target word frequency: low-frequency words elicited larger negative amplitude than high-frequency words, regardless of the target status of the words. This indicated that words of both languages were active during the task.

2.3 Discussion

In Experiment 1, bilinguals were required to respond to English real words in one session and to Spanish real words in the other session. Behavioral data showed that the bilinguals were significantly faster at recognizing high-frequency than low-frequency words, irrespective of the target language. However, they were slower at identifying Spanish low-frequency words than English low-frequency words. ERP frequency effects were observed between 350–650 msec. There was a main effect of frequency, with larger negative amplitude for low than high frequency words, across all recording sites for all target words and for non-target Spanish words, and at medial-posterior sites for English non-target words.

Overall, the findings were consistent with those of Rugg (1990): more posterior negative-going ERPs to low-frequency than high-frequency words around the N400 region (in this study, 350–650 msec). Most importantly, the effect was found for words of both target and non-target languages, which indicated that these bilinguals accessed both languages

⁵Although the interaction effect appears to approach significant, pairwise comparisons did not indicate main effects of Language in the two experiments (Experiment 1: $F_{1,23}=1.670$, $p=.209$; Experiment 2: $F_{1,23}=.873$, $p=.360$). There were nevertheless very significant main effects of Experiment in the two languages (Spanish: $F_{1,23}=146.590$, $p<.001$; English: $F_{1,23}=178.551$, $p<.001$).

regardless of processing demands. This finding is contrary to that of Rodriguez-Fornells et al. (2002), in which the Spanish/Catalan bilinguals showed no N400 frequency effect for the non-target words.

It is not entirely clear why Rodriguez-Fornells et al.'s and the present study yielded opposite results. A few differences between the two studies deserve notice. First, the two bilingual populations differed in many respects. The Spanish/Catalan bilinguals in Rodriguez-Fornells et al.'s study lived in Germany at the time of testing. Their L1 was not reported but it was stated that the bilinguals had acquired both languages in the early years of their life. All the Spanish-English bilinguals in our study had Spanish as their native language and lived in the USA at the time of testing. As mentioned before, they were first exposed to English at different ages (range: 0–17 years).⁶ It therefore appeared that our participants showed more variation in acquiring their second language and they were tested at the place where their L2 was spoken. The immersion language may have non-negligible influence on lexical access, as will be discussed later. All in all, the two bilingual groups behaved differently perhaps because of their language exposure and the way their languages were acquired. Second, task demands were different. The participants in Rodriguez-Fornells et al.'s ERP study were required to identify a target word based on language, and make phonetic judgment (vowel or consonant) on the first letter of the target word. Experiment 1 of this study only required the participants to identify a target word based on language. It is possible that the additional requirement of attention to phonology in Rodriguez-Fornells et al.'s study reduced cognitive resource available for lexical processing, weakening the non-target frequency effect. Third, Rodriguez-Fornells et al. did not exclude Catalan words with language-specific features, e.g., words with the grave accent and specific letters like “ç” (Grosjean, Li, Münte, & Rodriguez-Fornells, 2003). We avoided accented words and words with letters particular to a language. Thus, our participants might not be able to use simple orthographic strategies to exclude a word as target. Interestingly, Rodriguez-Fornells et al. used Catalan and Spanish words, which share more orthographic similarities than Spanish and English words. Despite the reduced similarity of languages in our study, clear frequency effects were observed for words of the non-target language, which indeed provides strong support for non-selective lexical access.

Two characteristics of the ERPs for this experiment are worth notice. The frequency effects of the Spanish words emerged earlier (100 msec for the targets and 50 msec for the non-targets) than those of the English words (see Table 2). In addition, the frequency effect of the non-target English words concentrated in posterior locations only, compared to a broader distribution of the frequency effects of other three sets of stimuli. We believe this is a result of salience of the English words, given that they were more frequently used than the Spanish words. The bilingual population in this study was living in the USA and all but one were college students with English as the learning medium. According to their self-reports, they spoke English on average 55% (range: 25 – 95%; Spanish 45%) of the day. With English being the predominant language in the spoken and written medium, they were likely to encounter Spanish words less frequently, especially the low-frequency Spanish words. Thus, it is possible that they found the word frequency difference of English words less prominent than that of Spanish words. To corroborate this with empirical evidence, we compared the reaction time difference of the high-frequency and low-frequency words in the two languages for each participant. The averaged difference of English words was 74 msec and

⁶We performed Pearson's correlation coefficient analyses on various measures (participants' Woodcock scores in the two languages, age of first exposure to English, daily use of English and Spanish, English and Spanish target accuracy rates, and differential reaction times of low-frequency over high-frequency words) and the differential negativity (low-frequency minus high-frequency words) on selected 11 posterior medial channels (where the effects were largest) during the latency when the frequency effect was found for each set of stimuli. The analyses returned no significant correlation ($p > .1$). It therefore lends no evidence that any of these factors might considerably contribute to the effects observed.

that of Spanish words was 117 msec. There was a significant between-language effect ($t_{23}=4.8$, $p<.001$). Note that Duyck et al (2008) also found, in their lexical decision experiment with Dutch-English Bilinguals, a larger difference in the reading times of English (L2) high-frequency and low-frequency words, compared to Dutch (L1) high-frequency and low-frequency words. Thus, it appears that bilinguals are more sensitive to the frequency difference of words from their less-frequently used language. This different level of sensitivity could magnify the Spanish word frequency effects in our experiments, resulting in an earlier and a more distributed frequency effect.

3. EXPERIMENT 2

3.1 Stimuli

In this experiment, participants were required to make a language-specific semantic decision for a word. The relevant semantic feature was whether a word referred to a person or not, e.g., *sister* and *door*. The design of Experiment 2 is illustrated in Figure 5. The word list composition for this experiment was identical to that for Experiment 1: 160 Spanish nouns, 160 English nouns, and 160 pseudo-words, half derived from words of each language. These words were different from those used in Experiment 1. Words were categorized into 'people' and 'non-people' words; thus there were 80 'English people' words and 80 'English non-people' words. The number of words in each category was the same for Spanish. There were no main effects of Language or (Semantic) Category in the frequency per million of words and Log 10 frequency ($ps>.3$). Nevertheless, Spanish words had more syllables, more bigrams, and contained more letters ($ps<.01$), and English words had more orthographic and phonological neighbors ($ps<.05$). The only significant Language x Category interaction was found for phonological neighbors: 'English people' words had more phonological neighbors than 'English non-people' words ($p<.01$) but 'Spanish people' and 'Spanish non-people' words did not differ reliably ($p=.92$). The appendix summarizes the lexical information of the words used in this experiment.

This experiment was a 2×2 design, with the factor Language (Spanish vs. English) crossing the factor Semantic Category (people vs. non-people). The target words (i.e., the go-trials) were either 'Spanish people' or 'English people' words. The data from the two sessions in which either Spanish or English was the target language were analyzed separately because visual inspection of the data revealed substantial differences in the ERPs in the two sessions. The key contrast was the onset of the differential response to the four types of words, which is presumed to be related to decision-related activation pertinent to target detection. The comparison of interest was therefore on the latency when the waveforms of the target and non-target conditions diverged. The onset of the divergence was interpreted as the time when the target and non-target words were recognized as such. According to the findings of Thorpe, Fize, and Marlot (1996), the no-go trials in their paradigm, where the participants were required to identify animals in photographs, produced frontal negativity, relative to the go-trials, starting at roughly 150 msec after stimulus onset. The larger negative-going ERPs were argued to reflect the inhibition on the behavioral responses to the no-go trials. Thus, we would expect similar ERP patterns for the go and no-go trials in this experiment.

3.2 Results

Behavioral Findings—Table 1 shows the accuracy rates and reaction times of the English and Spanish words in Experiment 2. The only significant main effect was found for non-target accuracy rates. The bilinguals were more accurate at rejecting the non-target English words than the non-target Spanish words ($t_{23}=3.116$, $p=.005$). Hence, once again, the bilinguals performed slightly better in English than Spanish.

Electrophysiological Findings—Visual inspection of the waveforms revealed that a divergence of the ERPs for go and no-go trials might happen as early as 100 msec post-stimulus onset. Thus, statistical analyses started at 100 msec, in the increment of 25 msec until the end of the epoch, i.e., 700 msec. ANOVA and ERP results are shown in Table 3 and Figure 6, respectively. No significant effect was observed ($p > .05$) for the ERPs of the two sessions in the latency of 0–100 msec.

When English was the target language, ANOVA results showed main effects of Language and Language x Electrode interactions, starting 150 msec and persisting until 600 msec; 50 msec increments. Spanish words elicited more negative-going ERPs than English words. Category effect began at 275 msec; non-people words produced a larger negative amplitude than people words. Significant interactions of Language and Category were found at 300–625 msec; non-target words were more negative than target ‘English-people’ words. The scalp distribution of Language and Category effects is plotted in Figure 7. The earlier effects was concentrated over frontal sites, with a right hemisphere dominance, and then gradually shifted to posterior regions.

When Spanish was the target language, the Category effect occurred before the Language effect. The Category effect was found from 225 msec until 600 msec; non-people words elicit more negative amplitude than people words. A main effect of Language was found at 300 msec, with larger positivity for English than Spanish words. This Language effect was carried by the ‘English people’ condition, which was significantly more positive than all other conditions around 300 msec. Interestingly, ‘English people’ words are the key distracters in the paradigm, since the task requires a response to people words. At 350 msec the Language effect flips, with all English words eliciting greater negativity than all Spanish words. Visual inspection of occipital sites shows that the P300 to target ‘Spanish people’ words begins to form, but an interaction between Language and Category was seen only briefly between 475–525 msec, in which the target ‘Spanish-people’ words were more positive than all other conditions.

The scalp distribution of these effects is plotted in Figure 7. Note that the Category effect shows a similar distribution across the time windows for both Spanish-target and English-target sessions. In contrast, the Language effect looks different across language sessions. When English was the target language, there was a prominent negativity maximal over right fronto-central electrodes for the effect of Language, starting around 150 msec. The non-target language (Spanish) elicited larger negativity than the target language (English). When Spanish was the target language, a less prominent frontal negativity appeared around 350 msec. For both languages, an additional posterior negativity was visible from around 350 msec. The large posterior negativity is actually due to the appearance of the larger P300 to targets, given that the data in Figure 7 represent the subtraction of non-targets minus targets (i.e., a small positive amplitude minus a large positive amplitude equals a negative amplitude). The frontal negativity, given its distribution and timing, may reflect processes related to inhibition of the non-target words, as a right frontal negativity is often associated with no-go (inhibited) trials (e.g., Luus, van Snellenberg, & Liotti, 2007; Rodriguez-Fornells, et al., 2005; Thorpe, et al., 1996). Why we observe a difference across languages is not clear. One might expect that increased demand for inhibition, as we assume is occurring when English is the distracter language, should perhaps increase the frontal negativity. Alternatively, more negativity could reflect increased ability to inhibit the distracters, as is the case when English is the target language. Further studies are needed to elucidate the correlates of this frontal negativity.

In sum, the bilinguals were able to distinguish words based on language membership by 150 msec when English was the target language. Semantic category distinction followed at 275

msec. But when Spanish was the target language, the bilinguals distinguished semantic category before language membership. The Category effect emerged at 225 msec, followed by the Language effect at 350 msec. In both sessions, words from the non-target language and non-target category produced more negative-going ERPs than words from the target language and category. In addition, the effects generally began with a frontal concentration and then shifted to a posterior maximum. Evidence of target identification was observed in later time-windows. In the English session, the three non-target conditions diverged from the target 'English people' condition at 300 msec, with the non-target words producing more negativity than the target words. In the Spanish session, a brief interaction of Language and Category occurred around 500 msec.

3.3 Discussion

Experiment 2 aimed to investigate the time course of access to semantic category and language membership information during word recognition. The behavioral findings indicated that our bilingual population was slightly weaker in Spanish overall; in line with results from Experiment 1. Although the reaction times and accuracy rates of accepting target English and Spanish words were comparable, the accuracy rates of rejecting non-target Spanish words were reliably lower than those of non-target English words. In the ERP results, when English was the target language, the ERPs diverged based on language at 150 msec post-stimulus onset, and then based on semantic category at 275 msec, implying that language membership information was accessed before semantic information. However, when Spanish was the target language, the ERPs diverged first based on semantic category at 225 msec and then based on language at 350 msec, implying that semantic information was accessed before language membership information.

These findings seem to suggest that the order of these two levels of lexical processing can vary. We believe that this may be related to global activation level of a language. The bilinguals in the present study did not show measurable differences in proficiency across languages based on the language assessments and the overall behavioral results in the two experiments. However, they reported using English more frequently than Spanish at the time of testing. They could therefore have developed a sharper sensitivity to English than Spanish words, given that they lived in an environment where English was the predominant written and spoken language. This may explain why when the task demanded their attention to English words (i.e., English was the target language), they could separate English words from Spanish words 125 msec earlier than semantic category. But when the task demanded that they pay attention to Spanish words, the relative activation level of Spanish may not have been high enough to block the interference of the irrelevant semantic information from English words. Hence, the bilinguals had access to semantic information 125 msec earlier than language membership information.

Previous studies have provided empirical evidence that supports the effect of usage frequency of a language on language processing. Heredia (1997) discussed several studies which showed that performance of bilinguals on translation-equivalent word pairs depended on the active status of their languages, rather than on the order of language acquisition. The concept of 'active language' is close to "immersion": a bilingual is in an environment where the second language is used more frequently than the first language. Some studies indicate that immersion can weaken access to L1 and increase access to L2 in second language learners (Linck, Kroll, and Sunderman (2009). This suggests that bilingual memory is dynamic; the frequency of language use can change the process of lexical access. It is possible that we observed a similar effect in our sample of proficient bilinguals. In the current study, intrusions from English non-target words seemed to delay target identification: a Language x Category interaction occurred at 300 msec for 'English people' words, but at 475 msec for 'Spanish people' words. There was also a difference in scalp

distribution across languages that might hint at different processing depending on which language was the target.

Our ERP findings show that semantic information is accessed around 200 msec post-stimulus onset, coinciding with the time course of the N400 component found in many previous studies. Crucially, language membership information could be accessed before that, as early as 150 msec, as in the English-target session, or later at 350 msec, as in the Spanish-target session. The critical question is what strategy these bilinguals used in the two sessions to identify language membership of a word that might explain the timing and distribution difference. There are two possible strategies. First, the bilinguals might have been looking for orthographic clusters specific for a language. They adopted this strategy only for English perhaps because these words were more salient given the immersion environment.⁷ This would mean that language membership information is represented primarily at the sublexical level. Another possibility is that the bilinguals exercised top-down processing early in lexical processing. As mentioned before, our bilingual population could have a heightened level of global activation of English words. Hence, they might be able to match the whole words they saw to the members in their English lexicon early on. Once they found a familiar letter string, they could immediately include it as a potential candidate. Language membership information thus would be represented primarily at the lexical level.

The discussion hence brings up an interesting question about the processing level at which language membership information becomes available. Several studies have looked into the time course of different levels of word processing, and found that sensitivity to orthography can occur by 200 msec post-stimulus onset (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Grainger & Holcomb, 2009; Grainger, Kiyonaga, & Holcomb, 2006; Holcomb & Grainger, 2006; Ruz & Nobre, 2008). But the stimuli in these studies were manipulated in a way that sublexical processing may not even be necessary to spot the specific orthographic features required by the tasks, e.g., the size of the word, or the physical similarity between two letter strings. Results of our study show that lexical processing may happen even quicker than previously thought: some higher-order processing in the form of language membership identification can occur by 150 msec post-stimulus onset.

What are the implications of these findings to bilingual lexical access in isolation and in sentence context? In the English session, English words were separate from Spanish words as early as 150 msec, but there was still a brief period (275–300 msec) when there was a main effect of semantic category. This suggests that language membership information, even if it is available early enough, is not used to block semantic access to words of the non-target language (consistent with previous findings, e.g., Naylor, Stanley, & Wicha, 2012). As discussed earlier, in the latest version of the BIA+ model (e.g., van Heuven & Dijkstra, 2010), language nodes cannot block or inhibit access to words of the non-target language. The findings of the current study may support the argument that the putative language nodes are representational but not functional.

⁷We discount the possibility that the English words in our study had more orthographic clusters particular to the language than the Spanish words, which therefore facilitated the processing of language membership when English was the target language. We used the number of orthographic neighbors to test this. We put the English words used in Experiment 2 in the Spanish database and vice versa, and found that the English words had numerically, though not statistically significantly, more neighbors in the Spanish language, than the Spanish words in the English language. The total number of neighbors of all English words in the Spanish database was 81, and that of all Spanish words in the English database was 106. This difference was not reliably significant ($p=.5$). The proportion of Spanish words that had no neighbor in the English language was 79%, and that of English words was 76%. Thus, it is unlikely that the English words we used triggered the use of a special word-identification strategy.

When a word is presented in a sentence, the context provides a strong cue for the language in use. Previous studies have found access to meaning of cognates in the non-target language in low-constraint sentences, though not in high-constraint sentences (e.g., Duyck, et al., 2007; Schwartz & Kroll, 2006; van Hell & de Groot, 2008). Libben and Titone (2009) found cognate facilitation only in early measures of eye-tracking. But a more recent eye-movements study (Van Assche, Drieghe, Duyck, Welsaert, & Hartsuiker, 2011) showed cross-language cognate facilitation in both early and late measures for both low and high-constraint sentences. The findings of these studies are therefore consistent with those of the present study: strong language membership cues such as context and task demand may not be sufficient to restrict semantic access in lexical processing.

4. CONCLUSION

The present study addresses (i) whether Spanish-English bilinguals are sensitive to word frequency of a non-target language, and (ii) whether this sensitivity can be explained by the depth of lexical processing in terms of the time course of accessing semantic and language membership information. Our results indicate that there is a point in processing when words from a non-target language are treated as potential targets, allowing for processing as far as the meaning of the word. These findings support non-selective lexical processing⁸. However, the depth to which non-target words are processed before accessing language membership may depend on the frequency of using a particular language. The language that is more globally activated may make its vocabulary more readily accessible, something that we are currently testing. In sum, our findings make the case for a moment in processing when language membership matters less than meaning.

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⁸One could argue that our study cannot address selective lexical access because both languages are present in the stimuli. What we argue is that language membership, in principle, could be available from the outset during a reading task. That is, the orthographic information could give away what language the word is from (e.g., most of the words used in this study did not have orthographic neighbors in the other language and may therefore be identified as from one language). The fact that we observed a non-target frequency effect in Experiment 1 and an early effect of category in Experiment 2 indicates that word form level information in this case is insufficient to stop further processing of the non-target words. Therefore, even in a task where language membership could potentially lead to selective processing, the bilingual brain can still access the meaning of words non-selectively.

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APPENDIX

Lexical information of the words used in Experiment 1.									
		Freq./million	Log10 freq.	Familiarity	No. of syllables	Summed log bigram frequency	No. of letters	No. of orthographic neighbors	No. of phonological neighbors
High Freq. Spanish Words	Maximum	352.9	2.6	7.0	4.0	25.9	11.0	10.0	15.0
	Minimum	24.5	1.4	3.6	1.0	3.7	3.0	0.0	0.0
	Mean	80.6	1.8	6.0	2.7	14.3	6.4	2.1	3.3
Low Freq. Spanish Words	Maximum	9.1	1.0	6.8	4.0	22.5	10.0	18.0	27.0
	Minimum	2.1	0.5	1.5	1.0	3.9	3.0	0.0	0.0
	Mean	4.9	0.8	4.6	2.8	13.9	6.6	2.2	3.6
High Freq. English Words	Maximum	382.4	2.6	655.0	3.0	25.7	10.0	22.0	36.0
	Minimum	25.0	1.4	469.0	1.0	4.0	3.0	0.0	0.0
	Mean	82.5	1.8	553.5	1.7	12.7	5.8	3.1	7.6
Low Freq. English Words	Maximum	9.1	1.0	638.0	3.0	20.5	10.0	19.0	36.0
	Minimum	2.2	0.5	298.0	1.0	1.3	3.0	0.0	0.0
	Mean	5.0	0.8	469.8	1.8	12.3	5.9	3.2	7.6

Lexical information of the words used in Experiment 2.									
		Freq./million	Log10 freq.	Familiarity	No. of syllables	Summed log bigram frequency	No. of letters	No. of orthographic neighbors	No. of phonological neighbors
Spanish people Words	Maximum	689.8	2.8	6.9	4.0	22.7	10.0	20.0	20.0
	Minimum	2.1	0.5	2.3	1.0	4.0	3.0	0.0	0.0
	Mean	58.9	1.3	5.3	2.9	14.3	6.7	2.0	2.0
Spanish non-people Words	Maximum	295.4	2.5	6.9	4.0	23.8	11.0	11.0	11.0
	Minimum	2.1	0.5	2.2	1.0	5.1	3.0	0.0	0.0
	Mean	41.4	1.3	5.6	2.8	14.2	6.6	2.0	2.0
English people Words	Maximum	1061.8	3.0	645.0	3.0	21.2	10.0	22.0	22.0
	Minimum	2.2	0.5	387.0	1.0	1.9	3.0	0.0	0.0
	Mean	62.2	1.3	512.3	1.8	12.9	5.9	2.0	2.0
English non-people Words	Maximum	558.7	2.8	636.0	4.0	20.2	9.0	18.0	18.0
	Minimum	2.2	0.5	368.0	1.0	1.5	3.0	0.0	0.0
	Mean	54.9	1.3	520.5	1.6	12.5	5.6	3.0	3.0

Highlights

- We investigate visual word access by Spanish-English balanced bilinguals.
- Behavioral and ERP responses were recorded for two tasks.
- The bilinguals are sensitive to word frequency, including non-target words.
- Meaning of a word can be accessed before or after language membership information.
- Usage frequency of a language may explain the early access to language membership.

Figure 1.
The BIA+ model (van Heuven & Dijkstra, 2010).

Figure 2.
Diagram representing the 26-electrode placement in geodesic array.

Figure 3.

Grand average ERPs for 4 medial electrodes to high-frequency and low-frequency words in four sets of stimuli: Spanish targets, English targets, Spanish non-targets, and English non-targets. Negative is plotted upward. A significant difference (highlighted in green) in amplitude for all conditions was found between 350–650 msec, with low-frequency words more negative than high-frequency words.

Figure 4. Topographic scalp plots of difference wave activity (low-frequency words minus high-frequency words) for the four sets of stimuli in Experiment 1. The latency was where a main effect of frequency was observed for the Spanish target words, English target words and Spanish non-target words, and where an interaction of frequency and electrode was identified for the English non-target words.

	Correct category	Incorrect category	pseudo-word
English	sister	door	nain
Spanish	rey	cocina	treso

Figure 5.

Four categories of real words, and pseudo-words derived from the two languages were used in Experiment 2. In the English session, only the ‘English people’ words (e.g., *sister*) were the targets. In the Spanish session, only the ‘Spanish people’ words (e.g., *rey*) were the targets.

Figure 6.
Grand average ERPs of the four types of words in English and Spanish session.

Figure 7.
Topographic scalp plots of difference wave activity to show the Language and Category effect in English and Spanish session from 100 to 600 msec in Experiment 2.

Table 1

Accuracy rates, reaction times and response bias *c* values for Experiments 1 and 2. The non-target accuracy rate was the correct rate in rejecting the non-target real words.

	Experiment 1				Experiment 2	
	Spanish		English		Spanish	English
	high-freq.	low-freq.	high-freq.	low-freq.		
Target Accuracy (%)	98.6	84.0	98.1	90.2	88.7	88.3
Non-target Accuracy (%)	98.3	97.9	97.9	98.4	97	98
RT (msec)	642	759	637	711	778	769
<i>c</i>	-.20		-.31		.37	.41

Table 2

Results of ANOVAs of the frequency effect for the four sets of stimuli in Experiment 1. Analysis was performed every 50 msec from the latency of 200 msec to 650 msec.

	200-250	250-300	300-350	350-400	400-450	450-500	500-550	550-600	600-650
<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>
Spanish targets									
Frequency	0.246	0.099	1.313	5.571*	19.532***	35.915***	18.641***	5.282*	0.195
Freq x Electrode	1.077	0.706	0.787	1.461	2.692	6.376**	12.753***	9.523***	5.965**
English targets									
Frequency	0.036	5.454*	1.624	1.584	2.13	7.808*	22.372***	10.586**	0.153
Freq x Electrode	0.993	1.651	0.922	1.205	0.474	5.073*	9.387***	8.198***	4.674**
Spanish non-targets									
Frequency	0.028	3.463	2.497	0.607	11.843**	13.798**	11.305**	1.904	0.617
Freq x Electrode	1.231	0.714	0.556	1.000	0.857	3.119*	5.69**	5.927**	4.485**
English non-targets									
Frequency	0.28	4.789*	1.300	0.282	2.829	0.218	1.271	1.505	0.526
Freq x Electrode	0.42	0.725	0.894	0.486	1.462	6.508***	9.224***	6.720***	3.834**

* $p < .05$ ** $p < .01$;*** $p < .001$

Table 3

Results of ANOVAs for the ERPs in English and Spanish session of Experiment 2. Analysis was performed every 25 msec from the latency of 100 msec to 700 msec.

English session		100–125		125–150		150–175		175–200		200–225		225–250		250–275		275–300		300–325		325–350		350–375		375–400	
msec	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
Language	0.567	2.751	8.594**	15.719**	5.901*	10.182**	37.002***	25.137***	21.904***	20.069***	15.757**	13.065**													
Category	3.215	0.56	0.904	0.085	0.519	0.772	2.071	8.356**	12.716**	12.003**	21.418***	48.733***													
Language x Category	0.100	0.144	0.639	2.841	1.315	0.343	0.563	2.07	5.478*	7.363*	11.748**	11.122**													
Language x Electrode	1.162	1.050	5.970***	3.394*	1.590	2.782*	5.996**	8.499***	6.097***	4.871**	7.730***	7.661***													
Category x Electrode	0.717	0.902	1.026	1.000	0.645	1.245	2.141	4.138**	7.024***	11.248***	13.913***	11.036***													
Lang x Cat x Electrode	0.345	0.685	0.251	0.937	1.323	0.802	0.931	0.904	1.624	1.148	2.761*	4.496*													

Spanish session		100–125		125–150		150–175		175–200		200–225		225–250		250–275		275–300		300–325		325–350		350–375		375–400	
msec	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
Language	0	1.473	0.007	0.795	0.639	0.307	0.73	3.12	4.96*	0.599	0.015	0.515													
Category	0.002	0.289	0.383	0.003	0	7.596*	8.781**	15.732**	18.644***	17.868***	31.025***	26.922***													
Language x Category	1.5	0.178	2.029	1.102	0.032	0.013	0.162	0.102	0.161	0.646	0.936	0.087													
Language x Electrode	0.384	0.746	0.194	0.542	0.402	0.373	0.677	2.498	3.77*	4.211**	3.5*	4.417**													

Spanish session

msec	100–125	125–150	150–175	175–200	200–225	225–250	250–275	275–300	300–325	325–350	350–375	375–400
	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>
Category x Electrode	0.884	1.164	1.898	3.236 *	0.927	2.213	3.06 *	3.875 **	4.657 *	6.71 **	7.925 ***	8.946 ***
Lang x Cat x Electrode	0.251	0.152	0.546	0.374	0.579	0.433	0.402	0.304	0.4	0.664	0.475	1.547
msec	400–425	425–450	450–475	475–500	500–525	525–550	550–575	575–600	600–625	625–650	650–675	675–700
	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>
Language	1.551	1.317	0.897	0.087	0	0.131	0.189	0.435	0.778	1.369	3.201	2.328
Category	16.667 ***	17.579 ***	24.244 ***	33.478	18.501 ***	18.721 ***	19.976 ***	8.481 **	3.84	3.269	0.725	0.045
Language x Category	0.751	1.457	4.247	7.193 *	6.029 *	2.773	2.019	1.653	0.544	0.967	1.356	1.127
Language x Electrode	3.65 *	4.577 **	3.507 *	4.619 **	4.671 **	5.266 ***	4.678 **	4.103 **	4.979 **	5.525 **	4.656 **	3.077 *
Category x Electrode	4.939 **	3.191 *	3.579 *	4.261 **	3.474 *	5.065 **	5.578 **	5.225 **	6.131 ***	9.322 ***	12.167 ***	15.576 ***
Lang x Cat x Electrode	1.713	0.82	1.156	1.724	1.952	1.351	2.591	2.601	3.158 *	2.144	1.623	3.099 *

* $p < .05$;

** $p < .01$;

*** $p < .001$