Co-activation of the L2 during L1 auditory processing: An ERP cross-modal priming study

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Abstract

Several studies have shown that unbalanced bilinguals activate both of their languages simultaneously during L2 processing; however, evidence for L2 activation while participants are tested exclusively in their L1 has been more tenuous. Here, we investigate whether bilingual participants implicitly activate the label for a picture in their two languages, and whether labels activated in L2 can prime activation of cross-linguistically related L1 lexical targets. We tested highly proficient early Spanish-Basque bilinguals on an ERP cross-modal priming task conducted only in their L1, Spanish. Participants activated prime picture labels in both Spanish and Basque. More importantly, participants activated Basque translations of Spanish auditory targets, even in a Spanish experimental environment with no reference to Basque. Results provide strong evidence for non-selective bilingual lexical access, showing co-activation extending to lexical levels beyond phonological overlap. Our results add to the growing body of evidence for the interconnective nature of bilingual language activation.

Keywords: language co-activation; priming; bilingualism; Basque; Spanish; event-related potentials

1. Introduction

A central question in the study of bilingualism has been whether there is co-activation of a bilingual's languages when hearing, reading, or speaking in one language alone. So, when a Spanish-Basque bilingual hears the Spanish word *perro* "dog," will the Basque word for dog, *txakur*, also be activated? Early accounts of bilingualism proposed the equivalent of a mental switch that allowed the bilingual to turn off the irrelevant language during speech processing or production (Penfield & Roberts, 1959). It is by now a recognized phenomenon, however, that bilinguals display concurrent activation of both languages, regardless of whether they are reading, speaking, or listening to one language alone (e.g., Colomé, 2001; Costa, Miozzo, & Caramazza, 1999; Hermans, 2000; Macizo, Bajo, & Martín; Martín, Macizo, & Bajo, 2010; Spivey & Marian, 1999).

Based on these results, recent accounts of bilingualism argue that the cognitive architecture of the bilingual is fundamentally nonselective, but under certain circumstances operates selectively (Kroll, Bobb, & Wodniecka, 2006; Martin, Molnar & Carreiras, 2016; Molnar, Ibáñez-Molina, & Carreiras, 2015). The question now is no longer *whether* co-activation can occur, but under what (experimental and language) conditions it does or does not, and what levels of language processing are typically affected. In the current study, we present evidence from an ERP experiment with highly proficient Spanish-Basque bilinguals for language co-activation at the phono-lexical level. We show that Basque language representations are co-activated at both the phonological and the lexical level in a Spanish-only experimental environment, especially with regard to Basque translations and rhyme words.

Recent calls in the literature (e.g., Wu & Thierry, 2010a) have emphasized that new work must pay particular attention to the context of language processing, and especially situations that may inadvertently engage both languages due to experimental requirements or broader social context. In particular, one criticism of studies showing coactivation to the lexical level is that the methodological paradigm frequently requires the use of both languages (Costa et al., 1999; Hermans, Bongaerts, de Bot, & Schreuder, 1998; Guo & Peng, 2006). Recent studies have addressed this concern through experimental designs using one language alone (e.g., Thierry & Wu, 2007; Wu & Thierry, 2010b), but even these studies are open to criticism, as they have often tested participants in their non-dominant language, which is thought to be mediated through the dominant language until high levels of proficiency have been reached (Kroll & Stewart, 1994). In other words, it is less surprising that the L1 would be active during L2 language use if the L2 requires the L1 for processing in the first place. We argue that a stronger case for language coactivation at the lexical level would be to show coactivation of the L2 in highly proficient bilinguals in a situation that only requires the L1 to be used.

Indeed, several past studies suggest that the non-dominant language may be active in an L1-only context (e.g., Marian & Spivey, 2003a; Spivey & Marian, 1999; Von Holzen & Mani, 2014), but crucially only under conditions that induce bottom-up activation of the L2 (but see Villameriel, Dias, Costello, & Carreiras, 2016, for evidence from hearing bimodal bilinguals). Specifically, these previous experimental paradigms still required overt auditory input from the L1 to overlap with the non-target L2 phonology. In the visual-world paradigm studies by Marian and colleagues, participants saw four objects and heard instructions to pick up one of the objects. The spoken L1 name of the target object (e.g., *marka*, Russian for “stamp”) overlapped in phonology with the L2 label of one of the four objects presented in the display (e.g., English “marker”). In Von Holzen and Mani (2014), participants saw a picture prime, followed by an auditorily presented target word in the L1. In the critical condition, the auditory L1 label (e.g., *Kleid*, German for “dress”) rhymed with the L2 label of the picture prime (e.g., English “slide”). In both of these paradigms that showed activation of the non-dominant L2, participants physically heard an L1 target word that overlapped in phonology with the L2 picture label. It is possible that activation of the non-dominant L2 label for the picture prime is triggered by the overt presentation of the phonologically related L1 auditory target. These findings, therefore, limit the scope of language co-activation to bottom-up acoustic/phonetic input from the L1 target word and cannot speak to the automaticity of L2 activation in the absence of overt L1 phonological overlap, as is the case in most real-world situations of L1 language processing (see Von Holzen & Mani, 2012, for similar investigations in children). Connectionist models such as the Bilingual Language Interaction Network for Comprehension of Speech (BLINCS; Shook & Marian, 2013) allow for extensive cross-language interactions within the bilingual lexicon, and yet experimental evidence to-date has not been able to substantiate the extent of these possibilities (see also the Bilingual Interactive Activation Model of Lexical Access, BIMOLA, Léwy & Grosjean, 2008, which allows for both bottom-up and top-down spreading activation).

To address this question, we expand the scope of inquiry to further investigate lexical-level L2 co-activation in the *absence of overt phonological overlap* between L1 and L2. In the present experiment, we use the intermodal priming paradigm (Desroches, Newman, & Joanisse, 2009; Von Holzen and Mani, 2014) to further test the limits of cross-language activation and cascaded activation in a balanced bilingual population. Similar to other recent EEG studies, we exploit a rhyming relationship between primes and targets to investigate language co-activation (cf., Wu & Thierry, 2011; Desroches et al., 2009; Von Holzen & Mani, 2014). However, to examine whether both languages are active at the lexical level, we ask whether there is bilingual language co-activation in a condition where there is no overt phonological overlap between prime and target.

1.1. Predictions

In the present study, participants were presented with unlabeled prime pictures, followed by an auditory target in the L1 Spanish while they completed an unrelated picture matching task. We recorded participants' ERP response time-locked to the onset of the L1 Spanish auditory word targets. To investigate the level of language co-activation, we manipulated the phonological overlap between the picture prime label and the auditory target. Specifically, we created rhyming relationships between the prime label in Spanish (L1) or Basque (L2) and the auditory Spanish target or its Basque translation. The relationship between primes and targets was manipulated in five critical conditions (see Figure 1 for an illustration). To determine whether participants were sensitive to the phonological overlap between prime label and auditory target, we focused on the N400 component. The N400 is a negative deflection in the ERP peaking 400 ms after the onset of a stimulus sensitive to context or reduced processing of the stimulus. We anticipated that if participants were sensitive to our manipulations of the relationship between primes and targets, the N400 component would be reduced, indicating facilitated auditory recognition. Indeed, previous monolingual and bilingual studies have shown a reduced N400 for rhyme words in reading, picture naming, and cross-modal picture-auditory word paradigms (Barrett and Rugg, 1990; Desroches et al., 2009; Grossi et al., 2001; Praamstra & Stegeman, 1993; Von Holzen & Mani, 2014).

Of particular interest to us was the condition in which the Basque label for the silently presented prime image rhymed with the Basque translation of the Spanish auditory target. In other words, after seeing a picture prime of a needle (Basque *orratz*), when balanced bilinguals hear the Spanish auditory target *lápiz* ("pencil"), do they co-activate its L2 Basque translation *arkatz*? We believed this condition would provide the strongest test of the hypothesis that the L2 Basque was co-activated during L1 Spanish processing as it would require co-activation of the L2 label for the silently presented picture prime in the absence of any overt phonological overlap with the auditory presented Spanish target. If the Basque prime image label influences the recognition of the target, we anticipated a reduced mean N400 amplitude for this cross-language prime-target rhyme pair relative to the unrelated prime-target pair.

2. Materials and methods

2.1. Participants

28 Spanish-Basque bilingual participants from the Basque region of Spain (7 male, 21 female) participated in the study (*M* = 23.55 years, *SD* = 5.04, *Range* = 19 - 36). Four additional participants were tested, but were removed from analysis because they had too much noise in the signal. All participants were right-handed and had no history of hearing loss or neurological impairments. We were careful to recruit participants without referring to their bilingual status (e.g., Marian & Spivey, 2003b). Thus, participants were recruited through a central database without mentioning their bilingual status or

knowledge of Basque. To be included in the database, participants had previously filled out a short language history questionnaire adapted from other questionnaires commonly used in the literature (e.g., Li, Sepanski & Zhao, 2006; Marian et al., 2007). Bilinguals were selected by including their language profile in the search criteria. When potential participants were contacted to participate in the study, they were only contacted in their L1 (Spanish), and no mention was made of their L2 (Basque) or that the study was a bilingual language study. Prior to the study, participants completed a picture naming task (BEST; De Bruin, Carreiras, & Duñabeitia, 2017) and were interviewed by a native Speaker of Spanish and Basque. Table 1 summarizes their language background. Although highly proficient in both languages, participants were clearly dominant in Spanish across the language background measures. While they learned both languages before the age of three, they learned their L1 Spanish earlier than their L2 Basque and also had more daily exposure to Spanish than to Basque. They rated their L1 as more proficient than their L2. They were also more accurate at naming pictures in Spanish and were rated more proficient in Spanish interviews.

<< Insert Table 1 about here >>

Table 1. Participant Characteristics for their L1 (Spanish) and L2 (Basque)

Measure	**L1 (Spanish)**	**L2 (Basque)**	**Comparison**
AoA (years)	0.18 (0.48)	1.67 (1.92)	***
Composite Self-rating (10 pt scale):	9.87 (0.36)	8.92 (1.03)	***
Speaking	9.89 (0.31)	8.41 (1.23)	***

Understanding	9.89 (0.31)	9.30 (1.09)	**
Writing	9.81 (0.48)	8.70 (1.24)	***
Reading	9.89 (0.42)	9.26 (1.08)	**
% Exposure	57.41 (10.95)	29.26 (9.58)	***
Picture Naming (% Correct)	99.58 (1.00)	86.15 (9.50)	***
Interview Score (out of 5 points)	5.00 (0.00)	4.48 (0.79)	**

Note. SDs are in parentheses. Comparisons denote paired *t*-tests for numerical variables and Wilcoxon tests for ordinal variables with * $p < .05$, ** $p < .01$, and *** $p < .001$.

2.2. Stimuli and procedure

Stimuli consisted of 150 visual primes and 150 auditory targets. Visual primes were familiar, imageable, nouns. Auditory targets were always Spanish. A female native speaker of Spanish recorded all targets (*M* length = 698 ms, *Median* length = 683 ms, *Range* = 436 – 1172). Digital files were recorded at a sampling rate of 44.1 kHz and edited post recording using Praat (Boersma, 2002) to remove clicks and silent periods at onset and GoldWave digital audio editing software (GoldWave, Inc.) to reduce hiss and match volume. The prime-target pairs were divided into five groups, 30 items in each group, to form five conditions, described below. Note that the picture prime was always presented as a *silent* picture prime and was never overtly labeled. To illustrate relationships between picture primes and auditory targets, in the examples that follow, SPANISH/BASQUE picture prime labels are respectively presented in capital letters;

Spanish auditory targets/Basque translations are presented in lower case; rhyme relations, when present, are underlined: 1) Identity: the Spanish label of the picture prime was identical to the auditory target, (AJO/BARATXURI-ajo/baratxuri) 2) L1prime-L2translation: the L1 Spanish label of the picture prime rhymed with the L2 Basque translation of the auditory target, (MANO/ESKU-aguila/arrano) 3) L2prime-L1target: the L2 Basque label of the picture prime rhymed with the L1 Spanish auditory target, (COCHE/BEREBIL-barril/upel) 4) L2prime-L2translation: the L2 Basque label of the picture prime rhymed with the L2 Basque translation of the auditory target, (AGUJA/ORRATZ-lápiz/arkatz) or 5) Unrelated: there was no relationship between the prime label in either language and the auditory target (ALCACHOFA/ORBUTU-horno/labe).

Figure 1 contains example stimuli from each condition. To control for lexical properties of the stimuli, we compared log frequency, number of letters, and number of syllables across conditions, languages, and presentation type (prime vs. target) and found no significant interactions that could have potentially influenced our results (presentation type * condition, presentation type * language, condition * language, presentation type * condition * language, all Fs < 2, all ps $> .3$). Separate univariate ANOVAs within each prime and target type (Spanish labels of primes, Basque labels of primes, Spanish auditory target, Basque translation of auditory target) showed no significant differences in lexical properties across conditions (all Fs < 2, all ps $> .2$). The auditory length of Spanish target words also did not differ across conditions ($F < 2$, $p > .2$). We recorded ERPs to the onset of Spanish auditory targets. Each participant was presented with all 150 nouns.

<< Insert Figure 1 about here >>

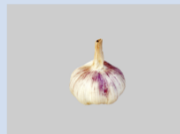
Condition	Prime Picture	Auditory Target
Identity	 AJO (baratxuri)	"ajo" (baratxuri)
L1prime-L2translation Spanish picture label rhymes with Basque translation of Spanish auditory target	 MANO (esku)	"aguila" (arrano)
L2prime-L1target Basque picture label rhymes with Spanish auditory target	 COCHE (berebil)	"barril" (upel)
L2prime-L2translation Basque picture label rhymes with Basque translation of Spanish auditory target	 AGUJA (orratz)	"lápiz" (arkatz)
Unrelated	 ALCACHOFA (orbutu)	"horno" (labe)

Figure 1. Stimuli Examples. This figure illustrates examples for each of the five experimental conditions: "Identity," "L1prime-L2translation," "L2prime-L1target,"

“L2prime-L2translation,” and “Unrelated”

2.3. Main experiment

During testing, we were careful not to focus participants’ attention on the linguistic nature of the experiment, and more specifically the phonological overlap between words (see Von Holzen & Mani, 2014 for a similar approach). Studies such as Wu and Thierry (2011) explicitly asked participants to make rhyme judgments on word-pairs in one language. In the present study, participants performed a non-linguistic picture-matching task in order to mask the phonological relationship between prime and target. By not biasing participant attention toward the linguistic relationships between stimuli, we provide, yet again, a more stringent measure of language co-activation.

Participants were seated in a quiet, dimly lit experimental room facing a computer screen. All instructions, visual and verbal, were given in Spanish. Stimuli were presented using Presentation Software (Neurobehavioral Systems). A fixation sign began each trial, displayed in the center of the screen for 1000 ms. Participants then saw the prime image in the center of the screen for 500 ms. 50 ms after offset of the prime image, participants heard the auditory target word. 1500 ms after onset of the target word, participants saw a second image that was either identical to or different from the prime image. The image was displayed for 500 ms, followed by a blank screen for 1000 ms, during which participants indicated via button press on a game controller whether the second image was the same or different from the first image. Figure 2 shows a sample trial.

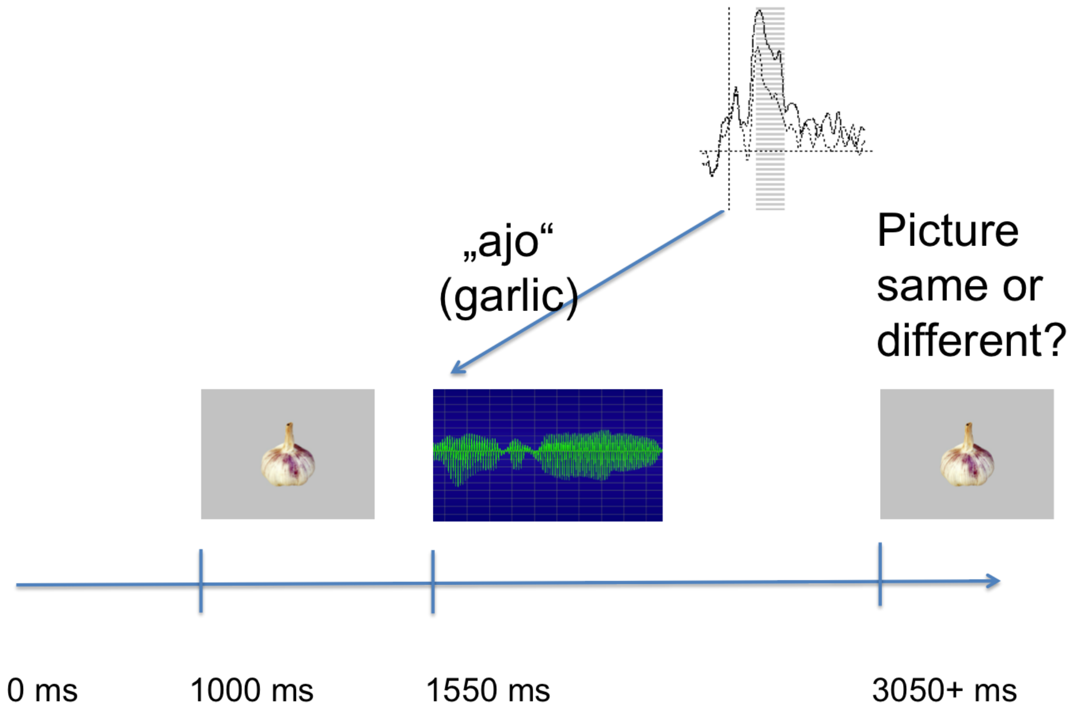


Figure 2. Sample trial. This figure illustrates an experimental trial from trial onset at 0 milliseconds to trial offset. EEG recording was time-locked to the onset of the auditory target.

2.4. Electrophysiological recording and data analysis

Electrophysiological data were recorded using the BrainAmp DC (Brain Products GmbH) system with Brain Recorder software. Data were recorded with reference to the left mastoid at a sampling rate of 500 Hz from 32 Ag/AgCl electrodes placed according to the 10-20 convention. The EEG data were digitally re-referenced to an averaged mastoid activity. Impedances were kept < 5 kΩ, and EEG activity was filtered on-line with a band pass between 0.01 Hz and 1000 Hz and re-filtered off-line with a 20 Hz low-pass, .1 high-pass digital filter. Eye-blink and movement artifacts were automatically rejected using a 100 μV amplitude cut-off across mastoid and eye electrodes. Epochs ranged from -200 to 1000 ms after the onset of the auditory target presentation. Baseline correction was performed in reference to pre-stimulus activity (-200 to 0 ms). Data were examined visually and analyzed in 10 ms time windows from 0 to 1000 ms to establish the locus of significant differences between conditions. Visual inspection of the components revealed a general pattern of an initial negative peak around 100 ms, followed by a positivity maximally peaking just before 200 ms, consistent with an N_1 – P_2 complex. These components were followed by a sustained negativity, although consistent with other studies using a cross-modal paradigm, there was no clear delineation of the components in the N400 complex (e.g., Desroches et al., 2009; Von Holzen & Mani, 2014). Based on these observations and the known onset of the N400 (Kutas & Hillard, 1984), we focused on two time windows, an earlier time window between 250 ms and 400 ms and a later time window between 400 ms and 700 ms.

First, for purposes of data reduction, a selection of electrode locations was entered into data analysis, 18 electrodes divided into two hemispheres and four regions: left frontal (F7, F3, FP1), left fronto-central (FC5, C3, FC1), left centro-parietal (T7, CP5, CP1), left parietal-occipital (P7, P3, O1), right frontal (FP2, F4, F8), right fronto-central (FC2, C4, FC6), right centro-parietal (CP2, CP6, T8), and right parietal-occipital (O2, P4, P8). A repeated measures ANOVA was conducted on mean amplitudes with the factors hemisphere (2; left, right), region (4; frontal, fronto-central, centro-parietal, parietal-occipital), and condition (5; Identity, L1prime-L2translation, L2prime-L1target, L2prime-L2translation, Unrelated). See Figure 3 for the electrode groupings. A second repeated measures ANOVA was conducted on mean amplitudes from the midline with the factors electrodes (Fz, Cz, Pz) by condition (5; Identity, L1prime-L2translation, L2prime-L1target, L2prime-L2translation, Unrelated). For both ANOVA analyses, only main effects of condition, and interactions with condition are reported and further investigated. Only significant t-test results for the four condition comparisons are reported (identity vs. unrelated/L2prime-L1target vs. unrelated/L1prime-L2translation vs. unrelated/L2prime-L2translation vs. unrelated) following Von Holzen and Mani (2014). Greenhouse-Geisser corrected *p*-values are reported where appropriate. Because of the non-linguistic nature of the task, behavioral results are not reported (e.g., Von Holzen & Mani, 2014).

<< Figure 3 about here >>

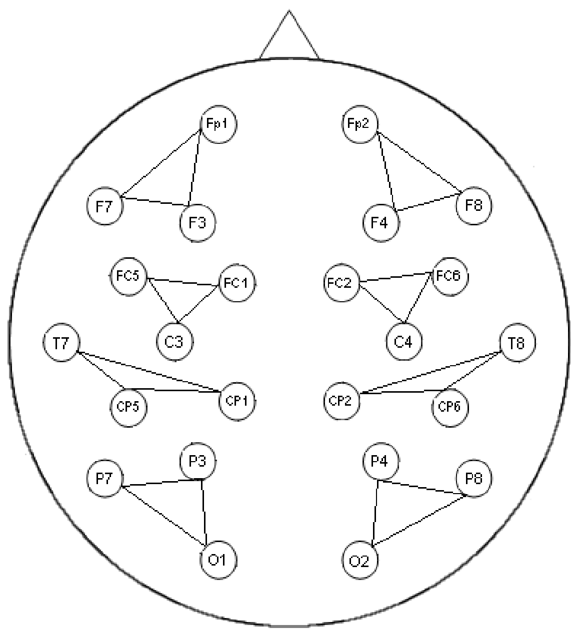


Figure 3. Electrode groupings used for the analysis. 18 electrodes were divided into two hemispheres and four regions: left frontal (F7, F3, FP1), left fronto-central (FC5, C3, FC1), left centro-parietal (T7, CP5, CP1), left parietal-occipital (P7, P3, O1), right

frontal (FP2, F4, F8), right fronto-central (FC2, C4, FC6), right centro-parietal (CP2, CP6, T8), and right parietal-occipital (O2, P4, P8). We also analyzed Fz, Cz, and Pz.

3. Results

Omnibus ANOVA

Figure 4 plots the mean distribution of differences for the condition comparisons for both the early (250-400 ms) and late (400-700 ms) time windows. In the 250-400 ms time window, a repeated measures ANOVA with the factors hemisphere, region, and condition revealed significant interactions between condition and hemisphere, $F(4,108) = 8.97$, $p < .001$, *np2* = .25, condition and region, $F(12,324) = 3.35$, $p = .009$, *np2* = .11, and condition, hemisphere, and region, $F(12,324) = 2.97$, $p = .014$, *np2* = .10. Following up on this 3-way interaction, for the left hemisphere, there was a significant condition by region interaction, $F(12,324) = 2.92$, $p = .016$, *np2* = .10. For the right hemisphere, there was a significant condition by region interaction in the right hemisphere, $F(12,324) = 3.69$, $p = .006$, *np2* = .12. A repeated measures ANOVA over the midline electrodes revealed no significant effect of condition, $F(4,108) = 1.37$, $p = .249$, *np2* = .05, or interaction between electrodes and condition, $F(8,216) = 2.13$, $p = .078$, *np2* = .07, precluding further analyses on the midline in the early time window.

In the 400-700 ms time window, a repeated measures ANOVA with the factors hemisphere, region, and condition revealed a significant main effect of condition, $F(4,108) = 3.01$, $p = .021$, *np2* = .10. The interactions condition by region, $F(12,324) = 4.83$, $p = .001$, *np2* = .15, and condition by region by hemisphere, $F(12,324) = 3.11$, $p = .009$, *np2* = .10, were also significant. Following up on this 3-way interaction, for the left hemisphere, there was a main effect for condition ($F(4,108) = 2.52$, $p = .045$, *np2* = .09) and a significant condition by region interaction, $F(12,324) = 6.07$, $p < .001$, *np2* = .18). For the right hemisphere, there was a main effect for condition ($F(4,108) = 3.36$, $p = .012$, *np2* = .11) and a significant condition by region interaction in the right hemisphere, $F(12,324) = 3.41$, $p = .007$, *np2* = .11. A repeated measures ANOVA over the midline electrodes revealed a significant effect of condition, $F(4,108) = 5.10$, $p = .002$, *np2* = .16, and a significant interaction between electrodes and condition, $F(8,216) = 4.49$, $p = .002$, *np2* = .14.

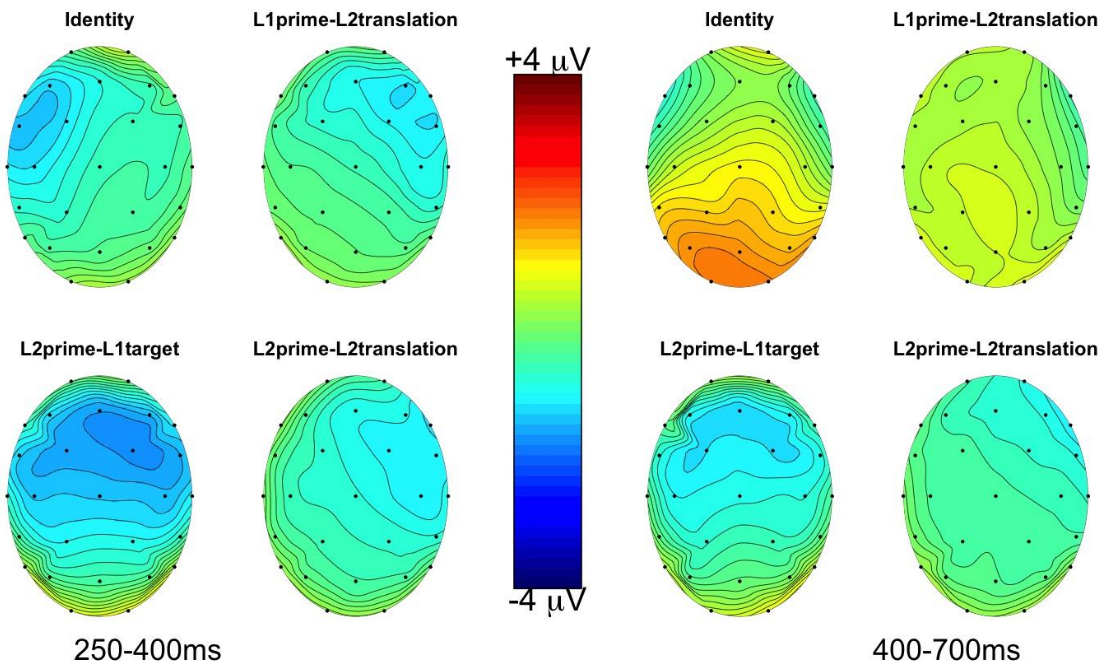


Figure 4. Condition Comparisons. The figure illustrates the mean distribution of the differences for the condition comparisons for both the early (250-400 ms; left panel) and late (400-700 ms; right panel) time windows.

Identity/Unrelated

Figure 5 plots the ERP waveforms for the Identity and Unrelated conditions aggregated across Hemisphere and Region. In the early time window, from 250-400 ms, amplitude in the Identity condition was significantly more negative than the Unrelated condition in the left fronto-central region, $t(27) = -3.38$, $p = .002$, $d = -0.90$, and left centro-parietal region, $t(27) = -2.39$, $p = .024$, $d = -0.64$. In the later time window, from 400 to 700 ms, the direction of effects switched to a significantly more negative amplitude for the Unrelated condition compared to the Identity condition in the left centro-parietal region, $t(27) = 2.47$, $p = .020$, $d = 0.66$, left parietal-occipital, $t(27) = 5.02$, $p < .001$, $d = 1.34$, right centro-parietal, $t(27) = 2.17$, $p = .039$, $d = 0.58$, and right parietal-occipital regions, $t(27) = 4.41$, $p < .001$, $d = 1.18$. Over midline electrodes, the Identity condition was significantly more positive than the Unrelated condition, $t(27) = 2.64$, $p = .014$, $d = 0.71$. Comparisons on individual midline electrodes confirmed this pattern on both Cz, $t(27) = 2.56$, $p = .016$, $d = 0.68$, and Pz, $t(27) = 3.80$, $p = .001$, $d = 1.02$.

L1prime-L2translation/Unrelated

Figure 6 plots the ERP waveforms for the L1prime-L2translation and Unrelated conditions aggregated across Hemisphere and Region. An analysis of the earlier time window, from 250-400 ms, revealed no significant differences between the L1prime-L2translation and unrelated conditions. In the later time window, from 400-700 ms, however, the amplitude in the L1prime-L2translation condition was significantly less negative than the unrelated condition in the right parietal-occipital region, $t(27) = 2.09$, $p = .046$, $d = 0.56$. Over midline electrodes, there were no significant differences between the L1prime-L2 translation and unrelated conditions.

L2prime-L1target/Unrelated

Figure 7 plots the ERP waveforms for the L2prime-L1target and Unrelated conditions aggregated across Hemisphere and Region. In the early time window (250-400 ms) amplitude in the L2prime-L1target condition was significantly more negative than the unrelated condition in the left fronto-central, $t(27) = -3.83$, $p = .001$, $d = -1.02$, right fronto-central, $t(27) = -3.64$, $p = .001$, $d = -0.97$, left centro-parietal, $t(27) = -2.40$, $p = .023$, $d = -0.64$, and right centro-parietal regions, $t(27) = -2.49$, $p = .019$, $d = -0.66$. This negativity continued into the later time window (400-700 ms) in the left fronto-central $t(27) = -2.68$, $p = .012$, $d = -0.72$, and right fronto-central regions, $t(27) = -2.50$, $p = .019$, $d = -0.67$. Over midline electrodes, although the overall difference between L2prime-L1target and Unrelated conditions was not significant, $t(27) = -2.03$, $p = .052$, $d = -0.54$, the L2prime-L1target condition was significantly more negative than the Unrelated condition on both Fz, $t(27) = -2.43$, $p = .022$, $d = -0.65$, and Cz, $t(27) = -2.19$, $p = .037$, $d = -0.59$.

L2prime-L2translation/Unrelated

Figure 8 plots the ERP waveforms for the L2prime-L2translation and Unrelated conditions aggregated across Hemisphere and Region. In the early time window (250-400 ms), the amplitude in the L2prime-L2translation condition was significantly more negative than the unrelated condition in both the right fronto-central, $t(27) = -2.59$, $p = .015$, $d = -0.69$, and right centro-parietal regions, $t(27) = -2.37$, $p = .025$, $d = -0.63$. In the later time window (400-700 ms), the amplitude in the L2prime-L2translation condition significantly increased in negativity compared to the Unrelated condition in the right frontal, $t(27) = -2.27$, $p = .031$, $d = -0.61$, right fronto-central, $t(27) = -2.36$, $p = .026$, d

= −0.63, and right centro-parietal regions, $t(27) = -2.25$, $p = .033$, $d = -0.60$. Over midline electrodes, there were no significant differences between the L2prime-L2 translation and unrelated conditions.

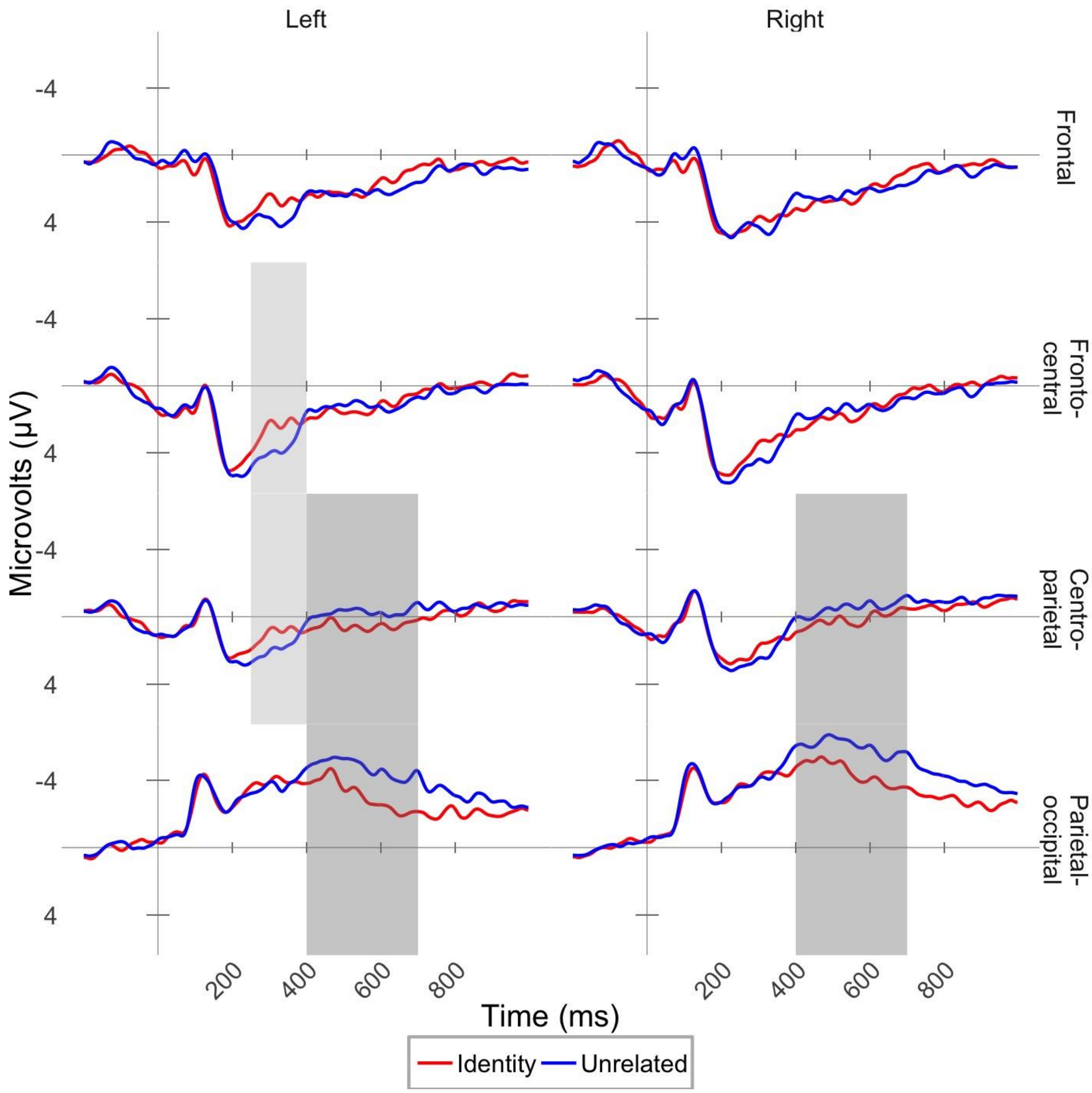


Figure 5. Event-related potential (ERP) waveforms for the Identity and Unrelated conditions. Graphs present averaged data from -200 to 1000 ms from the onset of the L1 target word. Significant effects revealed by planned comparisons are highlighted in light

grey for the early time window (250-400 ms) and dark gray for the late time window (400-700 ms).

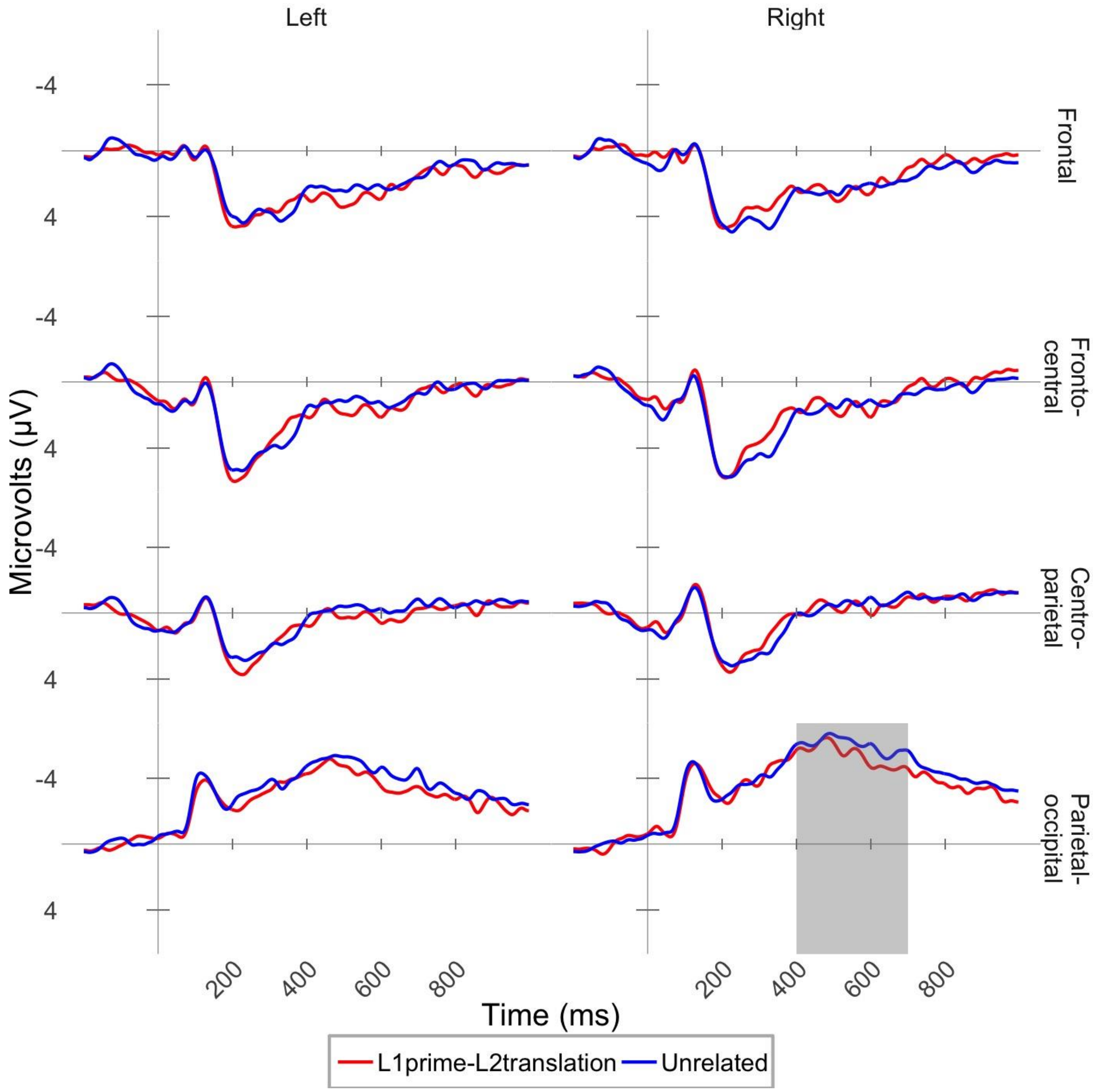


Figure 6. Event-related potential (ERP) waveforms for the L1prime-L2translation and Unrelated conditions. Graphs present averaged data from -200 to 1000 ms from the onset of the L1 target word. Significant effects revealed by planned comparisons are highlighted in dark gray for the late time window (400-700 ms).

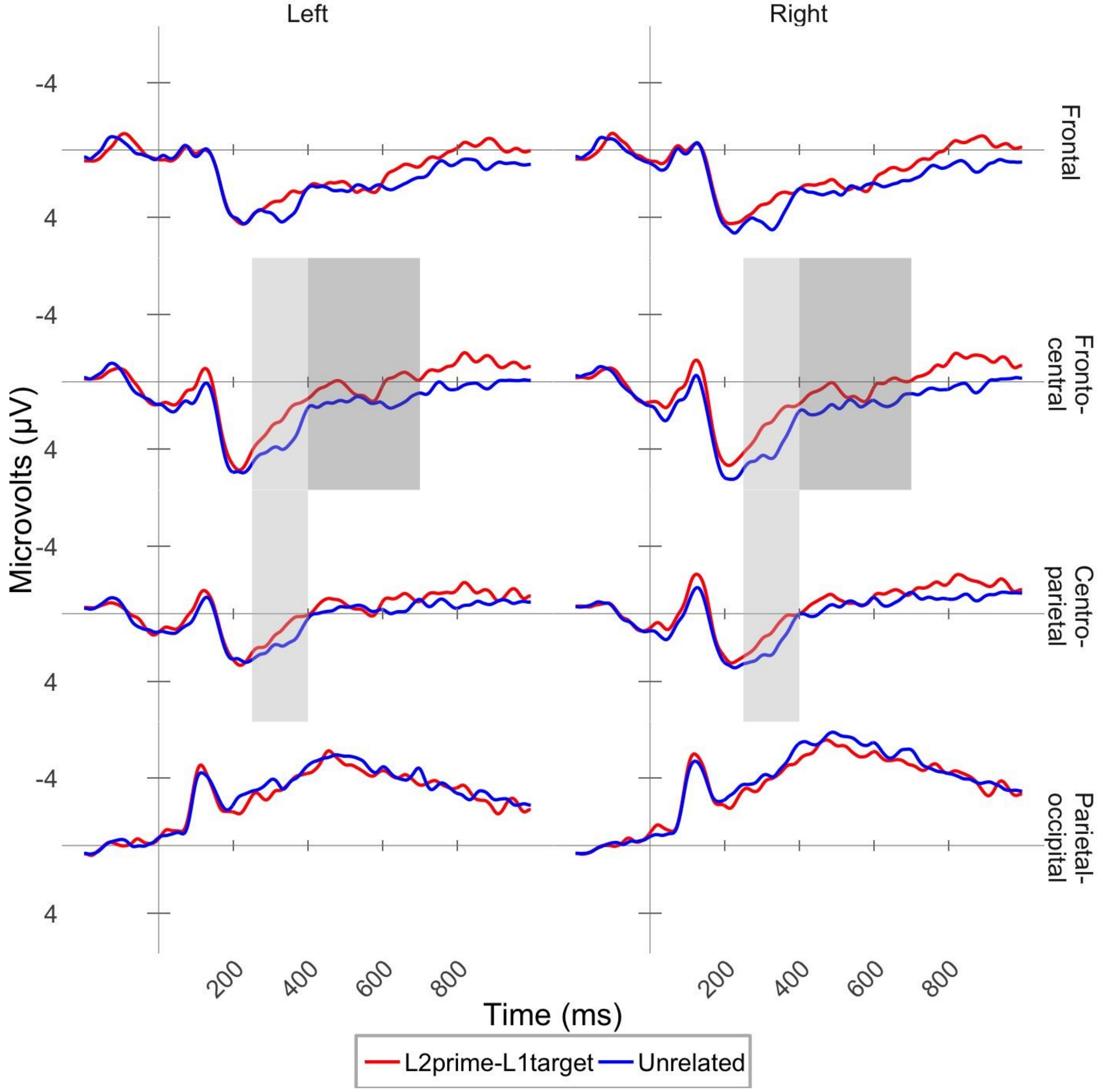


Figure 7. Event-related potential (ERP) waveforms for the L2prime-L1target and Unrelated conditions. Graphs present averaged data from -200 to 1000 ms from the onset of the L1 target word. Significant effects revealed by planned comparisons are highlighted in light grey for the early time window (250-400 ms) and dark gray for the late time window (400-700 ms).

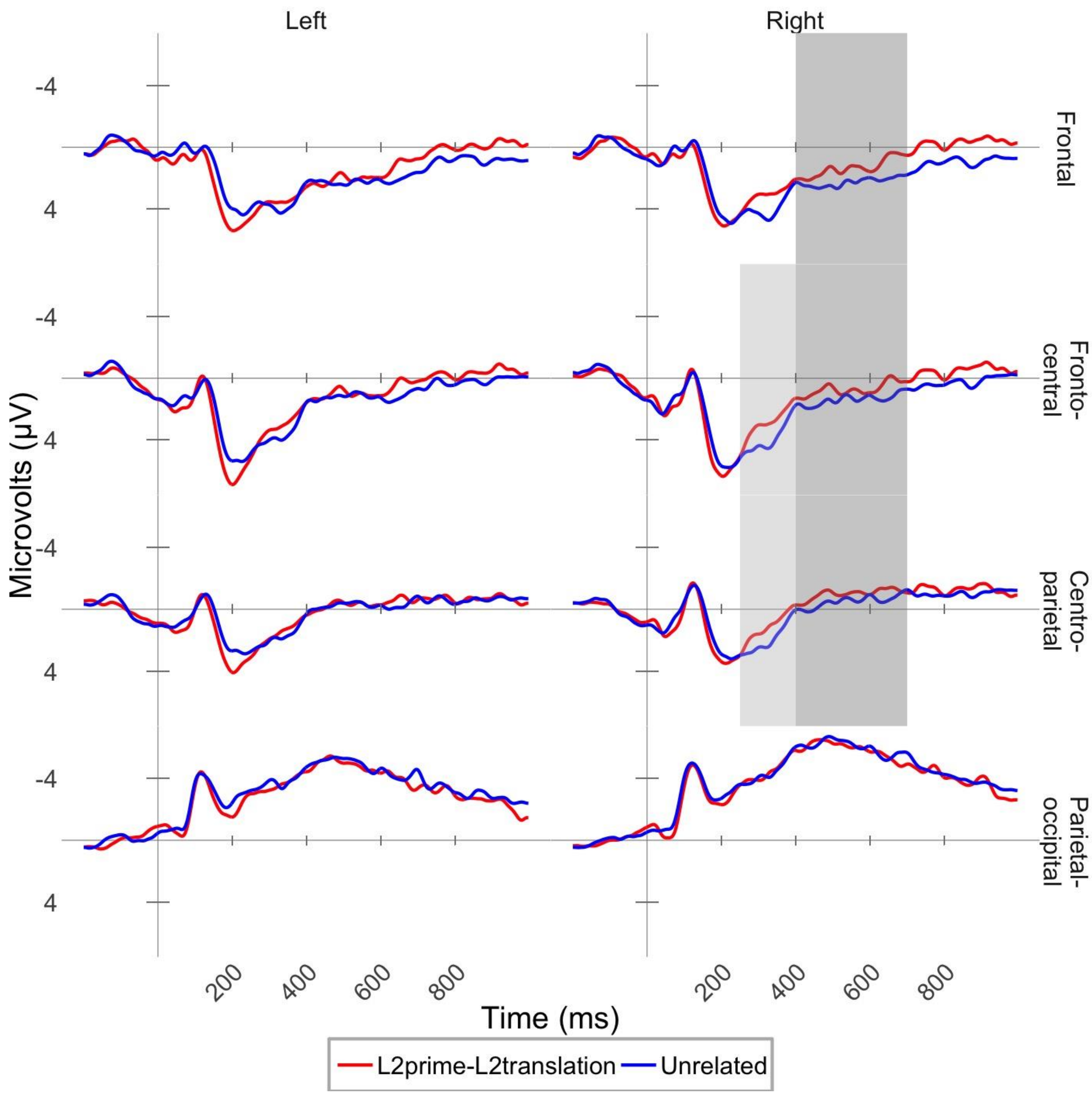


Figure 8. Event-related potential (ERP) waveforms for the L2prime-L2translation and Unrelated conditions. Graphs present averaged data from -200 to 1000 ms from the onset of the L1 target word. Significant effects revealed by planned comparisons are highlighted in light grey for the early time window (250-400 ms) and dark gray for the late time window (400-700 ms).

4. Discussion

In the present study, we considered the extent to which the non-dominant language is active while processing the dominant language alone. Using an intermodal priming paradigm, participants saw picture primes followed by an auditory target in their L1 Spanish. We manipulated the extent of phonological overlap between the prime labels and auditory target or target translation. Consistent with the idea that the target is processed easier when there is a complete match between the label of the prime image and the heard target word, we found that the amplitude in the Identity condition was significantly less negative than the Unrelated condition during the 400 to 700 ms time window. Furthermore, we found a similar difference between waveforms in the L1prime-L2translation condition and the Unrelated condition limited to the right parietal-occipital region, suggesting that the Basque translation of the Spanish auditory target was also activated during processing of the Spanish auditory target.

In both the L2prime-L1target and L2prime-L2translation conditions, we found significant differences in amplitude compared to the unrelated condition, but in the opposite direction and with a different topographical distribution: Mean amplitudes in both the 250 to 400 and 400 to 700 ms time windows increased in these conditions compared to the Unrelated condition (for other reversal effects in a similar time window and distribution, see Chauncey, Holcomb, & Grainer, 2009; De Cat, Klepousniotou, & Baayen, 2015; Midgley, Holcomb, & Grainer, 2009). We interpret these results as indicative of the fact that the Basque label of the prime picture was co-activated along with the Spanish label. The results for the L2prime-L2translation condition, the condition of particular interest in our study, extends the findings from the L2prime-

L1target condition and suggests that the Basque translation of the Spanish auditory target was also activated.

Our results add to the growing body of evidence for the interconnective nature of bilingual language activation. Significantly, the present results provide – for the first time – ERP evidence of co-activation of the L2 translation of the L1 auditory target word in the absence of overt phonological overlap between L1 and L2 targets. This is an effect that has not been previously found when participants have been tested in their L1 environment. We therefore provide the strongest evidence yet for the non-selectivity of bilingual lexical access.

Our conclusion is driven by the results found in the L2prime-L1target and L2prime-L2translation conditions in the N400 time window. In particular, the L2prime-L1target results provide evidence of bilinguals activating both Spanish and Basque labels for the silent picture prime, especially when the subsequently presented Spanish auditory target overlaps phonologically with the Basque label for the picture prime. This finding supports other research suggesting that bilinguals activate the non-dominant L2 in an L1-only environment (e.g., Von Holzen & Mani, 2014). A potential caveat to this interpretation is the possibility that activation of the Basque label for the picture prime could have been primed by the subsequent presentation of the Spanish auditory target (which rhymed with the Basque label). In other words, would the Basque label of the picture prime have been activated in the absence of such an overt phonological cue from the auditory target?

Given this possibility, the L2prime-L2translation results extend the findings of the L2prime-L1target condition in a critical dimension. Here, not only was there no overt presentation of the Basque label for the picture prime (as in all other conditions) but there was also no overt phonological overlap between the subsequently presented Spanish auditory target and the Basque label for the silently presented picture prime. The selective modulation of ERP waveforms in this condition relative to the unrelated condition, therefore, presents strong evidence in support of the claim that bilinguals activated both the Basque label for the silent picture prime and the Basque translation of the Spanish auditory target, despite the Spanish dominant environment in which testing took place and the absence of any cues as to the underlying Basque overlap in the items presented. This finding speaks, therefore, to the automaticity of co-activation of the other language during processing in one language.

Previous studies arguing for similar conclusions cannot rule out that findings of co-activation were phonologically driven (i.e., required bottom-up acoustic-phonetic input). The results of Ju and Luce (2004) found effects of the L2 on L1 only when they manipulated L2 pronunciation to be more L1-like, in essence increasing phonological overlap between the L2 and the L1, which would argue for phonological effects of co-activation. Similarly, the results of Marian and Spivey (2003; see also Spivey and Marian, 1999) and Von Holzen and Mani showed activation of the L2 only when there was overt phonological overlap between the L1 and the L2. In support of this possibility, we note that Von Holzen and Mani (2014) found facilitatory priming effects, i.e., increased positivity to related primes relative to unrelated primes, which are typically indicative of phonological effects, but not lexical effects, at least in the behavioral literature (cf. Marslen-Wilson & Zwitserlood, 1989). In contrast, by showing effects of language co-activation in the absence of overt phonological overlap, the present results strongly suggest that effects of co-activation extend to lexical levels and are not due to phonological overlap alone.

The idea that activation cascades from the phonological input to the lexical item would be consistent with connectionist models such as the Bilingual Language Interaction Network for Comprehension of Speech (BLINCS; Shook & Marian, 2013). Indeed, our results provide the hereto missing empirical support for the extensive interconnected nature of the bilingual architecture as proposed by BLINCS. One of the few models to specifically address auditory speech comprehension and bilingualism, BLINCS comprises four interconnected self-organizing maps representing phonological, phono-lexical, ortho-lexical, and semantic processing levels. The goal of BLINCS is to trace activation within the lexicon over time. What makes this model so well suited to explaining co-activation in the present study is that it does not require incremental phonological activation focusing on word onset, but can also accommodate cross-language rhyme activation on the auditory target as in our experiment (for monolingual contexts, see TRACE, McClelland & Elman, 1986). The model also allows for the influence of visual stimuli on auditory processing. This was incorporated to account for the Visual World Paradigm, but can also accommodate cross-modal priming. In essence, the model “increase[s] the resting activation of semantic representations for items that … are currently visible” (Shook & Marian, 2013, p. 308). Their simulations show co-activation not just for phonologically overlapping words, but also for semantically related words: The word *road* activated phonologically related *ropa* “clothes” in Spanish, as well as the semantically related *car* in English. The results of Shook and Marian (2013) argue for strong cross-language interactions within the bilingual lexicon (and see Shook, 2014, for further evidence of L2 language co-activation in an L1 setting using eye-tracking). In-line with these findings, our study demonstrates the strength of cascaded activation across languages (see also Chabal & Marian, 2015; Marian & Spivey, 2003a, 2003b) and supports the view of a broad influence of the L2 on the native language (e.g., Dussias, Perrotti, Brown, & Morales, 2014; Dussias & Sagarra, 2007; Kroll, Bobb, & Hoshino, 2014).

While our results provide striking evidence for language co-activation, they also demonstrate constraints to the extent of co-activation: We found only limited effects in the N400 window for the L1prime-L2translation condition. Why do we find a broader distribution of effects across target translations in the L2prime-L2translation condition than in the L1prime-L2translation condition? We initially predicted that an N400 effect would be more likely for the L1prime-L2translation condition given that the experimental environment is Spanish, which may provide more support for the activation of Spanish. One possible explanation for the pattern of findings reported speaks to the strength of connections within and across languages. In particular, given the dominance of Spanish (L1), it is possible that the level of activation of the Basque translation of the Spanish target from the Spanish prime is reduced in the L1prime-L2translation condition. While there may be similarly reduced activation to the Basque translation of the Spanish target from the Spanish prime in the L2prime-L2translation condition, activation in this condition is further influenced by the overlap within one language (Basque) in this condition. In other words, the effect in the L1prime-L2translation condition relies on cross-language overlap, while this effect may be boosted by within-language overlap in the L2prime-L2translation condition.

In instances where there is cross-language overlap, there may also be increased competition between lexical items across languages, which may also explain a reversal in the N400 effect that we find in the present study. The conditions most influenced by the L1 Spanish prime label, the Identity and the L1prime-L2translation conditions, show the anticipated reduction in the N400 effect compared to the Unrelated condition during the later time window, consistent with lexical priming paradigms (e.g., Kutas & Van Petten, 1988). However, for the two conditions most influenced by the L2 Basque prime label, L2prime-L2translation and L2prime-L1target conditions, we found an increase in the N400 at both early and late time windows. Reversals have been documented elsewhere in the bilingual literature, including priming paradigms that require language translation. De Cat, Kepousniotou, and Baayen (2015) found a P400 effect in a primed visual lexical decision task at right frontal sites for a group of German-English bilinguals. In another bilingual study, Chauncey, Holcomb, and Grainger (2009) also report a reversed priming effect around 300 ms using masked priming and picture naming, which they attribute to an interaction of effects between masked priming and processing conflicts arising from translating the L2 prime into the L1 (see also Midgley, Holcomb, & Grainer, 2009). In our own case, it is the conditions mediated by the Basque prime label (L2prime-L2translation and L2prime-L1target), which show this reversal. While one possible explanation for the reversal targets the lexical competition that is incurred in this case, due to the co-activation of the Spanish and Basque rhyming words, an alternative possibility may be that the reversal may have to do with how the auditory target activates the non-dominant language (Basque) of the prime in an L1-only context (Spanish). Thus, rather than the prime image automatically co-activating the labels in both languages, the possibility remains that the Basque label may only be co-activated in a second step, after the Spanish auditory target has been heard and co-activated its Basque translation and or rhyme.

While the above explanation is tentative, this additional processing step may also be causing a delay or continuation of earlier effects. Our baseline comparison between the Identity and Unrelated condition also showed a greater negativity for the Identity condition in the earlier time window between 250 to 400 ms. Note that delays in N400 for bilinguals have been observed for semantic processing (e.g., Ardal et al., 1990; Weber-Fox & Neville, 1996), indicative of slower semantic integration. In view of the fact that participants completed a picture-matching task, the nature of our task is arguably conceptually driven and may be vulnerable to these delays, particularly in conditions where there is increased cross-language activation. The effect we document here then, especially for the Basque prime label conditions, may not be a traditional N400 effect but may rather reflect differences in L1 and L2 co-activation. This interpretation would be consistent with findings that the scalp distribution of the effect varies across condition comparisons -- found at frontal as well as posterior sites and sometimes in one, sometimes in both, hemispheres and not consistently along the mid-line. On the other hand, while the overall effect sizes in the present study are relatively small, this could be due to the experimental design. In contrast to the paradigm used by Thierry and Wu, the participants in our study were intentionally directed away from the linguistic nature of the experiment by using a picture judgement task. This may have reduced priming effects across all conditions, leading to smaller effects.

In conclusion, our results provide strong evidence that bilinguals momentarily activate both languages while immersed in their L1. The results of previous research indicated that the dominant language is sufficiently automatic to obscure activation of the L2 during L1 processing. Here, using a more fine-grained measure of language processing, we show implicit access of the L2 translation, both at the prime and the target, and even when the L2 is the language not in use and in the absence of any overt phonological cues to L2 lexical activation. Our results indicate that parallel language activation is pervasive, including to the phono-lexical level, and future work will need to further clarify the scope and contexts under which it manifests.

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Appendix

Condition	Image	Sp_label	B_label	Sp_auditory	B_transl
Identity	Garlic	Ajo	Baratxuri	Ajo	Baratxuri
Identity	Ring	Anillo	Eraztun	Anillo	Eraztun
Identity	Beret	Boina	Txapela	Boina	Txapela
Identity	House	Casa	Etxe	Casa	Etxe
Identity	Waterfall	Cascada	Urjauzi	Cascada	Urjauzi
Identity	Onion	Cebolla	Tipula	Cebolla	Tipula
Identity	Brain	Cerebro	Burmuin	Cerebro	Burmuin
Identity	Cross	Cruz	Gurutze	Cruz	Gurutze
Identity	Knife	Cuchillo	Laban	Cuchillo	Labán
Identity	Devil	Diablo	Deabru	Diablo	Deabru
Identity	Star	Estrella	Izar	Estrella	Izar
Identity	Fig	Higo	Piku	Higo	Piku
Identity	Ham	Jamón	Urdai	Jamón	Urdai
Identity	Brick	Ladrillo	Adreilu	Ladrillo	Adreilu
Identity	Owl	Lechuza	Hontz	Lechuza	Hontz
Identity	Moon	Luna	Ilargi	Luna	Ilargi
Identity	Mandarine (fruit)	Mandarina	Madari	Mandarina	Madari
Identity	Bat	Murciélago	Saguzar	Murciélago	Saguzar
Identity	Eye	Ojo	Begi	Ojo	Begi
Identity	Bear	Oso	Hartz	Oso	Hartz
Identity	Bread	Pan	Ogi	Pan	Ogi
Identity	Comb	Peine	Orrazi	Peine	Orrazi
Identity	Leg	Pierna	Hanka	Pierna	Hanka
Identity	Radio	Radio	Irrati	Radio	Irrati
Identity	Mouse	Ratón	Sagu	Ratón	Sagu
Identity	Wheel	Rueda	Gurpil	Rueda	Gurpil
Identity	Salmon	Salmón	Izokin	Salmón	Izokin
Identity	Grasshopper	Saltamontes	Matxinsalto	Saltamontes	Matxinsalto
Identity	Dryer	Secador	Lehorgailu	Secador	Lehorgailu
Identity	Fence	Valla	Hesi	Valla	Hesi
Unrelated	Artichoke	Alcachofa	Orburu	Horno	Labe
Unrelated	Angel	Angel	Aingeru	Baldosa	Lauza
Unrelated	Spider	Araña	Armiarma	Auricular	Entzungailu
Unrelated	Coffin	Ataúd	Hilkutxa	Cabra	Ahuntz
Unrelated	Hazelnut	Avellana	Hur	Castañuela	Kriskitin
Unrelated	Ostrich	Avestruz	Ostruka	Ascensor	Igogailu
Unrelated	Bed	Cama	Ohe	Guante	Eskularru
Unrelated	Shell	Caparazón	Oskol	Badajo	Gingil
Unrelated	rattle/bell	Cascabel	Kriskitin	Frío	Hotz

Unrelated	Gum	Chicle	Txingoma	Rojo	Gorri
Unrelated	Chest (of Jewelry)	Cofre	Kutxa	Rocío	Ihintz
Unrelated	Fang/Tusk	Colmillo	Letagin	Fila	Ilara
Unrelated	Rabbit	Conejo	Untxi	Mañana	Goiz
Unrelated	Freezer	Congelador	Izozkailu	Sonrisa	Irribarre
Unrelated	Cot	Cuna	Sehaska	Lágrima	Malko
Unrelated	broom	escoba	erratza	Discurso	Hitzaldi
Unrelated	Scorpio	Escorpión	Lupu	Pañuelo	Zapi
Unrelated	Crane	Grua	Garabi	Bocadillo	Ogitarteko
Unrelated	Ice cream	Helado	Izozki	Ciruela	Okaran
Unrelated	Lavender	Labanda	Ispiliku	Cursi	Pinpirin
Unrelated	Lion	León	Lehoi	Fresa	Marrubi
Unrelated	Slug	Limaco	Bare	Nido	Kabi
Unrelated	Wolf	Lobo	Otso	Nuez	Intxaur
Unrelated	Apple	manzana	sagar	Pantalón	Galtza
Unrelated	Medal	Medalla	Domina	Piso	Solairu
Unrelated	Otter	Nutria	Igaraba	Calor	Bero
Unrelated	Toothpick	Palillo	Zotz	Joya	Bitxi
Unrelated	Clock	Reloj	Erloju	Sartén	Zartagi
Unrelated	Chair	Sillón	Besaulki	Página	Orri
Unrelated	Nail	Uña	Azazkal	Borracho	Mozkor
L2prime_L1target	Pillow	Almohada	Buruko	Eunuco	Zikiratu (Gizona)
L2prime_L1target	Anchor	Ancla	Aingura	Figura	Irudi
L2prime_L1target	Rainbow	Arco Iris	Ortzadar	Paladar	Aho sabai
L2prime_L1target	Donkey	Burro	Asto	Pasto	Bazka
L2prime_L1target	Crab	Cangrejo	Karramarro	Tarro	Poto
L2prime_L1target	Toothbrush	Cepillo	Eskuila	Grulla	Kurrillo
L2prime_L1target	Beer	Cerveza	Garagardo	Pardo	Nabar
L2prime_L1target	Belt	Cinturón	Gerriko	Borrico	Astakume
L2prime_L1target	Car	Coche	Berebil	Barril	Upel
L2prime_L1target	Rope	Cuerda	Soka	Toca (Monja)	Buruko (moja)
L2prime_L1target	Scarecrow	Espantapajaros	Txorimalo	Palo	Makil
L2prime_L1target	Skirt	Falda	Gona	Mona	Tximino (emea)
L2prime_L1target	Flute	Flauta	Txirula	Insula	Irla
L2prime_L1target	Chickpea	Garbanzo	Txitxirio	Delirio	Eldarnio
L2prime_L1target	Gull	Gaviota	Kaio	Rayo	Tximista
L2prime_L1target	Church	Iglesia	Eliz	Feliz	Zoriontsu
L2prime_L1target	Corn	Maiz	Arto	Cuarto	Gela
L2prime_L1target	Coin	Moneda	Txanpon	Armazón	Egitura
L2prime_L1target	Navel	Ombligo	Zilbor	Favor	Mesede

L2prime_L1target	Chicken	Pollo	Oilasko	Vasco (Parlante)	Euskaldun
L2prime_L1target	Gate	Puerta	Ate	Petate	zaku
L2prime_L1target	Lung	Pulmón	Birika	Rica	Aberats (Femeninoa)
L2prime_L1target	Octopus	Pulpo	Olagarro	Barro	Lokatz
L2prime_L1target	Cheese	Queso	Gazta	Canasta	Saski
L2prime_L1target	Sleigh	Trineo	Lera	Pera	Udare
L2prime_L1target	Cider	Sidra	Sagardo	Bardo	Koblakari
L2prime_L1target	Market	Mercado	Azoka	Loca	Ero
L2prime_L1target	Braid	Trenza	Txirikorda	Gorda	Lodi (Femenino)
L2prime_L1target	Udder	Ubre	Errape	Rape	Itsas-zapo
L2prime_L1target	Carrot	Zanahoria	Azenario	Obituario	Hileta-liburu
L1prime-L2translation	Chess	Ajedrez	Xake	I.v.a.	B.e.z.
L1prime-L2translation	Wing	Ala	Hego	Grieta	Arrakala
L1prime-L2translation	Acorn	Bellota	Hur	Tipo	Mota
L1prime-L2translation	Dungeon	Calabozo	Ziega	Dulce	Gozo
L1prime-L2translation	Cherry	Cereza	Gerezi	Cura	Apeza
L1prime-L2translation	Carnation	Clavel	Krabelin	Moratón	Ubel
L1prime-L2translation	Hive	Colmena	Erlauntz	Todo	Dena
L1prime-L2translation	Lamb	Cordero	Arkume	Loco	Ero
L1prime-L2translation	Dragon	Dragon	Herensuge	Buenas noches	Gabon
L1prime-L2translation	Elf	Duende	Ipotx	Gente	Jende
L1prime-L2translation	Lighthouse	Faro	Itsasargi	Estación (Del año)	Urtaro
L1prime-L2translation	Barn Swallow	Golondrina	Enara	Atención	Grina
L1prime-L2translation	Hump	Joroba	Konkor	Nieto	Iloba
L1prime-L2translation	Key	Llave	Giltza	Pócima	Edabe
L1prime-L2translation	Hand	Mano	Esku	Águila	Arrano
L1prime-L2translation	Wave	Ola	Olatu	Cinta	Xingola
L1prime-L2translation	Dove	Paloma	Uso	Tirachinas	Tiragoma
L1prime-L2translation	Dance	Baile	Dantza	Pelo	ile
L1prime-L2translation	shepherd	Pastor	Artzain	Camisa	Ator
L1prime-L2translation	Duck	Pato	Ahate	Muchacha	Neskato
L1prime-L2translation	Chest	Pecho	Bular	Mosquito	Eltxo
L1prime-L2translation	Chin-beard	Perilla	Kokospeko	Hábil	Abila
L1prime-L2translation	Latch	Pestillo	Kisketa	Nudo	Korapilo
L1prime-L2translation	Beach	Playa	Hondartza	Hermano	Anaia
L1prime-L2translation	Frog	Rana	Igel	Piña	Anana
L1prime-L2translation	Sun	Sol	Eguzki	Paraguas	Goardasol
L1prime-L2translation	Bra	Sujetador	Bularretako	Cresta	Gandor
L1prime-L2translation	Green bean	Vaina	Leka	Lengua	Mingaina
L1prime-L2translation	Glass	Vaso	Edalontzi	Ataque	Eraso

L1prime-L2translation	Fox	Zorro	Azeri	Rugido	Orro
L2prime-L2translation	Coat	Abrigo	Beroki	Frente	Bekoki
L2prime-L2translation	Needle	Aguja	Orratz	Lapiz	Arkatz
L2prime-L2translation	fish hook	Anzuelo	Amu	Lamento	Damu
L2prime-L2translation	Plow	Arado	Golde	Inundación	Uholde
L2prime-L2translation	Plane	Avión	Hegazkin	Carbonero	Ikazkin
L2prime-L2translation	Wasp	Avispa	Liztor	Topo	Sator
L2prime-L2translation	Witch	Bruja	Sorgin	Carpintero	Zurgin
L2prime-L2translation	Ladle	Cazo	Burruntzali	Esconder	Estali
L2prime-L2translation	Cowbell	Cencerro	Zintzarri	Imponer	Ezarri
L2prime-L2translation	Lock	Cerradura	Sarraila	Nivel	Maila
L2prime-L2translation	Deer	Ciervo	Orein	Sembrar	Erein
L2prime-L2translation	Elbow	Codo	Ukondo	Bien	Ondo
L2prime-L2translation	Heart	Corazón	Bihotz	Excremento	Gorotz
L2prime-L2translation	Rib	Costilla	Sahiets	Sueño	Amets
L2prime-L2translation	Raven	Cuervo	Erroi	Gigante	Erraldoi
L2prime-L2translation	Beetle	Escarabajo	Kakalardo	Sidra	Sagardo
L2prime-L2translation	Shield	Escudo	Armarri	Cagalera	Kakalarri
L2prime-L2translation	clothes hook	Gancho	Kako	Tortazo	Zartako
L2prime-L2translation	Ant	Hormiga	Inurri	Fuente	Iturri
L2prime-L2translation	Lizard	Lagartija	Sugandila	Campana	Ezkila
L2prime-L2translation	Lettuce	Lechuga	Uraza	Respiración	Arnasa
L2prime-L2translation	Cloud	Nube	Hodei	Vaca	Behi
L2prime-L2translation	Ear	Oreja	Belarri	Sed	Egarri
L2prime-L2translation	Bow tie	Pajarita	Tximeleta	Tozudez	Seta
L2prime-L2translation	Newspaper	Periódico	Egunkari	Piedra	Harri
L2prime-L2translation	Dog	Perro	Txakur	Simbolo	Ikur
L2prime-L2translation	Colt	Potro	Zaldiko	Olla	Lapiko
L2prime-L2translation	Net	Red	Sare	Dedal	Titare
L2prime-L2translation	Tile	Teja	Ostraka	Portezuela	Ataka
L2prime-L2translation	Grape	Uva	Mahats	Tarde	Arrats