

**Electrophysiological correlates of the masked translation priming effect with  
highly proficient simultaneous bilinguals**

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## Abstract

In the present study, we examined whether there is a symmetrical masked translation priming effect for non-cognate words in a group of highly proficient (native-like) Basque-Spanish simultaneous bilinguals using event-related brain potentials. Participants were presented with a set of Spanish and Basque words that could be preceded by their repetitions (an identity condition), their translations in the other language, or by two unrelated words (one in each language). Results showed a significant masked repetition effect for Spanish as well as for Basque targets, mainly evident in the N250 and N400 components. Interestingly, a masked translation priming effect was also found in the N400 component in both language directions (L1-to-L2 and L2-to-L1). Furthermore, the magnitude of the N400 modulation for the translation priming effect was similar in the two directions. Finally, we also found a language switch cost effect in the N250 and N400 components, associated with primes (related and unrelated) that did not match the target word's language. This language switch cost effect was also highly similar across the two language directions.

Section: Cognitive and Behavioral Neuroscience.

Keywords: Masked translation priming; simultaneous bilinguals; event-related potentials.

## **Electrophysiological correlates of the masked translation priming effect with highly proficient simultaneous bilinguals**

### **1. Introduction**

It is well-known that when a bilingual consciously reads two consecutive words that refer to the same concept but in different languages (e.g., the Spanish word *casa* and the English word *house*), the latter is generally recognized faster and more accurately than when preceded by an unrelated word in the other language (e.g., the Spanish word *mesa*, which corresponds to *table*). This result establishes the basis of the so-called translation priming effect, which has been repeatedly reported (e.g., Altarriba, 1992). Considering that the conscious presentation of a prime (e.g., *casa*) and a target (e.g., *house*) can potentially generate a series of strategies in the perceiver, researchers have made use of the masked version of the translation priming paradigm, which taps onto automatic and unconscious stages of word processing and is not subjected to strategic effects (e.g., see Altarriba & Basnight-Brown, 2007; Schoonbaert, Duyck, Brysbaert, & Hartsuiker, 2009, for review). As a way of illustration, many studies have shown that when bilinguals are presented with a target word in their non-dominant language (L2) which is briefly preceded (for around 50 ms) by its masked non-cognate translation equivalent in their dominant language (L1; e.g., #####-*casa*-*HOUSE*, for a Spanish-English bilingual), a target recognition benefit is typically observed as compared to a control priming condition. However, as will be discussed below, this masked translation priming effect seems to be dependent on a number of factors.

So far, the evidence from masked translation priming studies has shown clear differences between the degree to which a word-form in one of the languages affects the recognition of its non-cognate translation in the other language, mainly depending on the task at hand, the degree of L2 proficiency of the bilinguals and the priming direction (forward vs. backward priming, that is,  $L1 \rightarrow L2$  vs.  $L2 \rightarrow L1$ ). In further detail, results from a large number of lexical decision studies have shown a clear forward masked translation priming effect that is of greater magnitude than the (generally elusive) backward translation priming effect, leading to the assumption of an asymmetrical spread of activation through the bilinguals' languages (e.g., De Groot & Nas, 1991; Dimitropoulou, Duñabeitia, & Carreiras, in press; Finkbeiner, Forster, Nicol, & Nakamura, 2004; Gollan, Forster & Frost, 1997; Grainger & Frenck-Mestre, 1998; Jiang, 1999; Jiang & Forster, 2001; Kim & Davis, 2003; Schoonbaert et al., 2009; Schoonbaert, Holcomb, Grainger, & Hartsuiker, 2010; Voga & Grainger, 2007; Williams, 1994; but see Duyck & Warlop, 2009; see Duñabeitia, Perea & Carreiras, 2010, for a summary). However, when the task involves a semantic categorization, symmetric and bidirectional masked translation priming effects appear in both priming directions (Finkbeiner et al., 2004; Grainger & Frenck-Mestre, 1998; Jiang & Forster, 2001; Wang & Forster, in press) while, when bilinguals perform an episodic recognition task the effect appears only in the backward,  $L2 \rightarrow L1$ , translation direction (see Jiang & Forster, 2001).

Regarding the issue of L2 proficiency, to the best of our knowledge, all these studies tested unbalanced bilinguals with a clear L1 dominance, meaning that they were clearly more proficient in their L1 than in their L2. However, two recent lexical decision studies with very high proficient bilinguals have shown a different pattern of results. Basnight-Brown and Altarriba (2007) showed forward and backward priming effects of the same magnitude for a group of very high proficient Spanish-English bilinguals.

Duñabeitia et al. (2010; see also Perea, Duñabeitia & Carreiras, 2008), have also shown that the asymmetric pattern disappears for completely balanced Basque-Spanish simultaneous bilinguals. Thus, the existing set of behavioural findings suggests that proficiency is a determinant factor for the appearance or vanishing of the masked translation priming asymmetry. With native-like balanced bilinguals effects of similar magnitude appear in the two language directions (namely, a symmetric pattern), while unbalanced bilinguals typically show the most reliable masked translation effects in the L1→L2 priming direction (namely, an asymmetric pattern).

The modulation of the masked translation priming effects as a function of language proficiency is in line with models of bilingual lexical access that assume a strengthening of inter-lingual lexico-semantic connections between translation equivalents as a consequence of increased proficiency. Such a modulation was first predicted by the Revised Hierarchical Model to account for word production evidence (RHM; e.g., Kroll & Stewart, 1994; Kroll & Tokowicz, 2001; 2005; Kroll, van Hell, Tokowitz, & Green, 2010). The RHM assumes that early in the L2 acquisition process, L2 words access their corresponding semantic representations through the prior activation of their L1 translations. In contrast, as L2 proficiency increases, the strength of the connections between L2 words and their conceptual representations would also increase, becoming somehow similar to the L1 lexico-semantic connections (i.e., for balanced bilinguals; see Talamas, Kroll & Dufour, 1999). This way, for highly proficient native-like bilinguals, the RHM would predict a symmetric pattern of translation priming effects. However, for unbalanced bilinguals the RHM predicts that translation from L2 to L1 should be faster than from L1 to L2, due to the strong direct link of L2 words to their L1 translations (see Kroll & Stewart, 1994, but see Kroll & de Groot, 1997; Kroll & Tokowicz, 2001 for a different interpretation of the masked

translation priming asymmetry). This final prediction is at odds with the vast majority of non-cognate masked translation priming studies reported so far (e.g., Dimitropoulou et al., in press; Gollan et al., 1997; Jiang, 1999; Jiang & Forster, 2001; Midgley et al., 2009; Schoonbaert et al., 2009).

The overall pattern of masked translation priming effects reported across the different levels of L2 proficiency can be better accounted for by the BIA and BIA+ framework (Van Heuven et al., 1998; Dijkstra & Van Heuven, 2002). According to these models, in the case of low and intermediate proficient bilinguals, L2 words have lower resting levels of activation due to the fact that they are infrequently used, as compared to L1 words. As a consequence, L2 words need more activation to surpass their activation threshold and therefore their recognition process is slower. Critically, in the case of highly proficient (balanced) bilinguals, the resting levels of activation of the words in the two languages should not differ, and therefore the amount of activation needed for recognition is predicted to be similar, entailing a lack of asymmetry in the masked translation priming effect.

In the present study we aimed at exploring the underlying electrophysiological correlates of the masked translation priming effect for balanced simultaneous bilinguals using event-related brain potentials (ERPs). Due to the high temporal resolution of the ERPs, they allow for a detailed analysis of the time-course of the cognitive processes underlying automatic translation. (Note that this is clearly difficult to track with purely behavioral techniques that only consider final reaction times). Furthermore, ERPs are able to capture very early occurring effects and to differentiate them from those occurring later in processing. As such, the use of this technique with a group of balanced bilinguals can reveal the temporal pattern of neural activation underlying the activation of the established inter-lingual lexico-semantic connections.

A large body of electrophysiological evidence on bilingual language processing has been so far gathered across different modalities (e.g., see Moreno, Rodríguez-Fornells, & Laine, 2008; Ye & Zhou, 2009, for comprehensive reviews), but only a small number of studies have focused on the processing of translation equivalents. Palmer, van Hooff and Havelka (2010) used a translation recognition task to examine whether the processing of visually presented translation equivalents was dependent on the direction of the translation (forward and backward) with two groups of unbalanced Spanish-English bilinguals. The authors found larger N400 effects during backward translation with both groups of bilinguals. They interpreted these effects as evidence in favor of the existence of asymmetric lexico-semantic connections across the two translation directions (e.g., RHM, Kroll & Stewart, 1994). Thierry and Wu (2007) presented late Chinese-English fluent bilinguals with semantically related or unrelated English prime-target pairs, which when translated to Chinese shared a single character. They found reduced N400 amplitudes for targets sharing a Chinese character with the prime through translation as compared with targets with no character repetition, thus providing strong evidence of automatic unconscious activation of the L1 translation equivalent of the L2 stimuli.

Recently, an increasing number of ERP studies have used the masked priming paradigm to test the automatic and unconscious activation of non-cognate translation equivalents (e.g., Hoshino, Midgley, Holcomb, & Grainger, 2010; Midgley, Holcomb, & Grainger, 2009; Schoonbaert, Holcomb, Grainger, & Hartsuiker, 2010). These studies tested unbalanced bilinguals and found in all cases asymmetric pattern of masked translation priming effects (i.e., larger or longer lasting effects in the L1→L2 translation direction than in the L2→L1 direction), which were mostly evident in the time windows corresponding to the N250 and to the N400 components. Within the masked priming

literature, the first of these components, the N250, is mainly proposed to reflect the activation of sub-lexical orthographic and phonological representations (Grainger & Holcomb, 2009), while the N400 is proposed to reflect mainly lexico-semantic interactions (e.g., Grainger & Holcomb, 2008). In further detail, Hoshino et al. (2010) and Midgley et al. (2009) examined the electrophysiological correlates of masked repetition and masked translation priming effects with relatively high proficient Japanese (L1)-English (L2) and French (L1)-English (L2) bilinguals, respectively, performing a semantic categorization go/no-go task. With regard to the masked repetition priming, symmetric effects were consistently observed in the N250 and the N400 components, with both L1 and L2 targets: larger negativities in the within-language unrelated conditions as compared to the within-language repetition conditions (e.g., *beach-BEACH* vs. *sleep-BEACH*). However, the translation priming effects obtained in both studies were found to be clearly dependent on the translation direction. When the task was in non-dominant language of the participants, both studies found more negative-going ERP waveforms in the N250 and the N400 time-windows for targets preceded by unrelated L1 primes as compared to targets preceded by their L1 translations (i.e., forward masked translation priming effects, e.g., *plage-BEACH*) [Footnote 1]. Critically, in both studies, when targets were in L1 and primes in L2 (i.e., backward translation), no modulations were observed in the N250 component, while Midgley and colleagues obtained an inversed positive going N400 effect, which had however, a different distribution than the one in the L1→L2 translation direction.

Schoonbaert et al. (2010) tested masked translation priming effects with a group of English (L1)-French (L2) unbalanced bilinguals. These authors used a lexical decision task and a relatively long SOA (120 ms). In both the behavioral and the electrophysiological data they collected, they obtained bi-directional asymmetric



masked translation priming effects: a larger masked priming effect for L1 primes and L2 targets as compared to that obtained with L2 primes and L1 targets and a longer lasting N400 effect in the L1→L2 translation direction. Asymmetric effects were also found in the N250 time-window, but surprisingly, in the opposite direction (i.e., a larger and earlier N250 effect in the L2→L1 translation direction than in the L1→L2 direction). Hence, the overall pattern of ERP masked translation priming effects reported so far provides evidence in favor of an asymmetrical conception of translation processes in unbalanced bilinguals, both at the prelexical-lexical interface (N250) and at the semantic-conceptual level (N400), coinciding with the predictions of bilingual models of visual word recognition and with preceding evidence from behavioral studies that have failed to obtain L2→L1 masked translation priming effects with unbalanced bilinguals (e.g., Gollan et al., 1997; Jiang & Forster, 2001). These masked translation priming studies further, corroborate that the asymmetric masked translation pattern that has been previously found with this type of bilinguals in behavioral studies can be also replicated with a technique that allows for a fine-grained temporal distribution of the underlying processes.

The question under scrutiny in the present study is twofold. On the one hand, we aimed to track the time course of automatic translation processes in balanced bilinguals, as a way to better understand the strength and automaticity of the existing inter-lingual connections. On the other hand, we aimed to investigate whether the symmetric behavioral pattern that has been previously found for balanced native-like bilinguals also has a reflection in participants' neural responses (see Kotz, 2001, for comparable ERP effects in L1 and L2 with native-like bilinguals). This reflection is expected mainly in two ERP components: N250 and N400. The N250 and N400 have been related to two distinct stages of visual word recognition: automatic sub-lexical processing and lexico-

semantic processing, respectively. Importantly, as abovementioned, these components have been identified as the electrophysiological markers of the cognitive processes underlying translation. Furthermore, we also expected to find modulations of these components depending on whether there was or not a language switch across the prime-target pairs, as has been previously found across different modalities and paradigms (e.g., Alvarez, Holcomb & Grainger, 2003; Christoffels, Firk & Schiller, 2007; Phillips, Klein, Mercier, & de Boysson, 2006). Recently, Chauncey, Grainger and Holcomb (2008) conducted a semantic categorization go/no-go masked priming ERP study aimed at testing language switching effects in a group of French participants with an intermediate level of English. In Experiment 1, they presented participants with English and French target words briefly preceded (for 50 ms) by masked unrelated words either in English or in French. Chauncey et al. showed effects associated to language switch in the N250 and in the N400 components, which were found to be more negative-going for target words following a prime in a different language than for words following primes in the same language (i.e., a language switch cost). The authors interpreted these results in the following way: At early automatic stages of visual word recognition, at the interface between orthographic and whole-word representations (i.e., N250 component; see Grainger & Holcomb, 2008; 2009), the prime word sends excitatory activation to its corresponding language node, inhibiting the lexical representation in the other language. When the target word's language does not coincide with the activated language node, a switch cost appears (see Midgley et al., 2009; see also Van Der Meij et al., in press, to some extent). These inhibitory processes also affect the subsequent form-meaning integration process, as shown by the modulation of the N400 component (see also Alvarez et al., 2003).

In the present ERP study, a group of simultaneous Basque-Spanish bilinguals with an excellent competence in both languages (i.e., native-like) were presented with a set of Basque and Spanish words (in different blocks), that were briefly preceded by masked primes that were either identical to the targets (e.g., *cuento-CUENTO*; the Spanish for *tale*), unrelated words in the same target language (e.g., *huelga-CUENTO*; *huelga* is the Spanish for *strike*), the non-cognate translations of the target in the other language (e.g., *ipuin-CUENTO*, *ipuin* is the Basque for *tale*), or unrelated words in the other language (e.g., *antza-CUENTO*; *antza* is the Basque for *appearance*). We employed the same experimental design as in the studies by Midgley et al. (2009) and by Hoshino et al. (2010; see also Perea et al., 2008), while the electrophysiological correlates associated with participants' neural responses to the words were recorded. As in these two previous masked priming ERP studies (see also Chauncey et al., 2008), the critical experimental target words had to be read passively for comprehension, and participants were asked to detect (by pressing a button) words that referred to animal names (i.e., go/no-go semantic categorization task). None of the critical experimental trials included animal names. A different set of target words was selected for this purpose, and this same set was also used as primes in a prime visibility test. According to recent ERP findings, several main results were predicted to emerge. We predicted a symmetric pattern of N400 translation and identity priming effects in the two language directions: We expected to obtain similar translation and identity priming effects in the N400 component when the related prime was in Basque and the target word in Spanish, and when the related prime was in Spanish and the target in Basque. We also expected to obtain a modulation of the N250 component as a consequence of prime-target relatedness: Related primes (especially in the Identity condition) were expected to produce N250 attenuation (i.e., N250 deflection). Besides, we also expected to obtain

modulation of early (N250) as well as of later (N400) components as a function of a language switch cost originated by the mismatch between primes and targets' language: Greater negativities as a consequence of language switching between primes and targets. The extent to which the N400 masked repetition and translation priming effects could differ from each other is, however, an open question.

## **2. Results**

### **Behavioral results**

Participants correctly categorized 97.71% ( $\pm 2.87\%$ ) of the Basque animal names and 97.71% ( $\pm 3.02\%$ ) of the Spanish animal names when these words were presented as targets. When the animal names were presented as masked primes, participants only identified them in 0.29% ( $\pm 0.88\%$ ) of the trials in the Basque block and in the Spanish block. None of the participants identified the masked animal names in more than 3% of the cases, confirming that participants were mostly unaware of the existence of the masked primes. Accordingly, none of the participants reported conscious knowledge of the existence of prime words when asked after the experiment.

### **ERP results**

After visual inspection of the ERPs time-locked to the target stimuli and following preceding ERP studies in similar or related topics (e.g., Chauncey, et al., 2008; Holcomb & Grainger, 2009; Hoshino et al., 2010; Midgley et al., 2009; Schoonbaert et al., 2010) two time windows were selected for analysis. The first window corresponded to a time epoch in which the N250 component is typically found

(175-300 ms post-target onset) while the second time window (400-550 ms post-target onset) was selected to best capture N400 activity.

#### *175-300 post-target*

The main effect of Prime Language (Same vs. Different) was significant,  $F(1,19)=11.04$ ,  $p<.01$ . The main effect of Relatedness (Related vs. Unrelated) was also significant,  $F(1,19)=7.45$ ,  $p<.02$ . Critically, the effect of Prime Language was further qualified by a significant interaction with the factor Relatedness,  $F(1,19)=8.49$ ,  $p<.01$ . On the one hand, follow-up comparisons showed that in the within-language conditions (i.e., primes and targets in the same language) targets preceded by unrelated primes elicited more negative-going waveforms than when preceded by related primes (namely, an identity priming effect),  $F(1,19)=10.47$ ,  $p<.01$  (see Figures 1 and 2). On the other hand, follow-up comparisons showed that when the conditions involved between-language manipulations (i.e., primes and targets in a different language), the Relatedness effect (namely, the translation priming effect) was negligible,  $F(1,19)=.44$ ,  $p>.51$ .

The identity priming effect observed in this time window was further qualified by a significant interaction with the factors Electrode and Laterality, which showed that this effect was more broadly distributed in the scalp for Spanish than for Basque targets. For Spanish targets, the identity priming effect was significant at frontal ( $F(1,19)=4.65$ ,  $p<.05$ ), central ( $F(1,19)=7.90$ ,  $p<.02$ ), parietal ( $F(1,19)=10.51$ ,  $p<.01$ ) and occipital sites ( $F(1,19)=11.19$ ,  $p<.01$ ). On the contrary, for Basque targets this effect was less spread out, reaching significance only at parietal ( $F(1,19)=4.87$ ,  $p<.05$ ) and occipital sites ( $F(1,19)=8.83$ ,  $p<.01$ ). The rest of effects or interactions did not approach significance.

## -Figures\_1\_and\_2-

*400-550 post-target*

The main effect of Prime Language (Same vs. Different) was significant,  $F(1,19)=4.76$ ,  $p<.05$ . The main effect of Relatedness (Related vs. Unrelated) was also significant,  $F(1,19)=11.50$ ,  $p<.01$ . Importantly, the interaction between these two factors was not significant, showing that the identity priming effect and the translation priming effect were highly similar to each other.

The effect of Prime Language significantly interacted with the factor Electrode,  $F(4,76)=4.25$ ,  $p<.05$ . Follow-up comparisons showed that that between-language manipulations elicited more negative-going waveforms than within-language manipulations at central sites ( $F(1,19)=5.99$ ,  $p<.03$ ), parietal sites ( $F(1,19)=11.39$ ,  $p<.01$ ) and occipital sites ( $F(1,19)=8.80$ ,  $p<.01$ ), but not at prefrontal sites ( $F(1,19)=.40$ ,  $p>.53$ ) and frontal sites ( $F(1,19)=.26$ ,  $p>.61$ ).

The effect of Relatedness also interacted significantly with the factor Electrode,  $F(4,76)=30.27$ ,  $p<.001$ . Follow-up comparisons showed that unrelated primes elicited more negative-going waveforms than related primes at central sites ( $F(1,19)=9.60$ ,  $p<.01$ ), parietal sites ( $F(1,19)=30.49$ ,  $p<.001$ ) and occipital sites ( $F(1,19)=33.80$ ,  $p<.001$ ), but not at prefrontal sites ( $F(1,19)=3.18$ ,  $p>.09$ ) and frontal sites ( $F(1,19)=1.02$ ,  $p>.32$ ). Also, the interaction between Relatedness and Laterality approached significance,  $F(2,38)=3.28$ ,  $p=.07$ , suggesting that the effect of Relatedness was of bigger magnitude at the right hemisphere (left hemisphere:  $F(1,19)=4.61$ ,  $p<.05$ ; midline:  $F(1,19)=9.96$ ,  $p<.01$ ; right hemisphere:  $F(1,19)=21.72$ ,  $p<.001$ ). The rest of effects or interactions did not approach significance.

### 3. Discussion

In the present study we explored automatic and unconscious translation processes in a group of balanced simultaneous bilinguals while ERPs were recorded. Based on recent behavioral evidence, we predicted that symmetric masked translation priming effects should be evident in this type of bilinguals, which were expected to be mainly evident in the N400 component, as compared to masked repetition priming effects that were also expected to appear in an earlier time window (corresponding to the N250 component). Furthermore, we also expected to find a general language switch cost effect, which was predicted to occur in the two critical components (N250 and N400). The results were clear-cut and fully confirmed our initial predictions. First, the within-language unrelated condition elicited larger negativities than the within-language related condition (i.e., an identity priming effect) in the time windows corresponding to the N250 and to the N400, as shown by the significant Relatedness effect in the within-language conditions. Second, the between-language unrelated condition only showed larger negativities as compared to the between-language related condition (i.e., a translation priming effect) in the epoch of the N400 component, as revealed by the general Relatedness effect found in this epoch. Third, no clear asymmetries were found as a function of language direction, as shown by the negligible impact of the factor Target Language. Fourth, the N400 identity and translation priming effects did not significantly differ from each other (note that the interaction between Prime Language and Relatedness was not significant in the N400 epoch). And fifth, a language switch cost effect was found for both language directions in the N250 and the N400 epochs, as reflected by the significant Prime Language effects.

The symmetric masked translation priming N400 effects we obtained across the two translation directions (reduced N400 amplitudes in the Translation as compared to the Translation Control conditions for L1 primes and L2 targets and vice versa) constitute the most important finding of the present study. When unbalanced bilinguals have been studied, typically N400 masked asymmetric translation priming effects have been shown, mainly dependent on the language direction (e.g., Hoshino et al., 2010; Midgley et al., 2009; Schoonbaert et al., 2010; see also Palmer et al., 2010, for asymmetric N400 translation effects with a different paradigm). However, native or native-like balanced bilinguals generally show a symmetric pattern of effects. Similar to the symmetric N400 translation priming effects we obtained with balanced simultaneous bilinguals, previous behavioral experiments testing this type of bilinguals have also reported symmetric bi-directional masked translation priming effects (e.g., Basnight-Brown & Altarriba, 2007; Duñabeitia et al., 2010). Importantly, the reason for this discrepancy seems to lay on the relative level of linguistic competence of the bilinguals, since, unlike the present study, all the studies reporting asymmetric translation priming effects had tested unbalanced bilinguals of different levels of L2 proficiency (e.g., Dimitropoulou et al., in press; Gollan et al., 1997; Jiang, 1999). Most of these studies have obtained significant effects in the forward translation direction but null or greatly reduced effects in the backward translation direction. Hence, the present ERP study provides further evidence in favor of a critical role played by the degree of proficiency on the automatic co-activation of translation equivalents in the bilingual lexicon. In a similar vein, behavioral masked priming studies examining the processing of cross-language associatively and/or semantically related words (e.g., *tejado*, which is the Spanish word for *roof*, and *HOUSE*) have shown such effects only with balanced and simultaneous bilinguals (Perea et al., 2008). In contrast, unbalanced bilinguals show



more elusive effects (Basnight-Brown & Altarriba, 2007; De Groot & Nas, 1991; Duyck, 2005; Schoonbaert et al., 2009). In the present experiment, the language direction had limited impact on the observed results, showing relatively comparable effects in the two language directions. These findings help to establish the idea initially proposed by Perea et al. (2008) and Duñabeitia et al., who indicated that for this type of bilinguals the terminology L1 and L2 is rather inappropriate, and both languages could be understood as being L1 (multiple L1s).

What do these N400 translation effects reflect? In Midgley et al.'s words (2009), “*non-cognate translation equivalents (...) provide the closest possible semantic relation between two distinct word forms*”. However, if these N400 effects supported such a conception of translation equivalents as semantically closely related items, then one would expect similar N400 masked priming effects for associatively/semantically related word forms (e.g., *gato-PERRO*, the Spanish words for “cat” and “dog”). Importantly, the ERP literature has been rather inconclusive at this respect, reporting largely mixed findings (see Brown & Hagoort, 1993; Holcomb & Grainger, 2009, for negative findings; but see e.g., Deacon, Hewitt, Yang, & Nagata, 2000; Grossi, 2006; Kiefer, 2002 for significant N400 effects). This suggests that the processing of associatively/semantically related words is not directly comparable to that of translation equivalents mainly due to the fact that the degree of associative/semantic overlap between two translation equivalents (referring to a unique concept) is markedly larger than that of two word forms referring to two distinct but closely related concepts. Consider, for instance, the Spanish words “*gato*” and “*perro*”. These two concepts do share many, but not all, of their base features and the strength of association between these two words approaches 20%, according to the Spanish norms. However, in these same terms, the translation equivalents “*dog*” and “*perro*” overlap in all their semantic

features and if there would be an association strength index for these words, it would be of 100% (see Finkbeiner et al., 2004). Thus, it is not surprising that whereas translation priming N400 effects are easily captured, effects for associatively/semantically related pairs are more elusive. In other words, even though Midgley et al. have defined translation equivalents as the maximum exponents of semantically closest items, we prefer to step over from this positioning and to assume that these two entities (translation equivalents and semantically/associatively related words) are different in essence. By definition semantically close items have neighbouring conceptual representations which are not identical. This definition does not hold for translation equivalents since they do not have neighbouring but identical conceptual representations. This way, it is easy to understand that in lack of associative/semantic ERP priming effects (e.g., Holcomb & Grainger, 2009), translation ERP priming effects can be found.

Following this line of reasoning, we believe that N400 masked translation priming effects are in line with previous proposed definitions of N400 priming effects according to which these effects are the reflection of the “interactions between levels of representations for whole-words and concepts” (e.g., Grainger & Holcomb, 2008). Thus, reduced N400 amplitudes may indicate a diminution of the effort needed to form links between lexical and semantic representations. Put differently, N400 priming effects may reflect ease of integration of a given concept within the contextual framework imposed by the previously presented one (e.g., Holcomb, 1993; see Barber & Kutas, 2007, for review). In the case of non-cognate translation equivalents prime-target pairs, different whole-word ortho-phonological representations map onto a single semantic representation. Considering that the contextual framework imposed by the conceptual representation corresponding to the prime word is identical to the one

corresponding to the target, the ease of integration of the latter is maximum (while this would not be the case for any unrelated prime-target word pairs).

Closely related to this issue, is the fact that in the N400 time window the masked identity and masked translation priming effects were almost identical, with related conditions producing reduced N400 amplitudes as compared to unrelated conditions (irrespective of the prime-target language concurrence). Typically, reaction time studies have shown a significant difference between the magnitude of masked translation priming effects and that of masked identity priming effects (e.g., de Groot & Nas, 1991; Gollan et al., 1997; Jiang & Forster, 2001; see Altarriba & Basnight-Brown, 2007, for review). However, masked N400 identity and translation priming effects seem to be identical. Considering that mean reaction times are the final product of a convolution of cognitive processes, while the N400 marker reflects a time-locked lexico-semantic processing stage (i.e., it is not a final product), it is not surprising that differences found at the reaction time level are not so evident in the N400 component. In this line, a recent ERP study by Carreiras, Duñabeitia and Molinaro (2009) exploring masked orthographic subset priming effects has failed to show N400 differences between totally overlapping prime-target pairs (e.g., *balcony-BALCONY*) and partially overlapping pairs (e.g., *blcn-BALCONY*), as compared to unrelated pairs, while behavioural data point to a significant difference (see Duñabeitia & Carreiras, submitted). Given that the N400 priming effects reflect integration of conceptual meanings and they are not influenced by sub-lexical overlap, and taking into account that non-cognate translation pairs are conceptually identical but ortho-phonologically different entities, one can easily take them as the perfect example of abstract identity priming effects. If this is so, then no differences are to be expected between identity and translation priming effects in a component which is not sensitive to formal overlap.

Hence, this finding fits with the conception of N400 as reflecting conceptual overlap between the semantic representations triggered by the prime and the target (see Barber & Kutas, 2007, for review): Since the conceptual representations of two translation equivalents are coincident, there are no expected differences between the N400 effects for identical primes and translation equivalents, at least in the case of the completely balanced bilinguals we tested. The assumption that for balanced native-like bilinguals lexico-semantic effects across languages are comparable to within-language effects has been also supported by the findings reported by Perea et al. (2008). These authors found masked associative/semantic priming effects of similar magnitude for cross-language and for within language associatively related prime-target pairs with a group of balanced Basque-Spanish bilinguals taken from the same pool as the ones who participated in the present study.

In accordance to our symmetric pattern of results, neuroimaging evidence suggests that at very high levels of L2 proficiency the cerebral substrates of a bilingual's two languages are largely overlapping (e.g., Perani & Abutalebi, 2005). Unfortunately, neuroimaging data regarding brain activation patterns associated with translation processes in balanced bilinguals is still very scarce (e.g., Price et al., 1999; Quaresima, Ferrari, van der Sluijs, Menssen, & Colier, 2002) and differences in the foci of those studies as well as in the paradigms and materials used disallow a direct comparison. However, there are two other sources of neuroimaging evidence that could help us identify a relationship between the present findings and the neural substrates of masked translation processes. As stated above, translation equivalents represent the strongest semantically related word pairs across languages, and can be also thought to reflect masked "repetition" effects (as indicated by the lack of any difference between the N400 translation and repetition effects). Rossel, Price and Nobre (2003) conducted

an ERP and fMRI semantic priming study with visible primes and suggested that the N400 decrease observed for targets preceded by semantically related primes as compared to unrelated primes in their ERP data was analogous to the decrease in activity in the medial-temporal cortex found in their fMRI data. Dehaene et al. (2001) examined the neural substrates of masked word repetition priming in monolinguals in an fMRI study and found repetition suppression effects in the left extrastriate and left fusiform gyrus. Interestingly, our N400 translation and repetition effects were mostly evident in a similar brain area (centro-posteriorly distributed effects; see also Midgley et al., 2009; for the same distribution of N400 effects). Thus, although tentatively, the general pattern seems to suggest that the areas directly implicated in translation priming could be located in the medial and temporal cortices.

How are these results explained in terms of models of bilingual memory and bilingual visual word processing? As said, the RHM (e.g., Kroll & Tokowicz, 2001, 2005) would effectively predict the symmetric pattern of N400 masked translation priming effects that we found with balanced and simultaneous bilinguals, since, according to this model, for this type of bilinguals words from both languages would have direct and equally effective access to the conceptual level (e.g., Talamas, Kroll & Dufour, 1999). However, the fact that for unbalanced bilinguals the RHM predicts a masked translation priming asymmetry in the opposite direction to the one observed in the vast majority of non-cognate masked translation priming studies reported, precludes the acceptance of the RHM as a valid model to account for the overall pattern of masked translation priming effects obtained so far (e.g., Dimitropoulou et al., in press; Gollan et al., 1997; Jiang, 1999; Jiang & Forster, 2001; Midgley et al., 2009; Schoonbaert et al., 2009; see Brysbaert & Duyck, 2010, for a comprehensive review). The symmetric N400 masked translation priming effects we obtained with balanced simultaneous bilinguals

as well as the previously reported asymmetric pattern found with unbalanced bilinguals can be easily accommodated within the BIA (+) framework (Van Heuven et al., 1998; Dijkstra & Van Heuven, 2002). These models propose that the difference in the resting levels of activation of L1 and L2 words will be diminished as a matter of increased L2 proficiency and that eventually, for balanced and simultaneous bilinguals, the resting levels of activation of words of the two languages will be equal, thus leading to symmetric effects as those reported in the present study.

Unlike the pattern of effects obtained in the N400 time window, in the N250 time window we found a clear dissociation between masked identity and translation priming effects, with N250 differences emerging only between the Identity and Identity Control conditions and not between the Translation and Translation Control conditions. In contrast to the present lack of N250 masked translation priming effects, previous ERP masked translation priming studies with less proficient unbalanced bilinguals have found significant N250 masked translation priming effects, which, with the exception of the study by Schoonbaert et al. (2010) [Footnote 2], were only evident with L1 primes and L2 targets (Hoshino et al., 2010; Midgley et al., 2009). In both of these studies the authors argued that this finding clearly demonstrated that semantic overlap across primes and targets can influence N250 modulations via top-down feedback mechanisms. Furthermore, Midgley and colleagues related their N250 effect to recent ERP findings showing that semantic transparency affected this component (see Morris, Frank, Grainger, & Holcomb, 2007) and to cascaded activation models of visual word recognition that predict early semantic effects in the absence of formal overlap (but see Lavric, Clapp, & Rastle, 2007). Living aside previous conceptions of the N250 as being purely sensitive to sub-lexical factors (see below), one might argue that the high level of activation of L1 primes is the determining factor for the appearance of the N250 masked

translation priming effects. Considering that the participants in the Hoshino et al. and in the Midgley et al. studies were clearly unbalanced bilinguals, L1 masked primes could have been processed faster due to the hyper-activation of the dominant L1 and to the small amount of inhibition exerted by the non-dominant L2. In contrast, in the present study participants were perfectly balanced bilinguals and the increased level of mutual interference and inhibition exerted by L1 and L2 could have been responsible for the vanishing of early automatic masked translation priming effects at the N250 time window. Nevertheless, this line of reasoning overlooks the fact that in the present experiment similar N250 priming effects were obtained for identical primes, and that switch cost effects have been also found in this epoch. However, due to the unclear and possibly multi-factorial nature of this component, it is feasible to assume that various N250 effects have different sensitivity levels to feedback activation depending on L2 proficiency degree.

We should also note that the lack of masked translation priming effects in the N250 component is a somehow expected finding considering the tight relationship between the N250 and sub-lexical processing (see Massol, Grainger, Dufau, & Holcomb, 2010; see also Holcomb & Grainger, 2009 for review). While identity primes entail a clear orthographic overlap with the target (and consequently produce a diminishing of the N250 amplitude), non-cognate translation primes do not match the targets in their orthographic and phonological units reducing the possibility of appearance of N250 effects. With the exception of very few studies, the most compelling evidence supporting N250 effects has shown that this component is predominantly sensitive to form-overlap effects (e.g., Grainger, Kiyonaga, & Holcomb, 2007; Holcomb & Grainger, 2006; 2007; Massol et al., 2010), with scarce influence from lexico-semantic levels of processing before 300 ms post-target onset (see

Duñabeitia, Molinaro, Laka, Estévez, & Carreiras, 2009, for review; see also Molinaro, Duñabeitia, Marín-Gutiérrez, & Carreiras, 2010, for supporting evidence). In this line, the lack of N250 masked translation priming effects that we have shown supports the classical conception of the N250 as being relatively blind to semantic prime-target relationships, in contrast to the L1-L2 N250 masked translation priming effects found in previous masked translation priming ERP studies. Clearly, even though this result is not critical for the purposes of the present study, future research is needed in order to explore the extent to which the N250 can be sensitive to lexico-semantic prime-target relations within and across languages.

With regard to previous ERP masked priming code switching effects, Chauncey et al. (2008) found different markers of the switch cost depending on the language direction: while L2→L1 mainly produced N400 differences, L1→L2 produced differences as early as in the N250 component (see also Midgley et al., 2009). Importantly, we have shown robust switch cost effects for the two language directions in the two components at stake (N250 and N400) for a group of simultaneous balanced bilinguals (see Figure 2). The studies reported by Chauncey et al. and Midgley et al., together with the present findings, show that even an unconscious language switch produces a cognitive cost represented by modulations in two distinct negative-going components. This pattern of negativities related to language switch cost effects observed in these studies has been repeatedly found in previous studies testing switch cost effects in bilinguals with different methodologies (see Christoffels et al., 2007; Jackson, Swainson, Cunnington, & Jackson, 2001; see also Proverbio, Leoni, Zani, 2004, and Van Der Meij et al., in press, to some extent).

The most popular interpretation of the processing cost associated to a language switch is that offered by the Inhibitory Control model (IC; e.g., Abutalebi & Green,



2007; Green, 1998), also adopted by the latest version of the Bilingual Interactive Activation model, the BIA+ (Dijkstra & Van Heuven, 2002). According to this account the activation of each of the bilingual's languages depends on the activation of the corresponding "task schema" (i.e., the control system linking the output of lexical activation to a behavioral response) and the inhibition of the schema associated with the other language. Switch cost effects would reflect the additional cost related to the activation of the language which had been previously inhibited. The original BIA model (e.g., Grainger & Dijkstra, 1992) proposed an alternative account of switch cost effects, based on the idea of the existence of "language nodes" which control the relative activation of the lexical representations in each language via top-down inhibition. This way, the BIA model predicts that, unlike task schemas, language nodes influence word recognition in a fast and automatic manner. Despite their subtle differences the theoretical interpretations of the switch cost offered by the IC and the BIA+ models and by the original BIA model are considered as complementary, and in fact do make similar predictions regarding the way proficiency of the non-dominant language would affect switch cost effects (see Chauncey et al. 2008; Dijkstra & Van Heuven, 2002). At low and intermediate levels of L2 proficiency, switch cost effects differ in magnitude across the two language switch directions (e.g., Chauncey et al.). But critically, in a recent study Costa, Santesteban and Ivanova (2006) reported a symmetric pattern of code-switch effects ( $L1 \rightarrow L2 = L2 \rightarrow L1$ ) for balanced bilinguals. The symmetric switch cost pattern observed by Costa et al. is in line with the symmetric pattern observed in the present study, and therefore helps to establish the idea that in the cases where there is not a clear language dominance (i.e., balanced bilinguals), the amount of inhibition applied to both languages seems to be equal, leading to symmetric switch cost effects (see also Costa & Santesteban, 2004). In this line, general task and modality-

independent switch cost effects can be understood as reflecting different recruitment degrees of control mechanisms regulating the relative activation of the different languages of a bilingual, which varies as a function of L2 proficiency and age of acquisition of the L2 (among other factors; see Rodríguez-Fornells, De Diego Balaguer, & Münte, 2006, for a comprehensive review).

Our results demonstrate that these switch cost effects are highly automatic and occur even at initial moments of visual word recognition (starting around 175 ms post-target onset). As pointed out in different studies, code switching effects in different tasks and with different stimulus presentation modalities have been shown to take place at early moments of word processing, suggesting an amodal fast-acting nature of those effects (see Moreno et al., 2008; Rodríguez-Fornells et al., 2006). Given that under masked priming conditions participants do not perceive consciously the primes, they are unaware of the language change taking place across primes and targets in the switch trials. Still, as found in the present study, the language the primes belong to greatly influence the pattern of the obtained effects, suggesting that this information is automatically computed. Crucially, the fact that this influence is reflected on the N250 and N400 ERP components, suggests that language switching effects observed in visual word recognition studies could be largely due to fast-acting automatic modulation in the activation of lexical and sub-lexical representations (see also Chauncey et al., 2008). Such an assumption is more in line with the original BIA model (e.g., Van Heuven, Dijkstra, & Grainger, 1998) rather than with the IC and the BIA+ models, since the former proposes that switch cost effects result from the automatic top-down activation of the lexical representations from the corresponding language node and that *“information concerning the language a word belongs to is automatically computed”*

(see Chauncey et al., 2008, p.172; see also Grainger & Beauvillain, 1987; Van Heuven et al., 1998, for supporting evidence). Contrarily, the IC and the BIA+ models posit that switch effects depend on extra-lexical executive control processes which regulate the activation of the task schemas. Accordingly, switch cost effects should not be reflected on early ERP components associated with low-level processing of the input and they should not be observed when the language switch is generated by a briefly presented masked prime, which is not sensitive to such extra-lexical processing. [Footnote 3]

In sum, the present study has provided electrophysiological evidence of neural response guiding fast and automatic translation processes in a group of balanced and simultaneous bilinguals. Our results showed symmetrical N400 effects in both translation directions, suggesting that at such high levels of proficiency conceptual access is direct for words in the two languages. Notably, this effect was comparable to that elicited by word repetitions (Identity condition). Finally, a general language switch cost effect was also consistently found, showing automatic activation of the corresponding language node of a word.

#### **4. Experimental Procedure**

**Participants.** 20 right-handed undergraduate students (15 females; mean age:  $19.9 \pm 2.3$  years) from the University of the Basque Country took part in this experiment in exchange for 15€. All were native speakers of Basque and Spanish (the two official languages in the Basque Country). Participants completed a questionnaire to assess their usage of Basque and Spanish. On a 1-to-7 Likert scale (1=only Basque, 7=only Spanish), participants rated the regularity in which they used each of the languages during childhood, youth and nowadays. Participants ensured that they had a balanced

used of both languages in a daily basis (childhood:  $2.6 \pm 1.6$ ; youth:  $3.0 \pm 1.6$ ; nowadays:  $3.3 \pm 1.4$ ). The questionnaire also included a section of self-evaluation of language proficiency in reading, writing, understanding and speaking (on a 1-to-4 scale; 1=lower proficiency, 4=higher proficiency). None of the scores was lower than 3.6 for any of the languages. [Footnote 4]

**Materials.** A set of 260 Spanish words were selected as targets for the Spanish block (e.g., *cuento*, [tale]). All these 260 words had a non-cognate translation in Basque (e.g., *ipuin*, [tale]). The 260 Spanish words were used as targets, and could be preceded by masked primes that were 1) identical to the target (*cuento*), 2) unrelated words in Spanish (*huelga*, [strike]), 3) the translations of the words in Basque (*ipuin*), 4) or unrelated words in Basque (*antza* [appearance]). The four sets of words were matched for frequency (all  $p > .20$ ) and length (all  $p > .53$ ; see Table 1). Following a counterbalanced design, four experimental lists were created, so that each Spanish target word was preceded by a prime of a different condition in each list. This led to a final number of 65 prime-target pairs per condition in each of the four experimental lists. In order to make the go/no-go semantic categorization possible, we included a set of 35 Spanish animal names in each list (*burro* [donkey]) (Note that none of the Basque or Spanish experimental words referred to an animal name). These words were primed by a new set of 35 unrelated non-animal Spanish prime words (*recreo* [break]). A prime visibility test was also included in order to check for conscious identification of the masked primes. To this end, the 35 animal names were presented as primes and followed by the 35 unrelated non-animal target words. For the Basque block, the 260 Basque translations from the Spanish block were used as targets (*ipuin*). These words could be preceded by masked primes that were 1) identical to the target (*ipuin*), 2)

unrelated words in Basque (*antza*), 3) the translations of the words in Spanish (*cuento*), 4) or unrelated words in Spanish (*huelga*). Following the same counterbalanced design, four lists were also created for the Basque block. The 35 animal names used for the go responses in the semantic categorization of the Spanish block were translated to Basque (e.g., *asto* [donkey]). A new set of 35 different non-animal Basque words were used as primes for these animal names in the semantic categorization task, and as targets in the prime visibility condition (*lapiko* [pot]).

-Table\_1-

**Procedure.** The experimental procedure was exactly the same as the one followed in the study by Duñabeitia et al. (2010). Each trial consisted in the presentation of a forward mask for 500 ms, followed by the displaying of the prime in lowercase for 50 ms, and immediately followed by the presentation of the target in uppercase which remained on the screen for 500 ms. The inter-trial interval varied randomly between 700 and 900 ms. After this interval, an asterisk was presented for 1000 ms in order to allow participants' blinks. Half of the participants completed the Spanish block first, and the other half completed the Basque block first.

**EEG recording and analyses.** Scalp voltages were collected from 58 Ag/AgCl electrodes which were mounted in an elastic cap (ElectroCap International, Eaton, USA, 10-10 system). The right mastoid was used as reference. Eye movements and blinks were monitored with two further electrodes providing bipolar recordings of the horizontal and vertical electro-oculogram (EOG). Inter-electrode impedances were kept below 5 K $\Omega$ . EEG was filtered with an analogue bandpass filter of 0.01-50 Hz and a digital 25 Hz low-pass filter was applied before analysis. The signals were sampled

continuously throughout the experiment with a sampling rate of 250 Hz, and digitally re-referenced to linked mastoids. Epochs of the EEG corresponding to 700 ms after target word presentation were averaged and analyzed. Baseline correction was performed using the average EEG activity in the 50 ms preceding the onset of the target stimuli (the duration of the prime) as a reference signal value. Those epochs free of ocular and muscular artifacts were averaged and analyzed (90.7% of the data; 92.0% of the Spanish block, and 89.3% of the Basque block). 15 out of the 58 electrodes were used for the analyses, creating the factors ELECTRODE (5 levels: pre-frontal, frontal, central, parietal and occipital) and LATERALITY (3 levels: right hemisphere, midline, left hemisphere). Together with these factors, three other factors were included, corresponding to the experimental materials: TARGET LANGUAGE (2 levels: Spanish, Basque), PRIME LANGUAGE (2 levels: same language, different language) and RELATEDNESS (2 levels: related, unrelated). The combination of the levels same language and related led to the Identity condition. The combination of the levels same language and unrelated led to the Identity Control condition. The combination of the levels different language and related led to the Translation condition. The combination of the levels different language and unrelated led to the Translation Control condition.

### Footnotes

Footnote 1. Hoshino et al. also reported a significant modulation of the N/P150 ERP component, with L2 targets producing more negative-going waves when preceded by unrelated L1 primes as compared to when preceded by their L1 translation pairs. The authors related this effect to an additional advantage in the processing of the L1 masked primes due to the change in script involved (i.e., primes were written with Kanji characters and targets with Roman letters).

Footnote 2. Unlike what has been reported in the existing ERP masked translation priming studies, Schoonbaert et al. (2010) obtained bi-directional N250 masked translation priming effects which followed an unexpected asymmetric pattern: the N250 effect was larger with L2 primes and L1 targets than the one obtained with L1 primes and L2 targets. The alternative explanations offered by the authors were based in the use of a longer SOA (120 ms) which under masked priming conditions has been found to modulate the N250 effects.

Footnote 3. With regard to the neurobiological substrates of code-switching effects, it should be noted that the clearest effects have been mainly found in the frontal lobe (a region traditionally related to executive control and attention processes; e.g., Price, Green & von Studnitz, 1999; Wang, Xue, Chen, & Dong, 2007; see also Hernandez, 2009 for review). However, it is somewhat unlikely that these regions would be responsible for the switch cost effects we obtained, since under masked priming conditions the influence of executive control may be limited. We found a centro-parietally distributed switch cost ERP effect (see Jackson, Mullin, Cunnington, & Jackson, 2004, for similarly distributed effects in a visual-code switching study). We should note that the limited spatial resolution of the ERPs prevents us from drawing any

further conclusions regarding the exact neuronal generators of the switch cost effects observed in the present study.

Footnote 4. All the participants were in possession of the Basque Proficiency Certificate (*EGA*), which officially certifies a perfect proficiency in Basque. Note also that all participants successfully passed a Spanish proficiency examination (which is mandatory for all Spanish students aiming to access the Spanish university system).



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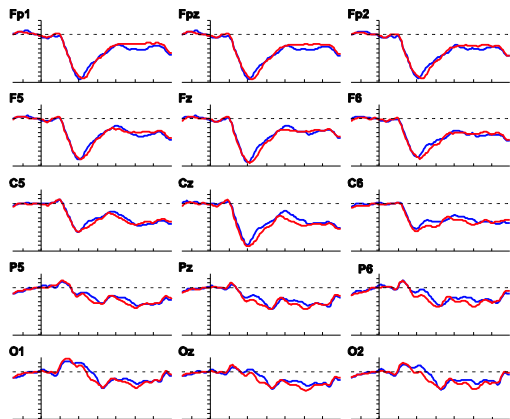
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## Figure captions

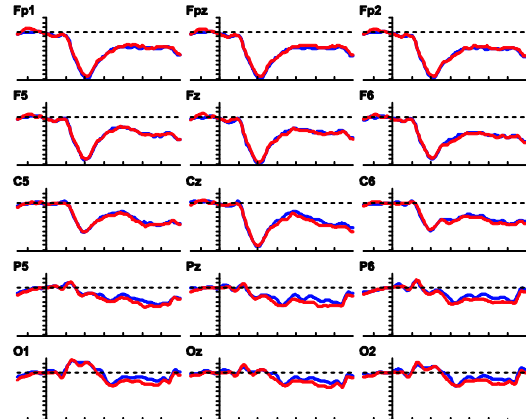
**Figure 1.** Upper panel: Grand average ERPs corresponding to the Spanish block in the 15 representative electrodes for the Related and Unrelated priming conditions separated for the Identity and the Translation conditions. Medium panel: Grand average ERPs corresponding to the Basque block in the 15 representative electrodes for the Related and Unrelated priming conditions separated for the Identity and the Translation conditions. Lower panel: Blow-ups of the Pz electrode for the different conditions. (Negative potentials are plotted upwards. Each hash mark in the x-axis represents 100 ms, and each hash mark in the y-axis represents  $1\mu\text{V}$ .)

**Figure 2.** a) Topographical distribution of the Identity and Translation effects for Basque and Spanish in terms of amplitude differences between the unrelated and related conditions, averaged between 175 and 300 ms post-stimuli (N250) and between 400 and 550 ms post-stimuli (N400). Larger negative amplitudes for the unrelated conditions are reflected in negative difference voltage values. b) Blow-up of the Pz electrode for the language switch cost effects in Spanish and Basque. Within-language condition is a composite of the averaged voltages of the within-language related and unrelated conditions. Between-language condition is a composite of the averaged voltages of the between-language related and unrelated conditions. (Each hash mark in the x-axis represents 100 ms, and each hash mark in the y-axis represents  $1\mu\text{V}$ .)

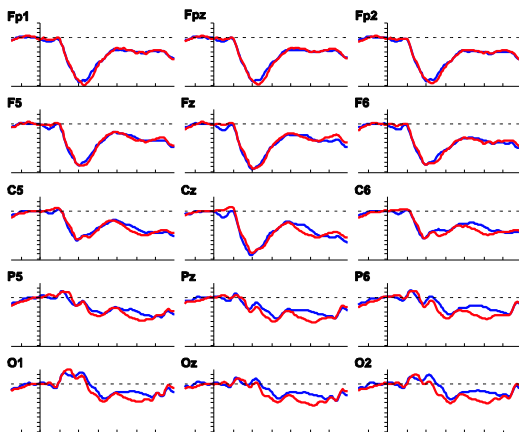
### SPANISH Identity



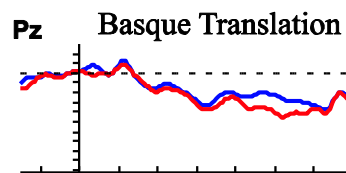
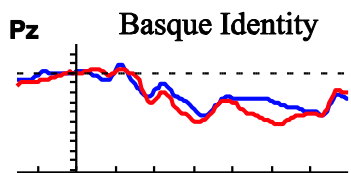
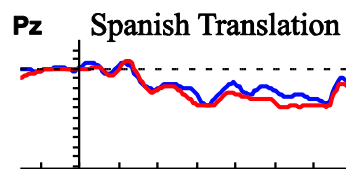
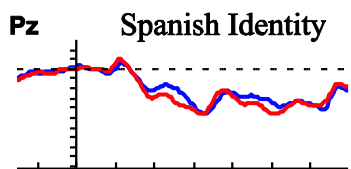
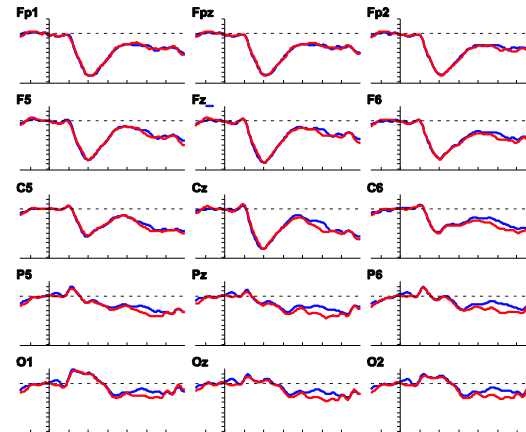
### SPANISH Translation





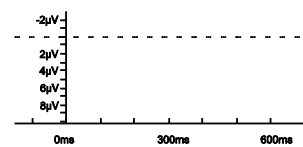
### BASQUE Identity



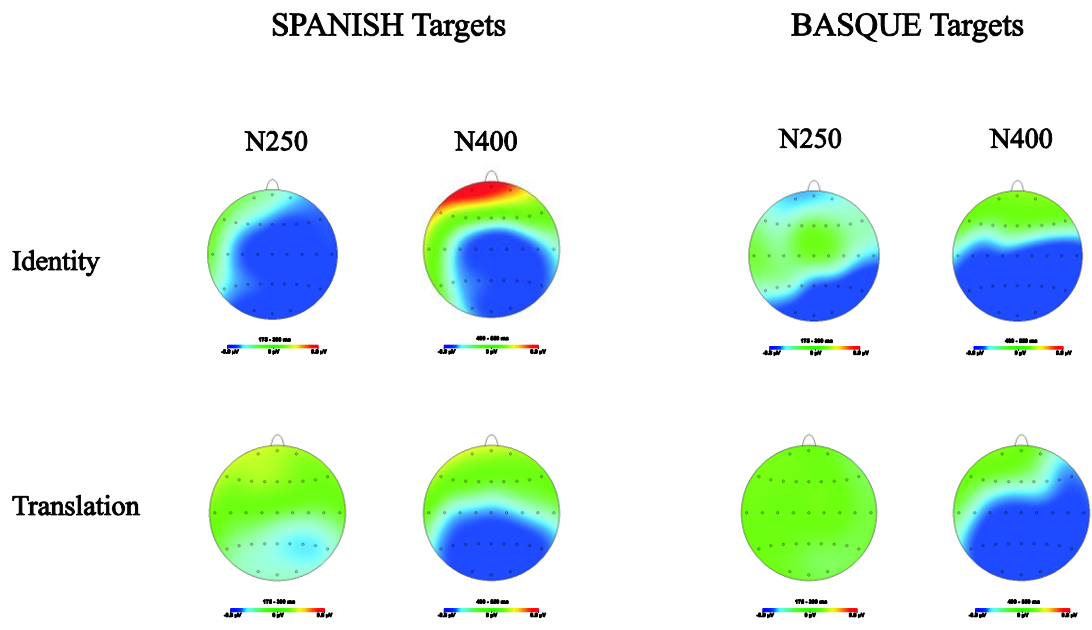
### BASQUE Translation



Unrelated  
  
 Related  




## a) Topographical Maps



## b) Switch Cost Effects

