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RESEARCH****Research Report****An ERP investigation of masked cross-script translation priming****Noriko Hoshino<sup>a,\*</sup>, Katherine J. Midgley<sup>b,c</sup>, Phillip J. Holcomb<sup>b</sup>, Jonathan Grainger<sup>c</sup>**<sup>a</sup>Bangor University, UK<sup>b</sup>Tufts University, US<sup>c</sup>CNRS and Aix-Marseille University, France

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## ABSTRACT

The time course of cross-script translation priming and repetition priming was examined in two different scripts using a combination of the masked priming paradigm with the recording of event-related potentials (ERPs). Japanese–English bilinguals performed a semantic categorization task in their second language (L2) English and in their first language (L1) Japanese. Targets were preceded by a visually presented related (translation equivalent/repeated) or unrelated prime. The results showed that the amplitudes of the N250 and N400 ERP components were significantly modulated for L2–L2 repetition priming, L1–L2 translation priming, and L1–L1 repetition priming, but not for L2–L1 translation priming. There was also evidence for priming effects in an earlier 100–200 ms time window for L1–L1 repetition priming and L1–L2 translation priming. We argue that a change in script across primes and targets provides optimal conditions for prime word processing, hence generating very fast-acting translation priming effects when primes are in L1.

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**1. Introduction**

There is now substantial evidence from research on language comprehension in bilinguals that when processing linguistic input from one language (the target language), access to representations of the other language (the non-target language) is not completely blocked (e.g., Dijkstra et al., 1999, 1998; Jared and Kroll, 2001; Lemhöfer and Dijkstra, 2004; van Heuven et al., 1998). Evidence for an influence of non-target language representations has been observed not only when reading in a second language (L2) but also when reading in a native language (L1) (e.g., Basnight-Brown and Altarriba, 2007; Duyck, 2005; Duyck and Warlop, 2009; Schoonbaert et al., 2009; van Hell and Dijkstra, 2002; van Wijnendaele and Brysbaert,

2002). A critical finding is that this cross-language permeability has been observed in situations where participants are only consciously processing target language stimuli. For example, van Heuven and his colleagues (1998) found an effect of number of orthographic neighbors in the non-target language, such that words in the target language were harder to recognize when they were orthographically similar to words in the non-target language (see also Midgley et al., 2008).

These cross-language interactions have been taken as evidence in favor of an initial non-selective access process in bilingual language comprehension, with incoming linguistic information making contact with representations in both languages. The bilingual interactive-activation model (BIA-model: Grainger and Dijkstra, 1992) was one of the first

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theoretical accounts of how such non-selective access could occur, and how the resulting interference controlled. Further developed and extended by [van Heuven et al. \(1998\)](#) and [Dijkstra and van Heuven \(2002\)](#), the BIA-model is today a major theoretical tool for understanding the mechanisms that enable and control cross-language interactions in bilinguals. In the model implemented by [van Heuven et al. \(1998\)](#), following this initial non-selective access, language selectivity operates top-down by the inhibition of representations in the non-target language. In this way, cross-language interference is minimized while never completely blocking access to non-target language representations. Thus, in normal circumstances, the influence of non-target language representations is kept to a minimum (e.g., [Lemhöfer et al., 2008](#)), and it is only by careful experimental manipulations that it can be revealed.

One such manipulation involves the masked priming paradigm and subliminal prime exposures. Prime words in one language have been found to influence the processing of target words in the other language, in conditions where participants are only processing visible words in the target language. Such cross-language masked priming has been demonstrated for orthographic relations (e.g., [Bijeljac-Babic et al., 1997](#)), for phonological relations (e.g., [van Wijnendaele and Brysbaert, 2002](#)), and for translation equivalents (e.g., [Basnight-Brown and Altarriba, 2007](#); [de Groot and Nas, 1991](#); [Duyck and Warlop, 2009](#); [Grainger and Frenck-Mestre, 1998](#); [Schoonbaert et al., 2009](#) — see [Duñabeitia et al., 2010](#), for a recent review). Masked translation priming has also been found in languages that are written with different alphabets (e.g., [Gollan et al., 1997](#); [Kim and Davis, 2003](#); [Voga and Grainger, 2007](#)) and different scripts (e.g., [Finkbeiner et al., 2004](#); [Jiang, 1999](#); [Jiang and Forster, 2001](#)).

Cross-script translation priming is a particularly interesting case to study because it provides the possibility of optimal processing of prime stimuli with minimal interference from the target. Indeed, within the general framework of the interactive-activation model ([McClelland and Rumelhart, 1981](#)) applied to understanding results obtained with masked priming ([Grainger and Jacobs, 1999](#)), priming effects depend on how well information extracted from the prime stimulus can be integrated with information extracted from the target. Visual, orthographic, phonological, and semantic representations are activated by the prime stimulus (given sufficient visual input) and integrated during target processing as a function of the overlap with representations activated by the target. Activation continues to develop in representations that are supported by the prime stimulus to the extent that they are not incompatible with the target. In the case of non-cognate translation primes in languages that share the same alphabet, there is maximum incompatibility at the level of prelexical orthographic representations (letters and letter combinations), and priming effects will depend on how rapidly semantic information can be activated by the prime stimulus before this incompatibility blocks prime processing. When primes and targets are in different scripts, on the other hand, although pre-orthographic visual interference may persist, the effects of prelexical orthographic interference will be greatly diminished. Furthermore, the different scripts provide a clear bottom-up signal as to which language the prime stimulus belongs to, once again reducing cross-lan-

guage interference at the level of whole-word form representations as postulated in the BIA model ([van Heuven et al., 1998](#)). Therefore, cross-script translation priming provides an ideal paradigm for evaluating the earliest semantic influences during visual word recognition.

The present study is the first investigation of cross-script translation priming to combine masked priming with the recording of ERPs. Much recent research has shown the utility of this combination of techniques for revealing the time-course of visual word recognition in monolinguals (e.g., [Holcomb and Grainger, 2006](#); see [Grainger and Holcomb, 2009](#), for review) and bilinguals ([Midgley et al., 2009](#)). Directly relevant to the present study is [Midgley et al.'s \(2009\)](#) examination of non-cognate translation priming in French–English bilinguals. Midgley et al. provided evidence for an early influence of translation primes in L1 on the recognition of L2 targets. The influence of L1 primes on L2 targets was evident in the N250 ERP component, thought to reflect the mapping of prelexical form representations onto whole-word form representations ([Holcomb and Grainger, 2006](#); [Grainger and Holcomb, 2009](#)). However, it is unlikely that the modulation of the N250 component reflects direct connectivity across word form representations because these translation priming effects were not evident when primes were in L2 and targets in L1. If anything, there should be stronger lexical connections from L2 words to their L1 translation equivalents ([Kroll and Stewart, 1994](#)). Furthermore, the N250 component in [Midgley et al. \(2009\)](#) was modulated earlier for L2–L2 repetition priming where there was form overlap compared to L1–L2 translation priming where there was no form overlap. This pattern of the results suggests that masked translation primes activate semantic representations and modulate processing of target words at the level of form representations via feedback connections from semantics to form representations (see also [Morris et al., 2007](#)). The fact that translation priming was mostly evident from L1 to L2 in the Midgley et al. study, was interpreted as being due to the more efficient processing of L1 words, and hence the faster access to semantic representations with L1 primes compared with L2 primes.

The present study provides a further examination of early influences of masked non-cognate translation primes, this time in the context of languages that are written with different scripts (Japanese and English). We examine within-language repetition priming in L1 and L2 and across-language translation priming from L1 to L2 and vice versa. If, as argued by [Midgley et al. \(2009\)](#), masked non-cognate translation primes modulate the processing of target words via feedback connections from semantics to form representations, the N250 as well as the N400 should be modulated by translation primes as well as repetition primes, and particularly for L2 targets. Furthermore, we predict that translation priming effects from L1 to L2 should be even stronger and arise earlier in the cross-script conditions of the present study. As argued above, by providing a clear signal as to which language a given stimulus belongs to and by limiting the effects of prelexical orthographic interference, the change of script from prime to target should provide optimal conditions for prime word processing in masked priming. However, although a change in script across prime and target might be beneficial for processing

primes in L1, this might not be the case for L2 primes. Indeed, the opposite argument could be made, given the possibly increased difficulty in learning to read L2 words written with a different script than the L1.

## 2. Results

In this section, we report the results of L2 English targets, followed by the results of L1 Japanese targets.

### 2.1. L2 English targets

#### 2.1.1. Behavioral data

The mean hit rate for body part probes in the target position on the semantic categorization was 75.4 % ( $SD=15.9\%$ ). Although there were two participants who detected one body part probe among 40 probes in the prime position, the morphology of their averaged ERPs was similar to other participants. Therefore, these two participants were kept in the following analyses.

### 2.2. Visual inspection of ERPs

On average, 8.6% of trials per participant were rejected due to artifacts such as blinks, eye movements, blocking, and muscle movements. An average of 40 trials per condition for each participant was included in the analyses reported below.

The compound ERPs (prime and target) to English target words from 29 electrode sites are plotted by language of prime in Fig. 1A (L2 English prime) and Fig. 2A (L1 Japanese prime). To facilitate viewing of priming effects Figs. 1B and 2B plot blowups of the ERPs from the CP1 electrode site. It is important to note that ERPs time-locked to the target in a paradigm with a short SOA such as 80 ms are an amalgamation of the neural activity generated by processing the prime and the backward mask as well as the target. As can be seen in these figures, the morphology of ERPs is different as a function of language of the prime, which was expected because ERPs are sensitive to physical features of stimuli. Although the backward mask and the target were identical for the L2 English prime conditions and for the L1 Japanese prime conditions, the primes were physically different — Roman alphabets vs. kanji characters. Specifically, when the L2 English target was preceded by the L2 English prime, a first visible component in the target epoch (i.e., after the vertical calibration bar) was a negativity peaking around 50 ms after the onset of the target, followed by another negativity which peaked around 130 ms and was greater at occipital sites (N/P150). Two negative components followed these early components — the first one peaking between 280 and 330 ms (N250) and the second one peaking between 400 and 600 ms (N400). On the other hand, when the L2 English target was preceded by the L1 Japanese prime, a first negative component was followed by two negativities for the 300 ms after the onset of the target. Following the first 300 ms epoch, another negative component peaked between 400 and 600 ms (N400). In the sections below, we consider the three ERP components, N/P150, N250, and N400, with two time windows separately for L2 English primes and for L1 Japanese primes.

### 2.3. Analyses of ERP data for L2 English primes (L2–L2 repetition priming)

N/P150 (100 to 200 ms target epoch). The main effect of relation was not significant [all  $ps>.1$ ]. None of the interactions between relation and hemisphere and/or electrode sites approached significance either.

N250 (200 to 350 ms target epoch). The main effect of relation was significant, such that L2 English targets preceded by unrelated L2 English primes were associated with a greater negativity than those preceded by related L2 English primes [midline:  $F(1, 17)=7.30, p<.05$ ; Column 1:  $F(1, 17)=5.16, p<.05$ ; Column 2:  $F(1, 17)=4.37, p=.05$ ; Column 3:  $F(1, 17)=7.22, p<.05$  — see Figs. 1A and B]. As can be seen in Fig. 1A, this difference in the epoch between 200 and 350 ms tended to be larger across the right hemisphere and in anterior and central posterior areas of the left hemisphere, which is reflected in marginally significant interactions [Relation $\times$ Hemisphere $\times$ Electrode Site, Column 3:  $F(4, 68)=3.02, p=.05$ ].

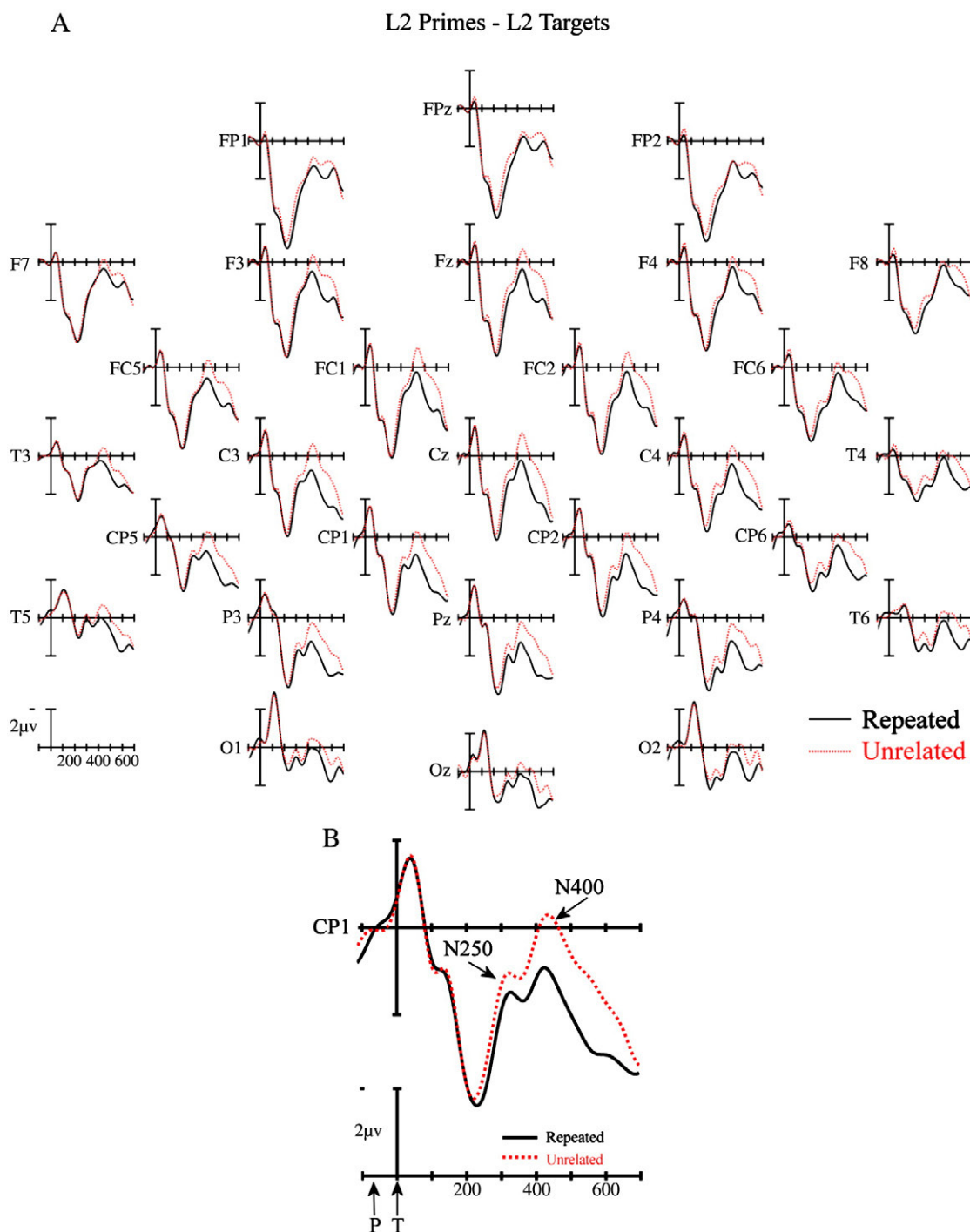
N400 (350 to 550 ms target epoch). The 350 to 550 ms time window includes a negative-going component peaking slightly after 400 ms. There was a significant main effect of relation at all columns [midline:  $F(1, 17)=18.11, p<.01$ ; Column 1:  $F(1, 17)=18.25, p<.01$ ; Column 2:  $F(1, 17)=12.76, p<.01$ ; Column 3:  $F(1, 17)=8.37, p<.05$  — see Figs. 1A and B]. As can be seen in Figs. 1A and C, the difference between unrelated targets and related targets was greater in the central and posterior sites than in the anterior site and in the left hemisphere than in the right hemisphere [Relation $\times$ Electrode Site interaction, midline:  $F(4, 68)=4.41, p<.05$ ; Relation $\times$ Hemisphere $\times$ Electrode Site interaction, Column 1:  $F(2, 34)=3.33, p=.05$ ].

### 2.4. Analyses of event-related potential data for L1 Japanese Primes (L1–L2 translation priming)

N/P150 (100 to 200 ms target epoch). The main effect of relation did not emerge [all  $ps>.1$ ]. However, the significant two-way Relation $\times$ Electrode Site interaction at Columns 1 and 3 indicates that L2 English targets following unrelated L1 Japanese primes were more negative going than L2 English targets following related L1 Japanese at the anterior sites [Relation $\times$ Electrode Site interaction, Columns 1 and 3:  $F(2, 34)=3.94, p=.05$ ;  $F(4, 68)=3.22, p<.05$ , respectively — see Fig. 2A].

N250 (200 to 350 ms target epoch). Figs. 2A and B show that in the epoch of 200–350 ms, L2 English targets following unrelated L1 primes were associated with a greater negativity than those following related L1 primes. This observation is confirmed by the significant main effect of relation [midline:  $F(1, 17)=6.21, p<.05$ ; Column 1:  $F(1, 17)=5.73, p<.05$ ].

N400 (350 to 550 ms target epoch). As can be seen in Fig. 2A, this epoch contains a negative going wave peaking around 450 ms. L2 English targets following L1 unrelated primes tended to elicit more negative going potentials than those following L1 related primes throughout the epoch (see Fig. 2B). The main effect of relation was significant at three analysis columns [midline:  $F(1, 17)=7.03, p<.05$ ; Column 1:  $F(1, 17)=9.54, p<.01$ ; Column 2:  $F(1, 17)=6.49, p<.05$ ].



**Fig. 1 – (A)** ERPs from all 29 scalp channels time-locked to the onset of L2 English targets in the repeated (solid) and unrelated (dotted) conditions. **(B)** Blowup of the CP1 site from 1A. Note that the relative timing of the prime (P) and target (T) are noted on the time scale x-axis.

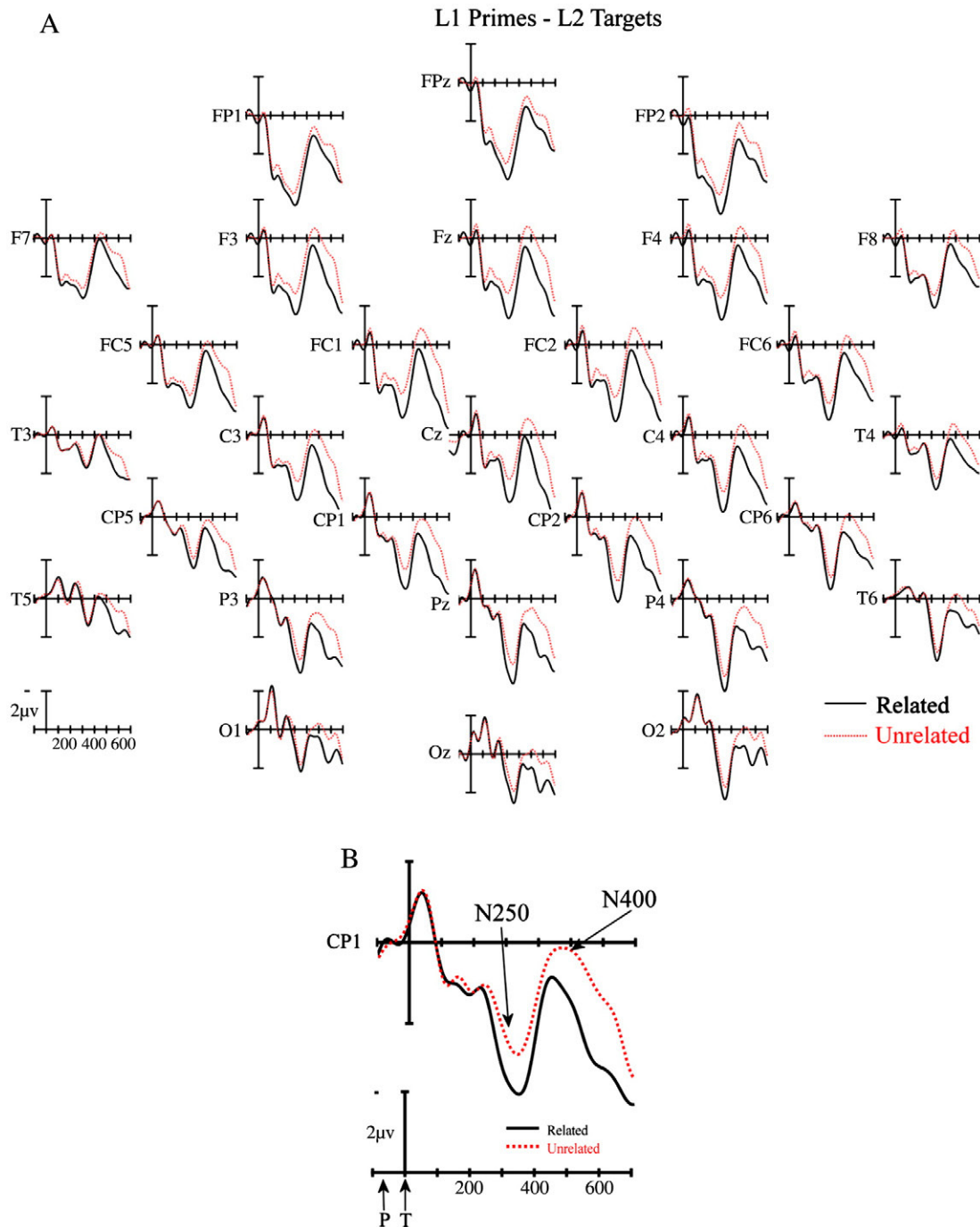
To summarize the results of L2 English targets, a significant priming effect was obtained both for the L1 and L2 primes. Specifically, amplitudes of the N250 and N400 components were smaller for the related primes than for the unrelated primes regardless of the language of the primes. Evidence for an even earlier effect of L1–L2 translation priming was also observed at anterior sites in the 100–200 ms time window.

## 2.5. L1 Japanese targets

### 2.5.1. Behavioral data

The mean hit rate for body part probes in the target position was 89.7% (SD=6.2%). Although there were two participants who detected one body part probe among 40 probes in the prime position, the morphology of their averaged ERPs was





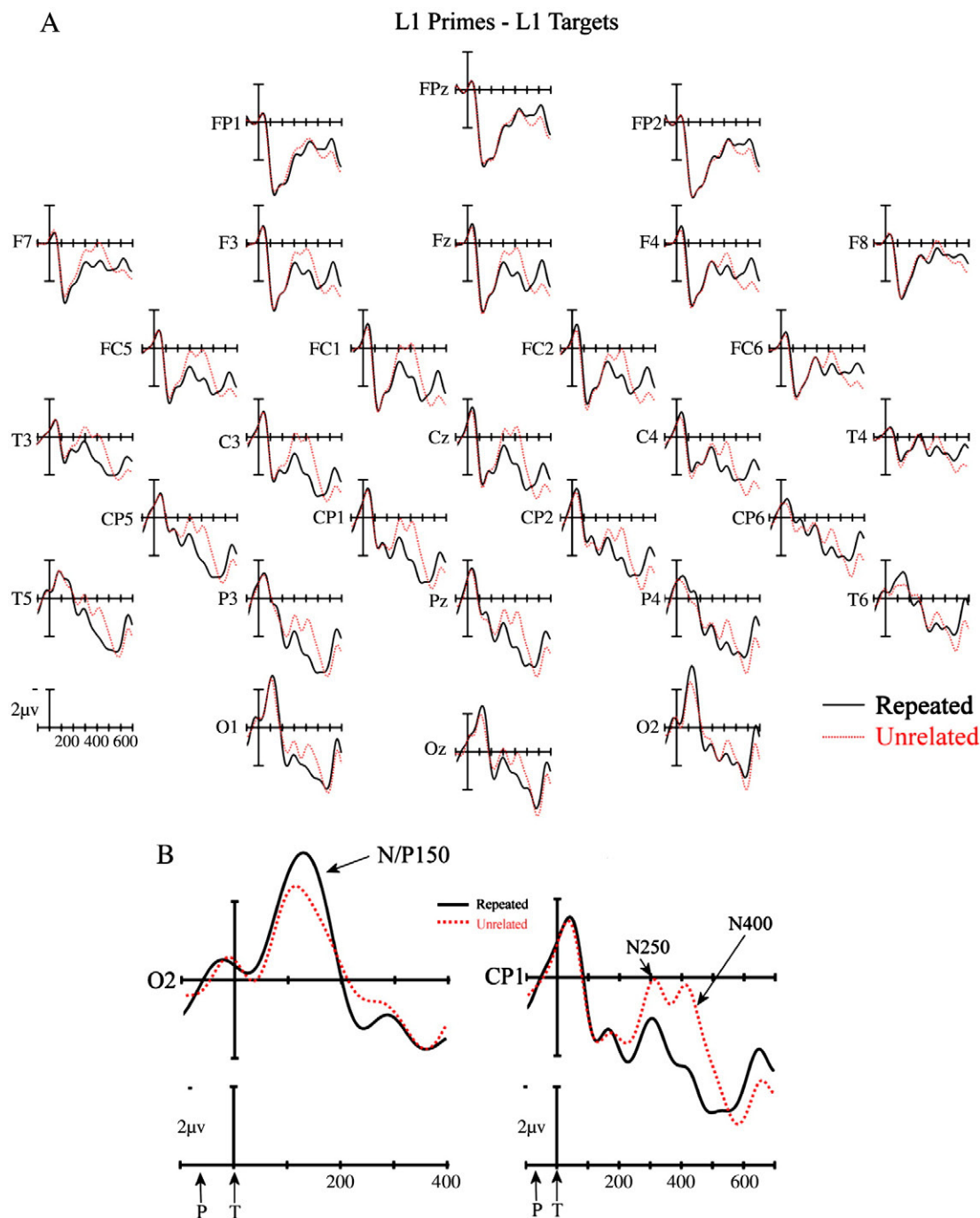
**Fig. 2 – (A)** ERPs from all scalp sites time-locked to the onset of the L2 English targets when primes were L1 Japanese words. The solid line is the related condition (L1 and L2 were translation equivalent words) and the dotted line is unrelated L1 and L2 words. **(B)** a blowup of the CP1 site from 2A.

similar to other participants. Therefore, these two participants were kept in the following analyses.

## 2.6. Visual inspection of ERPs

On average, 11.8% of trials per participant were rejected due to artifacts such as blinks, eye movements, blocking, and muscle movements. An average of 48 trials per condition for each participant was included in the analyses reported below.

The compound ERPs (prime and target) to Japanese target words from 29 electrode sites are plotted by language of prime in Fig. 3A (L1 Japanese prime) and Fig. 4A (L2 English prime). To facilitate viewing of priming effects Figs. 3B and 4B plot blowups of the ERPs from the CP1 electrode site. When the L1 Japanese target was preceded by the L1 Japanese prime, a first visible component in the target epoch (i.e., after the vertical calibration bar) was a negativity peaking around 50 ms after the onset of the target, followed by another negativity which



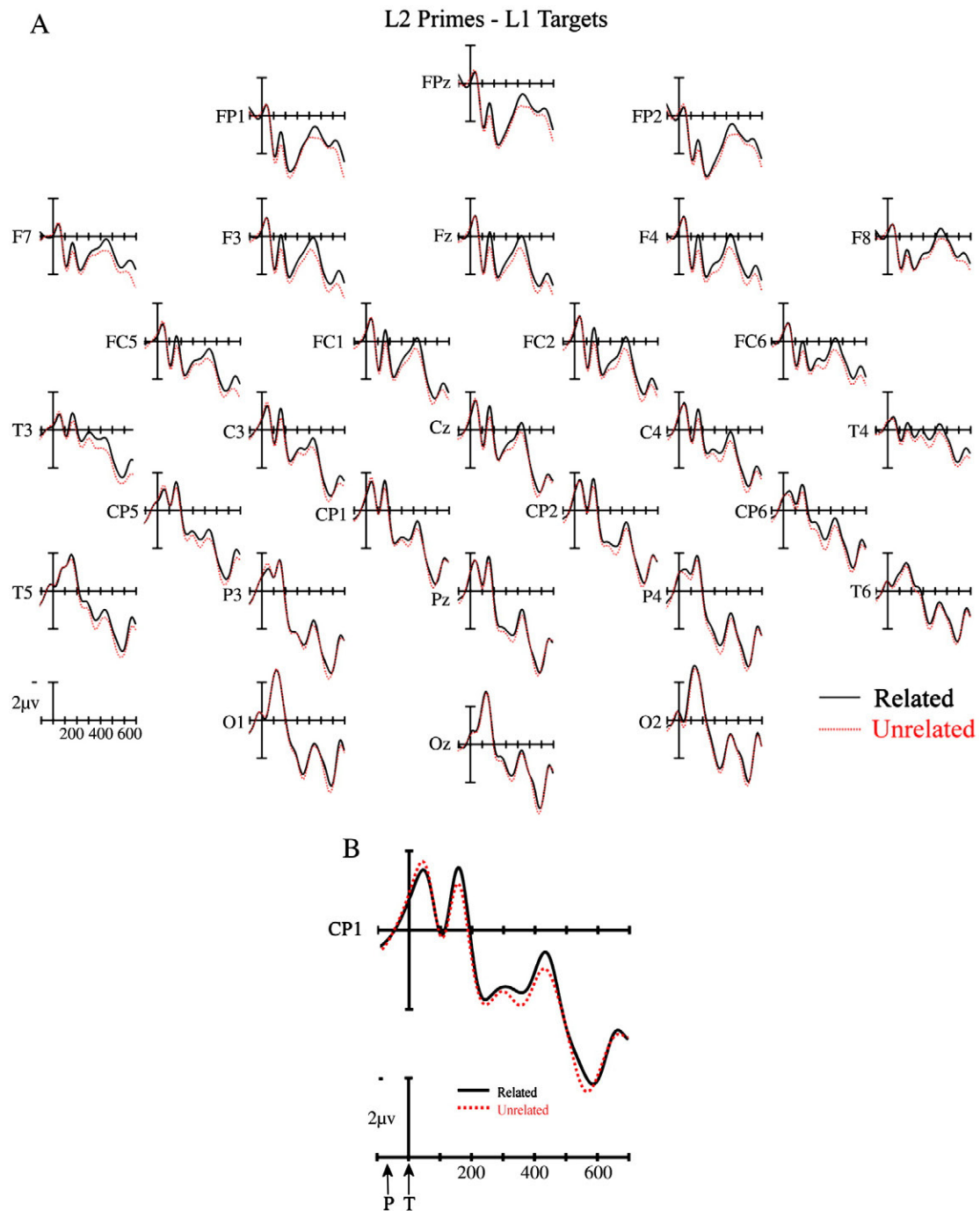
**Fig. 3 – (A)** ERPs from all 29 scalp sites time-locked to the onset of L1 Japanese targets in the repeated (solid) and unrelated (dotted) conditions when primes were L1 Japanese words. **(B)** a blowup of the O2 and CP1 sites from 3A.

peaked around 130 ms and was greater at occipital sites (N/P150). Two negative components were followed by these early components — the first one peaking between 290 and 340 ms (N250) and the second one peaking between 400 and 500 ms (N400). On the other hand, when the L1 Japanese target was preceded by the L2 English prime, a first negative component was followed by another negativity peaking around 260 ms. Following the first 300 ms epoch, there was a negative-going wave peaking around 420 ms. In the sections below, we consider the three ERP components, N/P150, N250, and N400,

with two time windows separately for L1 Japanese primes and for L2 English primes.

## 2.7. Analyses of ERP data for L1 Japanese primes (L1–L1 repetition priming)

*N/P150 (100 to 200 ms target epoch).* Although there was no main effect of relation [all  $F_s < 1$ ], the three-way (Relation  $\times$  Hemisphere  $\times$  Electrode Site) and two-way (Relation  $\times$  Hemisphere) interactions at Column 1 show that L1 Japanese targets



**Fig. 4 – (A)** ERPs from all scalp sites time-locked to the onset of the L1 Japanese targets when primes were L2 English words. The solid line is the related condition (L1 and L2 were translation equivalent words) and the dotted line is unrelated L1 and L2 words. **(B)** A blowup of the CP1 site from 4A.

following unrelated L1 Japanese primes were more positive going than L1 Japanese targets following related L1 Japanese in the left hemisphere than in the right hemisphere [Relation  $\times$  Hemisphere  $\times$  Electrode Site interaction, Column 1:  $F(2, 34) = 5.09$ ,  $p < .05$ ; Relation  $\times$  Hemisphere interaction, Columns 1:  $F(1, 17) = 8.44$ ,  $p < .05$ , see Fig. 3A].

N250 (200 to 350 ms target epoch). The main effect of relation did not emerge in the epoch from 200 to 300 ms when L1 Japanese targets were preceded by L1 Japanese primes [all

$ps > .10$ ]. However, the three-way interaction of Relation  $\times$  Hemisphere  $\times$  Electrode Site for the Column 1 and the two-way interaction of Relation  $\times$  Hemisphere at the Columns 1, 2, and 3 indicate that L1 Japanese targets following unrelated L1 Japanese primes were more negative going than L1 Japanese targets following related L1 Japanese primes in the left hemisphere than in the right hemisphere [Relation  $\times$  Hemisphere  $\times$  Electrode Site interaction, Column 1:  $F(2, 34) = 7.47$ ,  $p < .01$ ; Relation  $\times$  Hemisphere interaction, Columns 1, 2, and 3:

$F(1, 17)=25.03$ ,  $p<.001$ ,  $F(1, 17)=8.86$ ,  $p<.01$ ,  $F(1, 17)=5.63$ ,  $p<.05$ , respectively — see Fig. 3A].

N400 (350 to 550 ms target epoch). As can be seen in Figs. 3A and B, L1 Japanese targets preceded by unrelated L1 Japanese primes produced more negative going potentials than those preceded by related L1 Japanese primes, which was qualified by the main effect of relation [midline:  $F(1, 17)=7.53$ ,  $p<.05$ ; Column 1:  $F(1, 17)=10.91$ ,  $p<.01$ ; Column 2:  $F(1, 17)=7.90$ ,  $p<.05$ ]. More critically, the three-way interaction of Relation  $\times$  Hemisphere  $\times$  Electrode Sites and the interaction of Relation  $\times$  Electrode Sites show that the difference between unrelated and related primes was enhanced in the left anterior sites [Relation  $\times$  Hemisphere  $\times$  Electrode Site, Columns 1, 2, and 3:  $F(2, 34)=4.85$ ,  $p<.05$ ,  $F(3, 51)=3.87$ ,  $p<.05$ ,  $F(4, 68)=4.83$ ,  $p<.05$ , respectively; Relation  $\times$  Electrode Sites, midline:  $F(4, 68)=6.79$ ,  $p<.01$ ].

## 2.8. Analyses of ERP data for L2 English primes (L2–L1 translation priming)

N/P150 (100 to 200 ms target epoch). The main effect of relation was not significant (midline:  $p>.09$ ; all other  $ps>.10$ ).

N250 (200 to 350 ms target epoch). There was no main effect of relation for any analysis column (all  $ps>.10$ ). There was no significant interaction between relation and hemisphere and/or electrode sites either.

N400 (350 to 550 ms target epoch). Figs. 4A and B show that contrary to other comparisons, the L1 Japanese targets preceded by related L2 English primes appear to be more negative going than those preceded by unrelated L2 English primes. However, the main effect of relation was not significant (all  $ps>.10$ ). None of the interactions between relation and hemisphere and/or electrode sites approached significance either.

To summarize the results of L1 Japanese targets, a significant within-language repetition priming effect was reflected in the N250 and N400 components such that the

amplitudes of the N250 and N400 were less negative in the repetition condition than the unrelated condition. Furthermore, there was a significant L1–L1 repetition priming effect in the earlier 100–200 ms time window. Contrary to the results of L2 English targets, however, no translation priming was observed from L2 primes to L1 targets in any of the time windows.

## 3. Discussion

In the present study, we compared repetition and translation priming in Japanese–English bilinguals using the masked priming paradigm combined with ERP recordings. The results showed that the amplitudes of two widely distributed ERP components, the N250 and N400, were modulated by within-language repetition priming in L1 and L2, as well as by L1–L2 translation priming. However, no such modulation was observed for L2–L1 translation priming. There was also evidence for both L1–L1 repetition priming and L1–L2 translation priming in an earlier 100–200 ms time-window. A time-course analysis of the different priming effects tested in the present study, and voltage maps (calculated by subtracting related target ERPs from their matched unrelated target ERPs) at 150 ms, 250 ms, and 500 ms after the onset of the target are given in Table 1 and Fig. 5 respectively. The results of the time-course analysis confirm those reported in the main analysis above. L1–L1 repetition priming and L1–L2 translation priming showed the earliest effects, with L2–L2 repetition priming effects emerging later, between 250 and 300 ms post-target onset. Again, there was no evidence for translation priming with L2 primes and L1 targets.

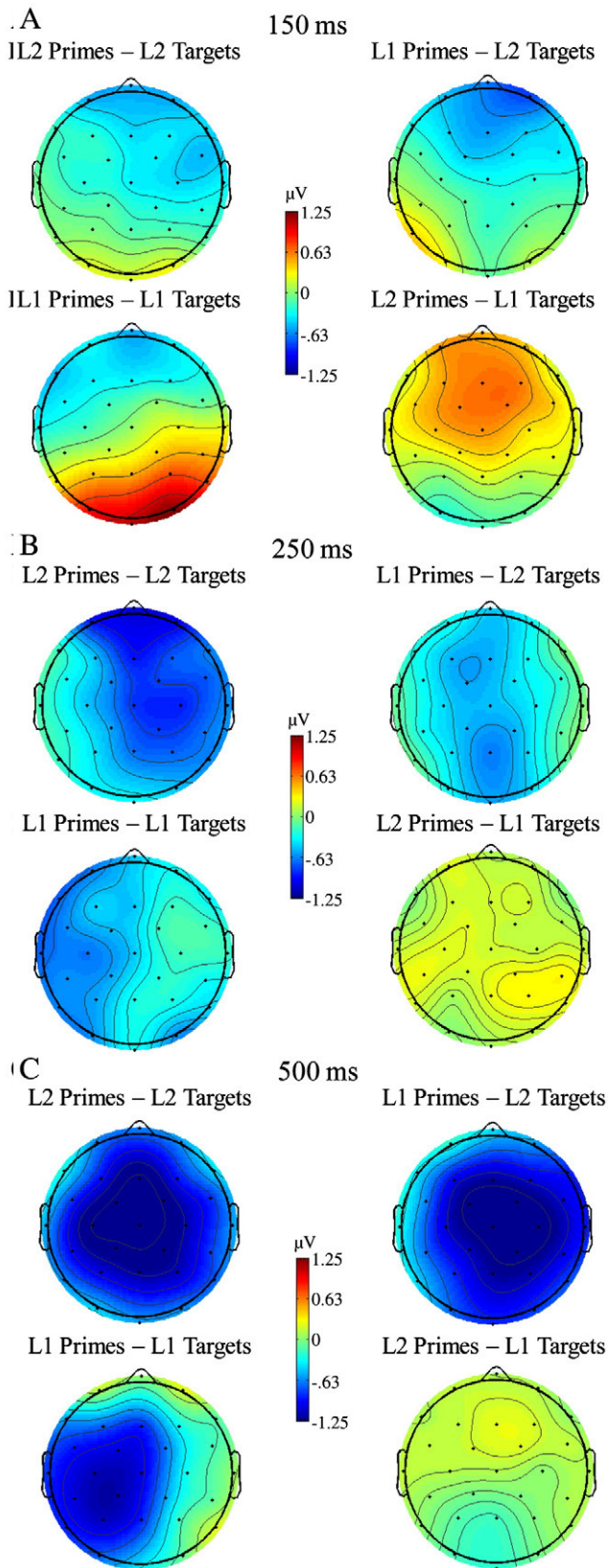
In the following discussion, we apply the general framework proposed by Holcomb and Grainger (2006, 2007) see Grainger and Holcomb, 2009, for review) for interpreting ERP effects obtained with the masked priming paradigm. In these studies, the earliest effect of within-language repetition

**Table 1 – Time-course analyses of repetition and translation priming.**

	100–150	150–200	200–250	250–300	300–350	350–400	400–450	450–500	500–550	550–600
L2 prime–L2 target										
Relation				*	*	*	**	**	**	**
Relation $\times$ Hemisphere										
Relation $\times$ Electrode										
L1 prime–L2 target										
Relation				**	**	**		*	**	**
Relation $\times$ Hemisphere										
Relation $\times$ Electrode	*									
L1 prime–L1 target										
Relation						**	**	**		
Relation $\times$ Hemisphere	*	*	*	**	**	**	**	*	* a	* a
Relation $\times$ Electrode										
L2 prime–L1 target										
Relation										
Relation $\times$ Hemisphere										
Relation $\times$ Electrode										

\*  $p<.05$ .  
 \*\*  $p<.01$ .  
 a A reversed effect.





**Fig. 5 – Voltage maps for L2 primes–L2 targets, L1 primes–L2 targets, L1 primes–L1 targets, and L2 primes–L1 targets at (A) 150 ms, (B) 250 ms, and (C) 500 ms post-target onset, resulting from the subtraction of repeated/related from unrelated ERPs.**

priming is seen in the N/P150 ERP component, which is thought to reflect the mapping of visual features onto prelexical orthographic representations. The early L1–L1 repetition priming effect found in the present study therefore replicates and extends this finding to a logographic language. It should be noted that the different spatial distributions of the L1–L2 translation priming effect, seen in the same time-window, suggests quite logically that different mechanisms are driving this priming effect, since there was no visual overlap in the translation priming condition. Following the N/P150, the two major components modulated by masked repetition priming, the N250 and N400 components, are thought to primarily reflect form-level processing and semantic-level processing respectively. More precisely, the N250 component is thought to reflect the bulk of processing associated with mapping prelexical form representations onto whole-word form representations. The N400, as seen in single word paradigms, is thought to reflect the bulk of processing associated with mapping whole-word form representations onto semantics. We expect the effects reflected in each of these components to be strongest when feedforward and feedback processes resonate as the mapping process settles into a stable state (Grainger and Holcomb, 2009).

Within-language repetition priming effects in L1 and L2 were clearly visible in both the N250 and N400 components, because in this case prime stimuli activate form representations (and possibly, but not necessarily, meaning representations) that are compatible with the target stimulus. This leads to facilitation in target processing at the level of both form and semantic representations, and a modification in the ERP waveforms that is thought to reflect this differential ease of target processing. Non-cognate translation primes do not share form representations with their corresponding targets. Therefore, one might not expect to see a modification of the N250 component with these primes. However, there are two ways that translation primes could generate effects in the N250 component within our theoretical framework. It is possible that L1 primes can rapidly activate L2 whole-word form representations via direct associations established between the whole-word representations of translation equivalents, as postulated in the Revised Hierarchical Model (RHM — Kroll and Stewart, 1994). Midgley et al. (2009) argued that masked non-cognate translation priming effects on the N250 component are likely not due to direct associations between the word form representations of translation equivalents. In models that postulate such associations, such as the RHM, it is typically assumed that they are stronger in the direction of L2 to L1 than vice versa. One would therefore expect stronger priming with L2 primes and L1 targets, which was neither the case in the Midgley et al. study, nor in the present study. Following Midgley et al., we therefore argue that the L1–L2 translation priming effects in the N250 component seen in the present study more likely reflect feedback from semantic representations activated by the prime stimulus influencing the activation of form-level representations during target word processing. This argument is also in line with the findings of a recent ERP study by Guo et al. (submitted for publication). These authors found evidence that in relatively proficient bilinguals, upon presentation of an L2 word, the form-level representation of the L1 translation

equivalent is only activated after accessing meaning from the L2 word.

Alternatively, one could argue that clearly visible L2 target words automatically activate the lexical form representation of their L1 translation (see [Thierry and Wu, 2007](#)), hence generating a delayed L1–L1 repetition priming effect when primes are in L1. However, there was no evidence for such a delay in the L1–L2 priming effects. Indeed, one key result of the present study is the relatively early onset of L1–L2 cross-script translation priming effects on ERPs. Masked cross-script translation priming is possibly the ideal testing ground for early semantic influences on visual word recognition. The change in script across primes and targets provides optimal conditions for prime word processing by 1) removing prelexical orthographic interference from the target word, and 2) providing clear bottom-up cues as to the language the prime word belongs to. When the targets were L2 (English) words, the present study revealed quite large and widespread effects of translation primes in L1 (Japanese) on target processing in L2 (English). These cross-script translation priming effects started to emerge at around 100 ms post-target onset mostly in anterior sites, and were already robust in the 100–200 ms of the main analysis, and the 100–150 ms window of the time-course analysis. This is about 100 ms earlier than the corresponding L1–L2 priming effect in the [Midgley et al. \(2009\)](#) study that tested participants (French–English bilinguals) with very similar levels of self-rated proficiency in their L2. The timing of the L1–L2 translation priming effects seen in the present study therefore suggest that a change in script across primes and targets does indeed facilitate prime word processing in the highly limiting conditions of masked priming. It is the more efficient processing of prime stimuli in cross-script priming that is thought to be the source of the earlier emergence of translation priming effects found in the present study compared with the [Midgley et al. \(2009\)](#) study.<sup>1</sup>

As noted above, our prior research suggests that the bulk of the mapping of prelexical form representations onto whole-word form representations is reflected in the EEG signal in a time-window roughly spanning 200–300 ms (e.g., [Grainger and Holcomb, 2009](#); [Holcomb and Grainger, 2006, 2007](#)). The early onset of translation priming effects would therefore appear to contradict this interpretation of the influence of masked primes on ERP waveforms. However, in a cascaded processing system, semantic representations can have already been activated within this time window by the fastest feedforward processes, with the bulk of semantic processing lagging behind. Indeed our results suggest that, given the 80 ms SOA used in the present study, semantic representations were

beginning to have a significant influence on target word processing at about 200 ms post-prime onset. Moreover, it might be that speed of access to semantics was further facilitated in the L1–L2 condition of the present study by the fact that primes were kanji characters. Indeed, research on Japanese readers suggests that semantic access occurs earlier in kanji compared with syllabic kana script (e.g., [Ischebeck, 2004](#); [Yamada, 1998](#)). However, it should be noted that [Dell'Acqua et al. \(2007\)](#) provided a similar estimate of the time-course of semantic activation from Italian words, albeit in a different paradigm. Future research could compare kanji and kana (syllabic) primes in the paradigm of the present study or test English–Japanese bilinguals in the same experimental setting as in the present study in order to examine to what extent it is the logographic nature of the kanji script as opposed to a change of script across primes and targets that is the source of the early translation priming effect. If the source of the early translation priming effect were the nature of the writing system, the early effect would emerge only for kanji primes. Likewise, English–Japanese bilinguals would not show such an early effect because their L1 English is not logographic but alphabetic. In contrast, if the source of the effect were a change of script across primes and targets, we would observe the early translation priming effect regardless of the writing system of the prime (logographic, syllabic, or alphabetic).

Although some studies have found L2–L1 translation priming (e.g., [Basnight-Brown and Altarriba, 2007](#); [Duñabeitia et al., 2010](#); [Duyck and Warlop, 2009](#); [Schoonbaert et al., 2009](#)), L2–L1 and L1–L2 translation priming effects are typically asymmetrical. Prior behavioral masked priming studies with different script bilinguals found a reliable L2–L1 translation priming effect when the task was semantic categorization ([Finkbeiner et al., 2004](#)), but not when the task was lexical decision ([Gollan et al., 1997](#); [Jiang, 1999](#)). Most relevant for the present study are the results of [Finkbeiner et al. \(2004\)](#), showing significant L2–L1 translation priming in a similar population of Japanese–English bilinguals performing a semantic categorization task. If task demands were the primary constraint on L2–L1 translation priming, we should have obtained a reliable L2–L1 translation priming effect in the present study, because the task was semantic categorization. Given that both studies tested Japanese–English bilinguals who were studying in the US at the time of testing, the discrepancy is unlikely to result from different levels of L2 English proficiency. One critical difference between [Finkbeiner et al. \(2004\)](#) and the present study is the SOA that was used — 200 ms in the [Finkbeiner et al.](#) study (a prime for 50 ms + a backward mask for 150 ms) vs. 80 ms (a prime for 50 ms + a backward mask for 30 ms). It could therefore be the longer SOA in the [Finkbeiner et al.](#) study that enabled L2–L1 translation priming effects to emerge in their semantic categorization experiment. In fact, [Schoonbaert et al. \(in press\)](#) have recently shown that a longer prime duration (100 ms) allows L2–L1 translation priming effects to emerge in both lexical decision RTs and in terms of modulation of the N250 and N400 ERP components with English–French bilinguals. We would therefore expect to see significant translation priming from L2 to L1 in Japanese–English bilinguals when using a longer prime duration than in the present study, or by testing participants with a higher level of proficiency in their L2.

<sup>1</sup> If we consider script as a clear cue to language identity, one might therefore expect to see stronger cross-language priming effects in same-script bilinguals with stimuli presented in the auditory modality, since phonology can provide a cue to language identity in this case (e.g., [Ju and Luce, 2004](#)). In an auditory cross-language priming study, however, a change in language produced a similar pattern of results to a within-language change in meaning ([Phillips et al., 2006](#)). This result appears to suggest that phonology may not provide as strong a cue as script.

Why then is there no L2–L1 translation priming while there is robust L2–L2 repetition priming in the current study? If the absence of L2–L1 translation priming were simply due to the relatively slow processing of L2 primes, there should have been no L2–L2 repetition priming either (see Gollan et al., 1997, for a similar explanation). However, this line of argument ignores the fact that repetition priming involves both form and semantic overlap across primes and targets (as pointed out above). Therefore, if primes are processed up to the point of activating form-level representations but not semantic representations, then repetition priming effects will be observed in the absence of non-cognate translation priming. Furthermore, these within-language repetition priming effects could modulate the N400 component even if semantic representations were not activated by the prime stimulus. This is because pre-activation of form-level representations by the prime stimulus would suffice to facilitate the subsequent mapping of form representations onto semantics during target processing.

In conclusion, the present study found evidence for fast access to semantic representations from L1 prime stimuli in a masked priming study testing Japanese–English bilinguals. These prime stimuli were found to modulate the ERPs generated by L2 target stimuli starting at around 100 ms post-target onset, and continuing their influence throughout the time windows of the N250 and N400 ERP components. A similar time-course of priming effects was also found for within-language repetition priming in L1, and L2–L2 repetition showed priming effects on the N250 and N400 components with a delayed onset compared with the L1–L1 condition. On the other hand, no priming effects were seen when primes were in L2 and targets L1, which we interpret as reflecting the relatively slow processing of L2 prime words, which might be exaggerated in bilinguals whose L2 is written in a different script.

## 4. Experimental Procedures

### 4.1. Participants

Eighteen right-handed native speakers of Japanese who spoke English as an L2 participated in the experiment for payment (age:  $M=27.3$  years,  $SD=3.4$  years; age of L2 acquisition:  $M=10.1$  years,  $SD=3.3$  years). Although the participants were living in the environment where their L2 English was predominant at the time of testing (length of living in English speaking countries:  $M=40.8$  months,  $SD=29.6$  months), they were all L1 Japanese dominant — rating L1 higher than L2 on a 7-point Likert scale of self-assessed language proficiency in reading (L1 self-rating:  $M=6.8$ ,  $SD=0.4$ ; L2 self-rating:  $M=4.9$ ,  $SD=0.7$ ).

### 4.2. Materials

A total of 330 English words and their Japanese translations comprised the critical materials in the present study. All of the English words were three to eight letter words [ $M=5.0$ ,  $SD=1.1$ ] and the mean frequency per million words was 84.7 [ $SD=154.2$ ] (Kučera and Francis, 1967). The Japanese translation equivalents were one to three character words

[ $M=1.7$ ,  $SD=0.6$ ]. All the words were selected based on the following criteria: (1) words were noncognate in English and Japanese; (2) Japanese equivalents of English words were typically written in kanji<sup>2</sup>; (3) words were given only one translation in each direction.<sup>3</sup> The third criterion was important because the number of translations is related to the semantic similarity of translation pairs (Tokowicz et al., 2002). Eight types of pairs of words were formed where the first word is the *prime* and the second word the *target*: *related L2–L2 trials* in which the target was a repetition of the prime in the same language, L2 English (e.g., angel-ANGEL), *unrelated L2–L2 trials* in which the target and the prime were unrelated but in the same language, L2 English (e.g., diary-ANGEL), *related L1–L2 trials* in which the target was a translation of the L1 Japanese prime (e.g., 天使-ANGEL), *unrelated L1–L2 trials* in which the target and the prime were unrelated and differed in language (e.g., 日記-ANGEL), *related L1–L1 trials* in which the target was a repetition of the prime in the same language, L1 Japanese (e.g., 天使-天使), *unrelated L1–L1 trials* in which the target and the prime were unrelated but in the same language, L1 Japanese (e.g., 日記-天使), *related L2–L1 trials* in which the target was a translation of the L2 English prime (e.g., angel-天使), and *unrelated L2–L1 trials* in which the target and the prime were unrelated and differ in language (e.g., diary-天使). In the present study, the language of targets was blocked. In each target language, six lists of 220 pairs of critical words (55 pairs for each condition) were constructed from the 330 English words and their Japanese translation equivalents so that each participant was tested in all four priming conditions in the context of a different target, with lists counterbalanced across participants. That is, the list of English targets consisted of *related L2–L2 trials*, *unrelated L2–L2 trials*, *related L1–L2 trials*, and *unrelated L1–L2 trials*, whereas the list of Japanese targets included *related L1–L1 trials*, *unrelated L1–L1 trials*, *related L2–L1 trials*, and *unrelated L2–L1 trials*. It is important to note that the same 330 stimuli appeared in these four different conditions in each language across participants, which allowed us to minimize the possibility that observed differences in ERPs across conditions are due to differences in physical features or lexical properties of stimuli.

In addition to the critical pairs, 80 unrelated filler pairs that met at least the first two criteria were included in each stimulus list. Half of the fillers had body part names in English in the target position for the lists of English targets and in Japanese in

<sup>2</sup> In Japanese, some words can be written both in kanji and in kana (hiragana and katakana), whereas others can be written only in kana (hiragana and katakana). Although some words can be written in either writing system, there are preferences for one rather than the other. Because of this criterion, all the stimuli needed to be nouns.

<sup>3</sup> A list of 600 words was translated from English into Japanese or from Japanese into English by an independent group of four Japanese–English bilinguals. In this norming experiment, the bilinguals were asked to write one translation that came to their mind first (see Tokowicz et al., 2002). A total of 330 words were selected among words that were assigned only one translation in both languages.



the target position for the lists of Japanese targets, preceded by either an unrelated English word or Japanese word in the prime position. The other half had body part names either in English or in Japanese in the prime position, followed by an unrelated English target for the English target lists and by an unrelated Japanese target for the Japanese target lists. None of the filler items were the same as the experimental words. These body part names served as probes in a go/no-go semantic categorization task in which participants were asked to press a button when they saw a body part word. All the critical pairs were no-go trials in the present study. The reason that we included body parts in the prime position as well as in the target position was to provide an estimate of prime visibility.

In the present study, none of the experimental items in each list were repeated except for the same words appearing as their translation in the prime position in the L2–L2 and L1–L2 related conditions or in the L1–L1 and L2–L1 related conditions. Each list had five blocks and each of the five blocks included 44 critical trials and 16 filler trials. There were 11 items for each experimental condition per block and half of the 16 fillers were probes for the go/no-go semantic categorization task. Each block started with three non-probe fillers and the critical trials and the rest of the filler trials were pseudo-randomized so that no more than three items from the same condition or three probes were presented in a row.

#### 4.3. Procedure

Stimuli were presented in white at the center of a black background on a 19-inch display that was set to a refresh rate of 100 Hz. As illustrated in Fig. 6, each trial began with a forward mask that was a mosaic of features taken

from Roman alphabets and Japanese kanji characters. The mosaic was used instead of hash marks in order to mask both English and Japanese prime words. The forward mask remained on the computer screen for 500 ms and then a prime word was presented for 50 ms in lower case letters in the Arial font (if it is English) or in kanji characters in the MS Mincho font (if it is Japanese). The prime word was immediately replaced by a backward mosaic mask that was different in features and in font type for a duration of 30 ms. The backward mask was followed by an English target word in upper case letters in the Arial font or by a Japanese target word in the MS Gothic font for 500 ms and then by a blank screen for 800 ms. At the end of the trial, a blink sign “(- -)” was inserted for 1500 ms, followed by a 500 ms blank screen. Participants were asked to blink only when the blink sign was displayed on the screen.

All participants took part in two experimental sessions which were at least two weeks apart. Half of the participants received a list of English targets first and the other half a list of Japanese targets.

#### 4.4. Electroencephalogram recording

The Electroencephalogram (EEG) was recorded from 29 tin electrodes placed on the scalp by using an elastic cap (Electro-Cap International; see Fig. 7). Vertical eye movements and blinks were monitored through an additional electrode attached below the left eye and horizontal eye movements through the one attached at the outer canthus of the right eye. These 32 electrodes were referenced to an electrode attached over the left mastoid bone. Another electrode was placed on the right mastoid bone to monitor for differential mastoid

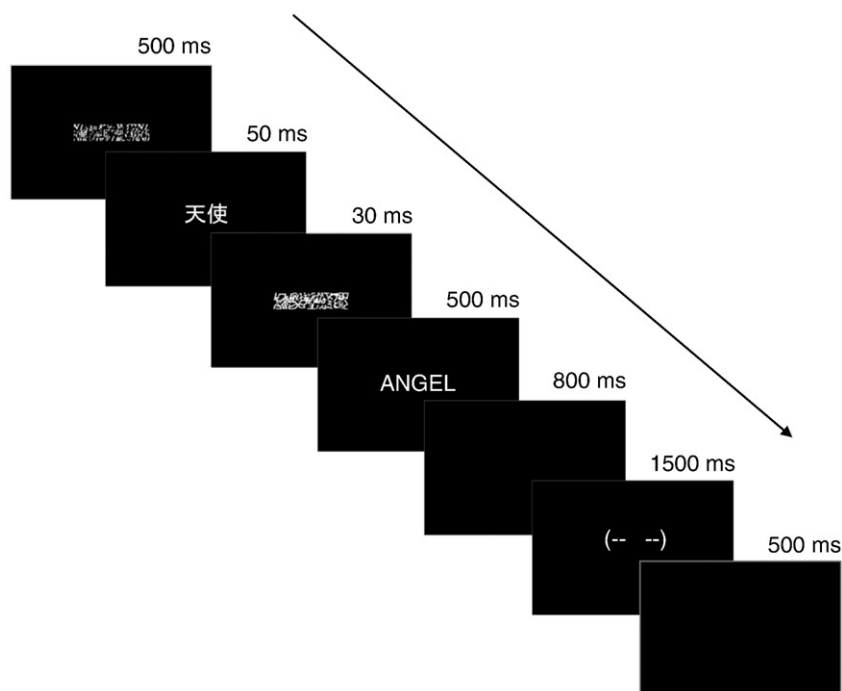


Fig. 6 – Illustration of a trial in the go/no-go semantic categorization task.





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