

Testing asymmetries in noncognate translation priming: Evidence from RTs and ERPs

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Abstract

In this study, English–French bilinguals performed a lexical decision task while reaction times (RTs) and event related potentials (ERPs) were measured to L2 targets, preceded by noncognate L1 translation primes versus L1 unrelated primes (Experiment 1a) and vice versa (Experiment 1b). The prime–target stimulus onset asynchrony was 120 ms. Significant masked translation priming was observed, indicated by faster reaction times and a decreased N400 for translation pairs as opposed to unrelated pairs, both from L1 to L2 (Experiment 1a) and from L2 to L1 (Experiment 1b), with the latter effect being weaker (RTs) and less longer lasting (ERPs). A translation priming effect was also found in the N250 ERP component, and this effect was stronger and earlier in the L2 to L1 priming direction than the reverse. The results are discussed with respect to possible mechanisms at the basis of asymmetric translation priming effects in bilinguals.

Descriptors: N250, N400, Bilingualism, Visual word recognition, Masked translation priming

Although bilinguals have been the focus of study for years now, there is still much debate about how knowledge concerning each language is represented in long-term memory and how their representations interact. While many researchers agree that bilinguals' first language (L1) might influence their second language (L2) processing, there is less of a consensus about L2 influences on L1. For instance, conflicting data have been obtained using the masked translation priming paradigm and lexical decision task to study L2 to L1 influences. Many studies have failed to find faster lexical decision times to L1 targets (e.g., *BOY*) when preceded by masked noncognate L2 translation primes (L2 translation of *boy*) than when preceded by an unrelated L2 word (e.g., Finkbeiner, Forster, Nicol, & Nakamura, 2004; Gollan, Forster, & Frost, 1997; Jiang, 1999; Jiang & Forster, 2001). However, some recent behavioral studies have found significant L2 to L1 priming effects (Basnight-Brown & Altarriba, 2007; Duñabeitia, Perea, & Carreiras, 2010; Duyck & Warlop, 2009; Perea, Duñabeitia, & Carreiras, 2008; Schoonbaert, Duyck, Brysbaert, & Hartsuiker, 2009; we refer to the latter study for a recent review of behavioral masked translation priming studies,

using the lexical decision task), suggesting that L1/L2 representational differences are quantitative rather than qualitative. However, because the L2 of learners of a second language is unlikely to be as strongly represented as their L1, priming from L1 to L2 should be stronger than priming from L2 to L1.

One limitation of the above mentioned behavioral studies is that they cannot separate out a semantic from a lexical locus of the effects. Holcomb and Grainger (2006) suggested a way to do this with event-related potentials (ERPs) in masked priming. Using ERPs, one can track the time course of language processing during priming more precisely, in order to explore if the priming effects originate at a lexical (earlier effects) or semantic level (later effects). In some recent electrophysiological studies (Grainger, Kiyonaga, & Holcomb, 2006; Holcomb & Grainger, 2006, 2007), Holcomb and colleagues described a range of ERP components that are modulated in within-language repetition priming paradigms. Two of these components are of particular relevance for the present bilingual study. The first component, namely, the N400, is a negative-going component that peaks between 400 and 600 ms after target onset and is typically larger at middle and posterior scalp sites. In masked priming, this component is known to be reduced for targets preceded by repeated items, as opposed to targets preceded by unrelated items. Because the semantic representation of the target (e.g., *BOY*) is preactivated by an identity or repetition prime (*boy*), the N400 component, reflecting semantic integration (see Kutas & Federmeier, 2000; Kutas & Hillyard, 1980, 1984; Kounios & Holcomb, 1992, 1994), is less negative and thus reduced. Finding this N400 modulation in masked priming from L2 to L1 would

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thus clearly indicate the use of a semantic route to transfer activation from L2 to L1, in other words, conceptual mediation. A second ERP component that has recently been identified in masked repetition priming studies is the N250. This negative-going wave peaks around 250 ms. Its amplitude is reduced mostly (less negative) for targets that were preceded by identity primes and increases with decreasing lexical overlap from targets with the preceded primes (Holcomb & Grainger, 2006). Holcomb and Grainger (2006) proposed that the N250 reflects a process whereby prelexical orthographic representations are mapped onto lexical representations. It remains to be seen if N250 effects will be observed across languages (when using noncognates translation pairs; see below; Midgley, Holcomb, & Grainger, 2009). Following the Revised Hierarchical Model (RHM; Kroll & Stewart, 1994), it could be hypothesized that L2 to L1 priming will show strong “lexical” N250 effects—yet less evidence of “semantic” N400 effects—than L1 to L2 priming, because the model posits that L2 has strong direct lexical connections with L1, whereas activation from L1 to L2 will heavily rely on semantic mediation and therefore should show larger semantic N400 effects.

The one neurophysiological study that investigated the translation priming paradigm used a semantic categorization task (Midgley et al., 2009). Midgley and colleagues tested unbalanced French–English bilinguals under masked translation priming conditions using a short 50-ms prime duration and 17-ms backward mask (i.e., 67 ms stimulus onset asynchrony [SOA]). Significant priming effects, indicated by a typical (i.e., more posterior) N400 change across conditions, were observed for L1 to L2 priming, but not for L2 to L1 priming. Interestingly, Midgley et al. also observed a modulation of the N250 in the L1 to L2 priming condition, but not in the reverse L2 to L1 condition. This particular finding would seem to be inconsistent with the predictions of the RHM, where L2 to L1 lexical connections would be expected to result in lexical level priming as reflected in the N250. Furthermore, it is not simply the case that L2 primes were not able to produce priming effects, because Midgley et al. did observe significant N250 and N400 effects within the second language (i.e., priming from L2 to L2).

Midgley et al. (2009) interpreted the L1–L2 translation priming effect seen in the N250 component as reflecting flow of activation from semantic representations, rapidly activated by the prime stimulus, back down to whole-word form representations in L2. They argued that such feedback operates quickly enough to modulate ongoing feedforward processing of L2 target words at the level of prelexical and lexical form representations. Midgley et al. also speculated that the lack of an L2–L1 priming effect in the N250 could have been due to the slower processing of L2 primes not allowing sufficient time to access semantic representations and feedback information to form level representations in L1. Of course, no such feedback is necessary in order to obtain an N250 priming effect when both primes and targets are in L2. They therefore predicted that with longer prime durations, L2–L1 priming effects should be observable in the N250 component. The present study provides a direct test of this prediction.

In the present study we investigated masked translation priming effects under slightly different conditions from the Midgley et al. (2009) study. First, we used a lexical decision task rather than a semantic categorization task. Based on the literature, we might expect that masked translation priming effects are more elusive in the lexical decision task than the semantic categorization task (e.g., Grainger & Frenck-Mestre, 1998), because these effects are believed to have a semantic locus, and semantic cat-

egorization taps deeper into semantics than lexical decision. However, recent masked priming studies using the lexical decision task have found significant cross-language priming effects (e.g., Duyck & Warlop, 2009; Schoonbaert et al. 2009). Furthermore, previous monolingual masked priming ERP studies have also shown similar effects in the ERP signal whether participants were performing a semantic categorization or a lexical decision task (Kiyonaga, Grainger, Midgley, & Holcomb, 2007; see Grainger & Holcomb, 2009, for review). Nevertheless, it remains to be seen if evidence for L2 to L1 priming can be found in ERPs when the task focuses participants’ attention on lexical rather than semantic processes. The second difference relative to the Midgley et al. study is that we used a longer prime duration (100 ms vs. 50 ms) in order to give priming more opportunity to take effect, but we continued to use the masked priming paradigm to avoid strategic priming effects (see Altarriba & Basnight-Brown, 2007, for methodological recommendations in performing cross-language priming).

In short, the present study provides a further exploration of masked translation priming, with the specific aim of providing information about the time course of such priming effects from L1 to L2 and L2 to L1. Most important is that we used a longer prime duration (and thus a longer SOA) than in prior research that found little evidence for priming from L2 to L1. We investigate whether specific ERP components can provide evidence for the existence of the much debated L2 to L1 priming effect and its lexical or semantic locus. Finding a N400 effect in this condition would indicate early semantic activation in L2. Below, we report a test of same-script translation priming effects in both directions (L1 to L2—see Experiment 1a—and, more critically, L2 to L1—see Experiment 1b) with noncognates, using unbalanced English–French bilinguals living in an L1 environment.

EXPERIMENT 1A: TRANSLATION PRIMING FROM L1 TO L2 AT 120 MS SOA

Methods

Participants

Twenty English–French bilinguals (16 women; mean age = 19.85 years; $SD = 0.99$) from Tufts University participated in the experiment and were monetarily compensated for their time. Participants were all English native speakers and primarily used their mother tongue in daily life. All of them learned French in school and were currently enrolled or recently finished advanced French classes. None of them had learned French or any other second language before the age of 4. Mean age of the beginning of acquisition for French was 11.85 years ($SD = 2.67$). The number of months of immersion in a French-speaking environment ranged from 0.25 to 15 (mean = 4.39, $SD = 3.62$). Detailed measures of language proficiency based on participants’ self-ratings are shown in Table 1. All participants were right-handed (Edinburgh Handedness Inventory; Oldfield, 1971), and all reported having normal or corrected-to-normal vision with no history of neurological insult or language disability.

Stimuli and Design

The critical stimuli in this experiment were 160 English–French translation pairs (all three to eight letter words; see the Appendix). The mean printed frequency for all French target words was 1.83 log10 per million and ranged from 0.45 to 2.98 (Lexique

Table 1. Mean (SD) Self-ratings in L1 and L2 in Experiments 1a and 1b

Measure	L1 (English) mean (SD)	L2 (French) mean (SD)
Reading ability	7.00 (0.00)	5.35 (0.59)
Speaking ability	7.00 (0.00)	5.33 (0.77)
Auditory comprehension	7.00 (0.00)	5.83 (0.85)
Overall proficiency	7.00 (0.00)	5.50 (0.76)

Note: 7-point Likert scale (1 = very poor; 7 = excellent).

database of New, Pallier, Brysbaert, & Ferrand, 2004). The mean printed frequency for all English translation primes (used as targets in Experiment 1a) was 1.94 log10 per million and ranged from 0.30 to 3.04 (Celex lexical database of Baayen, Piepenbrock, & van Rijn, 1993). Cognate or interlingual homograph/homophone prime–target pairs, as well as overly polysemous words, were excluded from our stimulus lists. The French word targets could be preceded by their English translation or by an unrelated English word. Prime–target pairing was counterbalanced using a Latin-square design. We created unrelated prime–target pairs by reassigning related primes to different targets, thus creating four lists. Each participant was assigned to one list and consequently saw each target only once, either with the translation prime or with its control. However, all stimuli occurred as both translations and unrelated an equal number of times across participants. The order of prime–target trials was pseudorandomized. An important feature of this design is that the prime and target ERPs in the different conditions are formed from exactly the same physical stimuli (across subjects), which should reduce the possibility of ERP effects across conditions due to differences in physical features or lexical properties. The experiment involved one repeated measures factor, namely Prime Type (translation vs. unrelated).

Additionally, 160 nonwords were created that followed the French GPC rules, serving as French filler targets for the lexical decision task. These nonword targets were matched with the French word targets on number of letters, bigram frequency, and number of orthographic neighbors (all $ps > .30$, two-tailed t tests) in order to ensure their word-likeness and pronounceability. The WordGen stimulus generation program (Duyck, Desmet, Verbeke, & Brysbaert, 2004) was used for all matching purposes. All nonwords were preceded by English word primes.

Procedure

Each trial consisted of a sequence of four visual events. First, a row of 10 hash marks [#####], serving as a forward mask and as a fixation mark, was presented for 500 ms. Second, the prime was displayed on the screen for 100 ms (10 refresh rates at 100 Hz). Third, a backward mask [#####] was presented for 20 ms, creating a 120-ms SOA (see recommendations by Altarriba & Basnight-Brown, 2007; these authors stated that preferably SOAs below 200–300 ms should be used).

Fourth, the target was presented for 500 ms. After each priming sequence, a blank interval of 1000 ms was presented and replaced by a 2000-ms blink stimulus [(- -)]. Participants were asked to blink only when the blink stimulus was displayed. All stimuli were presented in Verdana font type as centered white characters with a black background on a standard 19-in. monitor, located 143 cm directly in front of the participant. Primes appeared in lowercase (font width 15, font height 30), whereas

targets were presented in uppercase (font width 20, font height 40) to minimize visual feature overlap between primes and targets. For the masks, the same font size as for the primes was used.

Participants were asked to fixate the center of the screen and to decide as quickly and accurately as possible if the target stimulus was a French word or not. The two possible response buttons were the right key (for a “yes” response) and the left key (for a “no” response) of a millisecond-accurate game pad. The assignment of responses was reversed for half of the participants. Participants were not informed about the presence of the primes. Instructions were given in English (L1) by the experimenter (before the experiment). During the setup, participants filled out a handedness questionnaire (Edinburgh Handedness Inventory; Oldfield, 1971). After the experiment, participants were asked to complete a short questionnaire about their L2 learning age and L1 and L2 language proficiency (including self-ratings; see Table 1). They were also given a list of all L2 words in the experiment and were asked to type in the L1 translation. Mean performance on this posttranslation task was 88.39% correct ($SD = 6.61$, range 71.88% to 96.88%).

Event-Related Potential Recording Procedure

This study was run at the Neurocognition Lab at Tufts University, Medford, Massachusetts. Participants were seated in a comfortable chair in a sound-attenuating room. The electroencephalogram (EEG) was recorded from 29 active tin electrodes mounted on an elastic cap that was fitted on the participant’s scalp (Electro-cap International, Eaton, OH). Additional electrodes were attached below the left eye (LE, to monitor for vertical eye movement or blinks), to the right of the right eye (HE, to monitor horizontal eye movement), over the left mastoid bone (used as reference), and over the right mastoid bone (recorded actively to monitor for differential mastoid activity; see Figure 1 for the electrode montage). All EEG electrode impedances were maintained below 5 k Ω (except the impedance for eye electrodes, which was less than 10 k Ω). The EEG (200-Hz sampling rate, bandpass 0.01 and 40 Hz) was recorded continuously.

Data Analysis

Averaged ERPs time-locked to target onset were formed off-line, excluding trials with ocular and muscular artifact (<0.57%). Trials with lexical decision errors, RTs below 200 ms and above 1500 ms, and post-translation errors were also excluded from the RT and ERP analyses (18.56% of all data). One French item was unknown to all subjects, and therefore this item (as well as its translation in Experiment 1b) was excluded from all analyses (see the Appendix). ERP data from a representative subarray of the full 28-channel scalp montage was used for analysis. For the sake of clarity in presenting the results, we only report data from the sites where the effects are maximal. This included nine sites extending from the front to the back of the head as well as over left, center, and right hemisphere locations (see Figure 1). We have successfully used a similar approach to ERP data analysis in a number of previous reports (e.g., Grainger et al., 2006) and find it the best compromise between simplicity of design (a single ANOVA can be used in each analysis epoch) and a full description of the distribution of effects. For both behavioral (by subjects and by items) and ERP data, an ANOVA (per time window, see below) was performed with Prime Type (translation vs. unrelated) as the repeated measures factor, treating mean reaction time, mean error percentages, and mean amplitude as respective dependent variables and additional scalp distribution factors of

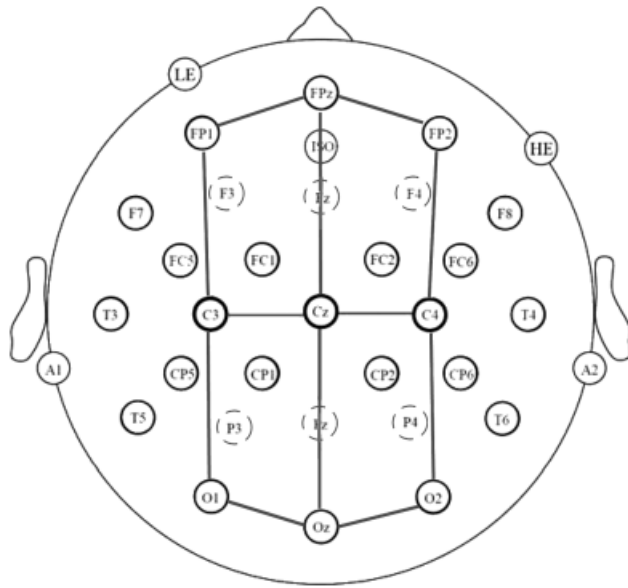


Figure 1. Electrode montage and nine sites used in analyses.

Electrode Laterality (left vs. center vs. right), and Front-to-Back Distribution (FP vs. C vs. O) were included in the analyses of ERP data. The Greenhouse and Geisser (1959) correction was applied to all repeated measures in the ERP analyses with more than one degree of freedom). The dependent measures in ERP analyses were the mean amplitude measurements in five consecutive time windows: 100–200 ms, 200–300 ms, 300–400 ms, 400–500 ms, and 500–600 ms. In previous work, similar windows have been used to assess activity in the N250/N300 and the N400 epochs (e.g., Eddy, Schmid, & Holcomb, 2006; Holcomb & Grainger, 2006). To get a detailed view on the scalp distribution across all electrodes, scalp maps of ERP difference waves (unrelated–translation) are presented (see Figures 3 and 4).

Results

Behavioral

French targets preceded by their English translation (583 ms) were recognized faster than those preceded by an unrelated English word (653 ms). This 70 ms (L1 to L2) priming effect was significant by subjects, $F_1(1,19) = 102.20$, $p < .001$, and by items, $F_2(1,155) = 85.89$, $p < .001$.

There was a significant effect of Prime Type on the *percentage of errors* to words (7%), $F_1(1,19) = 22.31$, $p < .001$, and $F_2(1,158) = 29.49$, $p < .001$. French targets preceded by their English translation yielded fewer errors (4%) than those preceded by English unrelated primes (11%).

ERPs

ERPs for Prime Type conditions are plotted for the nine electrodes used in the analyses. For this experiment, ERPs can be found in the left panel of Figure 2. Figure 3 presents the voltage maps (formed from all 29 scalp sites) calculated by subtracting translation ERPs from unrelated ERPs in several different time windows. Significant effects are reported below, per 100-ms time window (from 100 ms to 600 ms after target onset) in order to best capture our results.

100- to 200-ms target epoch. Inspecting Figures 2 and 3, between 100 and 200 ms, clearly shows no effect of the priming manipulation ($F < 1$).

200- to 300-ms target epoch. Inspecting Figures 2 and 3, between 200 and 300 ms, shows a small L1 to L2 priming effect (unrelated more negative than translation), which peaks at about 250 ms and is largest over anterior sites. This observation is supported by a significant Prime Type \times Front-to-Back Distribution interaction, $F(2,38) = 7.60$, $p < .01$.

300- to 400-ms target epoch. By inspecting Figures 2 and 3, a clear effect of priming can be seen at 350 ms. ANOVAs

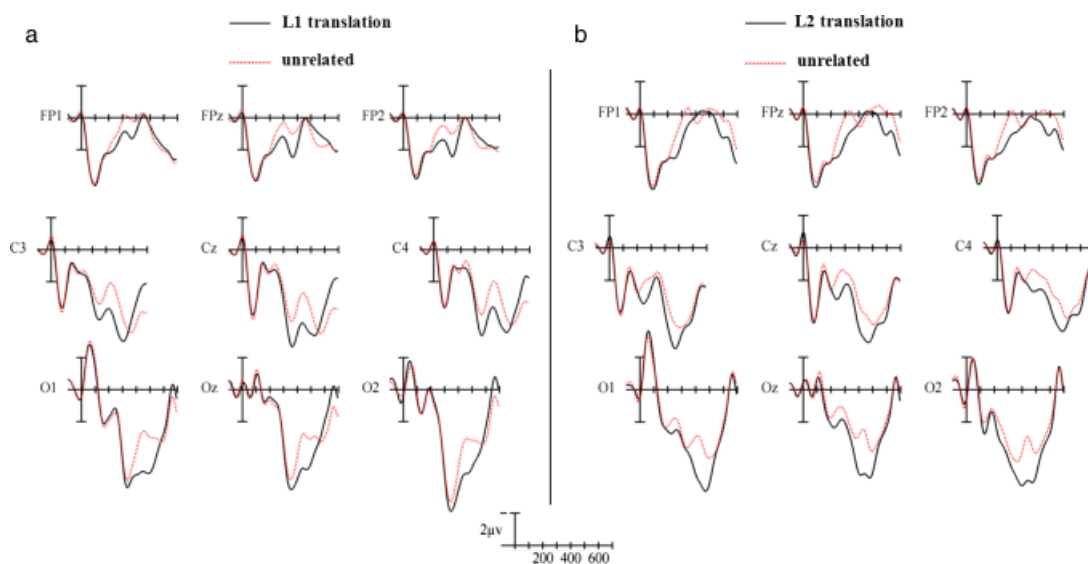


Figure 2. Event-related potentials time-locked to target onset in L1 to L2 translation priming conditions (1a) and L2 to L1 translation priming conditions (1b), plotted with the waveforms for their respective control conditions (Experiment 1). Note that target onset is marked by the vertical calibration bar and that negative is plotted up.

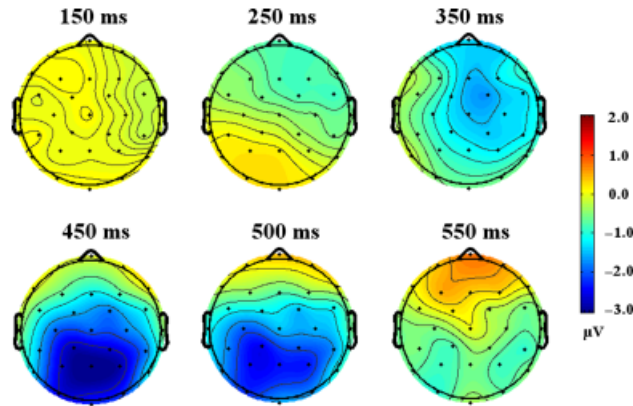


Figure 3. Voltage maps calculated from difference waves (unrelated–translation) in Experiment 1a (L1 to L2 priming) at each of five time points encompassing the ERP measurements windows reported in the text. Note that we have also included the voltage map at 500 ms because it shows most clearly the prolonged N400 to L2 targets.

confirmed that this L1 to L2 priming effect (unrelated more negative than translation) was significant, $F(1,19) = 21.12$, $p < .001$.

400- to 500-ms target epoch. Figures 2 and 3 show very strong effects of priming (unrelated more negative than translation) at about 450 ms, being largest over the more posterior electrode sites. ANOVAs confirmed that the main L2 to L1 priming effect was significant, $F(1,19) = 27.19$, $p < .001$, as well as the interaction of L2 to L1 priming with Front-to-Back Distribution, $F(2,38) = 22.29$, $p < .001$.

500- to 600-ms target epoch. Figures 2 and 3 continue to show a clear L1 to L2 priming effect around 500–600 ms, although it appears mostly at posterior electrode sites. ANOVAs confirmed that there was a significant interaction between Prime Type and Front-to-Back Distribution, $F(2,38) = 6.52$, $p < .05$.

EXPERIMENT 1B: TRANSLATION PRIMING FROM L2 TO L1 AT 120 MS SOA

Before providing a detailed discussion on the above mentioned data, we will present the data of the reverse priming direction, L2 to L1 (Experiment 1b). Experiment 1b used the same participants and stimuli (by swapping primes and target) as in Experiment 1a. Both experiments will then be discussed as one data set.

Methods

Participants

The same 20 English–French bilinguals who participated in Experiment 1a also participated in Experiment 1b.

Stimuli

Experiment 1b used the exact same critical stimuli as in Experiment 1a except that the primes and targets were swapped. The L1 translation primes of Experiment 1a now served as L1 target words, preceded by L2 translation primes (the L2 targets from Experiment 1a). Additional filler items (French word primes and English nonword targets) were created as in Experiment 1a.

Procedure

The procedure was identical to the procedure used in Experiment 1a. The order of the experiments was counterbalanced across subjects, with a lag of 2 weeks in between both experiments.

Data Analysis

Averaged ERPs time-locked to target onset were formed off-line, excluding trials with ocular and muscular artifact ($< 1.07\%$). Trials with lexical decision errors, RTs below 200 ms and above 1500 ms, and posttranslation errors were excluded (15.22% of all data).

Results

Behavioral

English targets preceded by their French translations (559 ms) were recognized faster than those preceded by unrelated French words (583 ms). This 24 ms priming effect was significant by subjects, $F(1,19) = 23.87$, $p < .001$, and items, $F(2,155) = 6.38$, $p < .05$.

The L2 to L1 priming effect on the percentage of errors to words (1%) was not significant, $F(1,19) = 4.00$, $p < .06$, and $F(2,158) = 1.08$, $p < .31$. English targets preceded by their French translation yielded almost as few errors (3%) as those preceded by English unrelated primes (4%).

ERPs

ERPs for Prime Type conditions in this experiment are shown in the right panel of Figure 2. Figure 4 presents the voltage maps of difference waves (formed from all 29 scalp sites) across different time windows.

100- to 200-ms target epoch. Figures 2 and 4, between 100 and 200 ms, show no effect of the priming manipulation ($p > .14$) and no interaction between Prime Type and Front-to-Back Distribution ($F < 1$).

200- to 300-ms target epoch. Inspecting Figures 2 and 4, between 200 and 300 ms, shows a strong and widely distributed L2 to L1 priming effect (unrelated more negative than translation) peaking at about 250 ms. This observation is supported by a significant main effect of Priming, $F(1,19) = 26.49$, $p < .001$.

300- to 400-ms target epoch. By inspecting Figures 2 and 4, an effect of priming can be seen at 350 ms. ANOVAs confirmed that this L2 to L1 priming effect (unrelated more negative than translation) was significant, $F(1,19) = 13.40$, $p < .01$.

400- to 500-ms target epoch. Figures 2 and 4 show very strong effects of priming at about 450 ms over the more posterior electrode sites. ANOVAs confirmed that the L2 to L1 priming effect (unrelated more negative than translation) was significant, $F(1,19) = 20.20$, $p < .001$, as well as its interaction with Front-to-Back Distribution, $F(2,38) = 34.00$, $p < .001$.

500- to 600-ms target epoch. Figures 2 and 4 still show some of the L2 to L1 priming effect around 500 ms. ANOVAs confirmed that there was a significant priming effect in this epoch, $F(1,19) = 6.53$, $p < .05$.

Discussion

The behavioral analyses showed a significant translation priming effect from L1 to L2 as well as from L2 to L1, although the latter

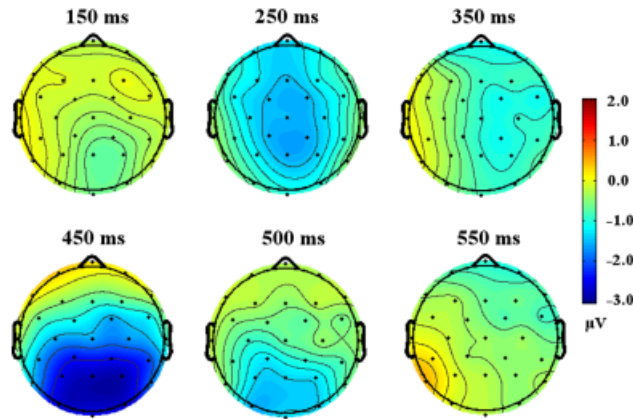


Figure 4. Voltage maps calculated from difference waves (unrelated-translation) in Experiment 1b (L2 to L1 priming) at each of five time points encompassing the ERP measurement windows reported in the text. Note that we have also included the voltage map at 500 ms to draw a comparison with Figure 3.

effect was smaller (70 ms vs. 24 ms). An additional analysis across both experiments, adding Direction (L1-L2 vs. L2-L1) as a within-subjects factor, confirmed this traditional translation priming asymmetry, $F_1(1,19) = 35.40$, $p < .001$, and $F_2(1,156) = 40.90$, $p < .001$. This analysis also indicated that targets were recognized faster and more accurately in L1 than in L2 (all $ps < .05$). This pattern of results is a replication of the data of Schoonbaert et al. (2009), where behavioral priming effects from L1 to L2 and vice versa ran to 100 ms and 19 ms, respectively, at 250 ms SOA and 28 ms and 12 ms at 100 ms SOA. The ERP analyses confirmed the existence of L1 to L2 priming effects as well as L2 to L1 priming effects. The effects start at about 250 ms, which is the typical N250 window (Holcomb & Grainger, 2006). We seem to observe a strong widely distributed N250 effect for the L2 to L1 priming condition (i.e., no interaction with distribution). There is also an N250 effect in the L1 to L2 condition, although it appears to be smaller than the L2 to L1 effect and was larger at anterior sites than posterior. A combined analysis confirmed this observation. The N250 was significantly smaller in the L1-L2 direction: Direction \times Prime Type interaction, $F(1,19) = 5.77$, $p < .05$. At about 450 ms, large N400 translation priming effects are observed for both priming directions. These effects have a typical N400 posterior distribution, which was confirmed in the combined analysis, Prime Type \times Front-to-Back Distribution, $F(2,38) = 49.23$, $p < .001$, and showed to be equally strong in both priming directions (no significant Prime Type \times Direction interaction, $F < 1$). Translation priming effects are still visible early in the 500–600 ms time window, but are larger for the L1 to L2 direction of priming, a trend that was confirmed in the combined analysis, Direction \times Prime Type \times Front-to-Back Distribution interaction, $F(2,38) = 6.44$, $p < .01$. A latency analysis, including the 400–500-ms and 500–600-ms time windows, further confirmed the existence of a more sustained N400 effect when priming from L1 to L2 than vice versa, Latency \times Direction \times Prime Type \times Front-to-Back Distribution interaction, $F(2,38) = 17.51$, $p < .001$. Follow-up analyses showed that the three-way interaction (Latency \times Direction \times Prime type) was only significant at frontal electrodes, $F(1,19) = 20.61$, $p < .01$, but not at central and occipital sites, $F(1,19) = 2.66$, $p < .12$, and $F < 1$, respectively.

GENERAL DISCUSSION

In this study, we tested masked translation priming for unique noncognate translation pairs with unbalanced English (L1)–French (L2) bilinguals engaging in a lexical decision task. Our key innovation was the inclusion of ERPs in this particular paradigm. Both behavioral and ERP measures were collected for the two priming directions (L1 to L2 and vice versa). We expected to find priming effects on the N400 component, as evidence for semantic activation across languages, and possibly effects on the N250 component as a measure of earlier lexical processing. To our knowledge, this is the first study to report masked cross-language priming effects with ERPs using a lexical decision task.

We observed large posterior N400-priming effects (peaking at about 450 ms) in both priming directions. However, the L1 to L2 priming effect was longer lasting than the reverse effect. This probably reflects an N400-latency shift for L2 targets, due to slower processing of L2 targets. Furthermore, we observed strong and widely distributed N250-priming effects from L2 to L1, whereas the N250 effect for the reverse priming direction (L1 to L2) seemed to be less pronounced. This would appear to be strong evidence for what we will argue are both form-based (N250) and semantic (N400) effects of translation primes in L2 on target processing in L1.

The first main conclusion that can be drawn with respect to the present results when compared with prior research is that noncognate translation priming effects from L2 to L1 are robust when sufficient time is allowed for processing of the L2 prime. We therefore confirm Midgley et al.'s (2009) prediction that L2-L1 priming effects in relatively unbalanced bilinguals should emerge with longer prime exposures. This fits with the general hypothesis that the typical asymmetric pattern of translation priming effects as a function of priming direction is being driven by quantitative rather than qualitative differences in processing. Such quantitative differences are likely related to the way in which amount of exposure to the L2 determines the speed with which L2 words are processed. Such an account is easily accommodated within the general framework of the BIA model (Dijkstra & van Heuven, 2002; Grainger & Dijkstra, 1992).

The present results are consistent with recent behavioral studies showing significant masked translation priming from L2 to L1 when more balanced bilinguals were tested (Basnight-Brown & Altarriba, 2007; Duñabeitia et al., 2010) or allowing unbalanced bilinguals more time between the prime and the target (Duyck & Warlop, 2009; Schoonbaert et al., 2009). Therefore, increasing participants' proficiency in L2 or increasing prime–target SOA can be thought of as having the same influence on the amount of processing of briefly presented L2 prime words. Increasing the SOA provides more time, and increasing L2 proficiency means that more processing can be performed for a fixed amount of time.

There is one aspect of the present results that contrasts with the pattern found by Midgley et al. (2009) using a shorter SOA. This is the fact that the N250 priming effect was actually stronger from L2 to L1 in the present study, whereas the more typical asymmetry (stronger effects from L1 to L2) was seen in the Midgley et al. study. We provide two tentative interpretations of this key finding that are not mutually exclusive. The first interpretation is based on the possibility that translation priming effects from L1 to L2 in the N250 component might actually get weaker as SOA is increased. Prior research with monolingual participants and a within-language repetition priming manipu-

lation has indeed shown that N250 priming effects diminish as prime–target SOA is increased (Holcomb & Grainger, 2007). In the same study, no such decrease in N400 priming effects was seen. Holcomb and Grainger (2007) argued that although semantic representations must remain active for sentence-level integration processes, word form representations must be rapidly suppressed in order to clear the way for the processing of upcoming words (see Grainger & Jacobs, 1999, for a discussion of this mechanism). Such a reset mechanism operating on whole-word form representations would lead to the suppression of activity in any whole-word representation activated by the prime word, including its translation equivalent. Because priming effects in the N250 component are thought to reflect the mapping of prelexical form representations onto whole-word representations, these priming effects will be affected by the above described mechanism. According to this proposal, the relationship between the size of N250 priming effects and prime–target SOA is non-monotonic, with a positive correlation up to some critical SOA value (corresponding to when the reset mechanism kicks in), followed by a decrease in the size of priming effects with further increases in SOA.

The stronger N250 translation priming effect from L2 to L1 than from L1 to L2 in the present study might also be driven by asymmetries in the connection strengths between the word form representations of translation equivalents, as postulated in the RHM (Kroll & Stewart, 1994). This pattern of priming effects would result from the stronger associations going from L2 to L1 than vice versa. In this framework, L2 primes will more rapidly activate the corresponding word form in L1 than L1 primes will activate their translation in L2. If one further assumes, following the RHM, that connection strengths from word forms to semantics are stronger in L1 than in L2, then a complete account of

the present findings emerges. Translation priming effects from L1 to L2 are driven mostly by semantic feedback (the L1 prime rapidly activates semantic representations that are compatible with the subsequent processing of the L2 translation equivalent), whereas L2–L1 priming effects are mostly driven by direct associations between word form representations (the L2 prime activates the corresponding word form representation in L1). Therefore, following Holcomb and Grainger's (2006) interpretation of the modulation of the N250 and N400 ERP components seen in single word priming paradigms, L1–L2 translation priming effects will be mostly visible in the N400 whereas L2–L1 effects will be mostly visible in the N250, the precise pattern that was seen in the present study. The fact that Midgley et al. (2009) failed to find such a pattern suggests that a minimal amount of processing of L2 primes is necessary before the associative links with L1 word forms can be activated. The longer SOA used in the present study could therefore be critical for obtaining such priming effects from L2 to L1 with the specific population of bilinguals tested here.

To conclude, our study replicated recent behavioral translation priming studies by showing robust priming from L1 to L2 and vice versa and extended this finding to English–French unbalanced bilinguals performing a lexical decision. We also contributed to the existing literature by including ERP measures, which mirrored the behavioral results by showing clear N400-priming effects, indicating semantic involvement during priming in both directions. We found strong evidence for asymmetric N400 effects (i.e., smaller priming effects in the L2–L1 direction compared to L1–L2 effects), mostly likely caused by the 100-ms processing delay for L2 targets. Furthermore, we observed asymmetric N250 effects, possibly indicating traces of a strong lexical route of processing when priming from L2 to L1.

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APPENDIX

Table A1. English–French Translation Pairs, Used as Critical Stimuli in Experiments 1a and 1b

	English (L1)	French (L2)		English (L1)	French (L2)		English (L1)	French (L2)		English (L1)	French (L2)
1.	advice	conseil	41.	fame	renom	81.	level	niveau	121.	sister	soeur
2.	anger	colère	42.	father	père	82.	life	vie	122.	size	taille
3.	another	autre	43.	fear	peur	83.	loss	perte	123.	skin	peau
4.	apple	pomme	44.	fire	feu	84.	lost	perdu	124.	skirt	jupe
5.	beach	plage	45.	fish	poisson	85.	love	amour	125.	sleeve	manche
6.	belief	croyance	46.	foot	pied	86.	meat	viande	126.	slippery	glissant
7.	belt	ceinture	47.	girl	fille	87.	milk	lait	127.	snow	neige
8.	better	mieux	48.	glove	gant	88.	monkey	singe	128.	soap	savon
9.	bird	oiseau	49.	goat	chèvre	89.	month	mois	129.	soon	bientôt
10.	boat	bateau	50.	god	dieu	90.	mood	humeur	130.	soul	âme
11.	book	livre	51.	goodness	bonté	91.	moon	lune	131.	speed	vitesse
12.	boredom	ennui	52.	guilty	coupable	92.	mouth	bouche	132.	state	état
13.	boy	garçon	53.	happy	heureux	93.	nail	ongle	133.	stone	pierre
14.	brain	cerveau	54.	hatred	haine	94.	need	besoin	134.	tail	queue
15.	breast	sein	55.	health	santé	95.	needle	aiguille	135.	taste	goût
16.	broken	cassé	56.	heart	coeur	96.	new	nouveau	136.	tear	larme
17.	brother	frère	57.	heavy	lourd	97.	next	prochain	137.	thought	pensée
18.	butter	beurre	58.	heel	talon	98.	noise	bruit	138.	ticket	billet
19.	cake	gâteau	59.	hell	enfer	99.	nothing	rien	139.	tomorrow	demain
20.	candle	bougie	60.	help	secours	100.	old	vieux	140.	tree	arbre
21.	care	soin	61.	hill	colline	101.	peace	paix	141.	truce ^a	trêve ^a
22.	castle	château	62.	hole	trou	102.	poor	pauvre	142.	truck	camion
23.	century	siècle	63.	hope	espoir	103.	pride	fierté	143.	truth	vérité
24.	cheese	fromage	64.	house	maison	104.	queen	reine	144.	ugliness	laideur
25.	chicken	poulet	65.	hunger	faim	105.	rabbit	lapin	145.	unknown	inconnu
26.	child	enfant	66.	hunter	chasseur	106.	rain	pluie	146.	useless	inutile
27.	chin	menton	67.	husband	mari	107.	reminder	rappel	147.	wait	attente
28.	church	église	68.	illness	maladie	108.	ring	anneau	148.	weak	faible
29.	cloud	nuage	69.	joke	blague	109.	river	fleuve	149.	wealth	richesse
30.	coal	charbon	70.	key	clé	110.	roof	toit	150.	week	semaine
31.	coat	manteau	71.	kitchen	cuisine	111.	school	école	151.	weight	poids
32.	curtain	rideau	72.	knee	genou	112.	screen	écran	152.	welcome	bienvenu
33.	disgust	dégoût	73.	knife	couteau	113.	shame	honte	153.	wheel	roue
34.	dish	assiette	74.	last	dernier	114.	sheep	mouton	154.	window	fenêtre
35.	dream	rêve	75.	late	tard	115.	shirt	chemise	155.	wing	aile
36.	duck	canard	76.	law	loi	116.	shoulder	épaule	156.	wisdom	sagesse
37.	early	tôt	77.	leaf	feuille	117.	sick	malade	157.	wish	souhait
38.	empty	vide	78.	leather	cuir	118.	sight	vue	158.	worse	pire
39.	english	anglais	79.	leg	jambe	119.	silk	soie	159.	worthy	digne
40.	faith	foi	80.	less	moins	120.	sin	péché	160.	young	jeune

^aItem excluded based on posttranslation data.