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Masked repetition and translation priming in second language learners: A window on the time-course of form and meaning activation using ERPs

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Abstract

Event-related potentials (ERPs) and masked translation priming served to examine the time-course of form and meaning activation during word recognition in second language learners. Targets were repetitions of, translations of, or were unrelated to the immediately preceding prime. In Experiment 1 all targets were in the participants' L2. In Experiment 2 all targets were in the participants' L1. In Exp 1 both within-language repetition and L1–L2 translation priming produced effects on the N250 component and the N400 component. In Experiment 2 only within-language repetition produced N250 effects, while both types of priming produced N400 effects. These results suggest rapid involvement of semantic representations during on-going form-level processing of printed words, and an absence of facilitatory connections between the form representations of non-cognate translation equivalents in L2 learners. The implications for bilingual theories of word processing are discussed.

Descriptors

Bilingualism; Second language acquisition; Visual word recognition; N400; N250; Masked priming

Bilinguals and second-language learners offer an interesting opportunity for testing general theories of how form and meaning representations interact during language comprehension. They also represent a fascinating example of the versatility with which humans manipulate abstract symbols in order to communicate complex information. Learning a second language (once a first language has been acquired) involves acquiring a new set of arbitrary forms to represent a pre-established set of concepts (although some new concepts will, of course, be acquired with the new language). This likely involves at least a partial restructuring of the form representations in the first language, as proposed by two prominent models of bilingual word comprehension and second language learning—the Revised Hierarchical Model (RHM; Kroll & Stewart, 1994) and the Bilingual Interactive Activation (BIA) model (Grainger & Dijkstra, 1992; van Heuven, Dijkstra, & Grainger, 1998). According to the RHM, newly acquired lexical form representations in L2 are connected to their equivalent lexical form representations in L1 in order to facilitate access to semantics. According to the BIA model, the newly acquired lexical form representations are gradually integrated into a common network of lexical form representations for both languages. One specific goal of the present study is to test the

predictions of these two models with respect to effects of non-cognate translation primes (i.e., translation equivalents having minimal form overlap).

A more general goal of the present study is to investigate the nature of form-meaning interactions at the level of individual words. Part of that general endeavor involves describing exactly when semantic information becomes available during visual word recognition, and the nature of the form-level processing that is necessary for that to occur. Demonstrations of early involvement of semantics during visual word recognition are few and far between. Standard semantic priming effects (e.g., bread-butter) are easily obtained when primes are clearly visible and targets immediately follow primes (e.g., Meyer & Schvaneveldt, 1971). However, when prime exposure duration is reduced such that primes are barely visible, then the standard result is no semantic priming, but significant form priming effects (e.g., teble-table). This is true for behavioral studies (e.g., Rastle, Davis, Marslen-Wilson, & Tyler, 2000), and for electrophysiological studies (e.g., Holcomb et al., 2005; Holcomb & Grainger, in press).¹ This pattern therefore fits with models of visual word recognition according to which form-level processing must be complete (or close to completion) before any semantic-level information can be accessed (e.g., Forster, 1976). In cascaded activation models, on the other hand, semantic-level processing ought to follow form-level processing very rapidly (McClelland, 1979; McClelland & Rumelhart, 1981). According to this account, as soon as form representations are even partially activated by a given stimulus, activation immediately starts to spread to higher levels.

The rather weak evidence for any early semantic activation obtained using the standard semantic priming paradigm might, however, be due to the relatively weak manipulation involved, and the fact that there is no general consensus as to how to measure semantic relatedness. Non-cognate translation equivalents (e.g., the English word “tree” and its French translation “arbre”) arguably provide the closest possible semantic relation between two distinct word forms. They therefore provide a fertile testing ground for the interplay between form-level and semantic-level processes during visual word recognition.

However, in line with the rather weak evidence for masked within-language semantic priming effects, behavioral studies investigating masked non-cognate translation priming effects have also produced mixed results. One standard finding in this area is that close-cognates (e.g., the English word “chair” and its French translation “chaise”) generate stronger priming effects than non-cognates (De Groot & Nas, 1991; Gollan, Forster, & Frost, 1997; Sanchez-Casas et al., 1992). Evidence for significant effects of non-cognate translation primes has mostly been obtained in language pairs with different scripts, such as Japanese and English, Hebrew and English, or Greek and French (Finkbeiner, Forster, Nicol, & Nakamura, 2004; Gollan et al., 1997; Voga & Grainger, 2007). The change in script across prime and target would allow improved processing of masked primes by providing the lexical processor with a distinct cue as to which language the word belongs to. However, robust non-cognate priming was reported by Grainger and Frenck-Mestre (1998) in same-script conditions (English-French bilinguals), but the effect was only robust when participants had to perform a semantic categorization task on target words (see Finkbeiner et al., 2004, for a replication with Japanese-English bilinguals). In the Grainger and Frenck-Mestre study, non-cognate translation primes did not significantly facilitate lexical decision responses to target words. The presence of translation priming in a semantic categorization task and not in the lexical decision task suggests that the effect is indeed

¹There is some controversy surrounding the presence/absence of N400 masked semantic priming effects. While Deacon et al. (2000), Kiefer (2002), and Grossi (2006) have reported significant N400 effects in masked semantic priming experiments, Holcomb et al. (2005) have shown that masked semantic priming N400 effects are predicted by conscious awareness of the prime. This suggests that monolingual masked semantic priming is unreliable at best and is most likely due to conscious processing of the primes.

semantically mediated, and not the result of direct form-level connections between translation equivalents as postulated in the RHM of Kroll and Stewart (1994).

The present study combines masked within-language and between-language (i.e., non-cognate translation) priming with event-related potential (ERP) recordings in order to: a) examine the relative contributions of form- and meaning-based representations in bilingual word processing, b) have a potentially overall more sensitive measure of priming effects, and c) provide finer-grained information about the time-course of priming effects both within and between-languages. Two prior ERP studies have examined unmasked non-cognate translation priming effects. (Alvarez et al., 2003; Phillips et al., 2006).² Of particular relevance to the current study is one by Alvarez et al. Using visually presented words, these authors found evidence for translation priming effects in the N400 component that were larger and started earlier when primes were in L2 and targets in L1. This result is in line with the predictions of the RHM (Kroll & Stewart, 1994). According to this model, L2 words should automatically activate their L1 translations, and should do so to a greater extent and more rapidly than L1 words activate their L2 translations. However, there is an alternative interpretation of the Alvarez et al. findings. Because the stimulus-onset-asynchrony (SOA) in their study was 2700 ms and the primes were unmasked, translation priming might have been due to participants using an overt translation strategy. If this strategy was employed, it would presumably be used primarily in one direction to aid in L2 comprehension. In other words, the L2 items during the long SOA would be overtly translated into L1 in order to facilitate the semantic categorization decision required on each trial, and the resulting priming on subsequent L1 targets would actually be more like L1-L1 priming. In the current study we rectify the problems of the Alvarez et al. study by using masked priming and by blocking by language. This combination should minimize the possibility of any strategic influences on processing as participants should be unaware of the occurrence of primes in the non-target language and therefore should not engage in overt prime translation (Forster et al., 2003). Blocking by language for target words should also minimize the bilingual nature of the study because participants should only be aware of words in a single language in each block. This is important because it has been suggested (Grosjean & Miller, 1994) that bilinguals may have different processing modes; one for situations where both the bilinguals languages are required and one for monolingual situations. In the current experiment we were interested in biasing the participants towards monolingual processing in order to more clearly explore the more automatic aspects of interactivity between languages, that is, those not under strategic control.

In recent monolingual research, the masked priming paradigm has been combined with ERP recordings to successfully map out the time-course of component processes in visual word recognition (e.g., Grainger et al., 2006; Holcomb & Grainger, 2006; Kiyonaga et al., 2007). Holcomb and Grainger (2006) described a cascade of ERP components found to be sensitive to their repetition priming manipulation. The first of these relevant to the current study is the N250, a negative-going component which peaks near 250 ms. Holcomb and Grainger reported that the N250 was more negative and had a slightly earlier peak latency to target words that were not full repetitions of or that had no overlap with their primes. Full repetitions produced the least N250 activity. Holcomb and Grainger postulate that the N250 reflects processes in visual word recognition where sublexical form representations (letters and letter combinations) are mapped onto the lexical system. The second component of relevance here was the N400, a negativity that starts around 350 ms and peaks between 400 and 600ms. The N400 was more negative for unrelated items than for items that were partial repetitions and was least negative for fully repeated items. The results of a host of studies are consistent with the hypothesis that

²Unlike the Alvarez et al. (2003) study and the current study, the bilinguals in the Phillips et al. (2006) study were nearly equally competent in both languages and the stimuli were auditory, which makes comparisons between studies difficult. However, Phillips et al. did report asymmetrical N400 effects for within- and between-language priming on the N400.

the N400 reflects some aspect of semantic processing (e.g., Kutas & Hillyard, 1980; Kounios & Holcomb, 1992, 1994). Given the influence of partially overlapping nonword primes (e.g., teble-table), Holcomb and Grainger (2006) argued, however, that the N400 may also be sensitive to processing at the interface between whole-word form representations and semantics.

In order to obtain an improved picture of the time-course of form and meaning activation both within and between the lexical and semantic systems of second language learners, the present study compares within-language repetition priming and non-cognate translation priming using the same paradigm as Holcomb and Grainger (2006). This methodology should allow us to observe and compare the time course of processing during L1 and L2 repetition priming as well as translation priming in both directions (L1–L2, L2–L1). The N250 and N400 ERP components will be used to infer form-level and semantic-level influences on processing. Even if these two components reflect to some extent a combination of form and semantic influences, we expect form-level influences to be greater on the N250, and semantic level influences to be greater on the N400. This then allows us to test the predictions of the RHM (Kroll & Stewart, 1994) and BIA model (Grainger & Dijkstra, 1992). In the RHM there are stronger links from L2 to L1 than from L1 to L2 lexical form representations, and weaker links between L2 lexical representations and meaning than between L1 lexical representations and meaning. L2 primes should therefore affect form-level processing of the upcoming translation in L1, and hence modulate the N250 component. In this same case the N400 would be subject to modulation as well due to the semantic relatedness of prime and target. L1 primes, on the other hand, should mostly affect semantic level processing of upcoming L2 translations, and therefore only modulate the N400 component. According to the BIA model, translation priming is always semantically mediated (i.e., there are no excitatory connections between lexical form representations of translation equivalents), hence most of the effects should be evident in the N400. Some priming effects are nevertheless expected on the N250 component via feedback from semantics to lexical representations (Voga & Grainger, 2007), and these should be most evident with L1 primes and L2 targets, simply because it is assumed that L1 words are processed more rapidly and efficiently than L2 words. If this is indeed the case, we should also observe smaller and later effects in L2–L2 repetition priming than L1–L1 repetition priming.

Experiment 1

In Experiment 1, ERP masked repetition priming effects of both within- and cross-language primes (L2–L2 repetition priming and L1–L2 translation priming) on L2 targets were measured in a 67ms SOA prime-target paradigm designed to decompose the different components elicited by priming. In this experiment all visible items are targets in participants' L2. Masked primes are either L1 or L2 words.

Methods

Participants—Thirty-six participants (32 female, mean age = 20.3, SD = 1.2) were recruited during their second year of English studies at the Université de Provence in Aix-en-Provence, France and paid for their participation. All were right handed (Edinburgh Handedness Inventory, Oldfield, 1971) and had normal or corrected-to-normal visual acuity with no history of neurological insult or language disability. French was reported to be the first language learned by all participants (L1) and English their primary second language (L2). All participants began their study of English in their sixth year of primary school at approximately the age of 12 years, as is customary in the French school system.

Participants' auto-evaluation of English and French language skills were surveyed by questionnaire. On a seven-point Likert scale (1 = unable; 7 = expert), participants reported their abilities to read, speak, and comprehend English and French as well as how frequently they

read in both languages (1 = rarely; 7 = very frequently). The overall average of self-reported languages skills in French was 6.8 (SD = 0.1) and in English was 4.9 (SD = 0.1). Our participants reported their average frequency of reading in French as 6.4 (SD = 0.9) and in English as 5.4 (SD = 1.3). After the experiment participants were asked to translate all of the L2 target words that they saw into their L1. The mean score on this post-test was 82.4% (SD = 9.0, range 63.9% to 97.7%).

Stimuli—The critical stimuli for this experiment were 400 four- to eight-letter English words and their translations into French. The English items had a mean CELEX (<http://www.ru.nl/celex>) log frequency of 1.74 (SD = 0.61, range 0.00–3.51). The French items had a mean Lexique (New et al., 2001) log frequency of 1.65 (SD = 0.63, range 0.00–3.14). The correlation of the log frequencies of the English and French items was 0.74 ($p < .001$). In selecting items care was taken to avoid any cross language homophones (e.g., *lasse-lace*) as well as cross language homographs (e.g., “coin” meaning corner in French). Overly polysemous words were also avoided (e.g., *carte* in French could mean map or menu, or card in English). Words with accents were excluded, to prevent the eventual identification of French items in the prime position and (important in Experiment 2 where all targets are in caps and in French) because the use of accents in upper case French words is non-standardized (*état* could be written *ETAT* or *ÉTAT*, or *PASSE* could be *passee* or *passé*). Finally, all stimuli were morphemically simple items. The non-critical stimulus pairs (used in probe trials) were formed by combining four- to eight-letter English animal names with unrelated non-animal words.

For both the critical and probe trials, the first stimulus was referred to as the *prime* and the second as the *target*. Primes were presented in lower case letters and targets in upper case (this was done in order to minimize the physical similarity between repeated items). Stimulus lists consisted of a pseudorandom mixture of trials where the target was a full repetition of the prime in L2 (e.g., beach—BEACH), trials where the prime was an L1 translation of the target (e.g., *plage*—BEACH), trials where the prime and target were unrelated L2 words (e.g., sleep—BEACH) and trials where the prime was an L1 word unrelated to the L2 target (e.g., *miel*—BEACH). Lists were formed so as participants saw a subset of 40 of the 400 critical items in each condition. Across lists (and participants), each target word appeared in each of the four conditions (REPETITION, TRANSLATION, UNRELATED WITHIN LANGUAGE, UNRELATED ACROSS LANGUAGE), but within lists each target stimulus was presented only once. An important feature of this design is that the prime and target ERPs in the repeated, translation, and unrelated conditions are formed from exactly the same physical stimuli (across participants) which should reduce the possibility of ERP effects across conditions due to differences in physical features or lexical properties.

Each list also contained 36% non-critical trials, half of which had an English animal name in the prime position and an English filler word in the target position and the other half of which had an unrelated filler word in the prime position and an English animal name in the target position. The animal names served as probe items in a go/no-go semantic categorization task in which participants were instructed to rapidly press a single button whenever they detected an animal name. Participants were told to read all other words passively without responding (i.e., critical stimuli did not require an overt response). Probe items were placed in the prime position to serve as a measure of prime detectability and provide an objective measure of the effectiveness of the masking procedure. A practice session was administered before the main experiment to familiarize the participant with the task.

Procedure—Visual stimuli were presented using an in-house stimuli presentation software on a 15” monitor set to a refresh rate of 60 Hz (which allows 16.67 ms resolution of stimulus control) and located 143 cm directly in front of the participant. Stimuli were displayed at high contrast as white letters on a black background in the Verdana font (letter matrix 20 pixels

wide × 40 pixels tall). Each trial began with a forward mask of 12 hash marks(#####) presented for a duration of 200 ms. The forward mask was replaced at the same location on the screen by a lower case prime item for 50 ms. The prime was then immediately replaced by a 10-character uppercase random consonant string backward mask (ZJGRRFMXHG). The backward mask remained on the screen for 17 ms (one frame) and was immediately replaced by the target in uppercase letters for a duration of 300 ms. All target words were followed by a 1000 ms blank screen which was replaced by a blink stimulus (see Figure 1). The participants were instructed to blink only during the 1500 ms that this stimulus was on the screen. The blink stimulus was followed by 500 ms of blank screen, after which the next trial began.

EEG recording procedure—Participants were seated in a comfortable chair in a sound attenuated darkened room. The electroencephalogram (EEG) was recorded from 29 active tin electrodes held in place on the scalp by an elastic cap (Electro-Cap International, Inc., Eaton, OH, USA—see Figure 2). In addition to the 29 scalp sites, additional electrodes were attached to below the left eye (to monitor for vertical eye movement/blinks), to the right of the right eye (to monitor for horizontal eye movements), over the left mastoid bone (reference) and over the right mastoid bone (recorded actively to monitor for differential mastoid activity). All EEG electrode impedances were maintained below 5 k Ω (impedance for eye electrodes was less than 10 k Ω). The EEG was amplified by an SA Bioamplifier (San Diego, CA, USA) with a bandpass of 0.01 and 40 Hz, and the EEG was continuously sampled at a rate of 200 Hz throughout the experiment.

Data analysis—Averaged ERPs time-locked to target onset were formed off-line from trials free of ocular and muscular artifact (less than 10% of trials) and were bandpass filtered at .5 and 15 Hz. Four types of targets were formed from two levels of PRIMING-TYPE (within-language v. between-language) and two levels of REPETITION (repeated vs. unrelated; note that between-language repetition is L1–L2 translation priming, e.g., *plage*—BEACH). The main analysis approach involved measuring mean amplitudes in three temporal epochs surrounding the two primary repetition ERP effects reported by Holcomb and Grainger: the N250 and N400. To best capture activity in the N250 epoch, we selected a typical window surrounding the component from 200–300 ms. To best capture N400 activity, which varied in its time-course as a function of language and priming (see Figures 3a and 3b), we selected two windows, the first of which was within the range typical for this component in many previous L1 studies (350–500 ms) and a second which was later (500–650 ms) and more in line with the later time-course of the N400 for L2 translation priming reported by Alvarez et al. (2003). Separate repeated measures analyses of variance (ANOVAs) were used to analyze the data in each of these three epochs. The Geisser-Greenhouse (1959) correction was applied to all repeated measures with more than one degree of freedom in the numerator. Separate follow-up analyses for the within- and between-language conditions were performed in cases of significant REPETITION by PRIME-TYPE interactions.

In order to thoroughly analyze the full montage of 29 scalp sites, we employed an approach to data analysis that we have successfully applied in a number of previous studies (e.g., Holcomb et al., 2005). In this scheme the 29-channel electrode montage is divided up into seven separate parasagittal columns along the antero-posterior axis of the head (see Figure 2). The electrodes in each of three pairs of lateral columns and one midline column are analyzed in four separate ANOVAs. Three of these analyses (referred to as Column 1, Column 2, or Column 3) involved an anterior/posterior ELECTRODE-SITE factor with either three, four or five levels, as well as a HEMISPHERE factor (Left vs. Right). The fourth “midline” analysis included a single anterior/posterior ELECTRODE-SITE factor with five levels.

Results

Visual inspection of ERPs—The ERPs time locked to targets from 29 electrode sites for the repetition and translation priming conditions are plotted in Figure 3a and b. Figure 4 presents enlargements of the CP1 and CP2 sites from Figure 3. Figure 5 and Figure 6 are the voltage maps for the repetition and translation priming conditions for time periods surrounding the N250 and N400. As can be seen in Figure 3, ERPs in the target epoch varied substantially as a function of both the REPETITION and the PRIMING-TYPE factors. In looking over these plots, one must keep in mind that at the short SOA used in this experiment, the ERPs time locked to the target are a composite of neural activity generated by both the target and the immediately preceding prime and masking stimuli. The influence of the pre-target stimuli can be seen in the sequence of positive and negative peaks, which start prior to the vertical calibration bar and run through the first 150 ms of the target epoch. However, starting at about 150–200 ms the morphology of the waveforms more closely conform to typical target ERP components, which include the anteriorly distributed P2 peaking at approximately 180 ms post-target onset and more posterior negativities, probably reflecting N1 target activity, also peaking just before 200 ms. Starting at approximately 180 ms, the various independent variables appear to start exerting their influence on the ERPs. In the following sections we detail these effects in each of four measurement windows.

Analyses of ERP Data

N250: 200–300 ms epoch—In this epoch an omnibus ANOVA on the mean amplitudes between 200 and 300 ms produced a main effect of PRIMING-TYPE at all columns (midline: $F(1,19) = 14.694, p = .001$; C1: $F(1,19) = 10.034, p = .003$; C2: $F(1,19) = 11.953, p = .001$; C3: $F(1,19) = 15.535, p < .001$) indicating that target ERPs were more negative going for trials with a language switch between the prime and target (i.e., L1–L2) than for trials where both the prime and target were in the same language (i.e., L2–L2). The main effect of REPETITION was also significant at all columns (midline: $F(1,19) = 5.071, p = .031$; C1: $F(1,19) = .162, p = .029$; C2: $F(1,19) = 5.562, p = .024$; C3: $F(1,19) = 7.746, p = .009$) indicating that targets following unrelated primes were more negative-going than targets that were repetitions or translations of the primes.

Although there was not a significant interaction between REPETITION and PRIMING-TYPE, examination of Figure 3 to Figure 6 suggests that the negativity in this measurement window has a somewhat different time-course for the within-language and between-language conditions. To assess this visual impression we employed an analysis strategy used by Phillips et al. (2006) for analyzing the time-course of bilingual priming. We divided the theN250 epoch into two sub-windows, an earlier 200–250 ms epoch and a later 250–300 ms epoch. TIME EPOCH was then entered as an additional factor into the ANOVA. These analyses resulted in significant TIME EPOCH (early vs. late) by REPETITION by PRIMING-TYPE by HEMISPHERE interactions in the C2 and C3 columns (C2: $F(1,35) = 5.08, p = .031$; C3: $F(1,35) = 6.29, p = .017$; marginal C1: $F(1,35) = 2.90, p = .098$). Following these significant interactions we then used separate follow-up analyses of the two priming types to better characterize the interactions in each sub-epoch for the three lateral analysis columns (C1, C2, and C3). In the earlier window (200–250 ms) only the within-language comparison resulted in significant REPETITION effects (C1: $F(1,19) = 3.635, p = .065$; C2: $F(1,19) = 5.606, p = .024$; C3: $F(1,19) = 5.477, p = .025$). However, in the later epoch (250–300 ms) there were no significant REPETITION effects for the within-language condition (all $F_s < 3; p > .098$), but in the between-language condition there were significant interactions between REPETITION and HEMISPHERE at all three lateral columns (C1: $F(1,19) = 4.617, p = .039$; C2: $F(1,19) = 4.237, p = .047$; C3: $F(1,19) = 6.793, p = .013$). As can be seen in Figure 4 and Figure 6, these later effects were due to the between-language REPETITION effect being larger over the right hemisphere in this later epoch.

N400 early: 350–500 ms epoch—There was a REPETITION by ELECTRODE SITE interaction at the midline sites ($F(4, 140) = 4.34, p = .026$; marginal at C3: $F(4, 140) = 3.51, p = .054$) indicating that the small REPETITION effect in this window tended to be larger at central and posterior sites. There were no interactions between REPETITION and PRIME-TYPE in this epoch (all $F_s < 1.0$).

N400 late: 500–650 ms epoch—There were robust effects of REPETITION across the four analysis columns (midline: $F(1, 35) = 5.18, p = .029$; C1: $F(1, 35) = 5.28, p = .028$; C2: $F(1, 35) = 4.81, p = .035$; C3: $F(1, 35) = 4.90, p = .033$) with unrelated targets producing more negative-going responses. At the midline and more lateral columns this effect tended to be larger at posterior sites as indicated by significant REPETITION by ELECTRODE SITE interactions (midline: $F(4, 140) = 6.39, p = .005$; C2: $F(3, 105) = 5.92, p = .011$; C3: $F(4, 140) = 6.59, p = .007$). There were no significant REPETITION by PRIME-TYPE interactions in this epoch (all $F_s < 2.2$).

Behavioral Data

Participants detected 81.5% ($SD = 6.6$) of animal probes in the target position and had on average 1.9 false alarms ($SD = 2.4$). No participants detected or pressed to any animal probes in the prime position, and no participants reported seeing any primes during debriefing at the end of the experiment.

Discussion

As in several recent ERP studies (e.g., Holcomb & Grainger, 2006; Chauncey et al., 2008), two negativities, the first peaking at around 250 ms (N250) and the second after 400 ms (N400), were modulated by repetition. The N250 has been argued to reflect the mapping of sublexical orthography onto lexical representations and the N400, the mapping of lexical form onto meaning (Grainger and Holcomb, in press). The effects on the N400 are consistent with two previous studies of unmasked repetition priming in L2 and translation priming from L1 to L2 (Alvarez et al., 2003; Phillips et al., 2006). Likewise, the extended time-course of the N400 translation priming effect found here is also consistent with these previous studies.³ New here is the observation that when primes are masked repetition effects occur within a second language (L2-L2) on both the N400 and the earlier N250. This is important proof that our L2 prime words were being effectively processed in the extreme masking conditions used in the present study.

Also new here is the finding of a clear modulation of both the N250 and N400 components when the prime words were presented in L1 and the targets in L2. This is a critical finding given that there was minimal form overlap in the non-cognate translation equivalents used in the present study. This therefore suggests a semantic influence on processing that is reflected in the N250 component. The architecture of the BIA model (Grainger & Dijkstra, 1992; van Heuven et al., 1998) enables such semantic influences on lexical form representations. For the RHM (Kroll & Stewart, 1994), on the other hand, such influences could arise via direct connections between lexical representations of translation equivalents. However, given the asymmetrical nature of these connections, the RHM predicts relatively weak effects from L1 to L2, which should be amplified when primes are in L2 and targets in L1. Experiment 2 tests this prediction by presenting all targets in L1.

³The continuation of the priming effects into the 550–650 ms range might appear too late to be an N400 effect. Therefore, it would be reasonable to entertain the alternative interpretation that the effects may reflect a late positive component. However Alvarez et al. (2003) and Phillips et al. (2006) both showed prolonged N400 effects in the case of L1–L2 translation priming and to a lesser extent for L2-L2 priming. Moreover, at least one previous study has concluded that LPC repetition effects are non-existent or greatly attenuated in masked priming (Misra, 2003). So it would seem that the most parsimonious explanation is that the late negative difference is due to a prolonged N400 for words processed in L2.

Experiment 2

In Experiment 2, ERP masked repetition priming effects of both within and cross-language primes (L1-L1 repetition priming and L2 to L1 translation priming) on L1 targets were measured in a 67ms SOA prime-target paradigm that was procedurally identical to Experiment 1 except that the targets were in participants' L1 while masked primes were in both L1 and L2.

Methods

Participants—The same 36 participants who served in Experiment 1 also participated in this experiment.

Stimuli and procedure—The critical and non-critical stimuli were the same as in Experiment 1, but the lists were constructed and counter-balanced with all of the targets in L1 (French). The lists were constructed with subsets of 400 critical items from each language so that there would be no repetition of primes or targets for any given participant between Experiment 1 and 2. The order of the experiments was counterbalanced across participants. The timing of the masked priming paradigm, the procedure, and the laboratory were the same as in Experiment 1, as well as the EEG recording, electrode montage, and the data analysis. The time between the experiments was varied according to the availability of the participants, from same day to four weeks. The average time between experiments was 21 days. The order of the experiments was counterbalanced across participants.

Data analysis—The same approach to data analysis as Experiment 1 was used for Experiment 2.

Results

Electrophysiological Data

Visual inspection of ERPs: The ERPs time locked to targets from 29 electrode sites for the repetition and translation priming conditions are plotted in Figure 7a and b. Figure 8 presents enlargements of the CP1 and CP2 sites from Figure 7. Figure 9 and Figure 10 are the voltage maps for the REPETITION effect in the within-language priming condition and the between-language priming condition for time periods surrounding the N250 and N400. As can be seen in the Figure 7 plots, ERPs in the target epoch varied substantially as a function of both the REPETITION and the PRIMING-TYPE factors.

Analyses of ERP Data

N250: 200–300 ms epoch: The omnibus ANOVA on the mean amplitudes between 200 and 300 ms produced an interaction between REPETITION and PRIMING-TYPE at all columns (midline: $F(1,19) = 5.046, p = .031$; C1: $F(1,19) = 4.873, p = .034$; C2: $F(1,19) = 5.482, p = .025$; C3: $F(1,19) = 7.110, p = .012$). To better understand this interaction, separate follow-up analyses of the two priming types were run. In these analyses there were significant effects of REPETITION at all columns for the within-language condition (midline: $F(1,19) = 8.203, p = .007$; C1: $F(1,19) = 8.339, p = .007$; C2: $F(1,19) = 8.502, p = .006$; C3: $F(1,19) = 12.371, p = .001$). No significant effects were found for the between-language condition in this epoch (all $F_s < 1$ —see Figure 7, Figure 8, and Figure 10).

N400 early: 350–500 ms epoch: In this window there were again significant REPETITION by PRIME-TYPE interactions (midline: $F(1,35) = 4.69, p = .037$; C1: $F(1,35) = 6.14, p = .018$; C2: $F(1,35) = 6.59, p = .015$; C3: $F(1,35) = 5.78, p = .022$). To better understand these interactions, separate follow-up analyses of the two priming types were run. For the within-language condition there were significant REPETITION effects (midline: $F(1,35) = 7.77, p = .008$).

009; C1: $F(1,35) = 10.28, p = .003$; C2: $F(1,35) = 10.75, p = .002$; C3: $F(1,35) = 7.63, p = .009$) and significant REPETITION by ELECTRODE SITE effects (midline: $F(4,140) = 6.69, p = .003$; C2: $F(3,105) = 4.50, p = .023$; C3: $F(4,140) = 4.99, p = .015$). Examination of Figure 7a, Figure 8, and Figure 10 reveals that the unrelated targets were more negative-going across the scalp than were the repeated targets. Unlike the previous epoch, there were now also significant REPETITION by ELECTRODE SITE effects for the between-language condition (midline: $F(4,140) = 3.56, p = .034$; C3: $F(4,140) = 4.10, p = .032$). However, while the within-language REPETITION effect was due to consistently more negative going potentials for unrelated compared for repeated targets across the scalp, for the between-language REPETITION there was a negative-going effect at the back of the head (unrelated more negative than translation targets), but a reversed positive-going pattern at more frontal sites (see Figure 9 and Figure 10). This latter effect took the form of amore positive potential for unrelated compared to translation targets.

N400 late: 500–650 ms epoch: In this temporal window there were again significant interactions between REPETITION, PRIME-TYPE, and ELECTRODE SITE at the midline and the more lateral sites (midline: $F(4,140) = 4.17, p = .023$; C2: $F(3,105) = 3.30, p = .061$; C3: $F(4,140) = 3.98, p = .03$). Separate follow-up analyses for the two prime types did not reveal any significant REPETITION effects for the within-language contrasts (all $F_s < 1$). However, like the previous epoch the between-language contrast revealed a posterior negativity for unrelated compared to translation targets, and an anterior positivity for this same contrast (REPETITION by ELECTRODE SITE effect, midline: $F(4,140) = 4.54, p = .02$; C3: $F(4,140) = 3.88, p = .039$).

Behavioral Data—Participants detected 95.7% ($SD = 5.5$) of animal probes in the target position and had on average 0.75 false alarms ($SD = 0.8$). No participants reported seeing any primes, even when prompted. Two participants detected or pressed to one animal probe in the prime position each. These were presumably false alarms to the targets associated to these animal probe primes.

Discussion

As in Experiment 1, we again found robust ERP repetition priming effects when the prime and target were within the same language. These effects replicate those of Holcomb and Grainger (2006) finding similar N250 effects and N400 effects for repetition priming. Moreover, the N400 effect for L1-L1 priming did not extend past the traditional N400 window as it did in Experiment 1 for L2-L2 priming. Also, unlike Experiment 1, but compatible with the bulk of the behavioral literature examining L2-L1 priming (e.g., Jiang, 1999), we found no evidence of a translation priming in the N250 epoch, although there was evidence of such priming in both the early and late N400 measurement epoch. The nature of these N400 effects was not like that found in Experiment 1 for translation priming. In Experiment 1 both within- and between-language priming in the N400 windows appeared to modulate a broadly distributed negativity. In Experiment 2, within-language priming followed this same pattern (although it terminated earlier). However, the between-language contrast revealed a very different pattern with what appeared to be a posterior N400 effect but a reversed anterior positive-going effect.

Finally, it is important to contrast the total absence of between-language priming (L2-L1) in the N250 component in Experiment 2 with the presence of within-language (L2-L2) priming found in Experiment 1. The absence of translation priming effects in this ERP component when primes are in L2, in association with the robust effects found in Experiment 1 when primes are in L1, counters the predictions of the RHM and provides support for the BIA model. The full implications of these findings are discussed below.

General Discussion

The present study tested within-language repetition priming and between-language non-cognate translation priming in second language learners using the masked priming paradigm and ERP recordings. It was argued in the introduction that this paradigm offers a strong test of the time-course of interactivity at the lexical and semantic level of representation between a bilingual's two language systems. It was also pointed out that non-cognate translation priming is an interesting testing ground for semantic priming effects in the absence of form overlap across primes and targets. On the basis of prior work combining masked priming and ERPs (e.g., Holcomb & Grainger, 2006), we expected to observe within-language repetition effects in an early component (N250), thought to reflect sublexical processing, and both within-language repetition priming and between language translation priming in the later N400 component (thought to at least partly reflect semantic-level processing).

The N400 was found to be sensitive to non-cognate translation priming, in both directions, although the distribution of the effect and the presence of a temporally coincident anterior positive effect in Experiment 2 suggest that there are likely differences in the mechanisms supporting priming in the two directions. The findings on the N400 then are in line with the general consensus that this component reflects processing at a semantic/conceptual level. The fact that the pattern of the effect with L2 primes and L1 targets is somewhat different could be due to the amount of processing necessary to generate such semantic-level effects (i.e., primes would be less efficiently and less rapidly processed in L2 than L1 in our participants who are learners and not balanced bilinguals).

The N250 was found to be sensitive to within-language repetition priming in both L1 and L2, and most important, non-cognate translation primes were also found to modulate N250 amplitude when primes were in L1 and targets in L2, although the time-course of this effect was somewhat later. No such translation priming effect on N250 amplitude was found in Experiment 2 when primes were in L2 and targets in L1. The fact that the N250 ERP component was found to be sensitive to non-cognate translation priming when primes were in L1 and targets in L2 (Experiment 1) is perhaps the key finding of the present study. Holcomb and Grainger (2006) suggested that the N250 reflects purely form-level processing—the mapping of sublexical form (letters and letter clusters) onto whole-word orthographic representations. The present results provide a clear demonstration that semantic overlap across primes and targets, in the absence of form overlap, can influence N250 amplitude. In the present study, this semantic influence occurred in the later phase of the N250, peaking at around 300 ms post-target onset (see Figure 6). This therefore provides us with an upper limit for the onset of semantic influences during visual word recognition. Based on the delayed time-course of the N250 in L1–L2 translation condition, this suggests that there is a rather short lag (around 50 ms) between sublexical form processing and availability of semantic information. This is in line with cascaded activation accounts of lexical processing (e.g., McClelland & Rumelhart, 1981), according to which higher level codes are activated with a minimal lag relative to lower-level processing. In a similar vein pointing to the possibility of cascaded processing, Grainger, Kiyonaga, and Holcomb (2006) have also shown a lag of approximately 50 ms between the earliest modulation of the N250 by an orthographic manipulation (transposed-letter priming) and a later effect produced by a phonological manipulation (pseudohomophone priming).

The observed effect of translation primes on the N250 fits nicely with a recent finding reported by Morris, Franck, Holcomb, and Grainger (2007) that the N250 is sensitive to the semantic transparency of morphologically related primes and targets. In this study, a distinct pattern of N250 priming effects was found for transparent prime-target pairs, where the prime has a clear semantic relation with the target (e.g., baker—bake) compared with opaque pairs, where there is no obvious semantic relation between primes and targets (e.g., corner—corn). Morris et al.

argued that these semantic influences on the N250 likely reflect interactive processing, whereby higher-level semantic information feeds back to influence on-going form-level processing. In such an account, semantic information is rapidly accessed during visual word recognition, after some minimal form-level processing. This information is then fed back to lower levels of processing in order to generate a resonant activation state allowing a single form-meaning association to emerge as the best interpretation of the stimulus.

In terms of models of bilingual word recognition, the present results fit well with the bilingual extension of McClelland and Rumelhart's (1981) interactive-activation model—the BIA model (Grainger & Dijkstra, 1992; van Heuven et al., 1998). L1 primes would rapidly activate the corresponding semantic representation that would in turn feed back information to appropriate form-level representations in L1 and L2, hence modifying processing of L2 targets that are translations of the L1 prime. One could argue, however, that this translation priming effect reflects direct connectivity between the form representations of translation equivalents, as postulated in the RHM (Kroll & Stewart, 1994). In this case, translation priming would not reflect semantic-level processing, as argued above. The fact that the N250 translation priming effect was asymmetrical (i.e., observed only when translation primes were in L1 in Experiment 1 and not observed when translation primes were in L2 in Experiment 2), as has been found in behavioral studies of translation priming, would appear to be strong evidence against a lexically mediated (form-based) account of these effects as per the RHM. According to Kroll and Stewart's model, direct connectivity across translation equivalents is stronger from L2 to L1 than vice versa, particularly in second language learners such as the participants of the present study. Therefore, according to a direct connectivity account of translation priming, we ought to have observed stronger effects with L2 primes and L1 targets.

It is nevertheless possible that the absence of translation priming from L2 to L1 in the present study is simply a reflection of the inability of our participants to rapidly process briefly presented primes in their L2. This handicap in processing briefly presented primes in L2 would be further exaggerated when all visible words (i.e., targets) are in L1. This could arise via a global inhibition operating between languages, such that all L2 representations would be partially suppressed when processing in a seemingly monolingual L1 context. This would explain why we obtained robust effects on N250 amplitude when both primes and targets were in L2 (repetition priming), since L2 prime processing would be enhanced in this context. If this interpretation is correct, then we ought to be able to increase L2-L1 translation priming effects by having a large number of L2 targets intermixed with the L1 targets. This would disable any kind of monolingual processing mode and therefore prevent the global inhibition of L2 representations.

One problem with the above characterization is that, although there were no N250 effects for translation priming in Experiment 2, there were significant priming effects later during the N400 window. If L2 primes in an L1 processing mode are not being processed, then they should not have produced these later effects. Therefore it seems more likely that the L2 primes in Experiment 2 were processed but that, because processing of L2 items is less efficient and slower (as indicated by the later N400 effects to L2 targets), there was not sufficient time in this short SOA paradigm for feedback from the semantic level to the form level to exert its influence on the L1 N250. If this is correct, then lengthening the SOA so as to allow the prime processing to progress further might boost feedback enough to support N250 type effects with L2 primes and L1 translation targets.

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Figure 1.
A typical trial. Here is an L1-L2 translation prime.

Figure 2.
Electrode montage and four analysis columns used for ANOVAs.

Figure 3.

a and b. ERPs time-locked to L2 target onset in the repeated (solid) and unrelated (dashed) conditions for the: (a) within-language (L2-L2) and (b) between-language (L1-L2) comparisons. In this and all subsequent ERP figures, negative voltages are plotted upward and target onset is indicated by the vertical calibration bar marked by the arrow with a "T" below it in the lower left time scale legend (prime onset, which was 67 ms earlier, is marked by the arrow with a "P" below it). Refer to Figure 2 for electrode locations.

Figure 4.
Enlargement of CP1 and CP2 sites from Figure 3a and b. ERPs are time-locked to targets in L2.

Figure 5. Voltage maps calculated from difference waves (Unrelated-Repeated) for the within-language condition at each of nine time points encompassing the N250 and N400 epochs (L2-L2 priming).

Figure 6. Voltage maps calculated from difference waves (Unrelated-Translation) for the between-language condition at each of nine time points encompassing the N250 and N400 epochs (L1–L2 priming).

Figure 7.
a and b. ERPs time-locked to L1 target onset in the repeated (solid) and unrelated (dashed) conditions for the: (a) within-language (L1-L1) and (b) between-language (L2-L1) comparisons. All else is as in Figure 3.

Figure 8.

a: Enlargement of sites CP1 and CP2 from Figure 7a and b. Targets in L1. b: Enlargement of sites FPz and Oz from Figure 7a and b. Targets in L1.

Figure 9.

Voltage maps calculated from difference waves (Unrelated-Repeated) for the within-language condition at each of nine time points encompassing the N250 and N400 epochs (L1-L1 priming).

Figure 10.

Voltage maps calculated from difference waves (Unrelated-Repeated) for the between-language condition at each of nine time points encompassing the N250 and N400 epochs (L2-L1 priming).