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On the Time Course of Accessing Meaning in a Second Language: An Electrophysiological and Behavioral Investigation of Translation Recognition

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Abstract

In 2 experiments, relatively proficient Chinese–English bilinguals decided whether Chinese words were the correct translations of English words. Critical trials were those on which incorrect translations were related in lexical form or meaning to the correct translation. In Experiment 1, behavioral interference was revealed for both distractor types, but event-related potentials (ERPs) revealed a different time course for the 2 conditions. Semantic distractors elicited effects primarily on the N400 and late positive component (LPC), with a smaller N400 and a smaller LPC over the posterior scalp but a larger LPC over the anterior scalp relative to unrelated controls. In contrast, translation form distractors elicited a larger P200 and a larger LPC than did unrelated controls. To determine whether the translation form effects were enabled by the relatively long, 750-ms stimulus onset asynchrony (SOA) between words, a 2nd ERP experiment was conducted using a shorter, 300-ms, SOA. The behavioral results revealed interference for both types of distractors, but the ERPs again revealed different loci for the 2 effects. Taken together, the data suggest that proficient bilinguals activate 1st-language translations of words in the 2nd language after they have accessed the meaning of those words. The implications of this pattern for claims about the nature of cross-language activation when bilinguals read in 1 or both languages are discussed.

Keywords

bilingualism; lexicon; translation; electrophysiology; ERPs

To understand the meaning of words in the second language (L2), adult learners appear to exploit their existing knowledge of the first language (L1) as a means to bootstrap the new L2 into the language system (e.g., Kroll & Stewart, 1994). The reliance on the L1 translation to understand words in the L2 has been hypothesized to be a function of L2 skill, much like

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the evidence for transfer from the L1 to the L2 at the grammatical level (e.g., MacWhinney, 1997). As learners become more proficient in the L2, they are thought to be better able to understand the meaning of L2 words directly, without L1 mediation (e.g., Kroll, Michael, Tokowicz, & Dufour, 2002; Sunderman & Kroll, 2006; Talamas, Kroll, & Dufour, 1999). According to this hypothesis, although there is persistent activation of orthographically and phonologically similar lexical neighbors both within and across languages for even highly proficient bilinguals (e.g., Dijkstra, 2005; Guasch, Sánchez-Casas, Ferré, & García-Albea, 2008), the L1 translation equivalent itself does not impact L2 processing significantly unless the individual is at an early stage of acquisition or the words being processed are relatively difficult.

A number of past studies have challenged this account of the role of the L1 translation equivalent in L2 processing (see Kroll & Tokowicz, 2005, concerning the way in which translation has been used as a tool to reveal the architecture of the bilingual lexicon and Brysbaert & Duyck, 2010, and Kroll, van Hell, Tokowicz, & Green, 2010, for a recent discussion of these issues). One line of research has suggested that access to the meaning of L2 words may not require L1 mediation, even for learners at the earliest stages of acquiring the L2 (e.g., Altarriba & Mathis, 1997; Dufour & Kroll, 1995; Duyck & Brysbaert, 2004; Potter, So, Van Eckardt, & Feldman, 1984). On this account, learners immediately acquire the means to access the concepts associated with new words in the L2. Not surprisingly, many previous studies have shown that relatively proficient L2 speakers need not retrieve the L1 translation to access semantic information for L2 words (e.g., Duyck & Brysbaert, 2002, 2008; La Heij, Hooglander, Kerling, & Van der Velden, 1996). Indeed, if proficient bilinguals routinely retrieved the L1 translation equivalent, they would be unlikely to achieve the fluency normally associated with high levels of skill in L2 reading and speaking.

However, contrary to the claim that the translation equivalent may play no role in proficient performance and potentially little role in acquisition, another line of research, and the one that we address specifically in this article, has suggested that proficient bilinguals may continue to access the L1 translation equivalent even well after they have acquired a high degree of skill in the L2. Thierry and Wu (2007) asked Chinese–English bilinguals to perform a semantic relatedness judgment on pairs of words presented in English, their L2. These bilinguals were relatively proficient in the L2 and living in the United Kingdom in an English-dominant environment at the time that they were tested. Unbeknownst to the participants, on half of the semantically related and unrelated trials, the Chinese translations of the English words contained shared characters and were therefore related in lexical form. No Chinese words appeared in the experiment, but the logic was to determine whether the presence of shared characters in the Chinese translations would influence performance in English. If so, it would suggest that the Chinese translations of the English words were activated while deciding whether the English words were semantically related. Using both event-related potentials (ERPs) and behavioral measures, Thierry and Wu found evidence in the ERP record for an effect of the hidden Chinese characters. Although there was no effect in the behavioral data, the ERPs showed that the N400 was smaller for English word pairs with a shared character in their Chinese translations relative to word pairs without shared characters. This N400 attenuation was interpreted to reflect priming due to the similarity between the Chinese translations of the English words. Critically, the result suggested that not only learners at early stages of acquiring the L2 but also relatively proficient bilinguals access the L1 translation when they read words in the L2. In a more recent study, Wu and Thierry (2010) suggested that it is specifically the phonology, rather than the orthography, of L1 translation that is activated.

In the present study, we used both ERP and behavioral measures to ask whether relatively proficient Chinese–English bilinguals, immersed in an English L2 environment as were the participants in the Thierry and Wu (2007) study, would also show evidence of activating the L1 translation equivalent in a translation recognition task that has been used frequently to examine L2 learning. In translation recognition, participants are instructed to decide whether the second word in a pair is the correct translation of the first (de Groot, 1992; de Groot & Comijs, 1995). In the present study, we used a variant of the translation recognition task that has been used to identify learners' sensitivity to lexical form similarity or meaning relationships to the correct translation of an L2 word (e.g., Altarriba & Mathis, 1997; Ferré, Sánchez-Casas, & Guasch, 2006; Guasch et al., 2008; Sunderman & Kroll, 2006; Talamas et al., 1999). In this version of the task, participants need to first access the meaning of the first word and then compare it with the second word. The critical trials are those in which the two words are not correct translations. In the translation form condition, the second word resembles the lexical form of the translation (e.g., in Spanish a translation distractor for the English word *man* might be the word *hambre*, meaning "hunger," instead of *hombre* for "man"). In the semantic condition, the second word is related in meaning to the correct translation (e.g., a Spanish semantic dis-tractor for the English word *man* might be *mujer*, which means "woman"). By comparing performance on these critical conditions to controls matched on lexical properties but otherwise unrelated to the correct translation, it is possible to examine the relative sensitivity of learners at different levels of proficiency to the form and meaning of L2 words. If bilinguals can directly access the meaning of the first word, then a semantic interference effect will be observed when the later L1 word is related in meaning but not the correct translation equivalent. In contrast, if bilinguals must first access the translation equivalent to retrieve the meaning of the L2 word, then an L1 word related in form to the translation itself should produce interference.

Unlike the semantic relatedness task used by Thierry and Wu (2007), the translation recognition task explicitly requires that both languages be active. What is notable is that despite the requirement of this task to engage the translation equivalent, sensitivity to words that resemble the lexical form of the translation (i.e., interference for distractors like *hambre* that resemble *hombre*) is generally found only for relatively unskilled learners (e.g., Sunderman & Kroll, 2006; Talamas et al., 1999; but see Guasch et al., 2008). Virtually all studies using this task other than Talamas et al. (1999) have shown that there is sensitivity to semantics, even among the same less proficient L2 learners who reveal sensitivity to the form of the translation. The finding that activation of the lexical form of the L1 translation occurs for unskilled learners has been interpreted to suggest that they use the translation to mediate access to the meaning of the L2 words. Once they achieve L2 skill, the need to do so is eliminated and semantic access is hypothesized to be direct in that it does not require L1 mediation (e.g., Sunderman & Kroll, 2006; and see Linck, Kroll, & Sunderman, 2009, for evidence that semantic access may be enhanced and lexical mediation reduced for L2 learners in a language immersion context).

The conclusion based on the translation recognition studies stands in clear contradiction to the results of the semantic relatedness study reported by Thierry and Wu (2007), who reported effects of the lexical form of the L1 translation for highly skilled bilinguals. However, the evidence on translation recognition is largely based on behavioral findings alone. To our knowledge, there are only two previous published studies of translation recognition using ERP measures (Palmer, Van Hooff, & Havelka, 2010; Vigil-Colet, Perez-Olle, & Garcia-Albea, 2000). Vigil-Colet et al. (2000) did not specifically investigate the activation of the L1 translation. Palmer et al. (2010) examined translation recognition in the two directions, from the L1 to the L2 and the L2 to the L1, by comparing correct translation equivalents with incorrect translations. A larger N400 was observed for incorrect translations, and it was also larger for translations from the L2 to the L1 than for the reverse. Palmer et al. argued that their results supported the claim of the Revised Hierarchical Model (RHM) that the L1 translation equivalent is activated when processing the L2 for meaning.

Thierry and Wu's evidence for activation of the L1 translation by skilled bilinguals was based on ERP data in a semantic relatedness task that did not explicitly require activation of the L1. A number of recent experiments with unskilled L2 learners have shown that at both the lexical and grammatical levels, the ERP record may reveal implicit processes that are not evident in behavioral measures alone due to its sensitivity to the unfolding of cognitive events over time (e.g., McLaughlin, Osterhout, & Kim, 2004; Tokowicz & MacWhinney, 2005). If the behavioral evidence for activation of the L1 translation equivalent in translation recognition is observed only for unskilled L2 learners, then the relatively proficient Chinese–English bilinguals in the present study should be sensitive to semantically related distractors but not to translation form distractors. However, based on the Thierry and Wu findings, even in the absence of a translation form effect in the behavioral data, a translation form effect might be found in the ERP data. The first experiment tested that prediction.

Experiment 1: Comparing ERP and Behavioral Performance in Translation Recognition

In Experiment 1, relatively proficient Chinese–English bilinguals living in the United States immersed in their L2, English, performed a translation recognition task to assess their sensitivity to distractor words in Chinese that were related in lexical form or meaning to the correct translation of an English word. Both behavioral measures (reaction times [RTs] and accuracy) and ERP measures were examined to determine whether these relatively proficient bilinguals would reveal sensitivity to the L1 translation equivalent when processing words in the L2. Measures of both L2 proficiency in English and individual differences in cognitive resources (executive function and memory span) were taken to enable later between-groups comparisons across experiments.

Method

Participants—Participants for this and the subsequent experiment were right-handed, Chinese–English bilinguals residing in the United States in a university community. In Experiment 1, results are presented for 20 participants (11 females, ages 23.6 ± 3.9 years). A total of 33 participants initially completed the study, but data from 13 participants were excluded from the final analysis. Data from nine participants were excluded due to an insufficient number of trials: For six of these participants, trials were lost due to excess muscle artifact (primarily, but not exclusively, from blinks), for two participants trials were lost due to technical difficulties that prevented completion of the primary task, and one participant was unable to perform the primary task with the level of accuracy required to generate sufficient numbers of correct trials for analysis. In addition, four participants were excluded due to achieving lower than 60% accuracy in an English lexical decision task that was used to assess participants' L2 proficiency. The lexical decision task included low frequency but familiar four- to five-letter concrete nouns in English and matched pronounceable nonwords (i.e., pseudowords) that were orthographic neighbors of the English words. Participants saw only a given word or its matched pseudoword, although across participants each item was tested. Because the pseudowords were "legal" English forms, accurate performance on this task required knowledge of English vocabulary and could not be performed strictly with a basic understanding of English phonotactic or orthographic rules. Participants who were unable to perform this task with at least 60% accuracy were excluded to ensure that participants in the final set qualified as "highly skilled" Chinese–English bilinguals.

Participants were right-handed with no history of neurological disorders or language disorders and had normal or corrected-to-normal vision. They were all native Chinese speakers who could read simplified Chinese characters (i.e., Jian Ti Zi) and who were highly proficient in English. All except two of the participants began to learn English after the age of 6, primarily in a classroom setting. At the time of testing, all participants were living or studying in the United States. According to self-reports from a language history questionnaire, the participants' average written and spoken language proficiency on a 10-point scale ranging from 1 (*not literate/fluent*) to 10 (*very literate/fluent*) was higher in L1 than their proficiency in L2 (L1: *M* = 9.33, *SD* = 0.74; L2: *M* = 7.56, *SD* = 1.24). Although these bilinguals were relatively proficient in English as an L2, they were clearly L1-dominant. As noted earlier, they also completed a lexical decision task in English as an independent measure of L2 proficiency. Mean accuracy for nonwords for the final set of 20 participants was 81.99% (*SD* = 11.42%), and for words was 84.27% (*SD* = 9.85%). Lexical decision performance again suggests that the participants were relatively proficient in English as the L2.

Materials

In this experiment, 480 word pairs were constructed in which the first item in each pair was an English word and the second item was a Chinese word. All of the words used in the study were nouns. One hundred sixty of the pairs were correct translation pairs (*YES* trials), while the remaining 320 pairs were not correct translations (*NO* trials). Among the *NO* trials, there were two types of critical distractors: Chinese words that were related in lexical form to the correct translation of the English word (*translation form distractors*: e.g., the English word *sugar* was paired with the Chinese word for pond, "塘" [pronounced /tʰǎŋ/], which sounds like the Chinese word for sugar, "糖" [also pronounced /tʰǎŋ/] and also overlapping in visual form with this word); and Chinese words that were semantically related to the correct translation of the English word (*semantic distractors*: e.g., the English word *needle* was paired with the Chinese word for thread, "线" [pronounced/ɕiɛ̂n/], instead of the Chinese word for *needle*, "针" [pronounced /tʂə́n/]). Control items were also created where English words from the critical conditions were paired with Chinese words that were not lexically or semantically related to them (e.g., the English word *sugar* may have been paired with "弧" [pronounced /xǔ/, meaning "arc"]), creating a matched nonrelated distractor for each condition (i.e., *translation form controls* and *semantic controls*). Thus, there were four types of *NO* conditions, with 80 word pairs in each condition, and the same English words were used for the critical and control conditions of each type (translation form and semantic). Participants all saw the same *YES* trials, but the four types of *NO* trials were counterbalanced such that each English word was presented only once, paired with either its critical distractor or matched control. Because each participant saw 40 pairs in each of the four *NO* response conditions, participants were presented with equal numbers of *YES* and *NO* trials (160 of each). In each condition, half of the Chinese words contained two characters, while the remaining Chinese words contained only one character. Stimuli from the *NO* trials are provided in the Appendix, and Table 1 gives the lexical characteristics of the items in each of the four *NO* conditions.

Translation form distractors did not overlap in meaning with the correct translations, and semantic distractors did not share a form relationship (in phonology or orthography) with the correct translations. However, across trials within a given condition, distractors varied somewhat in their degree of overlap with the correct translations. Translation form distractors varied in phonological overlap with correct translations such that many were homophones with the correct translation, but some were not. In addition, character repetition for translation form distractors was minimized in order to avoid semantic priming effects, but some of the two-character translation form distractors and the correct translations shared a character (16 out of 80 trials; stimuli sharing a character are italicized in the Appendix). Semantic distractors also varied in the nature of their relationship with the correct translation (i.e., some were categorically related, some were associatively related). A separate group of

15 native Chinese speakers in Beijing were asked to rate the lexical similarity between translation form dis-tractors and the correct translations, and the semantic relatedness of semantic distractors and correct translations, using a 5-point scale ranging from 1 (*not similar in form or semantically related*) to 5 (*very similar or semantically related*). The control items and the correct translations from each condition were also rated for their lexical or semantic similarity. Results from these subjective ratings showed a significant difference in the lexical similarity of the translation form distractors to correct translations compared with their controls, $t(14) = 7.06$, $p = .000$, and a significant difference in perceived semantic relatedness to correct translations between the semantic distractors and their controls, $t(14) = 9.66$, $p = .000$.

Chinese words in the control conditions were matched to the critical items on word length and frequency. There were no significant differences between semantically related and unrelated Chinese words as well as Chinese translation form and their controls in word frequency or number of strokes. There were also no significant differences between the English words used in the semantic condition and the translation form condition in word frequency or in word length. However, the Chinese words across the semantic and translation conditions differed in word frequency, $t(159) = 3.78$, $p = .000$. Therefore, the comparisons that we report focus on within- rather than across-condition comparisons, since the critical comparisons were designed so that the related conditions were closely matched to their respective unrelated controls.

Procedure

Prior to beginning the experiment, participants were asked to provide informed consent. They then completed a 20-item handedness questionnaire and provided demographic information before completing four computerized tasks and a detailed language history questionnaire. Each participant first performed the translation recognition task. The other tasks were an English lexical decision task (LDT), the Simon task (Simon & Ruddell, 1967), and an operation span task performed in Chinese (Turner & Engle, 1989). Results from the LDT were used to verify self-reported English proficiency provided in the language history questionnaire. The Simon and operation span tasks were used to measure individual differences in attentional ability and memory resources for the purposes of matching participants across experiments (see Table 2). A number of recent studies have shown that bilinguals have advantages in both executive control ability and working memory (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004; Kroll et al., 2002). Although the present study did not specifically compare bilingual and monolingual performance, the inclusion of different bilinguals in the three experiments we report required that we demonstrate that they are otherwise similar on both language proficiency and cognitive abilities.

During the translation recognition task, participants were seated in a sound-attenuated and electrically shielded room under dim lighting conditions. Participants viewed the stimuli on a computer screen and made responses on a button box while an electroencephalograph (EEG) was monitored. Items appeared one at a time at the center of the screen in white font on a black background. English words were presented in lower case letters, while Chinese words were presented in simplified Chinese characters (i.e., Jian Ti Zi). Each trial began with a 2,000-ms fixation symbol (+), followed by a 200-ms interstimulus interval (ISI) and presentation of an English word for 500 ms. The English word was followed by a 250-ms ISI before the Chinese word appeared on the screen for 500 ms. Following the Chinese word there was a 600-ms ISI before the next trial began.

Participants were told to read each item as it was presented and to determine if the Chinese word was the correct translation of the English word. Their task was to press one button labeled *YES* for correct translations and another button labeled *NO* for incorrect translations as quickly and accurately as possible. Participants were also asked to try to limit blinks to the time during the presentation of the fixation symbol in order to reduce artifact. They were given practice with 16 similar items that were not presented elsewhere in the experiment. During the practice trials (and again during the experimental breaks where needed), participants were given feedback about their blink performance. A total of 320 word pairs were presented in the experiment, with a brief break following every 80 pairs. Participants were evenly distributed across the counterbalanced lists, and response hand was also counterbalanced across participants.

EEG recording

Twenty-nine channels of EEG activity were recorded from scalp electrodes in an elastic electrode cap (Electro-Cap International, Eaton, OH). Eleven electrodes measured from standard International 10–20 system locations at right and left hemisphere frontal (F3/F4), central (C3/C4), temporal (T3/T4), and parietal (P3/P4) sites as well as frontal (Fz), central (Cz), and parietal (Pz) midline sites. Ten additional sites were used from the Modified Combinatorial Nomenclature system representing the frontal pole (FPz), occipital pole (Oz), four left and right hemisphere frontocentral sites (FC1/FC2, FC5/FC6), and four centroparietal sites (CP1/CP2, CP5/CP6). Eight modified 10–20 system sites were also used that recorded from 33% of the distance from FPz to T3/T4 (FP1′/FP2′), 67% of the distance from FPz to T3/T4 (F7′/F8′), 33% of the distance from Oz to T3/T4 (O1′/O2′), and 67% of the distance from Oz to T3/T4 (T5′/T6′). Two electrodes measured the electro-oculogram to monitor for eye blinks and horizontal eye movements, one below the left eye (LE) and one lateral to the right eye (HE). All electrodes were referenced to the left mastoid (A1), and the right mastoid (A2) was also recorded, in order to determine if there was differential mastoid activity. Impedances for scalp and mastoid electrodes were reduced to less than 5 kilo-ohms (kΩ), and the impedances of eye electrodes were less than 20 kΩ. The EEG was amplified by an SA amplifier system with a bandpass of 0.1 to 40 hertz (Hz). Hardware filtering settings were selected to best capture the effects of interest, while minimizing potential interference due to amplifier blocking or ambient electrical noise. EEG was sampled continuously during the experiment at a rate of 200 Hz.

Data analysis—Both behavioral and electrophysiological measures were used to evaluate performance on the translation recognition task. Only correct responses were used for analysis. Behavioral reaction time (RT) and accuracy were measured based on button press responses to the second word of each pair (i.e., the Chinese word) recorded during collection of the EEG. Responses occurring between 200 ms and 2,000 ms poststimulus onset were considered valid. RTs slower than 2.5 standard deviations above a participant's mean RT were further excluded from analysis of the behavioral data as outliers. On average, 4.11% of the responses from each participant were excluded as outliers. We evaluated the interference from semantic and translation form distractors separately because each condition was paired with controls matched to the specific properties of the critical distractors. For each comparison, a paired-samples *t* test was performed.

ERPs were averaged offline for each participant at all electrode sites for each condition to provide waveforms beginning with a baseline 100 ms prior to presentation of the Chinese word and continuing until 900 ms poststimulus onset. Only correct trials free from eye and muscle artifact were included in the averages. Artifact rejection involved a two-stage process in which a standard algorithm was applied by the computer and then each participant's data were manually checked and validated as well. When needed, parameters from the standard algorithm were adjusted to ensure that the averages were based on artifact-free data. For the 20 participants included in the final sample, 10.64% (range: 0.63%–20.87%) of correct trials were rejected, with 7.86% (range: 0%–18.42%) rejected for the semantically related condition, 12.14% (range: 2.5%–21.05%) rejected for the semantic control condition, 13.21% (range: 0%–28.21%) rejected for the condition related to translation form, and 9.33% (range: 0%–20.51%) rejected for the translation form controls. Individual participants' data were subjected to a 15-Hz low pass filter, and the individual ERPs were then grand-averaged for presentation. Individual participant data prior to this filtering step were used for all statistical analyses.

Based on visual inspection of the results and prior reports, three time windows were selected for analysis of the mean amplitudes of components of interest: The P200 was analyzed from 150ms to 300 ms, the N400 was analyzed from 300 ms to 500 ms, and a late positive component (LPC) was evaluated from 500 ms to 700 ms. Repeated-measures analyses of variance (ANOVAs) were performed separately for the semantic interference effects (semantic distractors vs. their controls) and the translation form interference effects (translation form distractors vs. their controls). Additionally, separate analyses were done for the midline electrode sites (FPz, Fz, Cz, Pz, Oz) and for each of three concentric rings of lateral electrode sites (inner circle: FC1/FC2, C3/C4, CP1/CP2; middle circle: F3/F4, FC5/FC6, CP5/CP6, P3/P4; outer circle: FP1′/FP2′, F7′/F8′, T3/T4, T5′/T6′, O1′/O2′). Analyses were divided into these regions to allow for description of the topo-graphic distribution of the effects, taking into account the relative positions of the electrodes. Each set of sites allows for comparison of effects from anterior to posterior, and across the sets effects can be described along the dimension of medial (midline) to lateral (outer circle). For each set of analyses, factors of interest were experimental condition, hemisphere (if appropriate), and electrode site. The Geisser–Greenhouse correction for nonsphericity was applied when degrees of freedom were larger than 2, although nonadjusted degrees of freedom are presented. Adjusted p values are reported as significant at or below the .05 level. Only condition main effects and interactions of conditions with the other variables are reported here. Main effects and interactions involving only electrode site and hemisphere reflect topographical differences in the ERP signal that are not of primary relevance to the current work. When interactions involving condition differences were statistically significant, post hoc t tests and/or simple effects analyses were performed.

Results

Behavioral data—The behavioral results are shown in Figures 1 and 2. As noted earlier, paired-samples t tests were conducted for each distractor type and control pair separately, since semantic and translation conditions were not matched on frequency to each other. There was a significant difference between RTs for the semantically related versus unrelated conditions, $t(19) = 5.22$, $p = .000$, indicating that it took longer to reject semantically related distractors than controls. There was also a significant difference between RTs for translation form distractors and their controls, $t(19) = 4.40$, $p = .000$, indicating that participants were also slower to reject the translation form distractors. Participants were also less accurate at rejecting both the semantically related distractors, $t(19) = –6.75$, $p = .000$, and the translation form distractors, $t(19) = –5.01$, $p = .000$, relative to their corresponding unrelated controls.

ERP data: Figures 3 and 4 show the ERP waveforms for the critical *NO* conditions at all 29 scalp electrode sites. Figure 5 shows the waveforms for these conditions at three midline sites, with the components of interest labeled. All conditions elicited an N100 component (peaking about 125 ms after onset of the Chinese word), a P200 component (peaking around 250 ms), an N400 component (peaking around 360 ms), and a late positive component (LPC), beginning after approximately 500 ms. However, semantically related trials elicited a smaller N400 over the frontocentral scalp and a smaller LPC over the right posterior scalp but a larger LPC over the anterior scalp relative to semantically unrelated trials (see Figure 3). In contrast, translation form dis-tractors elicited a larger P200 and a larger LPC compared with unrelated trials (see Figure 4). These patterns were confirmed with the ANOVAs described next.

Semantic interference effect

P200: There were no significant effects of semantic distractors on the P200.

N400: There was a significant main effect of condition over the midline electrodes, $F(1, 19) = 4.93$, $p = .039$, and trends toward significance over most of the other electrode sites: inner circle: $F(1, 19) = 3.84$, $p = .07$; middle circle: $F(1, 19) = 3.23$, $p = .09$. This result reflects the fact that that the mean amplitude for the semantically unrelated control condition was more negative than that for the semantically related condition during the N400 epoch.

There was also a significant interaction between condition and electrode for each set of electrode sites: midline: $F(4, 76) = 4.27$, $p = .016$; inner circle: $F(2, 38) = 7.12$, $p = .003$; middle circle: $F(3, 57) = 4.12$, $p = .036$; outer circle: $F(4, 76) = 3.77$, $p = .041$. Further paired *t* tests showed a frontocentral distribution of the effect, such that there were significant differences or trends toward significant differences in N400 mean amplitude for the semantically related condition versus the unrelated condition at FPz, $t(19) = 2.80$, $p = .011$; Fz, $t(19) = 2.96$, $p = .008$; Cz, $t(19) = 2.10$, $p = .049$; FC1/2, $t(19) = 2.49$, $p = .022$; C3/4, $t(19) = 1.82$, $p = .08$; F3/4, $t(19) = 2.69$, $p = .014$; FC5/6, $t(19) = 1.83$, $p = .08$; FP1/2, $t(19) = 2.35$, $p = .03$; F7/8, $t(19) = 2.24$, $p = .037$; and T3/4, $t(19) = 1.78$, $p = .09$.

LPC: There was a significant interaction between condition and electrode for each set of comparisons: midline: $F(4, 76) = 20.20$, $p = .000$; inner circle: $F(2, 38) = 39.65$, $p = .000$; middle circle: $F(3, 57) = 25.51$, $p = .000$; outer circle: $F(4, 76) = 19.13$, $p = .000$. Further paired *t* tests showed that there were significant differences or trends between the LPC mean amplitudes for the semantically related condition versus controls at FPz, $t(19) = 3.32$, $p = .003$; Fz, $t(19) = 2.30$, $p = .033$; Pz, $t(19) = –2.03$, $p = .06$; Oz, $t(19) = –2.81$, $p = .011$; F3/4, $t(19) = 2.07$, $p = .05$; FP1/2, $t(19) = 2.57$, $p = .019$; F7/8, $t(19) = 1.83$, $p = .08$; T5/6, $t(19) = –1.87$, $p = .08$; O1/2, $t(19) = –2.68$, $p = .015$. However, it should be noted that the direction of the effect differed by electrode site, such that at frontal sites there was a larger LPC for the semantically related trials, while at the temporal, parietal, and occipital sites, the LPC was larger for the controls.

Translation form interference effect

P200: There was a significant main effect of condition over midline electrodes, $F(1, 19) = 4.88$, $p = .04$, and inner circle electrodes, $F(1, 19) = 6.07$, $p = .023$, and there was a trend toward significance over middle circle electrodes, $F(1, 19) = 3.65$, $p = .07$. This result indicates that translation form distractors elicited a larger P200 than did the controls. There was a trend toward a significant interaction between condition and channel at middle circle sites, $F(3, 57) = 3.07$, $p = .09$. There was also a trend toward a significant interaction between condition and hemisphere over the middle circle sites, $F(1, 19) = 4.27$, $p = .05$, and a significant interaction between condition and hemisphere over the outer circle electrodes, $F(1, 19) = 7.78$, $p = .012$. Over the outer circle electrodes, further paired *t* tests showed a trend toward a significant difference between the mean amplitude of the P200 for translation form distractors and that for controls over the right hemisphere, $t(19) = 1.91$, $p = .07$, but there was no significant difference between conditions over the left hemisphere, $t(19) < 1$.

N400: There was a significant interaction between condition and hemisphere over the middle circle electrodes, $F(1, 19) = 5.33$, $p = .032$, and outer circle electrodes, $F(1, 19) = 13.65$, $p = .002$. However, over the middle circle electrodes, further paired *t* tests showed no significant differences between conditions over the left hemisphere, $t(19) < 1$, or the right hemisphere, $t(19) = 1.19$, $p = .248$. Over the outer circle electrodes, there was a trend toward a significant difference between the N400 mean amplitude for translation form distractors and that for controls over the right hemisphere, $t(19) = 1.83$, $p = .08$. However, there was no significant difference between conditions over the left hemisphere, $t(19) < 1$. Overall, these results suggest that there was a small but unreliable N400 translation form interference effect.

Because visual inspection suggested that some differences may exist on the N400 that were not revealed in the statistical analyses, a second set of analyses were computed over a shorter N400 window. Specifically, the mean amplitudes from 350 ms to 450 ms were compared for the translation form distractors and their controls. The pattern revealed was similar to that found in the original analyses from 300 ms to 500 ms. The only effects that reached significance were for the Condition × Hemisphere interaction at middle circle sites, $F(1, 19) = 4.99$, $p = .038$, and outer circle sites, $F(1, 19) = 11.68$, $p = .003$. Further paired t tests resulted in no significant differences for either hemisphere for either set of electrodes. Trends were also observed at the inner circle sites, $F(2, 38) = 2.97$, $p = .09$, and middle circle sites, $F(3, 57) = 3.78$, $p = .06$, for an interaction between condition and channel, but these effects did not reach significance.

LPC: There was a significant main effect of condition over each set of electrode sites: midline: $F(1, 19) = 13.33$, $p = .002$; inner circle: $F(1, 19) = 5.11$, $p = .036$; middle circle: $F(1, 19) = 6.09$, $p = .023$; outer circle: $F(1, 19) = 5.65$, $p < .028$). This result indicates that translation form distractors elicited a larger LPC than did controls. There was also a trend toward a significant interaction between condition and electrode over inner circle electrodes, $F(2, 38) = 3.51$, $p = .06$.

Discussion

Experiment 1 asked whether relatively proficient Chinese–English bilinguals who are immersed in an English-speaking environment access the L1 translation equivalent of an L2 word when they are reading to understand its meaning. Both event-related potentials (ERPs) and behavioral responses were recorded while participants performed a translation recognition task in which they decided whether a Chinese word was the correct translation of an English word. The relationship between the Chinese and English words was manipulated such that the critical trials consisted of Chinese words that were not translation equivalents but that were related in meaning or in lexical form similarity (i.e., orthographically and/or phonologically) to the correct translation of the English words. Performance on each distractor type was compared with controls matched on lexical properties but otherwise unrelated to the translation.

Behavioral measures of response time and accuracy revealed interference for both distractor types such that related trials were more difficult to reject as being incorrect translations than were unrelated controls. Furthermore, similar magnitudes of semantic and lexical interference effects were observed even in these proficient bilinguals. These results are inconsistent with findings reported in most previous behavioral studies using the translation recognition task, which have shown a larger semantic interference effect than lexical interference effect in proficient bilinguals but an opposite pattern in less proficient bilinguals or individuals still at an early stage of learning a second language (Altarriba & Mathis, 1997; Sunderman & Kroll, 2006; Talamas et al., 1999). For example, Altarriba and Mathis (1997) taught monolingual English speakers a set of Spanish–English translations and then tested these monolinguals and Spanish–English bilinguals using the translation recognition task. Both orthographically and semantically related foils produced interference for both groups of participants, but less lexical interference and greater semantic interference were found in proficient learners compared with monolinguals. Other studies (e.g., Sunderman & Kroll, 2006; Talamas et al., 1999) have suggested that the role of L1 translation equivalents in L2 word processing is modulated by second language proficiency. In other words, dependence on the L1 translation equivalent appears to be reduced as the L2 becomes more proficient, so that more proficient bilinguals appear to be able to retrieve the meaning of a word in the second language directly. However, based on the behavioral results obtained in the present experiment, activation of the L1 translation is observed even in proficient Chinese–English bilinguals. A recent study by Guasch et al. (2008) also found evidence for L1 lexical activation in proficient Spanish–Catalan bilinguals. However, these results cannot provide unequivocal evidence for the L1 mediation hypothesis, because the apparent L1 lexical activation may occur after the L2 word has been comprehended and therefore be a byproduct of accessing the meaning of L2 words. We return to this alternative interpretation after discussing the ERP results.

Overall, the ERP results in the present experiment confirmed the behavioral results, such that effects of both semantic and translation form distractors were observed in the ERP waveforms. However, to our knowledge, the present study is the first to show that the temporal course of interference from the different types of distractors in the translation recognition task differs. Specifically, semantic distractors elicited effects primarily on the N400 and LPC, with a smaller N400 and a smaller LPC over the posterior scalp but a larger LPC over the anterior scalp relative to that in unrelated controls. In contrast, translation form distractors elicited a larger P200 and a larger LPC than did unrelated controls. Depending on the condition, then, effects were observed as early as 150 ms on the P200 and lasted until near the end of the recording epoch.

The earliest component implicated, the P200, was larger for translation form distractors than for controls. The P200 has been reported to be sensitive to lexical processing in past studies, although those that have addressed its significance in contexts relevant to the current study have produced somewhat mixed results. In a study that investigated orthographic and phonological processing, Barnea and Breznitz (1998) found that a larger P200 was elicited when word pairs rhymed. They suggested that this ERP component may therefore index an early stage of word recognition. Liu, Perfetti, and Hart (2003) also found evidence for P200 effects for orthographically related Chinese word pairs in a pronunciation judgment task, although their orthographically related pairs showed a reduction of the P200. Misra and Holcomb (2003) reported evidence for an enhanced P200 for masked repetition priming (in English) in the context of a semantic monitoring task, but a reduction in P200 amplitude was found when Chinese native speakers read Chinese word pairs in which one character of the items repeated in the semantic judgment task by Thierry and Wu (2007). These findings suggest that the P200 is sensitive even to automatic processing of form similarity between two words, although results have been inconsistent regarding whether lexical similarity contributes to a reduction or increase of the P200 amplitude. Unfortunately, the reasons for the inconsistent findings across studies are somewhat unclear. While the variation in results is likely due to differences in the tasks or procedures used in previous studies, those differences are not readily apparent. Variables such as degree of orthographic and phonological overlap between items or the type of task (semantic vs. form-based) do not appear to account for the different patterns. The current work adds to this body of literature. In the present experiment, all conditions elicited a P200 after about 150 ms of the second word onset, but translation form distractors produced a larger P200 relative to unrelated controls. The only difference between translation form distractors and their controls was that the former shared ortho-graphic and/or phonological information with the correct translation of the first word. This result suggests that lexical information about the L1 translation was activated when Chinese–English bilinguals read L2 words. When participants then saw a translation form distractor that partially overlapped with the correct translation, additional resources might have been required to determine whether it was a correct translation, thus resulting in a larger P200. However, because a fairly long period of time elapsed between the onset of the L2 word and the subsequent presentation of the L1 word in this task (i.e., 750 ms), it is unclear whether the lexical information for the translation was generated in order to read and understand the L2 word or as a strategy to prepare for comparing the L1 word with the correct translation.

The second ERP component observed to be sensitive to interference effects in the translation recognition task was the N400, which was attenuated for the semantic distractors compared with controls. The N400 was first reported by Kutas and Hillyard (1980) in a sentence reading study, in which semantically anomalous words elicited a larger negative ERP component, peaking over the centroparietal scalp about 400 ms after word onset. Many subsequent studies have found that the N400 is sensitive to a variety of different lexical and semantic manipulations, such that any situation that establishes context for a word may serve to attenuate the N400. For example, its amplitude is smaller when a word is preceded by a semantically related word than when it is preceded by an unrelated word (e.g., Brown, Hagoort, & Chwilla, 2000). Similarly, the N400 (or a slightly later component referred to as the N450) has been shown to be sensitive to whether two words rhyme (e.g., Grossi, Coch, Coffey-Corina, Holcomb, & Neville, 2001). N400 effects are typically interpreted to reflect the relative ease of lexical/semantic integration processes. In the present experiment, all critical conditions elicited an N400 after about 300 ms following the second word onset, but a smaller N400 was produced by semantic distractors than by unrelated controls. Attenuation of the N400 mean amplitude suggests that processing the L2 English words may have primed the meaning of the L1 Chinese words when they were semantically related. Only small, statistically unreliable effects on the N400 were observed for the translation form distractors in this study.

Finally, both types of critical distractors modulated a late positive component (LPC) beginning about 500 ms after the onset of the Chinese word. The LPC is often associated with experimental tasks requiring judgments to be made about stimuli and has been reported to be related to conscious recollection (e.g., Misra & Holcomb, 2003). The LPC may also overlap both temporally and spatially with another component, the P600, and it has been argued by some that these are the same component or part of the same family of components. While some research has suggested that the P600 is specifically sensitive to syntactic violations (e.g., Osterhout & Holcomb, 1992), other studies have shown that this component is also sensitive to orthographic misspelling in sentence reading (Münte, Heinze, Matzke, Wieringa, & Johannes, 1998; Vissers, Chwilla, & Kolk, 2006) and semantic violations (e.g., Kolk, Chwilla, Van Herten, & Oor, 2003; Münte et al., 1998). Recently it has been argued that the P600 reflects monitoring triggered by conflict processing and reanalysis of information processing to resolve response uncertainty (e.g., Kolk & Chwilla, 2007). The results of the present experiment may provide further support for the hypothesis that the P600/LPC is not specific to syntactic processing but instead that it more generally reflects reprocessing (Kolk & Chwilla, 2007). Specifically, when the Chinese words were related to Chinese translations of English words presented previously, either semantically or by resemblance to the translation equivalent, participants may have needed to recheck whether they were the correct translation to avoid incorrect responses, resulting in a larger LPC for the critical distractors in the translation condition and at anterior sites for the semantic condition. However, it is still not clear why semantic distractors generated an opposite pattern over the anterior scalp than the posterior scalp, especially since there was no such reversal for the translation form distractors. One possible reason for the different direction of the semantic LPC effect between anterior and posterior electrode sites, when compared with controls, may be that the processing of critical and control items involves different generators. Scalp topography of effects may vary with the location of the underlying neural sources. An alternative explanation is that the late semantic effect observed in our study may in fact reflect a pair of overlapping effects, one with a more anterior distribution and one with a more posterior distribution. For example, a frontal positivity might overlap with a more posteriorly distributed negativity. Future research may disentangle this result further, but either explanation suggests that while these late effects for the different types of distractors may have a similar time course, they likely reflect different underlying processes.

Taken together, the ERP results in Experiment 1 provide evidence that semantic and lexical interference effects observed in a translation recognition task have different time courses. Specifically, during the early phase of stimulus processing, translation form interference is indexed by the P200 (beginning around 150 ms), while semantic interference is indexed somewhat later, by the N400 (beginning around 300 ms). During the later decision-making stages, both types of interference are associated with the LPC (500–700 ms) but with different patterns for the two distractor conditions. These results suggest that the L1 translation is activated while reading L2 words, even for relatively proficient bilinguals, a finding that is consistent with the results reported by Thierry and Wu (2007). In addition, since evidence for activation of the L1 translation in proficient bilinguals has been observed in the behavioral study with proficient Spanish–Catalan bilinguals by Guasch et al. (2008), these findings cannot be attributed to script differences between Chinese and English. However, the present results are inconsistent with previous findings in several other behavioral studies (e.g., Talamas et al., 1999; Sunderman & Kroll, 2006), which have reported that only unskilled learners or less proficient bilinguals rely on access to the L1 translation equivalent when reading words in the L2. The discrepancy between the results across these studies raises the issue of whether these inconsistent findings are due to other factors. One factor that varies across different translation recognition studies is the stimulus onset asynchrony (SOA; i.e., the interval from onset of the first word to the onset of the second word). The studies that have found activation of the L1 translation in proficient bilinguals have used a relatively long SOA (e.g., an average of 1,100 ms in Thierry & Wu, 2007; 750 ms in the current study and Guasch et al., 2008) to allow sufficient time for the initial word to be processed before evaluating the ERP trace for the second word or to make sure that less proficient bilinguals had sufficient time to process words. However, those studies that did not find activation of the L1 translation in skilled bilinguals used a shorter SOA (e.g., 500 ms in Talamas et al., 1999, and Sunderman & Kroll, 2006). It is possible that the long SOA encouraged bilinguals to activate the translation equivalent once they understood the meaning of the L2 word. This tendency may be particularly great in tasks like translation recognition, which require participants to perform cross-language judgments; however, even in Thierry and Wu's study, later activation of L1 equivalents might be predicted by fully interactive models of lexical access. Although the present study and some past studies have provided evidence for activation of the L1 translation in relatively skilled bilinguals, that activation may follow a different time course than the activation of semantic alternatives. Thus, for relatively proficient bilinguals, the translation may be activated after the meaning of the L2 word has been processed.

To test the hypothesis that proficient bilinguals access the translation equivalent once they have understood the meaning of the L2 word but not as a means to access the semantics of the L2 word, we performed an additional experiment. In Experiment 2, we collected both behavioral and ERP data at a short SOA to further evaluate the electrophysiological correlates of processing at the short SOA. If Chinese–English bilinguals use the L1 translation to access meaning for the L2 words, then translation effects should also appear at a short SOA and semantic effects should follow the presence of translation effects, resulting in a P200 effect for translation effects and an N400 effect for semantic effects as in Experiment 1. However, if L1 translations are activated after accessing the semantics of the

L2 words, then semantic effects should be present earlier than translation effects at the short SOA, resulting in an N400 effect for semantic effects but no P200 effect for translation effects. In addition, behavioral interference and an LPC effect may still be observed for both distractor types because even if there is no early translation effect in the ERP data, the behavioral measures may reflect the later decision processes as well.

Experiment 2: Behavioral and ERP Performance in Translation Recognition at a Short SOA (300 ms)

In Experiment 2, a sample of Chinese–English bilinguals drawn from the same relatively proficient population tested in Experiment 1 performed the translation recognition task at a short, 300-ms SOA in place of the long, 750-ms SOA. The question in this experiment was whether relatively proficient bilinguals would show evidence of accessing the L1 translation equivalent even when the SOA is short. We predicted that under these conditions, there would continue to be a robust effect of semantically related distractors but that the effects of translation-related form distractors would diminish or disappear entirely.

Method

Participants—Thirty participants were recruited for Experiment 2. None of them had participated in Experiments 1, but they were selected from the same bilingual population using the same criteria. All of the participants began to learn English after the age of 6 and were classroom learners. They lived or studied in an English-speaking country when tested. Data from 12 participants were excluded. Eight participants were excluded because of missing data in the ERP analysis due to muscle artifact. Data from three other participants were excluded because their accuracy rate in the lexical decision task was lower than 60%. Data from one other participant were excluded due to insufficient knowledge of the simplified version of the Chinese characters.

The final group of 18 participants (15 females, age 22.9 ± 3.9 years) in Experiment 2 was closely matched with participants included in Experiment 1 based on self-rating scores in L1 and L2 as well as on performance on the lexical decision task, the Simon task, and the operation span task. Performance on these measures for all two groups is summarized in Table 2. According to the output of a 2 (group) × 2 (language) ANOVA performed to the self-rating scores, the main effect of language was significant, $F(1, 36) = 37.87$, $p = .000$, indicating that their self-ratings in L1 (Chinese) were higher than for their L2 (English). However, the main effect of group and interaction between group and language was not significant, indicating there were no differences in self-rating scores between participants in the two experiments. According to independent sample *t* tests, there were also no significant differences between groups in L2 proficiency measured by the lexical decision task in L2, memory span measured by the operation span task, or attentional control ability measured by the Simon task.

Materials—The same materials were used as in Experiment 1.

Procedure—A similar procedure was used for Experiment 2 as in Experiment 1 except that the durations of the English words and the following blank screen were changed to 250 ms and 50 ms, respectively, so that all items were presented in the short SOA condition (i.e., 300 ms).

EEG recording—The same EEG equipment and parameters were used for Experiment 2 as in Experiment 1.

Data analysis—The same criteria were used for behavioral data analysis in Experiment 2 as in Experiment 1. On average 3.02% of the responses from each participant were excluded as outliers.

ERPs were averaged offline for each participant at all electrode sites for each condition to provide waveforms beginning with a baseline 100 ms prior to presentation of the Chinese word and continuing until 800 ms poststimulus onset. The same criteria were used for ERP data analysis. For the 18 participants included in the final sample, 8.57% (range: 1.99%–15.29%) of correct trials were rejected, with 7.12% (range: 0%–18.52%) rejected for the semantically related condition, 9.41% (range: 2.56%–18.42%) rejected for the semantic control condition, 9.99% (range: 0%–32.00%) rejected for the translation form related condition, and 7.74% (range: 0%–13.89%) rejected for the translation form controls.

Results

Behavioral data—The behavioral results are shown in Figures 1 and 2. Paired-samples t tests were conducted for each distractor type and control pair separately. There was a significant difference between RTs for the semantically related versus unrelated conditions, $t(17) = 5.51$, $p = .000$, indicating that it took longer to reject semantically related distractors than controls. There was also a significant difference between RTs for translation form distractors and their controls, $t(17) = 5.95$, $p = .000$, indicating that participants were also slower to reject the translation form distractors. Participants were less accurate at rejecting both the semantically related distractors, $t(17) = –9.89$, $p = .000$, and translation form distractors, $t(17) = –3.23$, $p = .005$, than their corresponding controls.

ERP data—Figures 6 and 7 show the ERP waveforms for the critical *NO* conditions at all 29 scalp electrode sites. Figure 8 shows the waveforms for these conditions at three midline sites, with components of interest labeled. As expected, the baseline data were much noisier than those for the long SOA experiment, and early ERP components such as N100 were contaminated by carryover effects from the ERPs elicited by first words. All conditions elicited a P200 (peaking around 260 ms), an N400 (peaking around 400 ms), and a late positive component (LPC), beginning after about 500 ms. However, semantically related trials elicited a smaller N400 and a larger LPC relative to semantically unrelated trials (see Figure 6). In contrast, ERPs elicited by translation form distractors and unrelated trials were similar in the early part of the waveform but differed in a later time window (see Figure 7). These patterns were confirmed with the ANOVAs described later.

Semantic interference effect

P200: There were no significant effects of semantic distractors on the P200.

N400: There was a significant main effect of condition over each set of electrode sites: midline: $F(1, 17) = 13.35$, $p = .002$; inner circle: $F(1, 17) = 8.53$, $p = .01$; middle circle: $F(1, 17) = 10.69$, $p = .005$; outer circle: $F(1, 17) = 13.14$, $p = .002$. This result reflects the fact that the mean amplitude for the semantically unrelated control condition was more negative than that for the semantically related condition during the N400 epoch. The interaction between condition, hemisphere, and electrode for the outer circle sites was marginally significant, $F(4, 68) = 2.55$, $p = .06$.

LPC: There was a significant main effect of condition over three sets of electrode sites: midline: $F(1, 17) = 6.64$, $p = .02$; middle circle: $F(1, 17) = 4.52$, $p = .048$; outer circle: $F(1, 17) = 5.06$, $p < .038$. This result indicates that semantic distractors elicited a larger LPC than did controls.

There was a significant interaction between condition and electrode for each set of comparisons: midline: *F*(4, 68) = 9.91, *p* = .001; inner circle: *F*(2, 34) = 24.75, *p* = .000; middle circle: *F*(3, 51) = 11.68, *p* = .001; outer circle: *F*(4, 68) = 9.46, *p* = .002. Further paired *t* tests showed that there were significant differences or trends between the LPC mean amplitudes for the semantically related condition versus controls at FPz, *t*(17) = 3.81, *p* = .001; Fz, *t*(17) = 3.38, *p* = .004; FC1/2, *t*(17) = 2.76, *p* = .013; F3/4, *t*(17) = 3.33, *p* = .004; FC5/6, *t*(17) = 2.53, *p* = .022; FP1/2, *t*(17) = 3.21, *p* = .005; F7/8, *t*(17) = 2.55, *p* = .021; T3/4, *t*(17) = 1.78, *p* = .09. This result further reflects that a larger LPC was elicited by the semantically related trials relative to the controls and suggests a frontocentral distribution of the effect.

There was also a significant interaction between condition, hemisphere, and electrode over the outer circle sites, *F*(4, 68) = 3.22, *p* = .041, and a trend toward significance over the middle circle sites, *F*(3, 51) = 2.88, *p* = .09. Further 2 (experimental condition) × 5 (electrode) ANOVAs were performed to investigate the significant three-way interaction over each hemisphere at the outer circle sites. Over the left hemisphere, there was significant interaction between experimental condition and electrode, *F*(4, 68) = 10.87, *p* = .001. Further paired *t* tests found that there were significant differences or trends between the LPC mean amplitudes for the semantically related condition versus controls at FP1, *t*(17) = 2.98, *p* = .008; F7, *t*(17) = 2.54, *p* = .021; and O1, *t*(17) = –2.00, *p* = .06. Over the right hemisphere, there was a significant main effect of experimental condition, *F*(1, 17) = 5.19, *p* = .036, and an interaction, *F*(4, 68) = 5.69, *p* = .015. Further paired *t* tests found that there were significant differences or trends between the LPC mean amplitudes for the semantically related condition versus controls at FP2, *t*(17) = 3.08, *p* = .007, and F8, *t*(17) = 2.00, *p* = .06. This result again reflects that a larger LPC was elicited by the semantically related trials relative to the controls at frontal sites and that there was a trend suggesting a larger LPC for the controls over the left occipital site.

Translation form interference effect

P200: There were no significant effects of translation form distractors on the P200.

N400: There were no significant effects of translation form distractors on the N400 either. There was only a trend toward a significant interaction between condition, hemisphere, and electrode over the inner circle sites, *F*(2, 34) = 2.89, *p* = .09.

LPC: There was a significant interaction between condition and electrode over each set of electrode sites: midline: *F*(4, 68) = 10.10, *p* = .000; inner circle: *F*(2, 34) = 16.24, *p* = .000; middle circle: *F*(3, 51) = 12.86, *p* = .000; outer circle: *F*(4, 68) = 10.67, *p* = .001. Further paired *t* tests showed that there were significant differences or trends between the LPC mean amplitudes for the translation form distractors versus controls at FPz, *t*(17) = 3.07, *p* = .007; Fz, *t*(17) = 3.04, *p* = .007; Pz, *t*(17) = –1.90, *p* = .07; Oz, *t*(17) = –1.99, *p* = .06; FC1/2, *t*(17) = 2.23, *p* = .04; F3/4, *t*(17) = 2.80, *p* = .012; P3/4, *t*(17) = –1.99, *p* = .06; FP1/2, *t*(17) = 2.73, *p* = .014; F7/8, *t*(17) = 1.95, *p* = .07; O1/2, *t*(17) = –2.98, *p* = .008. However, it should be noted that the direction of the effect differed by electrode site, such that at frontal sites there was a larger LPC for the translation form distractors, while at the parietal and occipital sites, the LPC was larger for the controls.

Discussion

Experiment 2 aimed to test and confirm the hypothesis, based on the data reported in Experiment 1, that relatively proficient bilinguals activate L1 translation equivalents after accessing the meaning of L2 words. Other than the use of a short, 300-ms SOA between the presentation of the English and Chinese words, the materials and procedures were identical to those used in Experiment 1.

The behavioral data in Experiment 2 replicated the findings of Experiment 1 in that there were significant interference effects for both semantic and translation form distractors in RTs and accuracy. Independent of the hypothesized locus of the translation effect, the pattern of results suggests that the L1 translation is indeed activated even at a short SOA.

However, the ERP results showed a markedly different time course for the semantic and translation form interference effects. A significant semantic interference effect was observed in the time windows for both the N400 and the LPC, but a translation form interference effect was seen only at the LPC. The significant P200 effect for the translation form interference observed in Experiment 1 was not replicated in Experiment 2. However, it should be noted that the significant translation form interference in the LPC in Experiment 2 occurred approximately 800 ms after the onset of the first (English) word. This result is actually consistent with the finding of translation form interference during the P200 in Experiment 1, which occurred about 850 ms after the onset of the English word. These results further support our claim that the meaning of the L2 words can be accessed directly without relying on L1 translation. However, with sufficient time after processing of the L2 word, L1 translations may be activated, resulting in behavioral evidence for the L1 activation. Combined with our finding of translation form interference in the LPC time window in Experiment 1 (i.e., about 1,250 ms after the first word onset), the ERP results of both experiments suggest that L1 translation equivalent is activated after relatively proficient bilinguals already understand the meaning of an L2 word. Such postlexical activation can extend over time and may begin before a behavioral response is initiated. We hypothesize that this is the reason why we and others have observed evidence for translation interference in the behavioral data.

By necessity, Experiments 1 and 2 differed not only on SOA but also on presentation duration for the two words. One potential concern is that the different stimulus durations may have contributed to different patterns of results at two SOA conditions. However, if this were true, the semantic interference effect would also have been expected to show different patterns across experiments, as it may be more difficult to access the meaning of an L2 word in the short SOA condition. However, a similar magnitude of semantic interference was observed in two experiments; the modulation of SOA affected only the translation form interference effect. This result suggests that the factor modulating the translation form interference effect was not the difference in the stimulus durations across conditions but the time required to activate the translation in proficient bilinguals who can read L2 words for meaning without L1 mediation.

General Discussion

In two experiments, relatively proficient Chinese–English bilinguals judged whether a Chinese word was the correct translation of an English word. In Experiment 1, both ERP and behavioral data showed that the meaning of the L2 word was available to these bilinguals. Response times to reject Chinese words that were semantically related to the English words were longer than for unrelated controls. Furthermore, semantic distractors elicited a smaller N400 relative to unrelated controls as well as a smaller LPC over the posterior scalp and a larger LPC over the anterior scalp. The same bilinguals were also sensitive to the lexical form of the translation equivalent in Chinese, with longer RTs to reject translation form distractors than controls. However, the ERP data followed a different pattern for the translation form distractors than for the semantically related distractors.

Translation form distractors elicited a larger P200 and a larger LPC than did controls, with only small, inconsistent effects on the N400.

To test the hypothesis that the activation of the L1 translation equivalent in Experiment 1 was a consequence of the relatively long, 750-ms SOA, a second ERP experiment with identical materials was carried out at a short SOA of 300 ms. Behavioral results provided robust evidence for activation of L1 translation, but the ERP results showed that this activation occurred only in a late time window. Taken together, the results of the two experiments suggest that for proficient bilinguals, access to the L1 translation equivalent follows the retrieval of the meaning of an L2 word. The translation equivalent may be likely to be activated only when the conditions of the task provide sufficient time.

The results of the present study support the claim that proficient bilinguals are able to access conceptual information directly from L2 words. In fact, semantic distractors generated the slowest, least accurate behavioral responses, even though they were actually higher frequency than the translation form conditions. That pattern suggests that the bilinguals in the present study were highly sensitive to the semantics of the L2 word. The results also serve to clarify the somewhat contradictory past evidence about the role of translation equivalents for proficient bilinguals. As noted in the introduction, there is evidence that L2 learners who are not yet proficient in the L2 may use the L1 translation equivalent as a means to mediate access to meaning when direct conceptual processing of the L2 word is not yet possible (e.g., Talamas et al., 1999). However, a number of recent studies have shown that proficient bilinguals appear to access the translation equivalent (e.g., Thierry & Wu, 2007) although by all accounts they should be past a stage of L2 learning when mediation via the translation equivalent may be required. The experiments reported in the present article support the observation in the Thierry and Wu (2007) study in showing that relatively proficient bilinguals activate the L1 translation of the L2 word. However, the present results also go beyond the past studies in demonstrating that it is likely that sensitivity to the translation for highly skilled bilinguals is related to the time course of processing afforded by the task.

Further support for the hypothesis that relatively proficient bilinguals are likely to translate words in L2 when given sufficient time was reported in a recent behavioral study that adapted the Thierry and Wu (2007) design for deaf signers who read English as their L2. Morford, Wilkinson, Villwock, Piñar, and Kroll (2011) asked deaf readers who were bilingual in American Sign Language (ASL) and written English to perform a semantic relatedness judgment in English. As in the Thierry and Wu study, no ASL was presented but some of the English words had translations in ASL that were similar in form. Using a relatively long, 1,000-ms SOA in a behavioral paradigm, there was clear evidence that deaf signers were sensitive to the form similarity of the ASL translations even when they were not explicitly presented, suggesting that they were activating the ASL translations of the English words.

Results from the present ERP experiments show that the effects generated by the two types of distractors are quite different. The N400 effect for the semantically related distractors is similar to the type of semantic priming that might be observed where attenuated N400s are typically interpreted to reflect greater ease of lexical integration for related items (e.g., Holcomb, Reder, Misra, & Grainger, 2005). In our study, processing of the initial L2 word may ease integration of the semantically related L1 word, providing further evidence for conceptual access by the L2 word. The fact that our behavioral results suggest inhibition, rather than facilitation, is likely related to the demands of the task. In the paradigms usually used for semantic priming experiments, such as lexical decision tasks or even category-monitoring tasks, there is no need to make fine semantic distinctions between items.

However, in the translation recognition task, these distinctions are critical and may adversely impact performance on measures of RT and accuracy when words that are closely related semantically in two languages must be rejected as not being translation equivalents. Task differences may also account for a recent result reported by Zhang, Van Heuven, and Conklin (2011) that suggests that it may not only be time course that determines whether the translation is activated but also the convergence with the semantics. Using a masked priming paradigm with a lexical decision task, Zhang et al. found that Chinese–English bilinguals, similar to those in the present study and in the Thierry and Wu (2007) and Wu and Thierry (2010) studies, were facilitated when an English prime was related to the first character/ morpheme of the Chinese translation equivalent of an English target word. Because no Chinese words were explicitly present, the results were taken to suggest that the L1 translation equivalent is accessed implicitly under conditions in which there is not sufficient time to develop a strategy that might induce translation processing. However, although the masked priming paradigm is thought to reflect early and automatic processes, the behavioral response to the target word in lexical decision is a process that is open to decision processes that may themselves reflect later stages of processing than those observed in the ERP record. The L1 translation equivalent may be activated automatically, but the consequence of that activation may have its locus later rather than earlier in processing.

The results for translation form distractors on the P200 in Experiment 1 under the long SOA conditions suggest that the L2 word may activate its translation. Effects on the P200 may be based on the feature overlap (orthographic and/or phonological) between two items, and because feature overlap is present only when both words are in the L1 (i.e., the English word and the Chinese word did not share orthographic or phonological form), this result suggests that participants internally generated a representation of the translation of the L2 word, which was compared with the L1 word. It is of note that while Thierry and Wu (2007) found effects on both the P200 and N400 when they directly presented pairs of Chinese words with a repetition of one character to participants, when they presented pairs of English words with a hidden repetition of one character of their Chinese translations, only a reduction of the N400 was found. Thierry and Wu's failure to find a P200 effect in the English-only trials suggests that activation of L1 translation equivalents may have occurred fairly late for their participants in a task that itself did not encourage a translation strategy. This hypothesis was confirmed by the failure to find a P200 effect in Experiment 2 in the present article under short SOA conditions, even using a task that required explicit translation.

In our study, no reliable effects were noted on the N400 for the translation conditions in either of the ERP experiments, seemingly in contrast to previous studies, which have found reliable N400 attenuations for word pairs related phonologically within a language in rhyme judgment tasks (e.g., Grossi et al., 2001). However, N400 attenuations are not always found when words are related phonologically. Niznikiewicz and Squires (1996) conducted a semantic judgment task with word pairs of various types including homophones, orthographic neighbors (or near neighbors), semantically related words, and unrelated words. This paradigm might be seen as the monolingual homologue to the translation recognition task, and many of the items in the translation distractor condition in our task were in fact homophones of the correct translation. Niznikiewicz and Squires failed to find effects for homophones on the N400, although they did differ at an earlier point on the N200 (but see also Liu et al., 2003, for evidence of N400 effects for homophones in a meaning judgment task). Thierry and Wu (2007) did find an N400 effect in a semantic judgment task for the hidden character overlap condition, but unlike in their study, in ours only some of the items had identical characters in the items to be compared. Repetitions (even hidden) of the same character may prime not only orthography and phonology but also semantics, which may lead to greater N400 effects.

In both critical conditions of the two ERP experiments, later effects were observed in a part of the epoch, which may represent a late positive component (LPC) and/or a P600. Differences in the waveforms between these conditions were observed earlier than the button press responses, consistent with a preresponse reanalysis or checking process. It is also possible that these later effects may simply reflect a more conscious recognition of the distractor's similarity to the correct translation. In Experiment 1, while the direction of this effect in the translation conditions was as expected (a more positive waveform for the distractors at all electrode sites), there was a front to back shift in the polarity of this effect for the semantic distractors. Namely, waveforms for the semantic distractors were more positive than for controls at the more anterior electrode sites, but the waveforms were more negative at the more posterior electrode sites. This shift occurred almost exactly at the central sites. In Experiment 2, the direction of the LPC effect shifted for the translation form distractors but not for the semantic distractors. The reasons for these shifts are currently unknown, but the results suggest that there are probably different underlying processes responsible for the late effects across conditions.

Direct comparisons across items in the semantic and translation conditions were not made, since items across conditions were not well matched to each other in frequency. However, if our observed effects simply reflected greater ease in processing higher frequency items, then one might have expected more rapid responses and/or earlier ERP effects for the semantic conditions, which were higher in frequency. However, the opposite result was found. RTs for the translation form trials were faster than those for the semantic trials, and ERPs for these items showed differences between critical and control trials beginning earlier than for the semantic conditions in the long SOA experiment. These results suggest that participants were able to process the words in the translation form condition efficiently despite their lower frequency.

The present results have a number of important implications. First, ERP effects on the N400 for the semantic distractor conditions provide further evidence that skilled bilinguals are sensitive to the conceptual, and not just lexical, information provided by L2 words. In addition, while there were significant ERP effects for translation form distractors, they patterned differently from the semantic effects throughout the recording epoch and were modulated by the SOA between first and second words. Evidence suggests that, when given sufficient time, the participants prepared the L1 translation of the L2 word and then compared this translation to the subsequently presented L1 word. Thus, these results suggest that access to the L1 translation can occur for different reasons. For learners at the early stages of L2 acquisition, the L1 translation may provide a means to access the meaning of L2 words, whereas translations may be activated in more proficient bilinguals as a consequence of an interactive lexical system. Proficient bilinguals may also use translations to enhance access to the richer semantic network associated with the dominant L1 and/or invoke them strategically to ease processing of a specific task.

Although the manipulation of SOA in the present study does suggest that there may be task-specific factors that encourage or discourage activation of the L1 translation, the observation that there is extensive cross-language lexical form activation for even highly proficient bilinguals makes the activation of the translation equivalent less surprising. An extensive body of research on bilingual word recognition (see Dijkstra, 2005, for a review) has shown that even highly skilled bilinguals activate orthographic and phonological neighbors when recognizing words in each language. The effects of cross-language activations tend to be greater when processing the less dominant L2; but with increasing skill in the L2, there come to be effects of L2 on L1 (e.g., van Hell & Dijkstra, 2002). Any delay in resolving the lexical form of a word will present an opportunity for feedback from the semantics that may eventually result in the activation of the L1 translation equivalent. With the exception of interlingual cognates, these L1 translation equivalents will not bear orthographic and phonological similarity across languages. Once the semantics are available, it is likely that there will be increased feedback to the stronger L1. Unlike the tasks used in most word recognition experiments (e.g., lexical decision, word naming, progressive demasking), the translation recognition task requires access to meaning. Therefore, this task may have been more likely to reveal the effects of semantic feedback, particularly when the SOA was sufficiently long to allow the hypothesized feedback process to be completed.

An interesting prediction is that it should be much more likely that the L1 translation equivalent will be activated when recognizing a word in L2 than the reverse. In the present experiments the L2 word in English always preceded the L1 word in Chinese. One advantage of this approach is that the ERPs were always time-locked to presentation of a word in the participant's native language. However, in future studies, one can examine the semantic feedback hypothesis by reversing the direction of the two words and asking whether even under long SOA conditions there is an effect of the L2 translation equivalent. It seems likely that the time course for activating L2 will be extended relative to L1. In future work it will also be important to evaluate these effects in less proficient L2 learners, for whom the lexical effects are likely to be larger, and where one might hypothesize that access to meaning would rely more directly on lexical processing and on the availability of the translation equivalent in L1. If the logic of the revised hierarchical model is correct (Kroll & Stewart, 1994), then less proficient L2 learners should be more likely to reveal an N400 for translation form distractors than would more proficient L2 learners.

A final general implication of the present findings concerns the design of studies that examine the interaction of processes that may be enabled or constrained by the time course defined by task parameters. Namely, the choice of SOA between sequential events may impose a set of task demands that influence the observed outcomes. This issue may be particularly relevant for ERP studies in which long SOAs have typically been used to allow investigators to minimize carryover effects, both in individual word recognition tasks such as the one used here and in sentence-processing tasks in which relatively slow rapid serial visual presentation is often used to examine online reading performance. The present study demonstrates the importance of the choice of SOAs and shows that even in an ERP paradigm in which the earliest time course of processing can be observed, there may be task contributions that influence the observed pattern of results. These experiments also highlight the power of using both behavioral and electrophysiological methods to examine language processing. The patterns of convergence and divergence across these methods hold promise for illuminating the source of apparent controversies in the past literature.

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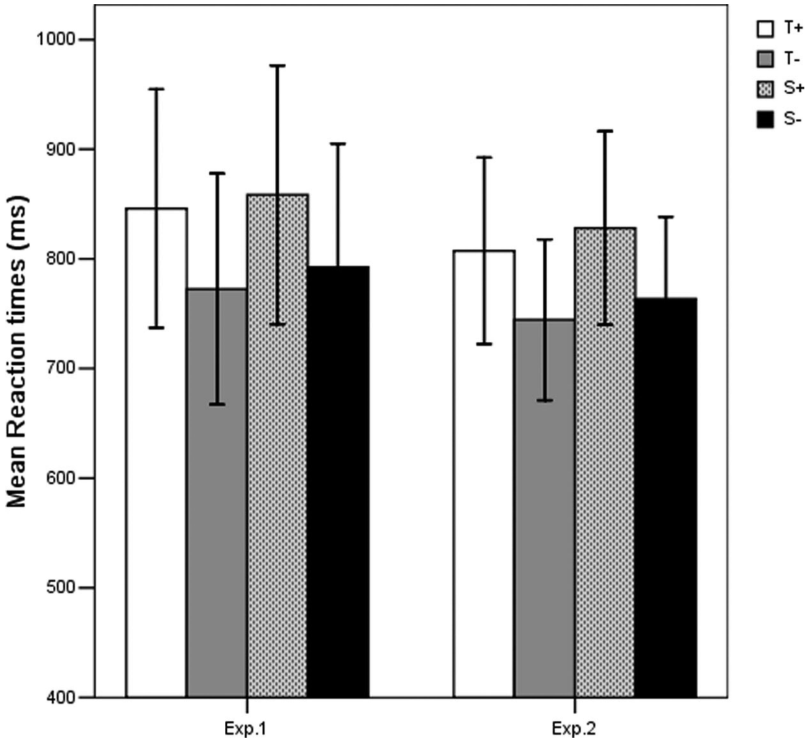

Figure 1.

Mean reaction times (in ms) for Experiments 1 and 2 for the four critical conditions: semantic distractors (S+), semantic controls (S–), translation form distractors (T+), and translation form controls (T–). Error bars show 95% confidence intervals. Exp. = experiment.

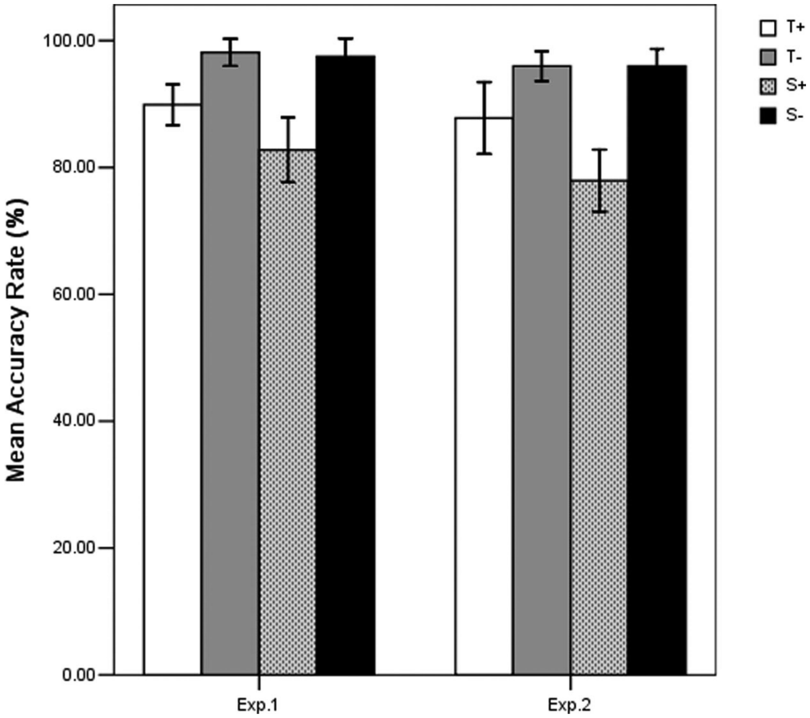

Figure 2.

Mean accuracy rate (%) for Experiments 1 and 2 for the four critical conditions: semantic distractors (S+), semantic controls (S–), translation form distractors (T+), and translation form controls (T–). Error bars show 95% confidence intervals. Exp. = experiment.

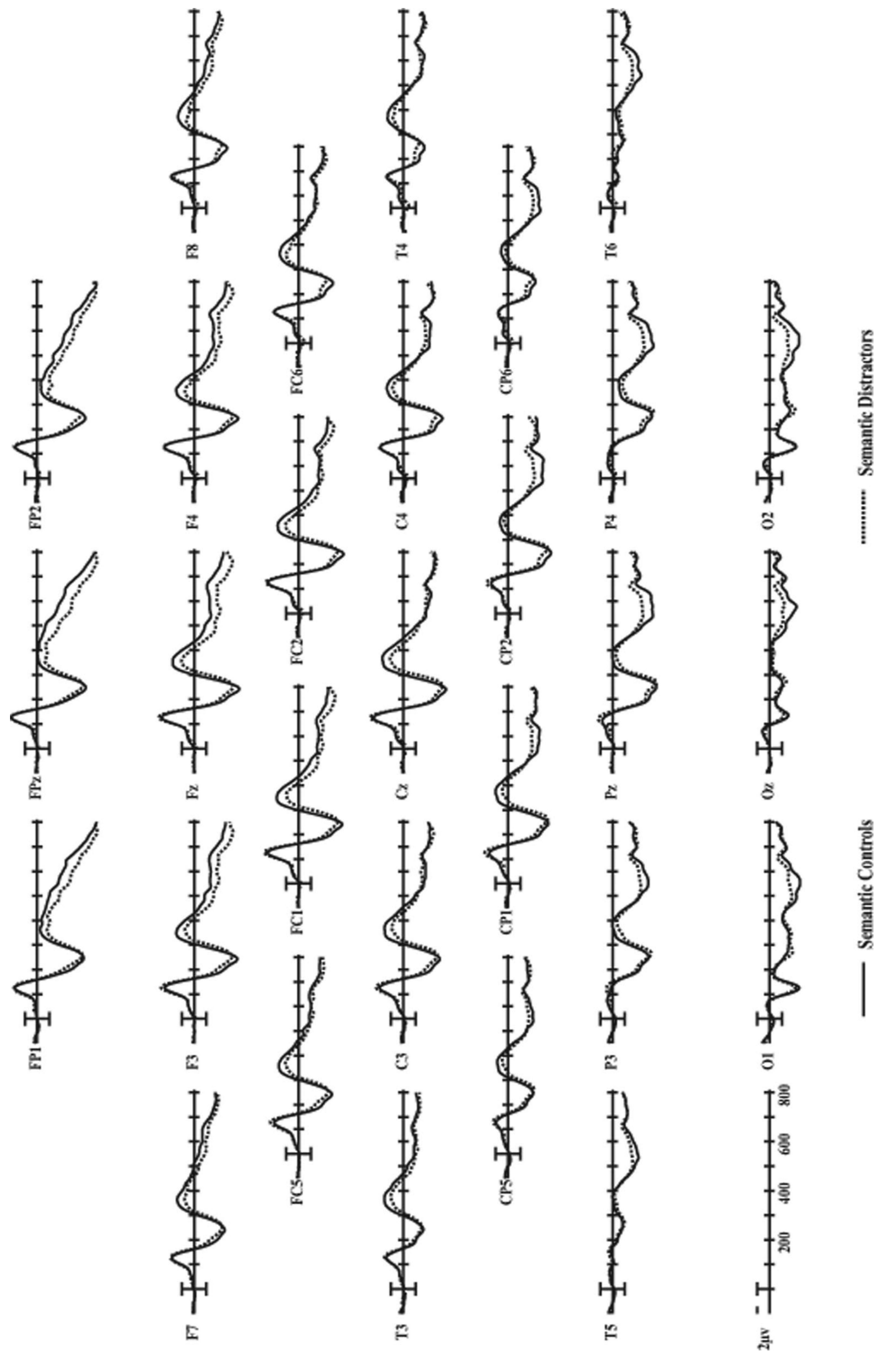

Figure 3.

Grand average event-related potentials elicited by semantically related distractors (dotted lines) and unrelated controls (solid lines) in Experiment 1 from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the second word in each trial until 800 ms poststimulus onset, and negative is plotted up. Significant differences between conditions begin around 300 ms, on the N400 component, and continue into the window of the late positive component.

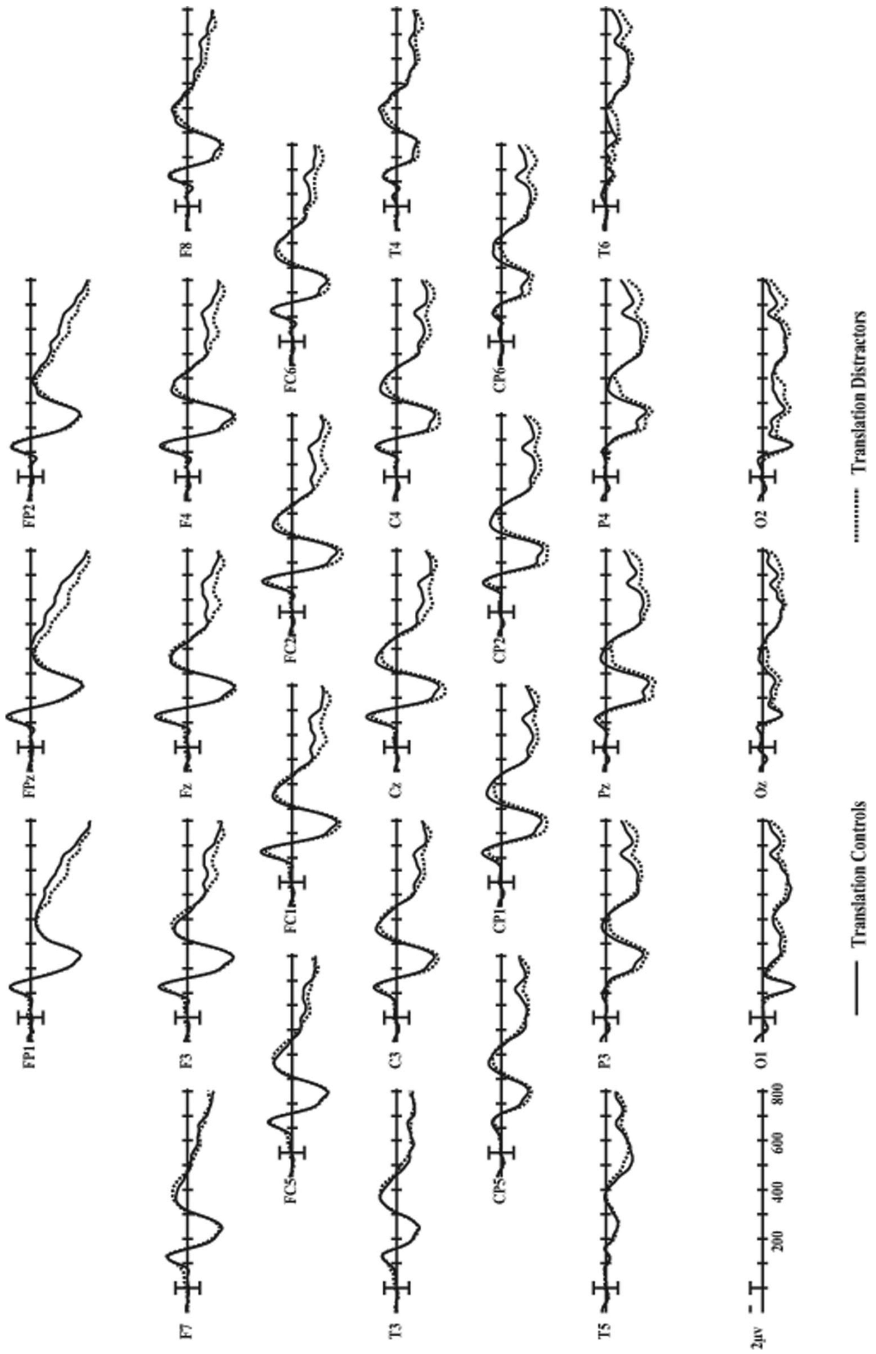

Figure 4.
Grand average event-related potentials elicited by translation form distractors (dotted lines) and unrelated controls (solid lines) in Experiment 1 from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the second word in each trial until 800 ms poststimulus onset, and negative is plotted up. Significant differences between conditions begin around 150 ms, on the P200 component, and are also observed during the window of the late positive component.

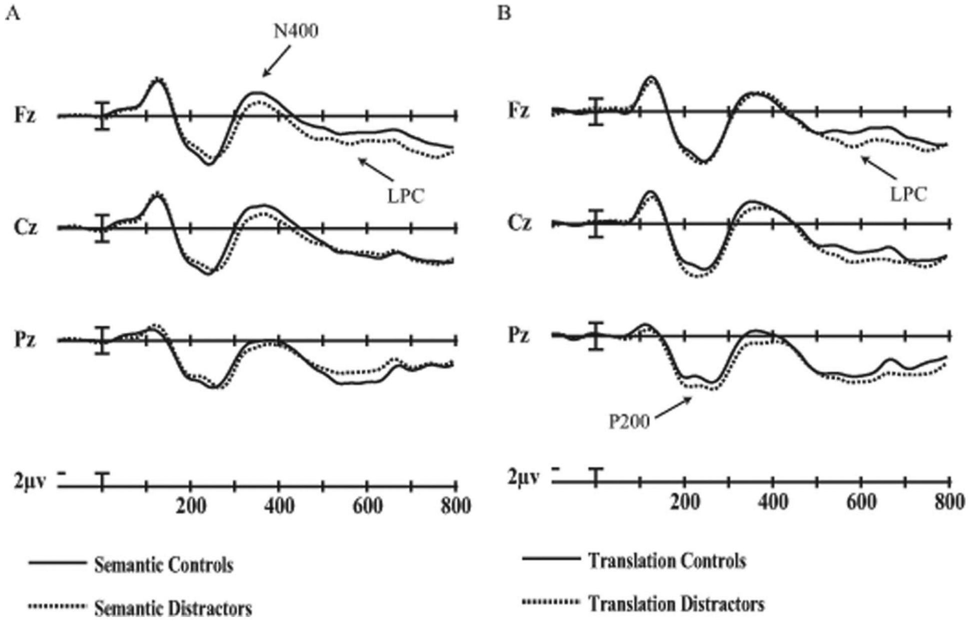

Figure 5.

Grand average event-related potentials for (A) semantic and (B) translation form conditions in Experiment 1 at three representative midline sites (Fz, Cz, and Pz), with peaks of interest labeled. For each condition, the controls are plotted with solid lines, and the critical distractors are plotted with dotted lines. Data are plotted from 100 ms prior to the onset of the second word in each trial until 800 ms poststimulus onset, and negative is plotted up. LPC = late positive component.

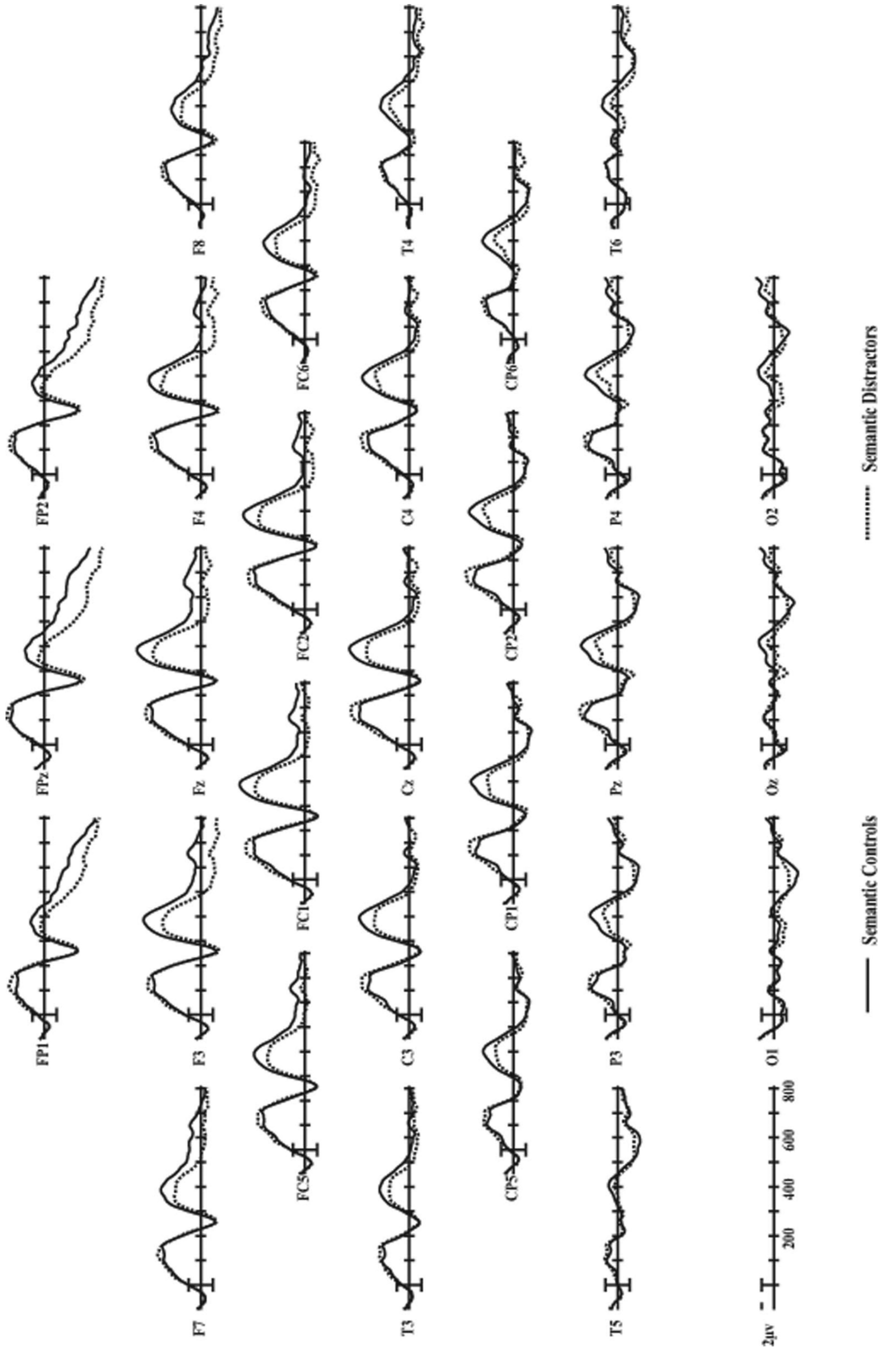

Figure 6.

Grand average event-related potentials elicited by semantically related distractors (dotted lines) and unrelated controls (solid lines) in Experiment 2 from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the second word in each trial until 800 ms poststimulus onset, and negative is plotted up. Significant differences between conditions begin around 300 ms, on the N400 component, and continue into the window of the late positive component.

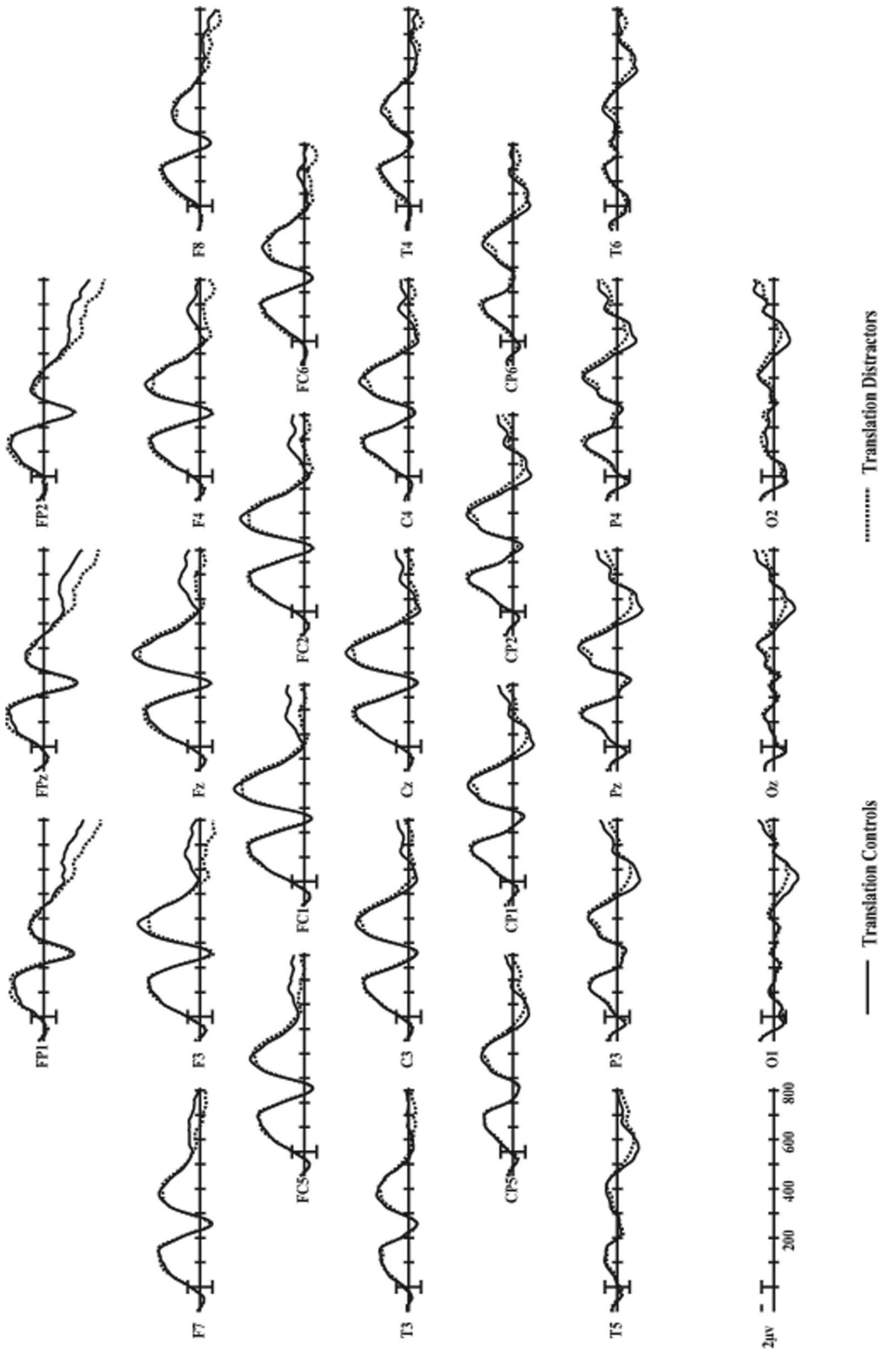

Figure 7.

Grand average event-related potentials elicited by translation form distractors (dotted lines) and unrelated controls (solid lines) in Experiment 2 from all 29 scalp electrodes. Data are plotted from 100 ms prior to the onset of the second word in each trial until 800 ms poststimulus onset, and negative is plotted up. Significant differences between conditions are observed during the window of the late positive component.

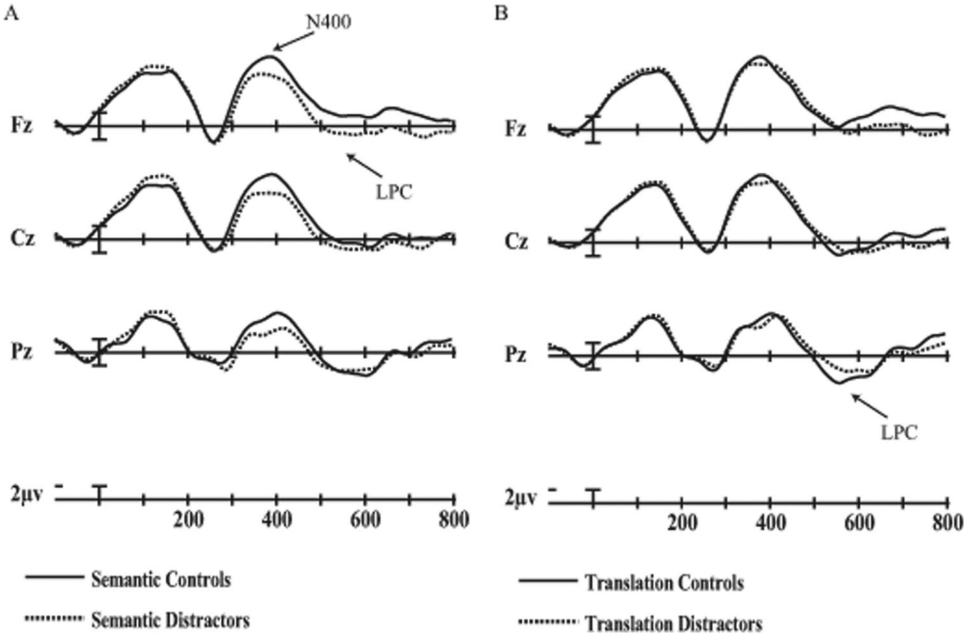

Figure 8.

Grand average event-related potentials for (A) semantic and (B) translation form conditions in Experiment 2 at three representative midline sites (Fz, Cz, and Pz), with peaks of interest labeled. For each condition, the controls are plotted with solid lines, and the critical distractors are plotted with dotted lines. Data are plotted from 100 ms prior to the onset of the second word in each trial until 800 ms poststimulus onset, and negative is plotted up. LPC = late positive component.

Table 1

Means (and Standard Deviations) for Characteristics of Stimuli for Critical NO Responses

Category	Language	Frequency[a]	No. of strokes/word length	Relatedness/similarity
First words for semantic conditions	English	85.51 (149.93)	5.58 (2.05)	
First words for translation form conditions	English	64.75 (84.43)	5.21 (1.56)	
Semantic distractors	Chinese	218.70 (408.59)	12.71 (5.79)	3.75 (0.82)
Semantic controls	Chinese	261.79 (491.58)	13.22 (6.21)	1.21 (0.27)
Translation form distractors	Chinese	89.74 (226.11)	13.51 (5.40)	3.29 (0.94)
Translation form controls	Chinese	89.75 (156.81)	13.09 (5.36)	1.33 (0.31)

Note. There were 80 words per category; distractors and controls were paired with same first words.

[a] Word frequency for Chinese words is based on the *Modern Chinese Frequency Dictionary* (Wang, 1986). Word frequency for English words is based on the Kučera and Francis Frequency Database (1967) and retrieved from the English Lexicon Project website (Balota et al., 2007; http://elexicon.wustl.edu/).

Table 2

Mean Proficiency Ratings (and Standard Deviations) for Individual Difference Measures

Measure	**Experiment 1 (*n* = 20)**	**Experiment 2 (*n* = 18)**
L1 self-rating	9.33 (0.74)	8.81 (1.61)
L2 self-rating	7.56 (1.24)	7.48 (1.28)
LDT (% ACC of PWs)	81.99 (11.42)	81.64 (11.02)
LDT (% ACC of Ws)	84.27 (9.85)	80.90 (12.21)
O-Span (% ACC of recall)	80.75 (12.29)	73.12 (15.80)
Simon effect (RT_{IC-C})	33.74 (23.51)	27.25 (28.08)

Note. L1 = first language; L2 = second language; LDT = lexical decision task; ACC = accuracy; PWs = pseudowords; Ws = words; RT = reaction time; IC = incongruent trials; C = congruent trials.

Appendix

Critical Stimuli Used in Experiments 1 and 2

Table A1

Semantic trials			**Translation/form trials**		
First word	**Distractor**	**Control**	**First word**	**Distractor**	**Control**
abstract (摘要)	提纲(outline)	胡须 (beard)	attention (注意)	主意 (idea)	电梯 (elevator)
accident (事故)	交通 (traffic)	午餐 (lunch)	balloon (气球)	汽油 (gasoline)	学期 (semester)
acrobatics (杂技)	表演 (performance)	医生 (doctor)	barrel (桶)	蛹 (pupa)	夏 (summer)
arm (臂)	腰 (waist)	天 (sky)	bee (蜂)	峰 (peak)	南 (south)
back (背)	胸 (chest)	盒 (box)	blue (蓝)	篮 (basket)	鸡 (chicken)
banana (香蕉)	水果 (fruit)	力量 (strength)	board (板)	饭 (rice)	狗 (dog)
bed (床)	枕 (pillow)	牙 (tooth)	bottle (瓶)	饼 (cake)	蚁 (ant)
beggar (乞丐)	贫穷 (poverty)	蝙蝠 (bat)	bowl (碗)	腕 (wrist)	钟 (clock)
biscuit (饼干)	零食 (snack)	报纸 (newspaper)	bride (新娘)	新闻 (news)	字典 (dictionary)
blood (血)	伤 (wound)	狐 (fox)	bridge (桥)	侨 (emigrant)	鞭 (whip)
bread (面包)	黄油 (butter)	困难 (difficulty)	cat (猫)	锚 (anchor)	箭 (arrow)
breath (呼吸)	生命 (life)	照片 (photo)	cell (细胞)	细节 (detail)	石头 (stone)
brick (砖)	瓦 (tile)	虾 (shrimp)	chain (链)	莲 (lotus)	雨 (rain)
cannon (炮)	枪 (gun)	日 (sun)	check (支票)	支配 (domination)	比赛 (match)
chair (椅)	座 (seat)	鹅 (goose)	child (孩子)	海藻 (seaweed)	教室 (classroom)
circle (圆)	方 (square)	墨 (ink)	coal (煤)	媒 (media)	汤 (soup)
citizen (公民)	国籍 (nationality)	农场 (farm)	colleague (同事)	同时 (meantime)	地图 (map)
coat (衣)	布 (cloth)	壶 (kettle)	computer (电脑)	佃农 (tenant)	胃口 (appetite)
comb (梳)	头 (head)	笔 (pen)	corn (玉米)	渔民 (fisherman)	蜘蛛 (spider)
company (公司)	员工 (staff)	冰箱 (fridge)	dam (坝)	狈 (wolf)	驴 (donkey)
cow (牛)	奶 (milk)	花 (flower)	debt (债)	渍 (stain)	蟹 (crab)
criticism (批评)	进步 (progress)	合同 (contract)	desert (沙漠)	纱布 (gauze)	耐心 (patience)
diary (日记)	习惯 (habit)	卫星 (satellite)	direction (方向)	芳香 (perfume)	工资 (salary)
disk (光盘)	数据 (data)	啤酒 (beer)	dragon (龙)	笼 (cage)	肩 (shoulder)
earthquake (地震)	灾难 (disaster)	网球 (tennis)	economy (经济)	经历 (experience)	钥匙 (key)
envelope (信封)	邮票 (stamp)	丝绸 (silk)	eye (眼)	银 (silver)	斧 (axe)
evidence (证据)	实验 (experiment)	技能 (skill)	face (脸)	剑 (sword)	云 (cloud)
foam (泡沫)	幻想 (fantasy)	窗帘 (curtain)	fact (实际)	世纪 (century)	国王 (king)
fork (叉)	盘 (plate)	烟 (cigarette)	flag (旗)	棋 (chess)	兔 (rabbit)
friend (朋友)	信任 (trust)	塑料 (plastics)	frog (蛙)	娃 (baby)	肺 (lung)
gap (沟)	坎 (pit)	节 (festival)	garden (花园)	化验 (test)	敌人 (enemy)
goldfish (金鱼)	宠物 (pet)	香皂 (soap)	goal (目标)	墓碑 (tombstone)	肌肉 (muscle)
hand (手)	掌 (palm)	虫 (worm)	gun (枪)	舱 (cabin)	蛇 (snake)
health (健康)	锻炼 (exercise)	抽屉 (drawer)	harvest (丰收)	封锁 (blockade)	动机 (motivation)
helmet (头盔)	安全 (safety)	绳子 (rope)	help (帮助)	帮派 (faction)	玩具 (toy)
history (历史)	将来 (future)	婴儿 (infant)	hero (英雄)	映像 (image)	地窖 (basement)
hole (洞)	缝 (crack)	风 (wind)	island (岛)	鸟 (bird)	松 (pine)
hypothesis (假设)	逻辑 (logic)	营养 (nutrition)	joke (笑话)	消化 (digestion)	建议 (advice)
investment (投资)	利润 (profit)	编辑 (editor)	journal (杂志)	杂质 (impurity)	果汁 (juice)
knife (刀)	菜 (vegetable)	泪 (tear)	kite (风筝)	疯子 (madman)	贡献 (contribution)

Table A1

Semantic trials			Translation/form trials		
First word	**Distractor**	**Control**	**First word**	**Distractor**	**Control**
landlord (房东)	租金 (rent)	借口 (excuse)	ladder (梯)	涕 (tear)	鸭 (duck)
law (法律)	罪犯 (criminal)	电视 (television)	lamp (灯)	钉 (nail)	井 (well)
leaf (叶)	黄 (yellow)	灰 (dust)	laser (*激光*)	*激情* (passion)	液体 (liquid)
lip (唇)	吻 (kiss)	光 (light)	leader (*领导*)	*领土* (territory)	教授 (professor)
lock (锁)	栓 (pin)	右 (right)	lesson (课)	稞 (wheat)	勺 (spoon)
love (爱)	恨 (hate)	凳 (stool)	liver (肝)	杆 (pole)	棍 (stick)
marriage (婚姻)	幸福 (happiness)	蝴蝶 (butterfly)	management (管理)	惯例 (convention)	声调 (tone)
medicine (药)	病 (illness)	绳 (rope)	mask (*面具*)	*面试* (interview)	站台 (platform)
movie (电影)	娱乐 (entertainment)	论文 (thesis)	memory (*记忆*)	*记号* (mark)	小偷 (theft)
nail (钉)	锤 (hammer)	油 (oil)	mirror (镜子)	竞走 (footrace)	冠军 (championship)
necklace (项链)	魅力 (charm)	培训 (training)	moral (*道德*)	*道具* (props)	屋顶 (roof)
needle (针)	线 (thread)	夜 (night)	mother (妈)	马 (horse)	雾 (fog)
net (网)	线 (fish)	裙 (skirt)	neck (颈)	劲 (strength)	杯 (cup)
novel (小说)	作家 (writer)	硬币 (coin)	neighbor (邻居)	领结 (tie)	信心 (confidence)
pot (罐)	坛 (jar)	西 (west)	notice (通知)	同志 (comrade)	预算 (budget)
referee (裁判)	公正 (fairness)	衬衣 (shirt)	nurse (*护士*)	*护膝* (kneecap)	毯子 (blanket)
restaurant (餐馆)	菜单 (menu)	问题 (question)	paddle (桨)	奖 (prize)	梦 (dream)
rose (玫瑰)	美丽 (beauty)	酒精 (alcohol)	pan (锅)	窝 (nest)	雪 (snow)
ruler (尺)	寸 (inch)	象 (elephant)	peach (桃)	兆 (omen)	星 (star)
sand (沙)	泥 (mud)	穷 (poor)	pear (梨)	犁 (plow)	帽 (hat)
saw (锯)	木 (wood)	墙 (wall)	pearl (珍珠)	诊所 (clinic)	厨房 (kitchen)
sheep (羊)	毛 (fur)	湖 (lake)	piano (钢琴)	感情 (feeling)	黑暗 (darkness)
ship (船)	艇 (boat)	球 (ball)	privacy (隐私)	饮食 (diet)	商店 (shop)
shoe (鞋)	靴 (boot)	窗 (window)	road (路)	露 (dew)	扇 (fan)
shovel (铲)	坑 (pit)	死 (death)	rule (规则)	贵族 (noble)	钻石 (diamond)
spy (间谍)	情报 (information)	机器 (machine)	sample (*样品*)	*赝品* (fake)	能量 (energy)
stove (灶)	炉 (oven)	伞 (umbrella)	sauce (酱)	浆 (syrup)	火 (fire)
teacher (老师)	知识 (knowledge)	篱笆 (fence)	shelf (*书架*)	*书记* (secretary)	戒指 (ring)
telephone (电话)	沟通 (communication)	教练 (coach)	steel (钢)	纲 (outline)	巷 (lane)
tiger (虎)	兽 (beast)	夫 (husband)	sugar (糖)	塘 (pond)	弧 (arc)
town (镇)	村 (village)	鹿 (deer)	suitcase (箱)	厢 (carriage)	壳 (shell)
train (火车)	乘客 (passenger)	钮扣 (button)	task (任务)	人物 (character)	漫画 (cartoon)
trash (垃圾)	废品 (scrap)	速度 (speed)	tea (茶)	茬 (stubble)	袜 (sock)
tree (树)	林 (forest)	北 (north)	temple (庙)	苗 (seedling)	岸 (bank)
university (大学)	教育 (education)	蜡烛 (candle)	ticket (票)	瓢 (ladle)	鹰 (eagle)
vase (花瓶)	装饰 (decoration)	工作 (job)	tomb (坟)	蚊 (mosquito)	舌 (tongue)
wheat (麦)	米 (rice)	漆 (paint)	trade (贸易)	毛衣 (sweater)	操作 (operation)
wheel (轮)	车 (car)	妻 (wife)	trap (陷阱)	馅饼 (pie)	校园 (campus)
word (词)	话 (words)	裤 (pants)	vinegar (醋)	错 (fault)	谎 (lie)
year (年)	月 (month)	鼠 (mouse)	wolf (狼)	浪 (wave)	盐 (salt)

Note. Whether a distractor or control was paired with each first word was counterbalanced across participants. Correct translations for all words are provided in parenthes es for reference, but participants were presented with only the first word in English and the distractor or control word in Chinese. Sixteen Chinese translation form distractors sharing a same character with the correct translations are italicized.