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Brain potentials reveal how emotion filters native language access when bilinguals read words in their second language

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Running title: Mechanism of lexical access blocking in bilinguals

Abstract

It is now well-established that reading words in a second language (L2) automatically activates native language (L1) translations in bilinguals. Whilst there is evidence that access to such representations is inhibited when words have a negative emotional valence, the mechanism underlying such inhibition is elusive, and it is unknown whether inhibition arises online as L2 is being processed or whether negative valence affects subsequent L1 processing. Here, we recorded event-related brain potentials in Chinese-English bilinguals engaged in an implicit translation-priming paradigm involving L2 (English) word pairs. Participants performed a semantic relatedness task, unaware that word pairs could conceal a sound repetition if translated into Chinese. When emotional valence was manipulated in prime position (first word), we observed form repetition priming through L1 translations for positive but not for negative words. However, when emotional valence was manipulated in target position (second word), priming occurred for both positive and negative word valences. This result begins to elucidate the mechanism by which emotion regulates language processing in bilinguals: Negative words in L2 induce a refractory period during which cross-language lexical access is blocked. These findings show that despite being neuroanatomically distinct in the human brain, emotional (limbic) regulation systems can penetrate language processing.

Keywords: bilingualism; emotion; event-related potentials; implicit priming; inhibitory control

Introduction

Over the past two decades, researchers in the field of bilingualism have debated whether native language representations are spontaneously accessed during second language processing. Mounting evidence now supports language non-selective access in L2 reading, listening, and speaking (Thierry and Wu 2007; van Heuven and Dijkstra 2010; Wu et al. 2013; Spalek et al. 2014) although some studies have also provided evidence for selective access under specific conditions (Rodriguez-Fornells et al. 2002; FitzPatrick and Indefrey 2010; Casaponsa and Duñabeitia 2016; Casaponsa et al. 2020).

In a seminal study using an implicit translation-priming paradigm, Thierry and Wu (2007) showed that reading L2 words unconsciously activates L1 translations. Chinese-English bilingual participants judged the semantic relatedness of English words presented in pairs. They were unaware that half of the words concealed a character repetition in their Chinese translations. The hidden character repetition reduced the amplitude of the N400, an electrophysiological index of priming that can be modulated unconsciously (see Kutas and Federmeier 2011 for a review). Using different types of hidden repetition (phonological vs. orthographic) in the implicit translation-priming paradigm, Wu and Thierry (2010) further demonstrated that the N400 priming effect was only found for sound repetition (as opposed to written character repetition) in L1 translations, suggesting that it is the phonological –not the orthographic– form that is unconsciously accessed when Chinese-English bilinguals read English words.

Intriguingly, however, Wu and Thierry (2012) later reported that access to translation equivalents is perturbated when L2 words have a negative emotional valence. They implemented a similar translation-priming paradigm and manipulated the emotional valence of prime words (positive, neutral, negative). When prime words had a positive or neutral valence, the expected priming effects were found, replicating previous evidence (e.g., Thierry and Wu

2007) for automatic access to L1 translations. However, when the prime words had a negative valence, the priming effect was abolished. The authors interpreted these results as showing that processing negative words in L2 impaired automatic access to L1 representations, thus eliminating translation-priming effects on the target word. Their findings showed that, in some circumstances, cross language-activation is blocked, as it has been shown in masked priming experiments manipulating language-specific orthographic cues (Casaponsa and Duñabeitia 2016; Casaponsa et al. 2020).

However, the pattern of results observed in Wu and Thierry (2012) can be accounted for by two distinct mechanisms: (*i*) Reading a L2 word prime with a negative valence "shuts down" access to its translation equivalents in L1 in real time, thereby abolishing the priming effect on the target word that follows or (*ii*) The L1 translation equivalent of the negative prime word is in fact accessed just like in the case of positive and neutral primes but, shortly afterwards, L1 access is inhibited at the locus of the target word. Although both hypotheses would predict the same observation, namely the absence of cross-language priming, the underlying mechanism would be very different in terms of the temporal dynamics of the inhibition applied and its implications for interactions between emotion and language systems in the human brain.

In Experiment 1, we contrastively tested scenarios (*i*) and (*ii*), by adding a manipulation of word order: In two experimental blocks, emotional (positive and negative) words were presented as primes (i.e., the emotional prime blocks) and in another two blocks, they were presented as targets, following primes that were always neutral (i.e., the emotional target blocks). In the emotional prime blocks, we expected reduced priming for negative as compared to positive primes (Wu and Thierry 2012). In the emotional target blocks, we expected one of two possible outcomes: (a) no measurable priming for negative words pointing to online inhibition of cross-language activation, or (b) full priming effects irrespective of valence, which would suggest that inhibitory effects on cross-language lexical access prompted by

negative valence are in fact triggered with a delay within a refractory period and affect the next encountered word. As was the case in all the studies cited above, the dependent measure of implicit translation-priming was the mean amplitude of the N400 component of event-related brain potentials (ERPs).

In order to confirm the mechanisms underlying the presence and absence of repetition priming effects in Experiment 1, we also conducted a control experiment in Chinese participants tested in Chinese (Experiment 2), featuring the same task manipulations as in Experiment 1 but using L1 instead of L2 words.

Materials and Methods

Participants. Twenty-seven Chinese-English bilinguals were recruited for Experiment 1 with the aim of retaining a minimum of 24 datasets for analysis. The target sample size was determined using G*Power 3.1 (Faul et al. 2007) based on a medium effect size (0.25) and a minimum power of 0.9 at α level of 0.05. Three participants were excluded due to excessive number of artifacts in their electroencephalogram (EEG), leaving 24 bilinguals (9 females, mean age 22.8 years, range 20–25 years) in the final analysis. All participants had passed the CET-6 (College English Test, Band 6), an advanced level of national English test for Chinese non-English majors, with a mean score of 516 (SD = 45.1) out of 710 points maximum, indicating that participants had an intermediate level of proficiency in English (Jin et al. 2022). They self-rated their Chinese and English proficiency (on a scale of 1–not literate, to 10–very literate; $M_{\text{Chinese}} = 8.5$, $SD = 1.32$; $M_{\text{English}} = 6.38$, $SD = 1.1$), which positively correlated with CET-6 performance ($r = 0.68$, $p < 0.001$, two-tailed).

The same number of participants (16 males and 8 females, mean age 21.8 years, range 19–26 years) were recruited for the Chinese control task in Experiment 2. There were no significant differences between the two experiments in terms of participant age or gender (both

*p*s > 0.05). Also, the two groups did not differ in terms of self-rated Chinese proficiency (t_{23} = 1.6, p = 0.124, two-tailed).

All participants were right-handed, had no vision problems or language disabilities, and reported no history of neurological or psychiatric disorders. After giving written informed consent in accordance with the latest version of the Declaration of Helsinki, participants took part in the experiment, which was approved by the ethics committee of the University of Electronic Science and Technology of China.

Stimuli. In Experiment 1, we selected 90 English word pairs that were not semantically related but concealed a sound repetition when translated into Chinese (e.g., 'grammar'– *Yu Fa* and 'umbrella'– *Yu San*). Half of the test word pairs (n = 45) involved a positive word (e.g., honesty – program) and the other half involved a negative word (e.g., failure – poet). A control condition featured 45 English word pairs which did not relate in meaning nor concealed a sound repetition in their Chinese translation equivalents (unrelated condition). As in Wu and Thierry (2012), we also included 45 word pairs featuring only neutral words (e.g., finance – metal). Finally, 45 word pairs that featured semantically related words but did not conceal a sound repetition when translated into Chinese were used as fillers. This amounted to 225 word pairs to be presented once in that order in emotional prime blocks, and once in the reverse order in emotional target blocks.

To reduce the likelihood of eye movements, taking into consideration aspect ratio, no word had more than 14 letters. Words were controlled for average number of letters across experimental conditions (*p*s > 0.1) and did not differ as regards lexical frequency across conditions (*p*s > 0.1) based on the SUBLEX-US corpus (Brysbaert and New 2009). Familiarity ratings for English word pairs were not significantly different across the conditions (*p*s > 0.1)

based on the Glasgow Norms (Scott et al. 2019). There was no significant difference in concreteness between positive and negative words (Brysbaert et al. 2014; $p = 0.726$) although their concreteness was lower than that of other words (ps < 0.01). Emotional valence and arousal of the English stimuli were also controlled (Warriner et al. 2013), such that positive and negative words differed significantly in terms of emotional valence ($p < 0.001$), but not in terms of arousal ($p = 0.278$), whereas both negative and positive words differed significantly from neutral ones with regard to arousal (ps < 0.001; see descriptive statistics of the stimuli in the supplementary Table S1 and S2, and the full set of stimuli in the supplementary Table S3).

The stimuli in Experiment 2 were the Chinese translation equivalents of the English words in Experiment 1 and each featured two characters. Lexical frequency did not differ between conditions (ps > 0.1) according to the SUBTLEX-CH database (Cai and Brysbaert 2010). Familiarity, concreteness, valence, and arousal values of the Chinese words were assessed in a pre-test conducted in an independent sample of participants ($n = 10$). Results showed that there was no significant difference in familiarity across conditions ($p = 0.808$) and no significant difference in concreteness between positive and negative words ($p = 0.969$). Positive and negative words differed significantly in emotional valence ($p < 0.001$) but not in terms of arousal ($p = 0.187$), whereas negative and positive words differed significantly from neutral ones with regard to both valence and arousal (ps < 0.001). To verify the reliability of the Chinese translations, we randomly recruited a further ten participants to perform a modified first translation task (Tokowicz and Kroll 2007), where participants are instructed to say aloud the first translation that comes to mind upon seeing an English word whilst voice response time and accuracy were recorded. Participants provided > 80% of the intended translations in the absence of any significant difference between conditions in terms of reaction time or accuracy (ps > 0.1; see supplementary Table S4).

Task and Procedure. Experiment 1 and 2 employed the same priming task, administered using E-prime 3.0 (Psychology Software Tools, Pittsburgh, PA). All words (English words in Experiment 1 and Chinese translation equivalents in Experiment 2) were presented in the center of a CRT monitor with a resolution of 1920 × 1080 dpi in 38-point Arial Narrow font. After a 500 ms fixation, the first word was presented for 500 ms, followed by the second word, also for 500 ms, with a randomized prime-target inter-stimulus interval ranging between 300–500 ms in steps of 100 ms. Participants were seated 120 cm from the screen and asked to report as fast as possible whether the second word (target) was related or unrelated in meaning to the first (prime) by pressing one of two keys on a keyboard (i.e., 'f' or 'j'), with response sides counterbalanced between participants.

Each word was presented twice, once as the prime in one of two emotional prime blocks, and once as the target in one of two emotional target blocks. Thus, in total, taking word order into account, participants were presented with 450 word pairs. Each block contained 112 or 113 word pairs, featured quasi-equal proportions of negative, positive, and neutral word pairs, and lasted about five minutes. Blocks were separated by 1–2 minutes rest periods. Block order was randomized across participants. The word pairs were presented in a pseudo-randomized order.

Prior to the experimental trials, participants had a practice run in the presence of the experimenter, making sure any question arising was answered before the beginning of the experiment proper. Then, participants made semantic relatedness judgments on word pairs presented in two emotional prime blocks (in which negatively and positively valenced words were presented as primes) and two emotional target blocks (in which the valenced words were presented in target position).

ERP Recording. EEG data were recorded from 64 Ag/AgCl electrodes placed according to the extended 10–20 convention in reference to electrode Fz at a sampling rate of 1 kHz. Impedances were kept below 5 kΩ. EEG activity was filtered on-line bandpass between 0.1 and 200 Hz and re-referenced to the global average reference. The data were refiltered off-line with a 25 Hz low-pass using an Infinite Impulse Response (IIR) Filter implemented in Brain Vision Analyzer Version 2.1.2 (Brain Products GmbH). The data were corrected for ocular artifacts via Independent Component Analysis (Makeig et al. 1997). The mean number of rejected components in Experiments 1 and 2 were 2.3 (*SD* = 0.8) and 2.6 (*SD* = 0.7), respectively. Artifacts exceeding ±100 μV were automatically discarded. There was a minimum of 30 valid trials per condition in every participant (see supplementary Table S5 for more details). Epochs ranging from –200 to 800 ms after target onset were averaged for each condition. Baseline correction was applied in reference to pre-stimulus activity.

Behavioral Data Analysis. Reaction times and response accuracy for semantic relatedness judgments were analyzed with (generalized) linear-mixed models, (G)LMM, using the lmerTest package (Kuznetsova et al. 2017). Reaction times to incorrect trials and shorter than 200 ms were discarded from the analyses. Two fixed effects were considered: Position (emotional prime vs. emotional target) and Condition (negative, positive, unrelated). All fixed effects were coded using sum contrast coding. For the factor with two levels (Position), we computed sum contrasts of [-0.5, 0.5]. For the factor with three levels (Condition), we computed two contrasts in a predictive manner (for a discussion, see Schad et al. 2020). Specifically, we included sum contrasts between negative and unrelated words (negative = -0.5, unrelated = 0.5, positive = 0) and between negative and positive words (negative = -0.5, unrelated = 0, positive = 0.5). We did not compare emotional conditions together to the unrelated condition given the expected asymmetry between negative and positive conditions

on the basis of Wu and Thierry (2012). For each (G)LMM, we first computed a maximal model with a full random-effect structure, including subject- and item-related variance components for intercepts and by-subject and by-item random-slopes for fixed-effects (Barr et al. 2013). If a maximal model did not converge and/or turned out to be too complex, we selected a parsimonious (G)LMM following the recommendations from Bates et al. (2018), see also Matuschek et al. (2017). Small variance parameters were removed using the lme4::rePCA and lme4::VarCorr (Pinheiro and Bates 2000) functions until both models were supported by the data (for the final structure of each model, see Supplementary Text). β estimates and significance of fixed effects and interactions (*p*-values) are based on the Satterthwaite's Approximation for LMMs and Laplace Approximation for GLMMs (lmerTest package; Kuznetsova et al. 2017).

ERP Data Analysis. ERP analyses were split into two sub-analyses: (1) The main analysis of priming effects elicited by form repetition in Chinese, and (2) A secondary analysis of modulation elicited by emotional valence reported in the supplementary materials (Supplementary Text). The main analysis involved comparison of N400 amplitudes elicited by target words in the positive, negative, and unrelated conditions, in the emotional prime and emotional target blocks. Note that the related neutral condition was excluded from analysis to avoid spurious cumulative effects of emotional valence and form relatedness in Chinese translations. Indeed, in Wu and Thierry (2012), the emotional primes (negative and positive) elicited greater ERP amplitudes than neutral primes. Therefore, comparing emotional and neutral word targets would run the risk of confounding priming effects induced by sound repetition in Chinese and modulations elicited by emotional valence.

The N400 component was measured based on mean ERP amplitudes between 300–500 ms following target onset in both Experiment 1 and Experiment 2 at electrodes FC1, FCz, FC2,

C1, Cz, C2, CP1, CPz, CP2, where the N400 is classically maximal (e.g., Thierry and Wu 2007; Martin et al. 2009; Wu and Thierry 2012; Blanchette and El-Deredy 2014; Jończyk et al. 2019; Naranowicz et al. 2022), including the electrodes focused on by Wu and Thierry (2012). Results were subjected to a repeated-measures ANOVA with Position of the emotional word (prime, target) and Condition (related negative, related positive, unrelated) as within-subject factors. Given the primary aim of this study, namely, to examine whether previously found valence-dependent priming effects would change when emotional words are used as targets instead of primes, we focused on the interaction between Block and Condition. To rule out potential confounding effects of emotional valence on sound repetition priming, we conducted an additional analysis of two ERP components extensively reported as being modulated by emotional valence, the early posterior positivity (EPN) and the late positive complex (LPC) (Frühholz et al. 2011; Zhang et al. 2014) elicited by positive, negative, and neutral words in prime or target position. The time window for the EPN analysis was 300–400 ms, which corresponds to the late EPN window as defined by Kissler and Bromberek-Dyzman (2021), since it was used also by Zhang et al. (2014) with Chinese participants. Electrodes for EPN analysis were P7, PO7, P8, PO8, O1, O2. LPC amplitudes were measured between 450–650 ms at electrodes C1, Cz, C2, CP1, CPz, CP2, P1, Pz, P2.

The Greenhouse-Geisser correction for non-sphericity was applied when required and Bonferroni correction for multiple comparisons via two-tailed *t*-tests was implemented in *post hoc* pairwise comparisons. Cohen's *d* was calculated as a measure of effect size.

Results

Behavioral Results

Experiment 1: Chinese-English bilinguals tested in English

We found a fixed effect of Condition on reaction times, showing that negative words (M = 515.49, 95% CI [508.44, 522.54]) led to faster responses than positive words (M = 525.88, 95% CI [518.82, 532.95]), β = –10.13, 95% CI [–20.21, –0.06], $t_{133.14}$ = –1.97, p = 0.051. We found no differences for the contrast between negative and unrelated words, β = –3.91, 95% CI [–13.99, 6.16], $t_{133.39}$ = –0.76, p = 0.448. A fixed effect of Position was not significant, β = 29.88, 95% CI [–3.14, 62.90], $t_{23.67}$ = 1.77, p = 0.089. The Condition-by-Position interaction was significant, β = 21.20, 95% CI [3.66, 38.74], $t_{4,708.92}$ = 2.37, p = 0.018, showing faster responses to negative words in the prime (M_{negative} = 492.40, 95% CI [483.10, 501.69]) compared to target (M_{negative} = 538.82, 95% CI [528.43, 549.21]) position. Furthermore, responses were faster in the negative than the unrelated condition in the prime position ($M_{\text{unrelated}}$ = 508.50, 95% CI [499.62, 517.38]) as compared to the target position ($M_{\text{unrelated}}$ = 531.45, 95% CI [521.20, 541.70]; see Fig. 1A). For accuracy, neither fixed effects nor interactions were significant (ps < 0.1; see Fig. 1A).

Experiment 2: Control Chinese participants tested in Chinese

With regards to reaction times, neither fixed effects nor interactions were significant (ps > 0.1; see Fig. 1A). We found a significant fixed effect of Condition for the contrast between positive and negative words on accuracy, β = 0.43, 95% CI [0.07, 0.78], z = 2.36, p = 0.018, with higher accuracy for negative (M = 92.08, 95% CI [90.94, 93.22]) than positive (M = 90.14, 95% CI [88.88, 91.40]) words. The difference between negative and unrelated words was not significant, β = –0.28, 95% CI [–0.65, 0.09], z = –1.49, p = 0.137. A marginal Position-by-Condition interaction, β = –0.53, 95% CI [–1.07, 0.01], z = –1.93, p = 0.054, showed that, in the emotional target position, accuracy was higher for unrelated (M = 93.24, 95% CI [91.74, 94.74]) than for negative (M = 91.76, 95% CI [90.12, 93.40]) words (see Fig. 1A). Other effects were not significant (ps > 0.1).

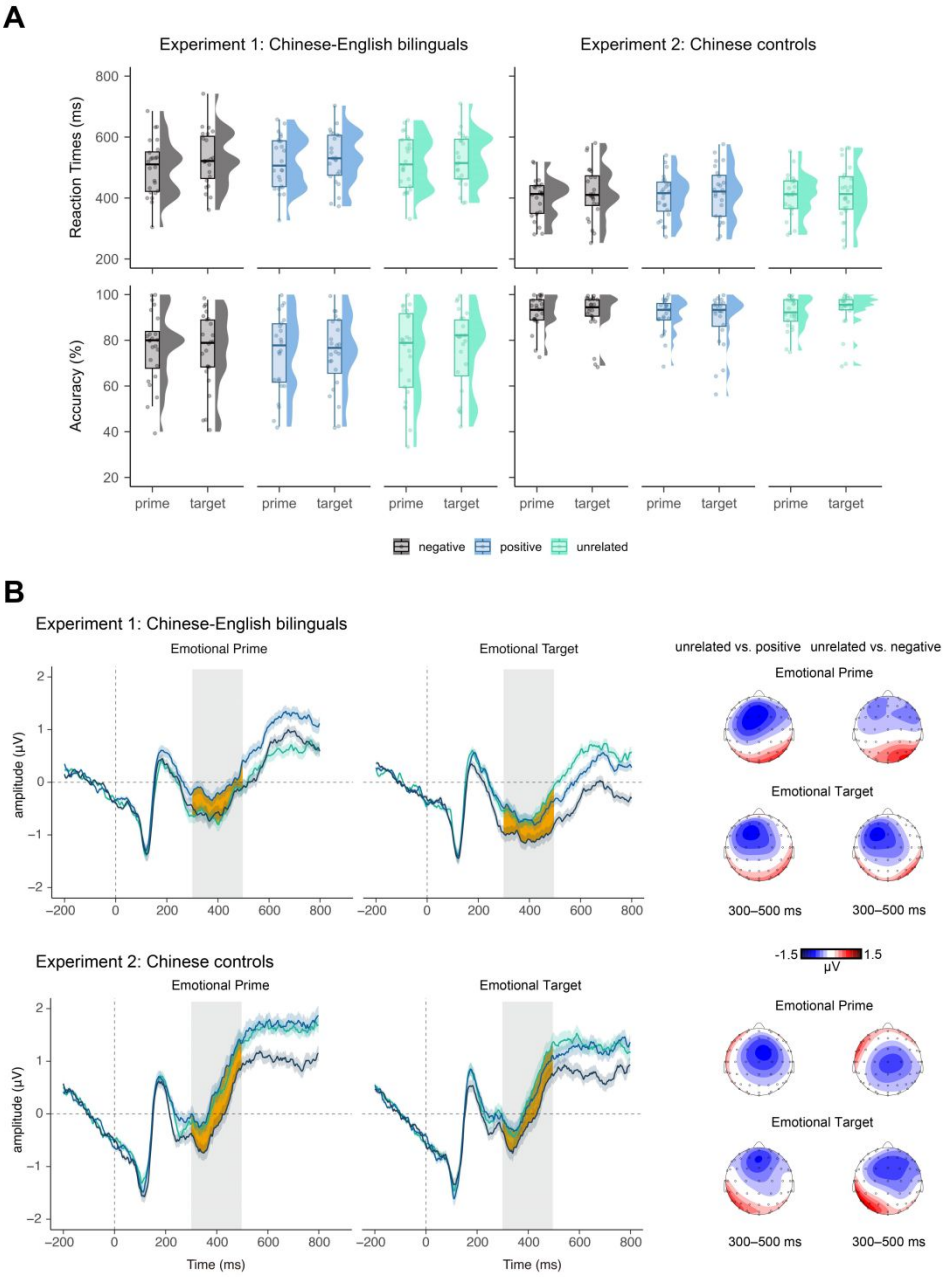

Figure 1. Behavioral and ERP results. (A) Box and violin plots of reaction times and accuracy of responses in the emotional prime and target blocks for the Chinese-English bilingual group and Chinese controls. (B) ERPs (left) and topomaps (right). ERPs were elicited by target words in the emotional prime and emotional target blocks in Experiment 1 featuring the English task and in Experiment 2 featuring the Chinese control task. Waveforms depict brain potential variations for a linear derivation of nine central electrodes (FC1, FCz, FC2, C1, Cz, C2, CP1, CPz, CP2) where the effect was maximal. Shaded areas around each curve depict s.e.m. and greyed-out rectangles highlight analysis windows (300–500 ms). Scalp topographies depict differences based on unrelated-positive and unrelated-negative contrasts in the emotional prime and emotional target blocks in Experiment 1 and Experiment 2 between 300 ms and 500 ms after the stimulus onset.

ERP Results

Experiment 1: Chinese-English bilinguals tested in English

We found a significant main effect of Position on N400 mean amplitude ($F_{1,23}$ = 5.20, p = 0.032, η_p^2 = 0.184), with amplified N400 responses when emotional valence was manipulated in target relative to prime position. There was also a significant main effect of Condition ($F_{2,46}$ = 8.20, p = 0.001, η_p^2 = 0.26). *Post hoc* pairwise comparisons corrected for multiple comparisons showed that N400 responses in the positive valence conditions were reduced in amplitude compared to the unrelated condition (t_{23} = 3.78, p = 0.003, Cohen's d = 0.77). However, the difference between negative and unrelated conditions was marginal (t_{23} = 2.54, p = 0.055, Cohen's d = 0.52).

Critically, we observed a significant interaction between Position and Condition ($F_{2,46}$ = 4.16, p = 0.022, η_p^2 = 0.15; Fig. 1B). *Post hoc* comparisons showed that N400 modulation was significant for positive primes (t_{23} = 2.67, p = 0.014, Cohen's d = 0.54), but not for negative primes (p = 0.926), whereas for the manipulation of emotional valence in targets, N400 amplitude was significantly reduced for both positive and negative targets (positive: t_{23} = 2.64, p = 0.014, Cohen's d = 0.54; negative: t_{23} = 3.48, p = 0.002, Cohen's d = 0.71) relative to the unrelated condition. Topomaps of differences between unrelated and positive conditions and between unrelated and negative conditions are presented in Fig. 1B.

Experiment 2: Control Chinese participants tested in Chinese

There was no main effect of Position (p = 0.682) but we found a significant main effect of Condition on N400 amplitude ($F_{2,46}$ = 19.46, p < 0.001, η_p^2 = 0.46). *Post hoc* pairwise comparisons showed that N400 amplitude was significantly reduced for Chinese word pairs featuring a character repetition irrespective of emotional valence (positive: t_{23} = 5.64, p < 0.001,

Cohen's $d = 1.15$; negative: $t_{23} = 6.13$, $p < 0.001$, Cohen's $d = 1.24$). The two factors did not interact ($p = 0.382$; Fig. 2B).

Note that in the analysis comparing ERP amplitudes as a function of emotional valence, the early posterior positivity (EPN) and the late positive component (LPC) were not modulated by valence whether words were presented in prime or target position (Supplementary Materials).

Discussion

Employing emotional words as either primes or targets in an implicit translation-priming paradigm, we investigated how access to the native language is modulated by emotional valence in Chinese-English bilinguals. More specifically, we tested whether negative L2 words trigger online inhibition of access to L1 translation equivalents (i.e., simultaneously as a L2 word is being processed) or whether inhibition intervenes with a delay, leaving current processing intact and rather filtering subsequent information processing.

In Experiment 1, positive prime words reduced N400 amplitudes whereas negative primes failed to do so, indicating spontaneous access to L1 translation when bilinguals processed positive L2 primes but not when they processed negative L2 primes (Wu and Thierry 2012). Interestingly, we found a different pattern when using the reverse order of stimulus presentation, that is, when emotional valence was manipulated in target rather than prime position. Therefore, inhibition resulting from a negative L2 word encounter must apply after a word has been processed, since access to L1 translation equivalents was found when negative words are presented as targets. Moreover, we found effects of character repetition for emotional words presented as either primes or targets and irrespective of valence in Experiment 2 conducted entirely in L1. This means that the inhibition effect reported here does not appear to affect L1 processing.

The contrasting priming effect between primes and targets is unlikely to have been confounded by emotional valence, since emotion-related ERPs (i.e., EPN and LPC) did not differ between positive and negative primes (see Supplementary Text for more details). These findings confirm that spontaneous access to L1 translation equivalents suffers some kind of inhibition when bilinguals encounter negatively valenced words in L2. We did not observe valence modulation when comparing emotional and neutral words, however. This may be because each word was repeated twice and the presentation rate was increased compared to that used by Wu and Thierry (2012), thus likely reducing the impact of emotional valence. This contrasts with the results of Kissler et al. (2007), who reported the EPN effect despite a fast presentation rate for emotional words. We suggest that the emotional words in Kissler *et al.* (2007) were more salient than in our study, possibly due to differences in the ratio of emotional to neutral words and experimental tasks (See Supplementary Text).

Critically, however, when negative words were presented as targets, priming effects in the N400 range did not differ significantly from those elicited by positive targets. As hinted above, we interpret this result as showing that bilinguals unconsciously access L1 translation equivalents of L2 words irrespective of whether they have a positive or a negative valence, and that it is only *after* a negative word has been processed that inhibition of cross-language lexical access occurs. Otherwise, we would have observed the absence of cross-language priming in word pairs featuring a negative word irrespective of position (prime or target). In other words, in the emotional prime blocks of Experiment 1, we contend that the translation of negative primes was accessed before L1 access was shut down for the subsequent (neutral) target word. In the case of valence manipulation in prime position, negative L2 words must thus have triggered inhibition of cross-language lexical access for a short period of time (a kind of refractory period) after they had been processed, thereby preventing access to L1 translation for the target word. Note that this mechanism was likely unconscious and incompatible with

cognitive strategy, given that the effects found here were extremely short-lived and incompatible with conscious decision-making.

Remarkably, bilinguals responded significantly faster when negative words were used as primes relative to targets and faster also for word pairs featuring a negative prime than to those involving an unrelated prime, whilst no such difference was found in the case of valence manipulation on the target. This is an interesting observation since Wu and Thierry (2012) failed to see any behavioral modulation by valence in their experiment. It could be explained as follows: When negative words are presented as primes, the shutdown of L1 access for target words prevents access to L1 translation equivalents, in turn suppressing form repetition priming. Such repetition priming is likely to interfere with the semantic relatedness judgement task at hand. If a target word spuriously relates in form to the prime word via translation in L1, when the two are semantically unrelated, form relationship likely interferes with semantic judgment. Therefore, when access to L1 representations is shut down for target words because the prime word has a negative valence, form repetition cannot interfere with semantic relatedness evaluation, allowing responses to be measurably faster. Previous research has indeed shown that hidden repetitions in L1 translation equivalents of L2 words that are otherwise semantically unrelated produce interference and increase reaction times in semantic relatedness judgments (but see Zhang et al. 2011; Kim and Kim 2018; Li et al. 2018; Qu 2019). Response times in the present study were overall faster than in Wu and Thierry (2010; 2012), which may be attributed to the experimental set up encouraging fast responses. Nevertheless, N400 modulation in the semantically related filler condition in both groups indicates that semantic processing occurred despite short reaction times and low accuracy[1] (See Supplementary Materials).

[1] The accuracy of Chinese-English bilinguals in the semantically related filler condition was relatively low but significantly above chance in both groups (M_{bil} = 63.7%, 95% CI [61.7, 65.8], M_{mono} = 68.4%, 95% CI [66.4, 70.3]), which is not too surprising given the difficulty of establishing relatedness compared to that of establishing semantic independence.

In Experiment 2, we tested native speakers of Chinese in the same task but in different participants, using Chinese instead of English words. We found that accuracy was higher for word pairs involving negative words than for those featuring positive words, consistent with the idea that negative stimuli are more salient and foster greater attentional engagement, thereby enhancing performance (Fehring et al. 2019). We also found an interference effect consistent with that discussed above, such that accuracy was lower for word pairs featuring a negative target (related to the prime via L1) than for those featuring an unrelated target. Recall that, in Experiment 2, N400 was reduced by sound repetition priming in the absence of any modulation by emotional valence, whether the emotional manipulation was implemented in prime or target position. Such findings are in line with those reported in previous studies (Thierry and Wu 2007; Wu and Thierry 2010) and suggest that the inhibition observed in the case of negative primes when bilinguals operate in English does not apply regardless of the language of operation but rather specifically concerns cross-language lexical access.

Overall, our findings corroborate previous evidence suggesting that access to negative emotional content is constrained or filtered in L2 comprehension (Jończyk et al. 2016; Jończyk *et al.* 2019). Jończyk et al. (2016), for instance, found that Polish-English bilinguals immersed in the L2 environment show reduced N400 modulations for sentences ending in a negative L2 word as compared to all other conditions (positive / L1). In that experiment, negative words were embedded in several locations within a sentence, thus enabling L1 access inhibition to take place throughout sentence processing. The current results are thus consistent with the view that negative words in L2 weaken semantic processing of subsequently presented words through inhibition of automatic cross-language activation of L1 translations (Kroll et al., 2010).

While cognitive mechanisms of language control have been extensively investigated in bilingual language production (Blanco-Elorrieta and Pylkkänen 2016; Liu et al. 2022), the delayed inhibition effect observed here provides the first evidence for a mechanism of emotion

regulation in bilingual language comprehension. In language comprehension, the flow of information between word forms and meaning representations is obviously reversed, albeit not symmetrical, as compared to production (van Heuven and Dijkstra 2010; Declerck and Philipp 2015). Unlike the case of production, during which bilinguals need to select the intended word form for output and (potentially) inhibit non-target language competitors, language comprehension is mostly (but not exclusively) driven by the input, especially in a multilingual context (van Heuven and Dijkstra 2010). It is thus unlikely that comprehension mechanisms involve top-down suppression of non-target language word candidates (Wang 2015), and even more so in Experiment 1 since it only involved L2 words.

However, our findings show that negative emotional content triggers inhibitory control affecting processing at a lexical level during (subsequent) L2 word recognition, equating to a kind of top-down gating or filtering mechanism in comprehension. Thus, inhibitory control could be triggered by the anticipation of potential emotional interference from the next word to be encountered, an effect that may relate to anticipatory activation of the lateral prefrontal cortex that has been shown previously in similar conditions (Braver 2012; Chiew and Braver 2017; Kar et al. 2018). A recent fMRI study found that language switching costs are reduced when participants name pictures after processing negative words. This is accompanied by decreased neural activity associated with language switching and increased activation in the right dorsolateral prefrontal cortex, thought to be involved in maintaining a state of alert (Liu *et al.* 2022). While Liu et al. (2022) did not compare between switching directions, our finding contributes new evidence on how negative emotion reduces language interference in language comprehension, especially in the L2 to L1 switching direction. We argue that this mechanism enables bilinguals to minimize interference from disruptive (emotional) information, which may be detrimental to understanding of further content, or increase the likelihood of anxiety when L2 comprehension is demanding. Indeed, lack of understanding is a latent source of

frustration in bilinguals (Dryden et al. 2021) and a mechanism seeking to minimize such anxiety makes sense for the bilingual cognitive ecosystem.

Our finding is consistent with previous observations showing that encountering negative stimuli, even if only presented briefly, impairs subsequent cognitive processing (Melcher et al. 2011; Sakaki et al. 2011; Gable et al. 2015). And others have suggested that transient affective states induced by a L2 negative word can lead to a narrowing of cognitive processing of the following words (Sakaki et al. 2011; Van Steenbergen et al. 2011), which would be consistent with a delayed valence-dependent mechanism gating lexical access during L2 word processing. It is noteworthy that the suppression of cross-language activation observed here was only short-lived (that is in the order of 1500 ms) rather than sustained since it had ended by the beginning of the next trial. Otherwise, inhibition of lexical access for the prime words following negative target words would have resulted in priming reduction throughout the emotional target block irrespective of valence. Since such reduction was not observed, it is likely that cross-language lexical access had resumed by the time the next pair of word was presented. This, however, could not be verified through analysis given the randomization of word pairs within each experimental block and was thus not tested. Future research might evaluate more precisely the duration of the refractory period by manipulating systematically the inter-stimulus intervals between words.

Our finding is also consistent with observations in other contexts. For example, visual target detection is slowed down by previous presentation of a strongly negative picture (Pereira et al. 2006). Kalanthroff et al. (2013) further showed that a negative stimulus elicited a "momentary freeze", as in the fight-flight-freeze response, during an emotional stop-signal task, manifesting as increased reaction times in no-stop trials following a negative stimulus as compared to a neutral one. Such brief freezes induced by negatively valenced stimuli possibly reflect the operation of a homeostatic emotional drive, that is, a kind of affective modulation

mechanism preventing individuals from suffering from further threats and stress so as to avoid destabilization or reaching a state of crisis (Craig 2003; Linton 2013). We contend that a similar mechanism is involved in the transient suppression of cross-language activation when bilinguals are exposed to a negative word in L2.

Our study had some limitations that may be addressed in the future. One issue is that to address the effects of character repetition and semantic relatedness independently, it would have been better to use a 2 (form repetition in L1) × 2 (semantic relatedness) × 2 (valence) design. This would have enabled us to examine potential interactions between L1 access and semantic relatedness. However, it is unlikely that we would have been able to find enough word pairs involving a positive or negative word and featuring a character repetition in Chinese as well as being semantically related to another (neutral) word. This would equate to generate a list of 30+ word pairs per condition akin to that compiled by Thierry and Wu (2007) but with valenced words, which is perhaps impossible. In addition, manipulating three factors simultaneously would mean that we would be targeting a three-way interaction and thus having to test many more participants than in the current study. In any case, the current experiment design meant that the semantically related condition only made up 1 in 5 stimuli, and thus all comparison with that condition was precluded, because it was likely to be contaminated by a P300 effect, and because the low incidence of related pairs made their detection more difficult (hence the high error rate). This aspect of the study could easily be improved in future replication, for instance by simply tripling the number of semantically related pairs. Another limitation of our study was the use of a two-alternative force choice task to indicate whether each pair was related or not. It would be interesting to see whether the result can be replicated when participants only respond to related pairs, therefore removing any response-related artifact from the critical trials. Finally, it might be highly valuable to replicate the current experiment in the auditory domain, to establish the generalizability of the finding across

modalities. This being said, none of the suggestions above could be implemented here, given that one of our objectives was to replicate the results obtained by Wu and Thierry (2012), which involved the same conditions, task, and stimuli as the current study.

To our knowledge, the present study is the first to investigate the operational *locus* of an emotional regulation mechanism that inhibits automatic access to L1 representations during L2 comprehension. The findings suggest that a negative word in L2 triggers inhibitory control of unconscious access to L1 *after* the translation equivalent of that word in L1 has been accessed. In other words, emotions appear to modulate language processing on a serial rather than parallel basis in bilinguals. Furthermore, this modulation reflects a generic affective control mechanism relating to emotional homeostasis, protecting individuals from suffering repeated threats. Future studies may elucidate the neural circuitry underpinning this delayed emotion-dependent mechanism gating lexical access during second language processing.

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Supplementary Materials for

• Brain potentials reveal how emotion filters native language access when bilinguals read words in their second language

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This file includes:

Supplementary Text

Figs. S1 to S3

Table S1 to S5

References (#6)

Supplementary Text

<u>(G)LMM model specifications.</u>

The final linear mixed-effects models for behavioral data analysis

(1) LMM~RT bilinual~ ::

lmer(RT~prime_vs_target*(negative_vs_unrelated+negative_vs_positive) +

(1+prime_vs_target|Subject) + (1|word))

(2) LMM~RT monolingual~ ::

lmer(RT~prime_vs_target*(negative_vs_unrelated+negative_vs_positive) +

(1+prime_vs_target+prime_vs_target:negative_vs_positive|Subject) + (1|word))

(3) GLMM~ACC bilingual~ ::

glmer(ACC~prime_vs_target*(negative_vs_unrelated+negative_vs_positive) +

(1+prime_vs_target|Subject) + (1|word))

(4) GLMM~ACC monolingual~ ::

glmer(ACC~prime_vs_target*(negative_vs_unrelated+negative_vs_positive) +

(1+prime_vs_target+negative_vs_unrelated|Subject) + (1|word))

Analysis of ERPs elicited by emotional words.

To rule out potential confounding effects of emotional valence on sound repetition priming, we conducted repeated-measures ANOVAs on the amplitudes of the late positive complex (LPC) and early posterior negativity (EPN) elicited by positive, negative, and neutral words in prime or target position in both Experiment 1 and Experiment 2, with Position (prime, target) and Valence (positive, negative, and neutral) as within-subject factors. The LPC was measured based on mean ERP amplitudes between 450–650 ms at electrodes, C1, Cz, C2, CP1, CPz, CP2, P1, Pz, and P2, and the EPN was measured based on mean amplitudes in 300 – 400 ms over electrodes P7, P8, PO7, PO8, O1, and O2, which corresponds to the late EPN window as defined by Kissler and Bromberek-Dyzman (2021), since it was used also by Zhang et al. (2014) with Chinese participants.

Results

Experiment 1: Chinese-English bilinguals tested in English

There was no significant effect of Position ($p = 0.552$), Valence ($p = 0.598$), or interaction between Valence and Position ($p = 0.345$) on the LPC (Fig. S1). The analysis of EPN revealed a significant main effect of Position ($F_{1,23} = 18.82$, $p < 0.001$, $\eta_p^2 = 0.45$), with enhanced EPN responses to emotional words in the prime position relative to those in the target position. Neither the main effect of Valence nor the interaction between Position and Valence was significant (Valence: $p = 0.6$; interaction: $p = 0.976$; Fig. S1).

Experiment 2: Chinese-English bilinguals tested in English

With regards to the LPC, no main effect or interaction was found either (Position: $p = 0.147$; Valence: $p = 0.221$; interaction: $p = 0.65$; Fig. S2). No main effect or interaction of the manipulated factors was found on the EPN (Position: $p = 0.759$; Valence: $p = 0.233$; interaction: $p = 0.588$; Fig. S2).

Discussion

The main effect of emotional valence on LPC amplitudes reported by Wu and Thierry (1) was not found in the present study. There was also no valence effect on EPN amplitudes. A possible reason for this is that each word was presented twice (once as the prime and once as the target) and the repetition likely reduced the affective impact of the valenced words. Moreover, with word stimuli being twice as many as in Wu and Thierry (2012), the presentation rate was increased in the present study. Thus, participants' overall responses became faster, leaving them insufficient time to re-evaluate the emotional content of the valenced words. This could also contribute to the absence of valence effect here. Kissler et al. (2007) manipulated the speed at which emotional words were presented and found that as compared to neutral words, pleasant and unpleasant words elicited an enhanced ERP response at both fast and low presentation rate. Also, they found that repetition does not reduce emotional valence modulation. However, note that there are some differences between their study and ours. In Kissler et al. (2007) emotional and neutral words formed one third of the stimulus pool, while, here, positive and negative corresponded to 1/10 each. A higher proportion of certain stimulus types has been shown to increase participants' anticipation of

such stimuli (Lau et al. 2013), associated with higher ratings of emotional intensity, as well as increased brain activity in regions associated with attention to emotional content (Bermpohl et al. 2006). In Kissler et al. (2007), participants' attention may thus have been more readily oriented towards emotional content than in our study. In addition, Kissler et al. (2007) implemented a passive reading RSVP task, which may have made emotional valence more salient as compared to our semantic relatedness judgement task. Any of the differences between paradigms highlighted here may explain the disparity in EPN results.

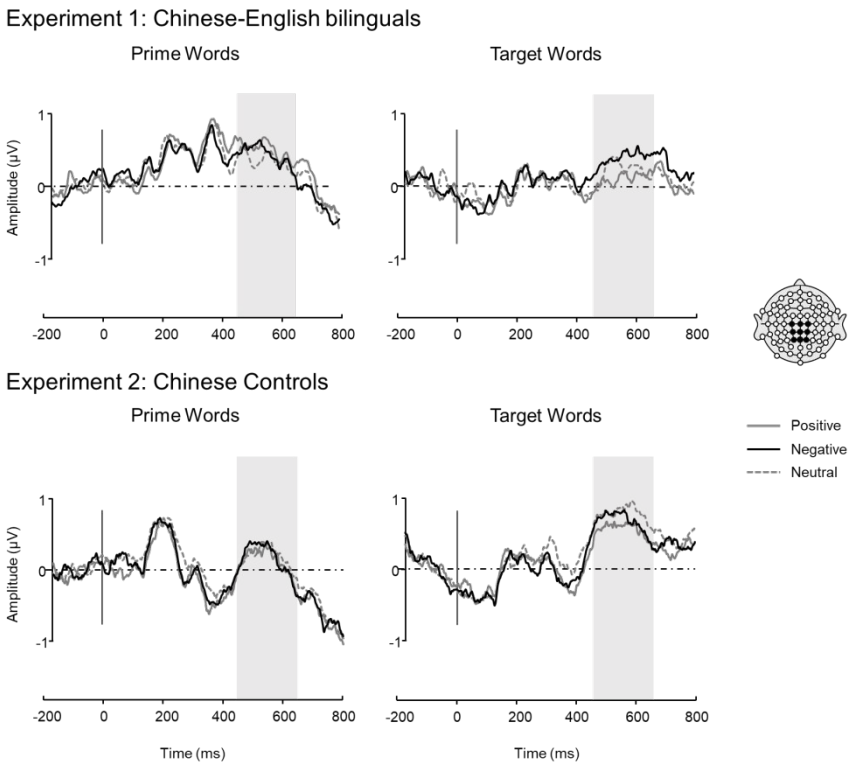

Fig. S1. ERPs elicited by the prime (left) and target (right) words in Experiment 1 featuring the English task and in Experiment 2 featuring the Chinese control task. Waveforms depict brain potentials variations for a linear derivation of nine central electrodes (C1, Cz, C2, CP1, CPz, CP2, P1, Pz, and P2) where the effect was maximal. Shaded areas represent LPC analysis windows (450–650 ms after stimulus onset).

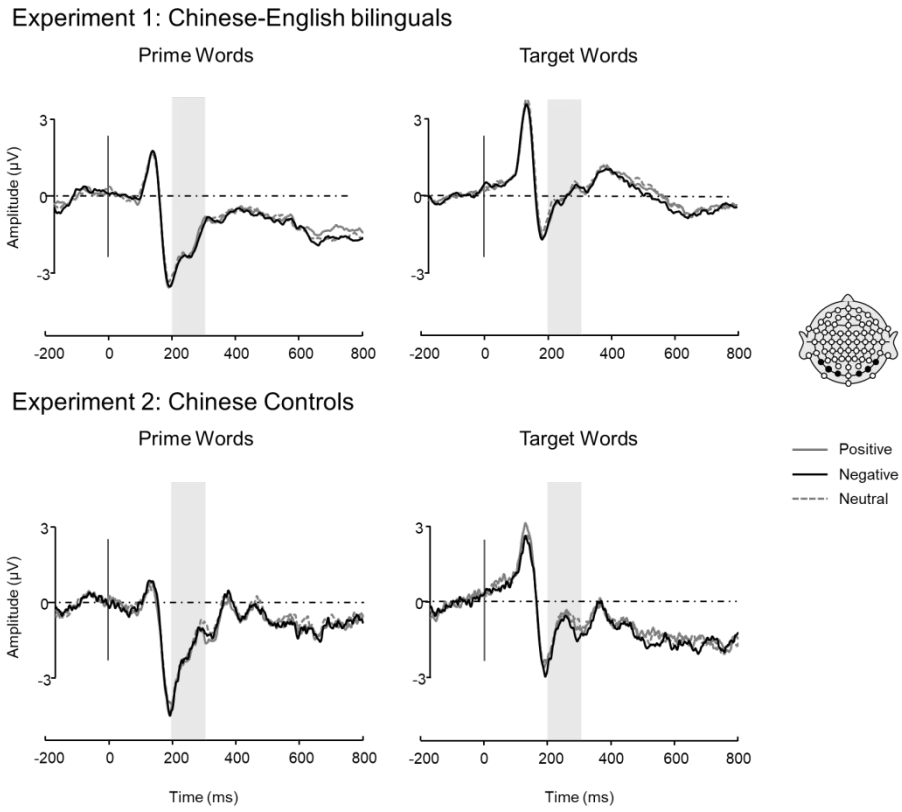

Fig. S2. ERPs elicited by the prime (left) and target (right) words in Experiment 1 featuring the English task and in Experiment 2 featuring the Chinese control task. Waveforms depict brain potentials variations for a linear derivation of six occipito-parietal electrodes (P7, P8, PO7, PO8, O1, O2) where the effect was maximal. Shaded areas represent EPN analysis windows (300–400 ms after stimulus onset).

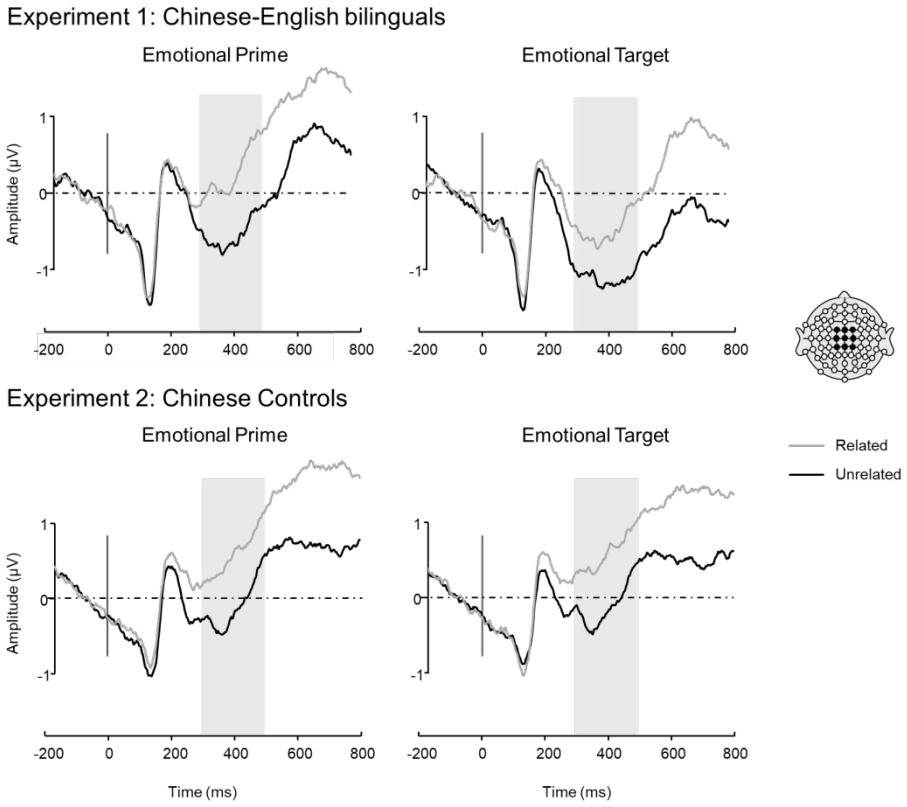

Fig. S3. ERPs elicited by target words in the emotional prime (left) and emotional target (right) blocks in Experiment 1 featuring the English task and in Experiment 2 featuring the Chinese control task. Waveforms depict brain potentials variations for a linear derivation of nine central electrodes (FC1, FCz, FC2, C1, Cz, C2, CP1, CPz, CP2) where the effect was maximal. Shaded areas represent N400 analysis windows (300–500 ms after stimulus onset). Theere was a main effect of Condition in Experiment 1 ($F_{1,23} = 10.37$, $p = 0.004$, $\eta_p^2 = 0.31$) and in Experiment 2 ($F_{1,23} = 49.42$, $p < 0.001$, $\eta_p^2 = 0.68$), with N400 amplitude reduced for semantically related targets.

Table S1. Means (*SD*) of word length, frequency, concreteness, valence, and arousal of English words in each pair in all conditions.

	Positive		Negative		Neutral		Unrelated		Related	
	Positive	Neutral	Negative	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Word length	6.11 (2.01)	6.22 (2.41)	5.93 (1.67)	5.58 (1.94)	5.69 (1.98)	5.69 (1.98)	6.31 (2.35)	6.40 (2.18)	5.93 (1.68)	5.93 (1.68)
Frequency	3.06 (0.38)	2.80 (0.42)	2.99 (0.55)	2.86 (0.48)	2.79 (0.43)	2.91 (0.46)	2.91 (0.39)	2.92 (0.35)	2.94 (0.52)	2.94 (0.43)
Concreteness	3.22 (1.13)	3.76 (1.03)	3.15 (1.01)	3.93 (0.84)	3.73 (1.05)	3.73 (1.05)	3.59 (1.15)	3.59 (1.15)	3.75 (0.95)	3.75 (0.95)
Valence	7.36 (0.45)	5.55 (0.87)	2.76 (0.60)	5.71 (0.68)	5.52 (0.62)	5.75 (0.58)	5.83 (0.91)	5.54 (0.79)	5.79 (1.05)	5.88 (0.97)
Arousal	5.47 (0.77)	3.84 (0.68)	5.29 (0.90)	3.69 (0.79)	3.79 (0.81)	3.73 (0.80)	3.93 (0.86)	3.93 (0.86)	3.78 (0.92)	3.78 (0.92)

Note: this is based on the condition when emotional words are in the prime position, with neutral words in the target position and the same values apply for the emotional target stimuli.

Table S2. Means (*SD*) of word length, frequency, concreteness, valence, and arousal of Chinese words in each pair in all conditions.

	Positive		Negative		Neutral		Unrelated		Related	
	Positive	Neutral	Negative	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Word length	2	2	2	2	2	2	2	2	2	2
Frequency	2.87 (0.38)	2.79 (0.52)	2.89 (0.42)	2.63 (0.42)	2.65 (0.47)	2.68 (0.49)	2.67 (0.53)	2.65 (0.45)	2.67 (0.59)	2.65 (0.54)
Concreteness	5.36 (1.54)	6.39 (1.51)	5.34 (1.51)	6.47 (1.44)	6.31 (1.43)	6.56 (1.45)	6.06 (1.68)	6.52 (1.44)	6.38 (1.31)	6.47 (1.34)
Valence	7.34 (0.67)	4.74 (0.79)	2.02 (0.65)	5.04 (0.81)	4.87 (0.76)	5.09 (0.87)	5.15 (1.10)	5.07 (0.81)	5.29 (1.33)	5.00 (0.99)
Arousal	6.06 (0.86)	2.99 (0.85)	5.81 (1.14)	3.15 (0.94)	2.99 (1.09)	3.13 (1.03)	3.41 (1.09)	3.24 (1.12)	3.65 (1.22)	3.54 (0.89)

Note: this is based on the condition when emotional words are in the prime position, with neutral words in the target position and the same values apply for the emotional target stimuli.

Table S3. Word stimuli used in the experiment.

Negative		Positive		Neutral		Unrelated		Related (fillers)	
Negative	Neutral	Positive	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
shame	repair	lover	servant	mood	news	introduction	sponge	autumn	season
羞辱	修理	爱人	佣人	心情	新闻	介绍	海绵	秋天	季节
worry	single	money	metal	public	company	pork	story	driver	transportation
担心	单个	金钱	金属	公共	公司	猪肉	故事	司机	交通
chaos	mixture	sun	goat	machine	chance	soul	information	reduction	increase
混乱	混合	太阳	山羊	机器	机会	灵魂	信息	减少	增加
pollution	roof	praise	pause	circle	principle	valley	behavior	foot	sock
污染	屋顶	赞扬	暂停	圆圈	原则	山谷	行为	脚部	袜子
attack	palace	holiday	value	necklace	coach	bath	trace	dynasty	empire
攻击	宫殿	假期	价值	项链	教练	洗澡	痕迹	朝代	帝国
violence	report	intelligence	quality	economy	experience	tank	explanation	professor	student
暴力	报道	智力	质量	经济	经验	坦克	解释	教授	学生
fight	open	cash	clue	method	direction	description	island	fly	wing
打架	打开	现金	线索	方法	方向	描述	岛屿	飞翔	翅膀
divorce	pear	strength	history	piano	pen	silk	corn	labor	job
离婚	梨子	力量	历史	钢琴	钢笔	丝绸	玉米	劳动	工作
flood	red	princess	industry	relation	observation	certificate	mystery	earth	planet
洪水	红色	公主	工业	关系	观察	证书	神秘	地球	行星
hell	address	sunshine	onion	truck	card	rubber	bean	law	rule
地狱	地址	阳光	洋葱	卡车	卡片	橡胶	豆子	法律	规则
prison	area	surprise	spirit	surface	performance	desk	atmosphere	partner	team
监狱	区域	惊喜	精神	表面	表演	课桌	气氛	伙伴	团队
hunger	foundation	romance	waste	department	step	root	equipment	interest	hobby
饥饿	基础	浪漫	浪费	部门	步骤	根源	设备	兴趣	爱好
accident	market	gift	task	topic	chemistry	lord	wire	army	soldier
事故	市场	礼物	任务	话题	化学	上帝	电线	军队	士兵
harm	business	loyalty	center	date	sunset	future	wheel	citizen	nation
伤害	商务	忠诚	中心	日期	日落	未来	轮子	公民	国家
noise	reason	friendship	translation	role	white	reality	bag	math	physics
噪音	原因	友谊	翻译	角色	白色	现实	袋子	数学	物理
anxiety	exchange	hero	inch	supply	tool	leader	period	week	month
焦虑	交换	英雄	英寸	供给	工具	领导	时期	星期	月份
pressure	duck	honesty	program	noun	name	standard	midnight	moonlight	evening
压力	鸭子	诚实	程序	名词	名字	标准	午夜	月光	晚上
forget	century	miracle	flag	bar	tail	plant	hammer	plan	goal
忘记	世纪	奇迹	旗帜	酒吧	尾巴	植物	锤子	计划	目标
burden	review	music	factor	rocket	file	population	gate	poetry	literature
负担	复习	音乐	因素	火箭	文件	人口	大门	诗歌	文学
tragedy	cup	wealth	repeat	lesson	visitor	ground	flame	shirt	tie
悲剧	杯子	财富	重复	课程	客人	地面	火焰	衬衫	领带
blame	duty	champion	jar	unit	member	purpose	apartment	shape	round
责备	责任	冠军	罐子	单元	成员	目的	公寓	形状	圆形
rat	boss	song	pigeon	sheep	cotton	afternoon	south	origin	beginning
老鼠	老板	歌曲	鸽子	绵羊	棉花	下午	南方	起源	开始
fever	development	joke	telephone	glove	guard	sale	evidence	closet	furniture

发烧	发展	笑话	电话	手套	守卫	出售	证据	衣柜	家具
hesitation	mail	game	tourist	theme	owner	balance	permission	knowledge	scholar
犹豫	邮件	游戏	游客	主题	主人	平衡	允许	知识	学者
poverty	channel	prize	lecture	storm	maple	independence	paint	speech	statement
贫穷	频道	奖品	讲座	风暴	枫树	独立	图画	讲话	陈述
punishment	passenger	honeymoon	secretary	grammar	umbrella	brush	revolution	bottle	drinks
惩罚	乘客	蜜月	秘书	语法	雨伞	刷子	革命	瓶子	饮料
war	stand	passion	chicken	skill	record	ant	shell	mile	distance
战争	站立	激情	鸡肉	技能	记录	蚂蚁	贝壳	英里	距离
doubt	aunt	hope	knee	skin	beer	biology	seat	question	answer
怀疑	阿姨	希望	膝盖	皮肤	啤酒	生物	座位	问题	答案
problem	title	marry	result	factory	cock	master	temperature	railway	train
问题	标题	结婚	结果	工厂	公鸡	主人	温度	铁路	列车
guilt	content	beauty	dollar	collection	income	nail	zone	science	research
内疚	内容	美丽	美元	收藏	收入	指甲	空间	科学	研究
conflict	surf	pleasure	fisherman	basket	blue	feeling	street	passage	paragraph
冲突	冲浪	愉快	渔夫	篮子	蓝色	感觉	街道	篇章	段落
nervous	article	peace	contract	watch	capital	cost	church	sound	silence
紧张	文章	和平	合同	手表	首都	花费	教堂	声音	寂静
gray	recovery	life	voice	signal	envelope	message	monkey	comedy	movie
灰色	恢复	生命	声音	信号	信封	信息	猴子	喜剧	电影
hospital	clothing	diamond	hour	captain	tradition	comfort	station	sea	river
医院	衣服	钻石	小时	船长	传统	舒适	车站	海洋	河流
failure	poet	travel	cream	drama	cell	society	receipt	deposit	bank
失败	诗人	旅游	奶油	戏剧	细胞	社会	收据	存款	银行
loss	lion	success	adult	vote	head	summer	guide	sleep	dream
失去	狮子	成功	成人	投票	头部	夏天	指导	睡觉	做梦
crisis	hen	genius	weather	aim	wood	level	salary	payment	bill
危机	母鸡	天才	天气	目标	木头	水平	薪水	付款	账单
thief	novel	food	stone	comparison	note	habit	device	talk	speaker
小偷	小说	食物	石头	比较	笔记	习惯	设备	说话	喇叭
stupid	yoga	luck	gender	base	muscle	detective	semester	newspaper	magazine
愚蠢	瑜伽	幸运	性别	基地	肌肉	侦探	学期	报纸	杂志
death	king	candy	outcome	corner	toe	audience	doll	orange	juice
死亡	国王	糖果	结果	角落	脚趾	观众	娃娃	橘子	橙汁
kill	sand	talent	material	pipe	management	sky	length	virus	bacteria
杀死	沙子	才能	材料	管子	管理	天空	长度	病毒	细菌
trash	plane	pride	communication	rock	fashion	candle	million	dinner	wine
垃圾	飞机	骄傲	交流	石头	时尚	蜡烛	百万	晚餐	红酒
bomb	egg	graduation	necessity	consideration	efficiency	letter	minute	theory	opinion
炸弹	鸡蛋	毕业	必要	考虑	效率	信件	分钟	理论	观点
toilet	measure	laughter	doctor	document	civilization	situation	diet	breath	oxygen
厕所	测量	笑声	医生	文件	文明	情况	饮食	呼吸	氧气
bullet	purple	art	end	web	tennis	wheat	judge	winter	cold
子弹	紫色	艺术	结束	网页	网球	小麦	法官	冬天	寒冷

Table S4. Reaction times and accuracy (*M* ± *SD*) for the stimuli translation task per condition.

	Positive		Negative		Neutral		Unrelated		Related	
	Positive	Neutral	Negative	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Reaction Times	1260.98 (398.80)	1337.43 (402.37)	1387.99 (258.15)	1333.85 (291.11)	1240.58 (369.11)	1326.40 (483.76)	1368.46 (446.67)	1361.12 (385.52)	1218.51 (493.33)	1212.30 (489.03)
Accuracy	0.85 (0.12)	0.84 (0.12)	0.83 (0.13)	0.83 (0.16)	0.81 (0.15)	0.80 (0.15)	0.85 (0.14)	0.84 (0.12)	0.81 (0.17)	0.82 (0.15)

Note: this is based on the condition when emotional words are in the prime position, with neutral words in the target position.

Table S5. Means and standard derivations (*M* ± *SD*) of trial number per condition.

	Positive	Negative	Unrelated
English			
emotional prime blocks	42.6 ± 3.9	42.5 ± 3.9	42.5 ± 3.7
emotional target blocks	41.5 ± 4.6	41.5 ± 4.5	41.6 ± 4.6
Chinese			
emotional prime blocks	42.5 ± 3.3	42.3 ± 3.6	42.4 ± 3.3
emotional target blocks	42.8 ± 2.6	42.2 ± 3.3	42.8 ± 2.8

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