**Neural Substrates of the Interplay between Cognitive Loading and
Emotional Involvement in Bilingual Decision Making**

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Abstract

Prior work investigated how foreign language impacts decision making by either reducing access to emotion or imposing additional cognitive demands. In this fMRI study, we employed a cross-task design to assess at the neural level whether and how the interaction between cognitive loading and emotional involvement is affected by language (native L1 vs. foreign L2). Participants completed a Lexico-semantic task where in each trial they were presented with either a neutrally or a negatively valenced word either in L1 or L2, and either under cognitive loading or not. After each trial, they had to decide whether to take a risky decision within a gambling game. During the Gambling task, left amygdala and right insula were more activated after having processed a negative word under cognitive loading. However, this was true for L1 but not for L2, suggesting that cognitive loading was germane and facilitated rather than hindered access to emotion only in L1. Further suggesting that cognitive load can enhance emotional sensitivity in L1 but not in L2, we found that functional connectivity between reward-related striatum and right insula increased under cognitive loading only in L1. Overall, results suggest that cognitive loading in L1 can favor access to emotion and lead to a more impulsive decision making, whereas cognitive loading in L2 can attenuate access to emotion and lead to a more rational decision making.

Keywords: foreign language effect, cognitive load, emotional involvement, amygdala, insula.

Neural Substrates of the Interplay between Cognitive Loading and Emotional Involvement in Bilingual Decision Making

Facing a decision making task, bilinguals are often less impulsive and more analytic if the information is presented in their second language (L2) rather than in their native language (L1), an effect that was termed *foreign language effect* (Caldwell-Harris, 2015; Costa et al., 2014, 2017; Geipel et al., 2015; Hayakawa et al., 2016, 2017; Keysar et al., 2012; Montero-Melis et al., 2020). For instance, foreign language may reduce or eliminate decision making biases such as the framing effect (Keysar et al., 2012), the aversion to losses (Costa et al., 2014), and the hot hand fallacy (Gao et al., 2015).

Foreign language effect can be attributed to the fact that L2 is less grounded in the emotional system compared to L1 (Dylman & Bjarta, 2018; Kuhne & Gianelli, 2019; Sulpizio et al., 2019). Messages processed in L2 overall elicit milder emotional arousal than messages processed in L1, which in turn may lead to a more careful and rational decision making (Díaz-Lago & Matute, 2019; Hadjichristidis et al., 2018; Keysar et al., 2012).

Another key factor can be that making decisions in L2 rather than L1 involves greater cognitive resources (Korn et al., 2019; Oganian et al., 2016). Indeed, orthography, phonetic, semantic and grammatical processing in L2 requires additional cognitive resources due to lower proficiency (Hasegawa et al., 2002; Stiller & Schworm, 2019). The less automatic and more difficult processing in L2 may thus be source for distancing and lead to a more deliberate and analytic decision making.

As of yet, however, emotional involvement and cognitive loading were often treated as two separate factors, and prior work did not systematically investigate the underlying interaction between them in the context of the foreign language effect. Since cognitive resources are limited (Franconeri et al., 2013; Lieder & Griffiths, 2019; Vroomen et al., 2001), the more they are recruited for orthography and semantic processing, the less they can be used for emotional processing. Despite this, cognitive load does not always hinder emotional processing (Berggren et al., 2012; Debue & van de Leemput, 2014).

Cognitive Load Theory argues that font emphasis, for instance, can reduce the extraneous cognitive loading related to the presentation of materials and improve the *germane cognitive loading* which is functional to the learning process (Paas & Sweller, 2014; Schneider et al., 2018). Therefore, a greater allocation of cognitive resources can sometimes, when germane, work alongside an enhanced processing of the emotional information in the lexico-semantic access. However, this is more likely to happen in L1 than in L2. Indeed, because of the additional cognitive resources needed to process written or spoken foreign language, it is less likely to find germane cognitive loading in L2. Accordingly, cognitive loading may promote or hinder emotional processing depending also on the language in which the message is presented.

Neural Bases of the Foreign Language Effect

Two brain regions have been shown to be crucially associated with emotional involvement: insula, which works for detecting emotion (Pedale et al., 2019; Simmons et al., 2012; Thom et al., 2012), and amygdala, which is implicated in inducing the emotional response (Dehdar et al., 2019; Guex et al., 2019; Janak & Tye, 2015;

Méndez-Bértolo et al., 2016; Namburi et al., 2015; Phan et al., 2004; Tye et al., 2011).

In L2, activation of insula and amygdala may be reduced under cognitive loading. This can be so because, given the weakness of the semantic access to orthography/phonology in L2 (Green, 1998; Runnqvist et al., 2019), a competition for resource allocation may arise between the semantic and the emotional access. In contrast, in L1, bilinguals need to recruit less cognitive resources to process the language, and thus germane loading likely triggers a more indepth processing of the emotional content (Dylman & Bjärtå, 2018; Pavlenko, 2012; Ponari et al., 2015). Different lexical—semantic activation thresholds may thus lead to different emotional experiences: cognitive loading may deepen the emotional experience if the message is presented in L1 but weaken it if the message is presented in L2.

A fMRI study did indeed reveal that cognitive load can influence the emotional processing in L1 (Van Dillen et al., 2009). Participants saw a negative or neutral picture, performed an arithmetic task, and then rated the perceived unpleasantness of the picture. The task load was shown to down-regulate the amygdala and right insula activity for negative stimuli, resulting in a reduction of the negative emotions.

Relevant is also a fMRI study in which the role of emotional involvement in bilinguals' decision making was assessed (Zheng et al., 2020). Participants made 'play' or 'leave' decisions in an equal-odds Gambling task where gambling feedbacks were presented in either L1 or L2. At the behavioral level, both in L1 and L2 participants showed the Gambler's fallacy, i.e. the tendency to bet more when losing rather than winning. However, the fMRI scanning revealed that language modulated the neural

responses associated to the gambling feedbacks and to the participants' decisions. Importantly, the activation of the reward brain networks in response to positive feedbacks was exaggerated in L2 compared to L1.

Authors thus found that receiving a positive message in L2 amplified the associated emotion. This evidence is somehow in contrast with the emotion-reducing hypothesis according to which L2 reduces the emotional reactions, but it is consistent with the positive-bias hypothesis according to which L2 specifically enhances positive emotions (Caldwell-Harris, 2015; Sheikh & Titone, 2016). In general, Zheng et al. (2020)'s work is relevant as it provides evidence of a foreign language effect on people's economic decisions at the neural level. However, it remains an open question whether and how the neural networks associated with emotional processing are differently regulated by cognitive loading depending on the language (L1 vs. L2).

This Study

The current study employed functional magnetic resonance imaging (fMRI) to characterize the neural activation underpinning the interaction between cognitive load and emotional involvement in the foreign versus native language context. Participants were first presented with a Lexico-semantic task widely used in semantics research (Fujimaki et al., 2009; Hinojosa et al., 2010; Pu et al., 2005). In each trial they were presented with either a neutrally or a negatively valenced word either in L1 or in L2, and either under cognitive loading or not. Three factors were thus varied in this task: language (L1, L2), emotion (valenced, not valenced), cognitive load (low, high).

We aimed at assessing the influence of these three factors and their interaction on participants' subsequent decisions in an even-probability Gambling task (Gao et al., 2015; Zheng et al., 2019). Moreover, we aimed at revealing the associated neural activity. We predicted coordination or competition varying across languages and cognitive load conditions between the dorsal striatum, which is associated with decision making (Korucuoglu et al., 2020; Sharpe et al., 2019; Wimmer et al., 2014), and insula and amygdala (Gorka et al., 2019; Korgaonkar et al., 2019; Shiv et al., 2005), two areas associated with emotion processing. If the automaticity of L1 processing enables more emotional access whereas the increased cognitive demands in L2 leave little room for emotionality, we should find that cognitive loading boosts access to emotion in L1 but hinders access to emotion in L2.

Methods

Participants

Thirty unbalanced Chinese-English (L1-L2) bilinguals participated in this study. They were right handed with normal or corrected-to-normal vision and no history of neurological or psychological impairments. None of them were receiving treatment with psychoactive medication. Due to the excessive head movement of five participants, the imaging data analysis included only 25 participants (9 male, $M = 22.56 \pm 2.35$ years). The behavioral data analysis included 28 participants (10 male, $M = 22.61 \pm 2.27$ years) because the answers of two participants in the Gambling task were extreme (gambling ratio > 85%). The research protocol was approved by the Institutional Review Board at the School of Psychology, Liaoning Normal University.

Participants' language proficiency was assessed through questionnaires asking the age of L2 acquisition and to self-rate the language skills on a scale that ranged from 1 (= *no knowledge of L1/L2*) to 6 (= *perfect knowledge*). Language proficiency was also measured with the Oxford Placement Test (OPT; Allan, 2004), by administering 25 multiple choice questions and a cloze test. Maximum score was 50 (see Appendix A). Table 1 shows participants' average language proficiency. Four paired t-test revealed that proficiency ratings were significantly higher for L1 than L2 in listening, speaking, reading and writing, $t(29) \geq 4.75$, $ps < 0.001$. Moreover, self-rating and OPT scores were similar to those of Chinese-English bilinguals with intermediate L2 proficiency who participated in prior research (Liang & Chen, 2014; Liu et al., 2016). At the end of the session, participants completed a Risk Attitude Scale ranging from 1 (= *conservative*) to 5 (= *adventure*), $M = 2.81$, $SD = 0.60$ (Weber et al., 2002; Appendix B).

Table 1

Participants' Characteristics (Mean $\pm$ SD).

	Behavioral data ($N = 28$)		fMRI data ($N = 25$)	
	L1	L2	L1	L2
AoA	----	9.32 ± 2.07	----	9.28 ± 2.19
Listening	5.32 ± 0.72	3.50 ± 1.17	5.28 ± 0.74	3.52 ± 1.22
Speaking	4.86 ± 0.71	3.46 ± 0.88	4.80 ± 0.71	3.44 ± 0.92
Reading	4.36 ± 1.13	3.00 ± 1.20	4.32 ± 1.14	3.04 ± 1.27
Writing	4.82 ± 0.72	3.25 ± 1.38	4.80 ± 0.71	3.16 ± 1.43
OPT		34.5 ± 6.04		34.0 ± 6.18

Note: AoA means Age of Acquisition of L2; OPT stands for Oxford Placement Test.

Materials

The Lexico-semantic task (Fujimaki et al., 2009; Hinojosa et al., 2010; Nakamura et al., 2020; Pauligk et al., 2019; Pu et al., 2005) included 79 Chinese words (42 negative, 37 neutral) translated into English by using the Oxford Advanced English-Chinese Dictionary (Appendix C). Words had two characters in Chinese and four to nine letters in English, $M = 5.80 \pm 1.33$. Their emotional valence was established by using the modern Chinese words emotion rating scale (Wang et al., 2008).

Forty words (20 negative, 20 neutral) in simplified L1 (e.g. 恐惧, 新闻) and lowercase L2 (e.g. fear, news) were chosen for the Low-load condition. Forty words in traditional L1 (e.g. 恐懼, 新聞) and capital L2 (e.g. FEAR, NEWS) were instead chosen for the High-load condition. Words in the two conditions were phonologically and semantically identical but written in a different form (see Figure 1a).

Words in L1 and L2 were matched for lexical frequency and emotional valence (Cai & Brysbaert, 2010; see Table 2). Both negative and neutral words did not have a different lexical frequency in the two languages, $t(19) \leq 0.63$, $ps \geq 0.536$, nor in both L1 and L2 neutral words had different frequency than negative words, $t(19) \leq 1.99$, $ps \geq 0.060$. To assess the emotional valence, 20 unbalanced Chinese-English bilinguals completed the emotional valence questionnaire rating words from 1 (= *extremely positive*) to 5 (= *very negative*). For both L1 and L2, negative and neutral words had a different valence, $t(19) \geq 12.87$, $ps < 0.001$, whereas L1 and L2 negative words, as well as L1 and L2 neutral words, showed no such difference, $t(19) \leq 1.50$, $ps \geq 0.147$.

In addition, 40 pseudo-words were used (20 Chinese, 20 English). Chinese pseudo-words were constructed by changing a character of a Chinese word, making a corresponding pronounceable and orthographically legal pseudo-word (e.g. 打驾). English pseudo-words were instead constructed by randomly by substituting or adding one letter (e.g. flyy; see Figure 1a). Pseudo-words were not analyzed.

Table 2

Lexical Frequency (Occurrences per Million) and Emotional Valence of L1 and L2 Words (Mean $\pm$ SD).

		Lexical frequency	Emotional valence
Negative	L1	29.13 $\pm$ 35.21	3.17 $\pm$ 0.21
	L2	37.57 $\pm$ 69.87	3.18 $\pm$ 0.15
Neutral	L1	65.53 $\pm$ 72.71	2.46 $\pm$ 0.21
	L2	68.87 $\pm$ 64.28	2.40 $\pm$ 0.15

In the Lexico-semantic task, participants were presented with four blocks, each including 50 trials: 20 Chinese words, 5 Chinese pseudo-words, 20 English words, and 5 English pseudo-words. In total, participants thus read 200 words, 160 correct and 40 pseudo-words. After each trial, participants played in a Gambling task trial.

Materials used for the Gambling task were adapted from Gao et al. (2015). Participants received four blocks of 50 trials. Each block included 25 possible gambling options each randomly repeated twice. Options were 50/50 gambles made up from five gain values (+100, +80, +60, +40, +20) paired with five loss values (-50, -40, -30, -20, -10). For each gamble, participants saw two numbers preceded by a sign indicating the

prospective gain and loss (e.g. +100 and -50). These numbers were separated by a horizontal bar indicating that the probability of winning or losing was 0.50 (see Figure 1b). In 76% of the trials the magnitude of prospective gain was larger compared to loss, in 16% was smaller, and in 8% of the trials was equal. A large magnitude of prospective gain was used in most of the trials to lead participants to gamble more often than not.

Procedure

In our cross-task study, participants were first presented with a practice block of 26 trials that helped them to understand the instructions. Participants were then presented with 200 trials, equally divided into four blocks, with two practice trials per block. L1 and L2 words were randomly mixed and presented in the four blocks. The order of blocks was counterbalanced across participants. Stimuli were white words or numbers presented on a black background using E-Prime 2.0 software on a Dell PC. Words and numbers were displayed in Courier New, words in size 34 and numbers in size 18.

In the Lexico-semantic task, participants' attention was directed to the lexico-semantic properties of the words by asking them to distinguish meaningful words from pseudowords. Each trial started with a fixation cross displayed for 500 ms, followed by a word displayed for 3000 ms to allow semantic processing (see Figure 1c). Participants had to judge, as quickly and accurate as possible, whether the word was correct by pressing 1 (= *yes*) or 3 (= *no*). Key buttons were counterbalanced across participants.

After each Lexico-semantic trial, participants received a Gambling task trial which started with a fixation cross displayed for 500 ms followed by a 50/50 gamble option (Figure 1b). Participants had to decide within 3000 ms whether to bet by pressing 1 (=

play) or not to bet by pressing 3 (= *leave*). Key buttons were counterbalanced across participants. If participants chose to leave or did not press any buttons, a blank screen appeared for 1000 ms, and the next trial started after another blank screen displayed for a random duration between 500 and 2000 ms. If participants chose to gamble, a feedback appeared for 1000 ms displaying the sum earned or lost in the trial. This outcome was randomly generated where each option was given 50% probability. Lastly, a blank screen was displayed for a 500-2000 ms time window.

Figure 1. (a) In the Lexico-semantic task, participants were presented with words combined for L1 and L2 into four clusters: LL Neu (Low-Load Neutral), LL Neg (Low-Load Negative), HL Neu (High-Load Neutral), HL Neg (High-Load Negative). (b) In the Gambling task, if participants chose to bet, they saw either the sum earned or lost, whereas if they did not gamble, a black screen appeared. (c) Design and timing of the

cross-task experiment, including a Lexico-semantic task followed by a Gambling task.

fMRI Data Acquisition

Functional and structural images were acquired with a GE Discovery MR750 3T scanner. Participant's head was secured to minimize movement during scanning. Functional scans were obtained using a T2*-weighted gradient echo planar imaging (EPI) sequence. The following scan parameters for functional images were used: slice thickness = 2 mm; sequential acquisition = 33 axial slices; repetition time (TR) = 2000 ms; echo time (TE) = 30 ms; flip angle = 90°; image matrix = 64 × 64; field of view (FOV) = 224 × 224 mm; voxel size = 3.5 × 3.5 × 4.2 mm. For a total of four blocks, functional scanning session contained 248, 245, 241 and 243 time points. Structural images were collected using a T1-weighted 3-D MPRAGE sequence to co-register with the functional images (TR = 6.652 ms, TE = 2.928 ms, flip angle = 12°, sequential acquisition = 192 slices, slice thickness = 1 mm, spacing between slices = 1 mm, image matrix = 256 × 256, FOV = 256 × 256 mm, voxel size = 1 × 1 × 1 mm).

Behavioral Data Analysis

Both participants' accuracy (ACC) scores and reaction times (RT) in the Lexico-semantic task were analyzed with a generalized linear mixed effect model using language, cognitive load and emotional valence as fixed effects. Participants was added as the random effect in the ACC analysis, whereas participants and words were added as random effects in the RT analysis. Participants' decisions and RTs in the Gambling task were analyzed with a liner mixed effect model using the three factors listed above

as fixed effects, and participants and potential gain/loss as random effects.

fMRI Data Preprocessing

fMRI data were preprocessed with DPABI (Yan et al., 2016). First, all the EPI DICOM data were converted to NIFTI format, and the first 15 volumes of each run were discarded because of T1 relaxation artifacts. Second, all volumes slice scan times were corrected to the middle time slice and realigned to the first scan to correct for head motion. Third, the structural images of each participant were co-registered with the mean functional images and next they were normalized to the Montreal Neurological Institute template. Fourth, all voxels were resampled to $3 \times 3 \times 3$ mm. Fifth, all functional volumes were smoothed by using a 6-mm FWHM isotropic Gaussian kernel.

fMRI Data Analysis

First-level statistical analysis was conducted using SPM12 software. General linear models were computed from the 100 z-normalized volume time courses (25 participants $\times$ 4 blocks). The blood oxygen level-dependent (BOLD) response was modeled using a double gamma hemodynamic response function. A general linear model was performed for each of the four blocks. For the the Lexico-semantic task, factors were language, cognitive load and emotional valence. For the Gambling task, factors were language, cognitive load, emotional valence and choice (gamble, no gamble).

We ran a full factorial analysis on the Lexico-semantic task and Gambling task data to test for main effects and interactions with one-way, two-way or three-way ANOVAs. Region of Interest (ROI) analyses were done with MarsBaR tool, using percent signal change to explore the dynamic changes of activation over time in ROI. To understand

the three-way interactions, we extracted the beta values of significant clusters by averaging over all voxels within a cluster. Post-hoc comparisons were performed on the extracted beta values.

Analyzing activation associated with decisions in the Gambling task, we found a two-way significant interaction between cognitive load and emotional valence in the right insula (Table 4). Thus, we assessed the cognitive load-dependent functional connectivity of the right insula with other regions using the PsychoPhysiological Interaction (PPI; Di et al., 2019; McLaren et al., 2012; O'Reilly et al., 2012).

We started by creating a seed region using a 3 mm diameter sphere in the right insula (27, 24, -15) activated for negative words compared to neutral words. At the first-level analysis, we used a standard context-dependent PPI (Stephan et al., 2003). We extracted the first mean time series within the right insula seed. We next created PPI regressor using element-by-element products of the extracted, deconvolved insula time series and a vector coding for the main effect of cognitive load (1 for High-load, -1 for Low-load). This product was reconvolved with the canonical hemodynamic response function and entered as PPI regressor along with the cognitive load (psychological), right insula time series (physiological) and the head motion (nuisance) regressors. Subject-specific PPI models were run, and contrast images were generated for High-load and Low-load PPIs. For cognitive load-dependent functional connectivity of the right insula with other regions in L2, the same operation was done.

Results

Behavioral Results

Lexico-semantic Task

Figure 2 displays average participants' accuracy (ACC) scores and reaction times (RTs) in the Lexico-semantic task. When analyzing RTs data, we focused only on the accurate responses, thus removing 12% of participants' answers.

Figure 2. Accuracy scores (left) and reaction times (right) in the Lexico-semantic task split by language, cognitive load and emotional valence. Points represent participants' means, the middle line reflects the median, other lines represent the quartiles (75% and 25%). Note: ACC = Accuracy, RT = Reaction time, LL = Low-load, HL = High-load, Neg = Negative, Neu = Neutral.

The analysis on ACC revealed significant main effects of language, $\beta = -1.55$, $z = -5.40$, $p < 0.001$, and cognitive load, $\beta = -2.89$, $z = -10.60$, $p < 0.001$. Average accuracy was higher in L2 than in L1 ($M = 0.90 \pm 0.30$ and $M = 0.85 \pm 0.35$, respectively), and

lower under cognitive loading ($M = 0.81 \pm 0.39$ in High-load condition, $M = 0.95 \pm 0.22$ in Low-load condition). Crucially, there was a significant Language $\times$ Cognitive load interaction, $\beta = 2.49$, $z = 7.67$, $p < 0.001$. Accuracy was lower under cognitive loading for L1 words ($M = 0.73 \pm 0.44$ and $M = 0.98 \pm 0.15$), but this was true only to a lesser extent in L2 ($M = 0.89 \pm 0.32$ and $M = 0.92 \pm 0.28$).

The analysis on RTs revealed significant main effects of language, $\beta = 126.45$, $z = 3.82$, $p = 0.001$, and cognitive load, $\beta = 236.10$, $z = 6.97$, $p = .001$. RTs in L1 condition were shorter than those in L2 ($M = 745 \pm 294$ ms and $M = 872 \pm 353$ ms, respectively), and longer under cognitive loading ($M = 920 \pm 367$ ms in High-load condition, $M = 717 \pm 265$ ms in Low-load condition). These results suggest that cognitive loading had a similar effect on the processing in the two languages.

Gambling Task

Figure 3 displays the average proportion of participants who chose to bet (Gambling ratio) and their average reaction times (RTs) for each condition. Only participants' decisions made after an accurate judgment in the Lexico-semantic task were analyzed (12% of the decisions were thus excluded).

Figure 3. Gambling ratio (left) and reaction times (right) in the Gambling task split by language, cognitive load and emotional valence. Points represent participants' means, the middle line reflects the median, other lines represent the quartiles (75% and 25%). Note: RT = Reaction time, LL = Low-load, HL = High-load, Neg = Negative, Neu = Neutral.

Participants gambled more as the potential gain increased, $\beta = 0.06$, $p < .001$, and gambled less as the potential loss increased, $\beta = -0.07$, $p < .001$. They spent less time making decisions as the potential gain increased, $\beta = -15.94$, $p < .001$, and needed more time as the potential loss increased, $\beta = 13.94$, $p < .001$. Instead, the generalized linear mixed effect model on gambling ratios and RTs, which was run to test the effect of the Lexico-semantic task on the Gambling task, did not reveal any significant effect (Appendix D).

fMRI Full Factorial Analysis Results

The full factorial analysis revealed a significant Language $\times$ Cognitive load $\times$ Emotional valence interaction in the left amygdala and right insula (Figure 4). Thus, we chosen left amygdala and right insula as Regions of Interest (ROIs). These areas are known to be associated with emotion processing (Gorka et al., 2019; Korgaonkar et al., 2019; Shiv et al., 2005; Xue et al., 2011; Zhang et al., 2019).

Lexico-semantic Task

With respect to the *right insula* (BA47_R: 27 24 -15), we found a main effect of language, $p = 0.030$, with greater activity in L2 trials than in L1 trials ($M = -2.31$, $SD = 4.01$, and $M = -3.17$, $SD = 3.75$, respectively). No significant result was instead found with respect to the *left amygdala* (BA28_L: -27 3 -24).

Gambling Task

For the *right insula* (BA47_R: 27 24 -15), the analysis revealed a significant interaction between cognitive load and emotional valence (see Table 3). The right insula was activated more under cognitive loading in the negative words condition, $p = 0.032$, but this was not true in the neutral words condition. The significant Language $\times$ Cognitive load $\times$ Emotional valence interaction was primarily due to robust activation under cognitive loading in the L1 negative words condition, $p < 0.007$, and an unexpected increased activation under cognitive loading in the L1 neutral words condition too, $p = 0.003$ (see Table 4).

With respect to the *left amygdala* (BA28_L: -27 3 -24), the analysis revealed significant main effects of language, $p = 0.032$, and cognitive load, $p = 0.002$. This area

was activated more in L1 than in L2 ($M = 0.07$, $SD = 3.08$, and $M = -1.03$, $SD = 3.56$, respectively), and more under cognitive loading ($M = 0.22$, $SD = 3.57$, and $M = -1.18$, $SD = 3.01$; see Table 3). The analysis revealed also a significant Language $\times$ Emotional valence interaction: Left amygdala was activated more for L1 than for L2 in the negative words condition, $p = 0.007$, but this was not true for the neutral words condition. Lastly, a significant Language $\times$ Cognitive load $\times$ Emotional valence interaction was primarily due to greater activation under cognitive loading for L1 negative words, $p < 0.001$ (see Table 4).

In sum, we found greater activation of left amygdala under cognitive loading in L1 but not in L2, suggesting that germane cognitive loading in L1 favored an indepth emotion processing. By contrast, L2 may have hindered further processing because of the greater cognitive resources needed to process words in L2. Furthermore, under cognitive loading L1 negative words but not L1 neutral words activated the right insula, again suggesting that cognitive load interplays with emotion processing in L1.

b.

Figure 4. Panel (a) displays the interaction between language, cognitive load and emotional valence in the right insula (yellow arrow) and left amygdala (red arrow) during the Gambling task (GRF correction, voxel = .001, cluster = .05). The charts on the right show the beta values that were extracted from the left amygdala and right insula (radius = 3 mm). Panel (b) displays the percent signal change in all the conditions for both L1 and L2 in right insula and left amygdala. The asterisks indicate significant pairwise differences between conditions (e.g. a red asterisk followed by a purple asterisk ****** indicates a significant difference between L1 HL Neg, red *****, and L1 LL Neg, purple *****). Note: LL = Low-load, HL = High-load, Neg = Negative, Neu = Neutral.

Table 3

Predictors of Right Insula and Left Amygdala Activation during the Gambling Task.

	Right insula			Left amygdala		
	<i>F</i>	<i>p</i>	η^2	<i>F</i>	<i>p.</i>	η^2
Language	2.10	0.161	0.084	5.24	0.032*	0.186
Cognitive load	0.23	0.636	0.010	11.76	0.002**	0.338
Emotion	1.92	0.179	0.077	0.01	0.927	< 0.001
Language × Cognitive load	0.46	0.505	0.020	1.55	0.225	0.063
Language × Emotion	0.35	0.560	0.015	5.52	0.028*	0.194
Cognitive load × Emotion	9.15	0.006**	0.284	4.00	0.058	0.148
Language × Cognitive load × Emotion	15.78	0.001***	0.407	12.72	0.002**	0.356

Note: Significant results are set in bold.

Table 4

Post-hoc Comparisons for the Analysis on Right Insula and Left Amygdala Activation during the Gambling Task.

Interaction	ROIs	Comparisons	<i>F</i>	<i>p</i>	η^2
Cognitive Load × Emotion	R_insula	LL: Neu > Neg	1.94	0.177	0.078
		HL: Neg > Neu	12.69	0.002**	0.355
		Neg: HL > LL	5.25	0.032*	0.186
		Neu: LL > HL	3.09	0.092	0.118
Language × Emotion	L_amygdala	L1: Neg > Neu	3.39	0.079	0.128
		L2: Neu > Neg	4.18	0.053	0.154
		Neg: L1 > L2	8.71	0.007**	0.275
		Neu: L2 > L1	0.02	0.901	0.001
Language × Cognitive load × Emotion	L_amygdala	L1-LL: Neu > Neg	0.96	0.337	0.040
		L1-HL: Neg > Neu	10.78	0.003**	0.319
		L2-LL: Neu > Neg	1.33	0.260	0.055
		L2-HL: Neu > Neg	4.13	0.054	0.152
		L1-Neg: HL > LL	37.90	< 0.001**	0.622
		L1-Neu: HL > LL	0.03	0.862	0.001
		L2-Neg: HL > LL	0.45	0.511	0.019
		L2-Neu: HL > LL	4.29	.050*	0.157
	R_insula	L1-LL: Neu > Neg	10.55	.004**	0.314
		L1-HL: Neg > Neu	16.98	< .001***	0.425
		L2-LL: Neg > Neu	0.25	.624	0.011
		L2-HL: Neu > Neg	0.00	.987	< 0.001
		L1-Neg: HL > LL	8.66	.007**	0.274
		L1-Neu: LL > HL	10.82	.003**	0.320
		L2-Neg: HL > LL	0.15	.706	0.006
		L2-Neu: HL > LL	0.73	.400	0.031

Note: Significant results are set in bold.

PsychoPhysiological Interaction (PPI) Analysis

Table 5

Cognitive Load-dependent Functional Connectivity of the Right Insula ($p < 0.005$, Uncorrected).

Functional Connectivity Areas			Hemisphere	Cluster size (voxels)	MNI coordinate(x,y,z)	T value
L1	R-insula	Dorsal striatum	R	8	18 9 6	4.26
		Superior Temporal Gyrus	L	29	-63 -48 18	4.37
L2	R-insula	Parahippocampal Gyrus	R	26	21 -24 -15	5.80
		Dorsal striatum	L	8	-18 -6 -3	4.30
		Thalamus_(aal)	R	24	21 -21 3	6.05

Figure 5. Cognitive load-dependent functional connectivity of the right insula. Panel (a) displays the coronal, sagittal and axial view for the connectivity between the right insula and the right dorsal striatum (R DS) in L1 context. Panel (b) displays the coronal, sagittal and axial view for the connectivity between the right insula and the right parahippocampal gyrus (R PG) in L2 context.

Since we found a significant interaction between cognitive load and emotion in the right insula, we selected the difference between right insula activation for negative and neutral words as PPI seeds. In L1 condition, we found a robust activation in regions of the right dorsal striatum (i.e. lentiform nucleus, putamen) dependent on cognitive loading (Appendix E) and a functional interaction between right dorsal striatum (region related to cognitive load) and right insula (region related to emotion) (see Table 5). In addition, there was a significant functional connectivity between the right insula and the left superior temporal gyrus under cognitive loading, but the activation of the left superior temporal gyrus was not itself dependent on the cognitive load condition (-63 - 48 18). For L2, instead, the right parahippocampal gyrus, responsible for memory processes and here activated differently as a function of cognitive loading (Appendix E), showed a strong connectivity with the right insula. Although the left dorsal striatum and right thalamus also connected with the right insula, they were not part of the cognitive load-dependent functional connectivity.

Correlation Analysis

Table 6 shows correlations between the activation of left amygdala, right insula, right dorsal striatum or right parahippocampal gyrus and either gambling ratio or participants' risk propensity (assessed with the Risk Attitude Scale), for L1 and L2 condition. A FDR correction ($q = 0.05$; Benjamini & Hochberg, 1995; Benjamini & Yekutieli, 2001) was applied to p values which are reported as corrected.

In L1 condition, the activation of left amygdala (L1 High-load negative > L1 Low-load negative) positively correlated with gambling ratio but not with risk propensity

(see Table 6 and Figure 6a). Participants whose amygdala was activated for negative L1 words more under cognitive loading than not also gambled more.

In L2 condition, the activation of right insula (L2 High-load negative > L2 High-load neutral) was negatively correlated with gambling ratio but unrelated to risk propensity. Participants whose right insula was activated under cognitive loading more for negative L2 words than for L2 neutral words also gambled less.

Table 6

Correlations between Gambling Ratio or Risk Propensity and Left Amygdala, Right Insula, Right Dorsal Striatum and Right Parahippocampal Gyrus.

	Gambling ratio				Risk propensity			
	L1		L2		L1		L2	
	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
Left Amygdala	0.62	0.003	0.24	0.331	-0.13	0.786	0.20	0.300
Right Insula	0.36	0.172	-0.47	0.044	-0.11	0.722	-0.06	0.939
Right Dorsal Striatum	0.11	0.722	-0.38	0.068	-0.07	0.757	0.41	0.068
Right Parahippocampal Gyrus	-	-	-0.32	0.312	-	-	0.10	0.673

Note: Significant correlations are set in bold.

a. The left amygdala activation in L1 Neg HL > L1 Neg LL

b. The right insula in L2 HL Neg > L2 HL Neu

Figure 6. Correlations between gambling ratio and brain activity in left amygdala (a) and right insula (b) regions.

Discussion

The current study adopted a cross-task design to investigate at the neural level how the interaction between cognition and emotion can be affected by language (L1 vs. L2). We found that activation of the left amygdala and right insula was increased under cognitive loading in L1 negative words condition but not in L2 negative words

condition. Both left amygdala and right insula modulate emotional processing (Gorka et al., 2019; Hassel et al., 2020; Korgaonkar et al., 2019; Shiv et al., 2005; Xue et al., 2011): the former is known to be involved in sympathetic emotional activation (Eimontaite et al., 2019; Korn & Bach, 2019; Orem et al., 2019; Williams et al. 2005), and the latter is associated with negative affect and avoidance behavior (Saga et al., 2019; Turel et al., 2020). Here these regions were found to interact differently with cognitive loading depending on the language context.

This study further revealed that cognitive load-dependent connectivity in L1 was different to the one in L2. The increased connectivity with the reward-related striatum in L1 under cognitive loading suggests that cognitive load can enhance emotional sensitivity in L1. By contrast, in L2 context, the connection between the insula and the parahippocampal gyrus, a memory area, indicates that the brain favored the semantics access over the emotion processing.

A different access to emotion in the two languages (native, foreign) may explain the neural-behavioral correlations that we found. While in L1 the gambling ratio was positively correlated with the difference in left amygdala activation between the High-load negative words condition and the Low-load negative words condition, in L2 it was negatively correlated with the difference in right insula activation between the High-load negative words condition and the High-load neutral words condition. This suggests that in L1 cognitive loading can facilitate or deepen the emotional experience leading to a more impulsive decision making, whereas in L2 it can attenuate or hinder the access to emotion leading to more rational decision making.

The correlation between gambling ratio and left amygdala activation in L1 is in line with research showing that amygdala modulates risk behavior (Takeuchi et al., 2018; van Holstein et al., 2020; Xue et al., 2011). For instance, Zheng et al. (2020) showed that the processing of gambling feedbacks was associated with activation in the bilateral caudate, right posterior insula and amygdala, and that the activation in these areas helps explain foreign language effect in participants' gambling choices. However, while in Zheng et al. (2020) L2 positive words enhanced neural response to rewards, here an enhanced amygdala activation was found in L1 negative words condition. It can be observed that finding that negative words and their associated emotion activation (as reflected by left amygdala activation) lead to impulsive decision making is consistent with work showing that people sometimes make risky decisions when under loss, i.e. while experiencing negative emotions (Scholer et al., 2010).

We also found a correlation between gambling ratio and right insula activation in L2. This area is known to be implicated in top-down control of sympathetic nervous system functioning which is involved in hunger, survival, addiction, negative affect and avoidance behavior (Craig, 2005; Naqvi et al., 2007; Saga et al., 2018; Turel et al., 2020; Xue et al., 2010). Moreover, Arsalidou et al. (2013) reported that the bilateral insula areas were modulated by cognitive loading in a working memory task, strengthening the hypothesis that insula activation reflects both cognitive loading and emotion.

Overall, the correlational results pattern reported here can be explained by different thresholds of lexical-semantic access in the two languages (L1, L2). After processing a L1 word, cognitive resources are often still available to be recruited in the processing

of the emotional valence of the word. In our study this may have led participants to a more emotional or impulsive decision making. By contrast, cognitive load in L2 hinders or attenuates access to emotion as more cognitive resources are needed to process the lexical-semantic components of the words.

In our cross-task study, participants first completed a Lexical-semantic task trial where they were provided with a L1 or L2 language stimulus, and then made their decision whether to gamble. Thus, the language stimulus can be conceptualized as an anchor. We were interested in assessing under which conditions this anchor would have had an effect on participants' decision making. The anchoring effect is a cognitive heuristic and refers to the process where the individual is systematically biased in their judgment by an information given before the judgment (Beggs & Graddy, 2009; Furnham & Boo, 2011; Furnham et al., 2012). For instance, an individual's numerical estimate can be affected by biased estimates toward arbitrary values presented before.

In the native L1 context of our study, bilinguals may have been biased toward a more emotional and less rational decision making by having been anchored to the emotion assessment in the Lexical-semantic task. By contrast, in the foreign L2 context, the anchoring effect may have been hindered because cognitive loading and processing did not leave room for emotion processing in the anchoring phase in the first place.

However, it should also be noted that we did not find any significant left amygdala activation specific for negative words vs. neutral words in the Low-load condition in both L1 and L2. A possibility is that the emotion processing of valenced words highly depends on the difficulty of the lexical-semantic processing needed to complete the task

(Hinojosa et al., 2010; Schacht & Sommer, 2009b). Perhaps Low-load trials were too simple to process, and participants did not direct their attention to the emotional aspects of the stimuli. By contrast, participants may have been more focused on the emotional aspects in the High-load trials because the higher difficulty of the task increased their attention. Needless to say, this phenomenon closely resembles the germane cognitive loading phenomenon we discussed in the Introduction.

An unexpected result was found in the L1 Low-load condition: the insula, an area associated with emotion detection (Pedale et al., 2019; Simmons et al., 2012; Thom et al., 2012), was activated for the neutral words more than it was for the negative words. A possibility is that emotion detection was processed almost automatically for negative stimuli, but effortfully for neutral stimuli. Under this hypothesis, activation of insula can be seen as reflecting participants' effort in assessing whether neutral words had emotional content or not. Ultimately, however, no emotion can be associated to neutral words, as evidenced by the lack of activation of the amygdala region. Of interest here is that such unexpected effect was not found in L2 context. This further evidence of interaction insensitivity in L2 supports a foreign language effect.

It is worth noting that a number of studies reported that loading cognitive processes reduces emotional influence on judgment and cognition more in general (Berggren et al., 2013; DeFraine, 2016; Mueller et al., 2017; Panasiti et al., 2018; Van Dillena et al., 2009). Instead, at least in L1 context, we found that loading cognitive processes led to increased emotionality: in L1 but not in L2, negative stimuli provoked higher amygdala activity under cognitive loading. Work reporting an emotionality reduction effect often

uses arithmetic-based tasks to interfere with the processing of affective stimuli (e.g. Chen & Epps, 2013; Clarke & Johnstone, 2013; Van Dillen et al., 2009). By contrast, we used linguistic stimuli which already carry an emotional significance. In particular, it can be observed that words can induce different emotional arousal depending on whether they are in L1 or L2. This is so because L1 is learned in a diversified set of situations including negative ones, whereas L2 is acquired and used mainly in decontexted classroom environments where negative experiences are scarce (Atkinson, 2010; Grauwe et al., 2014; Kühne & Gianelli, 2019). L1 words processing may thus be more closely associated with the emotional brain networks.

These observations help explain why in L1 but not in L2 a germane cognitive load as the one employed in the current study resulted in higher activation of areas associated with emotion processing. This higher emotion activation under cognitive loading in L1 led to a biased decision making where insula showed significant connectivity with the the dorsal striatum, an area related to decision making (Nguyen et al., 2019), action planning (Vink et al., 2005; Zandbelt & Vink, 2010), motivation (Gemikonakli et al., 2019), reinforcement and reward perception (Pan et al. 2017; Wimmer et al., 2014). Instead, in L2 context, words underwent a more declarative lexico-semantic processing: insula was indeed found to be more connected with the parahippocampal gyrus, which plays an important role in memory encoding and retrieval (Aberg et al., 2020; Bohbot et al., 2015; Murty et al., 2014; Suzuki & Amaral, 1994). This suggests that cognitive loading in L2 led participants to first make an extra-effort to access the semantics and only later process the emotional valence of the words (Hinojosa et al., 2010).

In sum, in L1, because of the ease of lexical-semantic access, cognitive loading can be germane and promote access to emotion, eventually affecting decision making. In L2 context, instead, the higher difficulty of the lexical-semantic access combined with cognitive loading can be too taxing for participants' cognitive resources and, as a result, hinder the emotional influence over decision making.

Conclusion

We investigated the neural substrates underlying the interaction between cognitive load and emotional involvement in bilingual decision making. We found that cognitive loading in L1 but not in L2 facilitated access to emotion which led to a subsequent impulsive decision making. Risky decisions were mediated by the emotion-related regions in both L1 and L2. However, while in L1 cognitive loading promoted emotion as evidenced by increased sensitivity of the dorsal striatum, an area involved in reward-related emotion, in L2 it led participants to rely on the parahippocampal gyrus, an area which contributes to the declarative memory formation. Thus, the current findings provide evidence of distinct neural pathways underpinning decision making in native vs. foreign language, opening new avenues for research by highlighting the importance of investigating the complex interaction between cognitive loading and emotional involvement in the context of the foreign language effect.

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Appendix A. Oxford Placement Test

Instruction 1: Please tick the corresponding number you think is the correct answer.

1	Water _____ at a temperature of 0° C.
	1、 be freezing; 2、 freezes; 3、 is freezing.
2	In some countries _____ dark all the time in winter.
	1、 there is; 2、 is; 3、 it is
3	In some countries people wear light clothes _____ cool.
	1、 for keeping; 2、 to keep; 3、 for to keep.
4	In Madeira they have _____ weather almost all year.
	1、 the good; 2、 good; 3、 a good.
5	Most Mediterranean countries are _____ in October than in April.
	1、 more warm; 2、 the more warm; 3、 warmer.
6	Parts of Australia don't have _____ rain for long periods.
	1、 the; 2、 some; 3、 any.
7	In the Arctic and Antarctic _____ a lot of snow.
	1、 it is; 2、 there is; 3、 it has.
8	Climate is very important in _____ people's lives.
	1、 most ; 2、 of most ; 3、 the most.
9	Even now there is _____ we can do to control the weather.
	1、 little; 2、 few; 3、 less.
10	In the future _____ to get a lot of power from the sun.
	1、 We'll need; 2、 We are needing; 3、 We can need.
11	Pele is still _____ famous footballer in the world.
	1、 the most; 2、 most; 3、 the more.
12	He _____ born in 1940.
	1、 had been; 2、 is; 3、 was.
13	His mother _____ him to be a footballer.
	1、 not want; 2、 wasn't wanting; 3、 didn't want.
14	But he _____ to watch his father play.

	1、 used; 2、 ought; 3、 has used.
15	His father ____ practice everyday.
	1、 made him to; 2、 made him ; 3、 would make him to.
16	He learned to use _____ and his right.
	1、 or his left foot or ; 2、 and his left foot and; 3、 both his left foot.
17	He got the name Pele when he _____.
	1、 had only ten years; 2、 was only ten; 3、 was only ten years.
18	By 1956 he _____ Santos and had scored in his first game.
	1、 joined ; 2、 had joined; 3、 has joined.
19	In 1957 he ____ for the Brazilian national team.
	1、 has been picked; 2、 was picked ; 3、 was picking.
20	The World Cup Finals were in 1958 and Pele was looking forward to _____.
	1、 playing; 2、 to play; 3、 to be playing.
21	But he hurt ____ knee in a game in Brazil.
	1、 the; 2、 his; 3、 this.
22	He thought he _____ be able to play in the finals in Sweden.
	1、 isn't going to; 2、 couldn't ; 3、 wasn't going to.
23	If he _____ so important to the team, he would have been left behind.
	1、 hadn't been; 2、 weren't; 3、 wouldn't be.
24	But he was ____ brilliant player, they took him anyway.
	1、 a such; 2、 such a; 3、 a so.
25	And _____ he was injured, he helped Brazil to win the final.
	1、 even though ; 2、 even so; 3、 in spite of.

Instruction 2: Please tick the corresponding number you think is the correct answer in the table after the passage.

The history of the World Cup is 26 one. Football 27 played for 28 a hundred years, but the first World Cup competition 29 held until 1930. Uruguay 30 the Olympic football final in 1924 and 1928 and wanted 31 World Champions for the third time. Four teams entered from Europe, but with 32 success. It was the first time 33 professional teams 34 for a world title. It wasn't until four years 35 that a European team succeeded 36 for 37 first time. The 1934 World Cup was again won by 38 home team, 39 has been the case several times since then. The 1934 final was 40 two European teams, Czechoslovakia and Italy, 41 won, went on 42 the 1938 final. Winning successive finals is something that 43 achieved again until Brazil did 44 in 1958 and 1962. If Brazil 45 in 1966, then the Authorities would have needed to 46 the original World Cup replaced. But England stopped the Brazilians 47 a successive win. An England player, Geoff Hurst, scored three goals in the final and won it almost 48. 1966 proved 49 the last year that England 50 even qualify for the finals till 1982, though they got in as winners in 1970.

26	1、 quite a	2、 a quite	3、 quite
27	1、 has been	2、 is being	3、 was
28	1、 above	2、 over	3、 more that
29	1、 wasn't	2、 didn't be	3、 was not being
30	1、 could win	2、 were winning	3、 had won
31	1、 be	2、 being	3、 to be
32	1、 a little	2、 few	3、 little
33	1、 which	2、 that	3、 when
34	1、 are playing	2、 would play	3、 had played
35	1、 later	2、 more	3、 further
36	1、 to win	2、 in winning	3、 at winning
37	1、 the	2、 a	3、 its
38	1、 a	2、 the	3、 one
39	1、 what	2、 this	3、 which
40	1、 among	2、 between	3、 against
41	1、 which	2、 that	2、 who
42	1、 to win	2、 winning	3、 to have won
43	1、 is not	2、 was not	3、 has not been
44	1、 them	2、 these	3、 it
45	1、 would have won	2、 would win	3、 had won
46	1、 have	2、 let	3、 make
47	1、 to get	2、 getting	3、 get
48	1、 by his own	2、 on himself.	3、 by himself
49	1、 being	2、 as being	3、 to be
50	1、 would	2、 will	3、 did

Appendix B. Domain-specific Risk-attitude Scale

For each of the following statements, please indicate the likelihood of engaging in each activity. Provide a rating from 1 to 5, using the following scale:				
1	2	3	4	5
Extremely unlikely		Not sure		Extremely likely
A1	Betting a day's income on the outcome of a sporting event (e.g. baseball, soccer, or football).			
A2	Gambling a week's income at a casino.			
A3	Betting a day's income at the horse races.			
A4	Betting a day's income at a high stake poker game.			
B5	Regularly riding your bicycle without a helmet.			
B6	Eating 'expired' food products that still 'look okay'.			
B7	Never wearing a seatbelt.			
B8	Not wearing a helmet when riding a motorcycle.			
B9	Engaging in unprotected sex.			
C10	Wearing provocative or unconventional clothes on occasion.			
C11	Deciding to share an apartment with someone you don't know well.			
C12	Raise your hand to answer the teacher's questions in class			
C13	Arguing with a friend who has a very different opinion on an issue.			
C14	After dating someone you like, ask how he feels			
C15	Speaking your mind about an unpopular issue at a social occasion.			
D16	Periodically engaging in a dangerous sport (e.g. mountain climbing or sky diving).			
D17	Walking home alone at night in a somewhat unsafe area of town.			
D18	Chasing a tornado or hurricane by car to take dramatic photos.			
D19	Going whitewater rafting during rapid water flows in the spring.			

Appendix C. Word List

The first eight elements were practice items, the remaining were experimental items.

Chinese		English	
Warm-up words			
马路		floor	
食物		work	
Warm-up pseudo-words			
工昨			WETER
	時潤		COD
Formal words			
声音	聲音	sound	SOUND
石头	石頭	stone	STONE
学生	學生	student	STUDENT
白纸	白紙	paper	PAPER
数字	數字	number	NUMBER
电话	電話	phone	PHONE
盘子	盤子	plate	PLATE
灯光	燈光	light	LIGHT
苹果	蘋果	apple	APPLE
手表	手錶	watches	WATCHES
山脉	山脈	mountain	MOUNTAIN
说话	說話	speak	SPEAK
新闻	新聞	news	NEWS
产品	產品	product	PRODUCT
枕头	枕頭	pillow	PILLOW
报告	報告	keyboard	KEYBOARD
键盘	鍵盤	report	REPORT
书桌	書桌	table	TABLE
系统	系統	system	SYSTEM
铅笔	鉛筆	pencil	PENCIL
该死	輕視	damn	DAMN
反感	懺悔	hate	HATE
糟糕	悲觀	terrible	TERRIBLE
抱歉	諷刺	sorry	SORRY
耻辱	恥辱	shame	SHAME
厌恶	厭惡	sick	SICK
恶心	噁心	disgust	DISGUST
贪婪	貪婪	greedy	GREEDY
恐惧	恐懼	fear	FEAR
尴尬	尷尬	awkward	AWKWARD

責備	責備	scold	SCOLD
沮喪	沮喪	depressed	DEPRESSED
担忧	擔憂	worried	WORRIED
疯狂	瘋狂	crazy	CRAZY
悲伤	悲傷	fear	FEAR
肮脏	骯髒	dirty	DIRTY
焦虑	焦慮	anxiety	ANXIETY
残酷	殘酷	cruel	CRUEL
质疑	質疑	suspect	SUSPECT
消极	消極	Negative	Negative
Formal pseudo-word			
菇儿	菇兒	patilnt	PATILNT
打驾	打駕	orphen	ORPHEN
纱漠	紗漠	flyy	FLYY
呕仕	嘔仕	hynger	HYNGER
病认	病認	faght	FAGHT
苍绳	蒼繩	disaple	DISAPLE
掺疾	摻疾	debert	DEBERT
失呗	失唄	taers	TAERS
眼钜	眼鉅	failura	FAILURA
饥娥	饑娥	vommt	VOMMT

Appendix D. Model Parameters for the Best-fitting Generalized Linear Mixed Model in Lexico-semantic Task and Gambling Task

Table D1

Model Parameters for the Best-fitting Generalized Linear Mixed Model on Accuracy in the Lexico-semantic Task.

	β	SE	Contrast	
			z	p
Fixed effects				
Intercept	3.76	0.29	12.78	< 0.001***
Language	-1.55	0.29	-5.40	< 0.001***
Cognitive load	-2.89	0.27	-10.60	< 0.001***
Emotion	0.59	0.42	1.40	0.468
Language $\times$ Cognitive load	2.49	0.33	7.67	< 0.001***
Language $\times$ Emotion	0.41	0.48	0.85	0.849
Cognitive load $\times$ Emotion	-0.06	0.44	-0.13	1.000
Language $\times$ Cognitive load $\times$ Emotion	0.10	0.55	0.19	1.000
Random effects				
Participants	0.58	0.76		

Table D2

Model Parameters for the Best-fitting Linear Mixed Model on Reaction Times in the Lexico-semantic Task.

	β	SE	Contrast	
			z	p
Fixed effects				
Intercept	688.06	30.70	22.41	< 0.001***
Language	126.45	33.09	3.82	0.001**
Cognitive load	236.10	33.88	6.97	< 0.001***
Emotion	-43.59	32.82	-1.33	0.619
Language $\times$ Cognitive load	-16.51	47.62	-0.35	0.999
Language $\times$ Emotion	-27.81	46.65	-0.60	0.985
Cognitive load $\times$ Emotion	-70.00	47.21	-1.48	0.508
Language $\times$ Cognitive load $\times$ Emotion	45.44	66.62	0.68	0.970
Random effects				
Participants	112.88	106.25		
Words	79.44	89.13		

Table D3

Model Parameters for the Best-fitting Generalized Linear Mixed Model on Gambling Ratio in the Gambling Task.

	β	SE	Contrast	
			z	p
Fixed effects				
Intercept	2.00	0.54	3.69	< 0.002***
Language	0.11	0.22	0.50	0.996
Cognitive load	-0.06	0.23	-0.26	0.999
Emotion	0.08	0.21	0.38	0.999
Language $\times$ Cognitive load	0.31	0.32	0.98	0.867
Language $\times$ Emotion	-0.41	0.30	-1.37	0.610
Cognitive load $\times$ Emotion	0.03	0.32	0.11	1.000
Language $\times$ Cognitive load $\times$ Emotion	0.19	0.43	0.44	0.998
Random effects				
Participants	3.56	1.89		
Potential gain/loss	3.53	1.88		

Table D4

Model Parameters for the Best-fitting Generalized Linear Mixed Model on Reaction Times in the Gambling Task.

	β	SE	Contrast	
			z	p
Fixed effects				
Intercept	767.41	32.91	23.32	< 0.001***
Language	6.50	18.01	0.36	0.999
Cognitive load	15.55	19.59	0.79	0.946
Emotion	-15.09	18.04	-0.84	0.931
Language $\times$ Cognitive load	-24.60	26.26	-0.94	0.889
Language $\times$ Emotion	15.19	25.20	0.60	0.987
Cognitive load $\times$ Emotion	17.57	27.28	0.64	0.981
Language $\times$ Cognitive load $\times$ Emotion	2.77	35.94	0.08	1.000
Random effects				
Participants	22.93	15.42		
Potential gain/loss	25.55	50.55		

Appendix E. Functional Connectivity (PPI)**Table 1**

Brain Activations Elicited in the High-load vs. Low-load and Negative vs. Neutral Contrast in L1 and L2 Conditions (L1: GRF Correction - Voxel p value = .001, Cluster p value = .05; L2: p = .005, Uncorrected).

Region	Hemisphere	Cluster size (voxels)	Peak Coordinates MNI (x, y, z)	Peak intensity (T value)
High-load > Low-load				
L1 Neg				
Dorsal striatum	R	53	27 12 3	5.0709
Amygdala	L	13	-27 3 -24	6.5187
L1 Neu				
none				
L2 Neg				
Dorsal striatum	R	16	15 -6 3	4.0877
Frontal_Inf_Orb	L	7	-36 36 -15	3.5513
Insula	L	6	-39 15 -3	3.3936
Middle Frontal Gyrus	L	22	-39 27 33	3.8676
L2 Neu				
Parahippocampal	R	5	33 -36 -12	3.8625
Insula	L	5	-45 9 6	4.3357
Negative > Neutral				
L1 low-load				
None				
L1 high-load				
Insula	R	12	30 24 -18	5.3164
L2 low-load				
Fusiform	R	8	36 -57 -9	4.4937
Middle Occipital Gyrus	L	4	-36 -96 9	3.6577
L2 high-load				
Middle Frontal Gyrus	L	20	-42 30 33	4.3089

Note: A more rigorous GRF correction (Voxel p value = .001, cluster p value = .05) was applied to comparison in L1 condition. However, the correction standard (p = .005, uncorrected) were relaxed in L2 condition because the activation attenuated.