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Effects of valence and arousal on emotional word processing are modulated by concreteness: Behavioral and ERP evidence from a lexical decision task

Zhao Yao [a,*], Deshui Yu [a], Lili Wang [b], Xiangru Zhu [c], Jingjing Guo [d], Zhenhong Wang [d,*]

[a] School of Humanities, Xidian University, Xi'an 710126, China
[b] School of Educational Science, Huaiyin Normal University, Huaian 223300, China
[c] Department of Psychology, Henan University, Kaifeng 475004, China
[d] School of Psychology, Shaanxi Normal University, Xi'an 710062, China

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ABSTRACT

We investigated whether the effects of valence and arousal on emotional word processing are modulated by concreteness using event-related potentials (ERPs). The stimuli included concrete words (Experiment 1) and abstract words (Experiment 2) that were organized in an orthogonal design, with valence (positive and negative) and arousal (low and high) as factors in a lexical decision task. In Experiment 1, the impact of emotion on the effects of concrete words mainly resulted from the contribution of valence. Positive concrete words were processed more quickly than negative words and elicited a reduction of N400 (300–410 ms) and enhancement of late positive complex (LPC; 450–750 ms), whereas no differences in response times or ERPs were found between high and low levels of arousal. In Experiment 2, the interaction between valence and arousal influenced the impact of emotion on the effects of abstract words. Low-arousal positive words were associated with shorter response times and a reduction of LPC amplitudes compared with high-arousal positive words. Low-arousal negative words were processed more slowly and elicited a reduction of N170 (140–200 ms) compared with high-arousal negative words. The present study indicates that word concreteness modulates the contributions of valence and arousal to the effects of emotion, and this modulation occurs during the early perceptual processing stage (N170) and late elaborate processing stage (LPC) for emotional words and at the end of all cognitive processes (i.e., reflected by response times). These findings support an embodied theory of semantic representation and help clarify prior inconsistent findings regarding the ways in which valance and arousal influence different stages of word processing, at least in a lexical decision task.

1. Introduction

Valence and arousal were identified as the most basic dimensions of emotional information. Valence refers to a continuum that varies from pleasure to displeasure. Arousal refers to a continuum that varies from calm to excited (Russell, 2003). Previous event-related potential (ERP) studies have suggested that valence and arousal influence the time course of emotional word processing in a wide variety of tasks (for a review, see Citron, 2012). Some early components have been reported in previous ERP studies. For example, the early posterior negativity (EPN) has been taken as evidence of early ERP effects, which has been taken as a reflection of attentional capture during early stages of meaning encoding (Herbert et al., 2006; Palazova et al., 2011). The N170 effect to emotional words has been observed in a few studies, suggesting that the emotional value of words may be detected during the early stages of emotional processing (Frühholz et al., 2011; Zhang et al., 2014). With regard to later ERP components, N400 (300–500 ms) and the late positive complex (LPC, 500–800 ms) have been associated with the processing of emotional words. The former reflects difficulty in semantic integration (Kutas and Federmeier, 2011) and facilitated semantic processing for emotional stimuli (Kanske and Kotz, 2007). The latter reflects enhanced motivated attention (Lang et al., 1997) and the sustained elaborate processing of emotional stimuli (Fischler and Bradley, 2006; Herbert et al., 2008; Kissler et al., 2009). Although the exiting data indicate that emotional ERP effects are evoked by valence and/or arousal (Citron, 2012), little consensus has been reached about the exact contributions of these two dimensions to ERPs during the processing of emotional word.

Some studies suggest that valence and arousal separately contribute to the processing of emotional words (Estes and Adelman, 2008; Gianotti et al., 2008; Bayer et al., 2010, 2012; Vinson et al., 2014; Kuperman et al., 2014; Nicolle and Goel, 2013; Delaney-Busch et al.,

* Corresponding authors.
E-mail addresses: zyao@xidian.edu.cn (Z. Yao), wangzhenhong@snnu.edu.cn (Z. Wang).

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2016). For example, Gianotti et al. (2008) used ERP microstate analysis and found different dynamics and neural assemblies in the processing of valence and arousal. They also found that information about the valence of emotional words was processed before information about arousal. Bayer et al. (2010) compared the effects of negative and neutral target verbs that were embedded within sentences on ERPs in a semantic decision task and found a larger LPC for negative than neutral words. This effect was unaffected by pure arousal variations when valence was kept constant. They also found no interactions between valence and arousal in any of the analyzed time windows (100–130, 190–260, 280–380, and 420–630 ms) in a lexical decision task and a reading task that employed high-arousal and low-arousal nouns with positive, neutral, or negative valence(Bayer et al., 2012). Moreover, Vinson et al. (2014) compared different models of emotion using the British Lexicon Project, a large-scale freely available lexical decision database and found that the effect of valence was not modulated by arousal after confounding variables (e.g., concreteness, imageability, familiarity, age of acquisition, number of letters, log frequency, and orthographic neighborhood size) were taken into account. Kuperman et al. (2014) collected empirical patterns observed in word-level and trial-level data from lexical decision and naming and also indicated that valence and arousal exert independent effects. Recently, Delaney-Busch et al. (2016) reported that valence and arousal act independently to influence the LPC component during word processing, and this influence depended on task demands. Specifically, the LPC had a larger amplitude in response to high-arousal words than low-arousal words, but no effect of valence was found in a semantic categorization task in which emotion was not directly relevant to task performance. In contrast, the LPC was affected by valence, in which unpleasant words elicited the largest positivity, but no effect of arousal was found in an overt valence categorization task. These findings suggest that valence and arousal independently impact word processing during early and late time windows.

Other studies reported that interactions between valence and arousal impacted emotional word processing (Larsen et al., 2008; Purkis et al., 2009; Hofmann et al., 2009; Eder and Rothermund, 2010; Fernandes et al., 2011; Citron et al., 2013; Recio et al., 2014). For example, Hofmann et al. (2009) found high-arousal negative words and low-arousal positive words elicited greater negative potentials (80–120 ms) than low-arousal negative and neutral words in a lexical decision task, suggesting that arousal differentially impacts the early lexical processing of positive and negative words. Citron et al. (2013) provided additional evidence of the interactive effects of valence and arousal in a lexical decision task by manipulating valence (positive, negative, and neutral) and arousal (low and high). This effect was observed in the early posterior negativity (EPN), with a larger amplitude for high-arousal positive words and low-arousal negative words. Recio et al. (2014) employed a full factorial design, with valence (positive, negative, neutral) and arousal (low, medium, high) as factors and found interactive effects of valence and arousal between 275 and 425 ms. These results suggest that valence and arousal indeed interactively influence the effects of emotion on ERPs during the processing of emotional words.

Despite recent efforts to explore the ways in which valence and arousal contribute to the effects of emotion on ERP during the processing of words, the results have remained inconclusive. Vigliocco et al. proposed an embodied theory of semantic representation and provided evidence that word concreteness, through differences in experiential information between concrete and abstract words, was engaged in emotional word processing and influenced the effects of emotional valence (Vigliocco et al., 2009; Kousta et al., 2011).

Embodied theories of cognition propose that cognition is grounded in bodily states, modal simulations, and situated action (Barsalou, 1999; Barsalou et al., 2003). The embodied theory of semantic representation proposes that knowledge that includes learning the emotional meaning of words is grounded in bodily states and situated action. Two foundational sources of experiential information have the potential to modulate the acquisition and processing of words. One experiential source of information consists of sensorimotor representations of sensory events (e.g., vision) and actions (e.g., movements) in the external world. Another experiential source of information consists of emotional representations of states in the inner world (e.g., positive and negative affect). In other words, words that denote concrete objects and actions develop from our experience with the external world. In contrast, our internal affective experience would provide at least initial grounding to abstract concepts (Vigliocco et al., 2009). Much evidence indicates that differences between the concepts of concrete and abstract are derived from the statistical preponderance of sensorimotor associations that underlie concrete word meanings, and affective associations underlie abstract word meanings (Kousta et al., 2011; Newcombe et al., 2012; Vigliocco et al., 2014).

Because of differences in experiential information between concrete and abstract words, recent studies controlled for a larger number of lexical variables (e.g., word frequency, arousal, and familiarity, among others), suggesting that concreteness influences the effect of emotional meaning on word processing (Vigliocco et al., 2009; Kousta et al., 2011; Vigliocco et al., 2014; Kanske and Kotz, 2007; Tse and Altarriba, 2009; Wang and Yao, 2012; Yao and Wang, 2013, 2014; Palazova et al., 2013; Sheikh and Titone, 2013; Kaltwasser et al., 2013). For example, Palazova et al. (2013) used a lexical decision task and found that an interaction between concreteness and valence was present at 250–300 ms and 400–450 ms post-stimulus, and the effects of the emotional valence of concrete verbs differed from abstract verbs. Wang and Yao (2012) also found that valence and concreteness influenced the N400 in a lexical decision task, indicating that the emotionality and concreteness affected each other at the semantic processing stage. Kanske and Kotz (2007) presented concrete and abstract nouns with positive, negative, and neutral valence in a Go/No-Go task, suggesting that negative concrete words enhanced LPC amplitudes compared with positive and neutral words, whereas this effect on LPC was absent for abstract words. Kaltwasser et al. (2013) asked participants to perform a semantic categorization task (abstract vs. concrete) using words with different valence and found an interaction between valence and concreteness that was reflected in response times and the LPC component. Hinojosa et al. (2014) investigated the divergence between the explicit and implicit processing of affective content during word comprehension and reported that the emotional effect on the anterior LPC was modulated by the concreteness of the words, in which larger LPC amplitudes were only observed when comparing abstract negative nouns with abstract neutral nouns. Sheikh and Titone (2013) used eye-movement measures of natural reading and also found an interaction between valence and concreteness with regard to gaze duration. The processing of emotional words was maximally faster than neutral words when the words had low levels of concreteness. These previous studies that investigated the role of concreteness during the processing of emotional word suggest that the effects of emotional meaning on word processing are modulated by the level of concreteness.

According to the embodied theory of semantic representation, abstract words with greater affective associations than concrete words may be the reason why concreteness modulates the effects of emotional connotation on word processing (Vigliocco et al., 2009; Kousta et al., 2011; Vigliocco et al., 2014). Evidence from behavioral and ERP studies indicate that greater affective associations can facilitate word processing in lexical decision tasks (Yao and Wang, 2013, 2014; Kousta et al., 2009; Kousta et al., 2011; Vigliocco et al., 2014). However, although numerous studies have sought to explore the effects of valence and arousal on word processing, the role of concreteness was not taken into account. Thus, remaining unknown is whether the influence of valence and arousal on the effects of emotion is modulated by word concreteness. Answering this question may explain the conflicting literature on the ways in which valence and arousal contribute to the effects of emotion on word processing. In the present study, the valence (positive and negative) and arousal (high and low) of concrete and abstract words were orthogonally combined. Concrete and abstract words were separately used in Experiments 1 and 2. The participants performed a lexical decision task while behavioral and ERP responses were recorded. We also utilized a neutral condition as a baseline and investigated whether emotion-neutral differences were also modulated by word concreteness. There are two reasons to conduct two separate experiments. First, our study aimed to explore whether the effects of valence and arousal on concrete word processing are different from the effects of valence and arousal on abstract word processing, thus concrete words and abstract words are presented to subjects in two experiments under equivalent experimental conditions. Second, to ensure an appropriate signal-to-noise ratio of the ERP averages, the whole experiment lasted for at least 1 h (not including time taken for subjects to wash hair and experimenters to place electrodes on the scalp, as well as short breaks between blocks and the practice experiment). It is necessary to conduct two separate experiments in order to avoid that participants may have been too tired to finish the task.

According to the embodied theory of semantic representation, we predicted that the effects of valence and arousal on concrete word processing are different from the effects of valence and arousal on abstract word processing. Based on the evidence described above that supports the effect of concreteness on emotional word processing, we expected that valence would act independently of arousal to influence the time course of concrete word processing, and the possible interaction between valence and arousal is limited to abstract words. Thus, we expected to observe N400 and LPC effects in response to emotional concrete words that arise from a single contribution of valence or arousal. By comparison, the N400 and LPC effects in response to emotional abstract words might arise from a common contribution of valence and arousal. Although we had no specific predictions about the early components that were elicited because the evaluation of the relationship between the emotional dimension and concreteness during early processing stages was exploratory, we predicted that concreteness would modulate early emotion effects (e.g., N170/EPN).

2. Experiment 1: effects of valence and arousal on concrete word processing

In Experiment 1, we manipulated the valence (negative and positive) and arousal (high and low) of concrete words that were matched with regard to familiarity, frequency, and strokes (i.e., the number of strokes that are used to write Chinese characters). Our aim was to investigate the ways in which valence and arousal influence the processing of emotional concrete words. Based on previous studies that reported the effects of emotion on words processing, we predicted that valence and arousal may affect behavioral performance and ERPs at early and late processing stages.

2.1. Method

2.1.1. Participants

Nineteen university students (10 women), ranging in age from 18 to 24 years (mean age ± SD = 21.4 ± 1.1), participated in the experiment in return for allowance. All of them were Chinese native speakers, and all were right-handed according to the Edinburgh Handedness Inventory (mean score 86.7 ± 28, Oldfield, 1971). They had normal or corrected-to-normal vision, and no history of neurological or psychiatric disorders. Each signed written informed consent forms prior to their participation.

2.1.2. Materials

We collected information regarding the valence, arousal, concreteness, and other variables for 1107 words (Yao et al., unpublished data) according to the procedure in the Chinese Affective Words System (CWAS; Wang et al., 2008). In this rating study, each item was rated by at least 48 participants using a 9-point scale. There were 399 words in common with the CAWS. The correlation between these ratings and the ratings for the CAWS was very high (valence: $r = 0.81$; arousal: $r = 0.75$), with very similar means and standard deviations.

From this pool of words, we selected 20 high-arousal positive words, 20 low-arousal positive words, 20 high-arousal negative words, 20 low-arousal negative words, and 20 neutral concrete words that were matched with regard to concreteness, familiarity, frequency, and strokes. Table 1 presents a summary of the descriptive statistics (means and standard deviations) for six variables and one-way analyses of variance (ANOVAs) for each factor. Valence ratings significantly differed across all of the valence categories [positive = 6.95 ± 0.51, negative = 2.73 ± 0.57, and neutral = 4.88 ± 1.07, $F(2, 97) = 677.81$, $p < 0.001$], and arousal ratings significantly increased from neutral (4.47 ± 1.01) over low-arousal (5.71 ± 0.47) to high-arousal words (6.85 ± 0.46) [$F(2, 97) = 165.15$, $p < 0.001$]. Post hoc analyses with the Bonferroni correction ($p < 0.05$) revealed that valence ratings were matched between high- and low-arousal, and arousal ratings were matched between positive and negative (all $ps > 0.13$). In addition, concreteness, familiarity, frequency, and strokes were matched across all five conditions (all $ps > 0.05$). There were 120 pseudowords that were based on the 100 original words, created by altering one random character within different real words. Some of the experimental items in Chinese and their English translations are presented in Appendix 1.

2.1.3. Task and procedure

Stimuli were presented in white letters (font: Song typeface, size: 36) over black background on a 17-in. monitor placed at 80 cm from participants' eyes. Participants were instructed to respond as quickly and accurately as possible whether each item was a word or a pseudoword by pressing one of two buttons ("Z" or "M" key) placed under their two index fingers. The correspondence of response and keys were counterbalanced across the participants.

Each trial began with a fixation point presented for 500 ms, followed by a black screen for 200–400 ms. Then a target stimulate was presented for 1500 ms, at which time the participants responded. The inter-trial interval was 1500–1800 ms. All 80 emotional concrete words as well as the 120 pseudowords were presented four times, and 20 neutral words were presented eight times, resulting in a total of 960 stimuli, shown in 16 blocks of 60 trials each. Eight of these blocks involved high-arousal words. Each block contained 10 high-arousal positive words, 10 high-arousal negative words, 10 neutral words and

Table 1
Descriptive statistics for selected concrete words. Means of Concreteness (1, Abstract to 9, Concrete), Valence (1, Negative to 9, Positive), Arousal (1, Calming to 9, Arousing), and Familiarity (1, Unfamiliar to 9, Familiarity) etc.

Variables	Concreteness	Valence	Arousal	Familiarity	Frequency	Strokes
High-arousal positive	6.73 ± 0.57	7.28 ± 0.47	6.91 ± 0.42	5.69 ± 0.68	14.26 ± 17.31	16.50 ± 4.31
Low-arousal positive	6.67 ± 0.47	6.62 ± 0.29	5.86 ± 0.27	5.67 ± 0.57	10.71 ± 13.28	17.00 ± 5.87
High-arousal negative	6.60 ± 0.57	2.42 ± 0.38	6.78 ± 0.50	5.14 ± 0.66	9.00 ± 14.29	15.65 ± 3.94
Low-arousal negative	6.71 ± 0.46	3.04 ± 0.56	5.56 ± 0.57	5.40 ± 0.73	14.30 ± 11.16	17.00 ± 4.32
Neutral words	6.61 ± 0.36	5.02 ± 0.39	4.46 ± 0.57	5.42 ± 0.68	10.47 ± 11.41	17.90 ± 3.18
One-way ANOVA on each factor	$F(4,95) = 0.32$, $p = 0.86$, n.s	$F(4,95) = 497.9$, $p < 0.001$	$F(4,95) = 85.9$, $p < 0.001$	$F(4,95) = 2.25$, $p = 0.07$, n.s	$F(4,95) = 0.62$, $p = 0.65$, n.s	$F(4,95) = 0.68$, $p = 0.61$, n.s

Notes. n.s. = nonsignificant. ANOVA = analysis of variance.

30 pseudowords. The remaining eight blocks involved low-arousal words. Each block contained 10 low-arousal positive words, 10 low-arousal negative words, 10 neutral words and 30 pseudowords. The orders of all blocks were randomized across participants, and the sequence of trials in each block was pseudo-random, with the constraints that identical words were not presented more than one time in a block. Between blocks there was a short, self-terminated break. Prior to the experiment trials, each participant performed 14 practice trials (these words did not appear in the formal experiment) to prove that they had completely understood the trial procedure. All experiments were programmed using E-Prime 1.0.

2.1.4. EEG recording and analysis

The EEG was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (Brain Products, Gilching, Germany). The FCz electrode was used as recording reference (a built-in reference electrode of EEG caps) and then re-referenced offline to an average mastoid reference (Luck, 2005), and a ground electrode was placed on the medial frontal location (AFz electrode). Electrodes were also placed below the left eye and at the outer canthus of the right eye to monitor vertical and horizontal eye movements. EEG activity was band-pass filtered (0.05–30 Hz). Sampling rate was 500 Hz. Impedances were below 5 KΩ for each electrode. EEG data were analyzed offline using the Brain Vision Analysis software (Version 2.0; Brain Product, Gilching, Germany). Eye movement artifacts were removed automatically via vertical ocular correction (Gratton et al., 1983). Trials with any EEG artifacts (exceeding ±75 μV, drifts) and trials with incorrect behavioral responses were discarded. The percentage of remaining trials was above 85% in all conditions. Average ERPs from −200 to 900 ms after the presentation of every type of target stimulus were computed separately. The EEG recordings over each electrode site for each participant were averaged separately within each of the experimental conditions.

Inspection of the grand-average waveforms indicated that there was an obvious negative ERP component around 170 ms at posterior lateral sites, which was measured by baseline-to-peak amplitude in the time window 140–200 ms in the bilateral parieto-occipital electrodes (P5/6, P7/8 and PO7/8). With regard to the analysis of the N170, we imitated the study by Rossion et al. (2003) and by Hinojosa et al. (2015), and measured the maximum peak within 140–200 ms time window. In line with previous research, mean amplitudes of two late ERP components were measured for the following time intervals: N400 from 300 to 410 ms, LPC from 450 to 750 ms. Based on their typical scalp distribution, ten electrodes were chosen for N400 (FC3/4, FC5/6, C3/4, C5/6, Cz, CPz) and LPC (FC5/6, C5/6, CP3/4, CP5/6, Cz, CPz).

Three-way ANOVA was applied: valence (positive, negative), arousal (high, low) and Electrode site. Significant main effects and interactions were followed up by simple effect analyses. Post hoc t tests were performed when necessary and were considered significant at $p < 0.05$, corrected for multiple comparisons (Bonferroni). Only interactions that yielded significant follow-up analyses were reported. Additional contrasts were carried out for neutral relative to both high- and low-arousal positive and negative words. The Geisser–Greenhouse correction was applied to all repeated measures with greater than one degree of freedom.

2.2. Results

2.2.1. Behavioral results

Participants accurately reported 98.1% of the target stimuli across all conditions (range: 96.9–99.8%), and only the correct response times were statistically analyzed. Mean correct response times (RTs) were submitted to analyses of variance (ANOVAs) with repeated measures. We excluded from the RTs above or below 2.5 standard deviations from the mean (2.01% of overall trials).

Mean RTs are presented in Fig. 1. Valence caused a significant main effect in the RTs [$F\ (1, 18) = 19.87$, $p < 0.001$, $\eta_P^2 = 0.5$]. Negative words

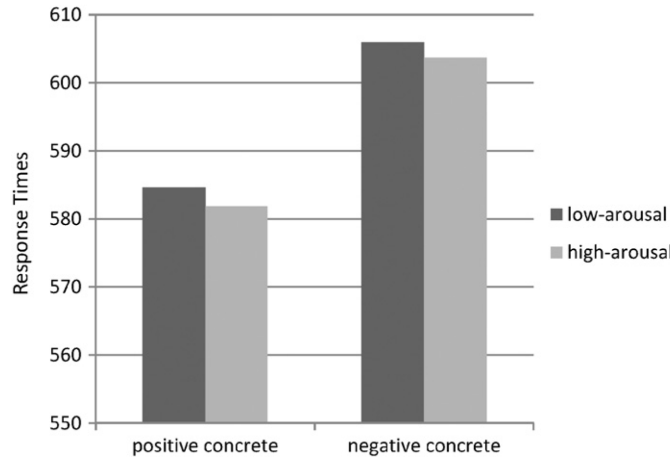

Fig. 1. Response times of positive high/low-arousal, and negative high/low-arousal concrete words in lexical decision task.

(603.9 ms ± 12.6) were slower than positive words (584.4 ms ± 14.3). There were no significant arousal main effect [$F\ (1, 18) = 1.67$, $p = 0.21$, $\eta_P^2 = 0.09$, high-arousal: 591.1 ms ± 13.8; low-arousal: 597.3 ms ± 13.2] and interaction between valence and arousal [$F\ (1, 18) = 0.62$, $p = 0.44$, $\eta_P^2 = 0.03$].

Post hoc tests with Bonferroni correction for multiple comparisons showed that there were no significant differed between neutral words (574.7 ms ± 33.4) and positive ones ($t = -0.41$, $p = 0.68$), but RTs of negative words were significant longer than neutral ones ($t = 2.18$, $p = 0.04$).

2.2.2. ERP results

We performed a 2 (Valence: Positive, Negative) × 2 (Arousal: High, Low) × Electrode Site repeated measures ANOVA on the maximum in N170 and on average voltage data in N400, LPC time windows.

2.2.2.1. N170 (140–200 ms). As represented in Fig. 2A, we did not find a significant main effect of Valence [$F\ (1, 18) = 0.23$, $p = 0.64$, $\eta_P^2 = 0.01$] or Arousal [$F\ (1, 18) = 0.09$, $p = 0.77$, $\eta_P^2 = 0.005$]. No significant interaction effect of Valence and Arousal [$F\ (1, 18) = 0.03$, $p = 0.86$, $\eta_P^2 = 0.002$] or the three-way interaction of Valence by Arousal by Electrode [$F\ (5, 90) = 1.84$, $p = 0.18$, $\eta_P^2 = 0.09$] was observed.

Multiple comparisons (Bonferroni) of N170 amplitudes for neutral concrete words relative to positive and negative items, finding that there was no significant difference between neutral and positive words ($t = 0.20$, $p = 0.84$) or between neutral and negative words ($t = -0.50$, $p = 0.62$).

2.2.2.2. N400 (300–410 ms). For the N400 mean amplitude (see Fig. 2B), we found a significant main effect of Valence [$F\ (1, 18) = 4.61$, $p = 0.04$, $\eta_P^2 = 0.20$], the N400 amplitudes for negative words (1.32 ± 0.36 μv) were larger than for positive words (1.68 ± 0.44 μv). Neither the main effect of Arousal [$F\ (1, 18) = 0.001$, $p = 0.98$, $\eta_P^2 = 0.001$, $M_{high} = 1.50 \pm 0.37$ μv, $M_{low} = 1.51 \pm 0.43$ μv] nor interaction of Valence by Arousal was significant [$F\ (1, 18) = 0.42$, $p = 0.52$, $\eta_P^2 = 0.02$]. The three-way interaction of Valence by Arousal by Electrode was significant [$F\ (9, 162) = 4.86$, $p = 0.002$, $\eta_P^2 = 0.21$]. Simple effect analysis revealed that the N400 amplitudes were more smaller for low-arousal positive words than for low-arousal negative words at Fc4 [$F\ (1, 18) = 6.23$, $p = 0.02$], Fc6 [$F\ (1, 18) = 9.22$, $p = 0.007$], and C4 [$F\ (1, 18) = 16.80$, $p = 0.001$]; whereas the N400 amplitudes elicited by high-arousal positive words were smaller than those by high-arousal negative words at Cpz [$F\ (1, 18) = 11.78$, $p = 0.003$].

Additionally, multiple comparisons (Bonferroni) of N400 amplitudes for neutral concrete words relative to both positive and negative ones,

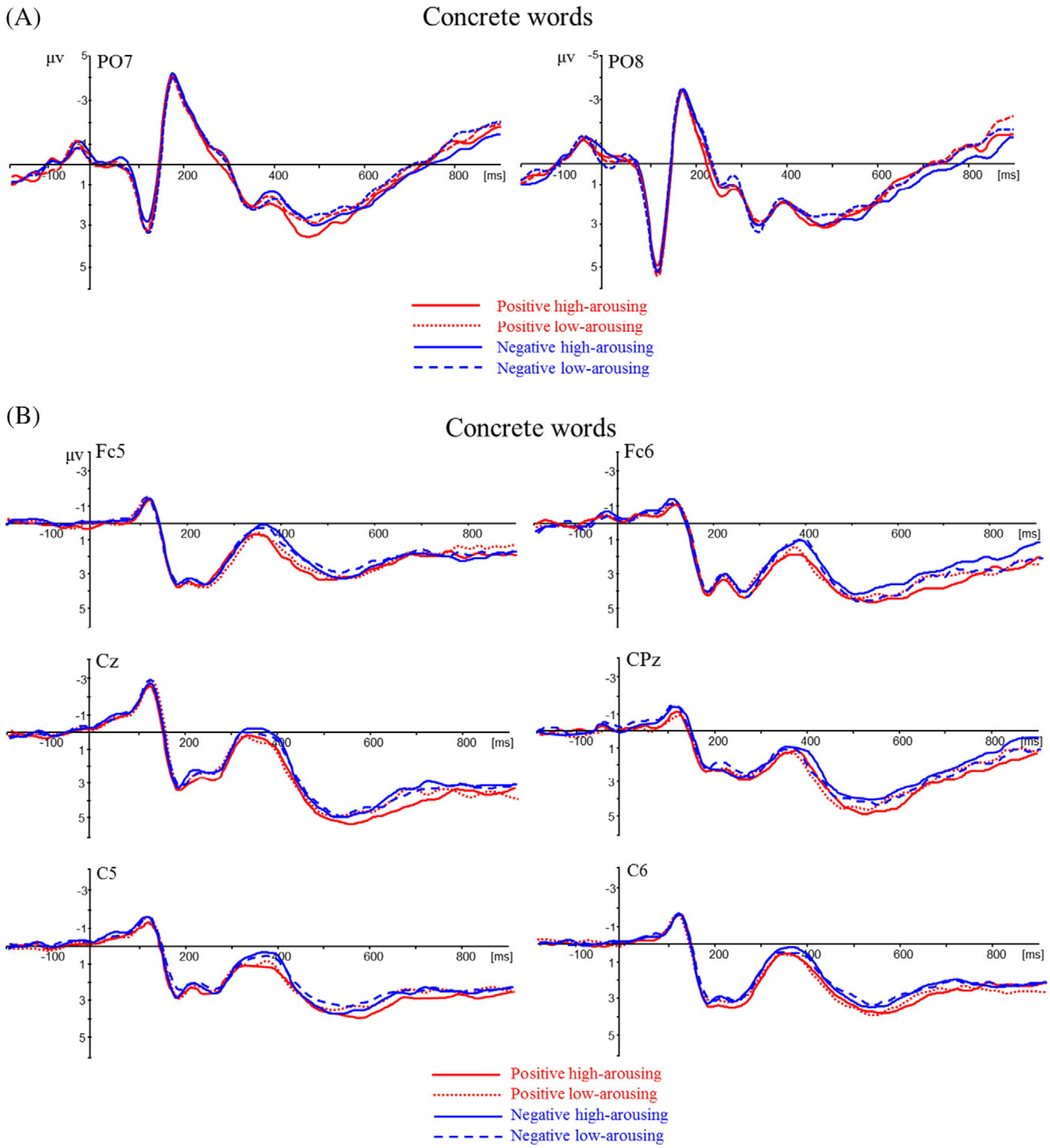

Fig. 2. (A). The N170 elicited by positive high−/low-arousing, and negative high−/low-arousing concrete words. No significant main effect of valence or arousal or the interaction of valence by arousal was observed. (B) Grand-averaged ERPs of the N400 and the LPC component evoked by positive high-arousing, positive low-arousing, negative high-arousing, and negative low-arousing concrete words. Compared to negative concrete words, positive ones were associated with reduced N400 and enhanced LPC amplitudes, whereas no arousal effects or interaction effects on the N400 and the LPC.

indicating the amplitudes for neutral words (1.33 ± 2.31 μv) were larger than those for positive (1.66 ± 2.40 μv, $t = 6.8$, $p < 0.001$) but no differ with negative words (1.31 ± 2.02 μv, $t = 1.4$, $p = 0.1$).

2.2.2.3. LPC (450–750 ms). For the LPC mean amplitude (see Fig. 2B), there was a significant main effect of Valence [F (1, 18) = 10.33, $p = 0.005$, $\eta_P^2 = 0.37$], the LPC amplitudes were larger in positive concrete words (4.77 ± 0.46 μv) than in negative ones (4.32 ± 0.37 μv). There were no significant main effect for Arousal [F (1, 18) = 0.09, $p = 0.77$, $\eta_P^2 = 0.005$, $M_{high} = 4.60 \pm 0.47$ μv, $M_{low} = 4.49 \pm 0.42$ μv] and interaction of valence by arousal [F (1, 18) = 0.21, $p = 0.66$, $\eta_P^2 = 0.01$]. Additionally, the three-way interaction of Valence by Arousal by Electrode was not significant [F (9, 162) = 4.47, $p = 0.71$, $\eta_P^2 = 0.03$].

Multiple comparisons (Bonferroni) of LPC amplitudes for neutral relative to both positive and negative words, indicating the amplitudes for neutral words (4.48 ± 3.15 μv) were smaller than those for positive words (4.77 ± 3.32 μv, $t = 4.91$, $p < 0.001$), but larger than negative words (4.32 ± 2.95 μv, $t = -2.53$, $p = 0.01$).

2.3. Discussion

In Experiment 1, the behavioral and electrophysiological results consistently showed that positive concrete words were associated with shorter response times, a reduction of N400 amplitudes, and an enhancement of LPC amplitudes compared with negative concrete words. No differences in response times or any of the ERP components were found between levels of arousal (high vs. low). This finding indicates that the effect of emotional meaning on the processing of concrete words was attributable to variations in valence (positive vs. negative) in the lexical decision task. No main effects of arousal on response times or ERPs were found, with no valence × arousal interaction.

Negative words elicited slower responses than positive words during the processing of concrete words, which was consistent with the automatic vigilance hypothesis (Estes and Verges, 2008). Our behavioral data support the hypothesis of negative delay and indicate that sustained attention to negative valence is evident for both high- and low-arousal concrete words. Attention was disengaged more slowly from negative concrete words than from other stimuli, regardless of the level of arousal.

Our ERP data suggest that the emotional valence of concrete words modulates two late ERP components. First, positive words elicited a reduction of N400 amplitudes compared with negative words. The underlying mechanisms of this N400 valence effect have been interpreted in terms of the integration of semantic information (for review, see Kutas and Federmeier, 2011) and facilitative semantic processing of positive stimuli (Kanske and Kotz, 2007). The reduction of N400 amplitudes in response to positive words relative to negative words in the present study indicated that positive information can facilitate the integration of semantic information, and this facilitatory effect occurred independently of arousal, with a slightly right-hemisphere bias. This result has been observed during silent reading (Herbert et al., 2008), lexical decision (Wang and Yao, 2012), free recall (Kiefer et al., 2007), and affective priming tasks (Yao and Wang, 2014). Second, we observed differences in LPC amplitudes between positive and negative words. Larger LPC amplitudes were induced by positive concrete words, which is consistent with previous studies that showed that positive information attracts attention more efficiently and leads to deeper processing than negative information in healthy individuals (i.e. nonclinical populations) (Herbert et al., 2008; Kissler et al., 2006; Kissler et al., 2009).

Additionally, the processing of emotional concrete words differed from the processing of neutral concrete words in Experiment 1. Compared with neutral concrete words, positive words evoked reduced N400 and enhanced LPC, and negative words elicited longer response times and reduced LPC. The larger LPC amplitude in response to neutral concrete words compared with negative concrete words is consistent with previous studies. For example, Hinojosa et al. (2009) asked participants to perform a perceptual discrimination task and found that neutral words always resulted in larger LPC amplitudes compared with negative words. Citron et al. (2013) reported similar results in a lexical decision task. No differences in N170 amplitudes were found for neutral words compared with positive and negative words. These results suggest that emotion-neutral differences in concrete word processing are reflected by response times and late word processing stages.

3. Experiment 2: effects of valence and arousal on abstract word processing

In Experiment 2, we used emotional abstract words and orthogonally manipulated the valence (negative and positive) and arousal (high and low) dimensions. The abstract words in Experiment 2 and concrete words in Experiment 1 had the same valence, arousal, familiarity, frequency, and strokes ($p > 0.05$, pairwise tests; Table 2) and differed only in the level of concreteness. Our aim in Experiment 2 was to investigate the ways in which valence and arousal affect abstract word processing. Based on differences in the affective association between concrete and abstract words, we hypothesized that the pattern of effects of valence and arousal on abstract word processing may be different compared with emotional concrete words.

Table 2
The abstract words in Experiment 2 and concrete words in Experiment 1 had the same valence, arousal, familiarity, frequency, and strokes ($p > 0.05$, pairwise tests; Table 2) and differed only in the level of concreteness.

Variables	Concrete words	Abstract words	t	p
Concreteness	6.67 ± 0.48	3.73 ± 0.56	−40.95	<0.001
Valence	4.88 ± 1.97	4.81 ± 1.95	−1.33	0.19
Arousal	5.92 ± 1.01	5.96 ± 1.04	0.68	0.50
Familiarity	5.27 ± 0.60	5.21 ± 0.68	−0.75	0.46
Frequency	11.86 ± 13.59	13.21 ± 15.44	0.65	0.52
Strokes	16.80 ± 4.40	17.35 ± 4.73	0.81	0.42

Notes. For all results, two-tailed tests were used.

3.1. Methods

3.1.1. Participants

Twenty university students (9 women), ranging in age from 17 to 26 years (mean age ± SD = 22.3 ± 2.1), participated in the experiment in return for allowance. All of them were Chinese native speakers, and all were right-handed according to the Edinburgh Handedness Inventory (mean score 84.3 ± 24, Oldfield, 1971). They had normal or corrected-to-normal vision, and no history of neurological or psychiatric disorders. Each signed written informed consent forms prior to their participation.

3.1.2. Materials

From the same word pool as in Experiment 1, we selected 20 high-arousal positive words, 20 low-arousal positive words, 20 high-arousal negative words, 20 low-arousal negative words, and 20 neutral abstract words that were matched with regard to concreteness, familiarity, frequency, and strokes. Valence ratings significantly differed across all of the valence categories [positive = 6.93 ± 0.46, negative = 2.70 ± 0.48, and neutral = 4.77 ± 0.37. $F(2, 97) = 867.24$, $p < 0.001$], and arousal ratings significantly increased from neutral (4.43 ± 0.75) over low-arousal (5.76 ± 0.27) to high-arousal words (6.93 ± 0.47) [$F(2, 97) = 185.86$, $p < 0.001$]. Post hoc analyses with the Bonferroni correction ($p < 0.05$) revealed that valence ratings were matched between high- and low-arousal, and arousal ratings were matched between positive and negative (all $ps > 0.11$). In addition, concreteness, familiarity, frequency, and strokes were matched across all five conditions (all $ps > 0.05$).Table 3 presents a summary of the descriptive statistics (means and standard deviations) for six variables and one-way ANOVAs for each factor. The 120 pseudowords were the same as those in Experiment 1. Some of the abstract words in Chinese and their English translations are presented in Appendix 2.

3.1.3. Task and procedure

The experimental task and procedure were the same as that of Experiment 1.

3.1.3.1. EEG recording and analysis. The EEG recording and analysis were identical to the one used in Experiment 1. Trials with any EEG artifacts (exceeding ±75 μv, drifts) and trials with incorrect behavioral responses were discarded. Data of one participant was excluded due to excessive EEG artifacts. The percentage of remaining trials was above 87% in all conditions.

Table 3
Descriptive statistics for selected abstract words. Means of Concreteness (1, Abstract to 9, Concrete), Valence (1, Negative to 9, Positive), Arousal (1, Calming to 9, Arousing), and Familiarity (1, Unfamiliar to 9, Familiarity) etc.

Variables	Concreteness	Valence	Arousal	Familiarity	Frequency	Strokes
High-arousal positive	3.88 ± 0.65	7.24 ± 0.41	6.79 ± 0.47	5.36 ± 0.43	15.87 ± 12.80	19.20 ± 5.23
Low-arousal positive	3.81 ± 0.47	6.62 ± 0.26	5.76 ± 0.30	5.36 ± 0.43	15.17 ± 14.60	17.45 ± 4.99
High-arousal negative	3.64 ± 0.66	2.34 ± 0.26	7.07 ± 0.45	5.02 ± 1.12	12.76 ± 14.06	16.95 ± 2.78
Low-arousal negative	3.74 ± 0.51	3.07 ± 0.38	5.76 ± 0.25	4.94 ± 0.71	9.29 ± 37.61	17.95 ± 4.43
Neutral words	3.56 ± 0.48	4.78 ± 0.37	4.43 ± 0.75	5.35 ± 0.34	13.03 ± 2.91	14.40 ± 3.87
One-way ANOVA on each factor	$F(4,95) = 1.11$, $p = 0.36$, n.s	$F(4,95) = 798.6$, $p < 0.001$	$F(4,95) = 95.1$, $p < 0.001$	$F(4,95) = 1.9$, $p = 0.12$, n.s	$F(4,95) = 0.91$, $p = 0.47$, n.s	$F(4,95) = 3.31$, $p = 0.014$

Notes. n.s. = nonsignificant. ANOVA = analysis of variance.

3.2. Results

3.2.1. Behavioral results

We analyzed the RTs for correct responses to abstract words, because the accuracy for each trial in all conditions was high (97.8%) and did not differ across conditions (range: 96.6–99.1%), thus only the correct response times were statistically analyzed. Mean correct response times (RTs) were submitted to analyses of variance (ANOVAs) with repeated measures. We excluded from the RTs above or below 2.5 standard deviations from the mean (1.73% of overall trials).

Repeated-measure ANOVA on RTs with Valence (positive vs. negative) and Arousal (high vs. low) revealed a significant main effect of Valence [$F(1, 19) = 39.07$, $p < 0.001$, $\eta_P^2 = 0.67$], reaction times to negative abstract words (620.3 ms ± 10.3) were longer than those to positive items (589.5 ms ± 8.5). There was no significant main effect of Arousal [$F(1, 19) = 0.20$, $p = 0.66$, $\eta_P^2 = 0.01$. high vs. low: 605.8 ms ± 8.4 vs. 603.8 ms ± 10.3]. Importantly, an interaction between Valence and Arousal was significant [$F(1, 19) = 7.96$, $p = 0.011$, $\eta_P^2 = 0.3$] (see Fig. 3). The simple effect analysis of the two-way interaction showed that the RTs of high-arousal positive words were significantly longer than those of low-arousal positive words [$F(1, 19) = 5.38$, $p = 0.032$, $\eta_P^2 = 0.3$], and the RTs of high-arousal negative words were significantly shorter than those of low-arousal negative words[$F(1, 19) = 6.30$, $p = 0.02$, $\eta_P^2 = 0.53$].

Multiple comparisons (Bonferroni) of RTs for neutral relative to both positive and negative abstract words, indicating there were no significant differed between neutral words and positive ones($t = 0.60$, $p = 0.56$), but the RTs of negative words were significant longer than neutral ones($t = 3.53$, $p = 0.002$).

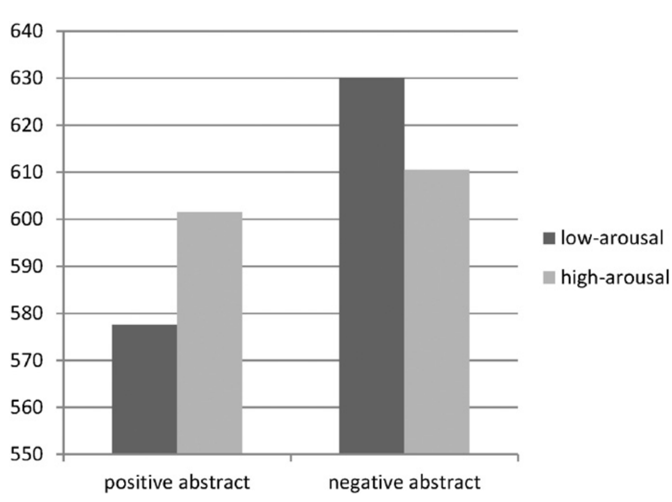

Fig. 3. Response times of positive high/low-arousal, and negative high/low-arousal abstract words in lexical decision task.

3.2.2. ERP results

3.2.2.1. N170 (140–200 ms). As represented in Fig. 4A, we found a significant main effect of Valence [$F(1, 18) = 4.50$, $p = 0.048$, $\eta_P^2 = 0.20$], the N170 amplitudes for negative abstract words (-5.50 ± 0.70 μv) were larger than for positive ones (-5.04 ± 0.70 μv). The Valence × Arousal interaction was also significant [$F(1, 18) = 5.26$, $p = 0.03$, $\eta_P^2 = 0.23$]. The simple effect analysis of the two-way interaction showed that high-arousal negative abstract words (-5.84 ± 0.73μv) evoked enhanced N170 amplitudes than for low-arousal negative ones (-5.12 ± 0.68 μv), $F(1, 18) = 8.07$, $p = 0.01$, but for positive abstract words, there was no difference between high (-5.02 ± 0.77 μv) and low arousal (-5.17 ± 0.68 μv), $F(1, 18) = 0.04$, $p = 0.84$. Moreover, no significant main effect of Arousal [$F(1, 18) = 2.45$, $p = 0.14$, $\eta_P^2 = 0.12$] or the three-way interaction of Valence by Arousal by Electrode [$F(5, 90) = 0.98$, $p = 0.40$, $\eta_P^2 = 0.05$] was observed.

Multiple comparisons (Bonferroni) of N170 amplitudes for neutral abstract words relative to both positive and negative ones, we found that neutral words (-5.24 ± 4.01 μv) elicited reduced N170 amplitudes than negative words ($t = -2.60$, $p = 0.01$), and enhanced N170 than positive words ($t = 2.13$, $p = 0.04$).

3.2.2.2. N400 (300–410 ms). For the N400 mean amplitudes (see Fig. 4B), we found a significant main effect of Valence ($F(1, 18) = 5.61$, $p = 0.03$, $\eta_P^2 = 0.24$), the N400 amplitudes for negative abstract words (1.95 ± 0.41 μv) were enhanced than for positive ones (2.26 ± 0.45 μv). There was no significant main effect for Arousal [$F(1, 18) = 0.10$, $p = 0.92$, $\eta_P^2 = 0.01$, $M_{high} = 2.12 \pm 0.41$ μv, $M_{low} = 2.09 \pm 0.46$ μv] or interaction effects between valence and arousal [$F(1, 18) = 0.03$, $p = 0.86$, $\eta_P^2 = 0.002$]. The interaction of Valence by Arousal by Electrode also failed to reach a level of significance [$F(9, 162) = 0.40$, $p = 0.84$, $\eta_P^2 = 0.02$].

Multiple comparisons (Bonferroni) of N400 amplitudes for neutral relative to both positive and negative abstract words, indicating the amplitudes for negative words were larger than those for neutral words (2.22 ± 2.4 μv), $t = 3.93$, $p < 0.001$, but there was no significant difference between positive and neutral abstract words, $t = 0.61$, $p = 0.50$.

3.2.2.3. LPC (450–750 ms). ANOVA on LPC amplitudes revealed no significant main effect for Valence [$F(1, 18) = 1.65$, $p = 0.22$, $\eta_P^2 = 0.08$. $M_{positive} = 4.86 \pm 0.33$ μv, $M_{negative} = 5.11 \pm 0.47$ μv]. However, A significant main effect for Arousal [$F(1, 18) = 7.18$, $p = 0.02$, $\eta_P^2 = 0.29$] was observed, the LPC amplitudes were larger in high-arousal abstract words (5.33 ± 0.38 μv) than in low-arousal ones (4.60 ± 0.45 μv). There was a significant interaction between Valence and Arousal [$F(1, 18) = 5.17$, $p = 0.04$, $\eta_P^2 = 0.22$]. The simple effect analysis of the two-way interaction showed that high-arousal positive abstract words (5.43 ± 0.27 μv) evoked larger LPC amplitudes than low-arousal positive ones (4.29 ± 0.46 μv) [$F(1, 18) = 10.85$, $p = 0.004$], but for negative abstract words, there was no significant difference between high-arousal words (5.23 ± 0.52 μv) and low-arousal words (4.99 ± 0.46 μv) [$F(1, 18) = 0.59$, $p = 0.45$]. The

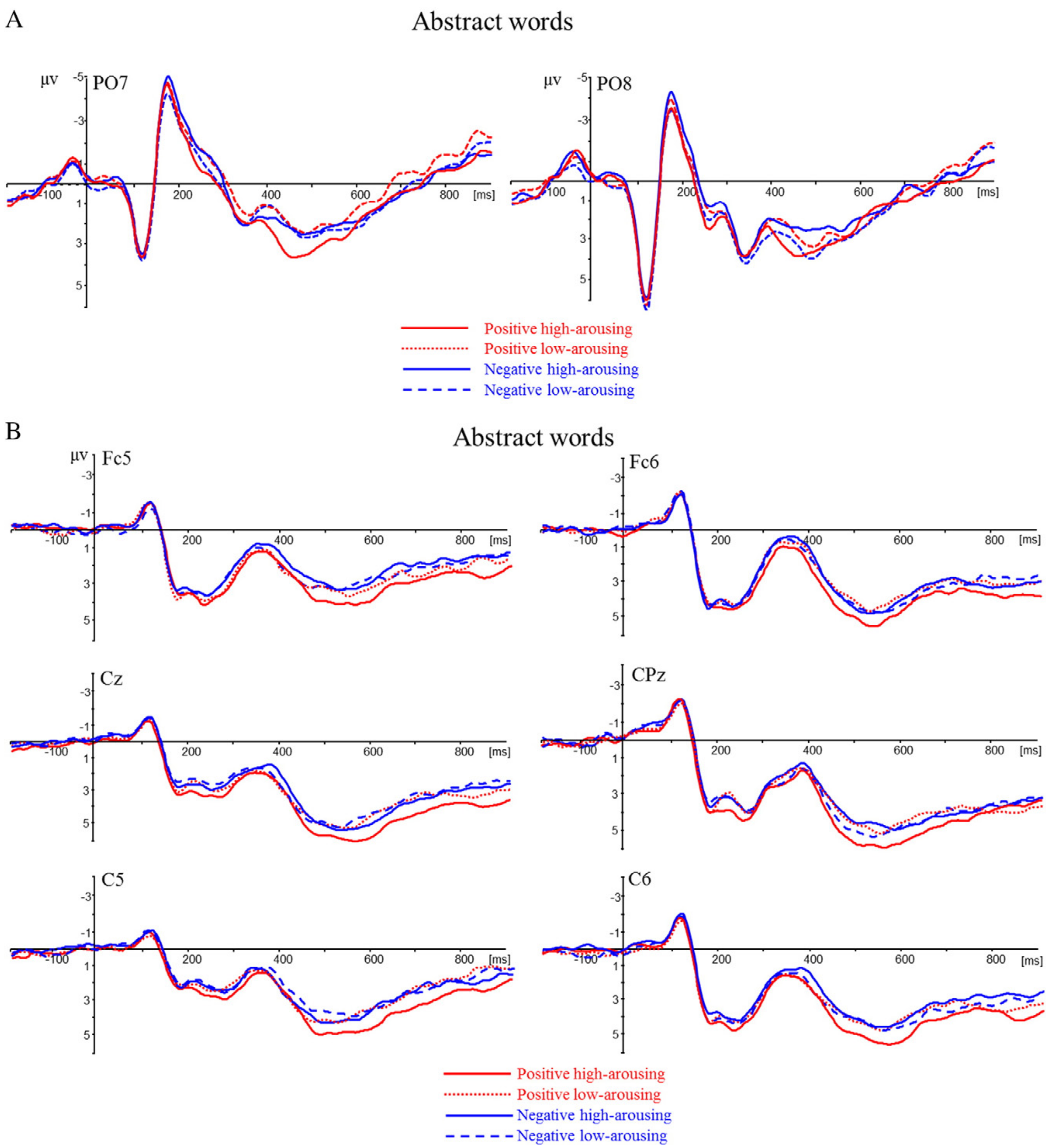

Fig. 4. (A). The N170 elicited by positive high/low-arousal, and negative high/low-arousal abstract words. An interaction effect of valence and arousal was observed, reflecting by a larger N170 for negative high-arousal than for negative low-arousal abstract words, but no differ in the N170 between positive high-arousal and positive low-arousal words. (B) Grand-averaged ERPs of the N400 and the LPC evoked positive high/low-arousing, and negative high/low-arousing abstract words. Positive abstract words evoked reduced N400 than negative ones. No arousal effect or interaction effect on the N400 component was observed. An interactive effect of valence and arousal was observed in the LPC, showing a larger LPC of positive low-arousal than of positive high-arousal abstract words, and no differ in the LPC amplitudes between negative high-arousal and negative low-arousal words.

interaction of Valence by Arousal by Electrode also was significant (F (9, 162) $= 9.04$, $p < 0.001$, $\eta_p^2 = 0.33$). Further analysis indicated that the LPC amplitudes for high-arousal positive were larger than for low-arousal ones at Fc5 [F (1, 18) $= 8.34$, $p = 0.01$], Fc6 [F (1, 18) $=$ 25.69, $p < 0.001$], C5 [F (1, 18) $= 9.84$, $p = 0.006$], and C6 [F (1, 18) $= 15.97$, $p = 0.001$], whereas the LPC amplitudes elicited by high and low arousal negative words showed no significant difference in any electrode sties (both ps > 0.05). Fig. 4B illustrates the LPC effects at a selected sample of electrodes.

Multiple comparisons (Bonferroni) of LPC amplitudes for neutral relative to both positive and negative abstract words, indicating the LPC amplitudes for neutral words (4.48 ± 3.10 μv) was smaller than either positive ($t = 3.53$, $p = 0.001$) or negative words ($t = 7.93$, $p < 0.001$).

3.3. Discussion

The major findings of Experiment 2 were that the interaction between the valence (positive vs. negative) and arousal (high vs. low) of abstract words contributed to the effects of emotion on response times and N170 and LPC components. For positive abstract words, low-arousal words elicited faster response times and a smaller LPC than high-arousal words. For negative abstract words, high-arousal words elicited faster response times and enhanced N170 compared with low-arousal words. These results indicate that both valence and arousal influence the processing of emotional abstract words, and arousal has different effects on the valence dimension.

Our behavioral findings suggest that valence and arousal affect the processing of emotional stimuli in an interactive way, which supports the multidimensional interactive model of emotion processing (Robinson et al., 2004). This model proposed that stimuli with negative valence or high arousal elicit a withdrawal tendency because they represent a possible threat. In contrast, stimuli with positive valence or low arousal elicit an approach tendency because they are perceived as safe. According to this account, low-arousal positive abstract words and high-arousal negative abstract words are processed faster because they elicit congruent tendencies (approach and withdrawal, respectively), whereas high-arousal positive stimuli and low-arousal negative stimuli are processed slower because they elicit conflicting approach/withdrawal tendencies.

An early interactive effect between negative valence and arousal was observed in the N170 component, reflected by larger N170 amplitudes for high-arousal negative abstract words than for low-arousal negative abstract words. The effect of emotion on N170 that was observed in the present study is consistent with previous studies that indicated that the emotional value of words may be detected during early stages of emotional processing (Scott et al., 2009; Frühholz et al., 2011; Zhang et al., 2014). A late interactive effect of positive valence and arousal was found in the LPC component, reflected by larger LPC amplitudes were enhanced by positive concrete words compared with negative concrete words and by high-arousal positive abstract words compared with low-arousal positive abstract words. We infer that the LPC component is more sensitive to positive information than to negative information and can easily distinguish subtle arousal differences between positive information. We also evaluated the effects of valence and arousal on the N400 component during the processing of abstract words and found that positive abstract words elicited a reduction of N400 compared with negative abstract words, indicating that positive information facilitated semantic integration that was unaffected by word concreteness and arousal.

Additionally, emotion-neutral differences in response times and ERP components were observed in Experiment 2. Compared with neutral abstract words, negative abstract words elicited slower response times and enhanced N400, indicating more difficult lexical processing of negative information. In the early and late word processing stages, the effects of emotion were evident in the N170 and LPC components in response to neutral abstract words compared with both positive and negative words.

4. General discussion

The present study investigated whether the effects of valence and arousal on emotional word processing are modulated by the level of concreteness, within embodied view of language that proposes abstract words have more affective experience information than concrete words (Vigliocco et al., 2009; Kousta et al., 2011). We employed a lexical decision task and orthogonally manipulated the valence and arousal dimensions of concrete (Experiment 1) and abstract (Experiment 2) words while taking into account other lexico-semantic variables, such as familiarity, frequency, and strokes. Our main findings indicate that the effects of valence and arousal on concrete word processing are different from abstract words, and this difference is reflected by response times and the N170 and LPC components.

Specifically, the impact of emotion on the effects of concrete words mainly resulted from their valence. Compared with negative concrete words, the processing of positive concrete words was associated with shorter response times, a reduction of N400, and an enhancement of LPC, but no differences in response times or other ERP components were found between words with high and low levels of arousal. However, an obvious interaction was observed between valence and arousal during the processing of abstract words. Low-arousal positive abstract words were associated with shorter response times and a reduction of LPC amplitudes compared with high-arousal positive words. Low-arousal negative abstract words were associated with longer response times and a reduction of N170 amplitudes compared with high-arousal negative abstract words. Regardless of concreteness and arousal, the effect of emotion on N400 was mainly attributable to the valence dimension, in which positive words reduced N400 compared with negative words. These findings demonstrate that the effects of valence and arousal on word processing are modulated by word concreteness, and this modulation occurs at the end of all cognitive processes and during the early perceptual processing stage (N170) or sustained elaborate processing stage (LPC) of emotional stimuli.

Our behavioral findings are important when considering previous studies of emotional word processing, the results of which have been contradictory. Some studies reported faster response times for negative and positive words compared with neutral words (Kousta et al., 2009; Kanske and Kotz, 2007). Other studies reported faster response times for negative words (Estes and Verges, 2008; Nasrallah et al., 2009) or faster response times for positive words (Kissler and Koessler, 2011; Hinojosa et al., 2010). This latter finding was partially replicated by our study, which also suggests that positive words are associated with shorter response times compared with negative words when the words have high levels of concreteness. Consistent with the automatic vigilance hypothesis (Estes and Verges, 2008), negative words may hold attention longer (delayed disengagement) than positive or neutral words in color naming, word naming, and lexical decision tasks, thus leading to slower responses to negative words. However, we found that arousal plays an important role in the processing of emotional words when the words are highly abstract. Specifically, low-arousal positive words and high-arousal negative words elicited shorter response times than high-arousal positive words and low-arousal negative words, respectively. This result supports the interactive model of emotion processing that was proposed by Robinson et al. (2004). These authors proposed that faster response times occur for congruent approach (positive valence and low arousal)/withdrawal (negative valence and high arousal) tendencies than for conflicting approach/withdrawal (positive valence and high arousal; negative valence and low arousal) tendencies. Our behavioral findings appear to reconcile past empirical discrepancies when the effects of concreteness on emotional word processing are taken into account.

Several ERP studies have reported that emotional connotation can enhance cortical responses during all stages of visual word processing (Kissler et al., 2006). Still debatable, however, is whether the effects of emotion on ERP components are specific to a particular category or dimension of emotion. Our work shows that the impact of emotion on the interactive effects of valence and arousal on word processing, reflected by early (N170) and late (LPC) ERP components, is modulated by word concreteness. This may explain the mixed pattern of results that is found across studies, in which word concreteness was not explicitly examined.

Our analysis of N170 (140–200 ms) revealed that the effects of emotion on N170 only occurred for abstract word processing. An enhancement of N170 amplitudes was elicited by high-arousal negative abstract words compared with low-arousal negative abstract words, whereas no significant differences were found between high- and low-arousal positive abstract words. We infer possible reason for this result is that abstract words provide much more affective associations(Vigliocco et al., 2009; Kousta et al., 2011), and negative valence and high arousal represent a possible threat and evoke a withdrawal tendency, possibly eliciting a similar response to fearful faces.

An enhancement of N170 in response to fearful faces compared with other emotional or neutral expressions has been demonstrated by numerous studies (Blau et al., 2007; Zhu et al., 2010). Additionally, the presence of the N170 effect corroborates the notion that word stimuli can also elicit N170 (Bentin et al., 1999; Rossion et al., 2003; Mahé et al., 2015), and is consistent with previous studies that indicated that the emotional value of words can be detected during early stages of emotional processing (Frühholz et al., 2011; Zhang et al., 2014). For example, Zhang et al. (2014) reported that positive and negative words elicited larger N170 amplitudes than did neutral words in a rapid serial visual presentation task. Frühholz et al. (2011) found that a larger N170 amplitude that was evoked by negative words than neutral words in the right hemisphere in a color naming task. In Scott et al. (2009), an early posterior N1 (135–180 ms post-stimulus) was found in a lexical decision task. Their ERP data suggested that high frequency negative words elicited a larger N1 amplitude than either positive or neutral words, whereas low-frequency neutral words tended to elicit a larger N1 amplitude than either positive or negative words. Although there are few empirical findings regarding the effect of emotion on N170, the aforementioned studies indicate that the N170 component can differentiate emotional words from neutral words during the early stages of emotional word processing.

We had expected to observe an effect of emotion on the LPC component. Although numerous previous ERP studies of word processing reported effects of emotion on LPC, the results have been mixed with regard to the direction of effect on LPC. In some cases, positive words show a processing advantage over negative words (Herbert et al., 2006; Herbert et al., 2008; Kissler et al., 2009; Kissler and Koessler, 2011). In other cases, negative words show an advantage over positive words (Hofmann et al., 2009; Kanske and Kotz, 2007). Still other studies show a general distinction between valenced (positive/negative) and neutral words (Hinojosa et al., 2010; Kanske and Kotz, 2007).The LPC amplitude has been thought to reflect the allocation of attentional resources, elaborate processing, and stimulus evaluation (Kissler et al., 2006). In the present study, we found that the effects on LPC are modulated by word concreteness. For concrete words, positive words generated a larger LPC amplitude than negative words, indicating that positive information captures more attention during the late stages of processing. For abstract words, high-arousal positive words elicited an enhancement of LPC compared with low-arousal positive words, whereas no significant differences were found between high- and low-arousal negative words, indicating that the LPC component is more sensitive to positive valance and can discriminate variations in the level of arousal of positive abstract words. One possible explanation for the difference in the pattern of effects of emotion on LPC between concrete and abstract words is based on the assumption that abstract words are generally associated with more affective experience information compared with concrete words (Vigliocco et al., 2009; Kousta et al., 2011), and affective experience may capture more attention and thus influence the elaborate processing of words. Our findings suggest that the effect of emotion on LPC may arise from combined contributions of positive valance, high arousal, and affective associations, which confirms that the human brain is more reactive to the valence of positive words compared with negative words (Bayer and Schacht, 2014; Zhang et al., 2014; Bayer et al., 2012; Kissler and Koessler, 2011; Herbert et al., 2008; Kissler et al., 2009) and easily perceives variations in arousal in the processing of positive abstract words (Yang et al., 2013).

Finally, we examined the N400 (300–410 ms) time window. The amplitude of the N400 component was smaller for positive words than for negative words, regardless of arousal and concreteness. This is consistent with previous findings that indicated better semantic integration of positive information compared with negative information (Kissler et al., 2006; Kanske and Kotz, 2007; Wang and Yao, 2012). For example, some studies reported that both positive tone in a free recall task (Herbert et al., 2008) and positive mood in a valence judgment task (Kiefer et al., 2007) evoked a reduction of N400 compared with negative stimuli. Generally, the N400 component indicates semantic processing, especially the integration of new semantic information into a current or long-term memory context (Kutas and Federmeier, 2011). Smaller N400 amplitudes usually indicate facilitated processing. In the present study, the reduction of N400 amplitudes in response to positive words compared with negative words confirmed that positive valence can facilitate semantic integration, and modulation of the N400 amplitude by positive valence is unaffected by the word's arousal dimension.

Altogether, our electrophysiological data largely parallel the behavioral pattern, indicating that the effect of emotional connotation on concrete word processing mainly results from variations in the valence dimension, whereas the effect of emotional meaning on abstract word processing arises from a combination of valence and arousal. These findings may impact future investigations of the processing of emotional words. Our findings support previous studies on word representation that inspired our present hypothesis, which proposes that abstract and concrete words are represented mostly by affective and sensorimotor experience information, respectively (Kousta et al., 2011; Vigliocco et al., 2009). The results of the present study also extend previous findings with regard to the interactive effects of valence and concreteness on word processing (Palazova et al., 2013; Sheikh and Titone, 2013; Kaltwasser et al., 2013; Wang and Yao, 2012; Yao and Wang, 2013, 2014). One notable finding was that the effects of valence and arousal on concrete word processing were different from abstract word processing.

The effects of valence and arousal on emotional word processing are modulated by concreteness, in which abstract words tend to be more affectively associated than concrete words, and affective associations can facilitate word processing in lexical decision tasks (Kousta et al., 2009; Kousta et al., 2011; Vigliocco et al., 2009). Furthermore, our findings indicate differences in affective experience information between concrete and abstract words, and the arousal plays differential roles in the processing of concrete and abstract words. The lack of an effect of arousal on concrete word processing may imply less affective association between sensorimotor information and arousal. According to the view of Vigliocco and colleagues, concrete words are grounded in our sensorimotor experience information, which develops from an interplay between perceptible events, actions, and physical experience in the external world. However, arousal describes the degree of excitation or calm associated with emotional experience in the internal world (Russell, 2003). Therefore, the effects of arousal on word processing may weaken and even disappear when a stimulus is both concrete and arousing. In contrast, abstract word processing can be influenced by valence, arousal, and affective experience information. Our internal affective experience may provide initial grounding to abstract words. Thus, the emotionality (i.e., valence and arousal) of abstract words has rich associations with affective experience. This property of abstract words is also consistent with previous studies that showed that abstract words more likely refer directly to emotional states (Altarriba et al., 1999) and have more emotional features than concrete words (Barsalou and Wiemer-Hastings, 2005). Moreover, the emotionality ratings of abstract words alter blood oxygenation level-dependent signals in the rostral anterior cingulate cortex, an area associated with emotional processing (Vigliocco et al., 2014).

Recently, Delaney-Busch et al. (2016) examined the ways in which valence and arousal influence different stages of word processing under different task demands. They found that the LPC effect in response to either negative or positive (vs. neutral) words might be primarily sensitive to the individual participants' perceived, subjective valence. Mueller and Kuchinke (2016) investigated individual differences in the implicit processing of emotional words in a lexical decision task, using happy, neutral, and fear-related words. They found that the different response times and error rates between happy and fear-related words were predicted by individual differences. Thus, we speculate that individual differences in sensorimotor and affective experience likely influence the effects of valence and arousal on word processing. Concrete words that denote objects or actions develop from our experience with the external world and are grounded in the same neural systems that mediate our physical experience (Dalla Volta et al., 2014). This implies that the same concrete word may have different emotional connotations for different people. For example, the word "*flower*" elicits more pleasure and an exciting feeling for people who may be in love, but it may elicit little pleasure or less of an exciting feeling for people (e.g., *florists*) who may rely on flowers for their livelihood. The word "*spider*" can also elicit more intense displeasure for some people than for others because of differences in sensorimotor experiences. In contrast, abstract words that denote emotional states are grounded in our internal affective experience and have the same neural systems of emotion processing (Vigliocco et al., 2014; Dalla Volta et al., 2014). Individual differences in affective experience may be less such differences in sensorimotor experience. For example, the words "*passion*" and "*contentmen*t" may be consistently evaluated as positive and arousing. Perhaps few people would perceive them as negative or calming. Moreover, an eye-movement measure of natural reading by Sheikh and Titone (2013) demonstrated that the effects of sensorimotor and affective experiences on word processing are modulated by individual differences in alexithymia. People who scored high on alexithymia presented a simultaneous attenuation of the influence of affective information and amplification of the influence of sensorimotor information. Apart from different embodied information that underlies concrete and abstract words, individual differences in sensorimotor and affective experiences may generally be a possible reason for the way in which the effects of valence and arousal on word processing are modulated by concreteness.

Moreover, several rating studies have investigated the relationship between concreteness and both valence and arousal. For example, Montefinese et al. (2014) evaluated a total of 1121 Italian words taken from the Affective Norms for English Words (ANEW, Bradley & Lang, 1999) and found that very abstract or very concrete words made people feel calm, whereas those in the middle of the range of concreteness increased excitement. Hinojosa et al. (2016) asked 660 native Spanish speakers to rate 875 Spanish words with regard to valence, arousal, and concreteness and found a negative correlation between valence and concreteness, and a positive correlation between arousal and concreteness. A rating study by Yao, Wu and Zhang (unpublished data) provided valence, arousal, and concreteness ratings for 1107 Chinese words and reported a linear relationship between valence and arousal when the words were highly abstract, whereas no clear relationship was found for concrete words. These studies indicate that concreteness is a crucial variable in the processing of emotional words, and modulates the contributions of valence and arousal to the effects of emotional words.

One important limitation of the present study is that high-arousal and low-arousal words were presented in separate blocks. Although high-arousal blocks and low-arousal blocks were randomized across participants in both experiments, it is possible to increase stimulus order effects. Future research should use a standard procedure to verify the findings of the current present. That is, all six stimulus categories (positive and negative words of high or low arousal, neutral words as well as pseudowords) should be presented in a block. Another limitation of this study lacks ratings of age of acquisition (AoA) of words used in both experiments. Several studies have attested to the importance of the AoA (Moors et al., 2013). For example, Brysbaert and Cortese (2011) reported that AoA explained up to 5% more variance in lexical decision times of English monosyllabic words. Moreover, it's known that abstract words are generally acquired later than concrete words (Vigliocco et al., 2009). Although concrete words in Experiment 1 and abstract words in Experiment 2 have the same valence, arousal as well as non-emotional variables (familiarity, frequency, and strokes), as an additional potentially confounding variable that also affect lexical decision latency, AoA should be taken into account for in future studies on emotional word processing in a concrete-abstract dimension.

5. Conclusions

The present study investigated whether the relative contribution of valence and arousal to the effects of emotion is modulated by word concreteness by focusing specifically on response times and the N170, N400, and LPC components of ERPs. We found that word concreteness modulated the interactive influence of valence and arousal on the effects of emotion in a lexical decision task. This modulation occurred during the early perceptual (N170) and late elaborate (LPC) stages of emotional word processing and at the end of all cognitive processes (reflected by response times). Valence contributed to the impact of emotion on the effects of concrete words, whereas valence and arousal interactively contributed to the impact of emotion on the effects of abstract words. These findings support an embodied theory of semantic representation and help clarify prior inconsistent findings regarding the ways in which valance and arousal influence different stages of word processing, at least in a lexical decision task.

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Appendix and Supplementary data

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