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The Interaction of Arousal and Valence in Affective Priming: Behavioral and Electrophysiological Evidence

Qin Zhang^{1,*}, Lingyue Kong², and Yang Jiang^{3,*}

¹Learning and Cognition Key Laboratory of Beijing, Department of Psychology, Capital Normal University, Beijing, 100048, China

²International College for Chinese Language Study, Peking University, Beijing, China

³Behavioral Science Department, University of Kentucky College of Medicine, Lexington, Kentucky 40536-0086, USA

Abstract

The affective priming paradigm has been studied extensively and applied in many fields during the past two decades. Most research thus far has focused on the valence dimension. Whether emotional arousal influences affective priming remains poorly understood. The present study demonstrates how arousal impacts evaluation of affective words using reaction time and event-related potential (ERP) measures. Eighteen younger subjects evaluated pleasantness of target words after seeing affective pictures as primes. The participants' responses were faster and/or more accurate for valence-congruent trials than for incongruent trials, particularly with high-arousal stimuli. An ERP affective priming effect (N400) also occurred mainly in high-arousing stimulus pairs. In addition, whereas valence congruency influenced both the N400 and the LPP, arousal congruency influenced only the LPP, suggesting that arousal congruency mainly modulates post-semantic processes, but valence congruency effects begin with semantic processes. Overall, our current findings indicate that the arousal level of visual images impacts both behavioral and ERP effects of affective priming.

Section—Cognitive and Behavioral Neuroscience

Keywords

Affective priming; Valence; Arousal; Evaluation decision task

1 Introduction

Affective Priming, first demonstrated by Fazio, Sanbonmatsu, Powell, and Kardes (1986), refers to the phenomenon in which the time needed to evaluate a target item as either emotionally positive or negative is shorter when prime and target pairs are affectively congruent (e.g., positive-positive) than when they are incongruent (e.g., negative-positive). The effects of affective priming (i.e., affective congruency) have been studied extensively

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*Correspondence should be sent to Qin Zhang at zhqian@cnu.edu.cn or to Yang Jiang at yjiang@uky.edu. Please send editorial correspondence to: Yang Jiang, Ph.D., Associate Professor, Department of Behavioral Science, University of Kentucky, 113 College of Medicine Office Building, Lexington, KY 40536-0086, USA, Tel: (859) 257-2122 (Office); 323-7263 (Lab), Fax: (859) 323-5350.

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(e.g., Hermans et al., 1994; Klauer et al., 1997; Vermeulen et al., 2006; Frings & Wentura, 2008), suggesting that attitudes on events or objects may be automatically activated and then direct behavior and judgment (Fazio, 2001; Klauer & Musch, 2003).

Different accounts have been proposed regarding the mechanisms that underlie affective priming (see Fazio, 2001; Klauer & Musch, 2003 for reviews). One account focuses on an analogy between affective priming and semantic priming and explains affective priming with a pre-activation of affectively-congruent targets via spreading activation in a semantic network (e.g., Bargh et al., 1992; Fazio et al., 1986). Another account focuses on the role of the response-related process in the affective priming and proposes that primes automatically activate the corresponding correct evaluative response in affectively-congruent trials, but the incorrect response in incongruent trials (e.g., De Houwer et al., 2002; Klinger et al., 2000). Recently, some researchers argued a combined view that both semantic and response-related processes might contribute to effects of affective congruency in the evaluative decision task (Klauer et al., 2005; Eder et al., 2012).

In contrast to behavioral measures that can be obtained only after a stimulus has been processed, event-related potentials (ERPs) provide an online measure of mental processes with a temporal resolution in the millisecond range. Moreover, certain components of the ERP are known to be related to discrete subprocesses. For example, the N400, an ERP component studied in this context, relates to semantic processing (e.g., Chwilla et al., 1995; Holcomb & Neville, 1990). Zhang et al. (2006) used an evaluative decision task to examine neural mechanisms underlying visual affective priming. They found that affectively-incongruent word-word pairs elicited a larger N400 than affectively-congruent trials. Zhang et al. (2010) and Eder et al. (2012) similarly showed an N400 affective priming effect. The authors associated this N400 priming effect with detection of affective conflict and/or integration of affective information (Zhang et al., 2010). The second ERP component investigated by some affective priming research is LPP (late positive potential), also termed the P3 (Werheid et al., 2005; Zhang et al., 2010). Werheid et al. (2005) used emotional face pairs to examine the ERP correlates of affective priming during participant decisions about emotional expression. They found an enhancement of the LPP following affectively-incongruent trials at parietal sites between 500 and 600 ms. Using picture-word pairs and an evaluative decision task, Zhang et al. (2010) also showed LPP priming effects associated with selective attention to emotional conflict. LRP (lateralized readiness potential) is another ERP component used to examine the role of the response system in the affective priming effect (Bartholow et al., 2009; Eder et al., 2012). In addition, Bartholow et al. (2009) associated their fronto-central N2 component with conflict monitoring and thought that conflict occurred when the response activated by the prime differed from the target response, irrespective of the affective congruency of the prime and target. These data support the hypothesis that the response-related process influences the affective congruency effects in the evaluative decision task.

On the whole, the literature suggests that effects of affective congruency in the evaluative decision task might stem from several subprocesses such as semantic and response-related subprocesses. However, an unresolved problem about affect priming remains. The vast majority of affective priming research has focused only on the valence dimension. In these studies, the “effect of affective congruency” is in fact the effect of valence congruency. However, human affective responses are determined by at least two dimensions: valence and arousal (e.g., Lang et al., 1993; Kissler et al., 2006), and these two dimensions are often correlated (Lewis et al., 2007; Robinson et al., 2004). Highly-arousing stimuli usually receive valence ratings as either highly pleasant or highly unpleasant; less-arousing material is generally regarded as more neutral with regard to valence (Kissler et al., 2006). It is important to explore the interaction of arousal and valence in the affective priming

paradigm. However, no research thus far has systematically manipulated arousal dimensions in a classic valence priming experiment. Theories of affective priming effects not involving the arousal dimension are also incomplete. Thus, the first objective of the current study is to determine whether and how the effects of valence congruency were influenced by the arousal dimension of primes and targets in the affective priming paradigm by using both behavioral and ERP measures. Two ERP components are of primary interest in this research. The first is the N400, which is hypothesized to index detection of affective conflict and/or difficulty of information integration, and the second is LPP which is associated with attention resource allocation during evaluation (Zhang et al., 2010). We hypothesized that arousal dimension affects behavioral responses [i.e., reaction time (RT) and error rate] and ERP responses (i.e., N400 and LPP) associated with valence congruency.

Recently, using ERP and RT measurements, Hinojosa, Carretié, Méndez-Bértolo, Míguez, and Pozo (2009) investigated whether the priming effects found for valence in the affective priming paradigm could be extended to target words that are primed in arousal. They manipulated arousal congruency of positive prime and target (congruent vs. incongruent) and target type (high- vs. low-arousing words) and asked participants to decide whether each target name was arousing or relaxing. Their results showed that the processing of high-arousing targets was facilitated by a previous exposure to a congruent arousal prime (i.e., high-arousing prime), as reflected by the reduction in the amplitude of a late positive ERP component thought to reflect attention and memory processes. However, no differences between low-arousing congruent (i.e., both prime and target were low-arousing words) and incongruent targets (i.e., target was low-arousing, but prime was high-arousing) were observed. These results diverge from the findings of previous studies that investigated the contributions of valence to affective priming, and they contribute to an understanding of the role of arousal in affective priming. However, Hinojosa et al. (2009) didn't include other kinds of prime-target pairs such as negative prime-target pairs or positive prime-negative target pairs in their experiment. Therefore, using both behavioral and ERP measures, the second purpose of the current study is to further examine effects of arousal congruency in the affective priming paradigm by employing four kinds of prime-target pairs including positive prime-target pairs, negative prime-target pairs, positive prime-negative target pairs, and negative prime-positive target pairs.

2 Results

The first purpose of the present study was to examine whether and how the arousal level of primes or targets would impact the effect of valence congruency between primes and targets. We also analyzed effects of arousal congruency in the affective priming paradigm.

2.1 Behavioral results

A three-way repeated measures ANOVA, 2 valence congruency for prime-target pairs (congruent or incongruent) $\times$ 2 arousal levels for primes (high or low) $\times$ 2 arousal levels for targets (high or low), was conducted for RT data. Error trials or responses outside a 200–1500 ms range were excluded from mean RT calculations (about 5% of trials).

Analysis of RTs revealed significant main effects of valence congruency [$F(1, 17) = 16.77$, $p = 0.001$], arousal level of primes [$F(1, 17) = 10.54$, $p = 0.005$], and arousal level of targets [$F(1, 17) = 4.95$, $p = 0.04$]. The interaction of valence congruency $\times$ arousal level of primes is significant [$F(1, 17) = 28.17$, $p < 0.001$]. Simple effects analyses indicated significant effects of valence congruency in the high-arousing priming condition [$F(1, 17) = 33.71$, $p < 0.001$], but not in the low-arousing priming condition ($p > 0.05$) (see Figure 1). That is, when prime pictures were high-arousing, participants' responses to valence-congruent trials were faster than those to valence-incongruent trials (for high-arousing prime-target pairs,

598 ms vs. 622 ms, $F(1,17) = 21.83$, $p < 0.001$; for high-arousing prime and low-arousing target pairs, 606 ms vs. 630 ms, $F(1,17) = 20.41$, $p < 0.001$). Simple effects analyses also indicated that participants' responses to targets from valence-incongruent pairs were faster in the low-arousing priming condition than those in the high-arousing priming condition [$F(1, 17) = 31.53$, $p < 0.001$]. The interaction between arousal level of primes and arousal level of targets was significant [$F(1, 17) = 4.82$, $p = 0.04$]. Simple effects analyses indicated that participants' responses to high-arousing targets were faster than those to low-arousing target when primes were high-arousing [$F(1, 17) = 11.35$, $p = 0.004$]. Participants' responses to low-arousing targets were faster in the low-arousing priming condition than those in the high-arousing priming condition [$F(1, 17) = 14.66$, $p = 0.001$]. That is, Participants' responses to arousal-congruent trials (i.e., high-arousing prime-target pairs and low-arousing prime-target pairs) were faster than those to arousal-incongruent trials (i.e., high-arousing prime and low-arousing target pairs and low-arousing prime and high-arousing target pairs). Arousal congruency influenced RT.

A similar ANOVA was performed for the arcsine of the square root of error rates. A significant main effect was found for valence congruency [$F(1, 17) = 21.45$, $p < 0.001$]. The interaction of valence congruency and arousal level of primes was significant [$F(1, 17) = 11.79$, $p = 0.003$]. Simple effects analyses indicated significant effects of valence congruency for the high-arousing prime condition [$F(1, 17) = 21.94$, $p < 0.001$] and the low-arousing prime condition [$F(1, 17) = 7.45$, $p = 0.014$]. Further analyses showed that participants' responses to valence-congruent trials were more accurate than those to valence-incongruent trials for the high-arousing prime-target pairs [error rates: 3.38% vs. 5.92%, $F(1, 17) = 12.05$, $p = 0.003$], the high-arousing prime and low-arousing target pairs [error rates: 3.94% vs. 7.13%, $F(1, 17) = 18.32$, $p = 0.001$], and the low-arousing prime and high-arousing target pairs [error rates: 4.91% vs. 6.44%, $F(1, 17) = 10.24$, $p = 0.005$], but not for the low-arousing prime-target pairs ($p > 0.05$) (see Figure 1). Simple effects analyses also indicated that participants' responses to targets from valence-incongruent pairs were more accurate in the low-arousing priming condition than those in the high-arousing priming condition [$F(1, 17) = 12.7$, $p = 0.002$]. The interaction between arousal level of primes and arousal level of targets was significant [$F(1, 17) = 24.63$, $p < 0.001$]. Simple effects analyses indicated that participants' responses to low-arousing targets were more accurate than those to high-arousing targets when primes were low-arousing [$F(1, 17) = 20.15$, $p < 0.001$]. Participants' responses to low-arousing targets were more accurate in the low-arousing priming condition than those in the high-arousing priming condition [$F(1, 17) = 5.72$, $p = 0.029$]. Moreover, participants' responses to high-arousing targets were more accurate in the high-arousing priming condition than those in the low-arousing priming condition [$F(1, 17) = 17.41$, $p = 0.001$]. That is, participants' responses to arousal-congruent trials (i.e., high-arousing prime-target pairs and low-arousing prime-target pairs) were more accurate than those to arousal-incongruent trials (i.e., high-arousing prime and low-arousing target pairs and low-arousing prime and high-arousing target pairs). Arousal congruency influenced error rates.

2.2 ERP results

Five-way repeated measures ANOVAs, 2 valence congruency (congruent, incongruent) $\times$ 2 arousal levels of primes (high, low) $\times$ 2 arousal levels of targets (high, low) $\times$ 3 coronal sites (frontal, central, and parietal) $\times$ 3 sagittal sites (left, middle, and right), were conducted in two latency intervals (300-450 and 500-700 ms post target onset). The significant main effects and interactions were showed in Table 1.

N400 effects (300—450 ms)—This time interval corresponded to a negative-going wave (N400) that peaked around 300-400 ms (see Figure 2). The analyses of N400 showed some

significant interactions of valence congruency and other factors (see Table 1). Simple effects analyses indicated that the N400 evoked by valence-incongruent trials was more negative than that of congruent trials at parietal sites of midline [$F(1, 17) = 6.89, p = 0.018$] and right hemisphere [$F(1, 17) = 10.91, p = 0.004$] when primes were high-arousing. Also, the N400 effects of valence-congruency occurred only for high-arousing targets at left hemisphere [$F(1, 17) = 4.54, p = 0.048$], midline [$F(1, 17) = 7.63, p = 0.013$], and right hemisphere [$F(1, 17) = 7.01, p = 0.017$] (see Figure 3). In addition, effect of target arousal level occurred in the midline for valence-congruent trials [$F(1, 17) = 4.58, p = 0.047$]. The N400 evoked by low-arousing targets was more negative than that of high-arousing targets. Effect of prime arousal level occurred at central site of left hemisphere for valence-incongruent trials [$F(1, 17) = 5.86, p = 0.027$]. N400 was more negative in the low-arousing priming condition than in the high-arousing priming condition.

LPP effects (500–700 ms)—This time interval encompassed a late positive-going ERP potential (LPP) peaking around 600 ms. The analyses of this epoch showed a significant main effect of valence congruency and several significant interactions (see Table 1). Valence-incongruent trials were associated with larger LPP than valence-congruent trials (see Figure 2). Tests for simple effects indicated that LPP effects of valence congruency occurred at left hemisphere for high-arousing targets [$F(1, 17) = 8.05, p = 0.011$], as well as left hemisphere [$F(1, 17) = 7.76, p = 0.013$], middle [$F(1, 17) = 22.39, p < 0.001$], and right hemisphere [$F(1, 17) = 6.11, p = 0.024$] for low-arousing targets (see Figure 3). Further analysis showed that there was not significant effect of valence congruency for low-arousal prime and high-arousal target pairs and effects of valence congruency were significant only at F3 and P3 ($ps < 0.05$) for high-arousal prime and high-arousal target pairs. For high-arousal prime and low-arousal target pairs, effects of valence congruency were significant at F3, Fz, F4, C3, and Cz ($ps < 0.05$). For low-arousal prime and low-arousal target pairs, effects of valence congruency were significant at Fz, Cz, C4, P3, Pz, and P4 ($ps < 0.05$).

2.3 Tests for effects of arousal congruency in four kinds of prime-target pairs

In order to further explore effects of arousal congruency, we conducted 2 arousal congruency levels for prime-target pairs (congruent or incongruent) $\times$ 2 arousal levels for targets (high or low) in four kinds of prime-target pairs.

Table 2 presents the mean RTs to target stimuli and response error rates for each condition. The two-way repeated measures ANOVAs were conducted for RTs and the arcsine of the square root of error rates in four kinds of prime-target pairs. In addition, the four-factor repeated measures ANOVAs, 2 arousal congruency (congruent, incongruent) $\times$ 2 arousal levels of targets (high, low) $\times$ 3 coronal sites (frontal, central, and parietal) $\times$ 3 sagittal sites (left, middle, and right), were conducted in two latency intervals (300–400 and 500–600 ms post target onset) for mean amplitudes in four types of prime-target pairs. The 300–400 ms time interval corresponded to the N400. The 500–600 ms time interval corresponded to the LPP. The significant main effects and interactions are shown in Table 3.

2.3.1 Positive prime-target pairs—Analysis of RTs found no significant main effect or interaction. Analysis of error rate data showed a significant main effect of target arousal level [$F(1, 17) = 9.92, p = 0.006$]. Participants' responses to high-arousing targets were more accurate than those to low-arousing targets.

Although analysis of the N400 showed interactions of arousal congruency, arousal level of targets, and location factors (see Table 3), tests for simple effects found no significant effects of arousal congruency or arousal level of targets. The ANOVA analysis of LPP found a significant three-way interaction of arousal congruency, arousal level of targets, and

sagittal sites. Tests for simple effects found that the significant effect of arousal congruency occurred at middle sites for low-arousing targets [$F(1, 17) = 4.86, p = 0.042$]. Arousal-incongruent trials were associated with larger LPP than arousal-congruent trials (see Figure 4).

2.3.2 Negative prime-target pairs—Analysis of RTs found no significant effects, but analysis of error rate data showed a significant main effect of target arousal level [$F(1, 17) = 10.65, p = 0.005$] and a significant interaction between arousal congruency and arousal level of targets [$F(1, 17) = 5.34, p = 0.034$]. Simple effects analyses indicated that participants' responses to arousal-congruent trials were more accurate than those to arousal-incongruent trials when targets were high-arousing [$F(1, 17) = 10.20, p < 0.001$]. Participants' responses to low-arousing targets were more accurate than those to high-arousing targets for the arousal-incongruent pairs [$F(1, 17) = 12.58, p = 0.002$].

Although analysis of N400 showed a significant interaction of arousal congruency, arousal level of targets, and coronal sites, tests for simple effects found no significant effects of arousal congruency or arousal level of targets. The ANOVA analysis and simple effects tests for LPP also didn't show any significant effects of arousal congruency or arousal level of targets.

2.3.3 Positive prime-negative target pairs—Analysis of RTs revealed a significant interaction between the arousal congruency and arousal level of targets [$F(1, 17) = 6.96, p = 0.017$]. Simple effects analyses indicated participants' responses to arousal-congruent trials were faster than those to arousal-incongruent trials when targets were low-arousing [$F(1, 17) = 11.75, p = 0.003$]. Participants' responses to low-arousing targets were faster than those to high-arousing targets for the arousal-congruent pairs [$F(1, 17) = 6.44, p = 0.021$]. A similar ANOVA for error rate data showed that participants' responses to arousal-congruent trials were more accurate than those to arousal-incongruent trials [$F(1, 17) = 14.89, p = 0.001$].

Analysis of N400 didn't reveal any significant effects of arousal congruency or arousal level of targets. In the 500-600 ms time window, the ANOVA analysis indicated a significant interaction of arousal congruency, arousal level of targets, and coronal sites. Simple effects analyses showed significant effects of arousal congruency occurred at frontal [$F(1, 17) = 6.82, p = 0.018$] and central sites [$F(1, 17) = 4.64, p = 0.046$] for low-arousing targets. Arousal-incongruent trials were associated with larger LPP than arousal-congruent trials (see Figure 4).

2.3.4 Negative prime-positive target pairs—Analysis of RTs revealed a significant main effect of target arousal level [$F(1, 17) = 6.49, p = 0.021$] and a significant interaction between arousal congruency and arousal level of targets [$F(1, 17) = 17.97, p = 0.001$]. Simple effects analyses indicated that participants' responses to arousal-congruent trials were faster than those to arousal-incongruent trials when targets were low-arousing [$F(1, 17) = 20.61, p < 0.001$]. When targets were high-arousing, participants' responses to arousal-incongruent trials were faster than those to arousal-congruent trials [$F(1, 17) = 5.44, p = 0.032$]. Participants' responses to high-arousing targets were faster than those to low-arousing targets for the arousal-incongruent pairs [$F(1, 17) = 26.09, p < 0.001$]. Analysis of error rate data showed significant main effects of arousal congruency [$F(1, 17) = 16.67, p = 0.001$] and arousal level of targets [$F(1, 17) = 8.39, p = 0.01$]. The interaction between arousal level of targets and arousal congruency was also significant [$F(1, 17) = 41.49, p < 0.001$]. Simple effects analyses indicated participants' responses to arousal-congruent trials were more accurate than those to arousal-incongruent trials when targets were low-arousing [$F(1, 17) = 37.19, p < 0.001$]. When targets were high-arousing, participants' responses to

arousal-incongruent trials were more accurate than those to arousal-congruent trials [$F(1, 17) = 8.74, p = 0.009$]. Participants' responses to low-arousing targets were more accurate than those to high-arousing targets for the arousal-congruent pairs [$F(1, 17) = 31.4, p < 0.001$].

Analysis of N400 revealed a significant four-factor interaction (see Table 3). Simple effects analyses indicated significant effects of arousal level of targets occurred at parietal site of left hemisphere for arousal-congruent trials [$F(1, 17) = 5.05, p = 0.038$] and at central site of left hemisphere for arousal-incongruent trials [$F(1, 17) = 6.25, p = 0.023$]. N400 of high-arousing targets were more negative than that of low-arousing targets. The analysis of LPP also showed a significant four-factor interaction. Simple effects analyses showed significant effects of arousal congruency occurred at central site of right hemisphere [$F(1, 17) = 5.68, p = 0.029$], parietal site of left hemisphere [$F(1, 17) = 8.23, p = 0.011$], and parietal site of right hemisphere [$F(1, 17) = 7.42, p = 0.014$] for low-arousing targets. Arousal-congruent trials were associated with larger LPP than arousal-incongruent trials (see Figure 4).

3 Discussion

Using an evaluative decision task, the current study investigated the contribution of arousal and valence to affective priming effects by behavioral and ERP measurements.

3.1 Influence of arousal level on valence congruency effects

Consistent with some previous affective priming studies varying valence dimension only (e.g., Fazio et al., 1986; Hermans et al., 1994; Zhang et al., 2006, 2010), our behavioral results indicated significant valence congruency effects. Responses to valence-congruent stimulus pairs were significantly faster and more accurate than responses to incongruent pairs. Similar to our previous study (Zhang et al., 2010), ERP results showed that valence-incongruent pairs were associated with more negative N400 (300-450 ms) and more positive LPP (500-700 ms) than valence-congruent pairs.

The new finding here is that the arousal level of stimuli showed a significant influence on automatic processing of valence congruency from both behavioral and ERP results. Behavioral results (RT and error rate data) consistently showed that participants' responses to valence-congruent trials were faster and more accurate than those to valence-incongruent trials when prime pictures were high-arousing. In addition, error rate results revealed that valence-congruent effects also occurred in the low-arousing prime and high-arousing target pairs. Both results support the hypothesis that arousal dimensions have influence on the evaluative decision task. To sum up, the current behavioral results revealed significant affective priming effects when at least one of two stimuli was highly arousing, especially when prime was highly arousing.

Moreover, our N400 data also supports the idea that arousal dimension influenced the affective priming effects when comparing valence-congruent pairs to incongruent pairs. Specifically, effect of valence congruency for N400 amplitude interacted with arousal level of targets. That is, during 300-450 ms after target onset, ERP evoked by valence-incongruent trials was more negative than that of valence-congruent trials mainly for high-arousing word targets. Valence-congruent effect for N400 amplitude also interacted with arousal level of primes. Parietal N400 priming effect occurred in the high-arousing priming condition. Figures 1, 2, and 3 indicated that the most consistent effects of valence congruency for RTs, error rate data, and N400 amplitude occurred in the high-arousing prime-target pairs. High-arousing prime and low-arousing target pairs and low-arousing prime and high-arousing target pairs also showed certain effects of valence congruency for

RTs, error rate data, or N400 amplitude. For low-arousing prime-target pairs, however, RTs, error rate, and N400 data did not show significant effect of valence congruency.

Our behavioral priming effects mainly interacted with prime arousal. A possible explanation is that high-arousing primes usually have stronger object-evaluation association and thus produce a more obvious evaluative or response bias than low-arousing primes. The evaluative or response bias then facilitates or inhibits the selection of the correct responses during the evaluation for targets and therefore produces a significant affective priming effect in RT and error rate data. In addition, error rate results indicated that the effect of valence congruency also occurred in the low-arousing prime and high-arousing target pairs, implying that arousal dimension of targets may have similar influence in the evaluative decision task. However, this kind of influence was not as strong as the arousal dimension of primes.

The N400 effect in affective priming is generated from centro-posterior locations overlapped temporally and spatially with the classic N400 component showed by the semantic priming research (e.g., Kutas & Van Petten, 1988). It has been suggested that the N400 reflects a process in which semantic information is integrated with preceding context (e.g., Brown & Hagoort, 1993; Holcomb, 1993). Furthermore, affective priming effects and conceptual priming effects were found to affect some common brain regions (e.g., the left middle/superior temporal gyrus), suggesting that the two types of priming might share a general semantic processing mechanism (Liu et al., 2010). Therefore, the N400 affective priming effect reported in the current study also reflected a violation of semantic expectations and difficulty with context integration. That is, the more negative the N400, the more conflicted the information integration processes might be. The next question is why N400 effects for high-arousing stimuli were more significant in the current study. A number of studies have reported that emotional arousal is relevant for attention capture and cognitive resource allocation during information processing (e.g., Herbert et al., 2008; Kissler et al., 2007; Lang et al., 1993; Schupp et al., 2003; 2007). Following this line of thinking, one likely interpretation is that high-arousing stimuli easily capture a viewer's attention and increase the cognitive resource during the stimulus processing, which may amplify the semantic processing of target words. Therefore, higher arousal leads to higher sensitivity to valence congruency between prime and target such that more effort is needed to overcome incongruent feelings and integrate semantic information when target words are presented in incongruent stimuli pairs. This explanation is consistent with the view that emotional arousal alters the allocation of attentional resources and heightens sensitivity to environmental cues related to the current emotional state induced by the provoking stimulus (Niedenthal & Kitayama, 1994; Lane et al., 1999).

In contrast to findings on RT, error rate, and N400, during the 500-700 ms following onset of the target (LPP), a significant valence congruency effect was observed irrespective of arousal levels of primes and targets. LPP, a late positive potential (which may be part of P3), has been linked to stimulus categorization, affect processing, working memory updating, encoding, and retrieval (e.g., Crites et al., 1995; Delplanque et al., 2006; Donchin & Coles, 1988; Paller et al., 1987; Guo et al. 2008; Zhang, et al., 2010; Schupp et al., 2000). In the present study, the LPP differences may reflect the increased attention engagement evoked by valence-incongruent trials during stimulus valence categorization. Zhang et al. (2010) also reported that valence-incongruent words elicited larger LPP than valence-congruent words in the interval 550–700 ms after the target onset. However, Bartholow et al. (2009) reported no such LPP effect. Zhang et al. (2006) used word-word pairs and ERP measurement to examine neural mechanisms underlying visual affective priming. We also reported that affectively incongruent pairs elicited a larger N400 than affectively congruent trials, but no affective priming effect in LPP was found. We suspect that one possible reason is that these

studies used different types of prime stimuli. That is, both the current study and Zhang et al. (2010) used pictures as prime stimuli but Bartholow et al. (2009) used words as primes. Affective pictures may evoke more evaluative information than affective words. The participants reported stronger emotional feelings when seeing pictures than when seeing words.

Note that that LPP is sensitive to emotional arousal of stimuli when ERPs are evoked by high- or low-arousing stimuli directly (e.g., Delplanque et al., 2006; Keil et al., 2002). However, what was measured in the current study was the influence of affective prime stimulus on the target stimulus. In the affective priming experiment, the affective congruency between prime and target items might have a larger influence on stimuli categorization reflected by LPP than arousal level of stimuli.

As mentioned above, the N400 effect reflected semantic integration processing and conflict detection, while the LPP is linked to stimulus categorization after semantic processing. Accordingly, our ERP results indicated that both semantic processing and stimulus categorization processes contributed to the affective priming effect. Meanwhile, our results also suggest that the semantic processing is sensitive to arousal level of stimuli, while this is not the case for stimulus valence categorization in the affective priming paradigm. Convergent evidence from both behavioral and ERP results indicate that affective priming is a robust effect involving several underlying mechanisms. The current findings suggest that arousal level of stimuli impact both semantic processing and response-related processes. Future research will further examine the contribution of arousal to automatic processing and responses.

3.2 Effects of arousal congruency

Another purpose of the current study was to test effects of arousal congruency in the affective priming paradigm. Hinojosa et al. (2009) first manipulated arousal congruency of positive primes and targets (arousal congruent vs. incongruent) to investigate whether an arousal congruency effect similar to the valence congruency effect could be observed. Their results showed significant effect of arousal congruency in a late positive ERP component (450-550 ms) only for high-arousing targets. The current study added three other types of prime-target pairs to replicate and extend arousal congruency effect found by Hinojosa et al. (2009).

On the whole, the present research showed significant interaction between prime arousal and target arousal in behavioral data. Participants' responses to arousal-congruent trials (i.e., high-arousing prime-target pairs, low-arousing prime-target pairs) were faster and more accurate than those to arousal-incongruent trials (i.e., high-arousing prime and low-arousing target pairs, low-arousing prime and high-arousing target pairs). However, there was not interaction between prime arousal and target arousal for ERP data during 300-450 ms (N400) and 500-700 ms (LPP) following onset of the target.

In order to better understand the effect of arousal congruency, the present research further tested this effect in four kinds of prime-target pairs respectively. The results showed weak effects of arousal congruency for positive prime-target pairs and negative prime-target pairs (i.e., valence-congruent pairs). Specifically, for positive prime-target pairs, significant effect of arousal congruency occurred only in LPP (the 500-600 ms after onset of the target). Arousal-incongruent trials were associated with larger LPP than arousal-congruent trials in the midline when targets were low-arousing. For negative prime-target pairs, a significant effect of arousal congruency occurred only for error rate data that showed that participants' responses to arousal-congruent trials were more accurate than those to arousal-incongruent trials when targets were high-arousing. We think that the weak effects of arousal congruency

mainly arise from post-semantic processes such as the evaluative process. In addition, for positive prime-target pairs, our research showed a significant effect of arousal congruency in LPP only for low-arousing targets. This result slightly differs from that of Hinojosa et al. (2009), which showed a significant effect of arousal congruency in a late positive ERP component only for high-arousing targets. The reasons possibly included that these two studies used different prime stimuli (picture primes vs. word primes) and categorization tasks (arousal categorization task vs. valence categorization task).

Unlike valence-congruent pairs, the effects of arousal congruency were found for positive prime-negative target pairs and negative prime-positive target pairs (i.e., valence-incongruent pairs). For positive prime and negative target pairs, our behavioral results indicated that participants' responses to arousal-congruent stimulus pairs were more accurate than those to incongruent pairs, but the effect of arousal congruency in RT was found only for low-arousing targets. Meantime, our ERP results showed that arousal-incongruent trials were associated with larger LPP (500-600 ms) than arousal-congruent trials at frontal and central electrode sites for low-arousing targets. We think that incongruent valence in positive prime and negative target pairs would interfere with stimuli categorization for targets during valence categorization. Especially when primes were high-arousing, this interference may be stronger. Thus, for low-arousing negative targets, participants responded more slowly and inaccurately when positive primes were high-arousing (i.e., arousal-incongruent trials) than when primes were low-arousing (i.e., arousal-congruent trials). Moreover, the enhanced attention engagement evoked by incongruent trials during stimulus valence categorization induced LPP effect.

For negative prime and positive target pairs, our behavioral results indicated that participants' responses to arousal-congruent stimulus pairs were significantly faster and more accurate than those to incongruent pairs for low-arousing targets. However, for high-arousing targets, participants' responses to arousal-incongruent stimulus pairs were significantly faster and more accurate than those to congruent pairs. According to the explanation above, incongruent valence in negative prime and positive target pairs would also interfere with stimuli categorization for targets during valence categorization, and when primes were high-arousing, this interference would be stronger. Thus, for low-arousing positive targets, participants responded more slowly and inaccurately when negative primes were high-arousing (i.e., arousal-incongruent trials) than when primes were low-arousing (i.e., arousal-congruent trials). However, for high-arousing positive targets, because primes in arousal-congruent trials were high-arousing, participants' responses to arousal-congruent trials were more slow and inaccurate than those to arousal-incongruent trials. That is, for negative prime and positive target pairs, arousal level of primes may be more important than arousal congruency of prime and target. Our ERP results showed that arousal-congruent trials were associated with larger LPP than arousal-incongruent trials at posterior electrode sites for low-arousing targets. This LPP pattern was surprising.

In conclusion, the current study provided behavioral and electrophysiological evidences that arousal level of stimuli modulates effects of affective priming. Responses to valence-congruent stimulus pairs were significantly faster and/or more accurate than those to incongruent pairs when primes or targets were high-arousing. Valence-congruent effects found in N400 also occurred in high-arousing stimulus pairs. For late ERP responses (LPP), the affective priming effect was robust regardless of the arousal level of primes or targets. Inconsistent with valence congruency that influenced on N400 and LPP, arousal congruency influenced only the LPP, suggesting that arousal congruency mainly modulates post-semantic processes, but valence-congruent effects begin with semantic processing. In a word, our current findings indicate that the arousal level of emotional images impacts both

behavioral and electrophysiological effects of affective priming. Theories of affective priming effects should account for the valence-arousal interaction.

There were several limitations in the current study, which will be improved in future investigations. First, some particular emotions like happiness, fear, sadness, disgust are considered discrete and have distinct adaptive valence (Izard, 1992; Stein & Oatley, 1992). For example, facial expressions indicative of fear and disgust had opposite effects on attention processes despite similar valence (Vermeulen et al., 2009). However, the present study didn't make a distinction based on the discrete emotional content. Second, valence and arousal were correlated in the experimental materials used. Greater arousal was associated with a more extreme valence scores. This reflects the naturalistic relationship between arousal and valence, but limits the interpretability of the interaction effects.

4 Method

4.1 Participants

Eighteen right-handed undergraduate students (mean age = 21; 9 males and 9 females) participated in the study. All participants were native Chinese speakers, had normal or corrected-to-normal vision, and had no history of head trauma or psychiatric disorder.

4.2 Materials

The stimuli consisted of 960 picture prime-word target pairs. There were 480 valence-congruent pairs (240 positive-positive, 240 negative-negative) and 480 valence-incongruent pairs (240 negative-positive, 240 positive-negative). In the 240 positive-positive, 240 negative-negative, 240 negative-positive, or 240 positive-negative pairs, there were 60 pairs with both high-arousing primes and targets, 60 pairs with high-arousing primes and low-arousing targets, 60 pairs with low-arousing primes and high-arousing targets, and 60 pairs with both low-arousing primes and targets.

240 prime pictures were selected from the International Affective Picture System (Lang et al., 1999). Each picture was used in four separate pairs (two valence-congruent pairs and two incongruent pairs). 480 two-character word targets were selected from the Chinese Affective Words System (Luo & Wang, 2004). Each word was used in two different pairs (one valence-congruent pair and one incongruent pair). Table 4 summarizes characteristics of the stimuli.

Our analyses showed that the valence difference between positive and negative pictures was significant ($p < .05$). Under positive or negative valence, the arousal difference between high-arousing and low-arousing pictures was also significant ($ps < .05$). However, the valence difference between high-arousing and low-arousing pictures didn't reach significance ($p > .05$). Similarly, the valence difference between positive and negative words was significant ($p < .05$), and under positive or negative valence, the arousal difference between high-arousing and low-arousing words was also significant ($ps < .05$). However, the valence difference between high-arousing and low-arousing words didn't reach significance ($p > .05$). The differences of the familiarity ratings and the number of strokes between high-arousing and low-arousing words also were not significant ($ps > .05$).

Figure 5 illustrates the distribution of mean ratings for each prime picture and target word by plotting the image valence and arousal ratings in a two-dimensional space. Both Table 4 and Figure 5 show the trend that extreme valence levels are associated with high arousal for both unpleasant and pleasant pictures or words, and arousal is somewhat stronger for unpleasant than pleasant stimuli. This trend also has been reported by other researchers (e.g., Olofsson, Nordin, Sequeira, & Polich, 2008). Additionally, an analysis for nonparametric correlations

(Spearman) showed that correlation between valence and arousal ratings for word targets didn't reach significance [$r_s = -.068$, $p > 0.10$], but there was significant negative correlation between valence and arousal ratings for picture primes [$r_s = -.333$, $p < 0.001$].

Twenty-nine (29) students from Capital Normal University were asked to evaluate semantic relatedness of prime-target pairs at a 1-5 point scale (with 5 being closest in the semantic relatedness). There was no significant difference in semantic relatedness between valence-congruent (mean 1.37) and incongruent pairs (mean 1.35) ($p > .05$).

960 prime-target pairs were assigned to 12 lists. Each list contained 40 valence-congruent pairs and 40 incongruent pairs. Stimuli in each list were presented in pseudo-random order. 12 lists of stimuli were administered to each participant.

4.3 Procedure

Each trial began with a fixation point presented for 300 ms. Following the fixation, a prime picture was displayed on the screen for 100 ms and was replaced by a fixation point for 100 ms (SOA=200 ms). A target word was then presented visually for 1000 ms, followed by a 1500~1700 ms presentation of another fixation point. The task for the participants was to judge the pleasantness of the target word and press one of two buttons to indicate their choices (pleasant vs. unpleasant). The assignment of key to response hand was counterbalanced across subjects.

4.4 ERP recordings and analysis

EEG was recorded from 64 scalp electrodes. All electrodes were referenced to an average of the two electrodes placed on the mastoid bone behind each ear. Two pairs of electrodes were used for monitoring vertical and horizontal eye movements. EEG signals were filtered with a bandpass of 0.05~40 Hz and the sampling rate was 500 Hz. Impedances were kept below 5 K Ω . Average ERPs were formed offline from correct-response trials free of ocular and movement artifacts ($> \pm 75\mu V$). Each epoch lasted 1100ms, including 100 ms prior to prime onset.

In order to examine the influence of prime and target arousal level on valence-congruent effects, ERPs were quantified by measuring mean amplitudes in two latency intervals (300-450 and 500-700 ms post target onset) relative to the mean amplitude of the pre-prime baseline. The ANOVA analysis was conducted by selecting 9 electrodes from left and right hemisphere and midline site at anterior, central, and posterior locations (F3, FZ, F4, C3, CZ, C4, P3, PZ, and P4). Since different electrode sites contribute to ERP differentially, we analyzed the electrode sites as an independent variable to show scalp distribution of N400 or LPP effects. Therefore, our analyses included the following factors and levels: 2 valence congruency (congruent, incongruent) $\times$ 2 arousal levels of primes (high, low) $\times$ 2 arousal levels of targets (high, low) $\times$ 3 coronal sites (frontal, central, and parietal) $\times$ 3 sagittal sites (left, middle, and right). Additionally, in order to further test effects of arousal congruency, four-way repeated measures ANOVAs, 2 arousal congruency (congruent, incongruent) $\times$ 2 arousal levels of targets (high, low) $\times$ 3 coronal sites (frontal, central, and parietal) $\times$ 3 sagittal sites (left, middle, and right) were conducted in two latency intervals (300-400 and 500-600 ms post target onset) for positive prime-target pairs, negative prime-target pairs, positive prime-negative target pairs, and negative prime-positive target pairs respectively. The p values were corrected using the Greenhouse-Geisser method where appropriate.

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Highlights

- > Whether emotional arousal influences affective priming remains poorly understood
- > Whereas valence congruency influenced both the N400 and the LPP, arousal congruency influenced only the LPP
- > Arousal congruency mainly modulates post-semantic processes
- > Arousal level of images impacts behavioral and ERP effects of affective priming

Fig.1.

Comparison of mean reaction times (ms) and mean error rates (%) for valence-congruent trials and valence-incongruent trials as a function of prime arousal (high and low) and target arousal condition (high and low). *Indicates $p < .05$. Error bars indicate ± 1 standard error. H-H indicates high-arousing prime and high-arousing target pairs; H-L indicates high-arousing prime and low-arousing target pairs; L-H indicates low-arousing prime and high-arousing target pairs; L-L indicates low-arousing prime and low-arousing target pairs.

Fig.2. Grand mean ERPs from FZ, CZ, and PZ to valence-congruent and incongruent trials for each condition. ERP affective priming effects were seen in both N400 and LPP components (shadowed periods).

Fig.3.

Topographic map of difference waves (subtracting congruent trials from incongruent trials) of 200-300 ms, 300-450 ms, 500-700 ms, and 700-800 ms after target onset for each condition.

Fig.4.

Grand mean ERPs from CZ, FZ, and P3 to arousal-congruent and incongruent conditions (left figures) and topographic map of difference waves (subtracting congruent trials from incongruent trials) in 500-600 ms after target onset (right figures) when targets were low-arousing for positive prime-positive target pairs (a), positive prime-negative target pairs (b), and negative prime-positive target pairs (c).

Fig.5. Mean ratings of the arousal and valence values from a 1-9 scale for each prime picture (top panels) and target word (bottom panels).

Table 1

Results of the ANOVAs testing the influence of arousal level on valence congruency effects in two latency intervals (only significant main effects and interactions are reported here)

	N400 effects (300—450 ms)	LPP effects (500—700 ms)
VC		$F(1,17) = 13.05, p = 0.002$
C		$F(2,34) = 13.83, p < 0.001$
S	$F(2,34) = 6.98, p = 0.007$	$F(2,34) = 29.90, p < 0.001$
VC $\times$ C	$F(2,34) = 4.12, p = 0.041$	
VC $\times$ S		$F(2,34) = 3.92, p = 0.035$
PA $\times$ C	$F(2,34) = 4.33, p = 0.038$	$F(2,34) = 7.67, p = 0.005$
PA $\times$ S		$F(2,34) = 4.55, p = 0.019$
C $\times$ S	$F(4,68) = 14.06, p < 0.001$	$F(4,68) = 12.17, p < 0.001$
VC $\times$ TA $\times$ S	$F(2,34) = 9.28, p = 0.001$	$F(2,34) = 6.24, p = 0.006$
VC $\times$ PA $\times$ C $\times$ S	$F(4,68) = 2.86, p = 0.049$	

VC: valence congruency; PA: prime arousal; TA: target arousal; C: coronal; S: sagittal

Table 2

Mean response times (ms) and error rates (%) for each condition

	positive prime-target pairs		negative prime-target pairs		positive prime-negative target pairs		negative prime-positive target pairs	
	High-arousing targets	Low-arousing targets	High-arousing targets	Low-arousing targets	High-arousing targets	Low-arousing targets	High-arousing targets	Low-arousing targets
Arousal congruent	583 (2.41)	592 (3.88)	612 (4.36)	616 (3.99)	632 (5.08)	616 (6.58)	611 (6.76)	602 (2.13)
Arousal incongruent	590 (2.14)	588 (3.89)	616 (7.68)	624 (3.99)	628 (7.77)	635 (7.97)	596 (5.11)	625 (6.29)
Difference	7 (-0.27)	-4 (0.01)	4 (3.32) *	8 (0)	-4 (2.69) *	19 * (1.39) *	-15 * (-1.65) *	23 * (4.16) *

Note:

* indicates $p < 0.05$

Table 3

Results of the ANOVAs testing arousal congruency effects in two latency intervals (only significant main effects and interactions were reported here)

Stimuli pairs	N400 effects (300—400 ms)	LPP effects (500—600 ms)
PP-PT	S: $F(2,34) = 4.22, p = 0.035$	C: $F(2,34) = 12.84, p = 0.001$
	C $\times$ S: $F(4,68) = 10.78, p < 0.001$	S: $F(2,34) = 23.31, p < 0.001$
	AC $\times$ TA $\times$ S: $F(2,34) = 3.46, p = 0.049$	C $\times$ S: $F(4,68) = 10.01, p < 0.001$
	AC $\times$ C $\times$ S: $F(4,68) = 2.75, p = 0.043$	AC $\times$ TA $\times$ S: $F(2,34) = 6.17, p = 0.006$
NP-NT	S: $F(2,34) = 4.20, p = 0.032$	C: $F(2,34) = 11.51, p = 0.001$
	C $\times$ S: $F(4,68) = 13.31, p < 0.001$	S: $F(2,34) = 21.00, p < 0.001$
	AC $\times$ TA $\times$ C: $F(2,34) = 6.73, p = 0.004$	C $\times$ S: $F(4,68) = 12.03, p < 0.001$
		TA $\times$ S: $F(2,34) = 7.20, p = 0.003$
PP-NT	C $\times$ S: $F(4,68) = 10.73, p < 0.001$	C: $F(2,34) = 11.87, p = 0.001$
		S: $F(2,34) = 20.10, p < 0.001$
		C $\times$ S: $F(4,68) = 9.64, p < 0.001$
		AC $\times$ TA $\times$ C: $F(2,34) = 7.66, p = 0.004$
NP-PT	S: $F(2,34) = 4.04, p = 0.039$	C: $F(2,34) = 8.44, p = 0.0051$
	C $\times$ S: $F(4,68) = 12.98, p < 0.001$	S: $F(2,34) = 24.84, p < 0.001$
	TA $\times$ C: $F(2,34) = 6.33, p = 0.008$	C $\times$ S: $F(4,68) = 10.11, p < 0.001$
	AC $\times$ TA $\times$ C $\times$ S: $F(4,68) = 2.71, p = 0.049$	AC $\times$ TA $\times$ C: $F(2,34) = 5.57, p = 0.017$
		AC $\times$ TA $\times$ C $\times$ S: $F(4,68) = 4.54, p = 0.006$

AC: arousal congruency; TA: target arousal; C: coronal; S: sagittal; PP-PT: positive prime-target pairs; NP-NT: negative prime-target pairs; PP-NT: positive prime-negative target pairs; NP-PT: negative prime-positive target pairs

Means and Standard Deviation (SD) of Valence (1 Negative to 9 Positive), Arousal (1 Calming to 9 Arousing), Word familiarity (1 unfamiliar to 9 familiar), and Word stroke

Table 4

	Types of stimuli	Number	Valence	Arousal	Familiarity	Stroke
Prime Pictures	high-arousing & positive	60	7.16(0.43)	5.97(0.50)		
	low-arousing & positive	60	6.86(0.57)	3.50(0.46)		
	high-arousing & negative	60	2.41(0.77)	6.66(0.34)		
	low-arousing & negative	60	3.30(0.55)	4.41(0.46)		
Target Words	high-arousing & positive	120	6.61(0.33)	5.46(0.36)	5.30(0.41)	18(4.4)
	low-arousing & positive	120	6.41(0.27)	4.35(0.39)	5.24(0.24)	19 (5.0)
	high-arousing & negative	120	3.20(0.38)	5.53(0.41)	5.23(0.36)	18 (4.7)
	low-arousing & negative	120	3.38(0.33)	4.51(0.38)	5.24(0.30)	18 (4.7)