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Electrophysiological evidence for emotional valence and competitive arousal effects on insight problem solving

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ABSTRACT

Accumulating evidence suggests that insight can be substantially influenced by task-irrelevant emotion stimuli and interpersonal competitive situation, and a close link might exist between them. Using a learning-testing paradigm and Event-Related Potentials (ERPs), the present study investigated the independent and joint effects of emotional and competitive information on insight problem solving especially their neural mechanisms. Subjects situated in either competitive or non-competitive condition learned heuristic logogriphs first and then viewed task-irrelevant positive or negative emotional pictures, which were followed by test logogriphs to solve. Both behavioral and ERP findings showed a more evident insight boost following negative emotional pictures in competitive context. Results demonstrated that negative emotion and competitive situation might promote insight by a defocused mode of attention (as indicated by N1 and P2), the enhanced semantic integration and breaking mental set (as indicated by N450), and the increased forming of novel associations activated by motivational arousal originating from competition (as indicated by P800–1600 and P1600–2500). These results indicate that the dynamic interactions between emotional valence and competitive arousal effects on insight.

"Feeling and longing are the motive forces behind all human endeavor and human creations."

—Albert Einstein, New York Times Magazine

1. Introduction

Insight is an important and particular phenomenon that has been identified as a form of creativity and linked to scientific and technical innovations (Dietrich and Kanso, 2010; Finke,

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1995; Friedman and Förster, 2005; Kounios and Beeman, 2009), and it is a topic of growing interest in psychological researches (Aziz-Zadeh et al., 2009; Bowden and Jung-Beeman, 2007; Jung-Beeman et al., 2005; Ludmer et al., 2011). Previous studies have revealed that an insight pops into the mind when one breaks free of the unwarranted assumptions (i.e., breaking mental sets) and forms efficient connections among the old concepts or cognitive skills (i.e., forming novel, task-related associations) (Bowden and Jung-Beeman, 2007; Luo and Knoblich, 2007; Mai et al., 2004; Qiu et al., 2008). Moreover, the relevant researches using ERPs have revealed different stages associated with these key and elementary processes of insight problem solving. Results showed that a negative component (N380 or N320) (Mai et al., 2004; Qiu et al., 2006a) may reflect the process of breaking a pre-established mental set or cognitive conflict. In addition, previous studies indicated that P1200–1500 (Wang et al., 2009), P900–1300 (Zhao et al., 2010) or P600–1100 (Xing et al., 2012) in the later stage might play an important role in the forming of novel associations during insight problem solving.

Just as important, understanding the mystery of insight requires exploring its important contributors which could give it impetus, such as emotional and motivational processes. This issue still remains ambiguous. Studies have indicated that emotion could act as a catalyst for creativity (e.g., Gasper, 2003; George and Zhou, 2002; Kaufmann and Vosburg, 2002). However, focusing more directly on neural mechanisms underlying this function presents an incomplete picture. To our knowledge, only two studies have empirically investigated the neural mechanisms of insight that are influenced by mood or emotion. Using fMRI, Subramaniam et al., (2009) examined the effects of moods on brain activity during preparation for insight problems via measuring individual baseline mood states. However, cognitive flexibility is not only modulated by the longstanding mood states, but also by simply viewing emotional stimuli for a short time (Sakaki and Niki, 2011). Even mild fluctuations in emotion can have the potential to produce significant effects on cognitive processing and neural activation (Mitchell and Phillips, 2007, Rudrauf et al., 2009; Yuan et al., 2011). Besides, because naturally existing mood states and unmeasured/unknown extraneous variables are generally in the relationship of co-variation, it is possible that a third variable might explain the effects of mood states on insight observed in this study. A recent neuroimaging research (Sakaki and Niki, 2011) examined how transient viewing of positive and negative images (660 ms) influenced subsequent understanding of solutions to insight problems. In this research, insightful riddle solving processes were catalyzed by presenting the correct answers. However, understanding the solution after being told it was not an insight in the strict sense but an apperception or an outsight (e.g., Sheth et al., 2009; Smith and Kounios, 1996). Receiving answers passively might lack the necessary and typical characteristics of insight (i.e., impasse experience or problem restructuring) (Luo and Knoblich, 2007). The cognitive and neural processes that support actively solving the problem and passively understanding the answer are actually different in insight (Luo and Knoblich, 2007; Qiu et al., 2010). Therefore, it is advisable to make comprehensive analysis of the effects of experimentally induced emotion on the cognitive processes of true insight.

Additionally, these studies lacked a consideration of situation-dependent influences (e.g., specific situations stimulating enhanced goal motivation and greater task involvement). Previous works revealed that there are certain conditions under which emotional processes may be more likely to be activated (e.g., Schultz et al., 2008). For example, emotion can impact information processing in a “state-dependent” manner on the basis of motivational processes (e.g., reward-related manipulations) (Pessoa, 2009). And some neural circuits might be specific to the hedonic valence and deploying different responses depending on the goal (Lang and Bradley, 2010). Therefore, based on these findings, it makes sense to assume that the effects of positive and negative emotion on insight are more complex and context-dependent.

Competition, as a situation-specific motivator and frequently used energizer, may have a particular relevance to creativity. It is suggested that creative work frequently involves interpersonal competition (Abra, 1993). Some of the most creative scientific discoveries have been ascribed to the rivalry between competing laboratories (De Dreu and Nijstad, 2008; White, 2001). The evidence from creative work and innovators demonstrates that competition could enhance the excitement and challenge (Conti et al., 2001), providing a crucial motivation and energy source for creating (Abra, 1993). Although previous researches have provided some information regarding competition and creativity, only little information is available about the impact of competitive stimuli on the specific cognitive processes involved in insight. Thus, we would like to know at which stage of insight problem solving (e.g., breaking mental sets and forming novel associations) competitive information exerts its impact on competitor's mind. Consequently, it is important to overcome some limitations of the traditional behavioral measures that dominate the relevant literature and examine the time course of insight problem solving during competition.

Also, most behavioral studies of competition–creativity link did not explore the potential role of emotion variation in it. Lazarus (2000) proposed that the important psychological functions that influence competitive performance could be influenced by emotion. In addition to this, previous studies have indicated that there is a reciprocal relationship between coping strategies and emotions of individuals during a stressful situation (Carver and Scheier, 1994; Cerin et al., 2000; Clark et al., 1995; Crook et al., 1998; Folkman and Lazarus, 1985; Lazarus and Folkman, 1984; Ntoumanis and Biddle, 1998). The emotion feelings might be the crucial moderators of stress-related (Cavanagh and Allen, 2008) or goal-oriented (Izard, 2009) performances of cognitive functioning. An integration of emotion and cognition in brain functional organization would allow the goal-directed behavior to depend on the emotional state (Gray et al., 2002). Moreover, the coping actions and emotional experience of individuals may change across situations and across different points in time during a stressful situation (e.g., competitive sport settings) (Lazarus and Folkman, 1984; Gaudreau et al., 2002). Based on these suggestions, it is likely that the influence of competition on the time course of insight may be mediated by the impact of emotion.

In sum, the evidence cited above highlights the importance and complexity of dynamic emotion-insight and competition-insight relationships. Nevertheless, existing empirical evidence does not include a direct test of the temporal dynamics of these two mechanisms together and hence not allow for any conclusions of the brain mechanisms related to the effects of these two critical variables on insight. Failure to do so is likely to lead to the inaccuracy and inconsistency of research results. Thus, it is necessary to run another ERP study with full consideration of the above factors to investigate the neural mechanisms related to competition-relevant and emotion-relevant information processing supporting insight problem solving. Additionally, of greater importance and interest, in life settings we often come across the extrinsic short-lived emotional stimuli, especially within the context full of competition and challenge. For example, when an athlete is competing for trophy in competitive sport setting, given uncertainty with respect to important events and outcomes in this competitive situation, the athlete may look to rivals and spectators for cues concerning his relative standing. In such situations, faces and body language of rivals and spectators are likely to be scanned for signals conveying emotional information and indicating whether he or she is in the lead. In this way, the athlete may become re-motivated, eager and excited, and finish the race with enthusiasm in the course of the competition.

Based on these considerations mentioned-above, the current study employed a learning-testing experimental paradigm (e.g., Qiu et al., 2008, 2010; Wang et al., 2009; Tian et al., 2011) to enable subjects to find a solution on their own initiative and analyzed ERPs elicited by successful insight problem solving. Of more importance, we systematically investigated the emotional valence effect on subsequent insight in competitive situation and its spatiotemporal dynamics in the brain from an integrative perspective on person-situation interactions. This approach could contribute to a more complete and detailed mapping of the specific ERP activation patterns of emotion-insight and competition-insight, which have been overlooked to date in the literature. Furthermore, based on previous studies (e.g., Mai et al., 2004; Qiu et al., 2006a; Wang et al., 2009; Zhao et al., 2010; Xing et al., 2012), we hypothesized that the amplitude differences of N400 and slow waves between negative and positive emotions are larger in competitive situation than in non-competitive situation, possibly due to the enhanced breaking mental sets and the increased forming novel associations.

2. Results

2.1. Manipulation checks

2.1.1. Self-reported emotion

There was no significant preexisting differences between the two experimental conditions in the subjects' emotional state [F (1, 35)=0.17, p=0.69, η^2=0.005] and intensity [F (1, 35)=1.48, p=0.23, η^2=0.042]. The groups were thus comparable. On valence ratings after each block, the ANOVA found that the mean valence scores significantly differed between the two sets of emotional pictures [F (1, 35)=81.05, p<0.001, η^2=0.698], with the valence scores higher after the positive (M=6.03) than after the negative set (M=1.89). On the other hand, there was no significant difference in emotional intensity ratings in both emotion blocks [F (1, 35)=0.05, p=0.82, η^2=0.001]. These results confirmed that the positive and negative picture sets respectively elicited the intended emotion.

2.1.2. Post-experiment competition and "Aha" assessment

Consistent with the manipulation, the ratings of competition demonstrated the competitive group had more intense competitive feelings relative to their counterparts in the non-competitive condition [F (1, 35)=22.62, p<0.001, η^2=0.400]. And this result attested to the effectiveness of the competition manipulation procedure. Moreover, relative to non-competitive condition, the "Aha" experience (feeling of insight) ratings showed higher scores for subjects during competition [F (1, 35)=29.30, p<0.001, η^2=0.461].

2.2. Behavioral performance

Table 1 showed the average numbers (solving rates) of solved test logographs and mean reaction times for the successfully solved trials across four experimental conditions.

The repeated-measures ANOVA showed significant main effects of competition condition [F (1, 35)=32.41, p<0.001, η^2=0.215] and emotional valence [F (1, 35)=4.70, p<0.05, η^2=0.152], with more logographs solved successfully for negative vs. positive emotion and competitive vs. non-competitive condition, respectively. However, the interaction between these two factors was not significant [F (1, 35)=0.001, p=0.97, η^2=0.000].

Further, the main effects of emotional valence and the interaction between competition and emotion on reaction times (RTs) were not significant [F (1, 35)=0.07, p=0.79, η^2=0.000; F (1, 35)=2.77, p=0.10, and η^2=0.001]. However, there was a significant effect of competition condition [F (1, 35)=6.54, p<0.05, η^2=0.153]. Longer RTs were observed under competitive situation, irrespective of emotion valence.

2.3. Electrophysiological scalp data

As shown in Table 2, the ANOVA on the N1 amplitudes demonstrated a significant main effect of emotional valence over the parieto-occipital scalp regions, with smaller amplitudes for negative emotion than for positive emotion, irrespective of competition condition. Subsequently, the main effect of emotional valence and competition condition was significant on P2 amplitudes over the fronto-central scalp regions. The P2 amplitudes reduced for negative vs. positive emotion, and the amplitudes were smaller in competitive than in non-competitive condition.

Moreover, the emotional valence effect and its interaction with competition were both significant in the time windows of 400–500 ms, 800–1200 ms, 1200–1600 ms and 1600–2500 ms over the fronto-central scalp regions (Table 2). The simple effect analysis showed that the amplitude differences between negative and positive emotions were larger in competitive situation than in non-competitive situation (Fig. 4). Besides, the

Table 1 – Means and standard deviation (Mean ± SD) of numbers of solved test logogriphs and reaction times for the successfully solved trials across four experimental conditions.

		Non-competition	Competition
Number of solved logogriphs (solving rate)	Positive emotion	35±15 (0.58±0.25)	41±14 (0.68±0.24)
	Negative emotion	36±16 (0.60±0.27)	42±14 (0.70±0.24)
Reaction time (ms)	Positive emotion	2301±583	2383±649
	Negative emotion	2326±570	2348±685

Table 2 – Summary of results for the ANOVAs in the 400–500 ms, 800–1200 ms, 1200–1600 ms and 1600–2500 ms intervals.

Time(ms)	Electrode sites	Competition			Emotion			Competition × Emotion		
		F	P	η^2	F	P	η^2	F	P	η^2
120–180 ms	Fronto-central	1.10	0.30	0.027	1.18	0.28	0.029	1.85	0.18	0.044
	Parieto-occipital	0.04	0.84	0.001	15.11	**0.00**	0.274	1.08	0.31	0.026
220–280 ms	Fronto-central	4.79	**0.04**	0.147	10.40	**0.00**	0.206	2.86	0.11	0.088
	Parieto-occipital	2.47	0.12	0.101	0.25	0.62	0.006	2.03	0.15	0.067
400–500 ms	Fronto-central	4.76	**0.04**	0.236	77.66	**0.00**	0.345	6.21	**0.02**	0.156
	Parieto-occipital	2.48	0.09	0.027	0.15	0.70	0.087	0.35	0.56	0.085
800–1200 ms	Fronto-central	2.96	0.09	0.012	17.95	**0.00**	0.250	6.16	**0.02**	0.146
	Parieto-occipital	2.55	0.14	0.074	2.50	0.12	0.060	1.26	0.27	0.000
1200–1600 ms	Fronto-central	2.65	0.11	0.053	9.48	**0.00**	0.231	3.47	**0.04**	0.165
	Parieto-occipital	2.46	0.13	0.043	1.49	0.23	0.012	0.66	0.12	0.005
1600–2500 ms	Fronto-central	0.91	0.35	0.007	7.59	**0.00**	0.268	3.24	**0.04**	0.154
	Parieto-occipital	4.49	**0.04**	0.167	2.60	0.12	0.015	0.33	0.57	0.009

competition effect was significant in the time windows of 400–500 ms over the fronto-central scalp regions and in the time windows of 1600–2500 ms over the parieto-occipital scalp regions (Table 2). Insight problem solving in competitive situation elicited more positive-going amplitudes than in non-competitive situation for both emotions.

In addition, during the time intervals above, the main effects of electrode sites were all significant, but no theoretically relevant interaction involving electrode sites was significant and hence results involving these factors are not reported.

Besides, to test whether the modulations in N450 amplitudes between the two competition conditions are accompanied by changes in “Aha” experience, supplementary correlation analyses conducted for the N450 amplitudes and showed significant correlations between N450 amplitudes and the “Aha” experience reports (positive emotion: $r = -0.52$, $p < 0.001$; negative emotion: $r = -0.49$, $p < 0.01$).

To better present these results, we computed topographic map of difference waves (competitive minus non-competitive) that directly index competition effect in brain potentials (Fig. 3). The spatio-temporal brain activation pattern showed stronger brain activation during negative than positive emotion condition. Also, it showed almost the same trends in both emotion blocks generally: from fronto-central sites to parieto-occipital scalp regions in ERP time course.

3. Discussion

A major goal of this research was to investigate the independent and joint effects of task-irrelevant transitory emotional stimuli and pre-existing competition situation on insightful problem solving as well as their spatiotemporal dynamics. Behavioral data suggested the number of solved insight problems overall increased following negative pictures compared with the positive ones and it also increased in competitive than in non-competitive condition. Moreover, ERP results showed enhanced neural processes during insight following negative emotional pictures in competitive context at N450 and later components (800–2500 ms). This was also in agreement with prior studies revealing that creativity entails tension and disequilibrium and could be greatly fueled by challenge and encouragement (Amabile et al., 1996; Runco, 1994).

Specifically, we found the posterior N1 and the anterior P2 were greater for positive emotion (vs. negative emotion), and the P2 showed greater amplitudes in non-competitive situation (vs. competitive situation). It has been argued that attention incorrectly directed to specific stimulus features by an invalid cue and re-orienting attention to relevant stimulus features would produce larger N1 amplitudes (Luck et al., 1994; Wright et al., 1995). Besides, many ERP studies found the fronto-central P2 is associated with bottom-up sensory processing involving involuntary attention (Thorpe et al., 1996), which would be a good index to mirror attention bias (Carretié et al., 2001; Thomas et al., 2007). Of the target-elicited component, the P2 component was much larger when the targets were improbable (Luck and Hillyard, 1994). We may infer that the decreased N1 and P2 amplitudes observed in negative emotion induction and competitive condition were probably because of relatively less engagement of attention resources and decreased perceptual load at the early stage of visual processing. Crucially, many previous studies suggested that insight might be related to defocused attention (e.g., Kasof, 1997; Martindale, 1999). A temporary decrease in interferential visual inputs may promote searching for a weakly activated solution, which is beneficial to the solution to pop into awareness (Kounios and Beeman, 2009). Moreover, the logographs we used in the study always contained misleading and solution-irrelevant information in the initial perceptual features. Therefore, negative emotion and competitive situation appeared to be more favorable to diffuse attentional focus and open awareness to unattended information within very early stages in the stream of information processing during logograph solving. In particular, because early ERP components generated at approximately 200 ms of stimulus processing may reflect processing mechanisms engaged by nonconscious perception (Del Cul et al., 2007; Sergent et al., 2005), the impact of negative emotion on the attentional resource allocation during insightful problem solving might be manipulated by automatic processing in some extent.

A more important finding was the significant competition and emotion interaction in the 400–500 and 800–2500 ms intervals over the fronto-central scalp regions (Table 2). As shown in Fig. 2, the maximum amplitude of the anterior 400–500 ms negativities was at approximate 450 ms. Based on the previous research, the spatio-temporal feature of this negativity might be similar to the N400 or the N380 (Kutas and Federmeier, 2000; Mai et al., 2004), which are related to semantic integration and breaking mental set. Moreover, it is worth noting that some other ERP studies have reported that the N450 component is associated with conflict detection or cognitive control/monitoring (Chen et al., 2008; Qiu et al., 2006b). In addition, previous studies showed the amplitude of the N450 was modulated by the amount of conflict; the larger the conflict, the larger the amplitude of the N450 (West and Alain, 1999, 2000). Within the current task, there was paradoxical and misleading information given in the logographs and a successful problem-solving required the inhibition of superficial meaning or interfering information of logographs. It is natural that the new and efficient thought processes might immediately compete with the older, more familiar but unsuitable ones in the course of insight problem solving. In this regard, our observation of anterior N450 might reflect higher-level semantic integration and successful breaking mental set during insight. In addition, the results of the correlation analyses showed that the modulation in N450 amplitude was accompanied by changes in “Aha” ratings significantly. The N450 amplitude would thus be an effective index for the subjective intensity of the “Aha” feeling. And subjects generally experienced greater intensity of “Aha” feeling when they were inspired by competition. This may suggest that better insight performance in competition condition might have a close association with the stronger “Aha” experience and larger N450 amplitude.

Regarding the later components (800–2500 ms), previous studies have consistently indicated that long-lasting working-memory processing is typically reflected in slow-wave ERPs, with significant amplitude differences between high and low working-memory span (Berti et al., 2000; Vos et al., 2001). Recently, De Dreu et al. (2012) have found that working memory capacity enables focused, persistent and systematic bonding of problem elements, which could influence creativity. In essence, insight demands retrieving relatively inaccessible information as well as combining and transforming them in working memory (Lang et al., 2006; Nijstad and Stroebe, 2006). Thus, the more positive-going amplitudes in competitive situation (vs. non-competitive situation) between 800 and 2500 ms at fronto-central sites might be associated with improved working memory operations, which facilitated forming richer cognitive associations. The present findings accord with previous studies which evidenced that the relative increase in positive wave activity (e.g., P1200–1500 for Wang et al. (2009) and P900–1300 for Zhao et al. (2010)) was indicative of insight and might play an important role in forming novel associations.

Furthermore, according to the current results (Fig. 3), we can observe stronger brain activation for negative emotion than for positive emotion. Put another way, the strength of competition effect on insight would be variable in different emotional states and could be intensified by negative emotion. As stated before, competitive situation generated increased cognitive activation and involvement (e.g., Csikszentmihalyi, 1990; Eisenberger et al., 1998), which potentially increased the brain vigilance and neural sensitivity to inconspicuous cues. And this could fuel competitors to search for the way out of mental impasse and restructure a novel representation. On this basis, accumulated evidence indicates that negative emotional inputs evoke stronger neuron activation and facilitate overall information recognition than other types of stimuli, even with limited processing resource (Derryberry and Tucker, 1994; Huang and Luo, 2007). The more detail-oriented processing strategy fostered by negative emotion would be advantageous when a person explores the optimized solutions required for insight tasks (Davis, 2009; Nijstad et al., 2010). This is especially true when subjects were searching and refining the related information to generate the most suitable answer at later processing stages in the present “five to five” two-stage experimental paradigm which contains more interferential information and alternatives. The above cognitive characteristics facilitated more effective retrieval and integration of relevant information to activate more problem–solution pairings in working memory, which increased formation of novel associations and promoted insight. Besides, recent studies have found that negative emotional stimuli can intensify inhibition of prepotent response (Albert et al., 2010), conflict resolution (Kanske and Kotz, 2011) and cognitive control (Kuhbandner and Zehetleitner, 2011). Accordingly, in the present study, negative emotion presumably increased inhibition of superficial meaning and greater recruitment of cognitive control-relevant resources involved in breaking pre-established mind set.

The superposition of negative emotional stimuli onto competitive context may allow the brain to enter a certain activation state which serves as a critical entry point and is best suited for insight. The present electrophysiological findings are consistent with previous studies which demonstrates that when difficulties and challenges appear or a person needs to self-regulate cognitive resources, negative emotional states could lead to important benefits that positive emotions do not (Gendolla and Krüsken, 2002; Gruber et al., 2011). When positive affect is attached to the cognitive representation of the learned means, the switching from a learned goal-directed means to a new means is slowed down and become more rigid (Marien et al., 2012). Indeed, it has been argued that negative moods, relative to positive, can bolster creative performance on tasks regarded as serious and important as well as in situations emphasizing performance standards, extrinsic rewards and evaluative requirements (Davis, 2009; Friedman et al., 2007). It may be that negative emotion, due to its significant adaptive value, is better at coordinating cognitive functions involved in insight especially in the troubled and high-pressure environment.

Additionally, the significant competition effect was observed in the 1600–2500 ms interval, with the more positive-going ERPs in competitive situation than in non-competitive situation at posterior clusters, irrespective of emotional valence. It has been found that the positive-going effect might reflect increased motivational significance (Lang and Bradley, 2010). Neuroimaging studies also found that the activation of this posterior region was involved in “motivated attention”, and motivation systems allocated neural resources to motivationally relevant cues via this region (Mohanty et al., 2008; Serences, 2008). Findings such as these provide clues that the late positive shift in the 1600–2500 ms interval during competition might be due to more motivational activation and energetic arousal. In the present “five to five” two-stage experimental paradigm, the cognitive processes of solving problems actually vary between different situations and different logographs. Previous studies indicated that creative and effective work can also grow out of motivated effort and systematic exploration of various potential solutions (e.g., Rietzschel et al., 2007; Simonton, 1997). And competition seems to meet requirement because of its positive effect on promoting the engagement of motivational system. Besides, we observed slower RTs and higher rates of correctly solved problems in the competitive condition in the behavioral results. These results also indicated that competitive setting may induce individuals to assign the higher priority to solving problems better (i.e., accuracy) and a secondary priority to performing quickly (i.e., speed), and reduce the guess or imprudent response based on any partial information that is available, which can ensure individuals gain more chances in competition.

It is notable that the above ERP components might embody the time points at which emotion stimuli and competition context interacted dynamically to modulate insight problem solving. This situation may imply the possibility that emotional variations within the same individual may affect not only the established influences of emotional experience on insight, but also the strength of competition effects on insight. As previously stated, it is speculated that this latent interaction might be one of the reasons for the multifaceted and variable findings observed in previous researches on emotion-creativity and competition-creativity relations, and thus a potential confounder. The results also underline the importance of allowing for the interaction between emotional and motivational factors and their specific components at each stage of the information processing. Attention to this can not only provide more reliable models of the interaction between emotional and motivational processes, but may also extend the evidence concerning the neural mechanisms underlying the modulatory effects of emotional feelings or motivational states on insight in specific and cognitive functions in general.

4. Experimental procedure

4.1. *Subjects*

A total of 36 college students (18 females and 18 males) aged 18–25 years (mean age, 20.5 years) from Southwest University in China took part in this experiment as paid volunteers. All subjects were right-handed with normal or corrected-to-normal vision and reported no prior affective disorder and neurological/psychiatric history. The study was approved by the Academic Committee of the School of Psychology, Southwest University in China and informed consent was obtained from each subject after procedures were fully explained.

4.2. *Materials*

4.2.1. *Logogriphs*

Chinese characters are formed by radicals, and some complex characters are composed of simple characters. A logogriph may be a phrase, a Chinese proverb or a sentence in a poem. The answer to a logogriph is a Chinese character. The critical approach in solving a logogriph is first fully comprehending the meaning of the logogriph and then finding the answer by analyzing the Chinese character into certain components (i.e., certain radicals or simpler characters), or by catching the implicit meaning the logogriph intends. The Chinese logogriph problems we used are traditionally classified as “insight problems” and they meet the three formal characteristics of creative insightful problems proposed by Schooler et al. (1993): (1) these logogriphs always contain some paradoxical misleading information and people could not comprehend initially, which is likely to produce an impasse; (2) people without special knowledge and expertise could solve the logogriphs ultimately; and (3) pilot testing and previous studies (Luo and Niki, 2003; Qiu et al., 2006a, 2008, 2010) have consistently indicated that one gained an “Aha” experience when one guessed the answer to the given logogriph successfully. Thus, this Chinese logogriph task could be considered as a proxy for insight problem and the “Aha” experience could be produced in a short time in our experiment.

In a pilot experiment, an independent sample (12 females and 10 males, range 18–24 years, mean age, 21.5 years) rated their comprehensions of each logogriph (180 available logogriphs presented in a random order) on a scale from 1 (extremely boring/old) to 5 (extremely interesting/novel). We selected 125 logogriphs (5 logogriphs for practice stage use) which were evaluated as being interesting/novel (mean scores > 3) as test logographs.

This experiment adopted a guessing Chinese logogriph task by using a learning-testing paradigm. For each of the 125 test logogriphs, a relevant heuristic logogriph was made for subjects to learn. The heuristic logogriph learned earlier would provide heuristic information or indicate a potential solution to the corresponding test logogriph, so that the test logogriph could be solved in a few seconds once the heuristic information is activated and utilized successfully. For further information about the samples, please refer to our previous works (Qiu et al., 2010; Tian et al., 2011). Furthermore, we found the English counterparts to these Chinese logogriphs. As an example, "It has an apple in it, but when you get it, there is no apple to eat" is the heuristic logogriph and the word "pineapple" is the answer. This logogriph can be used as the heuristic logogriph for the test logogriph "It has an egg in it, but when you get it, there is no egg to eat." The answer to the test logogriph is "eggplant".

Most logogriphs were between 2 and 6 characters in length, while all the answers were a single character. The words that appeared in both the questions and answers were familiar and common Chinese characters selected from the Contemporary Chinese Dictionary (more than 50 occurrences per million on average). They were presented in the center of a 17-inch screen in the Song Ti font, at size no. 16.

4.2.2. *Emotional pictures*

In order to avoid culture-specific bias for the International Affective Picture System (IAPS) found in Chinese subjects (Huang and Luo, 2004), 120 emotional pictures used to emotion elicitation were selected from the standardized native Chinese Affective Picture System (CAPS; Bai et al., 2005). The two emotional categories differed significantly from each other in valence [positive: 7.10 ± 0.42 ($M \pm SD$), negative: 2.53 ± 0.52; F (1, 119) = 2815, $p < 0.001$], but no differences in arousal level [positive: 5.88 ± 0.50, negative: 5.89 ± 0.42; F (1, 119) = 0.01, $p > 0.05$]. Positive pictures included pictures such as romantic couples, scenes of weddings/celebration and happy faces. Negative pictures showed images of funeral scenes, plane crashes, angry faces, and the like. Both categories were matched for frequencies of pictures containing human images. In addition, 5 emotionally neutral pictures with medium arousal level were selected from the CAPS for practice session (valence: 4.92 ± 0.23, arousal: 2.54 ± 0.39). All the picture stimuli were 15 cm × 10 cm. The resolution and luminance of the pictures were matched for two emotional categories. And the contrast of the monitor was set to be constant across subjects.

4.3. Procedures

4.3.1. *Stage 1 (competition manipulation)*

After providing consent, subjects were randomly assigned to either competitive or non-competitive group. In these two experimental conditions, the instructions were identical apart from the competition manipulations. Competition arises from the combination of several factors including evaluation, reward, and a win-lose aspect that is unique to competitive situations (Amabile, 1996). To manipulate the evaluation and reward aspects of competition, we told subjects that we would determine the winners by evaluating carefully their overall performance compared with that of other subjects, and the winners would be eligible for the rewards. Furthermore, we created the "contrient interdependent goals" (Deutsch and Stroebe, 1991) to manipulate the win-lose aspect. With such goal structure, goal achievement by anyone reduces the ability for others to simultaneously reach their respective goals. For standardized instruction for competitive group see Appendix A.

Given that activating the creativity-related expectancies might affect the creative performance (Hicks et al., 2011), in the present study, subjects were matched with the strange opponents without the information about their abilities. So the subjects would assume that all of them are roughly of comparable capabilities. In addition, in the competitive condition, the other subjects were introduced in the lab and met the subject before the experimental session. This was done in order to reinforce the idea that other subjects were actually taking part in and competing with each other. In the non-competitive condition, the instructions explicitly stated that the logogriph task was not meant to be competitive and there was no mention of performance evaluation, financial rewards or the win-lose structure. Furthermore, at the beginning of each separate block, the experimenter reminded the subjects either to "do your individual best" (non-competitive condition), or "solve your logogriphs more and faster than others" (competitive condition). Next, they did the experimental task.

4.3.2. *Stage 2 (emotion induction and insight problem solving)*

The flowchart of the learning–testing procedure in each sub-block is shown in Fig. 1. Each sub-block was initiated by a learning stage in which 5 heuristic logogriphs appeared in screen along with the answers. They were created to match the subsequent 5 test logogriphs and provide subjects with the heuristic information (i.e., the "five to five" two-stage experimental paradigm). Firstly, in the learning stage, 5 heuristic logogriphs (including answers) were presented in the center of the screen one at a time for 8000 ms. They were randomly presented one after the other to each subject. Subjects were asked to try to understand the logogriphs and their answers fast and to press the corresponding keys to indicate whether they understood their meanings. If subjects understood, they were asked to press the "1" key quickly, and not to press any key in the other case. After they had seen all 5 heuristic logogriphs, the test stage began. Then, the test stage started with a 2000 ms ready signal ("Ready?") and was followed by a fixation cross between 800 and 1200 ms at random to avoid expectancy effects. Subsequently, a positive or negative emotional picture was centered in the screen one at a time for 2000 ms. Subjects were instructed to attend to the content of each picture actively. After the picture was replaced by a blank screen (varied randomly from 400 to 800 ms), a test logogriph was then presented one at a time in the center of the screen and persisted until subjects solved the problem or a 4000 ms time limit reached. Subjects were required to guess the answers according to the information they gained in the learning stage under 4000 ms. They pressed "1" key as soon as possible once the answer came into their mind and did not to press any key if they could not find the answer. The display of the logogriph was followed by

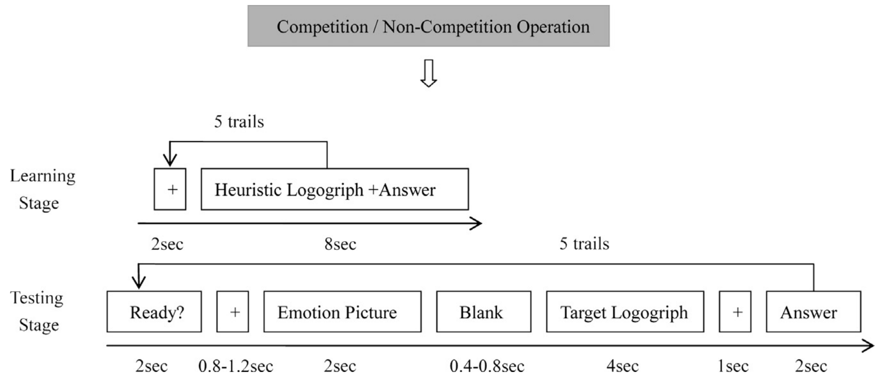

Fig. 1 – The flow of learning and testing logogriphs in each sub-block.

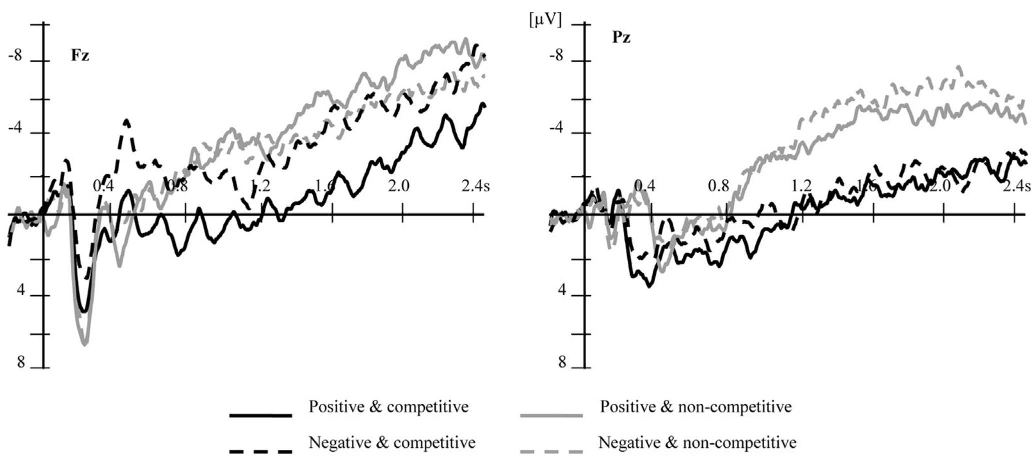

Fig. 2 – Averaged ERPs in the test stage for positive emotion (competitive: black solid lines; non-competitive: gray solid lines) and negative emotion (competitive: black dashed lines; non-competitive: gray dashed lines) conditions.

a 1000 ms presentation of a plus sign, and lastly an answer to the logogriph was presented in the center of the screen for 2000 ms. At this point, subjects indicated whether the solution they made by themselves was consistent with the answer and hereby made the corresponding response. They pressed “1” key if their own answer was consistent with the answer, press “2” key if they did not guess the logogriph but could understand the answer and pressing “3” key if they neither guessed the logogriph nor understood the answer. Following this sequence, 5 emotional pictures and 5 test logogriphs presented successively in the test stage. The presentation order of them was randomized for each subject.

To ensure the success and sustainability of the emotion-induction procedure, the formal ERP experiment was divided into two blocks (positive and negative) in both competitive and non-competitive conditions. In one block, only one category of emotional pictures was presented immediately before the test logogriphs to induce a type of emotion. Each block was composed of 12 sub-blocks and each sub-block contained 5 trials (5 emotional pictures and 5 logogriphs). The order of positive and negative emotion inductions were counterbalanced across subjects.

Subjects were seated in a quiet room, in front of a computer screen placed at a viewing distance of approximately 120 cm, with the horizontal and vertical visual angles below 6°. They were instructed to respond as fast and accurately as possible by pressing the corresponding buttons of the keyboard. Subjects were asked to try to make few movements and little eye-blinks. An appropriate rest was given after every 6 sub-blocks. To avoid carrying over a previously induced emotion to the next block, a 10 min break separated the two emotion blocks. And after subjects reported that they had calmed down and restored emotional balance, the second block was initiated. Before formal ERP experiment, a set of similar practice materials (5 neutral pictures and 5 logogriphs) using the same procedure helped familiarize subjects with the procedure and pace of this task. None of the pictures and logogriphs used in the practice session was used in the formal experiment. And there was no repetition of stimuli in the formal test. Upon completion of the study, subjects were debriefed, paid and thanked.

4.4. *Manipulation checks*

At the beginning of the experiment, all subjects rated their current emotional states and the general intensities on the 5-point Likert-type scales anchored at 1 (unpleasant/ not arousing at all) and 5 (pleasant/ extremely arousing). At the end of each block, subjects rated on the same 5-point scales the degree to which they experienced positive and negative emotion and the global intensity of emotional feelings after the presentation of the emotional pictures.

Immediately after the experimental task, subjects rated on the 5-point Likert scale (1=not at all; 5=extremely) about how competitive the atmosphere they had felt during the task. They also completed one additional scale concerning the intensity of their feelings of insight (i.e., "Aha" experience) (1=No "Aha" feeling; 9=Strongest "Aha" feeling).

4.5. *ERP recording and analysis*

The electroencephalogram (EEG) was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (Brain Product, Brain Products GmbH, Stockdorfer, Munich, Germany). All channels were referenced to a channel located between Fz and FCz. They were also re-referenced offline to represent recording with respect to linked mastoids. The horizontal electrooculogram (EOG) was recorded with electrodes placed by the outer canthi of each eye, and vertical EOG was recorded with electrodes placed above and below the left eye. All electrode impedances were maintained below 5 kΩ. The EEG and EOG were amplified using a 0.05�80 Hz bandpass and continuously sampled at 500Hz/channel for off-line analysis. Eye movement artifacts (blinks and eye movements) were rejected offline. Trials with EOG artifacts (mean EOG voltage exceeding ±80 μV) and those contaminated with artifacts due to amplifier clipping, bursts of electromyographic activity, or peak-to-peak deflection exceeding ±80 μV were excluded from averaging.

According to the results of guessing logogriphs, EEG activity for successful solving trials in each condition was averaged separately. We analyzed ERP elicited by the test

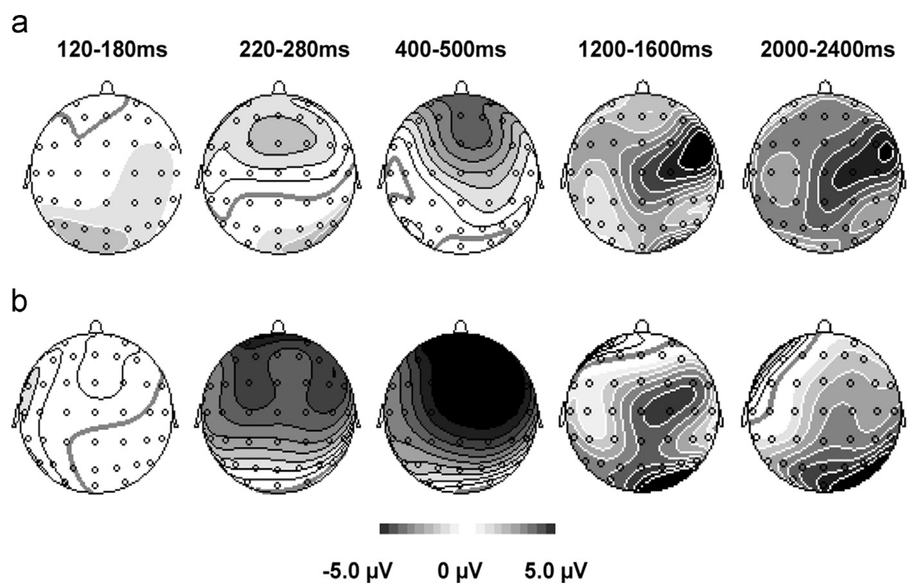

Fig. 3 – Topographical maps of difference waves (competitive vs. non-competitive) for each emotion condition. (a) Positive emotion and (b) Negative emotion.

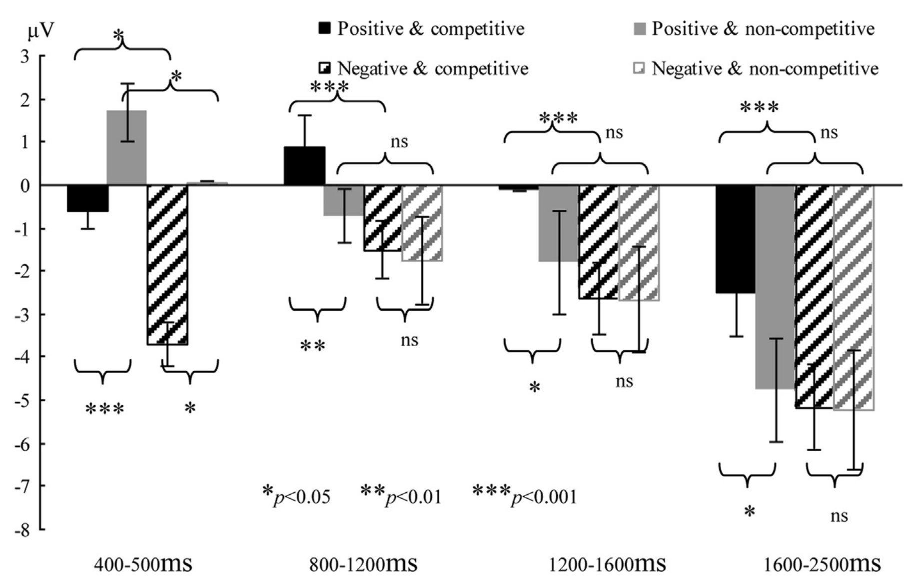

Fig. 4 – The amplitudes of 400–500 ms, 800–1200 ms, 1200–1600 ms, and 1600–2500 ms for each condition. Error bars indicate ±1 standard error.

logogriph and the average epoch was 2500 ms, with a 200 ms pre-stimulus baseline. According to the grand-average waveforms and topographical maps (Figs. 2 and 3), as well as the existing insight ERP literatures adopting similar learning-testing experimental paradigm (e.g., Qiu et al., 2008, 2010; Wang et al., 2009), we analyzed the peak latencies and amplitudes of the N1 (120–180 ms) and P2 (220–280 ms) components as well as the mean amplitudes in the time window of 400–500, 800–1200, 1200–1600 and 1600–2500 ms by using a series of repeated measures analysis of variance (ANOVA). The ANOVA factors were Competition Condition (2 levels: non-competitive vs. competitive) as between-subjects factor and Emotion Valence (2 levels: positive vs. negative) as within-subjects factor. The following 19 electrode sites were selected for statistical analysis: FPZ, FZ, CZ, AF3, AF4, F1, F2, F5, F6, C3 and C4 (11 fronto-central sites), PZ, OZ, Pl, P2, P5, P6, O1 and O2 (8 parieto-occipital sites). P-value of analyses of variance was corrected for deviations according to the Greenhouse–Geisser method.

5. Conclusion

The findings of the current study reflect task-irrelevant momentary emotion and pre-existing competitive context interacted dynamically to modulate insight problem solving at different stages and in different ways in the brain. To summarize, negative emotion and competitive situation might promote insight by broader attentional focus as reflected in N1 and P2, semantic integration and breaking mental set to a greater extent as indexed by N450, better forming of novel associations and more sustained motivated engagement as manifested by late positive deflections 800–2500ms. Moreover, the N450, P800–1600 and P1600–2500 reflect the time period in which competition context and emotion stimuli interact in the ERP. Fig. 4

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Appendix A. Instructions for competitive condition

On this set of logogriph problems you will be competing with 9 other subjects in the laboratory. We will randomly build the group of ten. Scientific studies suggest the students' abilities to analyze and solve insight problems are similar. Now, try to outperform the others in the same group by solving more logogriphs as soon as possible. After everyone completes the task, your performance will be carefully evaluated compared to that of others with objective criteria. We will provide you with our evaluations and tell you if you won this competition. Only the top two amid the group of ten will win a cash prize of 100 RMB and a good-player certificate severally.

REFERENCES

Abra, J.C., 1993. Competition: creativity's vilified motive. Genetic, Social, and General Psychology Monographs 119 (3), 289–342.

Albert, J., López-Martín, S., Carretié, L., 2010. Emotional context modulates response inhibition: neural and behavioral data. NeuroImage 49, 914–921.

Amabile, T.M., 1996. Creativity in Context: Update to the Social Psychology of Creativity. Westview Press, New York.

Amabile, T.M., Conti, R., Coon, H., Lazenby, J., Herron, M., 1996. Assessing the work environment for creativity. Academy of Management Journal 39 (5), 1154–1184.

Aziz-Zadeh, L., Kaplan, J.T., Iacoboni, M., 2009. "Aha!": the neural correlates of verbal insight solutions. Human Brain Mapping 30 (3), 908–916.

Bai, L., Ma, H., Huang, Y.X., Luo, Y.J., 2005. The development of native Chinese affective picture system-A pretest in 46 college students. Chinese Mental Health Journal 19 (11), 719–722.

Berti, S., Geissler, H.G., Lachmann, T., Mecklinger, A., 2000. Event-related brain potentials dissociate visual working memory processes under categorical and identical comparison conditions. Cognitive Brain Research 9, 147–155.

Bowden, E.M., Jung-Beeman, M., 2007. Methods for investigating the neural components of insight. Methods 42, 87–99.

Carretié, L., Martín-Loeches, M., Hinojosa, J.A., Mercado, F., 2001. Emotion and attention interaction studied through event-related potentials. Journal of Cognitive Neuroscience 13 (8), 1109–1128.

Carver, C.S., Scheier, M.F., 1994. Situational coping and coping dispositions in a stressful transaction. Journal of Personality and Social Psychology 66, 184–195.

Cavanagh, J.F., Allen, J.J.B., 2008. Multiple aspects of the stress response under social evaluative threat: an electrophysiological investigation. Psychoneuroendocrinology 33, 41–53.

Cerin, E., Szabo, A., Hunt, N., Williams, C., 2000. Temporal patterning of competitive emotions: a critical review. Journal of Sports Sciences 18, 605–626.

Chen, A.T., Xu, P., Wang, Q.H., Luo, Y.J., Yuan, J.J., Yao, D.Z., Li, H., 2008. The timing of cognitive control in partially incongruent categorization. Human Brain Mapping 29, 1028–1039.

Clark, K.K., Bormann, C.A., Cropanzano, R.S., James, K., 1995. Validation evidence for three coping measures. Journal of Personality Assessment 65, 434–455.

Conti, R., Collins, M.A., Picariello, M.L., 2001. The impact of competition on intrinsic motivation and creativity: considering gender, gender segregation and gender role orientation. Personality and Individual Differences 31, 1273–1289.

Crook, K., Beaver, B.R., Bell, M., 1998. Anxiety and depression in children: a preliminary examination of the utility of the PANAS-C. Journal of Psychopathology and Behavioral Assessment 20, 323–350.

Csikszentmihalyi, M., 1990. The domain of creativity. In: Rounco, Albert (Eds.), Theories of Creativity. Harper & Row, New York, pp. 190–214.

Davis, M.A., 2009. Understanding the relationship between mood and creativity: a meta-analysis. Organizational Behavior and Human Decision Processes 108, 25–38.

De Dreu, C.K.W., Nijstad, B.A., 2008. Mental set and creative thought in social conflict: threat-rigidity versus motivated focus. Journal of Personality and Social Psychology 95, 648–661.

De Dreu, C.K.W., Nijstad, B.A., Baas, M., Wolsink, I., Roskes, M., 2012. Working memory benefits creative insight, musical improvisation, and original ideation through maintained

task-focused attention. Personality and Social Psychology Bulletin 38 (5), 656–669.
Del Cul, A., Baillet, S., Dehaene, S., 2007. Brain dynamics underlying the nonlinear threshold for access to consciousness. PLoS Biology 5, 1–16.
Derryberry, D., Tucker, D.M., 1994. Motivating the focus of attention. In: Niedenthal, P.M., Kitayama, S. (Eds.), The Heart's Eye: Emotional Influences in Perception and Attention. Academic Press, New York, pp. 167–196.
Deutsch, M., Stroebe, W., 1991. Productivity loss in idea-generating groups: Tracking down the blocking effect. Journal of Personality and Social Psychology 61, 392–403.
Dietrich, A., Kanso, R., 2010. A review of EEG, ERP, and neuroimaging studies of creativity and insight. Psychological Bulletin 136 (5), 822–848.
Eisenberger, R., Armeli, S., Pretz, J., 1998. Can the promise of reward increase creativity?. Journal of Personality and Social Psychology 74, 704–714.
Finke, R.A., 1995. Creative insight and preinventive forms. In: Sternberg, R.J., David-son, J.E. (Eds.), The Nature of Insight. MIT Press, pp. 255–280.
Folkman, S., Lazarus, R.S., 1985. If it changes it must be a process: study of emotion and coping during three stages of a college examination. Journal of Personality and Social Psychology 48, 150–170.
Friedman, R.S., Förster, J., 2005. Effects of motivational cues on perceptual asymmetry: Implications for creativity and analytical problem solving. Journal of Personality and Social Psychology 88, 263–275.
Friedman, R.S., Förster, J., Denzler, M., 2007. Interactive effects of mood and task framing on creative generation. Creativity Research Journal 19, 141–162.
Gasper, K., 2003. When necessity is the mother of invention: mood and problem solving. Journal of Experimental Social Psychology 39, 248–262.
Gaudreau, P., Blondin, J.-P., Lapierre, A.-M., 2002. Athletes' coping during a competition: relationship of coping strategies with positive affect, negative affect, and performance–goal discrepancy. Psychology of Sport and Exercise 3, 125–150.
Gendolla, G.H.E., Krüsken, J., 2002. Informational mood impact on effort-related cardiovascular response: the diagnostic value ofmood counts. Emotion 2, 251–262.
George, J.M., Zhou, J., 2002. Understanding when bad moods foster creativity and good ones do not: the role of context and clarity of feelings. Journal of Applied Psychology 87 (4), 687–697.
Gray, J.R., Braver, T.S., Raichle, M.E., 2002. Integration of cognition and emotion in the lateral prefrontal cortex. Proceedings of the National Academy of Sciences 99 (6), 4115–4120.
Gruber, J., Mauss, I.B., Tamir, M., 2011. A dark side of happiness? How, when, and why happiness is not always good. Perspectives on Psychological Science 6 (3), 222–233.
Hicks, J.A., Pedersen, S.L., Friedman, R.S., McCarthy, D.M., 2011. Expecting innovation: psychoactive drug primes and the generation of creative solutions. Experimental and Clinical Psychopharmacology 19 (4), 314–320.
Huang, Y.X., Luo, Y.J., 2004. Native assessment of international affective picture system. Chinese Mental Health Journal 9, 631–634.
Huang, Y.X., Luo, Y.J., 2007. Attention shortage resistance of negative stimuli in an implicit emotional task. Neuroscience Letters 412, 134–138.
Izard, C.E., 2009. Emotion theory and research: highlights, unanswered questions, and emerging issues. The Annual Review of Psychology 60, 1–25.
Jung-Beeman, M., Bowden, E.M., Fleck, J., Haberman, J., Kounios, J., 2005. New approaches to demystifying insight. TRENDS in Cognitive Sciences 9 (7), 322–328.
Kanske, P., Kotz, S.A., 2011. Emotion speeds up conflict resolution: a new role for the ventral anterior cingulate cortex?. Cerebral Cortex 21 (4), 911–919.
Kasof, J., 1997. Creativity and breadth of attention. Creativity Research Journal 4, 303–315.
Kaufmann, G., Vosburg, S.K., 2002. Mood effects in early and late idea generation. Creativity Research Journal 14 (3–4), 317–330.
Kounios, J., Beeman, M., 2009. The Aha! moment: the cognitive neuroscience of insight. Current Directions in Psychological Science 18 (4), 210–216.
Kuhbandner, C., Zehetleitner, M., 2011. Dissociable effects of valence and arousal in adaptive executive control. PLoS ONE 6 (12), e29287.
Kutas, M., Federmeier, K.D., 2000. Electrophysiology reveals semantic memory use in language comprehension. Trends in Cognitive Sciences 4 (2), 463–470.
Lang, P.J., Bradley, M.M., 2010. Emotion and the motivational brain. Biological Psychology 84, 437–450.
Lang, S., Kanngieser, N., Jaśkowski, P., Haider, H., Rose, M., Verleger, R., 2006. Precursors of insight in event-related brain potentials. Journal of Cognitive Neuroscience 18 (12), 2152–2166.
Lazarus, R.S., 2000. How emotions influence performance in competitive sports. The Sport Psychologist 14 (3), 229–252.
Lazarus, R.S., Folkman, S., 1984. Stress, appraisal, and coping. Springer, New York.
Luck, S.J., Hillyard, S.A., 1994. Electrophysiological correlates of feature analysis during visual search. Psychophysiology 31, 291–308.
Luck, S.J., Hillyard, S.A., Mouloua, M., Woldorff, M.G., Clark, V.P., Hawkins, H.L., 1994. Effects of spatial cuing on luminance detectability: Psychophysiological and electrophysiological evidence for early selection. Journal of Experimental Psychology. Human Perception and Performance 20, 887–904.
Ludmer, R., Dudai, Y., Rubin, N., 2011. Uncovering camouflage: amygdala activation predicts long-term memory of induced perceptual insight. Neuron 69, 1002–1014.
Luo, J., Knoblich, G., 2007. Studying insight problem solving with neuroscientific methods. Methods 42, 77–86.
Luo, J., Niki, K., 2003. The function of hippocampus in 'insight' of problem solving. Hippocampus 13, 274–281.
Mai, X.Q., Luo, J., Wu, J.H., Luo, Y.J., 2004. 'Aha!' effects in guessing riddle task: an ERP study. Human Brain Mapping 22, 261–270.
Marien, H., Aarts, H., Custers, R., 2012. Being flexible or rigid in goal-directed behavior: when positive affect implicitly motivates the pursuit of goals or means. Journal of Experimental Social Psychology 48, 277–283.
Martindale, C., 1999. Biological bases of creativity. In: Sternberg, R. J. (Ed.), Handbook of Creativity. Cambridge University Press, New York, pp. 137–152.
Mitchell, R.L.C., Phillips, L.H., 2007. The psychological, neurochemical and functional neuroanatomical mediators of the effects of positive and negative mood on executive functions. Neuropsychologia 45, 617–629.
Mohanty, A., Gitelman, D.R., Small, D.M., Mesulam, M.M., 2008. The spatial attention network interacts with limbic and monoaminergic systems to modulate motivation-induced attention shifts. Cerebral Cortex 18 (11), 2604–2613.
Nijstad, B.A., De Dreu, C.K.W., Rietzschel, E.F., Baas, M., 2010. Towards a dual-pathway to creativity model: creative ideation as a function of flexibility and persistence. European Review of Social Psychology 21 (1), 34–77.
Nijstad, B.A., Stroebe, W., 2006. How the group affects the mind: a cognitive model of idea generation in groups. Personality and Social Psychology Review 10, 186–213.
Ntoumanis, N., Biddle, S.J.H., 1998. The relationship of coping and its perceived effectiveness to positive and negative affect in sport. Personality and Individual Differences 24, 773–788.

Pessoa, L., 2009. How do emotion and motivation direct executive control?. Trends in Cognitive Sciences 13 (4), 160–166.
Qiu, J., Li, H., Jou, J., Liu, J., Luo, Y.J., Feng, T.Y., Wu, Z.Z., Zhang, Q.L., 2010. Neural correlates of the “Aha” experiences: evidence from an fMRI study of insight problem solving. Cortex 46, 397–403.
Qiu, J., Li, H., Jou., J., Wu, Z.Z., Zhang, Q.L., 2008. Spatiotemporal cortical activation underlying the mental preparation of successful riddles solving: an event-related potential study. Experimental Brain Research 186, 629–634.
Qiu, J., Li, H., Luo, Y.J., Chen, A.T., Zhang, F.H., Zhang, J.M., Yang, J., Zhang, Q.L., 2006a. Brain mechanism of cognitive conflict in a guessing Chinese logogriph task. NeuroReport 17, 679–682.
Qiu, J., Li, H., Yang, D., Luo, Y.J., Li, Y., Wu, Z.Z, Zhang, Q.L., 2008. The neural basis of insight problem solving: an event-related potential study. Brain Cognition 68, 100–106.
Qiu, J., Luo, Y.J., Wang, Q.H., Zhang, F.H., Zhang, Q.L., 2006b. Brain mechanism of Stroop interference effect in Chinese characters. Brain Research 1072, 186–193.
Rietzschel, E.F., Nijstad, B.A., Stroebe, W., 2007. The effects of knowledge activation on the quantity and quality of ideas. Journal of Experimental Social Psychology 43, 933–946.
Rudrauf, D., Lachaux, J.P., Damasio, A., Baillet, S., Hugueville, L., Martinerie, J., Damasio, H., Renault, B., 2009. Enter feelings: somatosensory responses following early stages of visual induction of emotion. International Journal of Psychophysiology 72, 13–23.
Runco, M.A., 1994. Creativity and its discontents. In: Shaw, M.P., Runco, M.A. (Eds.), Creativity and affect. Ablex, Norwood, NJ, pp. 102–123.
Sakaki, M., Niki, K., 2011. Effects of the brief viewing of emotional stimuli on understanding of insight solutions. Cognitive, Affective, and Behavioral Neuroscience 11 (4), 526–540.
Schooler, J.W., Ohlsson, S., Brooks, K., 1993. Thoughts beyond words: When language overshadows insight. Journal of Experimental Psychology 122, 166–183.
Schultz, W., Preuschoff, K., Camerer, C., Hsu, M., Fiorillo, C.D., Tobler, P.N., Bossaerts, P., 2008. Explicit neural signals reflecting reward uncertainty. Philosophical Transactions of the Royal Society B 363, 3801–3811.
Serences, J.T., 2008. Value-based modulations in human visual cortex. Neuron 60, 1169–1181.
Sergent, C., Baillet, S., Dehaene, S., 2005. Timing of the brain events underlying access to consciousness during the attentional blink. Nature Neuroscience 8, 1391–1400.
Sheth, B.R., Sandkühler, S., Bhattacharya, J., 2009. Posterior beta and anterior gamma oscillations predict cognitive insight. Journal of Cognitive Neuroscience 21 (7), 1269–1279.
Simonton, D.K., 1997. Creative productivity: a predictive and explanatory model of career trajectories and landmarks. Psychological Review 104, 66–89.
Smith, R.W., Kounios, J., 1996. Sudden insight: all-or-none processing revealed by speed-accuracy decomposition. Journal of Experimental Psychology: Learning, Memory and Cognition 22 (6), 1443–1462.
Subramaniam, K., Kounios, J., Parrish, T.B., Jung-Beeman, M., 2009. A brain mechanism for facilitation of insight by positive affect. Journal of Cognitive Neuroscience 21, 415–432.
Thomas, S.J., Johnstone, S.J., Gonsalvez, C.J., 2007. Event-related potentials during an emotional Stroop task. International Journal of Psychophysiology 63, 221–231.
Thorpe, S., Fize, D., Marlot, C., 1996. Speed of processing in the human visual system. Nature 381, 520–522.
Tian, F., Tu, S., Qiu, J., Wei, D.T., Su, Y.H., Zhang, Q.L., 2011. Neural correlates of mental preparation for successful insight problem solving. Behavioural Brain Research 216, 626–630.
Vos, S.H., Gunter, T.C., Kolk, H.H.J., Mulder, G., 2001. Working memory constraints on syntactic processing: an electrophysiological investigation. Psychophysiology 38, 41–63.
Wang, T., Zhang, Q.L., Li, H., Qiu, J., Tu, S., Yu, C.Y., 2009. The time course of Chinese riddles solving: evidence from an ERP study. Behavioural Brain Research 199, 278–282.
West, R., Alain, C., 1999. Event-related neural activity associated with the Stroop task. Cognitive Brain Research 8, 157–164.
West, R., Alain, C., 2000. Effect of task context and fluctuations of attention on neural activity supporting performance of the Stroop task. Brain Research 873, 102–111.
White, M., 2001. Rivals: Conflict as the fuel of science. Secker & Warburg, London.
Wright, M.J., Geffen, G.M., Geffen, L.B., 1995. Event related potentials during covert orientation of visual attention: effects of cue validity and directionality. Biological Psychology 41, 183–202.
Xing, Q., Zhang, J.X., Zhang, Z.L., 2012. Event-related potential effects associated with insight problem solving in a Chinese logogriph task. Psychology 3 (1), 65–69.
Yuan, J.J., Lu, H., Yang, J.M., Li, H., 2011. Do not neglect small troubles: moderately negative stimuli affect target processing more intensely than highly negative stimuli. Brain Research 1415, 84–95.
Zhao, Y.F., Tu, S., Lei, M., Qiu, J., Ybarra, O., Zhang, Q.L., 2010. The neural basis of breaking mental set: an event-related potential study. Experimental Brain Research 208, 181–187.