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Acute stress reduces the emotional attentional blink: Evidence from human electrophysiology

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Abstract

The present study is the first to examine the time-dependent mechanism of acute stress on emotional attentional blink (EAB) with event-related potential (ERP) measures. We explored the stage characteristics of stress affecting EAB, whether it affects the early selective attention process (marked by early posterior negativity) or the late working memory consolidation (marked by late positive potential). Sixty-one healthy participants were exposed to either a Trier Social Stress Test (TSST) or a control condition, and salivary cortisol was measured to reflect the stress effect. ERPs were recorded during an attentional blink (AB) paradigm in which target one (T1) were negative or neutral images. Results showed stress generally reduced AB effects. Specifically, stress promoted the early selective attention process of target two (T2) following a neutral T1 but did not affect T2 consolidation into working memory. Correlational analyses further confirmed the positive effect of cortisol and negative emotional state on AB performance. Moreover, the ERP results of acute stress on AB conformed to the trade-off effect between T1 and T2; that is, stress reduced T1 late working memory consolidation and improved T2 early selective attention process. These findings further demonstrated that stress did not change the central resource limitation of AB. In general, stress generates a dissociable effect on AB early- and late-stage processing; namely, acute stress reduce the AB effect mainly from the improvement of participants' overall ability to select the targets in the early stage.

Keywords Acute stress · Emotional attentional blink · Cortisol · Event-related potential

Introduction

Stress is a nonspecific systemic response that could activate autonomic nerves system and hypothalamic-pituitary-adrenal (HPA) axis (Allen, Kennedy, Cryan, Dinan, Clarke, 2014). Hormones (mainly cortisol) released in response to stress can cross the blood-brain barrier and widely act on various human brain regions that are rich in stress hormone receptors (such as the prefrontal cortex and the amygdala), thereby affecting selective attention, emotional processing, and various advanced cognitive functions (Berke, Reidy, Gentile, & Zeichner, 2019; Herzog, D'Andrea, DePierro, & Khedari, 2018; Szőllősi, Pajkossy, Demeter, Kéri, & Racsmány, 2018).

Directing their attention to certain aspects is the most basic way humans understand the world. The underlying changes in attention-related brain mechanisms when a person is under stress is of great significance to human survival, especially regarding immediate reactions. The attentional blink (AB) effect is a form of functional blindness that occurs in rapid serial visual presentation (RSVP) paradigm. During RSVP, participants need to find the two targets from a quick series of distracting stimuli and report their attributions. When the target two (T2) appears between 200 and 500 ms after the target one (T1), the recognition of T2 becomes impaired (Raymond, Shapiro, & Arnell, 1992). Theories based on limited central resources or a bottleneck have been proposed to explain this deficit (Chun, & Potter, 1995; Jolicoeur & Dell'Acqua, 1998; Potter, Staub, & O'Connor, 2002) and suggest two major information-processing stages. Specifically, in the first stage, all objects are allocated primary sensory processing and conceptual representations. However, in the second stage (which

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is characterized by limited capacity), targets need to compete for cognitive resources to be selected from large quantities of distractors and further consolidated into working memory. When the interval between the two targets is too short, the limited resources mean that not enough can be allocated to both targets, so T2 cannot be fully processed at the level of consciousness, and blindness occurs. Because of these limited central resources, studies have confirmed a trade-off effect between T1 and T2 (Kranczioch, Debener, Maye, & Engel, 2007; Shapiro, Schmitz, Martens, Hommel, & Schnitzler, 2006). Because T1 and T2 share the same limited central resources, if fewer resources are allocated to T1, more resources will be reserved for T2. Thus, T2 could be better processed, and the AB effect will be reduced.

Recognizing emotional information is very important to human evolution (Frischen, Eastwood, & Smilek, 2008). The brain prioritizes processing and gives attention to emotionally salient stimuli (Vogt, De Houwer, Koster, Van Damme, & Crombez, 2008; Vuilleumier, 2005). Accordingly, an emotional T1 could enhance the AB effect in the two-target RSVP task; this is known as the emotional attentional blink (EAB; Mathewson, Arnell, & Mansfield, 2008). Emotional stimuli generally induce increased early posterior negativity (EPN) and late positive potential (LPP) amplitudes at the electrophysiological level (Macleod, Stewart, Newman, & Arnell, 2017; Schupp, Flaisch, Stockburger, & Junghöfer, 2006; Schupp, Junghöfer, Weike, & Hamm, 2004). These two components also could reflect the conscious-level processing (capacity-limited stage) during the AB effect, similar to the classic ERP components (N2-P3; Kissler, Herbert, Winkler, & Junghofer, 2009; Macleod et al., 2017; Schupp et al., 2004, 2006). Specifically, EPN is a negative-going potential that occurs in temporal-occipital regions and peaks around 200-300 ms after the presentation of emotionally salient stimuli (Schupp et al., 2007). Because of the similar scalp distribution, time window, and induced condition, EPN is thought to be a regulatory component of N2 (Schupp, Junghöfer, Weike, & Hamm, 2003) and reflects the process by which the target is selected from the distractors (Kissler et al., 2009; Woodman, Arita, & Luck, 2009). LPP, on the other hand, corresponds to the P3 family representing the advanced cognitive processing of emotional information; it is a positive-going slow wave over the central-parietal regions beginning around 300-540 ms and lasting for several hundred milliseconds, which reflects the visual information consolidation into working memory (Dell'Acqua et al., 2015; Schupp et al., 2006; Vogel, & Luck, 2002). Given the similarity of brain regions, times windows, and inducing conditions, LPP and P3 are treated as the same components in many studies (Kennedy, Rawding, Most, & Hoffman, 2014; Kissler et al., 2009). Because AB is generated from insufficient conscious-level processing, the amplitudes of the EPN/N2 and LPP/P3 are suppressed during AB (Sergent, Baillet, & Dehaene, 2005; Vogel, Luck, & Shapiro, 1998; Woodman et al., 2009).

There are only a few studies on the effect of acute stress on emotion-related AB. Schwabe and Wolf (2010) first demonstrated the effect of acute stress (induced by a socially evaluated cold pressor test) in the emotional regulation of AB. The two targets were set as either negative or neutral. The results showed that acute stress reduced the AB effect overall. These findings confirmed that the beneficial effect of stress was unrelated to the emotionality of the target itself. Kan et al. (2019) further clarified the reciprocal effect of the emotional target and attentional resources in women and found that acute stress only enhanced the accuracy of a neutral T2 when it appeared 200 ms after T1. This outcome was not affected by the emotionality of T1. They also performed a time-course analysis at the behavioral level, which indicated that the cortisol concentration in the later phase of the stress response was the main contributor in reducing the AB effect. Combining these two studies, we speculated that AB could be reduced under stress. Furthermore, various other factors can affect temporal attention and may regulate the effect of acute stress on AB. For example, acute stress can enhance the individual arousal level and induce a negative affective experience. Vermeulen (2010) found that an increased AB effect from negative emotions is associated with a narrowing of attention, whereas a reduced AB effect from positive emotions is related to a broadening of attention. Actually, valence and arousal of emotional states also interact to affect performance during an AB task (Jefferies, Smilek, Eich, & Enns, 2010). Kever et al. (2015) suggested that physiological arousal activation has a facilitation effect on the awareness of emotional words in the AB task when their arousal values are congruent with the current context. Arousal information promotes the access to awareness by reducing the attentional prerequisites for perceptual consolidation (Anderson, 2005). High physiological arousal may further amplify this prerequisite-reduced effect of information-processing with a high arousal level. Hence, we can speculate that stress also may promote temporal attention processing through such a mechanism.

At present, no studies have focused on the underlying processing mechanisms of acute stress on AB. Specifically, it is unknown at what cognitive processing stage acute stress affects AB or whether the stage corresponds to early selective attention processing (marked by EPN/N2) or late working memory consolidation (marked by LPP/P3). Some cognitive neuroscience studies have focused on the early and late processing characteristics of acute stress. Qi, Gao, and Liu (2018) studied acute stress' underlying mechanisms on attention processing and found that stress strengthened N2 amplitudes, indicating enhanced early selective attention. ERP studies on stress' effect on response inhibition also showed that stress could amplify the early premotor response inhibition represented by N2 and enhance the cognitive control process

(Dierolf, Fechtner, Böhnke, Wolf, & Naumann, 2017; Qi, Gao, & Liu, 2017). Additionally, the flanker task has been consistently used to investigate selective attention and has shown a facilitation effect reflected in N2 under stress (Qi, & Gao, 2020). Overall, previous studies have suggested that stress could enhance the general attentional control process and promote the motivational selective attention processing.

The late P3/LPP is a complex brain component and reflects the multiple processes involved in different tasks. Specifically, under stress, negative images could induce a larger LPP amplitude over the central-parietal area than neutral images, further supporting the idea that stress promotes the attention processing of emotionally salient stimuli (Weymar, Schwabe, Löw, & Hamm, 2012). Stress also could decrease the P3 amplitudes of neutral probe stimuli and impair late resource allocation (Qi et al., 2018). In the AB task, P3/LPP reflects the process of encoding information into working memory. Stauble, Thompson, and Morgan (2013), using a change-detection task, found that the cortisol released by stress is positively correlated with the working memory encoding sub-process. Later studies have shown that the threat of shock-induced anxiety is domain-specific for the facilitation and impairment of working memory encoding process; specifically, it enhanced the encoding of visuospatial working memory but impaired the encoding of emotional face recognition (Bolton, & Robinson, 2017). Conversely, other studies found that stress have no effect on the performance of working memory encoding (Kim, Woo, & Woo, 2017). In general, the previous research suggest that stress could improve the motivational attention process reflected by P3/LPP. Nevertheless, no consistent conclusion can be drawn about the effect of stress on working memory consolidation.

To our knowledge, this study is the first to examine the effect of acute stress on EAB using ERP measures. We explored the stage characteristics of EAB affected by acute stress. Specifically, we measured the cortisol levels to reflect the effect of stress and recorded the EPN and LPP amplitudes to represent the stage characteristics of early selective attention and late working memory consolidation during the EAB task, respectively. According to previous studies (Dierolf et al., 2017; Kan et al., 2019; Qi, & Gao, 2020; Schwabe & Wolf, 2010), we hypothesized that stress would reduce the AB effect at the behavioral level and improve the early selective attention process of T2. Based on the trade-off effect (Kranczioch et al., 2007; Shapiro et al., 2006) and the impaired encoding of emotional faces under the threat of shock-induced anxiety (Bolton, & Robinson, 2017), it is tempting to speculate that stress will reduce the working memory consolidation of T1. For the late stage of T2, according to the overall facilitation effect of stress on AB, we speculated that there would be two possibilities: (a) if stress enhances neutral stimuli encoding into working memory (Bolton, & Robinson, 2017; Stauble et al., 2013), stress will increase general target processing, that is, the early and late stage will coordinate to improve the AB performance; (b) if stress processes neutral and negative stimuli to the same extent (Kan et al., 2019; Schwabe & Wolf, 2010), stress will generate a dissociable effect on the early and late-stage processing of AB, namely early selective attention processing will improve, but late working memory consolidation will not be sensitive to stress. This would indicate that the contribution of stress in reducing AB mainly comes from the early stage.

Method

Participants

Sixty-one healthy undergraduates recruited from Shaanxi Normal University and Xian University of Architecture and Technology joined this experiment for appropriate cash reward, of which 32 (16 males and 16 females; mean age = 20.34 years, SD = 1.91) were randomly assigned to stress group and 29 (14 males and 15 females; mean age = 19.97 years, SD = 1.53) were randomly assigned to control group. All participants were prescreened with the State-Trait Anxiety Inventory (STAI) and Beck Depression Inventory (BDI) to avoid the influence of trait factors on experimental results (Booij et al., 2015; Vreeburg et al. 2009). Participants were required to refrain intake of medicine or caffeine foods 3 days before the experiment and avoid intensive exercise or eating 3 hours before the experiment. The requirements for the participants also excluded any genetic history of heart disease or hypertension (Kudielka, Hellhammer, & Wüst, 2009). All subjects filled in the informed consent before starting the experiment. To ensure that endogenous cortisol concentrations were only affected by experimental manipulations, all experiments were performed at 2:00 to 6:00 pm (Izawa, Sugaya, Yamamoto, Ogawa, & Nomura, 2010). The study was conducted in accordance with the Declaration of Helsinki (World Medical Association, 2013) principles and was permitted by the Academic Committee of the Ministry of Education of Key Laboratory of Modern Teaching Technology, Shaanxi Normal University in China.

Measures

Subjective measures The Positive and Negative Affect Scale (Watson, Clark, & Tellegen, 1988) contains 20 items, which include 10 positive affect items and 10 negative affect items. Each item is scored in the five-point scale. The emotional states of participants were measured by PANAS before and after the TSST/control task.

Physiological measures We used Enzyme-Linked Immuno Sorbent Assay to measure the cortisol levels in saliva samples.

The saliva samples were collected with Salivette collection devices (salivette, Sarstedtstr.1 D-51588. Germany) and kept in −20 °C freezer. Thawed saliva samples were centrifuged at 2–8 °C for 20 min (3,000 rpm). The centrifugal fluid was used for the final cortisol data analysis (Zhuocai, China).

Stress induction and control condition

Trier Social Stress Test (TSST) has been considered as the most effective way to induce acute stress in laboratory (Kirschbaum, Pirke, & Hellhammer, 1993; Williams, Hagerty, & Brooks, 2004). In the current experiment, participants in stress group were required to give a 5-minute speech in a simulated job interview applying for the position of college counselors. The interviewer panel consisted of three experimenters who kept indifferent and asked questions during the whole speech. After that, participants were required to complete a mental subtraction task (2023 − 17) for 5 min as quickly and accurately as possible. The entire process was recorded by a video. Correspondingly, participants in control group were required to give a presentation on an unlimited topic and perform simple addition tasks. The type of tasks in the stress and control groups was consistent aiming to avoid the effect of additional variables, and the control condition was simply with neither interview panel nor video to supervise during the whole procedure (Kudielka, Hellhammer, Kirschbaum, Harmon-Jones, & Winkielman, 2007).

Attentional blink task

Stimuli The T1 were negative (involves in injuries or violence) (n = 30) or neutral (n = 30) (people or animals) images that selected from the International Affective Picture System (IAPS) (Lang, Bradley, & Cuthbert, 2008). The T2 were landscape or architectural images (n = 60, the viewing angle was 8.6° × 7°) that selected from the copyright-free photo site (https://pixabay.com/), as well as the distracting images (n = 252). The T2 were rotated landscape or building images (90° left or right), while the distracting images were upright landscape or architectural images. The image materials were the same as those used by Kan et al. (2019) and referred to Kennedy et al. (2014). The undergraduates who did not join the formal experiment completed the evaluation of images. They were asked to judge the attributes of emotional images and the rotated direction of landscape and architectural images respectively in the RSVP paradigm. There were no significant difference in accuracy between the negative (M = 0.93, SD = 0.06) and neutral images (M = 0.93, SD = 0.06) (t(58) = −0.15, $p = 0.88$), as well as between the landscape (M = 0.98, SD = 0.02) and architectural images (M = 0.98, SD = 0.02) (t(58) = 0.12, $p = 0.92$). The arousal of negative images (M = 7.50, SD = 0.79) were significantly higher than neutral images (M = 4.21, SD = 0.45) (t(58) = −26.14, $p < 0.001$) and the pleasure of negative images (M = 2.07, SD = 0.64) were significantly lower than neutral images (M = 5.04, SD = 0.47) (t(58) = 27.34, $p < 0.001$).

Procedure The AB task was presented on a 24-inch monitor with a 100-Hz refresh rate and 1,980 × 1,080 resolution via E-prime 2.0 software. In the formal experiment, each trial contained 21 images, including 2 targets and 19 distracting images. The T1 were randomly presented at the third and fourth positions in the sequence, and the T2 were randomly represented at the second and eighth positions after T1 (lag2, lag8). We also set baseline condition in which the T1 and T2 was respectively replaced with distractors (T1 and T2 absent), aiming at purifying the ERP amplitudes. Each trial began with a 1,000-ms fixation cross followed by the targets and distractors. Every image was shown for 100 ms. During the AB task, the participants were asked to complete the dual-task, i.e., first to report the emotionality of T1 and then report the rotated direction of T2. Participants used the keyboard to make response. When reporting the emotionality of T1, the keys 1, 2, and 3 corresponded to the negative, neutral, and T1 absent. When reporting the rotated direction of T2, the keys ←, →, and ↓ corresponded to the 90° left, 90° right, and T2 absent. Stimuli in the sequence were freely rendered. The positions of the two targets were matched among various conditions. To control the effect of response bias, participants were required to avoid inferring the probability of stimuli during the entire experimental task. When they were unsure about their response, they were instructed to avoid adopting strategies to report more on a certain response to improve accuracy and just respond according to their actual perception. We excluded the condition when both the T1 and T2 were not presented in the same trial due to the lack of research significance. Each other experimental condition was repeated 60 times. The formal experiment contained 600 trials divided into 8 blocks. Participants were given a regular 2-min rest between the blocks for purpose of better control on the experimental time consuming and accurately collect saliva samples. There was an exercise experiment consisting of 16 trials before the formal experiment. The parameter setting of exercise experiment was same to the formal experiment except that the T1 were all neutral or baseline conditions to avoid the impact of negative stimuli on participants' emotional state, as well as the T2 only appeared at lag8 to familiarize participants with the task procedure (Fig. 1).

General procedure

Participants who met the criteria came to the laboratory. Previous studies have shown that the AB task might be a potential stressor (Kan et al., 2019; Skoluda et al., 2015). Hence, we asked the participants to complete the exercise experiment first, and then they performed a 20-min

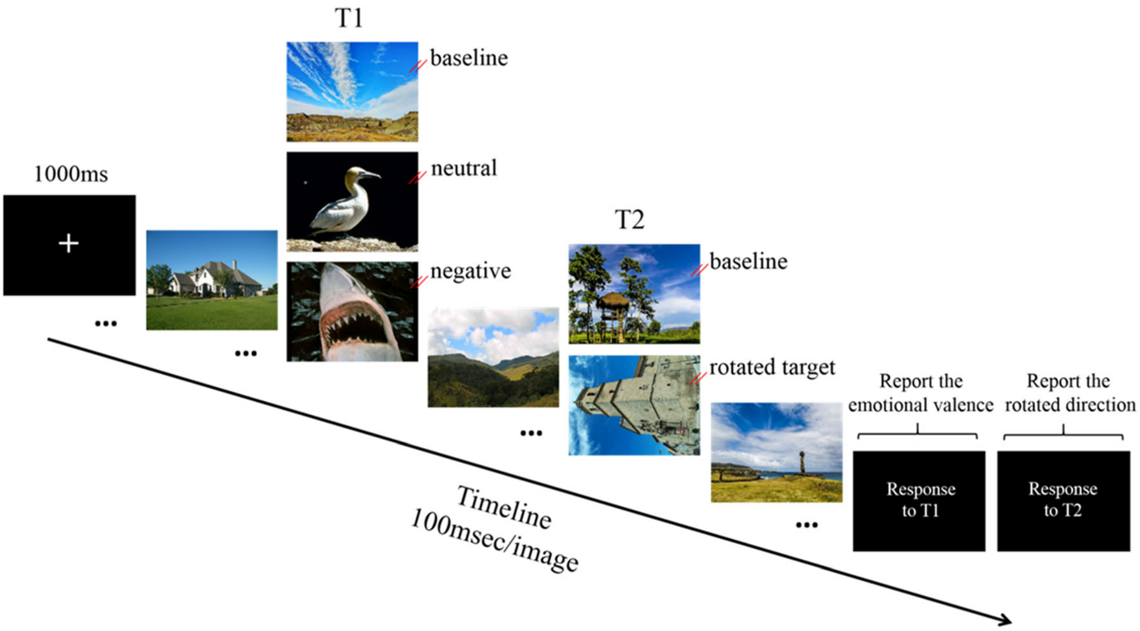

Fig. 1. Overview of a sample experimental trial

electroencephalographic (EEG) preparation (including scalp cleaning, electrode cap placement, and resistance reducing) and were given a 10-min rest period to exclude the effect of exercise experiment. Following this, the participants were randomly assigned to experience the TSST or control conditions for 10 min. Within the last block, the AB task was administered. Throughout the study, three times subjective scale evaluations were performed, i.e., pre-TSST/control task (t1), post-TSST/control task 10 min (t2), after AB task (post-TSST/control task 60 min) (t4) (Fig. 2). The saliva were collected simultaneously with PANAS, and an additional saliva sample was taken in the middle of the AB task (t3, after the first four block) (post-TSST/control task 35 min).

Behavioral data analysis

All of the participants' data in the current study were included in the data analysis. The data of PANAS was analyzed by a 3 (time:pre-TSST, post-TSST 10 min, post-TSST 60 min) × 2 (group: stress, control) repeated measures ANOVA to reflect the subjective feeling. The cortisol data also was analyzed by a 4 (time: pre-TSST, post-TSST 10 min, post-TSST 35 min, post-TSST 60 min) × 2 (group: stress, control) repeated measures ANOVA to represent the activation of HPA axis and the effect of acute stress. The accuracy of T2 was analyzed only in trials that T1 was correctly reported. A repeated measures ANOVA was performed to assess the performance of AB task with group as the between-subject variable (stress vs. control), T1 emotion (negative vs. neutral), and lag (lag2 vs. lag8) as the within-subject variables. The two-tailed bivariate Pearson correlation analysis also was performed to examine whether the PANAS scores and the cortisol level might moderate the AB performance. All of the behavioral data were analyzed with SPSS statistics 20 and corrected by Greenhouse-Geisser. The Bonferroni was used to correct the comparison between conditions. The partial η^2 was reported for F statistics as effect size.

Electrophysiological recording and analysis

The raw EEG was acquired by a 64 Ag/AgCl electrode sites according to the 10-20 system (Neuroscan, Herndon, VA) with the reference to left mastoid. Horizontal and vertical electro-oculograms (EOG) were recorded from the left versus the right orbital rim and from above and below the left eye, respectively. A SynAmps2 amplifier in AC mode was used to record the brain electrical activity at 500 Hz with a 0.01-100 Hz band-pass. The resistance of the interelectrode was

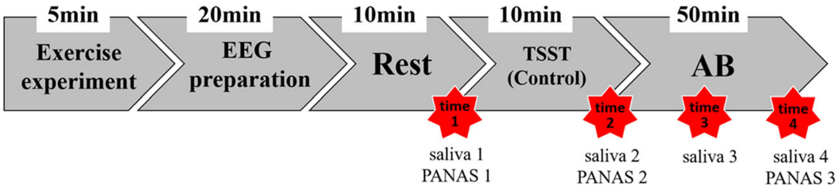

Fig. 2. Schematic diagram of the general experimental procedure

kept below 5 kΩ during the experiment. For the data analysis, raw EEG data were processed off-line using the EEGLAB toolbox loaded in MATLAB (Delorme & Makeig, 2004). EEG data were resampled at 250 Hz, referenced to the average reference (referred to Kennedy et al., 2014), and filtered using 0.01-30 Hz band-pass. After excluding electroencephalogram events with obvious electromyography (EMG) and offset, independent component analysis (ICA) was used to correct the interference of eye movements and eye-blink activity. The amplitude greater than ±75 μv was considered as artifact to be removed.

ERPs were time-locked to the onset of the T1 and T2, respectively. The baseline was corrected with respect to the 200 ms before the two targets. The EEGs were segmented into 800-ms epochs surrounding the onset of the T1 and T2. In order to eliminate the interference of the distractors presented in the sequence on the target-induced ERPs waveform, difference waves were performed in this experiment to analyze the ERPs induced by the two targets (Luo, Feng, He, Wang, & Luo, 2010; Vogel et al., 1998). Specifically, the ERP waveform of T1 was analyzed by subtracting the T1 absent condition from the conditions of negative and neutral images, and the ERP waveform of T2 was analyzed by subtracting T2 absent condition from the conditions of T2 appearance. Multiple difference waves data under different conditions were superimposed to obtain the corresponding waveform. The cases where the targets absent were only used as baseline condition, and not involved in analysis. After removing the EEG trials with artifacts and false reactions of T1, the number of superimpositions at each level was no less than 40 times. According to the previous studies (Kennedy et al., 2014; Macleod et al., 2017) and topographic map of the current experiment, we analyzed the mean EPN amplitudes induced by T1 at PO5/PO7 and PO6/PO8 in the left and right hemispheres between 180-300 ms, as well as the mean LPP amplitudes induced by T1 at CPz and Pz between 380-600 ms. We also analyzed the mean EPN amplitudes induced by T2 at PO5/PO7 and PO6/PO8 in the left and right hemispheres between 200-300 ms, and the mean LPP amplitudes induced by T1 at CPz and Pz between 400-620 ms. For the amplitudes of EPN, a group (stress, control) × T1 emotion (negative, neutral) × lag (lag2, lag8) × hemisphere (left, right) repeated measures ANOVA was performed, and also a group (stress, control) × T1 emotion (negative, neutral) × lag (lag2, lag8) × electrode (CPz, Pz) was performed to analyze the LPP component.

Results

Subjective measures

The repeated measures ANOVA results for the negative affect showed that the main effect of time was significant, $F\,(1, 58) = 24.825$, $p < 0.001$, $\eta^2_p = 0.296$. The negative affect after the TSST/control task was significantly higher than other time points. The group main effect was significant, $F\,(1, 59) = 6.451$, $p = 0.014$, $\eta^2_p = 0.099$. The stress group induced the significantly higher negative affect compared with the control group. The interaction of time and group was also significant, $F\,(1, 59) = 9.569$, $p < 0.001$, $\eta^2_p = 0.140$. After the TSST/control task, the negative affect of participants in stress group was significantly higher than that in control group. These results indicated that the TSST task effectively induced the negative affect experience. For the positive affect, only the main effect of time was significant, $F\,(1, 58) = 13.075$, $p < 0.001$, $\eta^2_p = 0.181$. The initial positive affect was significantly higher than the positive affect after the stress task ($p = 0.003$) and the AB task ($p < 0.001$) (Fig. 3).

Cortisol

The repeated measures ANOVA results showed that the main effect of time was significant, $F\,(1, 57) = 40.235$, $p < 0.001$, $\eta^2_p = 0.405$. The group main effect was significant, $F\,(1, 59) = 41.610$, $p < 0.001$, $\eta^2_p = 0.414$. The interaction of time and group also was significant, $F\,(1, 59) = 12.137$, $p < 0.001$, $\eta^2_p = 0.171$. The concentration of cortisol in stress group was significantly higher than that in control group, except for the concentration at the baseline (time 1). In the stress group, cortisol concentrations at all time points were significantly higher than those at baseline, further indicating that the induction of stress was successful (Fig. 4).

Behavioral results

T1 The accuracy of T1 was 0.896 (SD = 0.109) overall. The three factors repeated measures ANOVA results showed that only the emotion main effect was significant, $F\,(1, 59) = 39.558$, $p < 0.001$, $\eta^2_p = 0.401$. The accuracy of negative T1 was significantly lower than that of the neutral T1. This result may be related to the intrinsic perceptual bias caused by the relatively complex perceptual features of negative T1 compared with the neutral T1. Other effects were not significant (Table 1).

T2 The accuracy of T2 was analyzed only in the condition that the T1 was correctly reported. The three factors repeated measures ANOVA results showed that the main effect of emotion was significant, $F\,(1, 59) = 102.843$, $p < 0.001$, $\eta^2_p = 0.635$. The T2 following the neutral T1 presented a higher accuracy compared to that following the negative T1. The lag main effect was significant, $F\,(1, 59) = 777.356$, $p < 0.001$, $\eta^2_p = 0.929$. The results accorded with the AB effect, and the T2 accuracy at the lag2 was significantly lower compared with that at lag8. The results showed that the AB effect was successfully induced in this study.

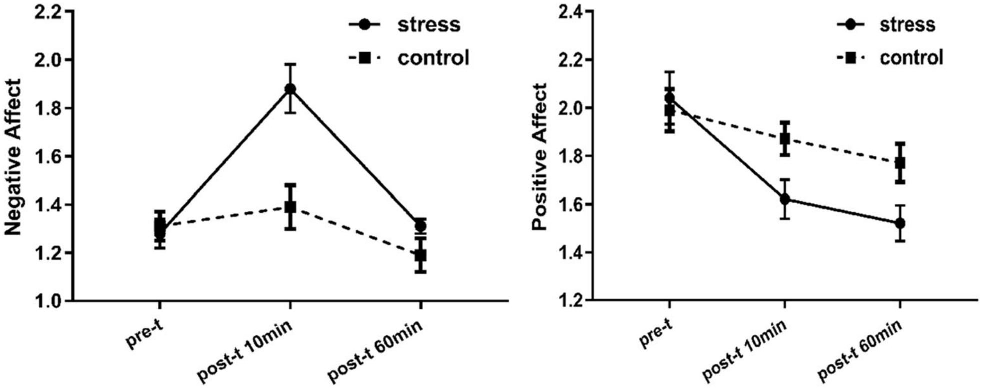

Fig. 3. Negative affect and positive affect at different times with respect to stress onset for the two conditions. "t" stands for TSST or control task. The bars are standard error

The interaction effect of emotion and group was significant, F (1, 59) = 10.396, $p = 0.002$, $\eta^2_p = 0.150$. The stress group presented a higher accuracy compared with that of control group when the T1 was neutral ($p = 0.007$). In the two groups, both the T2 accuracy following negative T1 was lower compared with that following neutral T1 ($p < 0.001$). This suggested that both the stress and control group appeared the EAB effect, and the improvement of stress on T2 cognition only following the neutral T1.

There also was an interaction of lag and group, F (1, 59) = 7.918, $p = 0.007$, $\eta^2_p = 0.118$. At lag2, during the time window of AB, the stress group accuracy was significantly higher compared with the control group ($p = 0.019$). In the two groups, both the accuracy of T2 at lag8 was significantly higher than that at lag2 ($p < 0.001$). This indicated that the stress did not affect the appearance of AB but significantly reduced the AB effect.

There was a significant interaction effect between emotion and lag, F (1, 59) = 85.840, $p < 0.001$, $\eta^2_p = 0.593$. The T2 accuracy at lag2 was significantly lower than that at lag8 whether T1 was negative or neutral ($p < 0.001$). At lag2, the accuracy of T2 following negative T1 was significantly lower than that following neutral T1 ($p < 0.001$). However, there were no significant difference between T2 accuracy following the different emotional T1 ($p = 0.17$) at lag8. This result indicated that there was a significant EAB effect, and it has been restored under the condition of lag8.

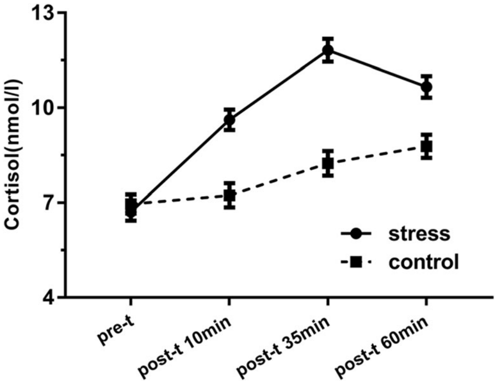

Fig. 4. Cortisol concentration at different times with respect to stress onset for the two conditions. "t" stands for TSST or control task. The bars are standard error

The interaction between three factors were significant, F (1, 59) = 4.453, $p = 0.039$, $\eta^2_p = 0.070$. During the time window (at lag2), when T1 was neutral, the stress group T2 presented a higher accuracy compared to control group ($p = 0.002$). This result suggested that the stress enhanced the processing of T2 following the neutral T1 during the AB time window. When it comes to compare the T1 emotion or lag in other conditions, both of that accorded with the classic AB effect. That is, the negative T1 induced a more severe AB than neutral T1. The AB effect have recovered at lag8, thereby the T2 accuracy significantly higher than that at lag2 (Table 1; Fig. 5).

ERP results

The effect of T1

EPN amplitudes We observed the interaction effect among emotion, lag and group, F (1, 59) = 4.704, $p = 0.034$, $\eta^2_p = 0.074$. Further post-hoc test revealed that the EPN amplitudes induced by negative T1 always higher than that induced by neutral T1 ($p < 0.001$) under each lag and

Table 1. Accuracy of T1 and T2 in two groups at each condition (M ± SD)

		Negative T1 condition		Neutral T1 condition	
		lag2	lag8	lag2	lag8
Stress	T1	0.84 ± 0.13	0.84 ± 0.12	0.96 ± 0.39	0.94 ± 0.51
	T2	0.58 ± 0.08	0.90 ± 0.08	0.76 ± 0.11	0.92 ± 0.60
Control	T1	0.84 ± 0.15	0.86 ± 0.11	0.95 ± 0.39	0.94 ± 0.46
	T2	0.56 ± 0.10	0.90 ± 0.05	0.67 ± 0.11	0.90 ± 0.47

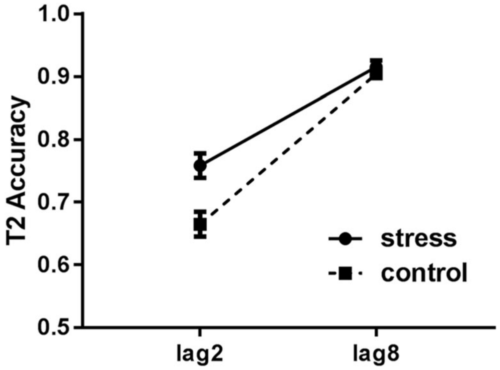

Fig. 5. T2 accuracy at lag2 and lag8 in two groups following neutral T1. Bars are standard error

group conditions, whereas the comparisons between groups and lags were not significant. There also was a significant main effect of emotion, F (1, 59) = 67.209, $p < 0.001$, $\eta^2_p = 0.533$. The negative T1 induced higher EPN amplitudes compared with the neutral T1. The results showed that the emotional T1 processing priority and could better selected from distractors. The hemisphere main effect was significant, F (1, 59) = 8.855, $p = 0.004$, $\eta^2_p = 0.131$. The EPN amplitudes induced by the left hemisphere was significantly higher than that induced by the right hemisphere. The main effect and interaction of other factors were not significant (see Table 2 and Fig. 6).

LPP amplitudes There was a significant main effect of emotion, F (1, 59) = 88.130, $p < 0.001$, $\eta^2_p = 0.599$. The negative T1 induced higher LPP amplitudes compared with the neutral T1. Similar to the EPN, the emotional T1 also processing priority in late stage and could better be encoded into working memory. A main effect of group was observed, F (1, 59) = 10.789, $p = 0.002$, $\eta^2_p = 0.155$. The stress group induced a significantly lower LPP amplitudes compared to the control group. The main effect of electrode was significant, F (1, 59) = 7.568, $p = 0.008$, $\eta^2_p = 0.114$. The LPP amplitudes at CPz were significantly lower than the LPP amplitudes at Pz (Table 3; Fig. 7).

Effect of T2

EPN amplitudes The results showed a significant emotion × lag × group interaction effect, F (1, 59) = 6.572, $p = 0.013$, $\eta^2_p = 0.100$. When T1 was neutral, under the condition of lag2, the EPN amplitude induced by T2 in the stress group was higher compared with that induced by T2 in the control group ($p = 0.016$). These results indicated that the stress improved the selective process of T2 during the AB time window under the condition of neutral T1. Within the stress group, when T1 was neutral, there was no significant difference in EPN amplitudes induced by lag2 and lag8 ($p = 0.506$). This suggested that the stress has basically restored the AB effect (at lag2) under neutral T1 conditions compared with the negative T1 conditions. In the stress group, under the condition of lag2, the EPN amplitude induced by T2 following the negative T1 was significantly lower than that following neutral T1 ($p = 0.07$). In other groups and emotional conditions, the EPN amplitude induced by T2 at lag8 was significantly higher than that at lag2 (within stress group, T1 negative, $p < 0.001$; within control group, T1 negative, $p = 0.005$; within control group, T1 neutral, $p < 0.001$). No significant main and interactions effects were observed in other conditions.

The interaction effect between the emotion and lag was also observed, F (1, 59) = 4.474, $p = 0.039$, $\eta^2_p = 0.070$. Further analysis revealed that the EPN amplitudes induced by T2 following the negative T1 at lag2 were lower than that following the neutral T1 ($p = 0.270$). For both the negative and neutral T1 conditions, the EPN amplitudes induced at lag2 were significantly lower than that induced at lag8 ($p < 0.001$; $p = 0.001$). The above results indicated that the T2 following the neutral T1 could make better target selection compared with following the negative T1.

The main effect of lag was also significant, F (1, 59) = 31.884, $p < 0.001$, $\eta^2_p = 0.351$, that is, the EPN amplitudes induced at lag2 were significantly lower than that at lag8. This result indicated that the AB effect reflected in early target selection stage was a gradual recovery process from lag2 to lag8. The hemisphere main effect was significant, F (1, 59) = 5.183, $p = 0.026$, $\eta^2_p = 0.081$. The left hemisphere induced a

Table 2. Mean EPN amplitudes of T1 and T2 in two groups at each condition (M ± SD)

		Negative T1 condition				Neutral T1 condition			
		lag2		lag8		lag2		lag8	
		PO5/PO7	PO6/PO8	PO5/PO7	PO6/PO8	PO5/PO7	PO6/PO8	PO5/PO7	PO6/PO8
Stress	T1	-1.08 ± 1.92	-0.73 ± 2.26	-1.11 ± 1.87	-0.72 ± 2.26	-0.02 ± 1.64	0.54 ± 1.75	0.26 ± 1.58	0.77 ± 1.81
	T2	-0.40 ± 1.19	-0.95 ± 1.47	-1.40 ± 1.53	-1.98 ± 1.87	-1.01 ± 1.24	-1.50 ± 1.64	-1.10 ± 1.47	-1.66 ± 1.70
Control	T1	-1.19 ± 1.88	-0.48 ± 2.26	-1.19 ± 1.83	-0.52 ± 2.21	0.35 ± 1.62	1.20 ± 1.72	-0.03 ±1.56	0.72 ± 1.83
	T2	-0.29 ± 1.18	-0.42 ± 1.51	-1.06 ± 1.51	-1.04 ± 1.88	-0.34 ± 1.24	-0.57 ± 1.62	-1.18 ± 1.45	-1.29 ± 1.67

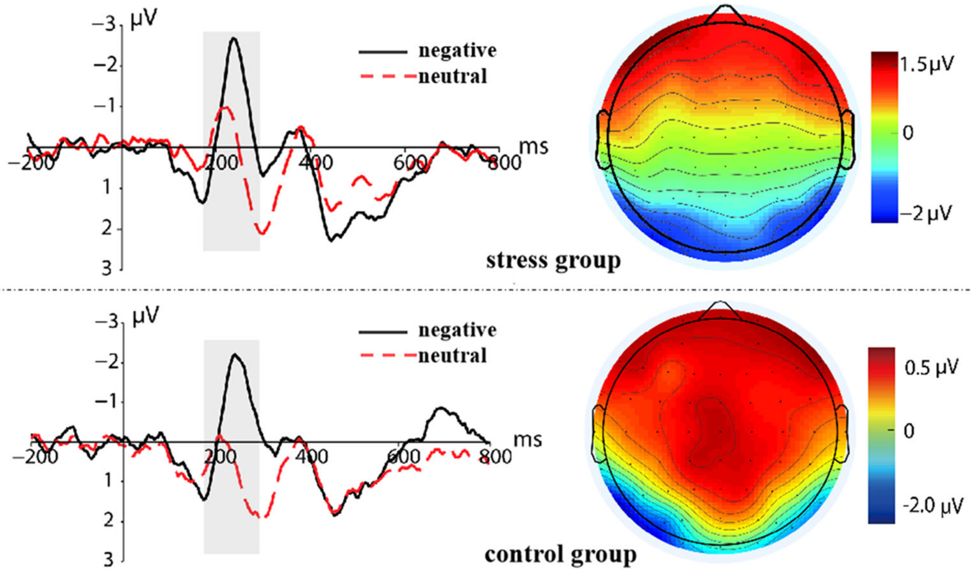

Fig. 6. T1 EPN waveforms and topography. The T1-locked difference waveforms obtained by subtracting the T1 empty screen (not present) condition waveform from the negative and neutral condition waveforms in lag2 and averaged across temporo-occipital regions electrode sites (PO5, PO6, PO7, PO8). Topographic map display the scalp distributions during the EPN time windows. The waveform and topographic map above is for the stress group and the below is for the control group

lower EPN amplitudes compared to the right hemisphere (Table 2; Fig. 8).

LPP amplitudes We observed an interaction between emotion and lag, F (1, 59) = 4.343, $p = 0.041$, $\eta^2_p = 0.069$. Under the conditions of lag2 and lag8, the LPP amplitudes following the negative T1 were significantly lower than that following the neutral T1 ($p < 0.001$; $p = 0.046$). The effect of lag under negative and neutral conditions was conformed to AB effect, that is, the amplitude of LPP induced by lag2 were significantly lower than that induced by lag8 ($p < 0.001$). The above results indicated that the T2 following the neutral T1 could be better consolidated in working memory compared to following the negative T1.

The analysis also showed a significant emotion main effect, F (1, 59) = 21.338, $p < 0.001$, $\eta^2_p = 0.266$. The LPP amplitudes induced by T2 following the negative T1 were significantly lower than that following the neutral T1. There was a lag main effect, F (1, 59) = 102.116, $p < 0.001$, $\eta^2_p = 0.634$. The amplitudes at lag2 were significantly lower compared with that at lag8. This showed that the late target consolidation in working memory also was conformed to the AB effect. The analysis showed a significant electrode main effect, F (1, 59) = 8.816, $p = 0.004$, $\eta^2_p = 0.130$. The LPP amplitudes in CPz were significantly higher than that in Pz (Table 3; Fig. 9).

Correlation analysis We also ran a two-tailed bivariate Pearson correlation analysis to examine whether the PANAS scores and the cortisol level might moderate the AB performance. Both the PANAS scores and the cortisol level were measured by the difference in the area under the curve with respect to ground (AUC_g) between the stress group and the control group (formulas of AUCg refer to Pruessner, Kirschbaum,

Table 3. Mean LPP amplitudes of T1 and T2 in two groups at each condition (M ± SD)

		Negative T1 condition				Neutral T1 condition			
		lag2		lag8		lag2		lag8	
		CPz	Pz	CPz	Pz	CPz	Pz	CPz	Pz
Stress	T1	1.98 ± 1.92	2.35 ± 1.98	2.17 ± 1.47	2.44 ± 1.81	0.71 ± 1.30	0.84 ± 1.64	0.80 ± 1.30	1.04 ± 1.41
	T2	1.17 ± 1.13	0.71 ± 1.24	2.33 ± 1.58	2.01 ± 1.70	1.63 ± 1.13	1.40 ± 1.13	2.91 ± 1.41	2.45 ± 1.36
Control	T1	3.13 ± 1.88	3.53 ± 1.94	3.14 ± 1.45	3.46 ± 1.83	1.55 ± 1.29	2.15 ± 1.62	1.60 ± 1.35	1.96 ± 1.40
	T2	0.52 ± 1.13	0.48 ± 1.24	2.84 ± 1.56	2.39 ± 1.72	1.55 ± 1.13	0.56 ± 1.13	2.97 ± 1.40	2.74 ± 1.35

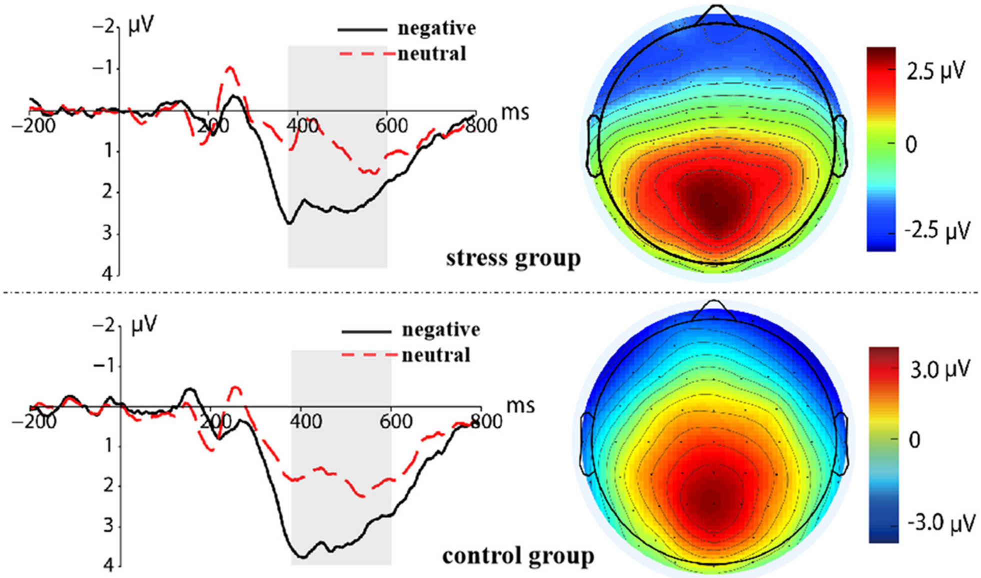

Fig. 7. T1 LPP waveforms and topography. The T1-locked difference waveforms obtained by subtracting the T1 empty screen (not present) condition waveform from the negative and neutral condition waveforms in lag2 and averaged across electrode sites (CPz, Pz). Topographic map display the scalp distributions during the LPP time windows. The waveform and topographic map above is for the stress group and the below is for the control group

Meinlschmid and Hellhammer, 2004). AB task performance and ERPs were measured by the difference in each condition between the stress group and the control group. All data were z-transformed to standardized measurements for the analysis.

The correlation analysis results showed that the negative affect and cortisol only regulated the processing of T2 at lag2 following neutral T1. Specifically, the negative affect were positively correlated with the accuracy (r = 0.394, p = 0.026) and the EPN amplitudes (r = 0.363, p = 0.041) of T2 at lag2 following neutral T1. The positive affectivity did not correlate with any AB findings, which may be due to the fact that the positive affect were not dominant after the stress task. The cortisol level also positively correlated with the accuracy (r = 0.414 , p = 0.018) and the EPN amplitudes (r = 0.449, p = 0.010) of T2 at lag2 following neutral T1. The correlation analysis indicated that the negative affect induced by stressful experiences, as well as elevated cortisol levels, were associated with the better accuracy of T2 at lag2 following neutral T1 in AB task and induced higher EPN amplitudes. There also was a marginal significant positive correlation

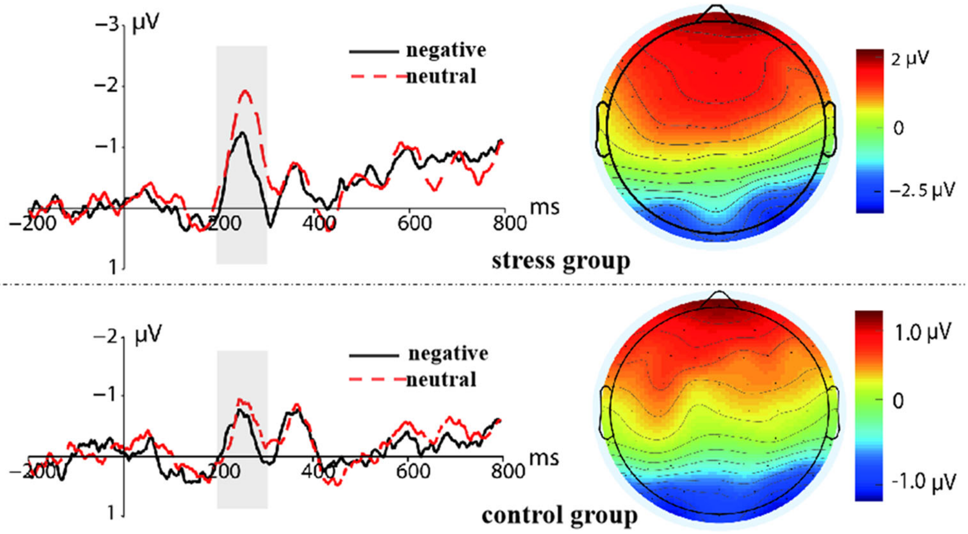

Fig. 8. T2 EPN waveforms and topography. The T2-locked difference waveforms obtained by subtracting T2 empty screen (not present) from the conditions of T2 appearance in lag2 and averaged across temporo-occipital regions electrode sites (PO5, PO6, PO7, PO8). Topographic map display the scalp distributions during the EPN time windows. The waveform and topographic map above is for the stress group and the below is for the control group

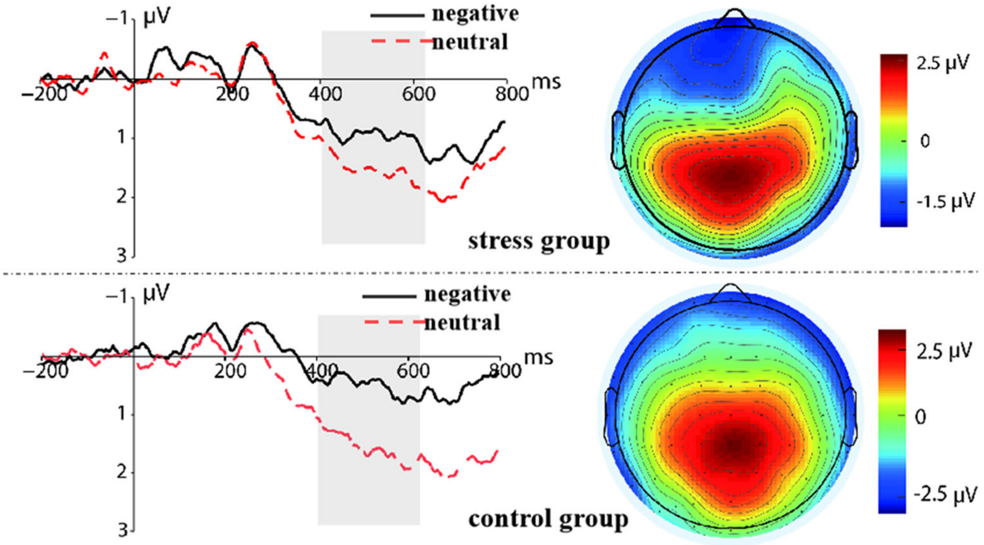

Fig. 9. T2 LPP waveforms and topography. The T2-locked difference waveforms obtained by subtracting T2 empty screen (not present) from the conditions of T2 appearance in lag2 and averaged across electrode sites (CPz, Pz). The waveform above is for the stress group and the below is for the control group. Topographic map display the scalp distributions during the LPP time windows. The waveform and topographic map above is for the stress group and the below is for the control group

between cortisol level and the accuracy of T2 at lag2 following negative T1 ($r = 0.348$, $p = 0.051$). Overall, there was a tendency that the higher the level of negative affect and cortisol caused by stress, the more the processing of T2 will be promoted.

Discussion

The present study examined the time-sensitive effects of acute stress on EAB using electrophysiological measures. The cortisol data showed that the stress group participants were continuously exposed to psychological stressors until the end of the experiment. The behavioral results revealed that the acute stress reduced AB and the main conclusion was consistent with the previous studies (Kan et al., 2019; Schwabe & Wolf, 2010). However, the reduction in AB occurred only when T1 was neutral. At the electrophysiological level, we found that stress increased the T2 selective attention process in the early stage, which was manifested as greater EPN amplitude induced by stress. For the late stage, stress reduced the LPP amplitude of T1. Nevertheless, the LPP of T2 was not sensitive to the stress. The ERP results of acute stress on AB are consistent with the trade-off effect between T1 and T2; that is, stress reduced the T1 late working memory consolidation and improved the T2 early selective attention process. Correlation analyses further confirmed the positive effect of cortisol and negative emotional state on AB performance. In general, acute stress contributed to dissociated consequences on AB in the early and late stages, and stress did not change the central resource limitation of AB.

Effect of stress on EAB

The current experiment revealed the classic EAB effect, that is, a negative T1 could result in a worse accuracy of T2 reporting compared with the neutral T1 (Mathewson et al., 2008). Consistent with the results of previous studies, a negative T1 induces higher EPN and LPP amplitudes, indicating that the emotional stimuli are preferred for processing and better consolidating into working memory (Keil, Ihssen, & Heim, 2006; Macleod et al., 2017; McHugo, Olatunji, & Zald, 2013; Vogt et al., 2008). According to the orientation of limited central resource (Chun, & Potter, 1995; Jolicoeur, & Dell'Acqua, 1998; Potter et al., 2002), the T1 and T2 share the common resources, the processing of a negative T1 will lead to even fewer resources available for T2 compared with a neutral T1 and, therefore, result in poorer performance. Thus, the EPN and LPP amplitudes induced by T2 at the lag2 following a negative T1 is lower than those following a neutral T1 (Macleod et al., 2017; McHugo et al., 2013). In fact, during the AB time windows, the early and late amplitudes induced by T2 are both suppressed because the AB arises from the lack of conscious processing (Luo et al., 2010; Vogel et al., 1998; Vogel, & Luck, 2002). The boost and bounce model of attention also can be used to explain the EAB effect. The model argues that the AB phenomenon is formed from the strong inhibitory feedback response (bounce) caused by the accidentally boost of the distractor after the target, which actually shuts down the gate of working memory (Olivers & Meeter, 2008). Thus, a bigger boost on a negative T1 might lead to a bigger bounce on the following T2 compared with a neutral T1.

The current study found that stress reduced the AB, which is consistent with the only two studies about the effect of stress on the emotional modulation of AB (Kan et al., 2019; Schwabe & Wolf, 2010). The stress hormone norepinephrine and the sustained effects of cortisol may play an important role in facilitating attention processing (Benedetto, Strange, & Dolan, 2008; Joëls, Sarabdjitsingh, & Karst, 2012; Roelofs, Bakvis, Hermans, Pelt, & Honk, 2007). In addition, the results showed that this enhanced processing only for neutral trials under stress and not for negative trials, which may be due to the reallocation of attention to an opposite valence (neutral stimuli) during a threatened state (Vermeulen, Pleyers, Mermillod, Corneille, & Schaefer, 2019). The stress experience is also an additional distraction for the performance of the AB task. Indeed, even after removing the stressor, participants experience the TSST may be continuously ruminating over their performance, which produces a diffuse mental state. Olivers and Nieuwenhuis (2006) found that the distraction caused by additional tasks could improve the AB task performance. This is likely one of the reasons for the reduced AB performance under stress.

Early posterior negativity affected by stress

We found that the EPN amplitudes induced by T2 in the stress group at lag2 following a neutral T1 were higher compared with that in the control group. That is, the stress enhanced the early EPN component under neutral conditions during the attentional blink time window. Previous studies have revealed that the EPN reflected the early target selection process at the level of consciousness (Kennedy et al., 2014; Macleod et al., 2017; Woodman et al., 2009). This means that the individuals under stress could better select the task-related information among distractors for more elaborate processing in the second stage. The results of this stage further support the boost and bounce model, that is, stress promotes a rapidly responding gating system to better filter irrelevant information, thus enhancing the selective attention processing (Olivers, & Meeter, 2008). As expected and consistent with the literature, the present findings revealed that stress promotes the early target selection. Dierolf et al. (2017) found that stress enhanced the early N2 amplitudes in healthy men, which means that the premotor response inhibition and conflict monitoring were strengthened by stress. This can be understood as stress being better able to suppress distractions and prompt individuals to concentrate on the current task (Chajut, & Algom, 2003; Hoskin, Hunter, & Woodruff, 2014). The significant increase in theta wave energy in the frontal-central region also supported the effect of stress on focusing attention (Lin, King, Fan, Appaji, & Prasad, 2018). As a matter of fact, elevated levels of norepinephrine caused by stress greatly promote the early selective attention processing (Aston-Jones & Cohen, 2005; Benedetto et al., 2008). Acute stress also facilitates the early attention processing of alcohol images in social drinkers by shortening the latency and enhancing the amplitude of the N2 component (Ceballos, Giuliano, Wicha, & Graham, 2012). In general, stress can improve the early selective attention process of task-relevant information, as reflected by EPN/N2.

In our study, stress increased the EPN amplitude at lag2 under neutral conditions, which was no different from that at lag8, indicating that stress almost completely restored the AB. Moreover, this facilitation effect of stress on T2 only appears under neutral conditions, not under negative conditions. Several studies have confirmed that individuals have a more severe attentional bias to threat stimuli under stress, resulting from the delayed disengagement toward threat (Luo et al., 2019; Macatee, Albanese, Schmidt, & Cougle, 2017; Nelson, Purdon, Quigley, Carriere, & Smilek, 2015; Wirz, & Schwabe, 2020), which makes it difficult to shift attentional resources from T1 to T2. Therefore, the person under stress needs to make every effort to deal with the resource occupation and attention release of negative T1, leading to insufficient resources for the early selective attention processing of T2.

Late positive potential affected by stress

Unlike the effect of stress on the early EPN component, none of the group-related effects were significant for the LPP amplitudes induced by T2; namely, stress was not sensitive to the late processing stage of AB. The LPP is thought to the number of P3 family indexing working memory consolidation (Dell'Acqua et al., 2015; Dierolf et al., 2017; Kranczioch et al., 2007; Vogel, & Luck, 2002). This means that the T2 encoding into the working memory was not affected by stress. Our result may be associated with undifferentiated processing for negative and neutral T1. Indeed, previous studies have found that stress enhanced temporal attention for neutral and emotional stimuli to the same extent (Kan et al., 2019; Schwabe & Wolf, 2010). The current study further confirmed that the undifferentiated processing appears in the late working memory consolidation stage. Specifically, in EAB studies, T2 processing is regulated by the resource allocation caused by the emotionality of T1. According to the current study's results for LPP, no interaction occurred between stress and emotionality of T1, which indicates stress does not affect the processing of negative or neutral T1 differently. In Alomari, Fernandez, Banks, Acosta, and Tartar's (2015) study, during the late period after exposure to stress, cortisol concentration reached its peak, and the cortisol level of stress group was significantly higher than that of the control group. They found that the high level of cortisol induced indiscriminately processing for negative and neutral stimuli reflected by LPP during the late period after exposure to stress (Alomari, et al., 2015). Indeed, previous studies have shown that stress or threat of shock increases the activation of the extrastriate visual cortex and amygdala (Joëls, & Baram, 2009; Shackman, Maxwell, McMenamin, Greischar, & Davidson, 2011; van Marle, Hermans, Qin, & Fernández, 2009), and a higher cortisol level could induce the greater intensity of threat detection and amygdala activity (Joëls & Baram, 2009; Roozendaal, Okuda, Zee, & McGaugh, 2006). It also may reduce the specificity of emotional information recognition, leading to indiscriminate processing of negative and neutral stimuli (Clewett, Schoeke, & Mather, 2013; Henckens, Wingen, van, Joëls, & Fernández, 2012). Therefore, stress has no effect on T2 memory encoding in EAB.

Moreover, the results showed that stress significantly reduced LPP amplitudes induced by T1. This might be associated with the impairment of prefrontal function caused by a high concentration of catecholamines and glucocorticoids (Diorio, Viau, & Meaney, 1993; Grundemann, Schechinger, Rappold, & Schomig, 1998; McEwen, & Morrison, 2013), which leads to the deterioration of working memory performance. The finding that shock-induced anxiety impairs the encoding of facial recognition of different emotions further supports the results (Bolton, & Robinson, 2017). Combining the results of the early and late stages, we found that stress did not lead to abnormal attention processing at the conscious level. The decrease in LPP amplitudes for T1 successfully improved the processing of T2, which demonstrates better selective attention of T2.

Stage characteristic of acute stress on the AB at the electrophysiological level

The present study was the first to examine the underlying electrophysiological mechanism of stress on EAB and found a dissociable effect in early- and late-stage attention processing. Stress improves the T2 early selective attention process under neutral conditions but has no effect on the T2 late target working memory consolidation. The idea of limited central resources suggests that the individual processing of a series of items involves two different stages for each item (Chun, & Potter, 1995; Jolicoeur, & Dell'Acqua 1998; Potter et al., 2002). The capacity of the first stage is not limited. All items undergo an initial sensory processing here, but this processing is very fragile and easily fades. Only items that enter the second stage for more detailed processing can be accurately reported. Thus, T1s and T2s need to compete for limited resources to be processed in the second stage. Specifically, in the second stage, the individuals first need to select the target consciously from many distractors and then encode it into working memory. Under stress, there are fewer available resources for T2 early processing after a negative T1 than a neutral T1 (Luo et al., 2019; Macatee et al., 2017; Nelson et al., 2015); hence, stress increases target selection in the second stage only under the neutral condition. The emotional information confusion in the second stage of working memory consolidation leaves the same resource for T2 processing (Alomari et al., 2015); therefore, stress does not affect this process. Taken as a whole, the stage characteristics of acute stress on AB demonstrate the trade-off effect. In this study, stress impaired working memory consolidation of T1 and increased the selective attention process of T2 at the conscious level, conforming to the trade-off effect. In other words, worse processing of T1 was accompanied by better processing of T2.

It is generally believed that targets need to go through a consolidation phase in working memory before being successfully reported. At first glance, the current results of stress insensitive to the LPP amplitude induced by T2 seem to be inconsistent with the two previous studies, which showed a facilitation effect of stress on AB at the behavioral level (Kan et al., 2019; Schwabe & Wolf, 2010). Indeed, the LPP only reflects the consolidation stage of working memory, while the accurate reporting of a target requires a combination of various stages, including the initial sensory perception processing, selective attention, and target consolidation into working memory. The results of this study further illustrate that the promotion of stress on AB mainly comes from the improvement of the early target selection, which provides a prerequisite for the consolidation of targets into working memory.

Limitations and future directions

The study is the first to investigate the stage characteristics of stress on temporal attention with ERP measures. Because of the specificity of perception and attention processing in the millisecond time frame, as well as the insufficient literature, there are still some shortcomings in this research that need to be further explored. Specifically, we focused on the interaction of the stress state and T1emotion on neutral T2s. However, the present study did not examine the role of stress when T2 is emotion-inducing. Schwabe et al. (2011) indicated that an emotional T1 and T2 represent different neural structures; that is, the capturing and maintenance of attention. Therefore, future studies should clarify the emotional modulation of the AB under stress with electrophysiological measures when T2 contains emotional information. Indeed, stress is the sum of physiological responses and subjective experiences. The current experiment only considered the acute stress response on the emotional modulation of AB and ignored the influence of past subjective stressful experiences. Studies have shown that a previous subjective stressful experience could affect an individual's assessment of the current situation (Calvo & Gutiérrez-García, 2016), thus changing cognitive functioning and the related neural substrates (Lennart, Florian, & Zsuzsika, 2018). Therefore, the previous subjective stressful experience should be taken into account to assess the impact of stress on attentional processing.

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Open practices statements None of the data or materials for the experiments reported here is available, and none of the experiments was preregistered.

Compliance with ethical standards

Declaration of interest No financial interest or benefit has arisen to the authors from the direct application of the research described in this report.

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