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Long-term academic stress increases the late component of error processing: An ERP study

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ABSTRACT

Exposure to long-term stress has a variety of consequences on the brain and cognition. Few studies have examined the influence of long-term stress on event related potential (ERP) indices of error processing. The current study investigated how long-term academic stress modulates the error related negativity (Ne or ERN) and the error positivity (Pe) components of error processing. Forty-one male participants undergoing preparation for a major academic examination and 20 non-exam participants completed a Go–NoGo task while ERP measures were collected. The exam group reported higher perceived stress levels and showed increased Pe amplitude compared with the non-exam group. Participants' rating of the importance of the exam was positively associated with the amplitude of Pe, but these effects were not found for the Ne/ERN. These results suggest that long-term academic stress leads to greater motivational assessment of and higher emotional response to errors.

1. Introduction

Exposure to sustained stress has a variety of consequences on the brain, cognition, and behavior. Both human and animal research has revealed that while declarative memory retrieval and executive functions may be impaired (Cho, 2001; Cho, Ennaceur, Cole, & Suh, 2000; Liston, McEwen, & Casey, 2009; Morgan, Doran, Steffian, Hazlett, & Southwick, 2006), emotion-related functions such as emotional reactivity, emotional learning, aggressive behavior, and orientation to threat may be enhanced (Lederbogen et al., 2011; Schwabe, Joels, Roozendaal, Wolf, & Oitzl, 2012; Sprague, Verona, Kalkhoff, & Kilmer, 2011; for reviews see Lupien, McEwen, Gunnar, & Heim, 2009; and Starcke & Brand, 2012). In the real world, errors are often considered potential sources of threat and can activate defensive motivation systems (Hajcak, 2012; Weinberg, Riesel, & Hajcak, 2012). Thus error processing has an important significance to an individual's adaptation and survival, especially in situations of environmental change and stress. Little, however, is known about how long-term stress modulates error processing.

Error processing constitutes a chain of dynamic neurocognitive processes including error monitoring and behavioral adjustment, involving continuous checking of ongoing actions, enhanced attention to error, and mobilization of cognitive control and corrective action (Gehring, Goss, Coles, Meyer, & Donchin, 1993; Gehring, Liu, Orr, & Carp, 2012; Ullsperger, 2006). Evidence from electroencephalography (EEG) studies has suggested two major response-locked components of error processing, the error-related negativity (Ne or ERN) and error positivity (Pe) (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1990, 1991). Although both components are observed after errors are committed, dissociations have been found in terms of timing, cognitive significance, and the neural sources underling these two error related components. The Ne/ERN presents as a negative deflection occurring 0–100 ms following an erroneous response (Falkenstein et al., 1991; Gehring et al., 1993), representing the automatic detection of errors or a mismatch between the actual response and the required response, and reflects this comparison process itself rather than the

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outcome of the response (Botvinick, Cohen, & Carter, 2004; Falkenstein, Hoormann, Christ, & Hohnsbein, 2000). Following the Ne/ERN, the Pe presents as a positive deflection 200–400 ms after an erroneous response (Endrass, Klawohn, Preuss, & Kathmann, 2012; Falkenstein et al., 2000; Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001; Van Veen & Carter, 2002b). The Pe represents a later aspect of error processing reflecting conscious error recognition or subjective motivational significance/emotional assessment of errors (Boksem, Tops, Wester, Meijman, & Lorist, 2006; Dhar, Wiersema, & Pourtois, 2011; Endrass et al., 2012; Falkenstein et al., 2000; O'Connell et al., 2007; Overbeek, Nieuwenhuis, & Ridderinkhof, 2005; Shalgi, Barkan, & Deouell, 2009; Van Veen & Carter, 2002a, 2002b).

Although both Ne/ERN and Pe are distributed around the fronto-central scalp area and have been localized to the anterior cingulate cortex (ACC) (Bediou, Koban, Rosset, Pourtois, & Sander, 2012; Ladouceur, Dahl, & Carter, 2007; Miltner et al., 2003), some studies suggest that the Ne/ERN is generated specifically by a caudal region of the ACC (O'Connell et al., 2007; Van Veen & Carter, 2002b). The source of the Pe, by contrast is less well understood. A variety of sources have been suggested, including more posterior cingulate cortex (Vocat, Pourtois, & Vuilleumier, 2008), posterior cingulate–precuneus (O'Connell et al., 2007) or supplementary motor area (Reinhart, Carlisle, Kang, & Woodman, 2012). Other results suggested the rostral ACC, an area often associated with affective processing and emotion regulation, as the source of the Pe (Bush, Luu, & Posner, 2000; Devinsky, Morrell, & Vogt, 1995; O'Connell et al., 2007; Reinhart et al., 2012; Van Veen & Carter, 2002b).

Studies have suggested that a wide range of mental disorders or psychological characteristics is associated with altered error processing. A number of studies have reported that Ne/ERN amplitude could be decreased by disorders such as borderline personality disorder (Ruchsow et al., 2006), and autism spectrum disorders (South, Larson, Krauskopf, & Clawson, 2010). Some studies have suggested an overactive early error monitoring as revealed by enhanced Ne/ERN in obsessive–compulsive disorder (Endrass, Klawohn, Schuster, & Kathmann, 2008); major depressive disorder (Chiu & Deldin, 2007; Holmes & Pizzagalli, 2008), and high trait anxiety (Hajcak, McDonald, & Simons, 2003). Pe amplitude can be reduced in major depressive disorder (Olvet, Klein, & Hajcak, 2010; Schrijvers et al., 2008). By contrast, research has also suggested increased amplitude of Pe with increased concern over mistakes (Schrijvers, De Bruijn, Destoop, Hulstijn, & Sabbe, 2010;Tops, Koole, & Wijers, 2013), with increased anxiety in healthy individuals (Chang, Davies, & Gavin, 2010), and with higher negative state affect under social evaluative stress (Cavanagh & Allen, 2008), suggesting an increased conscious evaluation after making an error. Despite considerable evidence suggesting that psychological factors can modulate error processing, to our knowledge, however, no studies have evaluated these error-related neurophysiological responses in healthy humans exposed to daily-life stressors.

The present study investigated how exposure to the long-term stress of preparation for a major examination (National Postgraduate Entrance Exam, NPEE) affects error processing indexed by the Ne/ERN and Pe. The NPEE is one of the most important and highly competitive exams within the Chinese educational system. The acceptance rate into a graduate program following this exam is <33% over the last ten years, and students spend about 6 months to effortfully prepare for this exam (Freekaoyan.com, 2011). The high importance and low acceptance rate based on examination performance make this examination a good model of long-term stress in an otherwise healthy population. Previous literature has established examination preparation as a long-term stressor (e.g., González-Cabrera, Fernández-Prada, Iribar-Ibabe, & Peinado, 2013; Liston et al., 2009). As previous research has demonstrated altered error processing associated with negative affect, we predict that exposure to a long-term stressor, such as preparation for a major examination, should also alter error processing. Specifically, we predicted increased Ne/ERN and Pe amplitude for the exam-group compared with the non-exam group.

2. Methods

2.1. Participants

Considering the well-documented sex differences in stress responses (Backovic, Zivojinovic, Maksimovic, & Maksimovic, 2012; Stroud, Salovey, & Epel, 2002), only male students were recruited through advertisements in Wannan Medical College. Sixty-one healthy students participated in this study, among them 41 participants were in the exam group and 20 participants were in the non-exam group. Students chose to prepare for this exam or not according to their own academic plan at that time. For the non-exam group, the participants had not taken part in any major exam/interview within one month before or after participation in the study and reported no other major stressors during the past month, as assessed by the Life Events Scale (LES) (Tennant & Andrews, 1976; Zhang & Yang, 1999). For the exam group, participants were also assessed with the LES to exclude other major life stressors. The exam group and non-exam group were matched with respect to age; the mean age of the exam-group was 22.49 ± 0.98 years; mean age of the non-exam group was 22.62 ± 1.10 years. The data from an additional two participants were discarded because of too few false alarm trials and/or excessive movement artifacts. All participants gave written informed consent and were paid for their participation. This experiment was approved by the Ethics Committee of Human Experimentation in the Institute of Psychology, Chinese Academy of Sciences.

To ensure that the observed differences between the groups are not due to pre-existing trait factors, we also measured their personality trait scores as described in the *questionnaires* section. Moreover, all these participants were male medical students from the same university and all of them had passed the same entrance requirements such as the university entrance exam, which minimizes the likelihood that the observed group differences can be explained by field of study or intelligence related factors.

2.2. Stimuli

Two letters ("O" and "X") were presented one at a time in the center of the screen with a visual angle of approximately 2.5° vertically and 2.2° horizontally.

2.3. Experimental procedure

This study reports the results obtained from a larger study addressing the relationship between long-term academic stress and cortisol response/cognition (Duan et al., 2013). Between 11 and 25 days before the National Postgraduate Entrance Exam (NPEE), all qualified subjects came to the experiment room and completed questionnaires. Next, participants were seated in a normally illuminated room. After an initial practice block of 20 stimuli, two experimental blocks each consisting of 240 stimuli (20% NoGo and 80% Go probability) were completed with 1–2 min breaks between blocks. Stimuli were presented for 150 ms with a random interstimulus interval of 1200–1500 ms. During each trial, one of the two letters was presented, and either a response (Go) or the withholding of a response (NoGo) was required. Participants were asked to respond as soon as possible on "Go" trials by pressing a button on the keyboard with the right index finger. The consecutive presentation of two Nogo trials was avoided. The association of stimuli and Go–NoGo responses was counterbalanced across participants.

2.4. Questionnaires

Long-term psychological stress was assessed with Cohen's Perceived Stress Scale (PSS) (10-item version) (Cohen, 1988; Wang et al., 2011). Personality traits, including openness, conscientiousness, extraversion, agreeableness, and neuroticism, were assessed by the Big Five Personality Scale (Donnellan, Oswald, Baird, & Lucas, 2006; Zhang, Shi, Zhao, & Wang, 2012). We also collected information on the duration of effortful preparation for the exam before participating in the experiment. Additionally, we asked three exam-related questions of the exam group, each on a 7 point scale: (1) Importance question: How much do you think that success on this exam will affect your life development? (1 totally no influence; 7 very large influence); (2) Back-up plans question: Do you have any back-up plans if you do not do well on the NPEE? (1 no back-up plan; 7 detailed back-up plan); (3) Stress question: How much psychological stress have you felt while preparing for the NPEE? (1 no stress; 7 very much stress).

2.5. EEG recording and preprocessing

During the Go–NoGo task, the electroencephalogram (EEG) was recorded from 64 scalp sites using Ag/AgCl electrodes mounted in an elastic cap (Neuroscan Inc.,

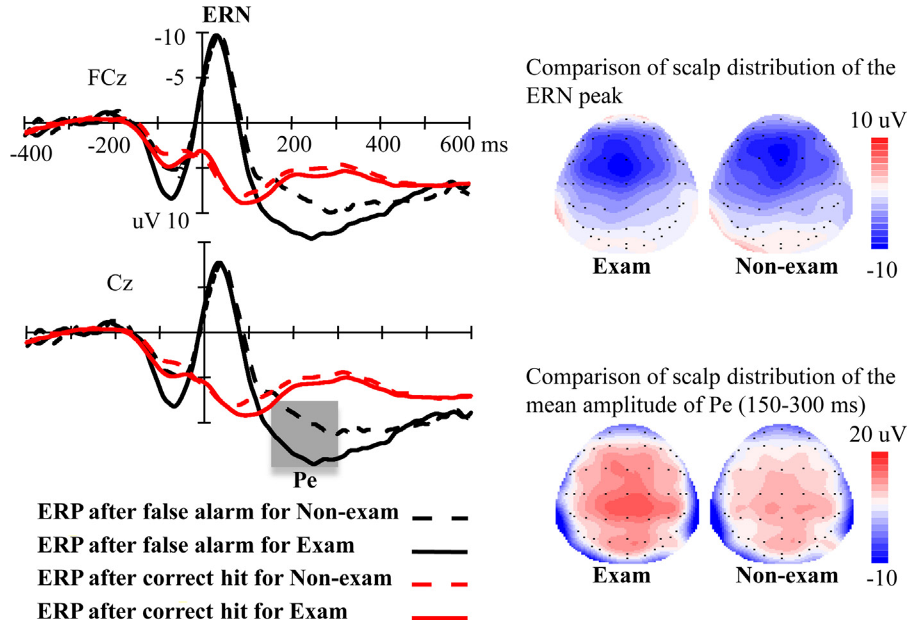

Fig. 1. Left: The ERPs time locked to the false alarm response (black line) and correct hit response (red line) for exam and non-exam group. Right: Comparison of the scalp distribution of the Ne/ERN and Pe between the exam and non-exam group. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Charlotte, North Carolina, USA) (placed according to the international 10–20 system), with an on-line reference to the left mastoid and off-line algebraic re-reference to the average of left and right mastoids. The vertical (VEOG) and horizontal electrooculogram (HEOG) were recorded from two pairs of electrodes, one placed above and below the left eye, and another 10 mm from the outer canthi of each eye. All interelectrode impedance was maintained <5 kΩ. Signals were amplified with a 0.05–100 Hz bandpass filter and digitized at 1000 Hz.

The EEG data were processed by Scan 4.3 software (Neuroscan, USA). Data were digitally filtered with a 30 Hz lowpass filter and were epoched into periods of 1000 ms (including 400–200 ms pre-response time as baseline) time-locked to the onset of button presses. This time window was chosen as the baseline based on previous Ne/Pe research (e.g., Hirsh & Inzlicht, 2010; Olvet & Hajcak, 2009; Riba, Rodriguez-Fornells, Munte, & Barbanoj, 2005) to avoid contamination of the baseline period with stimulus evoked potentials as Fig. 1 shows (i.e., there is a positivity before the response, which likely reflects the stimulus-locked P2 component). Ocular artifacts were removed from the EEG signal using a regression procedure implemented in the Neuroscan software (Semlitsch, Anderer, Schuster, & Presslich, 1986). Trials with various artifacts were rejected, with a criterion of ±100 μV.

2.6. Data analysis

Scores from questionnaires, the behavioral data, and the ERP amplitude/latency were analyzed via independent *t*-tests comparing the exam and non-exam groups. Behavioral data, such as the reaction time (RT) of the correct trials, the rate of omission errors (OE) in Go trials, and the rate of false alarm or commission errors (CE) in NoGo trials, were analyzed. Trials with response times below 50 ms and above 1000 ms were excluded from averaging for correct hit trials.

Only error trials of the NoGo condition (i.e., trials with false alarm) were averaged for Ne/ERN and Pe components. FCz and Cz were selected to measure Ne/ERN and Pe, respectively, where the maximum amplitude was observed for each component. The peak amplitude and latency of the Ne/ERN were measured between 0 and 100 ms after a false alarm response. The mean amplitude of the Pe was measured between 150 and 300 ms after false alarm response.

Pearson correlation analyses (two-tailed) were conducted between ERP measures (amplitude and latency) and PSS across all participants and between ERP measures and each of the three exam-related questions only for the exam group.

3. Results

3.1. Subjective measurements

Students in the exam group prepared for the exam an average of 5.9 ± 2.5 months ($N = 35$, with data from 6 subjects missing) and spent an average of 9.6 h each day preparing for the exam. The exam group reported significantly higher stress on the PSS10 than the non-exam group (17.3 ± 2.6 vs. 14.8 ± 4.8, $t(59) = 2.67$, $p < 0.01$). There were no significant group differences on the five personality traits ($ps > 0.05$). For the exam-related questions, participants generally reported high importance of this exam to their future development (5.0 ± 1.2), that they had some degree of detailed back-up plan(s) besides the NPEE (5.2 ± 1.5), and high mental stress brought on by the exam (4.9 ± 1.2).

3.2. Behavioral data

There were no significant group difference for miss rate (Exam 0.9 ± 1.5%, non exam: 0.7 ± 0.7%; $t(59) = 0.77$, $p > 0.05$), false alarm rate (exam: 24.8 ± 12.6%, non exam: 21.7 ± 9.0%; $t(59) = 0.96$, $p > 0.05$) and hit RT (exam: 293 ± 25 ms, non-exam:2 96 ± 24 ms; $t(59) = 0.40$, $p > 0.05$).

3.3. ERP results and their correlation with other variables

Fig. 1 shows the ERPs time locked to both correct hit response of Go condition and false alarm response of NoGo condition. To exclude a general effect of stress on response, we also measure the visible correct-related positivity at Cz. Results showed no significant difference between groups on the mean amplitude of this positivity (50–200 ms) ($t(59) = 1.20$, $p > 0.05$). We therefore focused our analyses on the ERPs of false alarm trials. There were on average 21 artifact-free trials (range 5–54) for the exam group, and 18 trials (range 7–33) for the non-exam group for ERP averaging. For the Ne/ERN, there were no significant group differences for latency or amplitude ($ps > 0.05$; see Fig. 1). Ne/ERN amplitude and latency were not associated with PSS measures and each of the three exam-related questions ($ps > 0.05$). For Pe, however, the exam group had a significantly larger Pe amplitude compared with the non-exam group (13.5 vs. 9.5 uV, $t(59) = 2.17$, $p < 0.05$; see Fig. 1). Correlation analysis revealed that Pe amplitude was positively correlated with the self-reported importance of the exam ($r = 0.38$, $p < 0.05$), and negatively correlated with the scores of the "Back-up plan" question ($r = -0.36$, $p < 0.05$). No significant correlation was found between Pe amplitude and the stress question ($r = -0.17$, $p > 0.05$) for the exam group; nor were PSS scores associated with the Pe amplitude across all participants ($r = 0.11$, $p > 0.05$) or only exam group ($r = -0.06$, $p > 0.05$).

4. Discussion

The present study investigated how long-term academic stress affects error processing. Participants in the exam group spent about six months preparing for the NPEE and reported significantly higher levels of perceived stress and showed a greater index of post-error processing, reflected by increased Pe amplitude, compared to the non-exam group. Behavioral results did not reveal significant differences between exam and non-exam group for either error rate or reaction times. We focus our discussion on ERP results and their correlation with other variables.

Unexpectedly, for Ne/ERN, there was no significant difference between the exam and non-exam groups. We expected that stress would increase the Ne/ERN, which reflects the automatic detection of errors or a mismatch between the actual response and the required response (Botvinick et al., 2004; Falkenstein et al., 2000). The research literature on the Ne/ERN, however, has reported that Ne/ERN amplitude is sensitive to punishment as indexed by the Behavioral Inhibition System (BIS), but not the response to reward as indexed by the Behavioral Activation System (BAS) (Boksem et al., 2006). The long-term examination preparation in this study can be considered as a challenge stressor within the construct of Challenge- and Hindrance Stress (Cavanaugh, Boswell, Roehling, & Boudreau, 2000), because the exam has great importance for students' future as suggested by self-reported importance of the exam. It has generally been considered that the challenge stressor affects performance and behavior through the reward and motivation system (Cavanaugh et al., 2000; LePine, Podsakoff, & LePine, 2005). The reward/motivation-related state stress in this study, which is analogous to the trait measure of BAS documented by Boksem and colleagues (2006), may not have the sensitivity to modulate the Ne/ERN amplitude.

The exam group produced significantly greater Pe amplitude compared with the non-exam group, suggesting that long-term academic stress modulates the later step of error processing. In the literature, the Pe is thought to reflect conscious error recognition that reflects the subjective motivational significance/emotional assessment of errors (Falkenstein et al., 2000; Overbeek et al., 2005). The increased Pe amplitude in the exam group of the current study might reflect more awareness of the error, specifically, an enhancement of motivation-related attentional allocation to error. This speculation is consistent with the literature suggesting an enhanced emotional response for chronically stressed individuals (Lederbogen et al., 2011; Sprague et al., 2011). Lederbogen et al. (2011) showed that city living people, who were supposed to have higher levels of chronic social stress, showed increased amygdala activity during exposure to an acute social stressor compared to a rural living group. Behavioral research also suggests that perceived chronic stress has a strong association with self-reported aggressive behaviors, and experiences of anger and hostility could mediate this association (Sprague et al., 2011). Our results, however, provide ERP evidence for the relationship between chronic stress and emotional/motivational response to a laboratory induced error.

Another interesting result was that students who placed more importance on the exam and those who reported making less detailed back-up plan showed greater Pe amplitude. This result further suggests that under long-term academic stress, high motivational significance of the stressor leads to greater allocation of attentional resources allocated after making an error. This assumption is also consistent with findings reported by Boksem et al. (2006) showing that the Pe is sensitive to positive motivation and reward as indexed by the BAS.

Our results support the idea that long-term academic stress has a differential impact on the two steps of error processing. The amplitude of the later Pe, but not the earlier Ne/ERN, was sensitive to long-term academic stress. These results also suggest that students under long-term academic stress were more sensitive to a negative event such as making an error. On the one hand, stress may promote behavioral adjustment with the goal of avoiding failure by the activation of the defensive motivation systems. On the other hand, the higher sensitivity to error might be a risk factor for disorders such as mood or anxiety-disorders (Hajcak, 2012), especially when facing long-term stress.

It is worth noting that our observed effects between the exam and non-exam groups cannot be readily explained by other variables that may differ between the groups. The similar personality trait scores between these two groups hinted that the observed differences between the groups are not due to pre-existing trait factors. All participants were medical students from the same university and all of them had passed the same entrance requirements such as the entrance exam a few years ago, which suggest that the observed differences between the groups cannot be explained by the area of studies or other intelligence related factors. The LES helped to exclude participants with other major life stressors, such as economic problems or interpersonal conflict. Even considering these factors, there may be some other variables that differentiate the two groups, such as academic motivation level. However, it is possible that stress and motivation may be affected by and thus be inextricably involved with each other (Kaplan et al., 2002; Park et al., 2012; Simmen-Janevska, Brandstätter, & Maercker, 2012). For example, academic motivation is among the key factors that contribute to academic stress (Park et al., 2012). As we have discussed above, preparing for the NPEE reflects positive motivation and challenge stress arises when positive motivation is needed. Our results suggested that higher level of challenge stress further leads to higher emotional response and greater allocation of attentional resources to laboratory-induced errors.

Our research has some limitations that should be mentioned. First, our study focuses on male students only. It is possible that the effects of long-term academic stress observed in this study might not generalize to a female sample. Second, we only measured the error processing during the examination preparation period. A longitudinal study is needed to exam how these psychological and electrophysiological responses changed over time. Third, results did not show significant correlation between PSS and Pe amplitude. Preparing for the NPEE can be considered as a challenge stressor rather than a more hindrance-related stressor (LePine et al., 2005). The PSS, however, measures the global perceived stress level over the past one month but does not differentiate challenge- and hindrance stress. In future work, biological indices of chronic stress over a longer term, such as hair cortisol (Russell, Koren, Rieder, & Van Uum, 2012), and perceived stress specific to challenge stress should be assessed when measuring the effects of long-term academic stress.

In conclusion, participants undergoing long-term preparation for a major academic examination reported higher perceived stress levels and showed enhanced awareness of the error as indexed by increased Pe amplitude as compared with the non-exam group. Further, the more important the students placed on the exam, the greater amplitude of Pe. These results suggest that long-term academic stress leads to greater motivational assessment of and emotional response to errors.

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