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

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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.,