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Emotional Stroop interference for threatening words is related to reduced EEG delta–beta coupling and low attentional control

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ABSTRACT

Previously, electroencephalographic (EEG) delta–beta coupling (positive correlation between power in the fast beta and slow delta frequency bands) has been related to affective processing. For instance, differences in delta–beta coupling have been observed between people in a psychological stress condition and controls. We previously reported relationships between attentional threat processing and delta–beta coupling and individual differences in attentional control. The present study extended and replicated these findings in a large mixed gender sample ($N=80$). Results demonstrated that emotional Stroop task interference for threatening words was related to self-reported attentional inhibition capacity and frontal delta–beta coupling. There was no clear gender difference for delta–beta coupling (only a non-significant trend) and the relationship between delta–beta coupling and attentional threat-processing was not affected by gender. These results replicate and extend an earlier finding concerning delta–beta coupling and cognitive affect regulation and further clarify relationships between delta–beta coupling, attentional control, and threat-processing.

1. Introduction

Neural activity as reflected in resting state encephalographic (EEG) signal can be represented as a distribution of signal power across different bands in the frequency spectrum. Activity in different frequency bands has been linked to various physiological states and psychological functions (Niedermeyer and Lopes Da Silva, 2004). By convention the delta band (1–3 Hz) is considered to represent slow oscillating neural synchronization, or slow wave (SW) activity, and the beta band (13–30 Hz) represents fast wave (FW) activity. A number of studies suggest that differential activation across the EEG frequency bands may reflect neural processes involved in affect regulation. On the basis of comparative and developmental physiology and a review of functional activity in various brain structures, Knyazev (2007) argues that relationships between SW and FW activity may represent functional cortical/sub-cortical interactions involved in affective processes. In accordance, relationships between SW and FW activity have been found to predict motivational and personality traits (Knyazev and Slobodskaya, 2003; Chi et al., 2005; Knyazev and Slobodskoy-Plusnin, 2009). Others have reported associations between SW/FW ratio and motivated decision making (Schutter and van Honk, 2005a) and inhibited response style for emotional stimuli (Putman et al., 2010).

The SW–FW measure that is of direct interest for the present study is delta–beta coupling, operationalized as positive correlation between delta and beta power. It has been suggested that increased delta–beta coupling may reflect stronger functional coupling between the cerebral cortex and sub-cortical limbic structures (cortical/sub-cortical cross-talk) reflecting emotion-regulation processes (e.g., Schutter and van Honk, 2005b; Schutter et al., 2006; Velikova et al., 2010; Miskovic et al., 2011a, 2011b; Schutter and Knyazev, in press). Frontal delta–beta coupling has been related to salivary concentrations of the stress hormone cortisol (Schutter and van Honk, 2005b). Van Peer et al. (2008) reported that cortisol administration acutely increased frontal delta–beta coupling. Other studies have reported associations between delta–beta coupling and motivational or affective traits (van Peer et al., 2008; Putman, 2011) or state anxiety and stress (Knyazev et al., 2006; Miskovic et al., 2010). Schutter and van Honk (2004) reported decreased delta–beta coupling after administration of the hormone testosterone, a hormone which is known to have various acute effects on affective functioning, including anxiolysis and increased approach motivation (Hermans et al., 2007; Hermans et al., 2008).

Although several converging findings suggest that delta–beta coupling increases in response to acute stressors (Knyazev et al., 2006; Miskovic et al., 2010; Knyazev, 2011), its relationship to affective traits is less clear. For instance, although van Peer et al. (2008) report increased delta–beta coupling in males with increased trait behavioral inhibition (which is closely related to trait anxiety), Velikova et al. (2010) reported reduced delta–beta coupling in anxiety disorder patients (obsessive compulsive disorder patients who as a rule report

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increased trait anxiety; e.g., Foa et al., 1993). The latter would seem consistent with Putman (2011) who reported reduced delta–beta coupling in healthy participants with increased trait anxiety.

Still less is known about relationships between delta–beta coupling and objective measures of affect regulation. We recently studied if delta–beta coupling was related to attentional processing of threatening information (Putman, 2011). A robust finding is that people who are more anxious demonstrate biased automatic selective attention to threat in early stages of attentional processing (for a review, see Bar-Haim et al., 2007). Such early and automatic attention toward threat might result in increasing anxiety via resulting biased cognitive schemata and fearful arousal activation. Specifically when such early vigilance toward threat is followed by later attentional and cognitive avoidance of threat, which would limit opportunities to correct maladaptive cognitions or to obtain habituation through attentive exposure, biased attention to threat may play a causal role in the etiology and maintenance of anxiety disorders (see e.g., Mogg et al., 2004). It is assumed that automatic threat-selective attention is stimulus-driven and operates via more posterior and automatic attentional networks which interact reciprocally with anterior (prefrontal cortical) attention networks and executive cognitive functions that allow more strategic control over attention when anxiety is low (Derryberry and Reed, 2002; Eysenck et al., 2007; Derakshan and Eysenck, 2009). Using a dot probe task, we demonstrated that attentional avoidance of threat pictures in later stages of attentional responding (higher trait anxiety predicted more later threat avoidance) was related to reduced delta-beta coupling (Putman, 2011). Planned sub-samples were created by allocating participants to sub- and supra-median attentional bias groups. The subsample that did not demonstrate attentional avoidance (participants who were evidently less vulnerable to this anxiety-driven attentional response) demonstrated stronger delta–beta coupling than the attentionally avoidant sub-sample whose cognitive performance was more affected by the task-irrelevant emotional stimuli. No significant coupling was observed in the latter group. This finding suggests that strong delta–beta coupling may either reflect reduced stimulus-driven anxious attentional reflex, or enhanced top-down attentional control over such automatic bottom-up responses to threat. This conjecture is supported by findings from van Peer et al. (2008) that cortisol administration (which seems to increase attentional control over automatic attentional processing of task-irrelevant affective information; e.g., Oei et al., 2009; van Peer et al., 2010) acutely increased delta–beta coupling.

The role of attentional control in affect regulation has received increasing interest in the past few years. Derryberry and Reed (2002) developed the Attentional Control Scale (ACS), a self-report instrument which measures trait attentional control and consists, among others, of items that measure attentional inhibition. Attentional inhibition (the ability to sustain attention for goal-relevant information and to inhibit irrelevant information or responses) is an important attentional function in the taxonomy of executive function (Derakshan and Eysenck, 2009; Miyake et al., 2000). Derryberry and Reed reported that anxious participants displayed threat-selective attention but participants who were also characterized by strong attentional control as measured with the ACS were apparently protected against this anxiotypical attentional bias. We also studied these issues and reported that trait anxiety positively predicted avoidance of threatening pictures in an emotional spatial cueing task (Putman et al., submitted for publication). This threat avoidance was stronger in people with low attentional control and moreover, the results suggested that attentional control mediated the association between anxiety and the threat-selective attentional response. Finally, Bishop et al. (2007) reported that attentional control as measured with the ACS predicted stronger prefrontal cortical effort to overcome a sub-cortically driven attentional response to distracting, interfering threat stimuli. Based on the role of attentional control in restraining automatic attention to threat (Derryberry and Reed, 2002; Putman, 2011), the assumption that delta–beta coupling reflects cortical/sub-cortical regulation of affect (Schutter and Knyazev, in press), and because ACS attentional control is related to cortical/sub-cortical regulation of attention during threatening distraction (Bishop et al.), we expected that ACS score should be positively related to delta–beta coupling.

The present study aimed at replicating and extending these previous findings concerning the role of attentional control and delta–beta coupling using another method for measuring threat-selective attention. For this purpose, participants' resting state EEG was recorded before performance of an emotional Stroop task with neutral and threatening words. In an emotional Stroop task, participants are instructed to color-name words that are presented in one of several colors as fast as they can. A typical finding is that anxious participants are slower to color-name these distracting words when their (task-irrelevant) meaning is threat-related, an effect called emotional Stroop interference (Williams et al., 1996; Bar-Haim et al., 2007). This is taken to reflect that anxious participants' attention is automatically drawn toward this emotional information, and/or that they cannot suppress a task-irrelevant and performance-detrimental emotional response to the emotional stimuli (Harvey et al., 2004). This interpretation of emotional Stroop task interference would seem to be closely associated with failure of attentional inhibition. Since the ACS subscale Focus is most closely related to the construct of attentional inhibition, we hypothesized that trait anxiety and the ACS, most notably ACS-Focus, should predict increased interference for threat words as measured with the emotional Stroop task (EST). As in Putman (2011) we predicted a negative relationship between ACS scores and EST interference. We expected that this relationship would be independent from trait anxiety and that ACS score might mediate an association between trait anxiety and interference. Secondly, we predicted that participants with higher ACS scores would demonstrate stronger delta–beta coupling. As a conceptual replication of Putman (2011) we expected that participants who demonstrated more EST interference would also demonstrate reduced delta–beta coupling. Finally, as a direct replication of a finding from our previous study, we also predicted that participants with lower trait anxiety (measured with the trait version of the State/Trait Anxiety inventory (STAI-t; Van der Ploeg et al., 1980; Spielberger, 1983)) would demonstrate stronger delta–beta coupling. As before (Putman, 2011), associations between variables of interest and delta–beta coupling were tested by comparing delta–beta correlations in sub- and supra-median groups for the variables of interest. Since this previous study tested only female participants, we also wished to explore possible gender differences for these relationships between delta–beta coupling and affect and attentional control. These hypotheses were tested in a relatively large sample of unselected young men and women.

2. Methods

2.1. Participants

Thirty three males and 47 females (aged between 17 and 30 years, $M = 19.6$, $SD = 2.4$) provided EEG, EST, and self-report questionnaire data. Males were somewhat older than females: mean age for males was 20.4 ($SD = 2.8$) and for females this was 19.0 ($SD = 2.0$; $t(53.73) = 2.504$, $p = .015$). These participants took part in a larger study wherein also another research question was studied (reported elsewhere) and came to the laboratory on two separate days. The EEG and EST data were collected at the start of the first day and self-report trait questionnaires were completed at the start of the second day. Participants were recruited on campus. Exclusion criteria were history of neurologic illness, dyslexia, and color-blindness.