Biological Psychology 83 (2010) 73–78

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

EEG theta/beta ratio in relation to fear-modulated response-inhibition, attentional control, and affective traits

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ARTICLE INFO

Article history:
Received 10 July 2009
Accepted 27 October 2009
Available online 6 November 2009

Keywords:
EEG
Theta/beta ratio
Inhibition
Approach motivation
Emotion regulation
Attentional control

ABSTRACT

Power density-ratios of fast and slow frequency spectrum-bands can be calculated from resting-state electroencephalography (EEG) recordings. A well-established phenomenon is that slow wave/fast wave ratios (SW/FW) are increased in attention-deficit/hyperactivity disorder. Several researchers have also begun to study relationships between SW/FW and affect. This work suggests that increased SW/FW may reflect reduced frontal cortical control over subcortical affective approach drive. The present study ($n = 28$) aimed to further examine this notion by testing several predictions derived from it. In line with these predictions, SW/FW was found to correlate negatively with fearful modulation of response inhibition in an emotional go/no-go task and with self-reported attentional control. Results also suggested a positive relation between SW/FW and trait approach motivation and a negative relation to anxiety, as predicted. These results are consistent with previous studies and support the notion that SW/FW may provide a useful tool in the study of affect and emotion regulation.

Spectrum analysis can be used to assess a resting-state electroencephalographic (EEG) signal in various conventional frequency bands. The β (beta) band (13–30 Hz) contains fast wave activity and δ (delta; 1–3 Hz) and θ (theta; 4–7 Hz) are slow wave bands. Differences in anterior cingulated cortex-generated θ activity have been related to affect and psychopathology (e.g., Mulert et al., 2007; Christie and Tata, 2009) and relations have been reported between different slow/fast wave measures and transient affect (Knyazev et al., 2005, 2006), motivational traits (Knyazev and Slobodskaya, 2003; Chi et al., 2005), performance on emotional–cognitive experimental tasks (Schutter and van Honk, 2005a), and endocrine measures and manipulations (Schutter and van Honk, 2004, 2005b; van Peer et al., 2008). Schutter et al. hypothesized that small slow/fast wave ratios (SW/FW) may predict anxiogenic (frontal) cortical downregulation of subcortically driven approach motivation and reward-seeking behaviour (see also Knyazev, 2007).

Several studies seem to corroborate this notion. Schutter and van Honk (2004) reported that a single administration of the fear-reducing and approach motivation-promoting hormone testosterone (e.g., van Honk et al., 2004; Tuiten et al., 2002; Hermans et al., 2008) increased frontal δ power, increasing δ/β ratio and diminishing the correlation between δ and β power. These authors also reported that higher SW/FW predicted more approach-driven and less risk-aversive motivated decision-making, suggesting that SW/FW may provide a useful tool to study emotional–cognitive interactions and psychopathology-related individual differences (Schutter and van Honk, 2005a).

The above suggests that SW/FW may be related to inhibition in response to motivationally relevant stimuli and emotional traits. The present study was designed to test various hypotheses in line with these general predictions to further investigate the proposed usefulness of SW/FW research for the study of emotion–cognition interactions and their relation to underlying biological functioning. In order to test if increased SW/FW predicts less fearful or inhibited and more reward-driven behaviour, we measured performance on an emotional go/no-go task. In a go/no-go task, participants are presented with different stimuli (here, pictures of fearful and happy faces) presented in succession on screen. They are instructed to respond as fast as possible to, for instance, a happy face, but to withhold response to a fearful face, or vice versa. These stimuli are termed 'go' and 'no-go' cues, respectively. Because a great majority (e.g., 75%) of the trials presents go cues, task performance is characterized by a predominant tendency to quickly respond and this primary tendency has to be inhibited on the no-go trials. Performance of this task, reflected in response times (RTs) and error patterns, reflects inhibitory control over approach-governed behaviour (Schulz et al., 2007). By examining the effect that the different facial expressions have on go and no-go trials, an index is obtained for the motivational modulation of behavioural approach and

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0301-0511/$ – see front matter
doi:10.1016/j.biopsycho.2009.10.008

inhibition. However, ease of perceptual discrimination can vary for different facial expressions and is reportedly low for fearful faces (e.g., Goeleven et al., 2008). This will likely influence latencies of go/no-go responses, so RT analysis may then be replaced by a signal detection theory measure of response bias, beta (throughout the remainder of this paper, "beta" designates this measure for response bias, while the Greek character β refers to the 13–30 Hz EEG frequency band). Beta (based on probabilities of observed accuracy of performance) provides an estimate of more conservative or progressive response bias (see also Schulz et al., 2007). Fearful facial expressions serve as cues of danger and potential punishment, and so people will demonstrate stronger inhibition and inhibited response bias in reaction to fearful compared to happy faces in an emotional go/no-go task (Hare et al., 2005). The strength of cognitive and neural responses to fearful faces is often positively related to fear and anxiety (e.g., Rauch et al., 2000; van Honk et al., 2002; Fox et al., 2005; Putman et al., 2006). Also for the emotional go/no-go task it can thus be expected that more anxious (and anxiously inhibited) participants will demonstrate greater inhibitory modulation of go/no-go behaviour. The inhibitory control functions that govern go/no-go behaviour are to a large extent based in prefrontal cortical structures and for emotional modulation of go/no-go tasks, amygdala and lateral orbitofrontal cortex have been implicated additionally (e.g., Hare et al., 2005, 2008; Schulz et al., 2007). All in all, the emotional go/no-go task should provide a good experimental tool to study SW/FW and anxious (frontal) inhibition. We hypothesized that participants would demonstrate more inhibited responding to fearful than to happy faces, that this difference would be related to self-reported anxiety or inhibition, and that higher SW/FW would predict attenuation of this adaptive anxiogenic response pattern.

The abovementioned literature on SW/FW also suggests that SW/FW should predict stable affective traits. Specifically, SW/FW should correlate positively to reward-driven motivation and negatively to anxious and inhibited traits. We also hypothesized that SW/FW correlates negatively with a self-report measure of attentional control which is known to predict (inhibitory) attentional control in response to emotional stimuli and distracters (Derryberry and Reed, 2002; Bishop et al., 2007; Koster et al., 2008; Verwoerd et al., 2008; Putman et al., in review). These hypotheses were tested in a sample of healthy young women for comparison with previous studies (which tested only women; Schutter and van Honk, 2004, 2005a,b).

1. Methods

1.1. Participants

Twenty-eight right-handed, medication and drug free healthy young females were tested. Age ranged between 19 and 28 years with a mean of 22.7 (standard deviation = 2.6). Written informed consent was obtained and volunteers were paid for participation. The study was approved by the local review board.

1.2. Materials

1.2.1. Self-report measures

For motivational traits, the Carver and White Behavioural Inhibition and Behavioral Activation (BIS/BAS) scale (Carver and White, 1994) and the trait version of Spielberger's State-Trait Anxiety Inventory (STAI-t; Van der Ploeg et al., 1980; Spielberger, 1983) were used. The STAI-t questionnaire measures a single scale of trait anxiety. The BIS/BAS consists of a scale measuring behavioural inhibition (BIS), and behavioral activation (BAS), comprised of the sub scales BAS Reward, BAS Drive, and BAS Fun Seeking. To assess attentional control, the Attentional Control Scale (ACS; Derryberry and Reed, 2002; Verwoerd et al., 2006) was used. ACS and STAI-t scores are typically negatively correlated (see e.g., Derryberry and Reed, 2002; Bishop et al., 2007; Koster et al., 2008; Putman et al., in review).

1.2.2. Photo stimuli

Photos of facial expressions were selected from the Karolinska's Directed Emotional Faces (Lundqvist et al., 1998). Happy and fearful expressions from 10 male and 10 female actors were selected. Based on a recent validation study (Goeleven et al., 2008), actors with the highest recognition hit rate for fearful faces were chosen. Photos were presented as 9.5 (w) by 12.5 (h) cm rectangles.

1.2.3. EEG set up

EEG data were acquired with a Biosemi ActiveTwo system and digitized at a sampling rate of 256 Hz. Resting-state EEG was recorded with active Ag/AgCl electrodes on the F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4 10/20 positions. Prior hypotheses concerned averaged frontal electrodes (c.f. Schutter and van Honk, 2004, 2005a); central and parietal recordings were done for unrelated and unreported investigative purposes. Electro-oculogram (EOG) was recorded with Ag/AgCl electrodes attached to the supra- and suborbital ridge of the left eye and on the external canthi of each eye. Common mode sense and driven right leg electrodes served as ground and EEG signals were offline re-referenced to the average of the left and right mastoid electrodes high- and low-pass cut-off frequencies were set at .1 and 100 Hz and amplification was set at 20,000 for all leads.

1.3. Procedures

Participants completed the emotional trait questionnaires at home, several days before the testing session. Resting-state EEG was measured in 8 alternating 1 min eyes open/closed recording periods (Allen et al., 2004). After the EEG measurement, participants filled out the ACS before cognitive performance testing.

1.3.1. Emotional go/no-go task

The emotional go/no-go task (EGNG) was programmed as an almost exact replication of the experimental procedure reported in Schulz et al. (2007). The only difference with that study concerns the choice of stimuli: presently happy and fearful faces were used instead of happy and sad faces. Either happy or fearful faces were designated as go and no-go cues in four alternating blocks (see Schulz et al., 2007). Each block presented 96 trials, 72 of which (75%) presented go cues and 24 trials (25%) presented no-go cues in semi-random order. Participants were first given opportunity to practice in two blocks of 8 'happy is go' and 8 'fearful is go' trials, with feedback on accuracy of their performance. Once it was determined that participants could perform the task, the experimental trials started. On each trial, a fixation cross was presented in the centre of the screen for a quasi-random duration of 1250–1750 ms (on average 1500 ms). Then, a face picture was presented for 500 ms. Participants could respond by pressing the down arrow key on the keyboard with the index finger of their right hand during presentation of a face or the subsequent fixation screen. They were instructed to respond to the go trials as fast as possible and to withhold responses to no-go trials, with repeated emphasis on fast responding.

1.4. Data reduction

1.4.1. EGNG data

False alarms (errors of commission) and hits (rightful responses to go cues) were calculated separately for happy = go and fearful = go conditions. For the correct responses to go trials, responses were discarded as slow outliers if RT > 1500. Remaining RTs were used to calculate mean RTs for happy = go and fearful = go conditions separately. For testing of perceptual sensitivity (d-prime) and response bias (beta), z-scores for proportionate hits and false alarms scores were calculated. A few participants had perfect scores in some conditions (proportionate false alarm scores and hit scores are then absolutely 0 or 1, for which z-values can not be given), so for all participants, false alarm scores were first increased with 1 and all hit scores were decreased with 1 before z-transformation. In this way, no data are lost and it is still possible to correlate individual differences in beta and d-prime with other measures. d-Prime was calculated as $z(\text{hits}) - z(\text{false alarms})$. Beta was calculated as $-\{[z(\text{hits}) + z(\text{false alarms})]/2\}$ (see Schulz et al., 2007). A lower d-prime indicates better perceptual sensitivity. For beta, a higher score indicates a more inhibited response bias. To analyze effect of expression condition on response bias, Expression Beta Contrast (EBC) was calculated as the difference between beta for fearful expressions minus beta for happy expressions. A higher EBC indicates a more inhibited response bias for fearful than happy expressions.

1.4.2. EEG data

Raw data were offline referenced to averaged mastoid sites, digitally low-pass filtered (35 Hz), and corrected for eye-movements (Gratton et al., 1983). Data of each minute of recording were subsequently segmented into segments of 4 s each with a 50% overlap. Segments containing residual muscle movements or other forms of artefacts, greater than ±175 μV were rejected prior to further analysis. All segments (eyes open and eyes closed) were collapsed for analysis A fast Fourier transform (Hamming window length 10%) was used to estimate spectral power density (μV^2) for frontal electrodes in the δ (1–3 Hz), θ (4–7 Hz), and β (13–30 Hz) frequency band (resolution 0.25 Hz). δ/β and θ/β EEG ratios were then calculated. Ratios were calculated by dividing slow wave power density by fast wave power density; i.e., θ/β and δ/β. Because of non-normal distribution, power density values and ratios were log-normalized. Finally, ratios for the three frontal leads were averaged to provide a single estimate of frontal SW/FW and the same was done for central and parietal recordings. For statistical tests, a two-tailed alpha of .05 was used unless explicitly stated otherwise.