International Journal of Psychophysiology 80 (2011) 63–68

Contents lists available at ScienceDirect

International Journal of Psychophysiology

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

Resting state EEG delta–beta coherence in relation to anxiety, behavioral inhibition, and selective attentional processing of threatening stimuli

Peter Putman *

Department of Psychology, Leiden University, The Netherlands

ARTICLE INFO

Article history:
Received 25 August 2010
Received in revised form 26 October 2010
Accepted 18 January 2011
Available online 25 January 2011

Keywords:
EEG
Delta–beta coherence
Cross-talk
Selective attention
Anxiety
Behavioral inhibition

ABSTRACT

Variability in human resting state electroencephalography (EEG) may reflect emotion regulation processes (for a review, see Knyazev, 2007). For instance, it has been suggested that correlation between slow (1–3 Hz) and fast (13–30 Hz) activity (or δ–β coherence) may reflect functional synchronization between limbic and cortical brain systems. Indirect support comes from several studies reporting relationships between δ–β coherence and subjectively reported behavioral inhibition and state anxiety. The present study sought to extend this work and tested the prediction that objectively, experimentally, measured threat-selective attention should also be related to δ–β coherence. EEG frequency band power and dot probe task performance were assessed in forty healthy women and results demonstrated a negative association between delta–beta coherence and automatic, anxiety-driven attentional avoidance of threatening pictorial stimuli. These first reported objective measures for cognitive-emotional behavior obtained in relation to delta–beta coherence provide additional support for the hypothesis that this EEG parameter may reflect emotion regulation processes and supports suggestions that δ–β coherence may be a useful tool in the experimental study of affect and psychopathology. In addition, results showed an unexpected negative association between δ–β coherence and self-reported trait anxiety (but no association with behavioral inhibition).

1. Introduction

Neural activity as reflected in resting state encephalographic (EEG) signal can be described as a distribution of signal power across different bands spanning the frequency spectrum. By convention the δ- and θ-frequency bands are considered to represent slow oscillating neural synchronization, or slow wave (SW) activity and the α and β bands represent fast wave (FW) activity. Activity in these frequency bands has been linked to various physiological states and psychological functions (Niedermeyer and Lopes Da Silva, 2004). An increasing number of studies suggest that differential activation across the EEG frequency bands and their topographical distribution can also be linked to affective functioning, such as emotional states and traits or personality factors. For instance, asymmetrical lateralization of α activity has been linked to individual differences in approach-avoidance motivation and affective psychopathology (Harmon-Jones et al., 2010). Relationships between fast and slow spectrum bands have been linked to behavioral inhibition and behavioral activation (Knyazev and Slobodskaya, 2003; Knyazev and Slobodskoy-Plusnin, 2009) and other authors have likewise linked various personality traits to variation of activity in different frequency bands (Chi et al., 2005).

On the basis of comparative 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. Several reports are in line with this view. SW/FW ratios have been linked to affect-related endocrine manipulations (Schutter and van Honk, 2004), motivated decision-making (Schutter and van Honk, 2005a), and personality traits and inhibitory response style for emotional stimuli (Putman et al., 2010a). Other studies have looked at coherence between SW and FW activity. The intriguing suggestion is that increased positive δ–β correlation (δ–β coherence) may reflect stronger functional coherence between the cerebral cortex and sub-cortical limbic structures (cortical-subcortical cross-talk) and may be indicative of emotion-regulation processes. Schutter and van Honk (2005b) reported stronger δ–β coherence in participants with higher levels of the hormone cortisol. Van Peer et al. (2008) reported a positive relationship between trait behavioral inhibition and δ–β coherence. Trait behavioral inhibition is conceptually and empirically closely related to trait anxiety, but the two studies that investigated relationships between anxiety and δ–β coherence only found evidence for relationships with transient state anxiety (Knyazev et al., 2006; Miskovic et al., 2010). One goal for the present study was to assess a possible relationship between δ–β coherence and trait anxiety and replicate evidence for the reported relationship between δ–β coherence and trait behavioral inhibition. However, rather than only study such relationships with self-reported affect, the main goal was to explore relationships between δ–β

* KGN, Wassenaarseweg 52 2333 AK Leiden, The Netherlands. Tel.: +31 71 5274818; fax: +31 71 5274678.
E-mail address: PPutman@FSW.leidenuniv.nl.

0167-8760/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpsycho.2011.01.011

coherence and more objective implicit experimental measures of cognitive affect regulation.

An important cognitive correlate to emotional states and traits is threat-related selective attention. Threat-selective attention, resulting from interactions between cortical and sub-cortical processes of emotion regulation (Eysenck et al., 2007; Monk et al., 2006, 2008) is thought to be an important factor in the aetiology and maintenance of affective disorders (mainly for anxiety disorders; Mogg and Bradley, 1998). Reduced prefrontal control over attentional reflexes during anxious states is thought to allow more automatic influence of task irrelevant threatening stimuli on attention (Eysenck et al., 2007). The vigilance–avoidance hypothesis states that in anxious people a primary involuntary shift toward threatening stimuli is followed by active attentional avoidance of those threatening stimuli, reflecting attempted counter-regulation of the fear activation that resulted from this initially enhanced threat-processing (Mogg and Bradley, 1998). The most widely used method for assessing automatic selective attention to emotional stimuli is the dot probe task which measures response times to target probes appearing in locations that were previously occupied by neutral or emotional cue stimuli. In spatial attentional tasks such as this, one can vary intervals between cues and targets which allows one to study the direction of attentional selectivity as it develops over time (Koster et al., 2005).

In summary, it was expected that attentional avoidance of threat as measured with a pictorial dot probe task, specifically after longer cue-target delays, should be related to δ–β coherence. Also, possible relationships between trait behavioral inhibition and δ–β coherence and trait anxiety and δ–β coherence were investigated. Although some studies suggest that a frontal midline electrode position should be the primary target to test such hypotheses (Schutter and van Honk, 2004, 2005a,b), this is not altogether clear (Knyazev et al., 2006; van Peer et al., 2008) and it was chosen to study lateral as well as midline frontal positions. These predictions were tested by comparing frontal δ–β coherences between healthy young women who scored either low or high on the various predictor variables (behavioral inhibition, trait anxiety, and dot probe attentional bias). Only women were tested for better comparison with the majority of previous reports that have tested associations between affect or cognitive-affective processing and slow and fast EEG power relationships.

2. Methods and materials

2.1. Participants

Forty right-handed and healthy women aged between 18 and 27 years (M = 20.6, SD = 2.1) participated in the study against a small financial compensation or for course credits. Behavioral inhibition (BIS) scores ranged between 16 and 27 (M = 21.9, SD = 3.0, median = 22). Trait anxiety scores (STAI-t scores) ranged between 35 and 59 (M = 41.0, SD = 6.4, median = 39). Written informed consent was obtained and the study was approved by the local review board.

2.2. Materials

2.2.1. Questionnaires

The BIS/BAS scale was used to assess self-reported behavioral inhibition scores (Carver and White, 1994). To assess self-reported trait anxiety, the trait version of the Spielberger State-Trait Anxiety Inventory was used (STAI-t; Spielberger, 1983).

2.2.2. Stimuli

48 neutral pictures (mostly mundane inanimate objects and flora) and 48 threat pictures (mostly scenes depicting interpersonal violence and accidents involving bodily harm) were selected from the International Affective Picture Set (IAPS; Lang et al., 1999) by a panel of psychologists.[1]

2.3. Procedures

When participants came to the lab, the resting state EEG recording was performed first. After that, participants were taken to another lab to complete the dot probe task. After computer testing, the STAI-t and BIS/BAS questionnaires were completed before debriefing.

2.3.1. Dot probe task

In each trial of the dot probe task, first a central fixation cross was shown for 500 ms. Then, two pictures (always one neutral and one threat picture) were presented on screen simultaneously, one above and one below the fixation cross. The pictures measured 150 mm width by 80 mm height; their centers were located 110 mm above and below the center of the screen. After a variable cue-target delay (~150, 500, or 1500 ms) followed by a blank screen shown for 17 ms, a target appeared in the center of the location previously occupied by the upper or lower picture. This target was always the letter E or F (measuring 4 (w) by 6 (h) mm) and participants had to indicate (by pressing one of two standard mouse buttons) which letter it was. After response, the screen would go blank for 1 s before another trial would start with presentation of the fixation cross. On half of the trials target position coincided with the position of the threatening picture (a congruent trial) and on the other trials (incongruent), the target appeared in the location of the neutral picture. There were 144 experimental trials in total, containing 24 congruent and 24 incongruent trials for all three cue-target delay conditions. Selection of all pictures occurred randomly with each picture being presented three times. Target type, location of emotional picture and target location (below or above the fixation cross), and cue-target delay were all counterbalanced and trials were presented in random order. Participants were instructed to look at the fixation cross when it appeared and to discriminate the target as fast as possible without sacrificing accuracy. Eight practice trials were done before performance of the 144 experimental trials. Participants sat at a viewing distance of ~60 cm.

2.3.2. EEG recording

Eight minutes of alternating 1-minute eyes open/eyes closed resting state EEG recordings were acquired with a Biosemi ActiveTwo system and digitized at a sampling rate of 256 Hz (Allen et al., 2004). Frontal Ag/AgCl electrodes were applied on the F3, Fz, and F4 10/20 positions. Electro-oculogram 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.

2.4. Data reduction and statistical analyses

2.4.1. Dot probe data

First, all trials with inaccurate responses were removed (on average 1.3%). Then, trials with a response time (RT) <300 or >900 ms were removed as premature responses or RT outliers due

[1] The IAPS pictures that were used were #s 1333, 1450, 1500, 1590, 1740, 1812, 2191, 2235, 2514, 2745.1, 5000, 5010, 5130, 5390, 5510, 5520, 5530, 5531, 5532, 5535, 5600, 5621, 5628, 5629, 5660, 5711, 5720, 5731, 5764, 5800, 5891, 2594, 7900, 7493, 7920, 7035, 7036, 7041, 7052, 7057, 2593, 7160, 7179, 7205, 7211, 7230, 7490, and 7547 for neutral stimuli and #s 3216, 6530, 6022, 7361, 9421, 6825, 9622, 9592, 6830, 9611, 6560, 9635.2, 9903, 9429, 3215, 9254, 6540, 9471, 6838, 9902, 6021, 3500, 6610, 3530, 9912, 3550.1, 9911, 6561, 6313, 6800, 9160, 6821, 9495, 9230, 9250, 9435, 6836, 6241, 6314, 3180, 6571, 9419, 6510, 6242, 9050, 9427, 9620, and 6370 for negative stimuli (see Lang et al., 1999).