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Cognitive Brain Research 24 (2005) 685 – 690

COGNITIVE BRAIN RESEARCH

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Research Report

Electrophysiological ratio markers for the balance between reward and punishment

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Accepted 6 April 2005
Available online 3 May 2005

Abstract

It has been argued that prototypical forms of psychopathology result from an imbalance in reward and punishment systems. Recent studies suggest that the ratios between slower and faster waves of the electroencephalogram (EEG) index this motivational balance and might therefore have diagnostic value for psychopathology. To scrutinize this notion, the present study investigated whether resting state EEG ratios would predict decision making on the Iowa gambling task (Iowa-GT), a well-known marker for motivational imbalance. A resting state EEG recording was acquired followed by the Iowa-GT in twenty-eight healthy right-handed volunteers. Results showed that higher versus lower EEG ratios were associated with disadvantageous versus advantageous decision making strategies indicating motivational imbalances in reward- and punishment-driven behavior, respectively. This finding provides the first direct evidence that the electrophysiologically derived EEG ratios can serve as biological markers for balance and imbalance in motivation.

Theme: Neural basis of behavior
Topic: Motivation and emotion

Keywords: Beta; Decision making; Delta; Electroencephalogram (EEG); Iowa gambling task; Motivation; Punishment; Ratio; Reward; Theta

1. Introduction

Prototypical forms of psychopathology such as psychopathy and anxious depression are characterized by an imbalance in the reward and punishment systems [6]. This motivational imbalance in psychopathy is observed as increased reward against reduced punishment sensitivity [4], whereas in anxious depression punishment sensitivity is high while sensitivity for reward is low [14]. The most established behavioral marker for motivational imbalance is the Iowa gambling task (Iowa-GT), a game in which decisions to choose from decks of cards become motivated by inherent reward and punishment schedules [2]. Illustrative for the reward-driven motivational imbalance in the Iowa-GT is disadvantageous decision making observed in clinical and subclinical psychopathic individuals on one hand [4,26], whereas the punishment-driven motivational imbalance in subjects with anxious depressive symptomatology results in advantageous decision making [26]. Human brain studies have indicated that a hypoactive prefrontal cortex (PFC) accompanies a reward-driven motivational imbalance [3], while a hyperactive PFC favors the processing of punishments [15].

Resting state EEG is a method that is able to capture personality characteristics, such as approach and withdrawal-related motivation [8], behavioral inhibition [9], and behavioral activation [13]. Research within the field of affective neuroscience has provided support for energetic-type models, in which resting state EEG is linked to motivational brain states [17]. While resting state frontal EEG asymmetries have traditionally been used for studying brain–emotion relationships [8,9,13,17,24], recently new indices have been developed that might more directly tap into the motivational circuitry. Psychophysiologists have

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0926-6410/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.cogbrainres.2005.04.002

suggested that the ratio between resting state PFC θ (4–7 Hz) and β (13–30 Hz) activity in the electroencephalogram (EEG) might give insights into the mechanisms of imbalanced motivational processing in the PFC [1,5]. For example, increased θ/β ratio has been observed in children with attention deficit/hyperactivity disorder (ADHD) [1], who seem to display a pattern of high-risk disadvantageous decision making on the Iowa-GT [11]. Furthermore, Schutter and Van Honk [21] recently provided evidence that a similar relationship might be present between the δ (1–3 Hz) and β oscillations. In a double-blind placebo-controlled crossover design, a single administration of testosterone (T) augmented frontal δ, but not β activity (i.e., resulting in a larger δ/β ratio) accompanied by a decoupling between δ and β activity. These findings were interpreted in terms of the anxiolytic effects of T, hence releasing reward drive. Indeed, an earlier study of Van Honk et al. [27] showed increased high-risk disadvantageous decision making on the Iowa after T administration in healthy volunteers, indicative for a shift in motivational balance towards more reward and reduced punishment sensitivity. Slow δ and θ waves have been linked to subcortical brain regions involved in affective processes [12,15], whereas fast β activity that is argued to reside at the thalamo-cortical and cortico-cortical level [18] has been associated with cognitive control processes.

A direct comparison between frontal δ/β and θ/β EEG ratios and motivational balance has to our knowledge never been reported. Such a comparison is of interest because distilling electrophysiological signatures of motivational imbalance might contribute to fundamental empirical research and have diagnostic applications in psychiatry.

The present study follows from prior research investigating the electrophysiological correlates of motivation, emotion, and decision making [15,21,22,24]. The specific aim of the current study was an attempt to establish a link between fundamental research and clinical research in search for biological markers for the balance between the sensitivity for punishment and reward. To obtain further insights, we investigated whether resting state frontal δ/β and θ/β EEG ratios would be associated with Iowa-GT performance in young healthy volunteers. It was hypothesized that if resting state frontal δ/β and θ/β EEG ratio can serve as electrophysiological signatures for motivational balance, then increased versus decreased resting state EEG ratios would be predictive for disadvantageous and advantageous decision making, respectively.

2. Materials and methods

2.1. Subjects

Twenty-eight healthy right-handed female students (mean age = 20 years, SD = 1.86) were recruited at Utrecht University, The Netherlands. All participants were medication free, had normal or corrected-to-normal vision, and had at least 12 years of education. Written informed consent was obtained. All volunteers were unaware of the aim of the study and were paid for participation. The study was approved by the local ethical committee of the Faculty of Social Sciences.

2.2. Electroencephalogram

Resting state EEGs were recorded from the Fz, Cz, Pz, Oz, F3, F4, Fp1, Fp2, P3, P4 electrode sites according to the International EEG 10/20 System and referenced to the right mastoid with a ground electrode attached to the forehead. Electro-oculogram (EOG) was recorded by placing Ag/AgCl electrodes to the supra- and suborbit of the right eye and on the external canthi of each eye in order to correct for vertical and horizontal eye movements. ECI EEG gel was used as conducting medium for both EEG and EOG electrodes. All impedances were under 5000 Ω, low pass cut-off frequency was 70 Hz with a time constant of 3 s, amplification (Ampligraph) was set at 20,000 for both the EEG and EOG leads, and the sample rate was 250 Hz. NeuroScan software (El Paso, Texas) was used for acquisition and analyses. Raw EEG data were offline re-referenced to a common average, digitally low-pass filtered (30 Hz), and corrected for eye movements. EEG signal containing residual muscle movements, or other forms of artifacts, greater than ±50 μV were rejected prior to further analysis. A fast Fourier transform method (Hamming window: length 10%) was used to estimate spectral power (μV^2) in the δ (1–3 Hz), θ (4–7 Hz), and β (13–30 Hz) frequency band. Resting state δ/β and θ/β EEG ratios of interest were calculated for the frontal (fz, f3, f4) and parietal (pz, p3, p4) electrode sites.

2.3. Iowa gambling task

A task that has been proven capable of simulating this punishment–reward construct is the Iowa gambling task. In this computerized version of the task, decisions to choose from decks of cards become motivated by inherent punishment and reward schedules. Insensitivity for punishment together with a strong reward dependency results in impaired performance on the Iowa gambling task. In the Iowa gambling task, players are instructed to try to gain as much money as possible by drawing selections from a choice of four decks, while starting with a loan. The task ended after 100 card drawings, although the participants were not told in advance how many cards selections they were going to make. Two of the decks are disadvantageous, producing immediate large rewards, but these are (after a pre-punishment phase of about 10–15 cards) accompanied by significant money loss due to extreme punishments. The other two decks are advantageous; reward is modest but more consistent and punishment is low. The decisions to choose from the decks should become motivated by reward and punishment schedules inherent in the task [2]. The following instructions were given before administrating the game. You are provided with a fictitious amount of money of € 2000. In this task, you will see four decks of cards facing upwards. You will draw one card at the time by clicking on the location of the deck with the mouse button and are free to switch from one deck to the other. Whenever you select a card you will see on the screen that you have gained or lost money. The aim of the task is to win as much money as you possibly can.

2.4. Procedure

Upon arrival, the laboratory procedures were explained to the volunteers and informed consent was obtained. Next, participants were prepared for EEG recording and a 4-min resting EEG was acquired. The session was completed by the Iowa-GT. The entire session took approximately 1 h.

2.5. Data reduction and statistical analysis

Performance on the game was divided into five periods of twenty card drawings and percentage disadvantageous choices were computed for each block [3]. A median split was applied to create two EEG ratio marker groups, for which then analyses could be performed to investigate group differences on decision making in the Iowa gambling task. For the δ/β and θ/β EEG ratio, separate two-way 6 × 5 ANOVAs were performed with Electrodes (fz, f3, f4, pz, p3, p4) × Block (5) as within-subject factors and Group (low versus high EEG ratio group) as between-subjects factor. The alpha level of significance was set at 0.05 two-tailed.

3. Results

The two-way δ/β EEG ratio ANOVA yielded statistically significant within-subjects effects for Block [$F(4,23) = 19.39$, $P < 0.001$], demonstrating the expected linear trend of decreased disadvantageous decision making across the five blocks. No other statistically significant within-subjects (all F's < 1.2) or between-subjects group effects [$F(1,26) = 2.50$, $P = 0.126$] for the δ/β EEG ratio were observed, as can be seen from Fig. 1a. The ANOVA for the θ/β EEG ratio showed a significant within-subjects effects for Block analysis [$F(4,23) = 6.08$, $P = 0.002$]. No other within-subjects effects were statistically significant (all F's < 1.3). Crucially, however, a significant between-subjects group effect was obtained [$F(1,26) = 10.28$, $P = 0.004$], indicating that the high as compared to the low frontal and parietal θ/β EEG ratio group made overall more disadvantageous choices; this can be seen from Fig. 1b. In Table 1, descriptives for the δ/β and θ/β EEG ratio groups on Iowa-GT performance are displayed.

Since a median split in unselected groups can result in information loss with respect to a possible continuity between dependent and independent variables, we computed correlations between the δ/β and θ/β EEG ratio in relation to overall percentage disadvantageous decision making to get further insights. Spearman's rho correlations showed significant positive associations of the frontal δ/β [rho(28) = 0.41, $P = 0.029$] and θ/β ratio [rho(28) = 0.59, $P = 0.001$] with overall percentage disadvantageous risky decision making. In addition, the parietal θ/β [rho(28) = 0.55, $P = 0.003$], but not the parietal δ/β [rho(28) = 0.23: $P = 0.24$], was linked to overall percentage disadvantageous decision making. In Fig. 2, the significant correlations

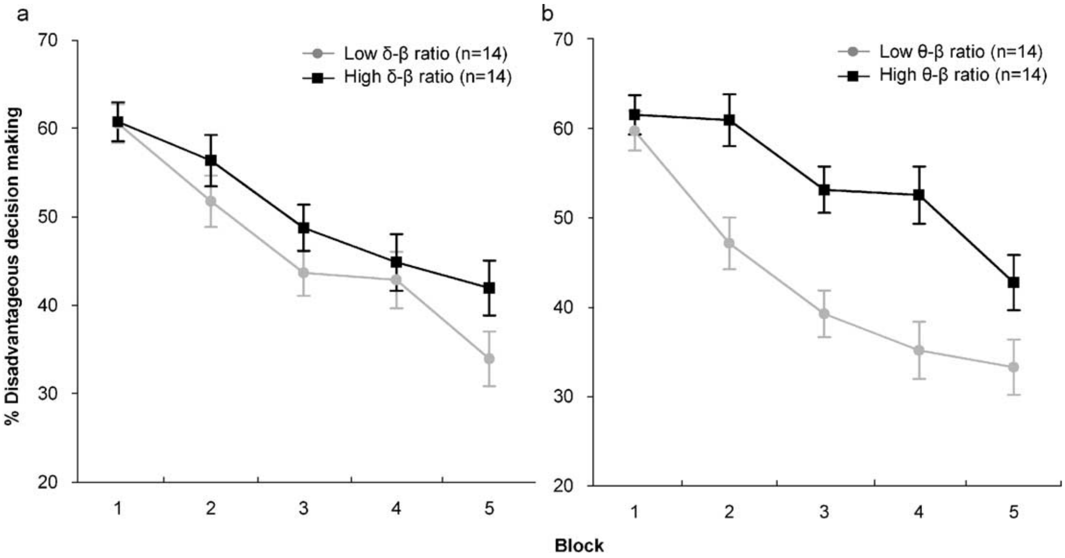

Fig. 1. Means ± SEM percentage disadvantageous decision making across the five blocks for the different low and high EEG ratio marker groups. Contrary to the δ/β EEG ratio group (a), a main between-subjects group effect demonstrated that low versus high ratios predicted advantageous versus disadvantageous decision making in the Iowa-GT (b).

Table 1
Means ± SEM for disadvantageous decision making across the five blocks in percentages for the different EEG ratio marker groups

		Block				
		1	2	3	4	5
δ/β	Low: 9.5 ± 0.4	60.6 ± 2.2	51.8 ± 2.9	43.7 ± 3.2	42.9 ± 3.2	34.0 ± 3.1
	High: 21.4 ± 2.4	60.8 ± 2.2	56.4 ± 2.9	48.8 ± 2.6	44.9 ± 3.2	42.0 ± 3.1
θ/β	Low: 3.7 ± 0.2	59.8 ± 2.5	47.2 ± 3.8	39.3 ± 4.1	35.2 ± 4.3	33.3 ± 4.7
	High: 7.3 ± 0.8	61.6 ± 2.5	61.0 ± 3.8	53.2 ± 4.1	52.6 ± 4.3	42.8 ± 4.7

between the frontal and parietal EEG ratios and disadvantageous decision making are plotted. Note that removal of the extreme score in the middle panel does in no way affect the observed relationship [rho(27) = 0.55, *P* = 0.003].

4. Discussion

The present study demonstrated that resting state δ/β and θ/β EEG ratios can be predictive for motivational balance. Although it was hypothesized that the EEG ratios would be most discriminative for decision making at the frontal sites, the relationship between disadvantageous decision making and the θ/β EEG ratio indicates a more global distribution. Post hoc correlations however revealed, in accordance with our expectations, significant relationships between both the higher frontal δ/β and θ/β EEG ratios and increased disadvantageous decision making. Only the parietal θ/β EEG ratio was in the correlational analyses significantly associated with disadvantageous decision making, which concurs with the initial finding of the globally distributed θ/β EEG ratio and suggests overall cortical hypoarousal in disadvantageous decision making. Interestingly, as noted in the Introduction, hypoarousal is assumed to be involved in the symptomatology of ADHD [1] and there is also evidence for disadvantageous decision making in ADHD [11]. However, interpretations of topographic distribution and source information of the EEG should be taken with caution given the small array of scalp recordings currently applied. Nevertheless, the frontal δ/β and θ/β EEG ratio findings as shown by the correlations are more in line with the assumed functional role of the PFC.

Disadvantageous decision making has been associated with a motivational imbalance towards increased reward and reduced punishment sensitivity and was presently observed in subjects with heightened frontal δ/β as well as θ/β EEG ratios. Logically, given the continuity across the spectrum, subjects with lower ratios displayed advantageous decision making indicative for a motivational imbalance of reduced reward and increased punishment sensitivity.

According to Damasio's somatic marker hypothesis, psychopathic individuals show increased reward sensitivity and absent punishment learning on the Iowa-GT, resulting from faulty integration of bodily feelings, which consciously or unconsciously guide behaviors that signal negative outcome [7]. Subjects with anxious depressive symptomatology on the other hand are hypersensitive to the bodily feelings signaling negative outcome, which should then lead to advantageous decision strategies in the Iowa-GT. In particular, the PFC plays a pivotal role in the interpretation and regulation of these bodily sensations. Neuropsychological studies have demonstrated that PFC dysfunction can result in faulty processing of somatic information and lead to psychopathic [4] or anxious depressive symptomatology [10]. Furthermore, neuroendocrinological studies have shown that the steroids of reward and punishment, testosterone, and cortisol are associated with disadvantageous and advantageous decision making strategies on the Iowa-GT, respectively [27,28]. Moreover, human research has recently shown that testosterone blocks

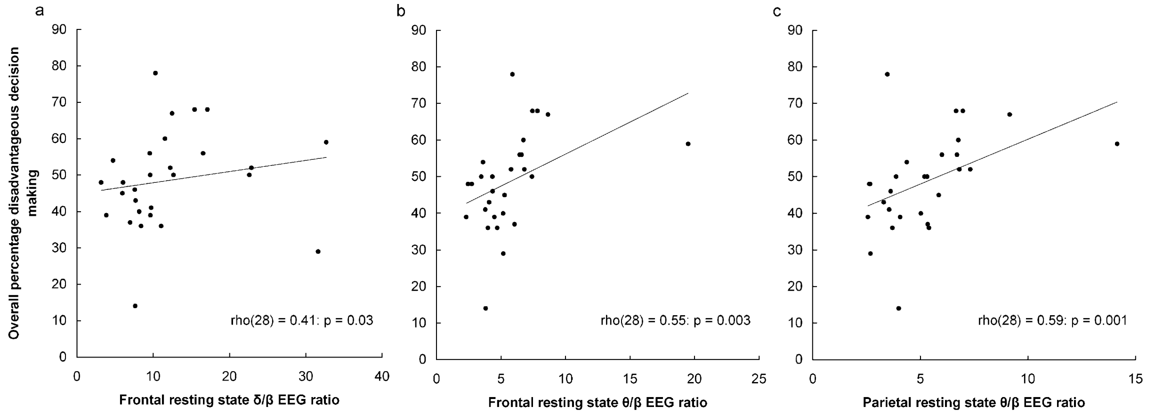

Fig. 2. Scatterplots of the relationships between resting state EEG ratios and overall percentage disadvantageous decision making. Higher frontal δ/β (a) and frontal θ/β EEG ratio (b) was associated with significantly increased disadvantageous decision making. Parietal θ/β (c), but not parietal δ/β EEG ratio, was linked to significantly increased disadvantageous decision making.

cortico-subcortical information processing [21], whereas cortisol relates to increased cortico-subcortical information processing [22]. In particular, reduced cortical inhibition over subcortical affective structures in terms of elevated δ/β and θ/β ratios might provide for a plausible underlying neurobiological mechanism for motivational imbalance. Hypothetically, whereas δ and θ activity might be associated with subcortical-implemented motivational aspects of reward and punishment, the cortical β rhythms might be involved in the cognitive modulation of subcortical drives [15]. The inverse relationships between θ rhythms and anxiety [16,23], as well as the association of δ activity with the appetitive system [15,21], are in the present respect notable. It might be conjectured that relative increased low frequency EEG as compared to high frequency EEG might be indicative for reduced cortical control function on subcortical drives, resulting in motivational imbalances. Interestingly, these data concur with findings in ADHD studies in which poor performance on the Iowa-GT and impulsivity [5] can be linked to increased θ/β ratios. It has been argued that beta activity reflects cortical regulatory processing and might be associated with descending inhibition (DI) [15]. Knyazev and Slobodskaya [15] have provided evidence that DI of subcortical structures is positively linked to behavioral inhibition. The ratio between the higher and lower EEG frequency bandwidths might therefore be an electrophysiological correlate of cortico-subcortical interaction in which relatively more slow as compared to fast frequency EEG signifies reduced behavioral inhibition. Notably, slow wave activity has been associated with both the vegetative system and cortical hypoarousal and is among the most replicated findings in psychopathy [20]. In particular, this hypoarousal provide a psychophysiological basis for reduced behavioral inhibition and increased behavioral activation [19]; the motivational stance responsible for disadvantageous risky decision making on the Iowa gambling task [25].

Finally, although the lower frequencies are being equated with motivational factors, the distinct functional nature of δ and θ activity in the EEG ratio remains unclear. The boundaries between the δ and θ frequency range are normally defined by convention, leaving the possibility of overlap in the transition phase from δ to θ activity.

In conclusion, the present findings demonstrate that the frontal δ/β and θ/β EEG ratio qualifies as electrophysiological markers for motivational balance between the reward and punishment systems. Experimental research in a clinical setting is necessary to ascertain the functionally distinct nature of resting state δ/β and θ/β EEG ratios and their possible diagnostic value in psychopathological conditions.

Acknowledgments

Dr. Schutter was supported by an Innovational Research Grant (# 451-04-070) and Dr. Van Honk was supported by an Innovational Research Grant (# 016-005-060) from the Netherlands Organization for Scientific Research (NWO).

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