NEUROPSYCHOLOGIA

Neuropsychologia 42 (2004) 939–943

www.elsevier.com/locate/neuropsychologia

Anterior asymmetrical alpha activity predicts Iowa gambling performance: distinctly but reversed

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Received 15 April 2003; received in revised form 15 April 2003; accepted 24 November 2003

Abstract

Animal research indicates that the prefrontal cortex (PFC) plays a crucial role in decision making. In concordance, deficits in decision making have been observed in human patients with damage to the PFC. Contemporary accounts of decision making suggest that emotion guides the process of decision making by ways of providing for reward–punishment contingencies. A task capable of assessing the influence of reward and punishment on decision making is the Iowa gambling task. In this task decisions become motivated by inherent punishment and reward schedules. Insensitivity for punishment together with a strong reward dependency results in risk taking, which is in the gambling task the disadvantageous strategy. Interestingly, the processing of punishment and reward is argued to be lateralized over the right and left PFC, respectively. Here we investigated whether more relative left compared to right-sided frontal brain activity (left-sided dominance) quantified as reduced alpha (8–12 Hz) activity in the electroencephalogram (EEG) would lead to a more risky, disadvantageous pattern of decision making. Contrary to what was expected, relatively more right compared to left frontal brain activity was strongly associated with the disadvantageous strategy. The results are discussed in terms of recent theoretical accounts which argue that the functional interpretation of baseline frontal alpha activity depends on the mental operation involved and does not necessarily imply inactivity.

Keywords: EEG; Frontal asymmetry; Alpha activity; Iowa gambling task

1. Introduction

Decision making is mediated by the individual's motivational stance in which the prefrontal cortex (PFC) plays an important role (Krawczyk, 2002). Electrophysiological studies have provided evidence for the involvement of the PFC in motivation and emotion. The left PFC has been implicated in approach-related emotion, whereas the right PFC is involved in withdrawal-related emotion (Davidson, 1988, 1998; Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997). Approach- and withdrawal-related emotions are paralleled by the so-called reward and punishment contingencies. Reward serves as a positive reinforcer for action (approach), whereas in punishment a negative reinforcer promotes avoidance (withdrawal). Due to the contralateral inhibition between the hemispheres the lateralized approach and withdrawal or punishment–reward system are mutually inhibitory. Activation of one system will result in the inhibition of the former (Arnett, 1997) and vice versa (Schutter, Van Honk, D'Alfonso, Postma, & De Haan, 2001). The Iowa gambling task (Bechara, Damasio, Damasio, & Anderson, 1994) is argued to be capable of indexing punishment–reward contingencies. In this task decisions become motivated by inherent punishment and reward schedules. Insensitivity for punishment together with a strong reward dependency results in a disadvantageous pattern of decision making. Recently, Van Honk, Hermans, Putman, Montagne, and Schutter (2002) demonstrated that punishment insensitive, reward-dependent subjects make more risky, disadvantageous choices on the Iowa gambling task. Furthermore, in another study of Van Honk, Schutter, Hermans, and Putman (2003) it was demonstrated that subjects with higher baseline levels of cortisol, a steroid hormone implicated in fear and behavioral inhibition, made more choices from the less risky, advantageous decks in the Iowa gambling task. From the above, it can be extrapolated that due to the profitable properties of punishment learning in the Iowa gambling task fear ensures for money gain. Interestingly, in nonhuman primates associations between cortisol, behavioral inhibition and lateralized PFC activation patterns have been found by Kalin, Larson, Shelton, and Davidson (1998). Relative left-sided dominance was not only accompanied by lower levels of cortisol, but also by less

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0028-3932/$ – see front matter
doi:10.1016/j.neuropsychologia.2003.11.014

extreme fearful defensive responses when provoked. More recently, Buss et al. (2003) showed similar relationships in 6-month-old human infants, again relative right-sided dominance in frontal brain activity was associated with higher levels of cortisol and more fearful responsivity. Finally, evidence for a relative left-sided PFC dominance in reward and a relative right-sided dominance in punishment derived from the approach-withdrawal model was provided by Sobotka, Davidson, and Senulis (1992). Reductions in alpha power in the left frontal brain regions were observed after money gain in reward trials, whereas punishment trials with decreases of alpha power in the right frontal cortex. The lateralized PFC model of reward and punishment suggests differential contributions of the left and right-sided PFC on decision making strategy in the Iowa gambling task.

The utilization of baseline electroencephalogram (EEG) recordings is a widely applied method that is sensitive for indexing stable personality characteristics, such as approach and withdrawal-related motivation (Davidson, 1998; Davidson, 2002), behavioral inhibition (Davidson & Fox, 1989) and behavioral activation (Harmon-Jones & Allen, 1997, 1998). Research within the field of the affective neuroscience has indicated that individual differences in approach- and withdrawal-related emotional reactivity and temperament are linked to stable differences in baseline measures of hemispheric activation asymmetry in the anterior regions. Phasic state changes in emotion through, for instance, mood induction can be assessed by event-related desynchronisation (ERD) and cause shifts in anterior activation asymmetry, which are superimposed upon these stable baseline differences (e.g. Davidson, 1992, 1998, 2002). Simply stated, baseline EEG measures in particular reflect emotional traits, whereas ERD is more strongly associated with emotional states. Although emotional traits and states are correlated, resting anterior asymmetry seems nevertheless to reflect a trait-dependent index of the individual's predisposition to respond effectively in terms of approach- and withdrawal-related motivation (Kalin et al., 1998; Tomarken, Davidson, & Henriques, 1990). Baseline anterior asymmetries have also shown to be predictive for the performance on cognitive-neuropsychological tasks (Hoptman & Davidson, 1998; Sutton & Davidson, 2000). In other words, it can be stated that resting anterior EEG asymmetry reflects the core motivational stance of the individual presently indexed by the balance between the sensitivity of punishment and reward in the Iowa gambling task.

Since the Iowa gambling task indexes motivational tendencies, i.e. on the physiological level reflected by the anterior activity asymmetry in the alpha frequency, a high relationship between function (i.e. Iowa gambling performance) and structure (i.e. left-right PFC activity) can be expected.

A well known electrophysiological correlate which can be used to investigate the lateralized involvement of the PFC in punishment–reward contingencies is the log transformed brain asymmetry between homologue scalp sites in the 8–12 Hz (alpha) frequency range (Davidson, 1988). Most theorists suggest that alpha activity is a measure for cortical inactivity, and thus informative regarding brain activation state in a reversed manner (Davidson, 1988, 1998; Harmon-Jones & Allen, 1997, but see Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003).

Here, we focused on tonic (e.g. resting EEG) rather then phasic (e.g. ERD) relationships between the anterior activation pattern and performance on the gambling task, because studies on basal cortisol levels (Van Honk et al., 2003) and personality traits (Van Honk et al., 2002) suggest that the Iowa gambling task is sensitive to tonic/stable physiological and psychological correlates of personality. The gambling task seems, on the other hand, not sensitive for different mood induction procedures (Clark, Iversen, & Goodwin, 2001). It was hypothesized that subjects with relatively less left-sided PFC baseline alpha activity (left-sided dominance) would show an overall disadvantageous pattern of decision making in the Iowa gambling task.

2. Methods

2.1. Participants

Eighteen right-handed healthy volunteers (nine males) ranging from 18 to 26 years participated in the study. The participants were recruited among students at the Utrecht University. Written informed consent was obtained. The study was approved by the medical ethical committee of the Utrecht University in accordance with the Declaration of Helsinki. All participants were unaware of the aim of study.

2.2. Iowa gambling task

In the Iowa gambling task (Bechara et al., 1994) players are instructed to try to gain as much money as possible by drawing 100 selections from a choice of four decks, while starting with a fictive loan of approximately 2000 Euros. The decisions to choose from the decks become motivated by reward and punishment schedules inherent in the task. Two of the decks are more risky and 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 overall pattern of gambling behavior during the task is argued to be a behavioral correlate for punishment and reward driven motivational stance (see Bechara, Damasio, Damasio, & Lee, 1999 for more details).

2.3. EEG recording

Baseline EEGs were recorded from frontal scalp positions (F3 and F4) according to the International 10-20 System of

EEG electrode positions, using an electro-cap with Ag/AgCl electrodes (Neurosoft Inc.). The reference electrode was placed behind the subject's right ear. 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 and all impedances were under 5000 Ω. An acquisition amplifier (Ampligraph) was used to filter incoming signals (low-pass cut-off frequency was 70 Hz with a time constant of 3 s). Amplification 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.

2.4. Procedure

Upon arrival the procedure was explained to the subjects and informed consent was obtained EEG recording was prepared which took on average about 15 min. Participants were seated in a comfortable chair in a dimly lit, quiet room, while the experimenter was in an adjacent control room. To obtain baseline measures of EEG, subjects were asked to relax and to keep head movements to a minimum. One-minute intervals of baseline EEG for a total of 4 min (two with eyes closed and two with eyes open) were recorded. Afterwards, the electro-cap and EOG electrodes were removed and participants performed a computerized version of the Iowa gambling task. The participants were instructed to make as much money they can and were told that the gambling task could be over at any given moment in time.

2.5. Analysis

For the Iowa gambling task overall money gain and percentage risky choices were calculated for each participant. Regarding the electrophysiological recording, raw EEG data was offline digitally filtered (low-pass setting: 30 Hz). Data were corrected for horizontal and vertical eye movements using a linear regression. EEG signal containing residual muscle movements, or other forms of artifacts, greater than −50 and +50 μV were rejected prior to further analysis. The designation of an artifact in one of the leads resulted in removal of that epoch for all channels in order to ensure that the remaining data were identical for all sites in time. Next, for each 1024 s chunk of averaged artifact-free EEG, a fast Fourier transform method (Hamming window: length 10%) was used to obtain estimates of spectral power (μV^2) in the 1 Hz frequency bins for each electrode site. Spectral power values were averaged across all epochs within a single baseline and were then transformed to power density values for the alpha (8–12 Hz) frequency band. Finally, the frontal brain log-transformed asymmetry for mean power density were calculated. A negative value indicated more left-sided alpha power, i.e. greater cortical activity in the right hemisphere, and a positive value implied relative right-sided alpha power, hence greater cortical activity in the left hemisphere.

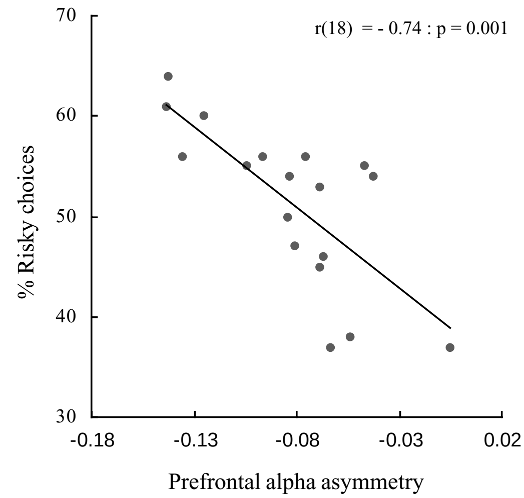

Fig. 1. Inverse relationship between frontal EEG asymmetry in the alpha frequency range and the percentage risky choices on the Iowa gambling task.

3. Results

A non-parametric Spearman rank-order correlation revealed a highly significant inverse relationship between percentage risky choices and the frontal alpha asymmetry ($r(18) = -0.74$; $P = 0.001$). Fig. 1 shows the inverse correlation between the frontal alpha asymmetry and percentage risky choices.

4. Discussion

The present study investigated the relationship between anterior asymmetrical brain activity and the sensitivity for reward and punishment using the Iowa gambling task. It was hypothesized that *reduced* left compared to right PFC activity in the alpha frequency range would be associated with a more disadvantageous pattern of decision making, indicating low punishment sensitivity and high reward dependency. Paradoxically, relatively *enhanced* left compared to right PFC alpha activity was related to the disadvantageous pattern of decision making. This finding seems to be at odds with traditional frontal lateralization models of emotion and motivation, since these suggest that electrical brain activity in the alpha bandwidth is associated with reduced cortical arousal (Davidson, 1988, 1998; Harmon-Jones & Allen, 1997). In agreement with the latter notion is the observation that sensory deprived visual cortex oscillates preferentially in the alpha frequency range. Moreover, a PET study by Sadato et al. (1998) have provided corroborating evidence for a negative correlation between regional cerebral blood flow (rCBF) in the visual cortex and alpha activity.

However, although previous studies (e.g. Davidson, 1998) have shown a concordance between frontal alpha asymmetry and "alpha as cortical idling", an increasing number of more recent studies suggest that alpha synchronization can also be linked to actual functional states (Basar et al., 2000; Pfurtscheller & Lopes da Silva, 1999). Knyazev and Slobodskaya (2003) argue that alpha synchronization refers to an active brain state in which neurons are ready to run at the sudden release of inhibition.

A positive relationship has also been observed between rCBF in the lateral frontal cortex and alpha activity, arguing against the notion of alpha power reflecting cortical inactivity. Furthermore, a recent study by Cooper et al. (2003) also challenges the notion of alpha activity and cortical idling. This study demonstrated increases in alpha activity during internal driven mental operations. Since the gambling task incorporates different aspects of cognitive and affective processing in decision making (Bechara, Damasio, & Damasio, 2000a), left-sided dominance in the alpha activity might be associated with internal directed attention to reward (Davidson, 1992). On the other hand, it can also be argued that since frontal alpha activity is associated with relaxed wakefulness, the observed tonic activation pattern predicts the reactivity in terms of ERD of the system. In crucial defense of the latter notion, Neubauer, Freudenthaler, and Pfurtscheller (1995) showed that subjects with higher baseline levels of alpha power exhibited more pronounced ERD when engaging in information processing. Thus, the frontal alpha power also predicts heightened readiness or susceptibility to engage in information processing. Since the cortical landscape can be divided in both morphologically and functionally distinct regions, the functional signature of alpha activity in various brain areas might differ concomitantly. In sum, further research is needed to scrutinize whether relative higher left-sided PFC alpha baseline activity might be predictive for more enhanced alpha ERD in the left PFC during Iowa gambling task. From the above it can be derived that the functional interpretation of alpha activity strongly differs depending on the mental operations at hand and does therefore not necessarily imply cortical inactivity. Furthermore, although various mechanisms may generate similar alpha activity and macroscopic distributions over the scalp (Sadato et al., 1998), the functional interpretations can be quite distinct, making the relation between alpha activity and its functional correlate even more ambiguous.

Bechara, Tranel, and Damasio (2000b) have shown that patients with bilateral ventromedial prefrontal cortex lesions exhibit overall poor strategy use, rather than oversensitivity to reward or punishment in the Iowa gambling task. Since the lesions of these patients extend to both sides, a contribution of the left and right prefrontal cortex in reward and punishment can not be disentangled with Bechara et al.'s database. Interestingly, Tranel, Bechara, and Denburg (2002) recently provided preliminary evidence for an association between right, but not left ventromedial prefrontal cortex lesions and poor performance on the Iowa gambling task. Tranel et al. (2002) demonstrated an association between right ventromedial prefrontal cortex lesions and enhanced risky, disadvantageous choices. Although the damage in Tranel et al.'s patients was restricted to the lower regions of the PFC, the results seem to concur with the present EEG data. Tranel et al.'s findings can be interpreted along the lines of lateralized involvement of the left and right prefrontal cortex in the processing of reward and punishment (Davidson, 1998; O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001).

In conclusion, the present study demonstrates that relative left-sided PFC activity in the alpha frequency range was reversibly associated with a disadvantageous pattern of decision making indicating low punishment sensitivity and high reward dependency. This finding contradicts the traditional electrophysiological models of emotion, which suggest that the frontal activity in the alpha frequency range reflects inactivity. It is argued that this interpretation does not take into account the mental operations involved and the differences between action readiness of a system and the operation of the system during the execution of the action itself.

Acknowledgements

This study was sponsored by an Innovational Research Grant (#016-005-060) from The Netherlands Organization for Scientific Research (NWO).

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