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Behavioural Inhibition System (BIS) sensitivity differentiates EEG theta responses during goal conflict in a continuous monitoring task

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ABSTRACT

Previous research has revealed that EEG theta oscillations are affected during goal conflict processing. This is consistent with the behavioural inhibition system (BIS) theory of anxiety (Gray & McNaughton, 2000). However, studies have not attempted to relate these BIS-related theta effects to BIS personality measures. Confirmation of such an association would provide further support for BIS theory, especially as it relates to trait differences. EEG was measured (32 electrodes) from extreme groups (low/high trait BIS) engaged in a target detection task. Goal conflicts were introduced throughout the task. Results show that the two groups did not differ in behavioural performance. The major EEG result was that a stepwise discriminant analysis indicated discrimination by 6 variables derived from coherence and power, with 5 of the 6 in the theta range as predicted by BIS theory and one in the beta range. Also, across the whole sample, EEG theta coherence increased at a variety of regions during *primary goal conflict* and showed a general increase during *response execution;* EEG theta power, in contrast, was primarily reactive to *response execution*. This is the first study to reveal a three-way relationship between the induction of goal conflict, the induction of theta power and coherence, and differentiation by psychometrically-defined low/high BIS status.

1. Introduction

The neurophysiological bases of personality have been long studied and increasing sophistication in theory development and methodologies have started to yield valuable insights. One of the most influential models of emotion, motivation and personality was developed by Jeffrey Gray (1982). This model, now known as *Reinforcement Sensitivity Theory* (RST; Gray and McNaughton, 2000; McNaughton and Corr, 2004, 2008), proposes three major systems of emotion processing; individual differences in the functioning and sensitivity of these systems comprise the foundations of ‘personality’ within RST.

First, the *Fight-Flight-Freeze System* (FFFS) is responsible for mediating reactions to aversive stimuli; secondly, the *Behavioural Approach System* (BAS) is responsible for mediating reactions to appetitive stimuli; and thirdly, the *Behavioural Inhibition System* (BIS) is responsible for resolving goal conflicts of all kinds, but especially those between the FFFS (avoidance) and BAS (approach) (unresolved goal conflicts potentially contributing to anxiety). These systems have been studied using EEG, with the following general findings. First, resting EEG linked to specific scalp locations has been related to individual differences in psychometrically-defined levels of BIS/BAS sensitivity. Secondly, inter-hemispheric EEG asymmetry response has been associated with emotional and motivational states which are linked to BIS/BAS sensitivity. Thirdly, studies have used EEG to determine the neural processes associated with phasic activation of BIS/BAS circuitry. A brief overview of each of these categories of EEG studies is provided below — the current study falls into the final category.

Regarding the first category, relationships between BIS/BAS sensitivity, as defined by questionnaire, and different resting EEG wavebands and EEG indexes, have been studied most prominently in the laboratory of Gennedy Knyazev (Knyazev and Slobodskaya, 2003; Knyazev et al., 2004, 2003, 2002). In general, these studies demonstrated that higher EEG frequencies (e.g. EEG alpha and above) relate to BIS sensitivity and lower EEG frequencies (e.g. EEG theta and below) to BAS sensitivity. Additionally, data have suggested that the oscillations associated with the BIS system (represented in the alpha EEG range) relate negatively to oscillations associated with the BAS system (represented in the delta EEG range); the strength of that relationship being positively related to psychometrically-defined BIS sensitivity (Knyazev and Slobodskaya, 2003).

Regarding the second category, studies have been reported which describe relationships between frontal EEG (alpha) asymmetries and withdrawal or approach related behaviours; the former linked to BIS

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sensitivity and the latter to BAS sensitivity. For instance, Sutton and Davidson (1997) reported that participants displaying greater relative left prefrontal EEG activity (8–13 Hz) had higher levels of BAS sensitivity; participants with greater relative right prefrontal EEG activity had higher levels of BIS sensitivity. Davidson (1998) argued that an individual's affective style can be partly moderated by their trait anterior frontal asymmetry; that is, a frontal EEG asymmetry which favours greater relative left hemisphere activation would predispose a person to positive approach type emotions, such as happiness (which are emotions thought to be linked to the BAS system).

In contrast, Harmon-Jones (2004, 2007) demonstrated that, whilst the approach motivational aspect of frontal anterior EEG asymmetry appears to hold, approach motivation is not always associated with positive emotion. Harmon-Jones reported data showing that trait anger, considered a negative emotion (and, hence, not traditionally a BAS emotion), had a positive relation with greater relative left hemisphere asymmetry. Therefore, the approach motivational tendencies associated with anger appear to override the negative emotional aspects of anger presenting a challenge to explanations of anterior asymmetry based purely on emotional valence (see Coan and Allen, 2004).

The third category employs experimental tasks likely to provoke activity in neural structures associated with BIS or BAS processing. For example, to activate neural structures and processes linked to the BIS, participants could be placed into a state of goal conflict. These studies often focus on EEG coherence as well as EEG power. Moore et al. (2006) reported scalp-wide theta coherence and power increases during a task stage requiring rapid resolution of a cognitive goal conflict. These theta effects did not extend into the alpha EEG range (Moore et al., 2008). In brief, EEG alpha response followed a different trend and was linked to the overt motor demands of the task rather than linked to BIS or BAS sensitivity per se.

The task used in Moore et al. (2006) was based on the idea that the primary role of the BIS is the detection and resolution of goal conflict (Gray and McNaughton, 2000; McNaughton and Corr, 2004). Moore et al. (2006) argued that the increased widespread theta coherence and power increase resulted from cognitive goal conflict. Specifically, and in accordance with BIS theory, increased theta coherence effects were explained as an effect of the septo-hippocampal system (SHS): limbic-neocortical interplay; the SHS being the neural structure which is regarded as central to the BIS (Gray and McNaughton, 2000). Moore et al. (2006) proposed that simultaneous communication between the SHS and two or more discrete neocortical regions led to the appearance (in terms of theta coherence) of phase consistency between those neocortical regions. This account is consistent with Gray and McNaughton's (2000) view that increased phase locking between the SHS and the neocortex maintains the discreteness of individual cycles of recursive calculations during goal-conflict resolution. Moore et al. (2006) also linked EEG theta power to resetting of the dentate theta rhythm; functionally, this was linked to the clearing of hippocampal circuits just prior to phases of active SHS goal conflict processing. This conclusion is also consistent with proposals made by Gray and McNaughton (2000) in their account of BIS activity, stimulus processing and SHS activity.

Andersen et al. (2009) experimentally explored the links between EEG theta and BIS mediated goal conflict resolution. Participants were induced into a state of internal, personally-meaningful goal conflict (i.e. rumination). The processing of unresolved goal conflict is thought to be experienced as anxious rumination (Gray and McNaughton, 2000; McNaughton and Corr, 2004, 2008). Results showed that EEG theta (coherence and power) were enhanced in the most personal form of rumination compared with a nominal form of rumination not entailing personally-meaningful stimuli. Andersen et al. (2009) concluded that these data show that increased theta coherence is an index of active attempts to resolve goal conflicts during anxious rumination.

In a related study, Neo et al. (2011) reported that right frontal EEG theta (7–8 Hz) power was greater in stop signal trials with an intermediate stop signal delay compared to a short or long delay. Theoretically, the immediate delay was reasoned to be the stage at which (go/stop) goal conflict was maximal (and, presumably, the point at which BIS was maximally activated); the intermediate delay was set individually for each participant to give a stop probability of 50%.

Additionally, Savostyanov et al. (2009) reported data which appeared to show an increase in low frequency EEG during a goal conflict stage. They showed that 1–7 Hz (i.e. delta and theta range) EEG was increased for 800 ms following presentation of a stop signal when participants were suppressing the pre-potent response — this mimics conditions for activation of goal conflict processing and, hence, neural structures inherent in BIS activity. These data are consistent with the results of Moore et al. (2006) and Andersen et al. (2009).

One major limitation of the above studies, specifically when relating observed EEG effects to anxiety, is the absence of psychometric measures of individual differences in BIS sensitivity. Although consistent with BIS theory, observing an association between goal conflict and theta power/coherence is not the same as showing that this association is related specifically to anxiety (which in humans is almost exclusively defined by self-report). In Neo et al. (2011), the revised Eysenck Personality Questionnaire (EPQ-R; Eysenck and Eysenck, 1991) and State Trait Anxiety Inverntory (STAI; Spielberger, 1983) were used to assess levels of threat sensitivity. Neo et al. (2011) reasoned that these questionnaires are more valid as measures of threat related mental disorder. However, trait anxiety and neuroticism are threat-related, but not specifically so (e.g., this anxiety scale includes depression variance) and it is not usual to omit purpose-developed BIS scales from experimental studies exploring BIS processes. The most widely used BIS scale comes from the Carver and White (1994) BIS/BAS scale.

Although questionnaire BIS scores do not provide a direct index of BIS system activity at a neural *state* level, they do provide a measure of the *trait* sensitivity of BIS system activation; that is, the consequences of longer-term activity itself, related (at least, under typical conditions; e.g., not continuous trauma) to *state* BIS sensitivity. This position is endorsed in Neo et al. (2011, p. 2) when they state that higher threat sensitive individuals are more likely to show enhanced activation of the BIS neural response. If true, it follows that there should be a differential EEG response during goal conflict conditional upon psychometrically-defined trait BIS scores.

In Moore et al. (2006) trait BIS was not measured so it could not be compared with state BIS activation, as revealed by EEG. In Andersen et al. (2009), trait BIS was measured, but no relationship was found with state BIS theta during personal goal conflict rumination — this study did not use extreme BIS groups and, in consequences of small sample size and absence of reliable measurement along the entire BIS scale, this study was under-powered. The aim of the current study is to remedy these limitations.

1.1. The current study

The primary goal of this study was to define EEG responses under a condition of goal conflict in low/high trait BIS participants. First, a large sample was surveyed and then two sub-samples at the extreme end of the trait BIS dimension were selected. The task reported in Moore et al. (2006, 2008) was adopted. As well as a conventional ANOVA analysis, a stepwise discriminant analysis (SDA) was applied to data associated with the low/high BIS sensitivity groups using a technique developed by Thatcher et al. (2005). This technique includes a stage which substantially reduces sources of error in the dataset — therefore even very small group differences which are not visible in an ANOVA approach should be apparent. The SDA considered EEG data across a 4–30 Hz spectrum (following Andersen et al.,