International Journal of Psychophysiology 71 (2009) 156–169

Contents lists available at ScienceDirect

International Journal of Psychophysiology

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

Electrophysiological correlates of anxious rumination ☆

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ARTICLE INFO

Article history:
Received 25 May 2008
Accepted 8 September 2008
Available online 25 September 2008

Keywords:
Theta
Coherence
Power
Rumination
Septo-hippocampal system
Rumination
Anxiety

ABSTRACT

EEG coherence and EEG power response were recorded as 63 participants engaged in one of three experimental conditions: 'personal rumination', 'nominal rumination', and 'baseline counting'. The rumination conditions were separated by a neutral (counting) task to eliminate neural carry-over effects. For personal rumination, participants spent 2 min ruminating about something in their life about which they were in two minds (i.e., in a state of personal conflict). For nominal rumination, they were presented with a conflict scenario (concerning buying a car) and instructed to ruminate about that for 2 min. The baseline counting task simply involved counting forwards from 1 at a speed comfortable to the individual. Participants completed various questionnaires to measure mood and also traits of personality (including trait anxiety). EEG data were analysed in the following wavebands: 4–6 Hz, 6–8 Hz, 8–10 Hz, 10–12 Hz, 12–20 Hz and 20–30 Hz. Results revealed that the scalp-wide EEG theta (4–6 Hz and 6–8 Hz) coherence associated with personal rumination was significantly greater than that associated with nominal rumination and baseline counting. Similarly, the scalp-wide 6–8 Hz and parietal–occipital 4–6 Hz power associated with personal rumination were significantly greater than power associated with the nominal rumination and power for baseline counting. For alpha, the 10–12 Hz scalp-wide EEG coherence associated with personal rumination was significantly greater than that associated with baseline counting. Otherwise, the scalp-wide 10–12 Hz power related to both nominal rumination and personal rumination were significantly greater than in response to baseline counting. For 20–30 Hz scalp-wide EEG power, data in response to the nominal rumination condition were significantly increased compared to data associated with the baseline counting condition. In terms of questionnaire data, tense arousal, anger/frustration, hedonic tone and energetic arousal were all influenced by rumination. This was largely in line with expectation. Also, mood state was influenced by neuroticism and state anxiety. Our EEG results are consistent with Gray and McNaughton's [Gray, J.A., McNaughton, N., 2000. The neuropsychology of Anxiety: An Anquiry into the Functions of the Septo-Hippocampal System. 2nd ed. Oxford University Press, Oxford.] account of recursive processing between the septo-hippocampal system and neocortex during goal-conflict resolution inherent in rumination. Evidence of posterior cingulate involvement in this processing was also discussed. Recommendations for future research, aimed at further evaluating the role of the SHS and the posterior cingulated, were outlined. Effects found in alpha were linked to increased vigilance whilst effects in beta were linked to cognitive and emotional aspects of the task. We conclude that these data provide new information of the neural processes associated with the psychological state of anxious rumination and, thus, hold implications for understanding normal and pathological anxiety.

1. Introduction

Rumination is "the class of conscious thoughts that revolve around a common instrumental theme" (Martin and Tesser, 1996, p. 1). Such thoughts are well known to be disruptive in everyday life. For instance, Lyubomirsky, Kasri, and Zehm (2003) demonstrated the debilitating effects that dysphoric rumination can have on different academic tasks including reading pace, comprehension, lecture comprehension and proof reading. In other research, using mediational modelling, Muris, Roelofs, Rassin, Franken, and Mayer (2005) provided evidence to suggest that the cognitive factor rumination (together with worry) mediates neuroticism. This further demonstrates the potential for rumination to mediate and to give rise to aversive psychological states.

Rumination has been assessed through measurements of the extent to which participants think about depressive symptoms

☆ This study was supported by a grant from the Economic and Social Research Council (RES-000-22-1444) to Dr Søren Bo Andersen, Dr Roger Moore and Professor Philip Corr.

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doi:10.1016/j.ijpsycho.2008.09.004

(Nolen-Hoeksema et al., 1993), the intrusiveness of thoughts about a distressing event (Horowitz et al., 1979), searching for meaning of negative events, and thinking about what can be done to change one's situation in regard to negative events (Fritz, 1999). The aim of the work presented here relates to the final category; namely the involvement of rumination in the processing of different courses of action. In the current study, our primary aim is to investigate the electrophysiological processes (using scalp EEG) which underpin this type of rumination.

1.1. Rumination, goal-conflicts and reinforcement sensitivity theory

It could be argued that the process of rumination is instigated when a person experiences a lack of progress with respect to the acquisition of a particular course of action or goal (e.g. a problematic period with a best friend/partner or conflict during work-related thoughts). However, this can also include conflict between two equally desirable goals (e.g. which of two job offers to accept). In such periods, we often have recurring thoughts about the situation and about the different ways in which it could be solved to avoid an aversive outcome. Where there is no immediate way to resolve the this conflict, different strategies are continuously processed, which take the form of ongoing risk assessment concerning the possible outcomes of one course of action over another. *Reinforcement Sensitivity Theory* (RST) is one theory which provides a possible explanation of the basis of rumination in terms of such goal-conflict.

The theory primarily addresses emotion, motivation and personality (Gray and McNaughton, 2000; McNaughton and Corr, 2004; for a review of entire field, see Corr, 2008). In brief, RST proposes three major systems of emotional processing, with individual differences in the functioning of these systems comprising 'personality'. 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 most importantly those between the FFFS (avoidance motivation) and BAS (approach motivation). Each system has a set of associated emotions: fear, anticipatory hope, and anxiety, respectively.

The BIS functions as a general risk assessment system, charged with evaluating potential danger, and is specifically activated during goal-conflict (e.g., approach-avoidance conflict) — in human beings, this is experienced as anxious rumination. The BIS is instantiated in a number of neural structures, the most important of which are the septo-hippocampal system (SHS; concerned with goal-conflict analysis) and the amygdala (concerned with emotional arousal). According to Gray and McNaughton (2000), activation of the BIS generates a particular neurophysiological rhythm in the SHS, namely the theta rhythm. There is now an extensive literature concerning BIS activation and the theta rhythm in experimental animals. Experimental work supports the connection between personality measures intimately linked to BIS levels and theta activity in humans (e.g. Razoumnikova, 2003).

In the most recent version of RST (Gray and McNaughton, 2000; McNaughton and Corr, 2004, 2008), risk assessment of conflicting goals is instigated when people ruminate as they weigh up alternative goals. The authors suggest that this process is regulated by the SHS as it is functionally involved in resolving conflicts between conflicting concurrently active goals. They suggest resolution is mediated by recursive networks between the SHS and the neural structures in which the various goals are encoded (e.g., memory stores in the temporal lobes or incoming stimuli gated through the thalamocortical perceptual systems). The recursive loops between the SHS and the neural 'goal' structures operate to increase the negative valence associated with these various goals. This subsequently results in the goal with the least negative association being selected as the one that controls input to the motor system.

To date, there have been few attempts to characterise the neural correlates of BIS activation (Corr, 2004). However, recently, one group of researchers reported data which, they claimed, reflected neocortical activity during goal-conflict processing (Moore et al., 2006). They demonstrated widespread, neocortical, theta coherence increases during (*cognitive*) goal-conflict resolution. A follow-up study showed that this did not extend into the alpha waveband (Moore et al., in press). Moore et al. (2006) argued this increased theta coherence resulted from goal-conflict driven increases in phase locking between the SHS and neocortical areas. In Gray and McNaughton's (2000) view, 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) speculated that the effect they had recorded reflected this recursive process. Assuming Moore et al. (2006) are correct in their speculation, it is reasonable to predict the same pattern of increased theta coherence activity during goal-conflict processing inherent in (*emotional*) anxious rumination. Additionally, this should, theoretically, be more evident in individuals with a more active BIS; a metric which can be measured using Carver and White's (1994) BIS/BAS scales.

1.2. Rumination, conflict monitoring and the anterior cingulate cortex

Whilst RST offers one possible explanation for the basis of anxious rumination, research and associated theory which has focused on the role of the anterior cingulate cortex (ACC) in conflict situations provides an alternative view. At the level of response options, conflict resolution during cognitive tasks has previously been related to dorsal ACC activity. Several studies have reported data from fMRI studies that shows ACC activation during conflict stages of Go/NoGo tasks (e.g. Picard and Strick, 1996; Van Veen et al., 2001). Botvinick, Cohen, and Carter (2004) described these response conflict effects within the framework of the *Conflict Monitoring Hypothesis*. They suggested that the ACC is activated in a range of conflict situations. They also described the ACC's role in dealing with response conflicts in situations where conflict was provoked by placing participants in experimental situations that required the selection of a response from a highly competing range of responses. In such situations, the participant is highly likely to make response errors of commission. These data showed an intimate link between ACC activation and tasks that present participants with inherent response conflicts.

However, Botvinick et al. (2004) also drew attention to research which was not easily explained within their conflict monitoring hypothesis. Chiefly, this included studies in which evaluation of action outcomes (in terms of positive or negative consequences) induced increased ACC activity when outcomes were evaluated negatively (e.g. Luu et al., 2003). By way of explanation, they cite Rushworth, Walton, Kennerley, and Bannerman (2004) who claim that action selection may be guided by the ACC, based on a cost-benefit analysis in which information about past action outcomes are considered. Effort likely to be expended pursuing each action alternative could be one consideration which might be made in this cost-benefit analysis.

Botvinick et al. (2004) did not feel Rushworth et al.'s (2004) account adequately covered the results of studies which gave rise to the conflict monitoring hypothesis and subsequently offered an account which integrated both the conflict monitoring hypothesis and Rushworth et al.'s (2004) action outcome evaluation account. They suggested that viewing the ACC's role as a general outcome monitoring system, in which conflict is simply one outcome to which the ACC is sensitive, may be more inclusive. In this sense, response conflicts during experimental tasks typical of those which the conflict monitoring hypothesis sought to explain could be construed as taking more time and giving rise to less accurate responses. Thus, this increases the degree to which this outcome is evaluated negatively.

With respect to the current study, anxious rumination could also be easily covered by this account. For instance, outcome monitoring