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Electrophysiological correlates of anxious rumination ☆

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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

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(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 during anxious rumination would, presumably, be of central importance as different courses of action, which could be taken to achieve potential goals, would be weighed up in the search for a solution which is minimally aversive. Therefore, this outcome monitoring function and processing would clearly suggest an increase in ACC activity during anxious rumination which would, presumably, also relate to the intensity in which the anxious rumination is engaged by the participant.

1.3. Frontal midline EEG theta: an index of anterior cingulate cortex activity

Various studies have found an apparent intimate link between frontal midline theta and conflict effort (typically recorded from electrodes close to the medial frontal lobe). These have led to the suggestion that frontal midline theta is a relatively reliable index of ACC activation evident in the superficial EEG.

Early studies linked increased frontal midline theta to cognitive effort (e.g. Nakashima and Sato, 1992, 1993). More recently, applying synthetic aperture magnetometry (SAM), Ishii et al. (1999) modelled the source of frontal midline EEG theta activity (derived from 64-channel whole-head MEG) and found specific activity in the bilateral medial prefrontal cortices, including most notably the ACC. Similarly, using dipole source modelling, Gevins, Smith, McEvoy, and Yu (1997) showed that a frontal midline theta rhythm which increased with memory load was localised to the ACC. In a further study, an ERN peak which was embedded in band pass filtered frontal midline theta was found to have one (of three) dipole sources located in the rostral ACC (Luu et al., 2004).

In each case, the data are consistent with the idea mentioned earlier that the ACC may be involved in a general monitoring function. In this sense, where there is a negative evaluation (i.e. increased cognitive effort; increased memory load; deployment of errors), ACC activity becomes more activated which, in turn, leads to increased frontal midline EEG theta. Following these data then, if the ACC were the neural site at which goals competing for dominance are evaluated, frontal midline theta should increase during periods of anxious rumination.

1.4. The current study

Our aim was to test electrophysiological predictions regarding rumination derived from the latest version of RST, using EEG methods of analyses in order to characterise electrophysiological activity which is evident during goal-conflict processing. In addition, the role of the ACC will also be evaluated in terms of frontal midline theta. We propose that emotionally-laden cognitive rumination constitutes a suitable task for each purpose, since it is characterised by the continuous evaluation of conflicting goals. EEG is especially valuable in this respect because of its excellent temporal resolution which enables recording of phase locked neocortical activity (using coherence) and also because of its widely reported role as an index of ACC activation (in terms of frontal midline theta power).

In our experimental procedure, we induce a cognitive ruminative state in participants during which neocortical activity is recorded using EEG. McNaughton and Corr (2004) reported that a nominal conflict inherent in a goal-conflict paradigm is not necessary or sufficient to activate the BIS; they went on to note that, instead, a conflict between goals, which is *subjectively experienced by the participant*, is necessary fully to activate the BIS. Therefore, in one condition of our study, instructions leading to self-referential rumination are given: participants are allowed to ruminate about something that is personally meaningful to them and which is likely to entail one or several goal-conflicts. Participants ruminate for a predetermined time period of 2 min, during which time their EEG is continually recorded. This self-referential condition is then contrasted with a nominal rumination condition comprising goal-conflict arising from the availability of three car purchase deals (designed as a much less personally meaningful conflict situation). We also assessed individual differences in participant's BIS levels, as measured by questionnaire. EEG data were analysed in a range of wavebands.

In summary, our main predictions are that, in line with previous research (Moore et al., 2006, 2008) and theory (Gray and McNaughton, 2000; McNaughton and Corr, 2004, 2008), theta waveband EEG coherence will differentiate the rumination tasks (where there is inherent goal-conflict) from the baseline counting task (no goal-conflict). In addition, we predict that this effect should be greater for participants who are highly anxious as measured by Carver and White's (1994) BIS/BAS scales, compared with those who are low on this measure of anxiety. And finally, considering the potential role of the ACC in rumination, we also predict increased frontal midline theta during the rumination tasks; an effect which should also be mediated by participant anxiety level.

2. Method

2.1. Participants

Sixty three university students participated in the experiment (31 female and 32 male), and all received £8.00 for taking part. The age of participants ranged from 18–45 years (M=23.9 years, S.D.=5.65). All participants were required to be right-handed and in general good health. Potential participants were excluded if they were on prescribed medication or had any known history of psychiatric or neurological disorders.

2.2. Self-reports

Prior to the experimental session, participants completed a range of personality scales, comprising: the BIS/BAS Scales (Carver and White, 1994), which assesses individual sensitivity to aversive and appetitive stimuli; the Eysenck Personality Questionnaire Revised (short scale) (EPQ-R: Eysenck and Eysenck, 1991), a well-known personality questionnaire that measures Psychoticism (P), Extraversion (E), Neuroticism (N), and a Lie scale (L); the Temperament & Character Inventory (TCI; Cloninger et al., 1994), which was designed to measure Novelty Seeking (NS), Harm Avoidance (HA), Reward Dependence (RD), and Persistence (P); the Fear Survey Schedule (FSS; Wolpe and Lang, 1977) which measures responses to a wide variety of objects and situations, including animals, interpersonal fears, tissue damage, noise, classic phobias, etc; the trait index of anxiety derived from the State-Trait Anxiety Inventory (STAI; Spielberger, 1983); and the Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ; Torrubia et al., 2001) measures individual's sensitivity to reward (SR) and punishment (SP) — SR and SP are reported to be good comparable measures of BIS/BAS, respectively (Caseras et al., 2003). Mood was measured by: the Negative Mood Regulation Scale (NMRS; Catanzaro and Mearns, 1990), which was designed to measure an individual's perceived ability to counteract a negative mood state; the Anger-Rumination Scale (ARS; Sukhodolsky et al., 2001) was devised to measure ruminative tendencies towards angry moods and experiences; the Rumination–Reflection Questionnaire (RRQ; Trapnell and Campbell, 1999) assesses self-ruminatory tendencies; and the Ruminative Responses Scale (RRS; Nolen-Hoeksema and Morrow, 1991) is a measure of depressive rumination. For this paper, the analyses focused solely on the BIS/BAS, EPQ, Fear Survey Schedule and Spielberger Trait Anxiety scale scores.

Subjective measures of current mood and moods experienced whilst performing the tasks were obtained using the UWIST-Mood

Adjective Checklist (UWIST-MACL; Matthews et al., 1990). The questionnaire examines different facets of mood including hedonic tone, energetic arousal, tense arousal, and anger/frustration. Participants were asked to complete a Self-Report Affect Circumplex (Larsen and Diener, 1992) (following both the personal and nominal rumination conditions). In addition, a post-experimental thought questionnaire was devised specifically for the current study. This questionnaire (comprised mainly of 10-point Likert scales) was designed to assess task-related emotional experiences felt during each of the two 2-minute experimental conditions (e.g., happiness, frustration, worry, confidence, eagerness, anxiety, threat/challenge, personal involvement, conflict, and the seriousness awarded to the task), and to provide information about the variety of (potential) solutions considered for the chosen area of conflict (in accordance with the task instructions). Not all questionnaire data will be reported here. In this instance, only those data linked with our main hypotheses will be covered.

2.3. Psychophysiological measures

Continuous EEG was recorded with a BioSemi Active-Two amplifier system (BioSemi Inc.), and analysed offline with BESA 5.1 software (www.Besa.de). These signals were referenced to the common mode sense (CMS) and driven right leg (DRL) ground (see www.biosemi.com/faq/cms&drl.htm for more information). Electrocortical activity was measured using 128 "active" electrodes covering the entire scalp (i.e., a modified nomenclature) by means of a 128 electrode cap (Electrocap International). Active electrodes do not require abrasion of the scalp or impedance testing; they are amplified at the source through each electrode. Vertical and horizontal electrooculargram (EOG) activity was also recorded (to monitor for eye movements and blinks), using active electrodes placed above and below the left eye, and at the outer canthi of both eyes, respectively. EEG and EOG activity were sampled at 512 Hz. Offline, for both EEG and EOG electrodes, the high pass filter was set to 3 Hz (12 dB roll off) and the low pass to 70 Hz (12 dB roll off). A 50 Hz notch filter was also included. An average reference was also applied offline.

Recording of participant EEG and EOG was continuous through all experimental tasks. Therefore, the resultant EEG and EOG record for each participant comprised of an EEG recording associated with each of the two experimental conditions (personal rumination condition, nominal rumination condition) and the initial counting condition which was included as a baseline with which to compare data associated with the rumination tasks. There was also an EEG record associated with the other counting tasks and the goal-conflict free condition (see Procedure for details). However, in this study we are primarily concerned with EEG response to the main experimental conditions in relation to the initial count baseline condition.

For all EEG data, eye movement related artefacts were reduced by following artefact reduction procedures described by Ille, Berg, and Scherg (2002). Here, horizontal EOG was set to 150.0 mV and vertical EOG (blink threshold) was set to 250.0 mV. Next, the EEG associated with each of the experimental conditions (2 min each per participant) and the baseline count condition was epoched into 120 two-second epochs in preparation for later derivation of EEG coherence and power associated with each of the experimental conditions and the baseline count condition. In addition, all EEG data were visually inspected and any periods contaminated with artefacts were removed from further analyses. In some recordings where a channel was consistently poor (due to a faulty electrode for instance), data were interpolated. However, if this was required for more than 6 electrodes for any one participant, this participant's data was excluded from further analyses.

ECG and electrodermal activity were also recorded. However, these will not be reported in this paper.

2.4. Procedure

Prior to their attendance at the main experiment, participants were asked to complete a series of randomly presented trait questionnaires at a specific time (all questionnaires listed above).

Upon entering the laboratory, participants were briefed about the nature of the study. (Participants were already fully informed as to the procedures involved in the recording of the physiological measures.) Following completion of a pre-task mood state questionnaire (UWIST-MACL), participants were prepared so their physiological response could be recorded (e.g., the positioning of the EEG cap, the attachment of the electrodes for EDA, EOG and ECG recordings, etc). A six-minute classic 'eyes open, eyes closed' baseline period was then carried out, during which participants had to alternate between 1 min of eyes closed and 1 min of eyes open. (Participants were instructed to relax, keep their minds free, not to count the passing seconds, and to refrain from internal monologue, whilst minimising movements and eye blinks as much as possible.)

In the first of five conditions, the baseline counting task, participants were required simply to count forwards from 1 at a speed comfortable to the them. Participants then performed one of two rumination tasks: nominal rumination or personal rumination (i.e., the order of the rumination tasks was counterbalanced across participants). For the personal rumination condition, participants were required to identify a current problematic situation in which they were in two minds about. Participants were asked to introspect about their chosen goal-conflict scenario and evaluate the different ways in which they might resolve the situation. The nominal rumination task, in contrast, required participants to reflect upon a goal-conflict situation that was not personal to them. Specifically, participants were given a choice of deals relating to the purchase of a car (these varied in terms of car purchase price, insurance and service offers), and were asked to think through these deals, weighing up their relevant pros and cons. The counting task was completed a second time following the first (either nominal or personal) rumination condition, to prevent carry over effects from one rumination condition to another. Finally, participants carried out the goal-conflict free task. This required that participants simply spell-out the sequential days of the week silently to themselves for 2 min, (i.e., m o n d a y t u e s d a y…). For each of the tasks, participants were asked to sit still with their eyes closed for the duration of the task until the 2 min were over when a bell would sound to alert the participant that the task had ended.

Following each of the two rumination tasks only, participants were presented with the (post-task) UWIST-MACL, the Self-Report Affect Circumplex and the Post-experimental thought questionnaire. Upon completion of these self-reports participants persisted with the next 2-minute task. The recording of the EEG and other psychophysiological measures was initiated at the start of each experimental condition. (Each 2-minute session recording was triggered by the participant (using E-prime) when they were ready to begin.) When all tasks had been completed, the electrodes were removed and participants were debriefed.

2.5. EEG data reduction

All EEG data (coherence and power) were considered according to the pooled regions of interest (ROI) shown in Fig. 1. These ROIs were loosely based on ROIs defined by Bosch, Mecklinger, and Frederici (2001).

2.6. EEG coherence

EEG coherence is a value between 0 and 1 which represents phase consistency between pairs of electrodes during a given time period (see Moore et al., 2006, for a more detailed account of coherence

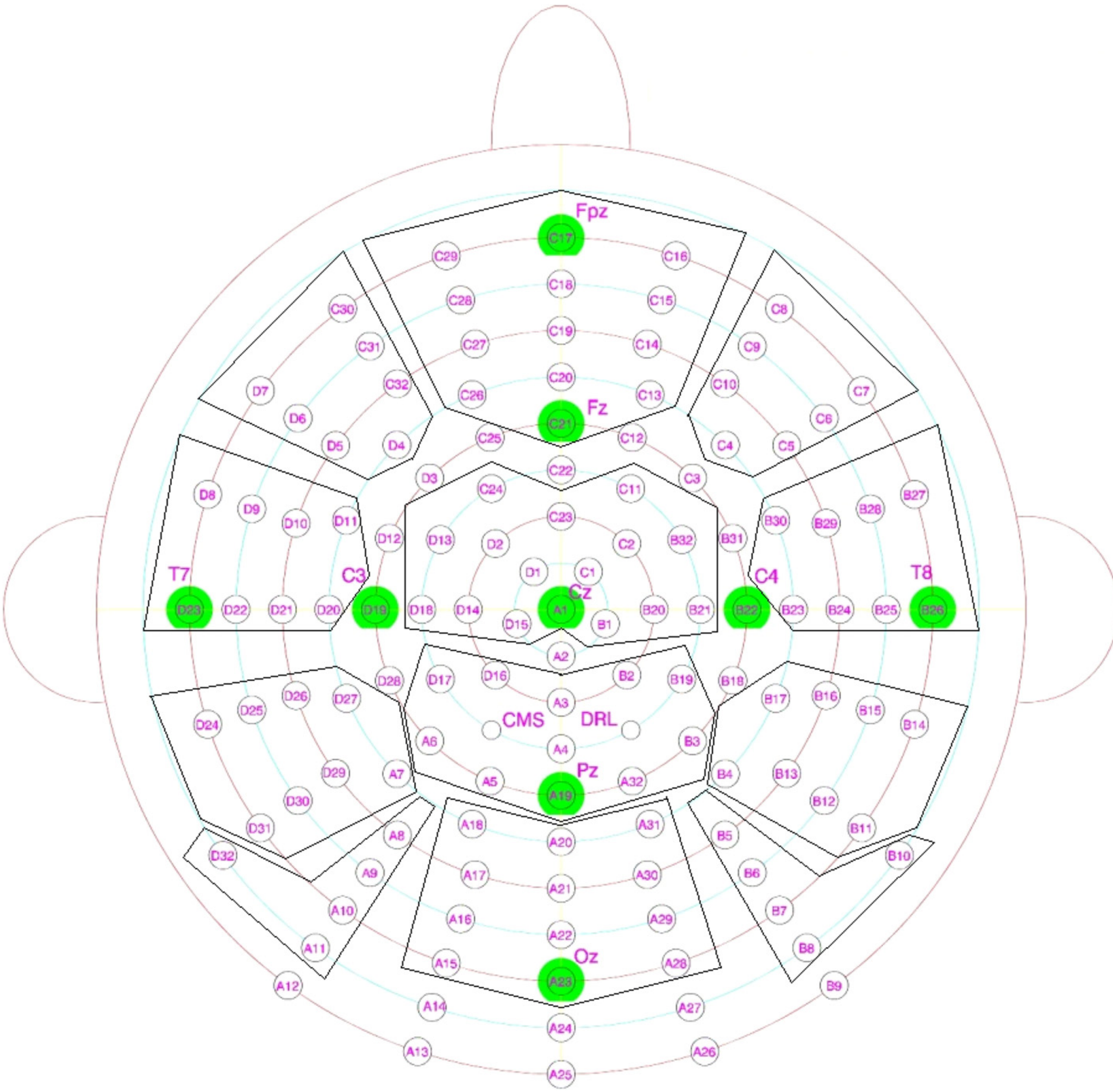

Fig. 1. ROIs into which all EEG power data and coherence data were pooled. Starting at “12 o'clock” and moving clockwise (following Bosch et al., 2001) the ROIs are named: mid frontal (MF), right frontal (RF), right fronto-central (RFC), right centro-parietal (RCP), right parieto-occipital (RPO), mid parietal occipital (MPO), left parieto-occipital (LPO), left centro-parietal (LCP), left fronto-central (LFC) and left frontal (LF). The remaining two ROIs are located in the centre of the Figure — the anterior one is named mid fronto-central (MFC) and the posterior one mid centro-parietal (MCP).

analysis). Coherence values for each possible combination of the 128 electrodes were derived.[1] For each condition (personal rumination condition, nominal rumination condition, baseline counting) and waveband (4–6 Hz, 6–8 Hz, 8–10 Hz, 10–12 Hz, 12–20 Hz and 20–30 Hz), this yielded 8128 possible electrode pairings. For each of these, discrete coherence values were described for each 0.25 s period (within epochs) and at discrete 0.2 Hz intervals between 4 and 50 Hz. Next, these discrete coherence values were collapsed in the following way to derive composite coherence values: discrete coherence data were averaged across time and frequency, to form a single composite coherence value (for each of the 8128 permutations) in each of the 3 conditions (these data were available in each waveband, as defined above). Overall, this yielded 3 (number of conditions)×8128 (number of electrode pairs for 128 channel configuration) composite coherence values per participant in each of the wavebands of interest.

To translate these data into coherence values which show phase consistency between ROIs, we first focused on a pair of ROIs and then calculated the mean of coherence levels associated with pairs of electrodes which bridged the two ROIs. For each pair of ROIs, this yielded a single inter-ROI value for each experimental condition. Since there were 12 ROIs, this yielded 66 possible ROI pairings. This was

[1] Please refer to “Tutorial on Source Coherence”, page 4 at http://www.besa.de/index_home.htm for details of calculation.

repeated for each waveband. Intra-ROI coherences were ignored. Therefore, for each participant we had 66 independent inter-ROI coherence levels for each of the 3 experimental conditions and for each of the 6 wavebands.

2.7. EEG power

To derive EEG power several steps were followed for each participant. Firstly, using complex demodulation, power spectra were described for each 0.25 s period (within epochs) and at discrete 0.2 Hz intervals between 4 and 50 Hz. These data were averaged across time and frequency to form a single power value (for each of the 128 channels) in each of the 3 main experimental conditions. These data were available in each waveband. Overall, this yielded 3 (number of conditions) × 128 (number of channels) power values per participant in each waveband. Then, according to the ROIs, a waveband-specific, mean power value was derived for each ROI. Collapsing EEG power data according to ROIs is a common EEG analysis strategy (see Rippon and Brunswich, 2000). This analysis was performed separately for each of the three main experimental conditions. Overall, for each participant, this yielded 12 power values for each of the 3 conditions and for each of the 6 wavebands.

3. Statistical analyses

3.1. EEG coherence

In order to control for Type I errors, all analyses were initiated with an omnibus ANOVA. The omnibus ANOVA incorporated the repeated measures factors inter-region (66 levels: coherence between all possible pairs of ROIs shown in Fig. 1), task (3 levels: nominal rumination, personal rumination, baseline counting), waveband (6 levels: defined above) and the independent groups factor BIS (2 levels: above median BIS scores and below median BIS scores). To control for Type I errors, alpha levels in subsequent follow-up analyses (justified by interactions uncovered in the omnibus ANOVA) were treated with Bonferroni correction (Rosenthal et al., 2000).

3.2. EEG power

3.2.1. Analysis 1

A similar approach was taken when analysing the EEG power data. Once again, in order to control for Type I errors, analyses of EEG power were initiated with an omnibus ANOVA. In this case, the repeated measures factors were ROI (12 levels: see ROIs in Fig. 1), task (3 levels: defined above), waveband (6 levels: defined above) and the independent groups factor BIS (2 levels: defined above). As before, probability levels in follow-up analyses, justified by interactions in the omnibus ANOVA, were treated with a Bonferroni correction procedure.

3.2.2. Analysis 2

This analysis was a follow-up to Analysis 1. It is possible that, through volume conductance, portions of EEG associated with ACC activity may have been recorded at each of the frontal regions (LF, MF, RF). Since each region was analysed separately in Analysis 1, it is possible that ACC related EEG activity recorded at an individual region was not strong enough to provide a true account of increased ACC activity during the tasks; if this were the case there is a possibility of Type II error.

Therefore, in the second analysis performed on the EEG power data, we created a new factor called *pooled ROI* which had 4 levels. These were *frontal* (which comprised of pooled EEG power data from regions LF, MF and RF), *fronto-central* (pooled data from regions LFC, MFC, RFC), *centro-parietal* (LCP, MCP and RCP) and *parieto-occipital* (LPO, MPO and RPO). Other factors in this analysis were the same as those described above for Analysis 1. Therefore, in Analysis 2 activity in broad horizontal chains from anterior through to posterior regions was evaluated.

3.3. UWIST ratings/personality scores

To examine changes in energetic and tense arousal, hedonic tone and anger/frustration, we used multivariate repeated measures analysis of variance and used the conservative Pillai's Trace as a criterion when evaluating the multivariate significance (Tabernack and Fiddell, 2001, p.330). For all analyses the Greenhouse-Geisser epsilon correction procedure was applied when the assumption of sphericity was being violated (Vasey and Thayer, 1987) (though, for clarity, uncorrected degrees of freedom are reported in the text following Moore et al., 2006). Subsequent zero-order correlation analyses were used to examine if personality influenced mood ratings. Finally, partial correlation and step-wise regression analyses were used to examine if personality influenced mood ratings after differences in mood before the rumination periods were controlled.

4. Results

4.1. EEG coherence

4.1.1. PR, NR and baseline counting coherence levels are differentiated by waveband

In the EEG coherence omnibus ANOVA (see method for details), a significant task × waveband interaction, $F(10, 560)=2.518$, $p<0.05$ (EPS:0.487), and a task × waveband × inter-region interaction, $F(650, 36400)=1.70$, $p<0.05$ (EPS: 0.024), were identified. Follow-up analyses were performed on the latter interaction since this subsumed the former. The follow-up analyses included task × inter-region analyses at each level of the waveband factor. These analyses yielded significant task main effects in 3 wavebands: 4–6 Hz, $F(2, 114)=5.80$, $p<0.05$ (EPS: 0.963); 6–8 Hz, $F(2, 144)=9.931$, $p<0.001$ (EPS: 0.952); and 10–12 Hz, $F(2, 144)=4.95$, $p<0.05$ (EPS: 1.00). Since there was no interaction with the region factor in these follow-up analyses, these data show that the scalp wide EEG coherence (i.e., overall mean coherence level) in response to each level of the task factor was differentiated within these three wavebands. Further analyses, reported below, were deployed to identify the nature of this waveband specific differentiation.

4.1.2. Scalp wide 4–6 Hz and 6–8 Hz coherence levels were significantly increased compared to the baseline count condition and the NR condition

For 4–6 Hz and 6–8 Hz, follow-up analyses on the task main effect showed that overall coherence in response to personal rumination was significantly greater than for the nominal rumination condition: 4–6 Hz, $F(1, 57)=7.91$, $p<0.05$ (EPS: 1.0); 6–8 Hz, $F(1, 57)=12.60$, $p<0.01$ (EPS: 1.0). Also, we found that overall coherence in response to personal rumination was significantly greater than for the baseline counting condition: 4–6 Hz, $F(1, 57)=9.17$, $p<0.05$ (EPS: 1.0); 6–8 Hz, $F(1, 57)=14.23$, $p<0.01$ (EPS: 1.0). These results supported the first of our experimental hypotheses confirming that personal rumination provoked greater levels of scalp wide theta coherence than the nominal rumination task and the baseline counting task. These effects are summarised in Fig. 2 together with associated coherence levels.

4.1.3. Scalp wide 10–12 Hz PR coherence levels were significantly increased compared to the baseline count condition

For 10–12 Hz, follow-up analyses on the task main effect showed that overall coherence for the personal rumination condition was significantly greater than for the baseline counting condition, $F(1, 57)=$

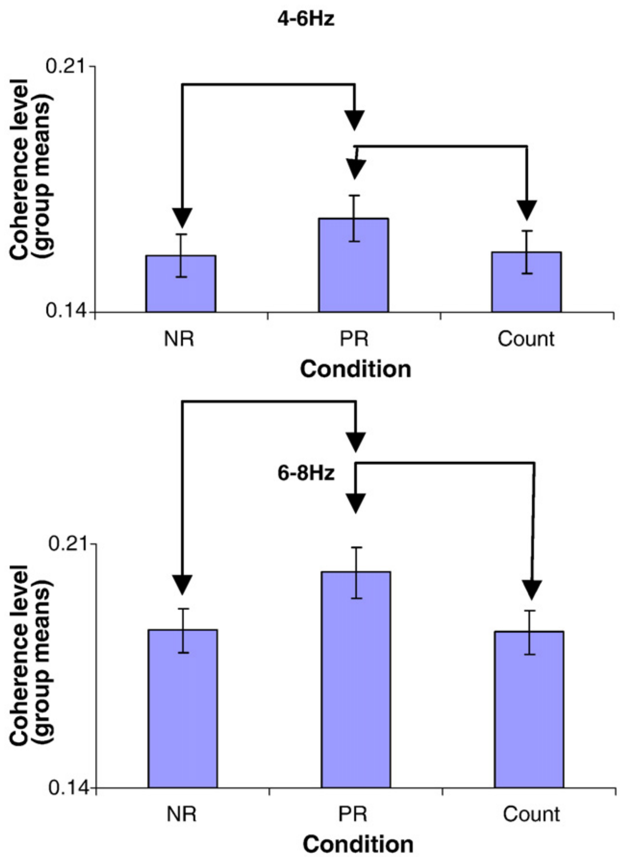

Fig. 2. 4–6 and 6–8 Hz scalp wide coherence levels (+/−standard errors) associated with each task condition (N=58). NR=nominal rumination; PR=personal rumination; Count=baseline count condition. The arrows show significant differences between each of the task conditions.

9.93, $p<0.01$ (EPS: 1.0). However, there was no difference between overall coherence for personal and nominal rumination, $F(1, 57)=2.14$, ns, or between nominal rumination or baseline counting, $F(1, 57)=2.81$, ns. In the sense that we hypothesized, that coherence would be greater for rumination conditions (particularly the PR condition) compared to the baseline count condition, these data are largely supportive. However, we hypothesized that that would be the case in the theta range (4–6 Hz; 6–8 Hz) so finding this effect in the 10–12 Hz range, was unexpected. These effects are summarised in Fig. 3 together with associated coherence levels.

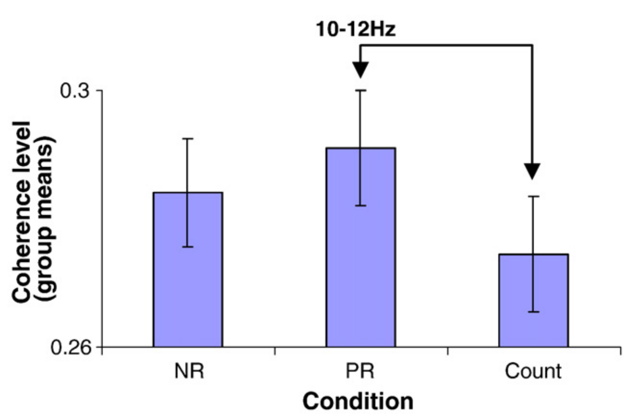

Fig. 3. 10–12 Hz scalp wide coherence levels (+/−standard errors) associated with each task condition (N=58). NR=nominal rumination; PR=personal rumination; Count=baseline count condition. The arrows show significant differences between each of the task conditions.

4.2. EEG power

4.2.1. PR, NR and baseline count data power levels are differentiated in 6–8, 12–20 and 20–30 Hz

As with the coherence data, when the omnibus ANOVA was performed on the power data for Analysis 1, no interactions which included the between groups factor (above and below median BIS score) reached significance. However, there was a significant two way task×waveband interaction, $F(10, 580)=3.344$, $p<0.05$ (EPS: 0.368). Since there was no interaction with the ROI factor, follow-up analyses considered scalp wide EEG power. Follow-up analyses were performed on the two-way interaction specifically by examining the task factor at each level of the waveband factor. The follow-up analysis revealed a significant task effect in the 6–8 Hz waveband, $F(2, 118)=9.751$, $p<0.01$ (EPS: 0.840), the 12–20 Hz waveband, $F(2, 118)=7.376$, $p<0.05$ (EPS: 0.820) and the 20–30 Hz waveband, $F(2, 118)=6.670$, $p<0.05$ (EPS: 0.859). These analyses show that the scalp wide EEG power (i.e., overall mean power level) in response to each level of the task factor was differentiated within these wavebands. Further analyses, reported below, were deployed to identify the nature of this waveband specific differentiation.

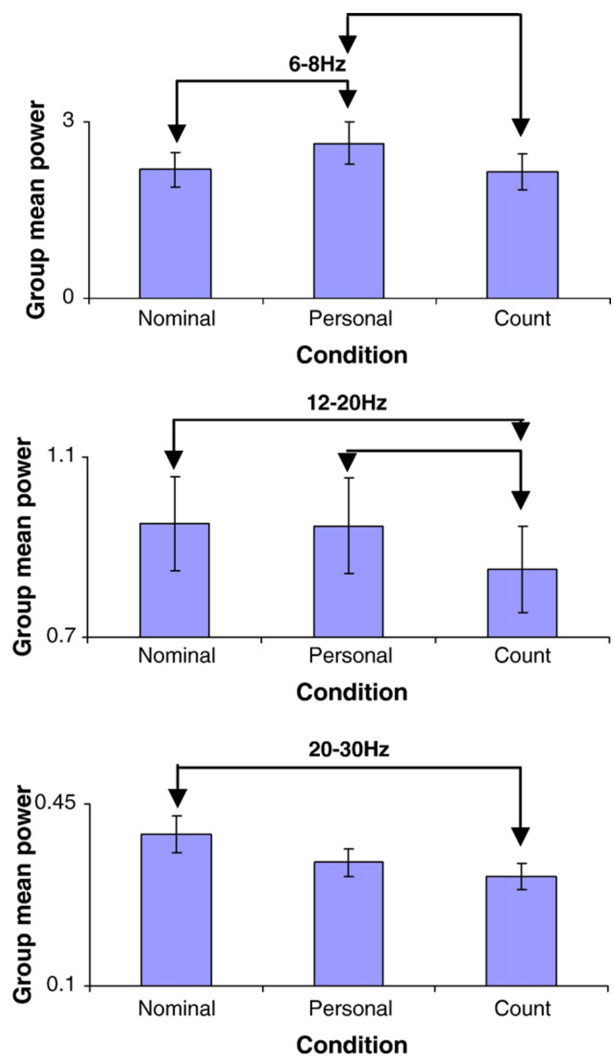

Fig. 4. 6–8 Hz, 12–20 Hz and 20–30 Hz scalp wide power levels (μV2) (+/−standard errors) associated with each task condition (N=60). The arrows show significant differences between each of the task conditions.

4.2.2. Scalp wide 6–8 Hz PR power levels were significantly increased compared to the NR and baseline count conditions

For 6-8 Hz, follow-up analyses on the task main effect in Analysis 1 showed that overall power in response to personal rumination was significantly greater than for the nominal rumination condition, $F(1, 59)=20.356$, $p<0.001$ (EPS: 1.0). We additionally found that overall power in response to the personal rumination condition was also significantly greater than overall power in response to baseline count condition, $F(1, 59)=11.31$, $p<0.01$ (EPS: 1.0). There was no significant difference between 6–8 Hz scalp wide EEG power associated with nominal rumination and the baseline count condition. These effects are summarised in left hand graph in Fig. 4 together with associated power levels.

4.2.3. Scalp wide 12–20 Hz baseline count power levels were significantly reduced compared to the NR and PR conditions

In the 12–20 Hz waveband, follow-up analyses of the task main effect in Analysis 1 revealed that baseline count power was significantly lower than for power associated with NR and PR ($F(1, 59)= 8.795$, $p<0.05$ (EPS: 1.0) and $F(1, 59)=19.097$, $p<0.001$ (EPS:1.0), respectively). There was no significant difference between power associated with NR and PR in this waveband. These effects were unexpected and hence did not support or refute any of our main experimental hypotheses. The significant effect reported for this waveband are summarised in right hand graph in Fig. 4 together with associated power levels.

4.2.4. Scalp wide 20–30 NR power levels were significantly increased compared to the PR and baseline count conditions

In this waveband, we found that scalp wide power in response to the NR condition was significantly increased with respect to power associated with the baseline count condition, $F(1, 59)=9.511$, $p<0.01$ (EPS: 1.0). There was no significant difference between power associated with the NR and PR conditions or between the PR condition and the baseline count condition. Once again, the significant effects which were recorded in response to power data in this waveband were unexpected and, hence do not support or refute our main hypotheses. As before, significant results found in power data associated with this waveband are shown in the bottom graph in Fig. 4.

4.2.5. Pooled parieto-occipital 4–6 Hz PR power levels were significantly increased compared to the NR and baseline count conditions

It was mentioned above that there was no interaction which involved the ROI factor in the omnibus ANOVA of Analysis 1. This appears to rule out the possibility that there was any task differentiation in any waveband at any individual anterior scalp regions. Therefore, this does not support our hypothesis that frontal midline theta would be increased during rumination task stages to reflect ACC involvement. However to recap, Analysis 2 was included to avoid making Type II errors which may have occurred as a result of volume conductance. More specifically, it is possible that ACC activity was smeared to each of the 3 anterior ROIs meaning that activity picked up at any of them individually was only sufficient to provide a partial, rather than complete, view of ACC activity during the task. Therefore, in Analysis 2, we introduced the *pooled ROI* factor which had four levels comprised of pooled data from individual frontal, fronto-central, centro-parietal and parieto-occipital ROIs.

Analysis 2 yielded a significant waveband X pooled ROI X task interaction, $F(30, 1740)=2.269$, $p<0.05$ (EPS: 0.163). Follow-up analyses which examined the effects of pooled ROI X task at each level of the waveband factor only revealed a significant interaction for 4–6 Hz, $F(6, 348)=3.778$, $p<0.05$ (EPS: 0.662). This indicated that the pooled ROI factor is modulated by task in, at least, one region. When this interaction was examined at each level of the pooled ROI factor, it was found that, within 4–6 Hz, the task factor was only differentiated at the parieto-occipital level (i.e. the one *furthest* from the ACC which comprised of ROIs LPO, MPO and RPO), $F(2, 118)=6.250$, $p<0.05$ (EPS: 0.959). Follow-up pairwise analyses revealed that power in response to personal rumination was significantly greater than for the nominal rumination condition: $F(1, 59)=8.939$, $p<0.05$ (EPS: 1.0). Also, we found power in response to personal rumination was significantly greater than for the baseline counting condition: $F(1, 57)=8.71$, $p<0.05$ (EPS: 1.0). These results are summarised in Fig. 5. Additionally, Fig. 6 shows a complete set of brain maps by waveband and condition and, through visual inspection, it can be seen that broad parieto-occipital scalp region shows most differentiation of the tasks in the 4–6 Hz waveband. There is evidence of repetition of this trend in other wavebands (though not statistically significant).

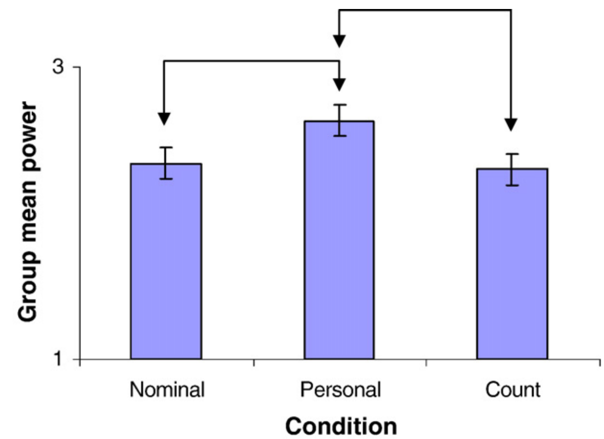

Fig. 5. 4–6 Hz parieto-occipital (pooled mean of regions LPO, MPO and RPO) power levels (μV^2) (+/−standard errors) associated with each task condition ($N=60$). The arrows show significant differences between each of the task conditions.

4.2.6. UWIST and personality scales

4.2.6.1. Tense arousal, anger/frustration, hedonic tone and energetic arousal were all influenced by at least one rumination task. Participants completed the UWIST-MACL mood state questionnaire which assessed how they felt at the time just prior as well as after each of the two rumination tasks. The mixed repeated measures MANOVA was significant, $F(8,54)=19.51$, $p<0.01$) justifying the inspection of univariate effects for each of the four mood measures. There were no main or interaction effects of sex of participant. The univariate analysis revealed a significant main effect of time for energetic arousal (EA), $F(2,122)=4.70$, $p<0.01$, tense arousal (TA), $F(2,122)=55.68$, $p<0.01$, hedonic tone (HT), $F(2,122)=108.29$, $p<0.01$, and anger/frustration (AF), $F(2,124)=50.27$, $p<0.01$.

As shown in Fig. 7, the tense arousal and anger/frustration ratings were significantly higher after the personal rumination condition than before the tasks and after the nominal rumination condition. Hedonic tone was similarly lower after the personal rumination condition compared to before the tasks and after the nominal rumination condition. Energetic arousal decreased slightly after the personal rumination condition compared to participants pre-task ratings. The results supported the first of our experimental hypothesis confirming that personal rumination increases tension and frustration levels whilst lowering general hedonic tone. These data act as an important means to validate our experimental manipulation.

4.2.6.2. UWIST mood states were influenced by neuroticism, state anxiety but not BIS scores. Firstly, to examine if the personality scales scores approximated a normal distribution, skewness, kurtosis and their respective standard error statistics were calculated. Variables were considered within the normal distribution range if the ratio of

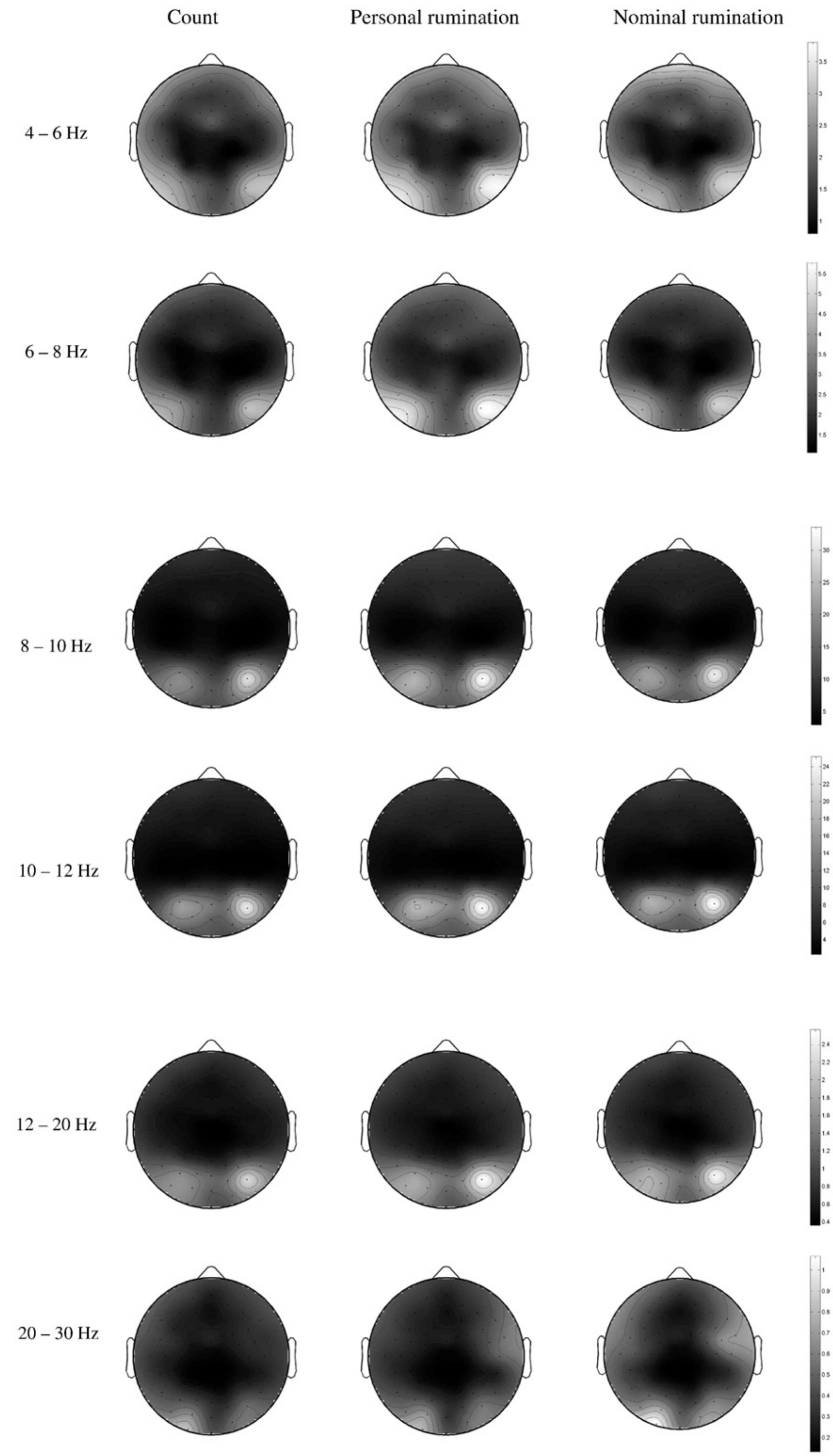

Fig. 6. Topographical maps of 4–6 Hz, 6–8 Hz, 8–10 Hz, 10–12 Hz, 12–20 Hz and 20–30 Hz power levels (μV2) associated with each task condition (N=60).

skewness and kurtosis to their respective standard errors was more than −2 and less than +2 (Tabernack and Fiddell, 2001). One-sample Kolmogorov–Smirnov tests were also run on scale scores and the observed cumulative distribution functions were compared with a theoretical normal distribution. Asymptotic significance tests below 0.05 show that the observed distribution of scores differs significantly from a theoretical normal distribution of scores. All personality scales except the FFS and the EPQ-L scales had a normal distribution of scores. The FFS and EPQ-L scale scores were slightly skewed, however, none of the scores deviated significantly from a theoretical normal distribution of scores. (These data are available on request from the corresponding author.)

Table 1 is a correlation matrix of the Fear Survey Schedule, BIS/BAS, STAI and EPQ-R and UWIST scales (energetic arousal, tense arousal, hedonic tone and anger/frustration) before the tasks and after personal rumination and nominal rumination.

The strongest relationship between mood state and personality scores was found for neuroticism scores which correlated positively with tense arousal and negatively with hedonic tone before the tasks and after the personal and nominal rumination task. Trait anxiety

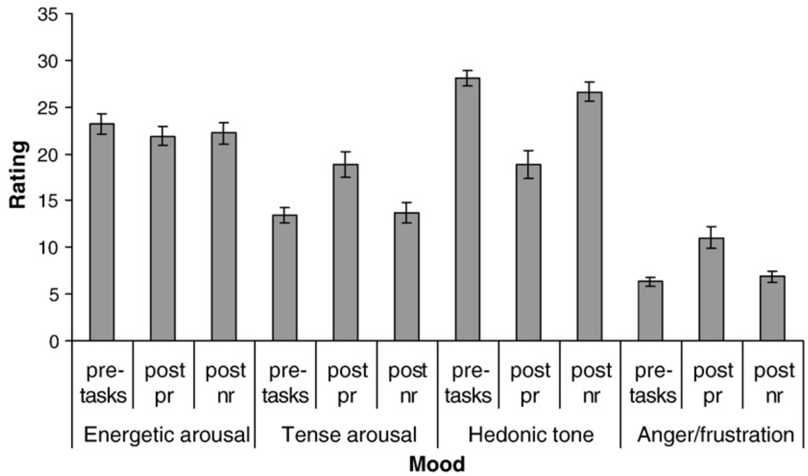

Fig. 7. Energetic arousal, tense arousal, hedonic tone and anger/frustration levels pre and post personal (pr) and nominal rumination (nr) periods (CI 95%, N=63).

correlated in the expected direction with pre-task and post personal rumination tense arousal and with pre-task hedonic tone. But unexpectedly, BIS scores failed to show any relationship with subjective mood states before and after each of the two rumination tasks. As predicted, fear survey schedule scores did not correlate with tense arousal (although this null result is open to a number of interpretations).

4.2.6.3. Corrections for baseline mood weakened the state-trait relationships. To control for differences in mood prior to the two ruminations conditions we performed partial correlation analyses between personality and mood post personal and nominal rumination. The results of the partial correlation analyses are listed in Table 2.

As shown in Table 2, the correlations between EPQ-N and personal and nominal rumination post tense arousal were reduced and no longer significant when controlling for differences in pre-test tense arousal. This is an unexpected result and does not support our hypothesis that personality would influence the impact of rumination on mood even after controlling for differences in baseline mood.

To further analyse these data and to reduce the likelihood of Type 1 errors from running multiple correlations, separate stepwise regression analysis were performed on each mood measure for the two rumination conditions. Only significant personality measures from the zero-order correlations and pre-test mood scores were included in the stepwise regression analysis with a probability to enter and leave set at 0.10 and 0.15 respectively.

4.2.6.4. Personality was a weak predictor of mood states. Table 3 shows the results of the stepwise regression analysis involving the UWIST mood ratings after the personal and nominal rumination periods. Mood after the personal and nominal rumination periods was positively predicted by mood before the tests, although there was a tendency for neuroticism positively to predict tense arousal after the personal rumination period. When controlling for pre-test mood, this remained non-significant. Psychoticism negatively predicted energetic arousal, whilst BAS drive positively predicted tense arousal following the nominal rumination period. The latter two results were not predicted.

5. Discussion

5.1. Theta coherence and rumination

Theta coherence in both of the wavebands traditionally associated with EEG theta (4–6 Hz and 6–8 Hz) was higher for the personal rumination than for the nominal rumination and baseline counting condition. This finding is consistent with our main experimental hypotheses regarding EEG coherence, namely that EEG theta coherence would differentiate the rumination tasks from the baseline counting task. In the Introduction, we reported that that a goal-

Table 1
Correlation matrix of personality scale scores and self-report mood measures (N=63)

Scale	Pre-test (UWIST)				Post personal rumination (UWIST)				Post nominal rumination (UWIST)			
	EA	TA	HT	AF	EA	TA	HT	AF	EA	TA	HT	AF
1. FSS	0.04	−0.01	0.09	0.14	0.06	0.10	0.01	0.03	0.17	0.24	0.02	0.08
2. BAS-DR	0.20	0.10	0.06	−0.02	0.20	−0.02	0.13	0.03	0.06	**0.30**	−0.01	0.01
3. BAS-FS	−0.18	0.18	−0.05	−0.10	−0.04	0.16	−0.22	0.25	−0.22	0.22	−0.13	0.18
4. BAS-RW	0.07	−0.23	**0.27**	0.01	0.00	−0.07	−0.02	0.16	−0.07	0.07	−0.02	0.14
5. BIS	−0.07	0.20	−0.15	−0.08	−0.13	0.20	−0.14	0.02	0.07	0.15	−0.04	−0.19
6. EPQ-E	0.00	−0.13	0.21	0.05	0.05	−0.09	−0.01	−0.04	−0.07	0.06	−0.06	0.12
7. EPQ-N	−0.04	***0.40***	***−0.33***	0.17	−0.09	***0.35***	**−0.27**	0.17	−0.03	**0.29**	**−0.26**	0.02
8. EPQ-L	0.13	0.06	0.17	−0.07	**0.28**	−0.03	0.15	−0.15	0.24	0.08	0.13	−0.24
9. EPQ-P	−0.09	−0.11	0.15	−0.09	−0.20	−0.11	0.07	0.02	**−0.32**	−0.08	−0.08	0.20
10. STAI	−0.14	***0.37***	***−0.50***	0.05	−0.23	**0.25**	−0.18	0.17	−0.11	0.16	−0.22	0.14

Note: FSS = Fear Survey Schedule; BAS-DR = BAS Drive; BAS-FS = BAS Fun-Seeking; BAS-RW = BAS Reward; EPQ-E/N/P/L = Eysenck Personality Questionnaire Extraversion/Neuroticism/Psychoticism/Lie; STAI = State Trait Anxiety Inventory (Trait): UWIST = UWIST Energetic Arousal (EA), Tense Arousal (TA), Hedonic Tone (HT), Anger/Frustration (AF) (N=63).
Bold: p<0.05.
Bold, italics: p<0.01.

Table 2
Correlation matrix of personality scale scores and self-report mood measures controlling for pre-test energetic arousal[(1)], tense arousal[(2)], hedonic tone[(3)] and anger/frustration[(4)] (*N*=60)

Scale	Post personal rumination (UWIST)				Post nominal rumination (UWIST)			
	EA[(1)]	TA[(2)]	HT[(3)]	AF[(4)]	EA[(1)]	TA[(2)]	HT[(3)]	AF[(4)]
1. FSS	0.05	0.12	−0.03	0.00	0.21	**0.29**	−0.01	0.02
2. BAS-DR	0.10	−0.08	0.12	0.01	−0.13	**0.30**	−0.03	0.02
3. BAS-FS	0.07	0.09	−0.22	**0.28**	−0.14	0.15	−0.12	0.25
4. BAS-RW	−0.05	0.04	−0.13	0.16	−0.19	0.23	−0.14	0.14
5. BIS	−0.11	0.13	−0.09	0.04	0.17	0.06	0.02	−0.18
6. EPQ-E	0.06	−0.04	−0.10	−0.05	−0.10	0.16	−0.15	0.11
7. EPQ-N	−0.09	0.21	−0.16	0.14	−0.01	0.10	−0.15	−0.05
8. EPQ-L	**0.26**	−0.06	0.10	−0.14	0.22	0.05	0.07	−0.23
9. EPQ-P	−0.18	−0.07	0.02	0.04	***−0.38***	−0.02	−0.15	**0.25**
10. STAI	−0.18	0.11	0.00	0.16	−0.01	−0.04	−0.04	0.13

Note: FSS = Fear Survey Schedule; BAS-DR = BAS Drive; BAS-FS = BAS Fun-Seeking; BAS-RW = BAS Reward; EPQ-E/N/P/L = Eysenck Personality Questionnaire Extraversion/Neuroticism/Psychoticism/Lie; STAI = State Trait Anxiety Inventory (Trait): UWIST = UWIST Energetic Arousal (EA), Tense Arousal (TA), Hedonic Tone (HT), Anger/Frustration (AF) (*N*=63).
Bold: p<0.05.
Bold, italics: p<0.01.

conflict needs to have personal meaning for it to activate the SHS (McNaughton and Corr, 2004). If the assumption is made that the SHS is core to these theta coherence effects reported here, our data support McNaughton and Corr's (2004) claims.

By Gray and McNaughton's (2000) account, the SHS resolves goal-conflict through recursive communication with the neocortex. This communication is phase mediated. We speculate that the increased theta coherence, which was linked with personal rumination, *relates* to this SHS–neocortex recursive communication during goal-conflict resolution of such a personal conflict. In other words, increased SHS–neocortex recursive communication relates to increased neocortical theta coherence. At this stage, we acknowledge that such a claim is highly speculative based on our coherence findings, however we will be returning to this speculation later with consideration for how, in further research, we can seek clearer evidence of the SHS–neocortex role in personal rumination.

Otherwise, the effects for coherence were general and the data did not show any significant effects which were specific to pairs of regions. This finding is consistent with the data reported by Moore et al. (2006). This outcome was somewhat unfortunate as inclusion of an inter-region factor in the coherence analyses was an extension of previous analyses carried out on EEG theta coherence data associated with goal-conflict and one which we hoped would bear fruit.

5.2. Theta power and rumination

We had two explicit hypotheses for theta power: frontal midline theta would increase during rumination and that this would be mediated by participant anxiety level. However, neither prediction were confirmed by the data. First, in both the analyses which dealt with EEG power data there were no interactions with the BIS level factor. Secondly, although EEG theta power associated with the personal rumination condition was significantly greater than EEG theta power associated with the nominal rumination and baseline counting condition, in one analysis (Power analysis 1) this effect was generalized across the whole of the scalp. Therefore, whilst this analysis confirmed that theta power increases when an individual engages in personal rumination, it did not help to shed light on which neural regions were active since the analysis did not uncover effects which were uniquely associated with any of the 12 ROIs.

Table 3
Significant zero-order personality measures as predictors of energetic arousal, tense arousal, hedonic tone and anger/frustration after the personal and rumination periods

		ΔR^2	*b*	SE	*ß*	*t*
	Personal rumination					
		Criterion:energetic arousal				
Step 1						
	Pre-test energetic arousal		0.56	0.1	0.58	5.6**
		R^2=0.34;[*F*(1,61)=30.86**]				
		Criterion:tense arousal				
Step 1						
	Pre-test tense arousal		0.58	0.2	0.36	2.94**
Step 2		0.04 [*F*(1,60)=2.83, *p*=0.09]				
	Neuroticism (N)		0.34	0.2	0.21	1.7
		R^2=0.24;[*F*(1,61)=9.25**]				
		Criterion:hedonic tone				
Step 1						
	Pre-test hedonic tone		0.65	0.22	0.36	3.02**
		R^2=0.13;[*F*(1,61)=9.13**]				
	Nominal rumination					
		Criterion:energetic arousal				
Step 1						
	Pre-test energetic arousal		0.76	0.09	0.71	8.82**
Step 2		0.07 [*F*(1,60)=10.05, *p*=0.02]				
	Psychoticism (P)		−0.55	0.17	−0.26	−3.2**
		R^2=0.61;[*F*(2,60)=46.78**]				
		Criterion:tense arousal				
Step 1						
	Pre-test tense arousal		0.6	0.13	0.5	4.76**
Step 2		0.06 [*F*(1,60)=5.74, *p*=0.02]				
	BAS Drive		0.37	0.15	0.25	2.40*
		R^2=0.34;[*F*(2,60)=15.47**]				
		Criterion:hedonic tone				
Step 1						
	Pre-test hedonic tone		0.45	0.14	0.39	3.3**
		R^2=0.15;[*F*(1,60)=10.87**]				

b and *ß* are unstandardized and standardized beta coefficients, respectively, from the final step of the regression equation.
* $p<0.05$;** $p<0.01$.

However, in the other analysis (Power analysis 2 — which was included directly to compare EEG power response dispersed across frontal, fronto-central, centro-parietal and parieto-occipital horizontal chains of ROIs) the global effect described above was specific to the parieto-occipital horizontal chain. With respect to the role of the ACC, in the case of the generalized effect in theta power, it could be argued that frontal EEG theta activity associated with ACC activation could simply have been 'smeared' across the whole of the scalp by volume conductance. However, it would be impossible to apply this logic to the second analysis applied to the EEG power data in which task differentiation effects were purely found at the parieto-occipital horizontal chain (i.e. the horizontal chain of ROIs which was *furthest away* from the ACC). Therefore, the primary role of the ACC in anxious rumination is not supported by these data. This indicates that anxious rumination does not activate the ACC and hence it is not appropriately explained by theories centered around ACC involvement in cognitive processes.

With respect to the parieto-occipital location of this effect, it is possible that this relates to activation of the posterior cingulate during goal-conflict resolution. Within the septo-hippocampal system, the posterior cingulate is a major target of hippocampal efferents (together with the subiculum). It also has unidirectional links with the subiculum (Gray and McNaughton, 2000). Furthermore, McNaughton (2006) makes the point that the posterior cingulate typically shows theta activity due to monosynaptic control from a specific septal area. Therefore, it is likely that during recursive processing between the SHS and the neocortex as goal-conflicts are considered, the posterior cingulate is also differentially activated (in terms of EEG theta power). Such an account is entirely consistent with Gray and McNaughton's (2000) model of BIS activity.

5.3. Alpha coherence and rumination

There was only one significant effect which occurred in the 10–12 Hz waveband, scalp-wide coherence in response to the personal rumination condition was significantly greater than in the baseline count condition. This is an effect which would have been expected in the theta waveband but not in the high alpha waveband. High alpha is a waveband which has traditionally been associated to task related cognition (Klimesch, 1999) and motor response (Pfurtscheller and Berghold, 1989).

However, in one group of studies from the laboratory of Gennadij Knyazev links have consistently been made between EEG measures and measures of personality (Knyazev et al., 2004; Knyazev and Slobodskaya, 2003; Knyazev et al., 2003, 2002). One consistent relation reported there is a link between EEG alpha and personality measures which quantify personality constructs akin to anxiety. One particular personality construct which receives a lot of attention in this work are measures of BIS. This association deserves further empirical attention.

Knyazev and Slobodskaya (2003) took the view that anxiety is predominantly cortically-based and represented in alpha in humans and that it has an influence over lower frequency oscillatory systems. In this framework, they suggested that alpha may reflect increased activity of cortical mechanisms promoting vigilance and rumination whilst suppressing spontaneous reactions associated with the brainstem region (represented by delta, in this case) which traditionally have been associated with appetitive behaviours (Edelman, 2001). This explanation is consistent with explanations they had offered previously regarding alpha's link with BIS, namely that it acts as an index of increased vigilance associated with higher BIS activity. Also, the idea of vigilance increase being associated with BIS activity is consistent with dominant models of BIS activity (Gray, 1983; Gray and McNaughton, 2000). In this sense then, the alpha results can be explained within Knyazev's theoretical framework, namely that alpha power increases reflect increased vigilance during anxious rumination.

5.4. Beta power and rumination

We also included an analysis of slow (12–20 Hz) and fast (20–30 Hz) beta despite having no specific hypotheses associated with this waveband. These analyses yielded interesting and unexpected results. First, in low beta, EEG power for the baseline counting condition was significantly lower than that for both of the rumination tasks. In a classic study carried out by Ray and Cole (1985), they reported a defuse pattern of activation of beta power in response to emotionally positive or negative tasks and also for cognitive tasks. It is fair to say that both of the rumination conditions would be laden with emotion and cognition to a far greater extent than the baseline counting condition and these data may reflect the trend identified in the earlier study. Therefore, it is likely that it is this emotional and cognitive content which elevates EEG slow beta power in response to both rumination tasks relative to the baseline counting condition. Another study which supports this view was carried out by Őzgören, Başar-Eroğlu, and Başar (2005), who reported that EEG beta power at a range of scalp electrodes increased when participants are exposed to unfamiliar compared to familiar faces. They chose to explain this effect within the context of semantic and episodic memory (i.e. cognition). However, given the fact that the familiar face was the participant's grandmother, there would almost certainly be an emotion element bound up in participants' beta responses. The authors of that study overlooked this fact. In this sense then, the beta increases recorded by Őzgören et al. (2005) can speculatively be linked to a combination of cognition and emotion — exactly the same as we are speculating for the slow beta response we have recorded in the current study.

A separate pattern of response was recorded for fast beta which presents a challenge to interpretation. For that waveband, we recorded significantly greater EEG power in response to the nominal rumination condition with respect to the baseline counting condition. No such difference was recorded when the personal rumination condition was compared to the baseline counting condition. Logically any difference between the cognitive and emotional demands of the personal rumination and the nominal rumination would be the best place to start in accounting for the fact that beta power associated with nominal rumination was significantly greater than the baseline counting beta power whilst beta power associated with the personal rumination condition was not. However, the nominal rumination condition was included as rumination *without* personal involvement whilst the personal rumination was included as rumination *with* personal involvement — by that logic it is tempting to speculate that it is the lack of personal involvement which would have caused the elevated levels of beta activity in the nominal rumination task. However, such speculation is counterintuitive as, presumably, the condition which would have had the least amount of personal involvement would have been the baseline counting condition and, therefore, would have been associated with the *highest* beta power level rather than the lowest. This effect was ancillary to our main experimental predictions and, for now, will have to remain largely unexplained but it is something which we will be following up in subsequent studies.

5.5. The neurological basis of ruminative theta: theoretical speculation and further research

In Moore et al. (2006), it was shown that, at stages of cognitive goal-conflict, theta coherence between multiple scalp regions increases. In the current study, we have shown that this theta coherence effect holds for anxious rumination which (following Gray and McNaughton's, 2000, model) we believe is underpinned by weighing up and evaluating goal-conflicts relating to different courses of action. As well as this, we believe we have also found evidence of posterior cingulate activity during personal rumination, an effect which we believe is embedded in theta power response. Moore et al.

(2006) speculated that, during cognitive goal-conflicts, when the hippocampus and the neo-cortex communicate through recursive processing, distinct areas of neocortex also concurrently show phase consistency measurable through EEG coherence. Therefore, the reported theta coherence effects were seen as a *byproduct* of hippocampus-neocortex phase mediated recursive communication. We believe this is also the case in this current study but acknowledge the highly speculative nature of such a claim based only on EEG data recorded from the surface of the scalp. We also extend the findings of the earlier study and speculate that the increase in parito-occipital theta power, reflecting the posterior cingulate's role, is a second effect which occurs as a byproduct of the recursive process which is activated during anxious rumination. Further research would be necessary to corroborate such speculation.

We have suggested that the posterior cingulate may be at the source of our main region specific theta power effects and the SHS our theta coherence results. If correct in this speculation, it would be reasonable to expect the posterior cingulate and one or more regions with in the SHS[2] to show differential activation during the three experimental tasks. It is possible that this could be identified using appropriate dipole source localization procedures. Whilst it is generally accepted in the EEG literature that theta activity generated by the hippocampus cannot be measured for the simple reason that it does not produce a scalp EEG signal, recent advances in source localisation raise the possibility that hippocampal-generated theta can be mathematically inferred. Based on spatial location, it would be reasonable to assume this is also the case for the posterior cingulate. Accordingly, to assess if these regions (or, in the case of the SHS, sub-regions within the SHS) are directly involved in the rumination process a follow-up study could analyse EEG data using low-resolution electromagnetic tomography (LORETA). LORETA has been used to approximate the neural sources responsible for the scalp recorded electrical activity with respect to specific wavebands (Mulert et al., 2001, 2004). LORETA computations are thought to have the capability to enable identification of neural sources in the cortical grey matter and the hippocampus (and surrounding structures), with a spatial resolution of 7 mm (Pascual-Marqui et al., 1999). Such a step would be important to add weight to speculation regarding SHS-neocortex activity during anxious rumination that we are introducing here.

5.6. BIS, neuroticism, anxiety and theta coherence

With respect to the effects of rumination on mood, the subjective results showed that the rumination tasks provoked mood changes as expected, with increased in tension and frustration levels along with lowered general hedonic tone. These findings are largely consistent with our main experimental hypothesis regarding rumination and are in accordance with the results from performance studies where neuroticism predicts tense arousal (Matthews and Gilliland, 1999); they serve to validate our experimental manipulation. The extent to which personality influenced these state changes were small to modest, however, once again they were in line with several studies on neuroticism and negative affect (Matthews and Gilliland, 1990). When controlling for baseline differences in mood (i.e., mood before the rumination phases), the impact of personality on mood in the different rumination conditions diminished considerably. Unexpectedly, the hypothesized relationship between BIS and subjective mood was not supported as BIS failed to predict tension and hedonic tone. Similarly, BIS also failed to predict increased theta coherence during personal rumination as expected. One possible explanation is that neuroticism and trait anxiety, closely related to BIS, had a pervasive impact on mood throughout all testing conditions which left little room for intraindividual variability as a function of testing condition. This may have affected theta coherence levels as well.

6. Conclusion

In this study we asked participants to ruminate over something personally meaningful to them and also something which was merely nominal. Each rumination phase included goal-conflicts, but the former was *subjectively* important. We found that EEG theta coherence associated with two theta wavebands, and global EEG theta power associated with one theta waveband together with parieto-occipital theta power associated with a lower theta waveband, were higher when participants ruminated about something personally meaningful. These results are consistent with the Gray and McNaughton's (2000) account of recursive processing between the hippocampus and neocortex during goal-conflict resolution, and we interpret them in these terms. In addition, the EEG theta power effects which were found in the parieto-occipital region were tentatively linked to posterior cingulate activity, a key structure within the BIS architecture. We also found that high alpha coherence was higher during personal rumination than during the baseline counting condition. These data were explained in terms of proposals from the laboratory of Gennadij Knyazev who linked increased alpha activity to increased vigilance during phases of anxious rumination. Otherwise, effects found in the high beta range were related to the cognitive and emotionally laden nature of rumination compared to the baseline count condition. In terms of subjective data, we found that mood changes as expected during the rumination tasks, but these were not linked to participants' BIS levels. The failing to find effects which differentiated based on participants' BIS levels also held for the EEG results.

Our conclusion is that these EEG findings provide new information on the neural basis of emotional rumination and, therefore, hold implications for the theoretical elucidation of normal and pathological anxiety, the full extent of which must await further empirical clarification.

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[2] The SHS is comprised of several structures including (most notably) the entorhinal cortex, the dentate gyrus, fields CA1-4 of the hippocampus proper, the subiculum (McNaughton, 2006).

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