

“Can waiting awaken the resting brain?” A comparison of waiting- and cognitive task-induced attenuation of very low frequency neural oscillations.

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Abstract

The default mode network (DMN) is characterised by coherent very low frequency (VLF) neural oscillations in the resting brain. The attenuation of this activity has been demonstrated following the transition from rest to performance of a broad range of cognitive *goal-directed* tasks. Whether the activity of resting state VLF oscillations is attenuated during non-cognitive *goal-directed* tasks such as waiting for rewarding outcomes is not known. This study examined the VLF EEG power from resting to performance of attention demanding task and two types of *goal-directed* waiting tasks. The association between the attenuation of VLF EEG power and Attention-Deficit/Hyperactivity Disorder (ADHD) symptoms was examined.

Direct current EEG (DC-EEG) data was collected from 32 healthy young adults (half high and half low ADHD symptom scorers) during (i) a rest state, (ii) while performing a cognitive demanding reaction time task (2CRT), and (iii) while undertaking each of two different *goal-directed* waiting conditions: “forced-to-wait (FW)” and “choose-to-wait (CW)” tasks. The spatial distribution of VLF EEG power across scalp was similar to that seen in previous resting VLF EEG studies. Significant rest-to-task attenuation of VLF EEG power occurred during the 2CRT and the CW task, but not during the FW task. The association between self-ratings of ADHD symptoms and waiting-induced attenuation was not significant.

This study suggests VLF EEG power attenuation that occurs following rest to task transition is not simply determined by changes in cognitive load. The *goal-directed nature* of a task, its motivated nature and/or the involvement of *effortful attention* may also contribute. Future studies should explore the attenuation of resting state VLF oscillations during waiting and impulsive choice.

Keywords: Very low frequency oscillations; Direct current EEG; Default mode network; Waiting; Attention Deficit/Hyperactivity Disorder.

Research Highlights:

- Attenuation of resting VLF EEG power occurred during *goal-directed* waiting.
- Resting VLF EEG attenuated when individuals *chose* to wait, not *when* forced to wait.
- Not only cognitive load but other *goal-directed* aspects determine VLF EEG attenuation.
- Reframing rest as waiting appears to alter brain processes.

Introduction

The default mode network (DMN) is a coherent network of brain regions which includes the anterior and posterior cingulate cortex, precuneus, medial prefrontal cortex and bilateral inferior parietal lobules. This network is characterised by temporally synchronous very low frequency (VLF) oscillations of around 0.1 Hz or less, i.e. cycles of 10 second or longer (Broyd et al., 2009; Fox et al., 2005). The DMN is most active during rest (Fox et al., 2005; Fransson, 2005; Fransson, 2006), and is thought to play a role in spontaneous cognitive processes including mind wandering (Christoff et al., 2009), meditation (Hasenkamp et al., 2012) and self-referential processing (i.e. autobiographic memory and prospective planning (Buckner and Carroll, 2007; Spreng et al., 2009). Attenuation of VLF oscillations within this network has been found following the switch to performance of *goal-directed* tasks (Broyd et al., 2009; Raichle et al., 2001). This has been demonstrated using a broad range of cognitive tasks including those involving response inhibition (Liddle et al., 2011) and working memory (Fassbender et al., 2009) measured with both functional magnetic resonance imaging (fMRI; Fransson, 2006; Liddle et al., 2011) and electroencephalography (EEG; Broyd, Helps, & Sonuga-Barke, 2011; Helps, Broyd, James, Karl, & Sonuga-Barke, 2009). Moreover, this task-induced attenuation of VLF oscillations appears to occur irrespective of task content (Fox et al., 2005) although the extent of attenuation is related to task difficulty (Fassbender et al., 2009; Gilbert et al., 2012; Singh and Fawcett, 2008). Notably, persisting VLF oscillations in the DMN during the completion of a *goal-directed* cognitive task have been proposed as a major source of attentional lapses which constrain cognitive performance (Sonuga-Barke and Castellanos, 2007). For instance, reduced task-induced attenuation of resting VLF oscillations in DMN regions is associated with increased response times (Weissman et al., 2006) and elevated response variability (Fassbender et al., 2009).

Perhaps not surprisingly given the dominant cognitive neuroscience focus on information processing, in this work *goal-directed* tasks have typically been equated with effortful laboratory based paradigms where individuals are required to process information presented on a computer screen. Nevertheless, the original formulation of the DMN proposed by Raichle (2001) highlighted the *goal-directed* nature of activity rather than its cognitive character. This leads to the prediction that the transition from rest to other types of *goal-directed* activity with little or no cognitive load should also provoke attenuation of VLF oscillations in the DMN. A simple task such as waiting for a delayed outcome is an important example of *goal-directed* activity which involves little or no information processing demands, but nonetheless requires an outcome-related focus and the application of effort to persist until the goal is achieved. Recognition of this fact raises two interesting questions: First, is there attenuation of VLF oscillations within the DMN in the transition from rest to waiting tasks similar to that seen from rest to cognitive tasks? Second, would failure to attenuate resting VLF oscillations predict difficulties in waiting similar to those disruptions in task performance when failures occur during traditional stimulus processing tasks?

The second question is important from a practical point of view as in daily life individuals are often required to wait for the outcome of a decision, or the commencement of an activity. Failures to wait are linked to a range of mental disorders such as mania, substance abuse disorders and personality disorders (Evenden, 1999; Luman et al., 2005; Moeller et al., 2001). From a scientific point of view the question is also important because waiting resembles resting in a number of ways. Not only do both waiting and resting situations have low information processing loads, but they also involve a period of idle time. In this sense, "waiting time" can be seen as reframed "resting time" and vice versa - the same event experienced in a different way by virtue of their antecedents and consequences. In daily life we often wait for a result or reward (the goal or outcome), but rest following exerted effort and the completion of a *goal-directed* task. Can reframing this idle time from a passive and recuperative, to a more

active and motivated *goal-directed* perspective (i.e. waiting), change the response of the brain? Moreover, in everyday life there are occasions when an individual is presented with the choice to wait for a future goal or reward, or alternatively, to forgo that delayed reward and to continue with the original activities. At other times waiting may be imposed on an individual, during which time an individual is forced to wait and endure the delay. Here we investigate whether framing waiting in these different ways alters resting brain VLF activity. The key aim of the present study is to address this issue by comparing the level of VLF oscillation attenuation occurring in the transition from rest to two types of waiting task to that seen in the transition from rest to a simple cognitive reaction time task. Direct current EEG (DC-EEG) was used to measure VLF oscillations as it has excellent temporal resolution and offers a more direct measure of neural activity than BOLD signals (Demanuele et al., 2013). The current study builds on previous research which has identified a robust resting state VLF EEG network with high spatial stability and temporal reliability (Helps et al., 2008). The intra-cranial sources of this network have been shown to overlap with the DMN identified using fMRI (Broyd et al., 2011). Consistent with the characteristics of the DMN, the neural activity within this resting VLF EEG network shows significant attenuation following the transition from rest to performance on cognitive tasks (Broyd et al., 2011; Helps et al., 2009; Helps et al., 2010). Therefore, DC-EEG could be a useful and participant-friendly platform for investigating resting state brain activity.

The study also examined the potential impact of Attention-Deficit/Hyperactivity Disorder (ADHD) symptoms on the *goal-directed* activity-induced attenuation of VLF oscillations during cognitive task performance and during periods of waiting. ADHD is a common childhood-onset psychiatric disorder with core symptoms of inattention, hyperactivity, and impulsivity (APA, 2000). Patients with ADHD often find *goal-directed* tasks involving waiting for delayed rewards difficult. They typically display a preference for immediate small rewards over delayed larger incentives, even if they are aware that they will gain less in the long term (Bitsakou et al., 2009; Marco et al., 2009; but see Scheres et al., 2006 for a negative study). Furthermore, there is

increasing empirical evidence suggesting DMN activity is altered in patients with ADHD. For example, patients with ADHD exhibit altered functional connectivity at rest and during task performance. They also display reduced task-induced attenuation of VLF oscillations in regions linked to DMN (Castellanos et al., 2008; Fair et al., 2010; Fassbender et al., 2009; Liddle et al., 2011; Tian et al., 2008). In line with neuroimaging findings, studies with DC-EEG have found reduced resting state VLF EEG power in adolescents with ADHD, along with decreased rest-to-task attenuation of VLF EEG power compared to healthy age-matched volunteers (Helps et al., 2010).

In sum, this study investigated whether *goal-directed* waiting would induce attenuation of resting state VLF EEG power in a similar manner to traditional *goal-directed* tasks, and whether this was affected by ADHD symptoms. To explore the importance of self-determination and incentives in waiting, we included two different waiting tasks: “forced-to-wait (FW)” and “choose-to-wait (CW)” (see *Procedure* section for detail). It was predicted that: (i) consistent with previous findings, VLF EEG power would attenuate during the transition from rest to a cognitive *goal-directed* task; (ii) resting state VLF EEG power would attenuate during waiting tasks in a similar way to that seen in the cognitive task (especially where waiting is incentivised and freely chosen); (iii) participants with elevated ratings of ADHD symptoms would show less attenuation between rest and both cognitive and non-cognitive (FW and CW) *goal-directed* tasks in comparison to participants with low self-ratings of ADHD symptoms.

Results

Spatial distribution of VLF EEG power at rest and cognitive task-induced attenuation

Figure 1 (a) shows the spatial localisation of VLF EEG power at rest. Visual inspection of the resting VLF EEG power showed maximal activity in the frontal pole regions extending to the centroparietal areas. Figure 1 (b) shows spatial distribution of the cognitive task-induced attenuation of resting VLF EEG power – i.e. the VLF EEG power difference from rest to performance of the cognitive task. The task-induced attenuation of resting VLF EEG power was most evident in midline regions, stretching from the frontocentral area to parietal and temporal regions.

Does ‘goal-directed waiting’ attenuate resting state VLF EEG power?

The scalp distributions of *wait*-induced attenuation of resting VLF EEG power are shown in Figure 2. The *CW*-induced attenuation of VLF EEG power had a similar spatial profile to the task-induced attenuation, while the *FW*-induced attenuation was more centralised and revealed maximal power in frontocentral and centroparietal regions.

Table 1 shows the VLF EEG power at rest and during each of the three *goal-directed* conditions for the whole samples. Two-way repeated measure ANOVAs showed significant main effect of *Network* and interactions between *Condition* and *Network* across the comparisons of resting and the three *goal-directed* activities ($p < .01$). In each case there was substantial attenuation of VLF EEG power. The *goal-directed* activity-induced attenuation of VLF EEG power was greater *within* the VLF EEG network comparing with the one fell *outside* the network for all task conditions. Within the VLF EEG network, the cognitive task brought about the greatest attenuation of resting VLF EEG power, closely followed by the *CW*. The difference between rest and *FW* did not reach statistical significance.

Are ADHD symptoms related to goal-directed activity-induced attenuation of VLF EEG?

Table 2 provides demographic information and self-ratings of ADHD symptoms by

participants. The two groups were comparable in terms of age and gender. As expected, the *high ADHD symptom* group reported significantly higher scores in terms of inattention and hyperactivity/impulsivity than the *low ADHD symptom* group. The ratings from close friends/relatives of participants confirmed significant group difference in inattentive subscale and total scores. Ratings of hyperactivity/impulsivity symptoms for the *high ADHD symptom* group showed a non-significant trend. Moderate correlations were found between self and friend/relative reports in total scores and inattentive symptoms. Three-way repeated measure ANOVA showed significant differences in *Condition* ($F(3, 28) = 6.49, p=.002$) and *Network* ($F(1, 30) = 4.24, p=.048$), but no effect of ADHD group status. *Group* did not interact with the other factors (all $p>.1$).

Discussion

Previous research has demonstrated that resting state VLF oscillations attenuate during the transition from rest to *goal-directed* cognitive tasks, e.g. with fMRI (Fox et al., 2005) and DC-EEG (Helps et al., 2009). This study extended this finding by examining whether *goal-directed* waiting tasks induce attenuation of VLF EEG power in a similar way despite the absence of need to process external cognitive stimuli. There were four findings of particular note. First, the cognitive RT task induced substantial attenuation consistent with previous VLF EEG work (Broyd et al., 2011; Helps et al., 2009). Second, we observed CW-induced attenuation of resting VLF EEG power, with a spatial distribution similar to the attenuation seen during the cognitive task. Third, the attenuation of resting VLF EEG power differed as a function on waiting task type: the attenuation was greater when waiting was freely chosen and incentivized (i.e. in the CW) compared to when participants were forced to wait (i.e. in the FW). Fourth, contrary to our prediction, the *high* and *low ADHD symptom* groups did not differ in terms of *goal-directed* activity-induced attenuation of resting VLF EEG power.

The results of this study raise some important questions regarding the nature of resting and waiting, and their impact on VLF oscillations. Resting and waiting both include periods of idle time, and are not defined by external cognitive demands. Why then were the neural signatures for resting and the CW so different given the prima facie similarity of these tasks? Is it possible that the instruction to wait reframed the experience of resting, changing the purpose of this period of idle time, and altering the pattern of VLF oscillations in a similar way to a cognitive *goal-directed* task? A recent fMRI study conducted by Benjamin et al. (2010) showed that in comparison with relaxed resting state, giving participants specific instructions during resting – i.e. to attend or ignore the scanner background noise – increased the neural activity in the dorsal medial prefrontal cortex (dmPFC), a core component of the DMN (Benjamin et al., 2010) even when there was no increase in cognitive load. In addition, the VLF oscillations in the DMN have been shown to activate differently in various stimulus-free conditions when the contents of thoughts were manipulated. For instance, the DMN is more active during prospective planning than alphabet- or text-recitation (Preminger, Harmelech, & Malach, 2011). Combined with the results of the current study it appears the cognitive reframing of the resting period has the power to alter brain processes and change engagement to task-related processes.

This raises fundamental questions about the necessary and sufficient task characteristics required to induce task-related attenuation of VLF oscillations. Clearly the requirement for information processing of external stimuli, of the sort found in the cognitive task used in this study, is not a necessary component since the CW had little or no cognitive load but still produced substantial attenuation. Taking this fact into consideration, what is the necessary condition for attenuation of VLF oscillations if it is not caused just by increased cognitive load? Considering the characteristics shared by the cognitive *goal-directed* task and the CW tasks in the current experiment, there are a number of possible characteristics to consider: i) *goal-directedness*; ii) *effortful attention to external stimuli or incentives*; and iii) a *motivated*

state.

First, the *goal-directed* nature of tasks may be crucial for the attenuation of resting VLF EEG power. In early formulations relating to the DMN, it was postulated that attenuation of resting neural activity occurred during *goal-directed* behaviors without reference to the cognitive character of these tasks (Raichle et al., 2001). *Goal-directedness* refers to an intrinsic drive to achieve certain objectives or desired results (Solway and Botvinick, 2012). In this sense, both 2CRT and waiting tasks could be considered *goal-directed* even if external stimulation and information processing demands were minimal as was the case in the waiting tasks. It was also interesting in this regard that significant attenuation of VLF EEG power was observed during the CW task but not during the FW task. One possible explanation was that the FW task was perceived as an intermediate session in-between the other conditions, and as a result it was less *goal-directed* and only produced a trend towards suppression of resting VLF EEG power. However, the idea that attenuation of VLF oscillations depends just on *goal-directedness* of a task is inconsistent with the finding in the literature that DMN increases during tasks which involve self-referential processes, such as autobiographical memory and prospective planning because these tasks are also *goal-directed* (Preminger et al., 2011; Spreng et al., 2009).

A second possibility is that attenuation of resting VLF EEG power requires effortful attention to external stimuli. Indeed the degree of attenuation of VLF oscillations in the DMN has been suggested to reflect the amount of mental effort or sustained attention required by a task (Fassbender et al., 2009). Empirical evidence suggests that task-related attenuation of VLF oscillations is more prominent during challenging tasks, whereas it is reduced during well-practiced or low attention demanding tasks (Fassbender et al., 2009; Jolles et al., 2010; Singh and Fawcett, 2008). While resting, subjects often “tune out” their attention from external stimuli and become more internally focused. This is reflected by increased activation of regions within the DMN, and often accompanied by task irrelevant thoughts (Christoff et al.,

2009). During waiting, rather than resting, attention is possibly directed, if not to the waiting task itself, to the longer term anticipated outcomes (the reward available in the future). We describe this voluntary, endogenous driven as “anticipatory attention” rather than sustained attention – the maintenance of a state of readiness in anticipation of the outcome as soon as the waiting period is over. Anticipatory attention is a *goal-directed* mental state in preparation for imminent external events. It involves mental effort and therefore results in attenuation of VLF oscillations. It can be argued that anticipatory attention is closely related to the concept of “prospection” which involves the introspective ability to project oneself into the future (Addis et al., 2007). However, prospection and anticipatory attention may involve different mental processes. For example, envisaging a future event has been associated with increased rather than decreased activity in DMN regions (Spreng et al., 2009). In the current study we observed the opposite patterns - resting VLF EEG power decreased rather than increased during periods of anticipatory attention, suggesting that anticipatory attention involves different neural mechanism than prospection. Furthermore, Sonuga-Barke & Fairchild (2012) have argued that it is the neural connectivity within regions of the DMN rather than the activity of VLF oscillations that influences the ability to form and focus on future goals. While the investigation of EEG coherence during task performance was beyond the scope of the current study, future research should examine VLF oscillations during waiting, anticipatory attention and prospective tasks, as well as the coherence of VLF oscillations in DMN-related regions to other brain areas of task-positive network.

Third, the CW-induced attenuation may be accounted for by differences in motivational state. Intrinsic motivation refers to the motivation originating from “inside” the individual because of the enjoyment or interest elicited by a task itself, while extrinsic motivation relates to the presence of extrinsic positive (or negative) consequences contingent on task performance (Ryan and Deci, 2000). Our study manipulated extrinsic motivation between waiting tasks by motivating participants to choose to wait for the incentive in the CW task, while

forcing them to wait passively during the FW task. Therefore the difference in attenuation of resting VLF EEG power between the two waiting tasks may potentially be due to the degree of extrinsic motivation in each task. However *intrinsic* motivation may also contribute to the attenuation of resting VLF EEG power because during the performance of the cognitive task, where individuals were asked to act the best they could, but were not rewarded. The importance of motivational factors in DMN attenuation has been highlighted by a number of studies. For instance, Liddle et al. (2011) reported a significant motivational effect on resting fMRI BOLD signals in patients with ADHD. The authors observed significant attenuation of signals in a high incentive condition but not in a low incentive condition when patients with ADHD were off medication. These effects were similar in scale to those related to stimulant medication (Groom et al., 2010). It should be noted that the current study included healthy adult volunteers only, while Liddle et al (2011) observed an effect of motivation in participants with ADHD. It is possible that the patients with ADHD required higher levels of incentive to modulate the resting brain effectively or that modulation occurred as a function of intrinsic as opposed to extrinsic motivation. There may also be a threshold for motivation to effectively attenuate resting VLF oscillations. Investigation of resting VLF oscillations during conditions with varying levels of incentives is needed to clarify this issue.

To summarise, it is suggested the attenuation of resting VLF EEG power may be induced by the *goal-directed* nature of activities, the involvement of effortful attention, and the motivated nature of task. The possibility that these components interact with each other cannot be ruled out. Therefore their contribution to the attenuation of resting VLF EEG power may be difficult to differentiate. Moreover, there are other possibilities which may also contribute to the attenuation of resting VLF EEG power during waiting which should be considered in future studies. For example, suppression of goal-irrelevant thoughts and preparation of attention may also influence the activity of VLF oscillations.

In the current study, the *high* and *low ADHD symptom* groups did not differ in terms of the

size of attenuation of resting VLF EEG power. The finding is consistent with one previous study (Broyd et al., 2011), but contradicts a third (Helps et al., 2009). This inconsistency may be due to the fact that those participants with higher self-ratings of ADHD symptoms did not have a clinical diagnosis of ADHD, rather they were healthy volunteers who reported having six or more ADHD symptoms. Although they were selected carefully according to ADHD symptom scores, both from self-report and the rating of one of their close friends or relatives, they may not show altered resting brain activity to the same degree as individuals with a clinical diagnosis of ADHD. Despite this result, the potential connection between waiting difficulty and disruptions of default mode brain system could not be ruled out as both deficits have been repeatedly found in patients with ADHD (Castellanos et al., 2008; Luman et al., 2005). Further, prospective planning, underpinned by DMN activity, appears to play a role in waiting abilities. Prospecting about a future event could possibly reduce the unpleasant feeling of waiting, and consequently increase the subject's ability to wait (Benoit et al., 2011). Exploration of the neural mechanism and functionality of VLF oscillations and its relation to waiting and prospection will help to further understand the psychopathology of ADHD.

The current study is the first to demonstrate *wait*-induced attenuation of resting VLF EEG power. There are a number of limitations that need to be taken into account. First, the resting conditions employed in the study were not fully randomised vis-à-vis the other conditions. Although data from the first and the later resting conditions were averaged, the influence of order effects through fatigue or some other mechanism cannot be completely ruled-out. Second, the FW task was designed as a compulsory session while the CW task was a voluntary condition. There was a risk of losing data of the CW task from those with low motivation to wait. Third, the findings of the study were based on non-clinical ADHD groups thus the results may be unable to represent the clinical group. Fourth, the sample size was relatively small and it may reduce the chance to show significant attenuation of VLF EEG power during the FW task. Finally, given the fact that VLF EEG studies are rare, the VLF EEG

network in this study was identified used a data-driven approach. Future studies should attempt to localise the intracranial sources of VLF EEG through co-registration with fMRI.

Materials and Methods

This study was approved by the School of Psychology Ethics Committee, University of Southampton.

Participants

287 undergraduate students from University of Southampton were screened on the basis of their self-ratings of ADHD symptoms using the *Current Symptoms Scale* (CSS, Barkley and Murphy, 1998). Students who scored above the top 20th percentile (i.e. *high ADHD symptom* group, reporting six or more ADHD symptoms) and those below the bottom 20th percentile (i.e. *low ADHD symptom* group, reporting zero or one symptom) were invited to take part in the study. The study excluded participants who reported a diagnosis of neurological disorders, a history of brain injury, use of any psychotropic substance more than twice in the last six months, or problems of substance abuse or dependence. Prior to testing, participants were asked to refrain from consuming caffeine or nicotine for at least two hours. One participant refused to complete the CW task and was excluded from further analysis. 21 participants with high self-ratings of ADHD symptoms and 19 participants with low self-ratings of ADHD symptoms (aged 18 to 43 years) completed all EEG sessions. Eight participants were further excluded because of excessive EEG artifacts even after artifact removal techniques had been applied (five from *high ADHD symptom* group and three from *low ADHD symptom* group). The final comparisons were conducted with data of the remaining 32 participants (16 per group).

ADHD symptoms screen

The *Current Symptoms Scale (CSS)* contains 18 items formulated in accordance with *DSM-IV* criteria. It includes two subscales: inattention and hyperactivity/impulsivity. It is scored using a four-point Likert scale (never, occasionally, often, and very often), and has validated psychometric properties: construct validity .35-.85; 4 week test-retest reliability.78-.86 (Collett et al., 2003). To reduce the potential self-report bias, two sets of *CSS* data were collected. The first set was from the participants themselves and the second was collected using an adapted version from a significant other, i.e. spouse, friends or relatives (Barkley and Murphy, 1998). For example, "I talk excessively" in the former became "He/she talks excessively" in the latter. This was completed for all but four participants.

Procedure

Participants were familiarised with the electrophysiology laboratory and EEG recording procedure before informed consent was taken. They were then seated in a comfortable chair in the testing room and fitted with an electrode cap. The halogen light in the testing booth was dimmed for the duration of the experiment.

The experimental sessions included one cognitive task, two resting and two types of waiting conditions. In the cognitive task condition participants were requested to complete a two-choice reaction time task (2CRT). The 2CRT was separated into two blocks (T1, T2). It required participants to indicate the direction of arrows presented on the computer screen by pressing a button on a response box. Left pointing arrows required left handed button presses and right arrows required right handed button presses. Each trial included stimulus a presentation time of 400ms, and inter-stimulus interval (ISI) of 600 ms. Each block had 600 trials, and the duration was 10 minutes. The fast ISI was adapted for the purpose of this study to ensure it was a simple but attentionally demanding task. Participants were instructed to focus their attention and respond as quickly and accurately as possible (In this study the

correct response rate was 92.88%).

In the resting conditions, participants were instructed to relax and focus on the fixation cross presented on the monitor for five minutes. The first session (R1) occurred at the start of the experiment, while the second one (R2) was presented after the completion of one task block. The waiting conditions included the “force-to-wait” (FW) task where participants were instructed to wait for five minutes before the next experimental session would commence; and the “choose-to wait” (CW) task, where participants were given a choice to decide if they wanted to wait five minutes for an incentive (a lottery ticket for £20 prize) or to opt out and terminate the waiting period. The order of conditions was counterbalanced across participants in order to ensure as far as possible within the constraints dictated by the different waiting and resting conditions that potential order effects were controlled. Each participant was randomly assigned to one of the following four sequences: i) R1; CW; T1; R2; T2; FW; ii) R1: CW: T1: FW: T2: R2; iii) R1: T1: R2: T2: FW: CW; iv) R1: T1: FW: T2: R2: CW. DC-EEG was continuously recorded throughout all conditions. The experiment, including EEG set up, took approximately 120 minutes.

EEG data acquisition and processing

The continuous scalp electroencephalogram was recorded using a Neuroscan Synamps² 70 channel EEG system at 500 Hz via 24 bit A/D converter with DC procedure, combined with a 70 Hz low-pass filter. Participants were fitted with an electrode cap with 66 equidistant electrodes and data referenced to the nose (EasyCap; Hershing, Germany). The electro-oculogram (EOG) was recorded using Ag/AgCl electrodes above and below the left and right eye. Impedance was kept below 5 k Ω for all electrodes. EEG data were processed with MATLAB (version R2010a) and re-referenced to an average reference. The linear trend caused by drift was removed using the ‘detrend’ command in MATLAB. Independent component analysis (ICA) was used to remove artifacts and ocular movements from the data.

This analysis was performed separately for each condition. The EEG signal was then reconstructed by back-projection of all artifact-free components.

EEG data from each participant for the first 55 electrodes were used for analysis. Data were subjected to fast Fourier transformation (FFT) for all conditions. One minute Hamming windows with 20 second overlap were used. The EEG power of the VLF band (0.02–0.20 Hz) was calculated for each condition (Penttonen & Buzsaki, 2003). The spatial location of the VLF EEG network was established using only the data from the *low ADHD symptom* group because it was assumed participants in the *high ADHD symptom* group may show atypical patterns of VLF oscillation activity. The group mean (N=16) of rest-to-task power attenuation (calculated by subtracting the VLF EEG power of the task condition from the power of the rest condition) for each electrode was calculated. The first 18 electrodes exhibiting the most prominent task-induced attenuation- i.e. the first third of the 55 electrodes with the highest rest-to-task attenuation of VLF EEG power were considered for the purposes of the current paper as being within the VLF EEG network, while all the others were considered to fall outside this network. Subsequently, the average of VLF EEG power across the electrodes within the VLF EEG network was calculated for each participant and for each condition respectively. Similarly, the mean power across electrodes outside of the network was calculated. Since EEG power was not normally distributed, the values were natural log transformed (Gasser et al., 1982).

Data analysis

Given the similarity of instruction and strength of VLF EEG power, data from T1 and T2, and R1 and R2 were averaged to increase the reliability of measurement and to further reduce the impact of potential order effects. Data from the FW and CW tasks were analyzed separately given their different characteristics. This produced four levels of the Condition factor: R: $(R1+R2)/2$; T: $(T1+T2)/2$; FW and CW. First we examined the spatial localisation of resting

state VLF EEG power, as well as the spatial distribution of activity-induced attenuation of VLF EEG power (the level of attenuation was calculated by subtracting the VLF EEG power in the T, FW, and CW conditions from the R condition). In order to address questions relating to the size of the attenuation for the whole sample, two-way repeated measures ANOVAs were run with the VLF EEG power as the dependent variable, *Network* (within or outside) and *Condition* (R versus T, R versus FW, R versus CW respectively) were within-subject factors. The difference in VLF EEG power between resting and *goal-directed* activities for within and outside network was calculated using Cohen's *d*. Finally, in order to examine whether these patterns of attenuation differed as a function of ADHD symptoms, *Group* (*high ADHD symptom* group vs. *low ADHD symptom* group) was added into ANOVA model as an independent variable.

Conclusions

The study identified significant attenuation of VLF EEG power following the transition from rest to waiting when participants actively chose to wait, but not when the waiting was imposed. The degree of wait-induced attenuation of resting VLF EEG power was similar to that found during the performance of cognitive task, even though the waiting task did not involve cognitive information processing and in many ways shared characteristics with rest. Comparing the results across the three conditions suggested that *goal-directedness*, rather than cognitive load, and the involvement of *effortful attention* and *motivated state* may be necessary conditions for attenuation of VLF EEG power. Future research should consider the role of extrinsic and intrinsic motivation in attenuation of resting VLF oscillations and also study the impact of DMN-related activity on impulsive choice (Benjamin et al., 2010; Penttonen and Buzsáki, 2003).

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Figure captions

Fig. 1 - Scalp distribution of very low frequency EEG power during rest and the task-induced attenuation: (a) VLF EEG power (0.02-0.2 Hz) at rest; (b) cognitive task-induced attenuation of VLF EEG power. The attenuation was calculated by subtracting the VLF EEG power during 2CRT condition from the resting condition. Red and yellow represented higher level of attenuation (i.e. difference) from rest to task performance.

Fig. 2 - Scalp distribution of the VLF EEG power difference from rest to waiting tasks: (a) the attenuation of VLF EEG power from rest and “force-to-wait” task; (b) the attenuation from rest to choose-to-wait task. The value of VLF EEG power attenuation was calculated by subtracting the power of waiting task conditions from the resting condition. Red represented higher attenuation.

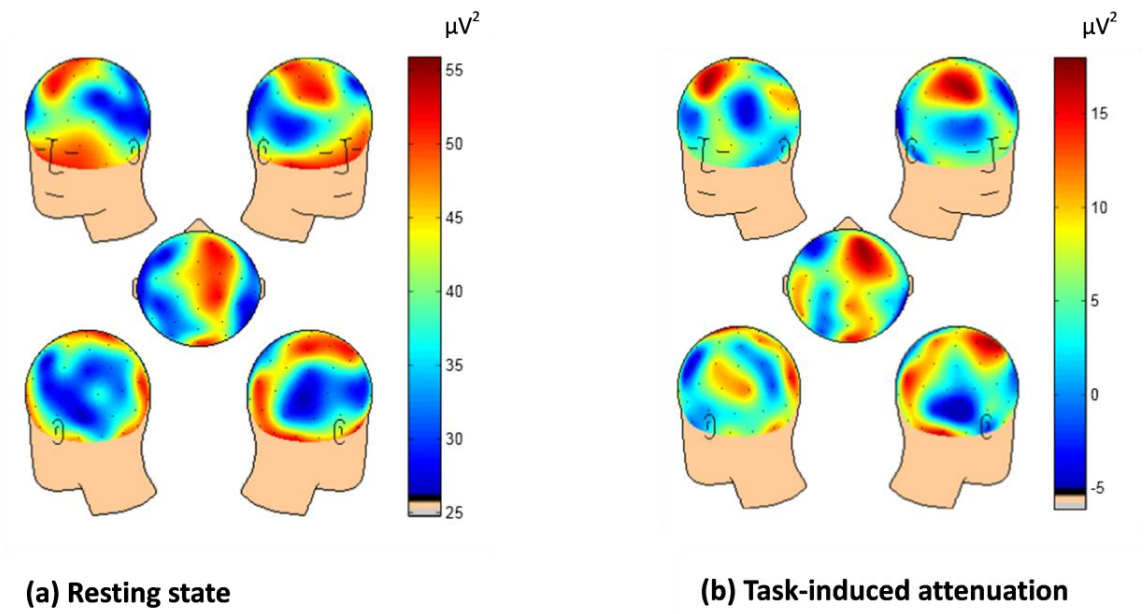


Figure 1.

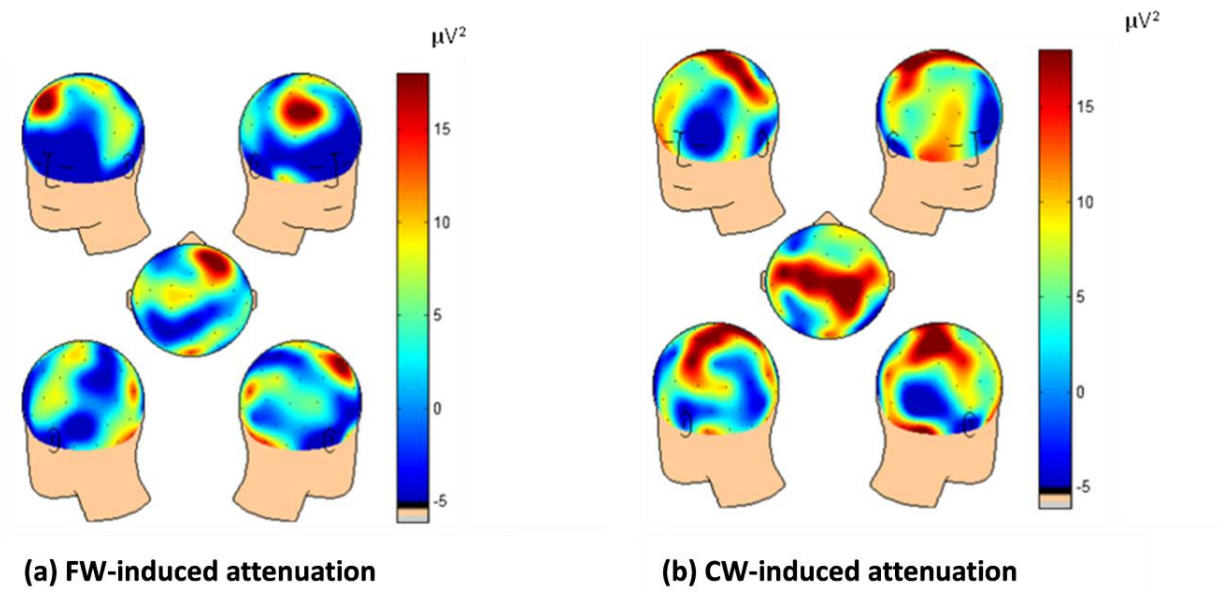


Figure 2.

Table 1 – VLF EEG power (In power) difference between rest and *goal-directed* activities, within and outside of the network, and the statistics of two-way repeated measure

ANOVAs

Within network			Outside network			Main effect (<i>Condition</i>)		Main effect (<i>Network</i>)		<i>C x N</i>	
Mean (SD)			Mean (SD)			<i>F</i>	<i>p</i>	<i>F</i>	<i>P</i>	<i>F</i>	<i>p</i>
Rest	Task	Cohen's <i>d</i>	Rest	Task	Cohen's <i>d</i>						
3.74 (0.35)	3.47 (0.31)	0.82	3.57 (0.30)	3.52 (0.28)	0.17	8.96	.005	8.94	.005	30.62	<.001
CW	Cohen's <i>d</i>		CW	Cohen's <i>d</i>							
3.41 (0.56)	0.72		3.39 (0.48)	0.44		11.51	.002	12.15	.001	15.44	<.001
FW	Cohen's <i>d</i>		FW	Cohen's <i>d</i>							
3.60 (0.49)	0.34		3.56 (0.42)	0.02		1.01	.323	13.59	.001	8.45	.007

Notes: CW = choose-to-wait task; FW= forced-to-wait task; *C x N*: *Condition* and *Network* interaction. To examine the VLF EEG power difference between resting and *goal-directed* activities, comparisons were run for Rest versus Task, Rest versus FW, and Rest versus CW respectively.

Table 2 - Demographics and ratings of ADHD symptoms.

	<i>High ADHD symptom group</i>	<i>Low ADHD symptom group</i>
	N= 16	N= 16
	Mean (SD)	Mean (SD)
Age (years)	22.75 (3.84)	21.31(6.06)
Number (%) males	4 (25%)	4 (25%)
<i>Current Symptoms Scale (CSS)</i>		
<i>Self-report</i>		
Total score	28.13 (6.26)	7.75 (3.09)**
Inattention	15.63 (3.61)	4.25 (1.92)**
Hyperactivity/ impulsivity	12.50 (3.33)	3.50 (1.83)**
<i>Friend or relative report</i>		
Total score	13.85 (9.42)	8.27 (6.91)*
Inattention	7.31 (5.45)	3.73 (3.69)*
Hyperactivity/ impulsivity	6.54 (5.03)	4.53 (4.19)

Notes: * $p < .05$, ** $p < .001$; *High ADHD symptom group*: Adult participants scored six or more self-rated inattentive or hyperactivative/impulsive symptoms. *Low ADHD symptom group*: adult participants scored just one or zero self-rated symptoms.