



## Resting EEG in alpha and beta bands predicts individual differences in attentional blink magnitude

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### ABSTRACT

Accuracy for a second target (T2) is reduced when it is presented within 500 ms of a first target (T1) in a rapid serial visual presentation (RSVP) – an attentional blink (AB). There are reliable individual differences in the magnitude of the AB. Recent evidence has shown that the attentional approach that an individual typically adopts during a task or in anticipation of a task, as indicated by various measures, predicts individual differences in the AB deficit. It has yet to be observed whether indices of attentional approach when not engaged in a goal-directed task are also relevant to individual differences in the AB. The current studies investigated individual differences in the AB by examining their relationship with attention at rest using quantitative measures of EEG. Greater levels of alpha at rest were associated with larger AB magnitudes, where greater levels of beta at rest were associated with smaller AB magnitudes. Furthermore, individuals with more beta than alpha demonstrated a smaller AB effect than individuals with more alpha than beta. Our results suggest that greater attentional engagement at rest, when not engaged in a goal-directed task, is associated with smaller AB magnitudes.

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### 1. Introduction

Attention allows for the selective processing of information. This selectivity can help to ensure that relevant information is available to influence behavior. However, attention is a finite resource, and there are limits on how much information one can attend to at any one time. When the relevant information available exceeds the available attentional resources, the probability that relevant information will be missed increases. The attentional blink (AB) is a deficit in performance attributed to such attentional limitations (Raymond, Shapiro, & Arnell, 1992).

#### 1.1. The attentional blink and attentional limitations

When the second of two to-be-attended targets is presented within half a second of the first target (T1) in a rapid serial visual presentation (RSVP) stream, report accuracy for the second target (T2) is impaired compared to when T2 is presented after a longer

interval following T1 (Broadbent & Broadbent, 1987; Raymond et al., 1992). This T1–T2 lag dependant dual-task effect is referred to as the attentional blink (AB; Raymond et al., 1992).

Generally, the AB has been attributed to a lack of sufficient attentional resources necessary for multiple targets to be appropriately processed into awareness. For some authors, this has been instantiated in terms of bottleneck information processing models. For example, bottleneck models of the AB (e.g., Chun & Potter, 1995; Jolicoeur, 1998) propose that encoding the temporary representation of T1 into working memory consumes resources to the extent that any subsequent encoding of relevant information, such as T2, would need to be suspended until encoding of T1 was complete. Suspending the encoding of the fragile, temporary representation of T2 when its processing overlaps with that of T1 is thought to reduce the fidelity of the T2 representation leading to decreased report accuracy for T2 at short lags.

For other authors, a shortage of attentional resources has been instantiated in terms of limitations on cognitive control functions. For example, in the temporary loss of control model (Di Lollo, Kawahara, Ghorashi, & Enns, 2005) top-down input filters control the efficient selection of task-relevant targets. However, because encoding T1 into working memory requires limited attentional resources, these resources are not available to exert top-down control over the input filter, and the filter falls under bottom-up control while T1 is being encoded. If T2 is presented before attention is again free to control this filter, then T2 selection is

*Abbreviations:* AB, attentional blink; DMN, default mode network; EEG, electroencephalogram; EOG, electro-oculogram; ERD, event-related desynchronization; FFT, fast Fourier transform; fMRI, functional magnetic resonance imaging; RSVP, rapid serial visual presentation; ROI, region of interest; T1, first target; T2, second target.

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impaired reducing the likelihood of accurate T2 report at short lags.

In the context of these accounts it appears that the AB is an unavoidable consequence of the way in which selective information processing is necessarily carried out. However, the AB is not observed in some individuals, so called “non-blinkers” (Martens, Munneke, Smid, & Johnson, 2006), and individuals differ reliably in the magnitude of their AB (i.e. the slope of the lag dependant effect on T2 performance; McLaughlin, Shore, & Klein, 2001). This suggests that individuals may differ in their speed and efficiency of information processing and/or their approach to selective information processing (i.e. their attentional approach), which then influences the magnitude of their AB.

Measures of fluid intelligence (Arnell, Stokes, MacLean, & Gicante, 2010; Colzato, Spapé, Pannebakker, & Hommel, 2007), information processing speed (Arnell, Howe, Joannisse, & Klein, 2006), and working memory capacity (Arnell & Stubitz, 2010; Arnell et al., 2010) do not appear to predict individual differences in the AB. This suggests that it is not the quality or amount of cognitive resources that determines the magnitude of an individual's AB (Arnell et al., 2006). There is, however, evidence that the attentional approach that an individual adopts, for example whether attention is generally diffused or focused (Dale & Arnell, 2010), or whether attention tends to be more or less invested in irrelevant information (Arnell & Stubitz, 2010; Dux & Marois, 2008; Martens & Valchev, 2009), predicts individual differences in AB magnitude. These results show that individuals who focus less on irrelevant information and have a diffuse, global processing style produce smaller ABs. Dispositional factors like trait affect (MacLean, Arnell, & Busseri, 2010) and personality (MacLean & Arnell, 2010) also predict AB magnitude. Individuals high in traits such as positive affect, openness to experience and extraversion (traits that have been linked to a diffuse processing style – e.g., Fredrickson & Branigan, 2005) show smaller ABs, while individuals high in negative affect and neuroticism (traits linked to a focused attentional style – e.g., Kramer, Buckhout, & Eugenio, 1990) show larger ABs. So, it appears that how an individual tends to employ their cognitive resources is relevant to the magnitude of their AB, rather than the amount of resources they possess.

### 1.2. Attentional approach and the AB

Recently, MacLean and Arnell (2011) operationalized attentional resource deployment in the AB task by measuring the amount of anticipatory attentional investment prior to each RSVP trial using alpha event-related desynchronization (ERD). Alpha ERD refers to a decrease in alpha power from baseline following an event; in the case of MacLean and Arnell the event was a cue that the RSVP was to begin shortly. Greater alpha ERD immediately before an RSVP trial began was shown to be beneficial for T1 performance and T2 performance at long T1–T2 lags. In contrast, alpha ERD was greater preceding short T1–T2 lag trials where T2 performance was subsequently incorrect (an AB trial) than on those trials where T2 performance was subsequently correct (a no-AB trial), providing evidence that greater investment of attentional resources in advance of the RSVP trial, is associated with the AB.

In summary, measuring attentional approach tendencies between individuals using cognitive task performance and self-report questionnaires, and using EEG to measure trial-to-trial changes in state attentional investment within individuals has provided evidence that individual differences in attentional approach and attentional investment are relevant to understanding the AB and individual differences in the AB.

Personality and trait affect measures index individual differences in general tendencies over relatively long epochs of time,

and alpha ERD was used to measure intra-individual states of anticipatory attentional investment several seconds before the first target appears. Thus, even before an RSVP stream begins, individuals appear to approach the trial in characteristic ways that influence performance outcomes. Therefore, it is possible that individual differences in attentional investment at rest, when not engaged in the primary goal-directed task of interest (i.e. the AB task), may predict individual differences in the AB. Enduring dispositions in attentional approach could be reflected in individual differences in attentional investment at rest. Individual differences in attentional investment at rest could be indicative of the level of investment that is likely to occur during the AB task. In the current study we examined electrophysiological measures of individual differences in attentional investment at rest for the purpose of predicting individual differences in the AB.

### 1.3. Electrophysiological measures of attention at rest

Oscillatory activity in the alpha range of frequencies (8–12 Hz) is characteristically observed in the resting state. Specifically, alpha range oscillatory activity is increased during periods of rest with eyes closed compared to periods of rest with eyes open, an effect which is attributed to the desynchronizing effect of visual stimulation on the cortex (for a review of alpha oscillations see Niedermeyer, 1997). The presence of alpha in the waking state is thought to denote an “idling” or unoccupied cortex (Pfurtscheller, Stancák, & Neuper, 1996), or alternatively, the presence of cortical inhibition (Klimesch, Doppelmayr, & Hanslmayr, 2006; Klimesch, Sauseng, & Hanslmayr, 2007). In support of these conceptualizations, investigations of alpha oscillations at rest with concurrent fMRI imaging have observed a negative correlation between alpha and metabolic activity such that when alpha is present metabolic activity is reduced in the cortex (Goldman, Stern, Engel, & Cohen, 2002; Laufs et al., 2003a; Laufs et al., 2003b; Laufs et al., 2006; Moosmann et al., 2003). Alpha is also seen to decrease in response to a signal that an attention-demanding event is soon to occur (Brunia & van Boxtel, 2001), a phenomenon referred to as alpha event-related desynchronization (ERD) previously discussed here in relation to attentional investment and the AB. The desynchronization of alpha in response to a warning stimulus is thought to represent an engagement of attention (Brunia & van Boxtel, 2001) and/or a release of inhibition (Klimesch et al., 2006).

However, there is evidence to suggest that alpha desynchronization is not sufficient to indicate an increase in attentional investment at rest. Laufs et al. (2003b), Laufs et al. (2006) suggest that the presence of alpha, more specifically alpha at rest, is indicative of an idling cortex and represents a baseline state. However, reduction of alpha at rest can accompany two different kinds of fluctuations in attention. Alpha reductions may accompany an increase in vigilance, which increases their attention-demanding cognitive processes – a state that is accompanied by increased beta oscillations and decreased theta oscillations. Alpha reductions may also accompany an increase in drowsiness and a decrease in vigilance – a pattern associated with increased theta oscillations and decreased beta oscillations. Indeed, when alpha reduction was observed to correlate with increases in metabolic activity in frontal–parietal cortical areas thought to compose the attention network, faster oscillations in the beta range were increased while slower oscillations in the theta range were reduced (Laufs et al., 2006). This pattern, which Laufs et al. call a state of high vigilance, appears to represent an increase in attentional investment at rest where the cortex is engaged in information processing and various mental activities could be occurring. However, when alpha reduction was seen to correlate with increases in metabolic activity in occipital and parietal areas of the cortex, beta was reduced and theta increased, indicating a state of drowsiness, or low vigilance.

In summary, levels of alpha are related to attentional investment such that when alpha is high, attention is not engaged and the cortex is “idling” (Brunia & van Boxtel, 2001; Pfurtscheller et al., 1996) or inhibited (Klimesch et al., 2007). The relationship between reduced alpha and attention at rest depends on the cortical areas that are activated during alpha desynchronization, which is indicated by levels of oscillatory activity in frequency bands that neighbor alpha (Laufs et al., 2006). Attentional investment at rest is accompanied by high beta and low alpha, while low alpha and high theta is indicative of drowsiness not attentional investment. Thus, by measuring the relative contribution of EEG oscillations in alpha and beta bands, one can estimate the degree of attentional investment of an individual at rest. In the current study we aimed to use individual differences in levels of oscillatory activity in the alpha and beta ranges of EEG frequencies to measure attentional investment at rest for the purpose of predicting individual differences in the AB.<sup>1</sup>

#### 1.4. Hypotheses

Previously we discussed evidence from various investigations indicating that increased attentional investment is associated with a larger AB. This might lead one to hypothesize that greater attentional investment at rest, operationalized in this study as more beta, less theta and less alpha power, should correlate positively with AB magnitude. However, there is additional evidence to suggest that the attentional investment at rest is not necessarily positively correlated with attentional investment during a goal-directed task as measured by alpha frequency oscillations.

As noted above, within participants, greater alpha ERD during the RSVP foreperiod predicted poor T2 performance at lags during the AB interval but better T2 performance at lags outside of the AB interval as well as better T1 performance (MacLean & Arnell, 2011). MacLean and Arnell (2011) also reported non-significant trend ( $r = .27$ ) where individuals with greater overall alpha ERD showed greater ABs.

Alpha power has been shown to predict cognitive performance on other tasks in specific ways. Several studies have shown that good performance on memory tasks is related to higher resting alpha power (Klimesch, Vogt, & Doppelmayr, 1999), and larger alpha ERD is associated with better performance on a task requiring semantic search (Doppelmayr, Klimesch, Hodlmoser, Sauseng, & Gruber, 2005). For perceptual tasks, good performance is related to low alpha immediately preceding the stimulus (Ergenoglu et al., 2004; Hanslmayr et al., 2005) – a pattern that matches the results observed by MacLean and Arnell (2011) outside the AB interval (i.e., where greater alpha ERD/lower pre-stimulus alpha was associated with better T1 performance and better T2 performance at longer lags). Klimesch et al. (2007) suggest that this is because performance on perceptual tasks is enhanced if the cortex is already activated. The MacLean and Arnell (2011) findings suggest that the alpha levels that benefit T1 performance and T2 performance at longer lags, which also apparently benefit perceptual performance more generally (Ergenoglu et al., 2004), are costly for T2 performance at shorter lags during the AB interval.

Finally, several studies have shown a positive relationship between alpha ERD and resting alpha power (tonic), in that greater desynchronization is seen in response to greater alpha power

(see Doppelmayr, Klimesch, Pachinger, & Ripper, 1998; Klimesch, 1999 for reviews).

Therefore, based on the within participant findings of MacLean and Arnell (2011), that greater alpha ERD is associated with poor T2 performance at short lags but better T2 performance at long lags and better T1 performance, and the positive relationship between resting alpha and alpha ERD (e.g., Klimesch, 1999), we hypothesized that individual differences in resting alpha power would predict AB magnitude in that lower resting alpha would be associated with better T2 accuracy at short lags, and therefore smaller AB magnitudes. Low resting alpha power would be expected to be accompanied by either high resting beta or high resting theta. We hypothesized that high resting beta, if accompanied by low resting alpha (indicating a state of attentional investment), would predict improved AB performance. However, high resting theta, if accompanied by low resting alpha (reflecting greater drowsiness), should not correlate with AB performance (Laufs et al., 2006). We examined these hypotheses in two independent investigations.

## 2. Methods: Study 1

### 2.1. Participants

The participants were 30 Brock University undergraduate students, recruited through the Brock Psychology Department's online system for participant recruitment. The data from two participants were excluded due to close to chance performance on the RSVP task (T1 accuracy was 57%) in one case and in the other case outlying T2 accuracy at lag 8 (more than three SD below the mean). The data from another participant were excluded due to an error in the EEG recording.

### 2.2. AB task

The AB task consisted of five blocks of 140 RSVP trials. Of the 700 total trials, 100 were no-target trials, and 600 were dual target (T1 and T2) trials. On half of the dual-target trials, T2 was presented 3 items, or 351 ms after T1 (lag 3), and on the other half, T2 was presented 8 items, or 936 ms after T1 (lag 8). T1 was always presented in white font as the 6th item in the stream. On 80% of trials at each lag, T1 was a string of five repeated uppercase letters (e.g., BBBBB) chosen randomly from the letter set B, C, D, E, F, N, P, S, U, X, or Z. On the remaining 20% of trials, T1 was a string of five repeated lowercase letters (e.g., bbbbb) chosen randomly from the same letter set. T2 was one of 10 different color words (e.g., “GREEN”), and appeared in black uppercase letters. The distracter items consisted of affectively neutral words that were unrelated to colors. Distractors were also presented in black uppercase letters. All trial types were presented randomly within each block. The T1 probability manipulation and the distracter-only trials were included for the purposes of a separate study.

Each trial began with a fixation cross (500 ms), followed by a foreperiod of 2 s before the onset of the RSVP stream. The RSVP stream consisted of 18 alphanumeric stimuli with an SOA of 117 ms per item presented on a gray background. At the end of each stream, participants indicated whether the white letter string was in upper- or lower-case letters, and then reported which color word was presented as T2. Participants were told that some of the trials would contain no targets, and on these trials they should simply press the spacebar to initiate the next trial. Participants made their T1 and T2 responses sequentially in an unspeeded manner using specified keys on the keyboard. Stimulus presentation and participant responses were controlled using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002).

<sup>1</sup> Other investigators have examined oscillatory EEG in the context of the AB (for a recent review see Hanslmayr, Gross, Klimesch, & Shapiro, 2011). However, these other investigations have examined oscillatory activity that accompanies the RSVP stream. Except for MacLean and Arnell (2011), this investigation is the first to examine the relevance of oscillatory activity outside of RSVP to the AB, and the only investigation examining the relationship of oscillatory activity to individual differences in AB magnitude.

### 2.3. Resting EEG procedure

Five blocks of resting EEG were recorded, one prior to each of the five blocks of the AB task. Each block of recording consisted of three 30 s segments of eyes closed alternating with three 30 s segments of eyes open, with 1 s between each segment. Instructions would appear before each segment to indicate whether the participant should keep their eyes open or closed and a tone indicated the beginning and end of each segment. Participants were instructed to sit quietly without moving. Participants were monitored during recording to ensure they did not fall asleep. Only resting EEG from the eyes closed segments were further analyzed.

### 2.4. Resting EEG acquisition

EEG was recorded continuously using tin electrodes embedded in an Electro-Cap® (Electro-cap International Inc., Eaton, Ohio) from 60 scalp sites distributed according to the 10–20 system, with an electrode placed anterior to Fz as ground. EEG was recorded using linked left and right earlobes as reference and was re-referenced to a common average of the EEG. EEG data were acquired with Neuroscan acquisition software (Compumedics USA, Charlotte, North Carolina), and using two 32-channel NeuroScan Syn-Amps. Data were sampled at a rate of 500 Hz. Electro-oculogram (EOG) recorded horizontal eye movements using electrodes placed on the outer canthus of each eye, and vertical eye movement and blinks using electrodes placed on the infra- and supra-orbital regions of each eye. Impedance for both the EEG and EOG was maintained below 10 k $\Omega$ . EEG was band-pass filtered offline with a high pass of .01 Hz, a low pass of 57 Hz and a roll-off of 48 dB/oct.

### 2.5. Resting EEG analysis

Each 30-s section of eyes closed resting EEG was visually inspected for artifact. EEG containing artifact was isolated and excluded from further analysis. Each section was then further segmented into 2-s epochs with 75% overlap. Epochs were spline fit to 512 points. These epochs were then submitted to a fast Fourier transform (FFT) using a Hanning window yielding absolute power values within pre-defined bands. Alpha was defined as the average power in the 8–12 Hz range, beta was defined as the average power in the 15–35 Hz range and theta was defined as the average power in the 4–8 Hz range. FFT power values were log transformed prior to statistical analysis.

Four topographic regions of interest (ROIs) were created by averaging power values across several electrode sites: frontal (F3, F4, Fz), central (C3, C4, Cz), parietal (P3, P4, Pz) and occipital (O1, O2, Oz). While the correlations Laufs et al. (2003) reported were based on power measured at occipital electrode sites (O1 and O2), they did note that these correlations were observed at the majority of electrode sites. We did not hypothesize that ROI would interact with the hypothesized correlations.

## 3. Results: Study 1

### 3.1. AB task performance

Mean T1 accuracy was 90.52% (SD = 7.84, range 70–98%). T2 accuracy was conditionalized on T1 performance. Mean T2 accuracy at lag 3 was 66.89% (SD = 16.65, range 22–95%). Mean T2 accuracy at lag 8 was 89.96% (SD = 5.45, range 78–97%). A paired-samples t-test indicated significantly lower T2 accuracy at lag 3 than lag 8 indicating the presence of an AB ( $t(26) = 8.26$ ,  $p < .001$ ). Individual AB magnitude was represented by subtracting

each participant's T2 accuracy at lag 3 from their T2 accuracy at lag 8. Mean AB magnitude was 23.07% (SD = 14.52, range 1–67%).

### 3.2. Spectral EEG

A  $3 \times 4$  repeated measures ANOVA performed on power values, with frequency range (theta, alpha, and beta) and ROI (frontal, central, parietal, and occipital) as factors, indicated a significant main effect of frequency band ( $F(2,50) = 230.96$ ,  $p < .001$ ) such that power was greatest in alpha band, and least in the beta frequency band, as well as a significant main effect of ROI ( $F(3,75) = 37.99$ ,  $p < .001$ ) and a significant interaction of frequency band and ROI ( $F(6,150) = 45.87$ ,  $p < .001$ ) such that that power decreased from occipital to frontal ROIs in the alpha and beta band but was similar across ROI for the theta band.

Absolute power in the different frequency bands for each ROI (e.g., the correlation between alpha at the frontal ROI with beta at the frontal ROI, etc.) was significantly positively correlated ( $r$ 's ranged from .47 to .73), indicating that some individuals had higher power values than others across all frequency bands. In order to account for this inter-individual variability in overall absolute power, which may obscure individual differences in the unique and relative contributions of theta, alpha, and beta necessary to address our hypotheses, we regressed power in each frequency band on power in the other two frequency bands for each ROI using three simultaneous multiple regressions. We then saved each of the residuals. This yielded a residualized measure of power for each frequency band (i.e. the unique variability in absolute theta, alpha, and beta power for each individual independent of overall absolute power level in the entire band from 4 to 35 Hz). This procedure allows removal of the inter-individual variability due to overall absolute power shared between the three different frequency bands (i.e. that some individuals have higher overall absolute power values than others), leaving the unique variability in absolute power in each of the frequency bands.<sup>2</sup>

Residual power values in alpha and beta within the same ROI were significantly ( $p < .05$ ) negatively correlated ( $r$ 's ranged from  $-.42$  to  $-.63$ ), as were residual power values in beta and theta ( $r$ 's ranged from  $-.43$  to  $-.49$ ), residual power values in alpha and theta were negatively correlated although not significantly ( $r$ 's ranged from  $-.12$  to  $-.35$ ). This pattern fits the findings of Laufs et al. (2006) where low alpha is accompanied by either high beta or high theta, but that high beta is accompanied by low theta and vice versa. In the present data it appears that low alpha at rest was consistently accompanied by high beta, but not high theta. This indicates that this sample predominantly displayed the high vigilance mode characterized by low alpha and high beta found when alpha correlated negatively with metabolic activity in the frontoparietal attention network (Laufs et al., 2006).

### 3.3. Correlations between resting EEG and AB performance

Tables 1–3 contain the correlations between residual power in the theta, alpha and beta frequency bands at each ROI (frontal, central, parietal, and occipital) and overall across ROIs with various

<sup>2</sup> Note that the variability referred to in the description of our residualized measure is inter-individual variability in absolute power. This is in contrast to relative power measures, which would concern inter-frequency variability within individuals. Thus our residualized power measures are not equivalent to relative power measures. The issue of inter-individual variability in overall absolute power is common to all individual differences approaches to spectral EEG, as inter-individual variability in overall absolute power can obscure individual differences in power for a given frequency band, e.g. alpha. Klimesch et al. (1999) accounted for this issue using a different method. They created what they termed "normalized percentage power" by calculating the absolute power in each frequency band as the percentage of absolute power in all frequency bands.

**Table 1**

Study 1 correlations between theta at each ROI, and overall theta, with AB performance measures.

	T1 accuracy	Lag 3 T2 accuracy	Lag 8 T2 accuracy	AB magnitude
Theta (frontal)	.19	.20	.12	-.19
Theta (central)	.03	.16	.03	-.18
Theta (parietal)	-.06	-.07	.07	.12
Theta (occipital)	-.10	-.09	.14	.19
Theta overall	.03	.07	.11	-.03

Note: \*  $p < .05$ .\*\*  $p < .01$ .\*\*\*  $p < .001$ .**Table 2**

Study 1 correlations between alpha at each ROI, and overall alpha, with AB performance measures.

	T1 accuracy	Lag 3 T2 accuracy	Lag 8 T2 accuracy	AB magnitude
Alpha (frontal)	-.16	-.68***	-.21	.72***
Alpha (central)	-.12	-.66***	-.24	.69***
Alpha (parietal)	-.19	-.64***	-.36	.61**
Alpha (occipital)	-.06	-.55**	-.25	.55**
Alpha overall	-.14	-.68***	-.28	.69***

Note: \*  $p < .05$ .\*\*  $p < .01$ .\*\*\*  $p < .001$ .**Table 3**

Study 1 correlations between beta at each ROI, and overall beta, with AB performance measures.

	T1 accuracy	Lag 3 T2 accuracy	Lag 8 T2 accuracy	AB magnitude
Beta (frontal)	.06	.39*	.19	-.39*
Beta (central)	.21	.43*	.30	-.37
Beta (parietal)	.31	.57**	.31	-.55**
Beta (occipital)	.19	.44*	.11	-.48*
Beta overall	.21	.50**	.25	-.49*

Note: \*  $p < .05$ .\*\*  $p < .01$ .\*\*\*  $p < .001$ .

measures of performance on the AB task. Theta power at rest was not correlated significantly with any of the AB task performance measures including AB magnitude (see Table 1 and Fig. 1a).

Alpha power at rest was negatively correlated with T2 accuracy, and these relationships were significant for lag 3. Alpha power at rest was also positively correlated with AB magnitude at all ROIs and overall across ROIs (see Table 2 and Fig. 1b). This pattern of correlations indicates that greater alpha power at rest is related to greater AB magnitudes, and that this relationship is due to a relationship between alpha power at rest and short lag, not long lag, T2 performance.

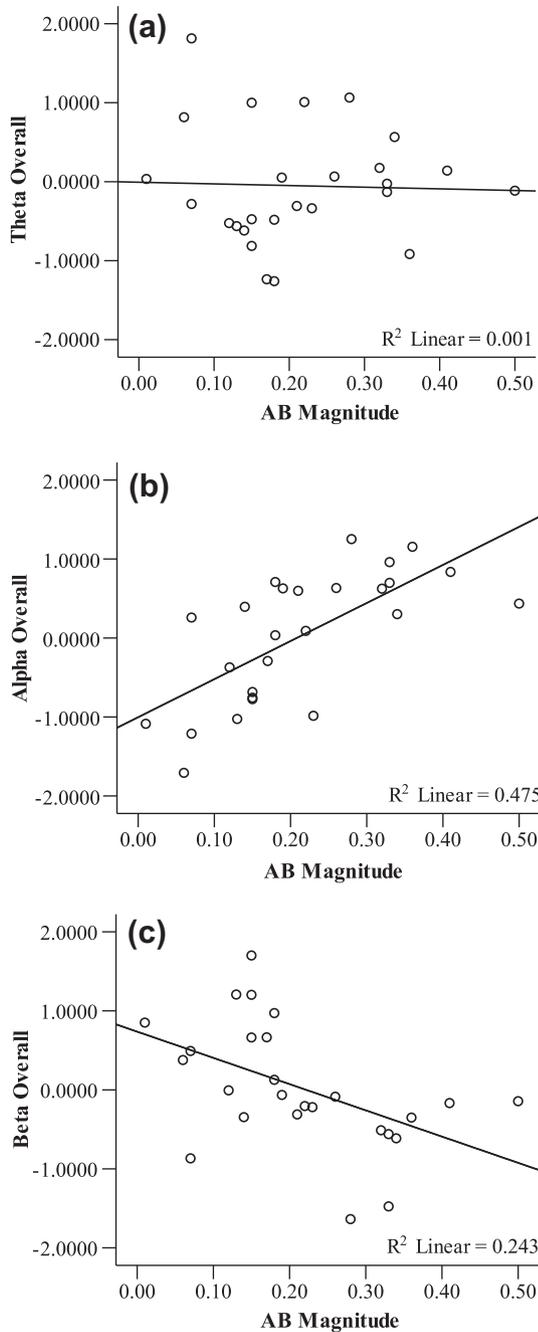
Beta power at rest was positively correlated with T2 accuracy, and these relationships were significant for lag 3. Beta power at rest was also negatively correlated with AB magnitude at all ROIs and overall across ROIs (with the exception that the correlation between beta power and AB magnitude at the central ROI was only marginally significant,  $p = .06$ ). This pattern of correlations indicates that greater beta power at rest is related to smaller AB magnitudes (see Table 3 and Fig. 1c), and that this relationship is due to a relationship between beta power at rest and short lag, not long lag, T2 performance as was also the case with resting alpha power.

Since alpha and beta power at rest were significantly negatively correlated with each other and both correlated significantly with AB magnitude we further investigated whether the trade-off between alpha and beta power at rest predicted performance on the AB task (see Table 4). The difference score of alpha minus beta power was negatively correlated with T2 accuracy at lag 3, and positively correlated with AB magnitude at all ROIs and overall

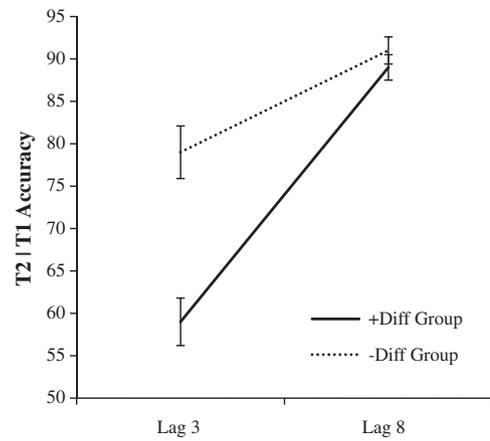
across ROI. This pattern of correlations indicates that the greater the preponderance of resting alpha power relative to resting beta power, the larger the AB magnitude.

Fourteen participants had positively signed difference scores averaged across ROIs (+Diff group) indicating more resting alpha than beta power, while 12 participants had negatively signed difference scores averaged across ROIs (-Diff group) indicating more resting beta than alpha power.<sup>3</sup> A mixed-model ANOVA of T2 accuracy with T1-T2 lag (3 or 8) as a within-subject factor and group (+Diff or -Diff) as a between subjects factor was performed to determine whether the nature of the absolute difference between resting alpha and beta power interacted with the AB (see Fig. 2). There was a significant interaction between lag and group ( $F(1,24) = 25.55$ ,  $p < .001$ ) such that the effect of lag on T2 accuracy was larger in the +Diff group ( $Mdiff = 29.07$ ;  $t(13) = 11.01$ ,  $p < .001$ ) than in the -Diff group ( $Mdiff = 12.42$ ;  $t(11) = 7.00$ ,  $p < .001$ ). An additional post-hoc analysis confirmed that the -Diff group had significantly higher T2 accuracy at lag 3 than the +Diff group ( $t(24) = 4.61$ ,  $p < .001$ ), but that the two groups did not differ in T2 accuracy at lag 8 ( $t(24) = 1.22$ ,  $p = .236$ ). This indicates that the AB was greater in the +Diff group than the -Diff group because of differences in short lag performance, within the AB period, but not because of differences in long lag performance.

<sup>3</sup> Our independent-groups analysis was intended to function as a median-split approach to a continuous variable (amount of alpha and beta within an individual). We do not suggest that there is something qualitatively different between the two groups, as defined by the zero point threshold used here.



**Fig. 1.** Scatterplots depicting correlation between levels of resting theta (a), alpha (b), and beta (c) with AB magnitude from Study 1. The solid line depicts the linear function of the zero-order correlation, and the squared zero-order correlation is indicated in the bottom right corner of the scatterplot.



**Fig. 2.** Study 1 T2 accuracy at each lag (3 and 8) for the +Diff (alpha–beta) and –Diff (alpha–beta) groups, depicting the interaction of alpha–beta group with lag. Error bars denote standard error.

**4. Introduction: Study 2**

Study 1 found that resting alpha and resting beta predicted AB magnitude in opposite directions. Greater resting alpha was correlated with larger AB magnitudes while greater resting beta was correlated with smaller AB magnitudes. Furthermore, a greater preponderance of resting alpha power over resting beta power was related to larger AB magnitudes, and individuals who had greater resting alpha than resting beta power had larger ABs than individuals with greater resting beta than resting alpha power. The purpose of Study 2 was to replicate the findings of Study 1. The same pattern of results was expected in this independent sample of participants using a different AB task and EEG recording system from a different lab. In addition, Study 2 also had a greater time interval between the AB task and the resting EEG recordings than Study 1.

**5. Methods: Study 2**

**5.1. Participants**

The participants were 38 individuals recruited from the Brock University population and surrounding community. The data from six participants were excluded due to their inability to perform the T2 task at greater than chance levels. The data from another three participants were excluded due to poor quality EEG data (artifacts or noise).

**5.2. AB task**

The AB task was modeled on the original AB task of Raymond et al. (1992). The present task included five blocks of 32 RSVP trials.

**Table 4**  
Study 1 correlations between alpha–beta at each ROI, and overall alpha–beta with AB performance measures.

	T1 accuracy	Lag 3 T2 accuracy	Lag 8 T2 accuracy	AB magnitude
Alpha–beta (frontal)	–.13	–.63**	–.23	.65***
Alpha–beta (central)	–.19	–.64***	–.32	.63**
Alpha–beta (parietal)	–.28	–.69***	–.38	.65***
Alpha–beta (occipital)	–.14	–.55**	–.20	.57**
Alpha–beta overall	–.19	–.67***	–.30	.67***

Note: \*  $p < .05$ .  
 \*\*  $p < .01$ .  
 \*\*\*  $p < .001$ .

T1 was present on every trial. Of the 160 total trials, 80 were T2 absent trials (only T1 presented), and 80 were T2 present (T1 and T2) trials. Among the 80 T2 present trials T2 was presented equally often at one of eight lag positions (1st–8th item, or 100–800 ms following T1 onset). T1 was presented as either the 7th or 10th RSVP item. T1 was a randomly selected upper-case letter (excluding X) presented in white font. T2 was the upper-case letter X presented in black font. The distracter items consisted of black upper-case letters (excluding X). All trial type combinations were presented randomly and equally within each block.

Each trial began with a fixation cross (1000 ms), followed by a blank foreperiod of 1000 ms before the onset of the RSVP stream. The RSVP stream consisted of 19 alphanumeric stimuli with an SOA of 100 ms per item presented on a gray background. At the end of each RSVP stream, participants identified the lone white letter, and then indicated whether an X was present or not. Participants made their T1 and T2 responses sequentially in an unspeeded manner using specified keys on the keyboard. Each RSVP trial was separated by a 1000 ms blank ITI. Stimulus presentation and participant responses were controlled using E-Prime software (Schneider et al., 2002).

### 5.3. Resting EEG procedure

Two blocks of resting EEG were recorded; one block was recorded 2 h prior to the AB task (at 09:00) and the other 2 h following the AB task (at 13:00). Each block of recording was performed as in Study 1 and resting EEG data was averaged across the blocks.

### 5.4. Resting EEG acquisition

EEG was recorded continuously using gold-plated electrodes from 12 scalp sites applied according to the 10–20 system, with an electrode placed anterior to Fz as ground. EEG was recorded using Fpz as reference and was re-referenced offline to the average of left and right mastoid sites. EEG data were acquired and analyzed with SPYDER (EBNeuro, Inc., Florence, Italy) software running on a desktop PC, and using Mizar digital amplifiers (Tyco Inc., Ottawa, Canada). Data were sampled at a rate of 128 Hz with 0.0099–57.6 Hz hardware filters. Electro-oculogram (EOG) recorded horizontal eye movements using electrodes placed on the outer canthus of each eye, and vertical eye movement and blinks using electrodes placed on the infra- and supra- orbital regions of each eye. Impedance for the EEG was maintained below 5 k $\Omega$  and for the EOG was maintained below 10 k $\Omega$ .

### 5.5. Resting EEG analysis

Analysis of resting EEG was identical to that performed in Study 1. ROIs were also identical to Study 1.

## 6. Results: Study 2

### 6.1. AB task performance

Mean T1 accuracy was 93.83% (SD = 4.18, range 82–100%). T2 sensitivity at each lag was calculated as  $d'$  ( $Z[\text{hits}] - Z[\text{false alarms}]$ ). T2 sensitivity was conditionalized on correct T1 performance. A repeated-measures ANOVA of T2 sensitivity with lag as the factor yielded a significant effect of lag ( $F(7, 196) = 33.04, p < .001$ ). T2 sensitivity increased from lag 2 to lag 8 and showed lag 1 sparing, indicating the presence of an AB. Individual AB magnitude was represented by subtracting each participant's T2 sensitivity at lag 2, the lag where T2 sensitivity was lowest in the AB, from their highest long lag (6–8) sensitivity (baseline). Mean T2

sensitivity at lag 2 was .89 (SD = 1.40, range –2.33 to 2.63). Mean T2 sensitivity at the baseline long lag was 2.32 (SD = 1.15, range –.44 to 4.08). Mean AB magnitude was 2.24 (SD = .88, range .19–3.61).

### 6.2. Spectral EEG

A repeated measures ANOVA was performed on the resting EEG power values with frequency range and ROI as factors. A significant main effect of frequency band was observed ( $F(2, 56) = 21.31, p < .001$ ), such that power was greatest in alpha band, and least in the beta frequency band. There was also a significant main effect of ROI ( $F(3, 84) = 349.68, p < .001$ ) and a significant interaction of frequency band and ROI ( $F(6, 168) = 184.24, p < .001$ ). Power decreased from occipital to frontal ROIs but this decrease was mostly seen in the alpha frequency band and less so in the beta and theta frequency bands.

As in Study 1, power in the different frequency bands for each ROI was significantly positively correlated ( $r$ 's ranged from .46 to .82), indicating that individuals differed in magnitude of log-transformed power values overall regardless of frequency band. Thus, the same residualized power values for each frequency band were created as in Study 1.

Residual power values in alpha and beta within the same ROI were negatively correlated ( $r$ 's ranged from –.31 to –.43) although only significantly at the parietal ROI. The residual power values in beta and theta also correlated negatively although not significantly ( $r$ 's ranged from –.13 to –.37), and residual power values in alpha and theta were significantly negatively correlated at all ROIs ( $r$ 's ranged from –.48 to –.69). This pattern fits the findings of Laufs et al. (2006) where low alpha is accompanied by either high beta or high theta, but that high beta is accompanied by low theta and vice versa. Contrary to what was observed in Study 1, however, in the Study 2 it appears that low levels of alpha at rest were accompanied, although not exclusively, by high beta but also high theta. This indicates that some participants displayed the low vigilance mode characterized by low alpha and high theta found when alpha correlated negatively with metabolic activity in parieto-occipital regions while others displayed the high vigilance mode (Laufs et al., 2006).

### 6.3. Correlations between resting EEG and AB performance

Tables 5–7 contain the correlations between residual power in the theta, alpha and beta frequency bands at each ROI (frontal, central, parietal, and occipital) and overall across ROIs with various measures of performance on the AB task. Theta power at rest was not correlated significantly with any of the AB task performance measures including AB magnitude (see Table 5 and Fig. 3a).

Alpha power at rest was negatively correlated with T2 sensitivity at lag 2 at the frontal ROI, and positively correlated with AB magnitude at each of the ROIs and overall across ROIs (see Table 6 and Fig. 3b). This pattern indicates that greater alpha power at rest is related to greater AB magnitudes, and that this relationship is due to a relationship between alpha power at rest and short lag, not long lag, T2 performance.

Beta power at rest was correlated positively with T2 sensitivity at lag 2 at the frontal ROI and negatively with AB magnitude at the frontal ROI. This pattern of correlations indicates that greater frontal beta power at rest is related to smaller AB magnitudes (see Table 7 and Fig. 3c), and that this relationship is due to a relationship between beta power at rest and short lag, not long lag, T2 performance.

The difference score of alpha minus beta power was negatively correlated with T2 sensitivity at lag 2 at the frontal ROI and positively correlated with AB magnitude across all ROIs and

**Table 5**

Study 2 correlations between theta at each ROI, and overall theta with AB performance measures.

	T1 accuracy	Lag 2 T2 sensitivity	Baseline long lag T2 sensitivity	AB magnitude
Theta (frontal)	-.08	-.04	-.14	-.12
Theta (central)	-.04	-.09	-.27	-.20
Theta (parietal)	.02	-.02	-.26	-.32
Theta (occipital)	-.02	-.11	-.29	-.20
Theta overall	-.03	-.07	-.27	-.24

Note: \*  $p < .05$ .\*\*  $p < .01$ .\*\*\*  $p < .001$ .**Table 6**

Study 2 correlations between alpha at each ROI, and overall alpha with AB performance measures.

	T1 accuracy	Lag 2 T2 sensitivity	Baseline long lag T2 sensitivity	AB magnitude
Alpha (frontal)	.06	-.37*	-.17	.38*
Alpha (central)	.02	-.32	-.01	.50**
Alpha (parietal)	-.01	-.28	.04	.49**
Alpha (occipital)	-.09	-.16	.11	.39*
Alpha overall	-.01	-.31	-.01	.49**

Note: \*  $p < .05$ .\*\*  $p < .01$ .\*\*\*  $p < .001$ .**Table 7**

Study 2 correlations between beta at each ROI, and overall beta with AB performance measures.

	T1 accuracy	Lag 2 T2 sensitivity	Baseline long lag T2 sensitivity	AB magnitude
Beta (frontal)	-.13	.42*	.21	-.39*
Beta (central)	-.12	.18	.06	-.21
Beta (parietal)	-.18	-.07	-.12	-.05
Beta (occipital)	-.09	-.23	-.22	.07
Beta overall	-.15	.08	-.02	-.16

Note: \*  $p < .05$ .\*\*  $p < .01$ .\*\*\*  $p < .001$ .

individually at frontal and central ROIs (see Table 8). This pattern of correlations indicates that the greater the preponderance of resting alpha power relative to resting beta power, the larger the AB magnitude.

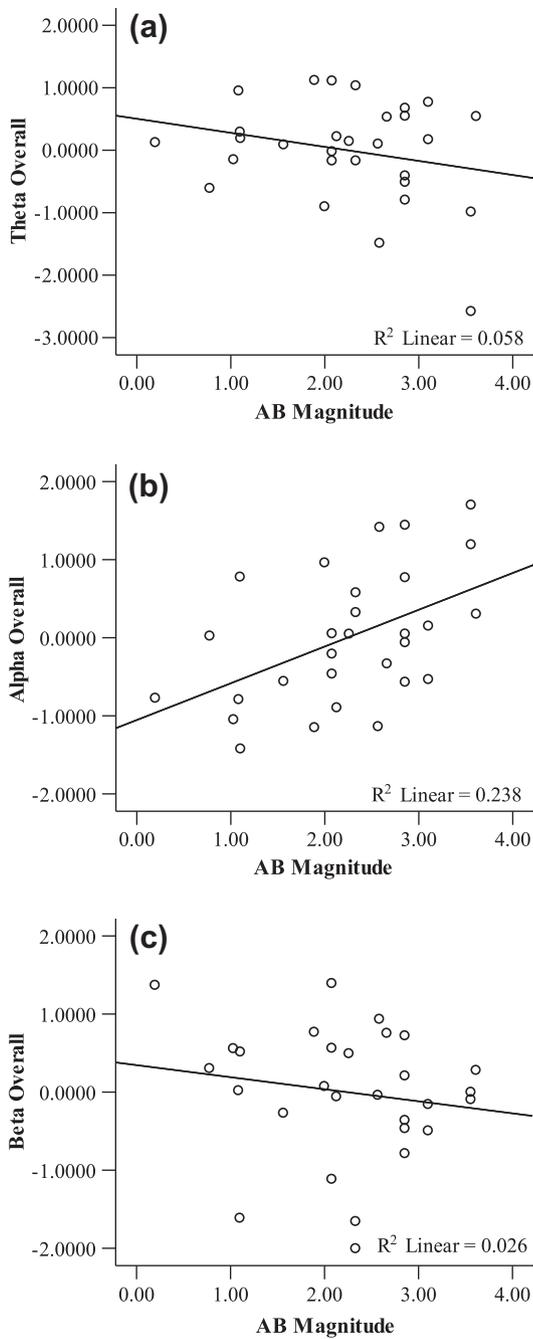
Thirteen participants had positively signed difference scores averaged across ROIs for the alpha–beta difference score (+Diff group) indicating more resting alpha than, while 16 participants had negatively signed difference scores averaged across ROIs for the alpha–beta difference scores (–Diff group) indicating more resting beta than alpha power. A mixed-model ANOVA of T2 sensitivity with T1–T2 lag (2 or long lag baseline) as a within-subject factor and alpha–beta group (+Diff or –Diff) as a between-subjects factor was performed to determine whether the nature of the absolute difference between resting alpha and beta power interacted with the AB (see Fig. 4). There was a significant interaction between lag and group ( $F(1, 27) = 7.03, p = .013$ ) such that the effect of lag on T2 sensitivity was larger in the +Diff group ( $M_{diff} = 2.67; t(12) = 13.35, p < .001$ ) than in the –Diff group ( $M_{diff} = 1.89; t(15) = 8.86, p < .001$ ). An additional post-hoc analysis confirmed that the –Diff group had significantly higher T2 accuracy at lag 3 than the +Diff group ( $t(27) = 2.38, p = .025$ ), but that the two groups did not differ in T2 accuracy at lag 8 ( $t(27) = .85, p = .405$ ). This indicates that the AB was greater in the +Diff group than the –Diff group because of differences in short lag perfor-

mance, within the AB period, but not because of differences in long lag performance.

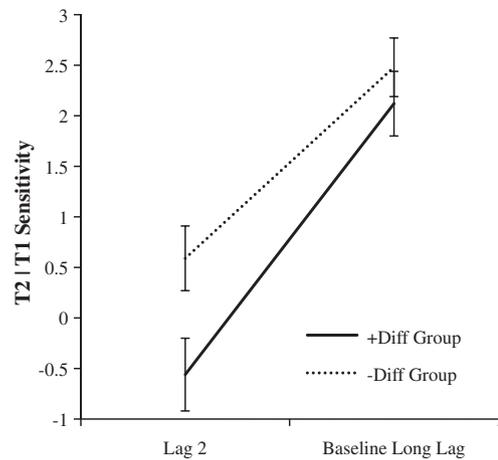
Except that the correlations between beta and AB task performance were primarily at the frontal ROI, the correlations of resting theta, alpha, and beta with AB task performance in Study 2 replicate the results of Study 1.

## 7. General discussion

In the current study we investigated whether tonic EEG power in alpha (8–12 Hz) and beta (15–35 Hz) frequency oscillation ranges (i.e., power values when the participant was at rest and not engaged in a goal-directed task), could predict individual differences in AB magnitude. We operationalized greater attentional investment at rest as less alpha and greater beta power. We hypothesized that attentional investment at rest as measured by alpha and beta power would correlate negatively with AB magnitude (i.e., that larger ABs would be associated with higher alpha and lower beta power). This hypothesis followed from evidence that greater alpha at rest (tonic alpha) was associated with a greater decrease in alpha (alpha ERD) during a task (Doppelmayr et al., 1998; Klimesch, 1999) and that good performance on difficult perception tasks has been shown to be related to low alpha power (Ergenoglu et al., 2004; Hanslmayr et al., 2005).



**Fig. 3.** Scatterplots depicting correlation between levels of resting theta (a), alpha (b), and beta (c) with AB magnitude from Study 2. The solid line depicts the linear function of the zero-order correlation, and the squared zero-order correlation is indicated in the bottom right corner of the scatterplot.



**Fig. 4.** Study 2 T2 accuracy at each lag (2 & baseline long lag) for the +Diff (alpha-beta) and -Diff (alpha-beta) groups, depicting the interaction of alpha-beta group with lag. Error bars denote standard error.

The results of both Study 1 and Study 2 supported our hypothesis. Resting alpha power correlated positively with AB magnitude, while resting beta power correlated negatively with AB magnitude. These correlations suggested that greater attentional investment at rest (less alpha and more beta power) was associated with smaller AB magnitudes. In support of this interpretation, it was observed that the relative trade-off between resting alpha and beta power (which were negatively correlated with each other) also predicted the AB and that individuals with greater resting alpha than beta power had larger ABs than individuals with greater resting beta than alpha power. The size of these relationships was surprisingly large in that individual differences in relative alpha-beta power across all ROIs predicted 45% of the variability in AB magnitude in Study 1, and 16% in Study 2.

It is important to note that the correlations between resting EEG measures and short lag T2 accuracy were considerably stronger than those with long lag T2 accuracy, indicating that the relationships with AB magnitude (a difference measure) are primarily due to variance in short lag T2 accuracy (i.e. variability during the AB interval). However, it is worth noting that, although they were not significant at the traditional level, the correlations of resting alpha, beta, and alpha-beta with long lag T2 accuracy in Study 1 were still of a considerable size ( $r$ 's ranging from .25 to .30). These correlations were all in the same direction as the significant correlations of alpha and beta with short lag T2 accuracy. This was also the case at the frontal site for Study 2. Thus, in addition to predicting AB magnitude, the present results provide evidence that that resting alpha is associated with lower T2 accuracy overall, and resting beta with higher T2 accuracy overall.

**Table 8**  
Study 2 correlations between alpha-beta at each ROI, and overall alpha-beta with AB performance measures.

	T1 accuracy	Lag 2 T2 sensitivity	Baseline long lag	AB magnitude
Alpha-beta (frontal)	.12	-.49**	-.23	.48**
Alpha-beta (central)	.09	-.31	-.04	.44*
Alpha-beta (parietal)	.09	-.13	.09	.32
Alpha-beta (occipital)	.00	.04	.20	.20
Alpha-beta overall	.08	-.24	.01	.39*

Note: \*  $p < .05$ .  
\*\*  $p < .01$ .  
\*\*\*  $p < .001$ .

While ROI did not appear to play a role in the relationships between resting state EEG and AB performance in Study 1, in Study 2 the relationship involving beta and AB performance was limited to frontal electrode sites. That ROI was relevant to the relationship between resting beta power and AB performance in Study 2 but not Study 1 could be attributed to different kinds of resting states being present in participants from the two different studies (i.e. participants feeling and/or thinking differently while at rest). The different spectral power results also support this hypothesis. Although speculative, this could result from the different experimental protocols used in the two studies given that Study 1 was part of a 3-h test session, whereas Study 2 was part of a full-day in-lab testing session.

We also hypothesized that correlations between power at rest and the AB would be confined to the alpha and beta ranges and would not include the theta range, given that theta power while at rest is indicative of drowsiness not attentional investment. Our results also support this hypothesis given that there were no associations between theta power and any AB variables. As noted by Laufs et al. (2006), low relative alpha power may be accompanied by high relative theta power (indicative of low vigilance at rest) or accompanied by high relative beta power (indicative of high vigilance at rest). The present results suggest that it is not merely that lower alpha is associated with smaller AB magnitudes; but that the combination of higher beta and lower alpha indicative of high investment is associated with smaller AB magnitudes (see Laufs et al., 2006).

Our findings replicate the negative correlations between alpha and beta/theta as well as the negative correlation between beta and theta observed by Laufs et al. (2006), and support the conception of levels of alpha at rest in combination with levels of beta and theta as indicative of different attentional states as suggested by Laufs et al. (2003b), Laufs et al. (2006). Specifically, the combination of low levels of alpha and high levels of beta at rest predict the AB, as a state of vigilance or attentional engagement was expected to, while the combination of low levels alpha and high levels of theta did not predict the AB, as was expected from a state of drowsiness.

### 7.1. The relevance of attention at rest to the AB

Our results are in line with previous evidence that the attentional approach adopted by the individual can predict the magnitude of their AB (Arnell & Stubit, 2010; Dale & Arnell, 2010; Dux & Marois, 2008; MacLean & Arnell, 2010; MacLean et al., 2010; Martens & Valchev, 2009). It is unclear from our evidence whether the attentional approach represented by attentional investment at rest is indicative of an enduring trait or a labile state. However, in Study 2, resting EEG recordings were obtained in two sessions, one two hours before and the other 2 h after the AB task was performed. That measures derived from resting EEG at such a distance in time from the AB task can predict performance on that task, suggests that levels of theta, alpha, and beta at rest could represent a more stable, trait-like measure. Further investigation would be required to determine whether attentional investment at rest, measured by relative levels of theta, alpha and beta remains consistent within the individual at longer intervals. Certainly it is possible that attentional investment at rest may predict AB magnitude in a trait-like fashion, as personality variables have also shown such an association with the AB (MacLean & Arnell, 2010).

Our hypotheses and results are consistent with the resting alpha and alpha ERD literature (see Klimesch et al., 2007 for a review). It has been suggested that levels of alpha are indicative of different orientations of attention (Cooper, Croft, Dominey, Burgess, & Gruzeli, 2003; Hanslmayr et al., 2011). Specifically, high levels of alpha are thought to indicate a state of internally oriented

attention, where attention is directed toward internally-generated information, for example, memories. In opposition to that, low levels of alpha are thought to indicate a state of externally oriented attention, where attention is directed toward incoming, externally-generated information, for example, an RSVP. In this case when alpha is high and attention is directed toward internally-generated information perception of externally-generated information would be impaired. In the case of our results this would suggest that the larger AB magnitudes observed in individuals with greater levels of alpha at rest could be the consequence of displaying an internally oriented state of attention while at rest. For example, one possibility is that the state of internally oriented attention is persistent in individuals who display greater levels of alpha at rest. In this case, if the internally oriented state of attention persisted during the AB task, it is possible that impaired perception of externally-generated information accounts for the relationship between greater alpha at rest and larger AB magnitudes. In other words, the internally oriented state of attention results in reduced perceptual identification which is exacerbated when identification is especially difficult at short lags within the time window of the AB, leading to larger AB magnitudes and poorer performance.

The present results appear to be at odds with findings that suggest that diffused, or decreased attentional investment is associated with smaller AB magnitudes (e.g., Dale & Arnell, 2010; MacLean & Arnell, 2010; MacLean et al., 2010; Olivers & Nieuwenhuis, 2005; Olivers & Nieuwenhuis, 2006) and that greater alpha ERD (a measure of anticipatory attention) in the foreperiod of the RSVP stream is associated with lower T2 accuracy during the AB period (MacLean & Arnell, 2011). Furthermore, the overinvestment hypothesis of Olivers and Nieuwenhuis (2005), Olivers and Nieuwenhuis (2006) suggests that the AB is caused by too much attentional investment. However, it is important to remember that the overinvestment hypothesis, and those results that support it, are concerned with attentional investment, or attentional approach, relative to a goal-directed task. In the present studies we examined attentional investment specifically in the absence of a goal-directed task, and there is evidence to suggest that indices of attention at rest and relative to a task are not necessarily positively correlated (Doppelmayr et al., 1998; Klimesch, 1999).

There is an alternative hypothesis for how a state of internally oriented attention at rest could account for the larger AB magnitudes of individual who display greater alpha at rest. One way to characterize the possible relationship between attentional investment at rest and during a task is to conceptualize greater alpha (synchrony) as a state of readiness (e.g., Klimesch et al., 2007). Higher alpha power at rest has also been proposed to reflect an “idling”, or alternatively, an actively inhibited cortex (Klimesch et al., 2006; Klimesch et al., 2007; Pfurtscheller et al., 1996). Regardless of whether one conceptualizes alpha as idling or inhibited, either way the cortex is unoccupied. When accompanied by lower levels of beta power, this is indicative of a disengaged attentional network (Laufs et al., 2006), in a state of readiness (Klimesch et al., 2007). Specifically, the cortex is unoccupied and the attentional network is disengaged such that the relevant resources remain available for the processing of incoming, externally-generated information. Individuals in a state of readiness at rest may then approach a task with a high degree of readiness, and this may account for the positive correlation observed between resting alpha and alpha ERD (Doppelmayr et al., 1998). Thus, an individual in this increased state of readiness may be able to deploy more resources to a subsequent stimulus. In contrast, individuals who are preoccupied (occupied cortex), rather than idling at rest may also be preoccupied during the AB task and therefore deploy fewer resources to the AB task. Thus, according to the overinvestment hypothesis (Olivers & Nieuwenhuis, 2005; Olivers & Nieuwenhuis, 2006), the high alpha individuals in a state of readiness at rest

would be more likely to overinvest in the AB task and would have larger AB magnitudes compared to the individuals preoccupied at rest. In this case we might expect that levels of alpha at rest should correlate with measures of attentional investment during the AB task, for example alpha ERD (see MacLean & Arnell, 2011). However, we found no evidence of a correlation ( $r = -.005$ ,  $n = 21$ ) in the sample from Study 1 between resting alpha as measured in this study and alpha ERD during the foreperiod that preceded each RSVP trials in the AB task.

Interestingly, there was evidence of a correlation between both levels of beta and theta at rest as measured in Study 1 with alpha ERD, although these correlations were not significant with the sample of 21 individuals. Specifically, resting beta correlated negatively with alpha ERD ( $r = -.25$ ,  $p = .28$ ) such that greater resting beta, which in this study was associated with smaller AB magnitudes, was associated with smaller reductions in alpha (ERD) preceding RSVP trials, which was found to relate to better T2 performance at the short lag (i.e. smaller AB; MacLean & Arnell, 2011). The opposite trend was observed for resting theta, such that greater resting theta was associated with larger reductions in alpha (ERD) preceding RSVP trials ( $r = .27$ ,  $p = .24$ ). That the correlations between alpha ERD and resting theta is in the opposite direction from that observed with resting beta indicates that the relationship with resting beta is unique, not a function of total resting power regardless of frequency. These correlations support the interpretation that less attentional investment at rest was associated with larger AB magnitudes in the current study because less attentional investment is indicative of readiness to invest attention, leading to overinvestment in the AB task and larger AB magnitudes.

Following this supposition, we wondered what attention was being invested in, at rest, when there is no goal-directed task. Although it is possible that our instructions to sit quietly and try not to move around demanded attentional investment, it is also possible that the attentional investment we observed at rest was the result of mind wandering. Mind wandering (a.k.a. day dreaming, stimulus independent thought, etc.) occurs when attention is diverted, usually without awareness, away from external tasks, such as detecting stimuli, toward internal tasks, such as reflection, and is more likely to occur when attentional resources are available, such as when engaged in a well-practiced task or at rest when not engaged in a goal-directed task (Smallwood & Schooler, 2006). Thus, a complimentary interpretation of our findings is that individuals who invest attention at rest, characterized by lower alpha and greater beta power, are mind wandering. Mind wandering, extended beyond rest to coincide with performance of a task, may divert attention away from the task. In the case of the AB task, mind wandering, and the accompanying diversion of attention, would prevent overinvestment, which according to the overinvestment hypothesis (Olivers & Nieuwenhuis, 2006) should reduce the AB. Indeed, in their 2005 study, Olivers and Nieuwenhuis may have induced mind wandering during the AB task by having participants think about holidays or dinner with friends in an unconstrained fashion such that they could allow their thoughts to wander from theme to theme (“free association” condition). They found that AB magnitude was reduced in the free association condition compared to the control condition.

Mind wandering has been associated previously with greater cortical activation at rest as measured by metabolic activity, specifically in areas of the default mode network (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Mason et al., 2007). The default mode network (DMN) is a network of cortical areas observed to decrease in activity, in most cases observed using PET or fMRI, when engaging in a goal-directed task from an awake, resting state such as the state from which we derived our measures in the current study (Raichle & Snyder, 2007; Raichle et al., 2001). Mason et al. (2007) observed that metabolic activity was greater in areas

of the DMN during a well-practiced task with a greater prevalence of mind wandering than during a novel task with less mind wandering. It was also observed that a greater tendency to mind wander correlated positively with the increase in DMN metabolic activity observed during periods with greater opportunity for mind wandering. So, it appears that when mind wandering occurs the DMN is engaged and that higher trait levels of mind wandering are also related to the greater DMN engagement.

Relevant to the findings of the current study, Laufs et al. (2003a) found that beta range oscillations (17–23 Hz) correlated with activity in cortical areas such as the posterior cingulate cortex and precuneus, areas thought to be part of the DMN. So, it is possible that the greater beta power we observed at rest in our study, which correlated with smaller AB magnitudes, was accompanied by the activated DMN which appears to characterize cortical activity when mind wandering occurs.

## 8. Conclusion

In conclusion, we observed that individual differences in both alpha and beta power during rest predicted individual differences in AB magnitude. Specifically, in two independent studies it was found that greater alpha at rest, less beta at rest, and greater alpha than beta at rest were related to larger AB magnitudes. We interpret these results as evidence that reduced attentional investment during rest is associated with larger AB magnitudes. It is possible that this relationship reflects the consequences of internally versus externally oriented attention (Cooper et al., 2003; Hanslmayr et al., 2011).

We further suggest that reduced attentional investment during rest may represent a state of readiness or anticipation that could contribute to greater investment in the AB task, and thus according to the overinvestment hypothesis (Olivers & Nieuwenhuis, 2006), a larger AB. We also suggest that individuals who display greater attentional investment during rest could be engaging in mind wandering. If mind wandering should occur during the AB task it could reduce investment in the AB task, and thus according to the overinvestment hypothesis (Olivers & Nieuwenhuis, 2006), reduce the AB.

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