BRAIN RESEARCH 1387 (2011) 99–107

available at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/brainres

BRAIN RESEARCH

Research Report

Greater attentional blink magnitude is associated with higher levels of anticipatory attention as measured by alpha event-related desynchronization (ERD)

*Mary H. MacLean, Karen M. Arnell**

Department of Psychology, Brock University, St. Catharines, ON, Canada L2S 3A1

ARTICLE INFO

Article history:
Accepted 19 February 2011
Available online 17 March 2011

Keywords:
Attentional blink
Attention
Alpha
Event-related desynchronization
Anticipatory
Cognitive neuroscience

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). Reducing the amount of attentional investment with an additional task or instructing the use of a more relaxed cognitive approach has been found to reduce the magnitude of the AB. As well, personality and affective traits, as well as affective states, associated with a more diffused or flexible cognitive approach have been found to predict smaller AB magnitudes. In the current study, event-related desynchronization in the alpha range was used to investigate whether the degree of attentional investment in anticipation of a RSVP trial was related to the behavioral outcome of that trial. As hypothesized, greater alpha ERD before the RSVP trial, indicating greater anticipatory attentional investment, was observed on short lag trials where an AB was present (inaccurate T2 performance) compared to short lag trials where an AB did not occur. However, on trials where T2 was presented after a longer period relative to T1, greater alpha ERD before the RSVP trial was found on trials with accurate T2 performance. Results support models of the AB that propose that greater attentional investment underlies the AB, and furthermore that this attentional investment is prepared in anticipation before each RSVP trial.

© 2011 Elsevier B.V. All rights reserved.

1. Introduction

When two to-be-attended targets are presented in a rapid serial visual presentation (RSVP) stream, accuracy for the second target (T2) is reduced when it is presented within 500 ms of the first target (T1), relative to longer T1–T2 separations—a phenomenon known as the attentional blink (AB; Raymond et al., 1992). The AB has been interpreted as reflecting attentional limitations where attentional processing of T1 interferes with and/or delays the allocation of attention to T2 if T2 is presented before T1 processing has been completed (Shapiro et al., 1997).

1.1. *Models of the AB*

Traditional models of the AB tend to characterize the AB in terms of bottlenecks on information processing (e.g., Chun and Potter, 1995; Jolicoeur, 1998). For example, in the two-

* *Corresponding author*. Fax: +1 905 688 6922.
E-mail address: karnell@brocku.ca (K.M. Arnell).

Abbreviations: AB, attentional blink; ERD, event-related desynchronization; RSVP, rapid serial visual presentation; T1, first target; T2, second target

0006-8993/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.brainres.2011.02.069

stage model of the AB (Chun and Potter, 1995), it is proposed that there are two stages to target processing. At the first stage, multiple stimuli can be processed in parallel and temporary fragile representations of the stimuli are created. In the second stage of processing, the fragile and temporary representations are encoding into more durable working memory representations that can be used for later report. Stage two processing is time and attention demanding such that a bottleneck is created at stage two processing if T2 is presented while T1 is still undergoing stage two processing, or if RSVP distractors are currently competing for stage two processing resources. Until that bottleneck is resolved, the encoding of any subsequent targets is delayed leaving their perceptual representations vulnerable to decay and reducing the probability that they will be accurately reported. Thus, any unnecessary investment of stage 2 processing resources in T1 would be expected to exacerbate the AB.

More recently, there have been models of the AB suggesting that some feature of cognitive control is responsible for the pattern of attentional investment that results in the failure to accurately report T2 at short target separations. For example, in the Temporary Loss of Control model (TLC; Di Lollo et al., 2005), it is suggested that cognitive control initially optimizes an input filter in favor of T1. When attention is needed to process the T1 stimulus, less attention is available to control the input filter and the filter falls under bottom-up control. If T2 is presented before cognitive control of the input filter is restored, this loss of cognitive control impairs selection of T2, resulting in the AB. Therefore, the TLC model implies that a lack of top-down cognitive control following T1 is responsible for the AB.

In the Boost-and-Bounce model (Olivers and Meeter, 2008), it is proposed that the T1 item elicits an excitatory "boost" that lasts long enough to also boost the distracter item that immediately follows T1 into working memory. Cognitive control then responds to the presence of this distracter with an inhibitory "bounce" that prevents subsequent items, including T2, from entering working memory. According to this model, poor cognitive control over the "bounce" response (i.e., an inability to prevent the "bounce") seems to initiate the context necessary for an AB.

The Threaded Cognition model (Taatgen et al., 2009) also suggests that a memory function initiated by T1 prevents the further detection of targets. Taatgen et al. (2009) characterize this memory function as an overexertion of control, and suggest that when this control function is not engaged, the probability of accurate T2 performance is increased.

In their Overinvestment Hypothesis, Olivers and Nieuwenhuis (2005, 2006) propose that the AB results from the unrestrained investment of attentional resources extending to all RSVP items such that distractors become effective competitors for entrance into working memory. When T2 appears soon after T1, it is particularly vulnerable to this interference given the additional attention required for encoding T1, resulting in the AB. However, Olivers and Nieuwenhuis (2005, 2006) suggest that if investment of attention was reduced to a level just sufficient to encode the targets, then interference would be reduced and the probability of accurate T2 performance would increase, particularly at short target separations.

In all of the above models, limited attentional resources and inappropriate application of attention underlie the AB. Cognitive control models further suggest that this is a result of maladaptive management of attentional resources by top-down cognitive control. If more or less adaptive cognitive control and the resultant investment of attentional resources could influence the magnitude of the AB, then that would imply that the AB does not reflect a fundamental attentional processing limitation. Instead, the AB would be conceptualized as resulting from a particular attentional style, where its magnitude is influenced by the kind of cognitive control or attentional investment of attentional resources with which an individual approaches the RSVP task.

Recent evidence where researchers have manipulated or measured the level of cognitive control and/or attentional investment supports this conceptualization of the AB—specifically the possibility that overly stringent cognitive control and inappropriate attentional investment contribute to the AB. For example, when participants engaged in concurrent task such as detecting yells in music or performing a match to sample task, Olivers and Nieuwenhuis (2005, 2006)[1] found that the AB was reduced relative to control conditions where participants performed only the AB task. Similarly, the AB has been reduced when task instructions emphasized a more passive target search strategy where you let the targets jump out at you (Olivers and Nieuwenhuis, 2005), and when AB task instructions emphasized reporting the two targets as a combination or pair (Ferlazzo et al., 2007). Olivers and Nieuwenhuis (2006) also observed a reduced AB when participants were exposed to positive affective pictures, relative to negative or neutral pictures. This result has implications for models of the AB given that positive affect is associated with an open and flexible cognitive processing style and diffused attention (e.g., Fredrickson, 2001) while negative affect is associated with heightened focusing of attention (e.g., Kramer et al., 1990).

Individual differences in trait affect (MacLean et al., 2010) and state affect (MacLean and Arnell, 2010) have been shown to predict AB magnitude where greater positive affect is associated with reduced AB magnitudes and greater negative affect is associated with increased AB magnitudes. Personality dimensions related to attentional investment and focus have also been shown to predict the magnitude of the AB where higher scores on extraversion and openness to experience predicted smaller AB magnitudes, and higher scores on neuroticism predicted larger AB magnitudes (MacLean and Arnell, 2010). Individual differences in the degree of global versus local processing also predict AB magnitude, where an individual's tendency to focus on the local information as opposed to seeing the global overall picture was positively associated with larger AB magnitudes (Dale and Arnell, 2010). Individual differences in the ability to effectively inhibit or ignore RSVP distractors have been shown to relate to the AB where greater inhibition of irrelevant RSVP distractors was

[1] Olivers and Nieuwenhuis indicated that the effect of music played concurrently with the RSVP stream on AB magnitude could not be consistently replicated (Olivers and Nieuwenhuis, 2006, Footnote 1).

associated with smaller AB magnitudes (Dux and Marois, 2008). Similarly, individual's ability to ignore irrelevant visual material presented beside the RSVP stream (Martens and Valchev, 2009), or in a separate visual working memory task (Arnell and Stubitz, 2010), was negatively related to AB magnitude, where greater ability to ignore the irrelevant material predicted smaller AB magnitudes. Notice that in each of these studies inappropriate allocation of attentional resources is associated with larger ABs.

While the above evidence supports models of the AB discussed previously, which propose that maladaptive applications of cognitive control and inappropriate attentional investment contribute to the AB, it also suggests that cognitive control and attentional investment are not determined once the RSVP stream starts or within the 500 ms following T1. Instead, these results suggest that even before the RSVP task begins the degree of cognitive control or attentional investment with which an individual approaches the trial can influence the AB. This suggests that there may be a relationship between readiness to invest attention before the RSVP trial, and T2 performance on that trial.

1.2. *Electrophysiological measurement of attentional investment*

Attentional investment during the RSVP stream has often been measured using event-related brain potentials (ERPs). Electrophysiological investigations of the role of the AB have focused on attentional investment only during the RSVP task, either relative to a target (Martens et al., 2006a; Martens et al., 2006b; Sessa et al., 2007; Vogel and Luck, 2002; Vogel et al., 1998) or distracters (Martens, et al., 2006b). Vogel et al. (1998) and Sessa et al. (2007) both demonstrated that the P3 component, (an ERP component thought by many to be related to updating working memory; e.g., Donchin, 1981), is absent following T2 at shorter target separations, suggesting that T2 fails to enter working memory when presented at shorter T1–T2 intervals. Martens et al. (2006a) showed that a low probability T1 resulted in a larger P3 component and a larger AB compared to a high probability T1 target, a finding they attributed to the greater attentional investment required for improbable T1s. Martens et al. (2006b) were also able to show that non-blinkers (individuals who reliably show no AB) had more discrete and significantly earlier P3's to T1 and T2, indicating that their attentional investment in targets differed from individuals who demonstrate an AB. Non-blinkers also had significantly reduced attentional investment in distracters, as measured by activation during distracter-only RSVP trials, suggesting that they were also investing less attention in distracter items compared to individuals who demonstrate an AB (Martens et al., 2006b).

The electrophysiological evidence reviewed above supports models of the AB that propose that an inappropriate investment of attentional resources underlies the AB in that greater ABs were associated with greater P3s to T1 and greater activation to RSVP distracters. However, the electrophysiological measures used (the P3 and distracter activation) were confined to measuring the attentional investment that occurs during the RSVP trial. The goal of this study is to investigate whether the degree of anticipatory attentional investment with which an individual approaches an AB trial influences the behavioral outcome on that trial.

1.3. *Alpha desynchronization and anticipatory attention*

Anticipatory attention has been captured by examining event-related changes in alpha frequency (~8–12 Hz) oscillations present in cortical electrophysiological activity (Bastiaansen and Brunia, 2001; Bastiaansen et al., 2002; Bastiaansen et al., 2001; Capotosto et al., 2009; Onoda, et al., 2007; Yamagishi et al., 2005). Alpha frequency oscillations are frequently observed over widespread cortical areas and are thought to be generated by thalamo-cortical connections as well as cortico-cortical communication (Lopes da Silva, 1991; Steriade et al., 1990). Specifically, during a particular thalamic state, afferent stimulus information is prevented from proceeding to the cortex and this thalamic state results in synchronized cortical activity in the alpha range and an increase in alpha power. When afferent information is then allowed to reach the cortex, synchronization is disrupted, in other words, a desynchronization in the alpha range and a reduction in alpha power results (Lopes da Silva, 1991; Steriade et al., 1990). Lopes da Silva (1991) suggest that the different thalamic states could represent a gating function very similar to an early attentional filter which controls the flow of specific information to the cortex as well as between cortical areas, and that the function of this gating system is reflected in changes to alpha frequency oscillations of the cortex. Brunia and van Boxtel (2001) suggest that anticipatory attention is initiated by top-down influences generated by cortical areas that control attention via the thalamus, such that the flow of information to the cortex is regulated in order to facilitate the processing of an upcoming relevant stimulus. These authors propose that the top-down influence is directed at the reticular nucleus which is thought to control the thalamic states which result in the synchronization and desynchronization of alpha frequency oscillations of the cortex (Lopes da Silva, 1991; Steriade et al., 1990). Therefore, event-related desynchronization (ERD) in alpha frequency oscillations could be considered an index of anticipatory attention facilitating, in a top-down manner, the flow of information from the thalamus to the cortex. If this assumption is true, then alpha ERD should be observed prior to a to-be-attended stimulus when that stimulus can be anticipated and greater alpha ERD should reflect greater anticipation.

In support of the idea of alpha ERD as a measure of anticipatory attentional investment, alpha ERD has been observed following a cue to shift attention toward the location of an upcoming target, and found to persist until the target appeared (Yamagishi et al., 2005). Alpha ERD has also been observed prior to a visual stimulus providing feedback on performance of a time-estimation task (Bastiaansen and Brunia, 2001; Bastiaansen et al., 2002; Bastiaansen et al., 2001). Furthermore, interrupting alpha ERD prior to a relevant stimulus, using trans-cranial magnetic stimulation on fronto-parietal areas of the attention network, impaired target performance in a spatial attention task (Capotosto et al., 2009). Alpha ERD has also been shown to be larger following a cue indicating that the upcoming affective stimulus was negatively-valenced, compared to when the cue indicated it was positively-valenced (Onoda et al., 2007). These authors interpreted this as evidence that cortical sensory-perceptual areas were activated via top-down control in anticipation of a relevant stimulus, in order to facilitate the processing of that stimulus.

1.4. The present study

It has been suggested that the assignment of limited attentional resources to T1 and distracters (Chun and Potter, 1995), an overexertion of cognitive control (Olivers and Meeter, 2008; Taatgen et al., 2009), and/or a general overinvestment of attention (Olivers and Nieuwenhuis, 2006) underlies the AB. These models have been supported in that: (1) manipulations meant to reduce the degree of attentional investment have been shown to reduce the AB (e.g., Olivers and Nieuwenhuis, 2005, 2006), (2) affective and personality traits associated with an open and flexible cognitive control and/or reduced attentional investment predict smaller ABs (MacLean and Arnell, 2010; MacLean et al., 2010), and (3) an individual inability to avoid processing irrelevant information predicts larger ABs (Arnell and Stubitz, 2010; Dux and Marois, 2008; Martens and Valchev, 2009).

The goal of this study is to test the hypothesis that an inappropriate investment of attention just prior to the onset of the RSVP stream contributes to the production of the AB. This was done by investigating whether the degree of anticipatory attentional investment with which an individual approaches an AB trial influences the behavioral outcome on that trial. To answer this question, we measured the level of anticipatory attentional investment prior to the RSVP stream, using alpha ERD as a more direct measure of anticipatory attention. If greater levels of anticipatory attentional investment are associated with a reduction in the probability of accurate T2 performance at shorter T1–T2 intervals, then alpha ERD should be greater prior to the RSVP stream on trials when T2 performance was incorrect than when T2 performance was correct at shorter T1–T2 intervals. We would not expect, however, that greater alpha ERD prior to the RSVP stream should be associated similarly with poor T2 performance at longer T1–T2 intervals. At shorter T1–T2 intervals, overinvestment of anticipatory attention would be expected to increase attention to T1, and this would leave less attention for a closely trailing T2. However, at longer T1–T2 intervals, T1 processing would likely be complete by the time T2 was presented, and thus overinvestment would not have a detrimental effect on T2 processing.

When T2 is presented at longer T1–T2 intervals (more than 500 ms after T1), T2 performance resembles single target performance (Raymond et al., 1992). Greater attentional investment would generally be expected to improve target performance, except in the particular circumstances in which an AB is found to occur as discussed above. So, when those circumstances are absent, as is the case for T1 processing or when T2 is presented following longer T1–T2 intervals, greater levels of anticipatory attentional investment as indicated by greater alpha ERD should be associated with better target performance. This hypothesis assumes that attentional investment beyond some minimum threshold required for accurate identification of a target stimulus could still increase target performance.

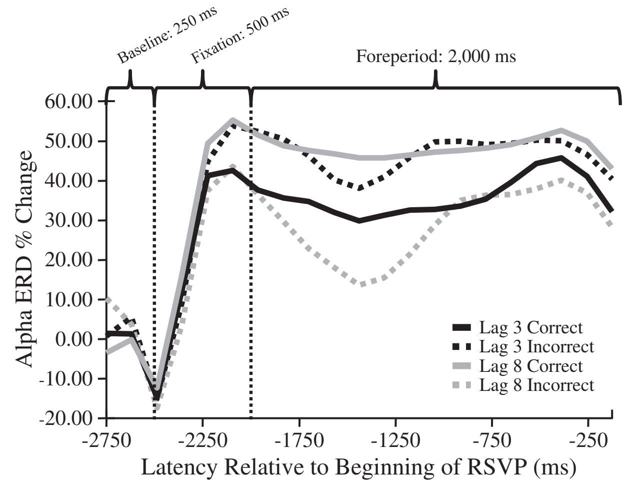

Fig. 1 – Group average alpha ERD during the foreperiod for each factorial combination of lag (black lines for lag 3 and gray lines for lag 8) and T2 accuracy (solid lines for T2 correct and dashed lines for T2 incorrect) at site CZA.

2. Results

2.1. AB task performance

Mean T1 accuracy was 90.67% (SD=8.34), and ranged from 70% to 98% for individual participants. T2 accuracy was calculated for T1 correct trials only. Mean T2 accuracy at lag 3 was 66.67% (SD=15.22), while mean accuracy at lag 8 was 89.33% (SD=5.54). A paired-samples t-test between T2 accuracy at lag 8 and 3 was significant (t (20)=8.15, p<.001), such that mean T2 accuracy increased from lag 3 to lag 8, indicating the presence of an AB.

2.2. Alpha ERD results

A widespread, sustained anticipatory alpha ERD was observed during the foreperiod with a mean of 37.85% across all regions of interest (regardless of condition). Fig. 1 depicts the group average alpha ERD during the foreperiod for each factorial combination of lag (black lines for lag 3 and gray lines for lag 8) and T2 accuracy (solid lines for T2 correct and dashed lines for T2 incorrect) at site CZA. Fig. 2 shows the topographical distribution of anticipatory alpha ERD averaged across participants.

2.2.1. T2 analysis

A 3×2×2×2 repeated-measures ANOVA was conducted to examine the effects of ROI, lag (3 and 8), and T2 performance (correct and incorrect) associated with anticipatory alpha ERD. ROI was divided into two separate factors: laterality (central, left, right) and frontal vs. parietal.[2] All effects were examined

[2] Additionally, we examined alpha ERD at an occipital ROI (average of O1, OZ, and O2). A 2 (lag)×2 (T2 correct/incorrect) repeated-measures ANOVA on alpha ERD at the occipital ROI showed a significant interaction of lag and T2 accuracy (F (1, 20)= 4.47, p=.047) with the same pattern of means as that observed across ROIs in the original analysis.

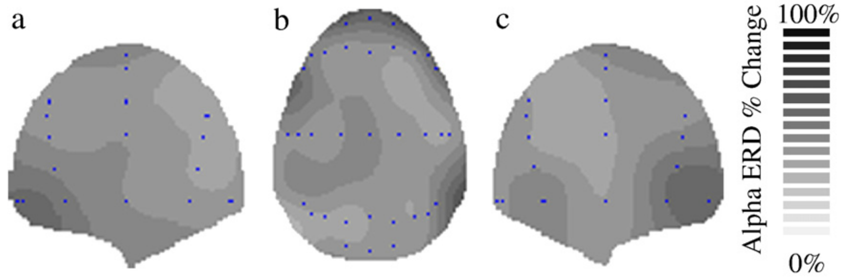

Fig. 2 – Topographical distribution of group average alpha ERD, averaged across all conditions and over the entire foreperiod: (a) view from left, (b) view from top, (c) view from right.

for violations of the sphericity assumption and Greenhouse–Geisser corrected values are reported where violations were present. The main effect of frontal vs. parietal was significant (F (1, 20) = 11.67, p = .003) such that anticipatory alpha ERD was greater at frontal sites than at parietal sites. The interaction of laterality (central, left, right) × frontal vs. parietal was significant (F (2, 40) = 7.12, p = .002), such that at frontal sites anticipatory alpha ERD was greatest at right-lateralized sites and at parietal sites anticipatory alpha ERD was greatest centrally. The interaction of lag × T2 accuracy was also significant (F (1, 26) = 6.63, p = .018).[3] Fig. 3 depicts the group average alpha ERD during the foreperiod for each factorial combination of lag and T2 accuracy averaged across ROI. The interaction of lag and T2 accuracy did not enter into any higher-order interactions with ROI variables, nor did lag or accuracy separately (all p's > .23). No other effects reached significance (all p's > .09).

In order to further explore the significant interaction between lag and accuracy, we examined the difference in anticipatory alpha ERD between T2 correct and incorrect trials separately for each lag. This would allow us to address our hypothesis that greater anticipatory attentional investment would be associated with incorrect T2 performance at lag 3, but that greater anticipatory alpha ERD would be associated with correct T2 performance at lag 8. Paired t-tests revealed that anticipatory alpha ERD was greater on T2 incorrect trials (M = 42.27, SD = 25.72) than T2 correct trials (M = 35.17, SD = 28.06) when T2 was presented at lag 3 (t (20) = 2.08, p = .05). This pattern of results was reversed when T2 was presented at lag 8, such that anticipatory alpha ERD was greater on T2 correct trials (M = 43.47, SD = 21.42) than T2

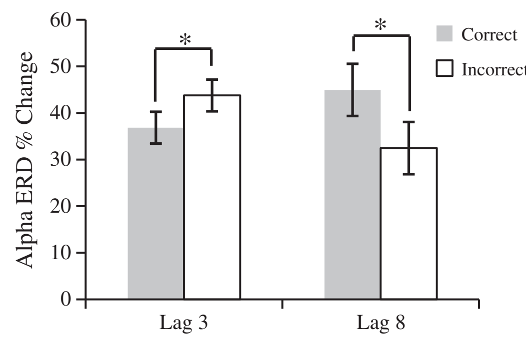

Fig. 3 – Mean alpha ERD during the RSVP foreperiod as a function of lag and T2 accuracy, averaged across ROI. Error bars represent standard error on the difference between correct trials and incorrect trials at each lag (* indicates p < .05 for the comparison indicated).

incorrect trials (M = 30.50, SD = 33.19) when T2 was presented at lag 8 (t (20) = 2.31, p = .031).[4]

2.2.2. *T1 analysis*

A 3 × 2 × 2 repeated-measures ANOVA was conducted to examine the effects of ROI and T1 performance (correct and incorrect) associated with anticipatory alpha ERD. ROI was again divided into two separate factors: laterality (central, left, right) and frontal vs. parietal. No main effects were significant (all p's > .15). The interaction of T1 performance and frontal vs. parietal was significant (F (1, 20) = 7.56, p = .012). In order to further investigate this interaction, two separate paired-

[3] As alpha ERD is calculated as percent change in alpha relative to the baseline, it is possible that the interaction effect of lag and T2 performance associated with alpha ERD is due to pre-existing differences in alpha power during the baseline period. In order to test this possibility, we performed the same 3 × 2 × 2 × 2 repeated-measures ANOVA with baseline alpha power as a covariate. The pattern and significance of the results from this analysis did not differ from the analysis without baseline alpha power as a covariate. Also, see Fig. 1 for an indication that the baseline ERD levels were very similar across the four conditions.

[4] As another test of whether greater anticipatory alpha ERD is associated with the AB, we calculated each participant's overall anticipatory alpha ERD value (ERD averaged across all possible conditions and ROIs) and each participant's AB magnitude, and examined the correlation between them. It was expected that those individuals with greater anticipatory alpha ERD would show larger ABs (i.e., that there would be a positive correlation between alpha ERD and AB magnitude). AB magnitude for each participant was calculated as the average difference in T2 accuracy between short and long lag trials (i.e. T2 accuracy long lag–T2 accuracy short lag) on trials where T1 was correct. Overall anticipatory alpha ERD was positively correlated with AB magnitude but not significantly (r = .27, p = .243).

samples *t*-tests were conducted comparing mean alpha ERD on T1 correct trials with mean alpha ERD on T1 incorrect trials for frontal and parietal ROIs (collapsed across laterality). The effect of T1 performance was significant ($t\,(20)=2.13$, $p=.045$) at frontal ROIs such that anticipatory alpha ERD was greater on trials where T1 was correct ($M=51.24$, $SD=16.16$) than on trials where T1 was incorrect ($M=45.03$, $SD=21.89$). In contrast, at parietal ROIs, there was no significant difference in anticipatory alpha ERD for correct ($M=45.73$, $SD=18.71$) and incorrect ($M=45.82$, $SD=21.08$) T1 trials, ($t\,(20)=-.026$, $p=.980$).

3. Discussion

The purpose of this study was to investigate whether the level of attention invested in anticipation of the AB task influenced target accuracy according to hypotheses derived from various models of the AB. Specifically, those models suggest that an overexertion of cognitive control and/or an inappropriate investment of attention underlies the AB (Olivers and Meeter, 2008; Olivers and Nieuwenhuis, 2006; Taatgen et al., 2009). We measured the level of anticipatory attentional investment by examining alpha ERD during a 2 second foreperiod following a cue that the RSVP stream was to begin.

We hypothesized that anticipatory alpha ERD would be larger on trials where an AB was present (incorrect T2 performance at short lag) than when no AB was present (correct T2 performance at short lag). In line with our hypothesis, we found that anticipatory alpha ERD was larger on short lag trials with incorrect T2 performance than on short lag trials with correct T2 performance. We also hypothesized that anticipatory alpha ERD on T2 incorrect trials would be smaller than or equal to alpha ERD on T2 correct trials at the long lag, as greater attention would not be costly to T2 accuracy once T1 processing had been completed. As predicted, anticipatory alpha ERD was greater on long lag trials with correct T2 performance than on long lag trials with incorrect T2 performance. This lag × T2 accuracy pattern was not specific to certain ROIs, but was observed across the scalp. Finally, we hypothesized that anticipatory alpha ERD on T1 incorrect trials would be smaller than or equal to anticipatory alpha ERD on T1 correct trials, as greater attention should benefit T1 accuracy. As predicted, greater anticipatory alpha ERD was observed on T1 correct trials than on T1 incorrect trials.

Our results suggest that the AB is associated with greater attentional investment, as measured by alpha ERD, and that this attentional investment is prepared in anticipation before each RSVP trial. However, our results cannot identify what patterns of investment during the RSVP stream may contribute to the AB. Furthermore, our results suggest that while greater attentional investment may cause low T2 accuracy at the short lag, when T2 is presented at the long lag, or in the case of T1, greater attentional investment results in higher target accuracy. So it is possible that, while overinvesting attention (i.e. applying as many perceptual or cognitive resources as possible) is a good strategy when interference from a preceding target is absent, when time restraints require greater control over the allocation of limited resources to multiple targets, overinvesting attention impairs performance. The finding that greater attention improves long lag accuracy may also explain why participants persist in overinvesting attention despite poor T2 accuracy at the short lag.

In this study, it was found that different levels of the same measure – anticipatory attentional investment as measured by alpha ERD – were associated with opposite behavioral outcomes at long and short lags (i.e., greater pretrial ERD was associated with impaired T2 accuracy at short lags, but improved T2 accuracy at long lags). This finding is in line with the relationship observed between trait affect and the AB (MacLean et al., 2010). MacLean et al. (2010) found that, while greater affect valence (positive affect > negative affect, which has been linked to an open and less focused attentional style) was associated with better T2 performance at the shorter lags, it was also associated with worse T2 performance at the long lag. In line with our conclusions here, MacLean et al. (2010) proposed that a more focused or invested attentional state is harmful to T2 performance at the short lag as it increases interference from T1 and its surrounding distracters, but that at longer lags, where the interference from T1 and its surrounding distracters is absent, a more focused or invested attentional state results in better target selection.

The significant and sustained alpha ERD we observed during the 2-second foreperiod following a cue indicating that the RSVP stream was to begin is consistent with considering alpha ERD as an index of anticipatory attention. While there was no significant interaction of either ROI factor with lag, T2 accuracy, or the lag × T2 accuracy interaction, there was a significant laterality by frontal/parietal interaction where alpha ERD was larger at frontal sites, where it was right-lateralized, than parietal sites, where it was centralized. Typically alpha ERD is examined over parieto-occipital sites (Bastiaansen and Brunia, 2001; Bastiaansen et al., 2002; Bastiaansen et al., 2001; Capotosto et al., 2009; Yamagishi et al., 2005). The rationale for examining alpha ERD effects at parieto-occipital sites is due to their position over the visual cortex. In the context of the attentional gating hypothesis, this makes sense as changes in alpha power in the cortex represent changes in the flow of stimulus information from the thalamus to the cortex, specifically to primary sensory areas (Lopes da Silva, 1991; Steriade et al., 1990). However, similar to our findings, Onoda et al. (2007) observed effects on alpha ERD over both occipital and right frontal areas using MEG. They proposed that the alpha ERD observed over right frontal areas represented top-down control of anticipatory attention by areas in the right frontal cortex, which may be part of a distributed frontal attention network, modulating activity in the visual cortex via the thalamus. If that were the case, it would suggest that the larger frontal alpha ERD we observed is representative of sustained top-down control over early perceptual processes. This would also be consistent with a variety of neurophysiological studies (e.g., Marcantoni et al., 2003; Marois et al., 2000; Martens et al., 2006b) showing that the AB is associated with activation in sites such as prefrontal cortex and lateral frontal cortex that are thought to be involved in executive control of attention (e.g., Posner and Dehaene, 1994).

In conclusion, using an electrophysiological index of anticipatory attention (alpha ERD), we found that anticipatory attentional investment was associated with both T1 and T2 performance outcomes during the AB task. Greater levels of anticipatory attentional investment were associated with, worse T2 performance at shorter T1–T2 separations, better T2 performance at longer separations, and better T1 performance. These results provide support for various models of the AB which propose that maladaptive cognitive control or inappropriate investment of attention underlies the AB.

4. Experimental procedures

4.1. *Participants*

The participants were 30 Brock University undergraduate students, recruited through the Brock Psychology Department's online system for participant recruitment. Participants (17 female, 11 male, 2 undeclared) varied from 18 to 28 years of age with a mean age of 20 years (SD = 2.33). All participants reported speaking English as their first language. None of the participants reported any perceptual or cognitive impairment. The data from one participant were excluded due to close to chance performance on the RSVP task (first target accuracy was 53%, and second target accuracy was 13%), and the data from another participant were excluded due to an error in the EEG recording.

Data from participants who had less than five remaining epochs in any one condition in either the T1 or T2 analysis were excluded from the analysis, resulting in the exclusion of six participants' data in the T2 analysis.[5] Data from participants demonstrating an event-related synchronization (negative ERD values) in any one condition in either the T1 or T2 analysis were also excluded from the analysis. This resulted in the removal of data from 6 participants for the T1 analysis and 1 participant for the T2 analysis. This removal was necessary given that it is inappropriate to consider negative ERD values (indicating an event-related synchronization, a different phenomenon) as relatively lower ERD values.

4.2. *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 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. All trial types were presented randomly within each block. Each trial began with a fixation cross (500 ms), followed by a foreperiod of 2 seconds before the onset of the RSVP stream. The T1 probability manipulation and the distracter-only trials were included for the purposes of a separate study. The RSVP stream consisted of 18 alphanumeric stimuli with an SOA of 117 ms per item. T1 was presented in white font on a gray background. T2 was one of 10 different color words (e.g., "GREEN"), and appeared in black uppercase letters. The distracter items consisted of non-color, affectively neutral words also presented in black uppercase letters. 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 et al., 2002).

4.3. *EEG acquisition*

EEG was recorded continuously during the RSVP blocks 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. EEG data were acquired with Neuroscan acquisition software (Compumedics USA, Charlotte, North Carolina) running on a Sony VAIO Pentium 4 desktop PC, and using two 32-channel NeuroScan SynAmps. 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 kΩ.

4.4. *EEG analysis*

Using Neuroscan software, EEG data were corrected for electro-oculogram activity. The software uses an algorithm that calculates the amount of covariation between each EEG channel and a vertical EOG channel and removes the EOG from each EEG electrode on a sweep-by-sweep, point-by-point basis to the degree that the EEG and EOG covary. An epoch was created for each trial that spanned 2750 ms. Each epoch began 250 ms before the onset of the fixation cross and ended just before the onset of the RSVP stream. Thus the epoch encompassed the 250 ms baseline period before the onset of the fixation cross, the 500 ms fixation duration, and the 2000 ms blank foreperiod prior to the onset of the RSVP stream. Epochs were rejected if they contained activity exceeding $\pm 75\ \mu V$ in any channel except linked-ear reference and EOG electrodes. Each accepted epoch was subsequently visually inspected for the presence of artifacts, and rejected if any were found.

[5] When data from these six participants were included, the interaction of laterality (central, left, right) × frontal vs. parietal in the T2 analysis was no longer significant. The significance of all other effects from the entire set of analyses did not change with the addition of these six participants' data. Also, the results of all T2 analyses were the same when the data from the participant with negative ERD values were included.

4.5. *Alpha ERD computation*

Alpha ERD is traditionally examined by dividing alpha frequencies into a lower bandwidth (8–10 Hz) and a higher bandwidth (10–12 Hz) as lower and higher frequencies of alpha have been shown to have dissociable effects (Klimesch et al., 1992). Klimesch et al. (1992) proposed that ERD in the lower alpha range is representative of general alertness and input/output processes, while ERD in the higher alpha range represents task specific, computational processes, such as stimulus identification and controlled processing that are more closely related to selective attention. In the present study, we were interested in examining anticipatory attention modulated by the top-down cognitive control processes discussed in cognitive control models of the AB (Di Lollo et al., 2005; Olivers and Meeter, 2008; Taatgen et al, 2009). Therefore, it was appropriate to confine our analyses of alpha ERD to the higher range of alpha frequencies, which are thought to represent such controlled cognitive processes.

In order to determine alpha ERD, epochs were bandpass filtered with a low-pass of 12 Hz and a high-pass of 10 Hz at 48 dB/oct. The amplitude of the filtered EEG was then squared to provide an estimate of power. The power estimate was then collapsed across 125 ms intervals by averaging the power within that interval in order to yield a more reliable estimate. ERD was then computed as the percent difference in power at each 125 ms interval and the baseline period, where baseline was defined as the average alpha power during the 250 ms preceding the fixation stimulus. For the T1 analysis, epochs were averaged according to T1 accuracy (correct or incorrect), resulting in two averages for each participant. For the T2 analysis, epochs where T1 was correct were then averaged according to two factors: lag (3 or 8) and T2 accuracy (correct or incorrect), resulting in four averages for each participant. Anticipatory alpha ERD was then computed as the mean alpha ERD during the 2,000 ms foreperiod by averaging across the sixteen 125 ms intervals that comprised the foreperiod.

The mean number of epochs per participant for the T1 correct average was 597.18 (SD=96.49, range from 314 to 689), T1 incorrect average was 103.07 (SD=97.89, range from 11 to 398).[6] The mean number of epochs per participant for the lag 3/T2 correct average was 57.67 (SD=29.85, range from 25 to 112); lag 3/T2 incorrect was 34.90 (SD=15.95, range from 7 to 65); lag 8/T2 correct was 99.10 (SD=28.43, range from 44 to 158); and for lag 8/T2 incorrect was 11.52 (SD=5.73, range from 6 to 26). The relatively low number of epochs for lag 8/T2 incorrect averages is due to the normally high accuracy of T2 at the long lag that is meant to reflect baseline T2 accuracy without a dual-task deficit.

Alpha ERD was analyzed across six ROIs. Those ROIs were defined as fronto-central (sites FZ, CZA, F1, F2), left frontal (sites F3, F5, C3A, C5A), right frontal (sites F4, F6, C4A, C6A), parieto-central (sites PZ, PZA, P1, P2), left parietal (sites P3, P5, P3P), and right parietal (sites P4, P6, P4P). Mean alpha ERD values for the foreperiod were averaged across the sites specified for each ROI.

[6] One may be concerned that the T1 results are an artifact of the large disparity in number of epochs for correct and incorrect trials. However, the same pattern of results was obtained when T1 correct averages were calculated based on a random sample of T1 correct epochs equal to the number of incorrect T1 epochs, with the exception that the interaction of T1 performance outcome with frontal vs. parietal (F (1, 21)=4.09, p=.057) just missed the traditional level of significance.

Acknowledgments

This work was supported by a Canadian Graduate Scholarship from the Natural Sciences and Engineering Research Council of Canada (NSERC) to the first author, and by grants from NSERC, the Canadian Foundation for Innovation (CFI), and Ontario Innovation Trust (OIT) to the second author. We thank Jesse Howell and Cassandra Lowe for their assistance with data collection.

REFERENCES

Arnell, K.M., Stubitz, S.M., 2010. Attentional blink magnitude is predicted by the ability to keep irrelevant material out of working memory. Psychol. Res. 5, 457–467.

Bastiaansen, M.C.M., Böcker, K.B.E., Brunia, C.H.M., 2002. ERD as an index of anticipatory attention? Effects of stimulus degradation. Psychophysiology 39, 16–28.

Bastiaansen, M.C.M., Böcker, K.B.E., Brunia, C.H.M., de Munck, J.C., Spekreijse, H., 2001. Event-related desynchronization during anticipatory attention for an upcoming stimulus: a comparative EEG/MEG study. Clin. Neurophysiol. 112, 393–403.

Bastiaansen, M.C.M., Brunia, C.H.M., 2001. Anticipatory attention: an event-related desynchronization approach. Int. J. Psychophysiol. 43, 91–107.

Brunia, C.H.M., van Boxtel, G.J.M., 2001. Wait and see. Int. J. Psychophysiol. 43, 59–75.

Capotosto, P., Babiloni, C., Romani, G.L., Corbetta, M., 2009. Frontoparietal cortex control spatial attention through modulation of anticipatory alpha rhythms. J. Neurosci. 29, 5863–5872.

Chun, M.M., Potter, M.C., 1995. A two-stage model for multiple target detection in rapid serial visual presentation. J. Exp. Psychol. Learn. Mem. Cogn. 21, 109–127.

Dale, G., Arnell, K.M., 2010. Individual differences in dispositional focus/diffusion of attention predict attentional blink magnitude. Atten. Percept. Psychophys. 72, 602–606.

Di Lollo, V., Kawahara, J., Ghorashi, S.M., Enns, J.T., 2005. The attentional blink: resource depletion or temporary loss of control? Psychol. Res. 69, 191–200.

Donchin, E., 1981. Surprise!…Surprise? Psychophysiology 18, 493–513.

Dux, P.E., Marois, R., 2008. Distractor inhibition predicts individual differences in the attentional blink. PLoS ONE 3, e3330.

Ferlazzo, F., Lucido, S., Di Nocera, F., Fagioli, S., Sdoia, S., 2007. Switching between goals mediates the attentional blink effect. Exp. Psychol. 54, 89–98.

Fredrickson, B.L., 2001. The role of positive emotions in positive psychology: the broaden-and-build theory of positive emotions. Am. Psychol. 56, 218–226.

Jolicoeur, P., 1998. Modulation of the attentional blink by on-line response selection: evidence from speeded and unspeeded task 1 decisions. Mem. Cogn. 26, 1014–1032.

Klimesch, W., Pfurtscheller, G., Schimke, H., 1992. Pre- and post-stimulus processes in category judgment tasks as measured by event-related desynchronization (ERD). J. Psychophysiol. 6, 185–203.

Kramer, T.H., Buckhout, R., Eugenio, P., 1990. Weapon focus, arousal, and eyewitness memory: attention must be paid. Law Hum. Behav. 14, 167–184.

Lopes da Silva, F., 1991. Neural mechanisms underlying brain waves: from neural membranes to networks. Electroencephalogr. Clin. Neurophysiol. 79, 81–93.
MacLean, M.H., Arnell, K.M., 2010. Personality predicts temporal attention costs in the attentional blink paradigm. Psychon. Bull. Rev. 17, 556–562.
MacLean, M.H., Arnell, K.M., Busseri, M., 2010. Dispositional affect predicts temporal attention costs in the attentional blink paradigm. Cognition and Emotion 24, 1431–1438.
Marcantoni, W.S., Lepage, M., Beaudoin, G., Bourgouin, P., Richer, F., 2003. Neural correlates of dual task interference in rapid visual streams: an fMRI study. Brain Cogn. 53, 318–321.
Marois, R., Chun, M.M., Gore, J., 2000. Neural correlates of the attentional blink. Neuron 28, 299–308.
Martens, S., Elmallah, K., London, R., Johnson, A., 2006a. Cuing and stimulus probability effects on the P3 the AB. Acta Psychol. 123, 204–218.
Martens, S., Munneke, J., Smid, H., Johnson, A., 2006b. Quick minds don't blink: electrophysiological correlates of individual differences in attentional selection. J. Cogn. Neurosci. 18, 1423–1438.
Martens, S., Valchev, N., 2009. Individual differences in the attentional blink: the important role of irrelevant information. Exp. Psychol. 56, 18–26.
Olivers, C.N.L., Meeter, M., 2008. A boost and bounce theory of temporal attention. Psychol. Rev. 115, 836–863.
Olivers, C.N.L., Nieuwenhuis, S., 2005. The beneficial effect of concurrent task-irrelevant mental activity on temporal attention. Psychol. Sci. 16, 265–269.
Olivers, C.N.L., Nieuwenhuis, S., 2006. The beneficial effects of additional task load, positive affect, and instruction on the attentional blink. J. Exp. Psychol. Hum. Percept. Perform. 32, 364–379.
Onoda, K., Okamoto, Y., Shishida, K., Hashizume, A., Ueda, K., Yamashita, H., Yamawaki, S., 2007. Anticipation of affective images and event-related desynchronization (ERD) of alpha activity: an MEG study. Brain Res. 1151, 134–141.
Posner, M.I., Dehaene, S., 1994. Attentional networks. Trends Neurosci. 17, 75–79.
Raymond, J.E., Shapiro, K.L., Arnell, K.M., 1992. Temporary suppression of visual processing in an RSVP task: an attentional blink? J. Exp. Psychol. Hum. Percept. Perform. 18, 849–860.
Schneider, W., Eschman, A., Zuccolotto, A., 2002. E-Prime User's Guide. Psychology Software Tools, Pittsburgh, PA.
Sessa, P., Luria, R., Verleger, R., Dell'Acqua, R., 2007. P3 latency shifts in the attentional blink: further evidence for second target processing postponement. Brain Res. 1137, 131–139.
Shapiro, K.L., Arnell, K.M., Raymond, J.E., 1997. The attentional blink. Trends Cogn. Sci. 1, 291–296.
Steriade, M., Gloor, P., Llinás, R.R., Lopes da Silva, F.H., Mesulam, M.M., 1990. Basic mechanisms of cerebral rhythmic activities. Electroencephalogr. Clin. Neurophysiol. 76, 481–508.
Taatgen, N.A., Juvina, I., Schipper, M., Borst, J.P., Martens, S., 2009. Too much control can hurt: a threaded cognition model of the attentional blink. Cogn. Psychol. 59, 1–29.
Vogel, E.K., Luck, S.J., 2002. Delayed working memory consolidation during the attentional blink. Psychon. Bull. Rev. 9 (4), 739–743.
Vogel, E.K., Luck, S.J., Shapiro, K.L., 1998. Electrophysiological evidence for a postperceptual locus of suppression during the attentional blink. J. Exp. Psychol. Hum. Percept. Perform. 24, 1656–1674.
Yamagishi, N., Goda, N., Callan, D.E., Anderson, S.J., Kawato, M., 2005. Attentional shifts towards an expected visual target alter the level of alpha-band oscillatory activity in the human calcarine cortex. Cogn. Brain Res. 25, 799–809.