

Endogenous and Rapid Serial Visual Presentation-induced Alpha Band Oscillations in the Attentional Blink

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Abstract

■ The attentional blink (AB) is a deficit in conscious perception of the second of two targets if it follows the first within 200–500 msec. The AB phenomenon has been linked to pre-target oscillatory alpha activity. However, this is based on paradigms that use a rapid serial visual presentation (RSVP) stimulus stream in which the targets are embedded. This distracter stream is usually presented at a frequency of 10 Hz and thus generates a steady-state visual-evoked potential (ssVEP) at the center of the alpha frequency band. This makes the interpretation of alpha findings in the AB difficult. To be able to relate these findings either to the presence of the ssVEP or to an effect of endogenously generated alpha activity, we compared AB paradigms with and without different pre-target distracter streams. The distracter

stream was always presented at 12 Hz, and power and intertrial phase coherence were analyzed in the alpha range (8–12 Hz). Without a distracter stream alpha power dropped before target presentation, whereas coherence did not change. Presence of a distracter stream was linked to stronger pre-target power reduction and increased coherence, which were both modulated by distracter stream characteristics. With regard to the AB results indicated that, whereas ssVEP-related power tended to be higher when both targets were detected, endogenous alpha power tended to be lower. We argue that the pattern of results indicates that in the pre-target interval several processes act in parallel. The balance between these processes relates to the occurrence of an AB. ■

INTRODUCTION

When two targets (T1, T2) are presented in close temporal succession (200–500 msec) and within a stream of distracter stimuli (rapid serial visual presentation [RSVP]; Raymond, Shapiro, & Arnell, 1992), detection of the second target (T2) often fails—a phenomenon known as the attentional blink (AB). Although considerable differences exist between theoretical accounts, most AB theories include a memory component, for the retention of target information, and an attention component, for selectively attending T1 and T2 while ignoring the distracters. In spite of the large number of theories, no single theory or model has so far been able to capture all aspects of the phenomenon (for an extensive review, see Martens & Wyble, 2010; Dux & Marois, 2009).

A large body of evidence suggests that both attention and memory functions are related to alpha oscillations (Klimesch, Sauseng, & Hanslmayr, 2007; Klimesch, Doppelmayr, Schwaiger, Auinger, & Winkler, 1999). Accordingly, in addition to ERP studies (for early studies, see for instance Kranczioch, Debener, & Engel, 2003; Rolke, Heil, Streb, & Hennighausen, 2001; Vogel, Luck, & Shapiro, 1998), electrophysiological studies of the AB

have focused on oscillatory brain activity in the alpha range (for reviews, see Hanslmayr, Gross, Klimesch, & Shapiro, 2011; Janson & Kranczioch, 2011). In one such study, Kranczioch, Debener, Maye, and Engel (2007) found an increase in alpha power and long-range alpha coherence well before the presentation of T1 in trials in which T2 was missed, that is, when an AB occurred. Further evidence for a role for alpha oscillations in the AB has come from a study by Slagter, Lutz, Greischar, Nieuwenhuis, and Davidson (2009), who investigated the effect of meditation on performance and oscillatory brain activity in an AB paradigm. A pre-T1 reduction in occipital alpha inter-trial phase consistency in the noAB trials was observed in the meditation practitioners' group after meditation training. In addition, after meditation training larger amplitude of the T1-induced alpha response in noAB trials was found in meditation practitioners compared with novices (Slagter et al., 2009). Taken together, these studies suggest that an increase in activity and/or a higher phase locking of oscillatory activity in the alpha frequency band is detrimental to the perception of T2.

The interpretation of the alpha-band findings is however hindered as the stream of stimuli that form the AB trial is normally presented at a rate of 10 stimuli per second or 10 Hz and thus falls in the middle of the alpha band. Endogenously generated alpha activity is therefore confounded with the steady-state visual-evoked potential

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(ssVEP) evoked by the stimulation (Regan, 1989; for a review, see Vialatte, Maurice, Dauwels, & Cichocki, 2010). Endogenous alpha refers to alpha activity that is always present and not evoked by an external stimulus. The specific peak frequency of endogenous alpha differs across individuals and is therefore also known as the individual alpha frequency (IAF). Endogenously generated alpha oscillations have been related to performance in both perceptual and memory tasks (Hanslmayr et al., 2005, 2007, 2011; Klimesch et al., 1999, 2007). The ssVEP frequency with highest power is determined by the frequency at which an RSVP stream is shown. An increase in power at the RSVP frequency could, for instance, indicate an increase in attention to the stimulus stream resulting in an increase in ssVEP amplitude (Klimesch et al., 2007; Müller, Malinowski, Gruber, & Hillyard, 2003; Müller & Hübner, 2002; Müller & Hillyard, 2000). Any effect observed in the EEG in the alpha range could therefore relate either to the ssVEP or to endogenously generated alpha activity, or both. Interpretation of observed effects is therefore difficult.

Studies focusing on stimulus stream-evoked responses support the notion that modulations of RSVP responses are related to the AB. For example, Martens, Munneke, Smid, & Johnson (2006), by separately measuring the response to the RSVP stream in individuals who do not show an AB (nonblinkers) and individuals who do (blinkers) found a smaller ssVEP to the stimulus stream for non-blinkers compared with blinkers. Similarly, Keil, Ihssen, and Heim (2006), using a lower presentation frequency of 8.6 Hz, found that a poststimulus increase in amplitude at the presentation frequency was significantly reduced for T1 in noAB as compared with AB trials, whereas the opposite pattern was found for T2. However, neither of these studies tried to separate or compare the effects of stimulus presentation and those of endogenous alpha.

One possible approach to this issue would be to focus on the period just before the onset of the stimulus stream, as this period is free of ssVEP activity. This approach was taken in a recent study by MacLean and Arnell (2011), who observed that the expectation of the onset of the rapid stimulus sequence reduced alpha activity overall. For short T1–T2 intervals, this effect was more pronounced in AB trials than in noAB trials. However, an obvious drawback of this approach is that the measured signal precedes not only the targets but also the pre-target RSVP stream and thus does not capture any dynamic changes in alpha activity occurring during this period. To avoid this problem in this study, the pre-target period was experimentally manipulated, whereas T1 and all subsequent stimuli were kept identical. Specifically, the pre-target period was either filled with an RSVP stream containing repetitions of the same stimulus or an RSVP stream containing a sequence of varying stimuli or it remained empty, thus manipulating the presence and the processing depth of information in the pre-target period. T1 and T2 were each followed by a single stimulus acting as a backward mask with no other

stimuli between T1 and T2 or following T2. In addition, stimuli were presented at 12 Hz to better separate ssVEP-related and endogenously generated activity.

We predicted that our experimental manipulation would affect the AB such that the Varying-RSVP condition would result in a larger AB than the Repeated-RSVP condition. The smallest AB was expected for the condition without an additional RSVP stream. We also hypothesized that if ssVEP-related intertrial coherence and power relate to the amount of processing resources invested in the RSVP stream both should be largest in the Varying-RSVP condition, followed by the Repeated-RSVP condition. They should be smallest for the condition without pre-target RSVP stream.

The second set of hypotheses concerned differences in brain activity between trials in which T2 was missed, that is, when an AB occurred, and trials in which T2 was detected. If pre-T1 endogenously generated alpha activity is related to the occurrence of an AB irrespective of the presence of ssVEP-related activity, then a clear AB effect, that is, higher pre-T1 power when an AB occurs, should be evident in the condition without RSVP stream, in particular in the frequency range corresponding to endogenously generated alpha power. If, however, pre-T1 AB effects in the alpha band depend on the presence of an RSVP stream, then the increase in power and intertrial coherence in AB trials should be evident only in the Varying-RSVP and the Repeated-RSVP conditions, with the effect most prominent in the ssVEP frequency range. Furthermore, the AB effect should be more pronounced in the Varying-RSVP condition, as in this condition a detrimental in-depth processing of the RSVP is most likely.

METHODS

Participants

A total of 25 participants initially took part in the study. Seven were excluded from further analysis as they performed either too well or too poorly in at least one of the three conditions and therefore had an insufficient number¹ of AB and/or noAB trials for further EEG analysis. One further participant was excluded because no individual alpha peak could be identified in the EEG. The final sample of participants therefore consisted of 10 men and 7 women with a mean age of 24.8 years (range = 21–35 years). Of this sample, 3 were identified as ambidextrous and 14 as right-handed using the Edinburgh Handedness Inventory. All participants were free of neurological or psychiatric illnesses. Before the start of the experiment, all participants gave written informed consent according to the Declaration of Helsinki. Participants received a monetary compensation of € 24.00 for their participation.

Stimuli and Behavioral Task

The experiment was run using Presentation version 14.5 software (Neurobehavioral Systems, Inc., Albany, CA).

Stimuli were created in Paint using Arial 72 pt. Stimuli were presented at a visual angle of 1.18°. The SHINE toolbox (Willenbockel et al., 2010) plug-in for Matlab (MathWorks, Inc., Natick, MA) was used to equalize luminance and spatial frequency across distracters, masks, and targets for all conditions. Distracter stimuli used in the pre-target sequence and masks consisted of digits (1–9). Target stimuli were uppercase letters, excluding I, O, Q, Z, because of their similarity to the digits 1, 0, 2 and 7. Targets, distracters, and masks were presented in black on a light gray background (see Figure 1) for 33.4 msec. SOA in the pre-target sequence was 83.3 msec, which created an RSVP stream of 12 Hz. SOA was the same for the first target (T1) and its mask as well as for the second target (T2) and its mask. T2 was presented at Lag 3 or Lag 7 following T1 (i.e., at 250 or 583.3 msec, after T1 onset, respectively). These lag durations were chosen as the AB typically occurs for stimuli presented between 200 and 500 msec after T1 presentation (Raymond et al., 1992). Accordingly, Lag 3 trials would fall in the AB window but trials in Lag 7 would not, and performance in Lag 3 trials could therefore be expected to be significantly worse than in Lag 7 trials. Target letters were randomly selected with the limitation that T1 and T2 would always be different letters. All stimuli were presented at fixation.

At the start of a trial, a fixation cross was presented in the center of the screen for 250 msec, which was followed by a blank screen for 400 msec. For the Repeated-RSVP condition, this was followed by 11–14 repetitions of the same digit, randomly selected from a fixed list, whereas for the Varying-RSVP condition, the blank screen was followed by 11–14 randomly selected digits. The length of the RSVP sequence was based, first, on the intention to avoid attentional awakening effects (Ariga & Yokosawa, 2008) and, second, to avoid the confound of systematic RSVP onset responses. In the No-RSVP condition, T1 was presented after 916–1166 msec, which corresponds to the duration of the RSVP stream in the other condition.

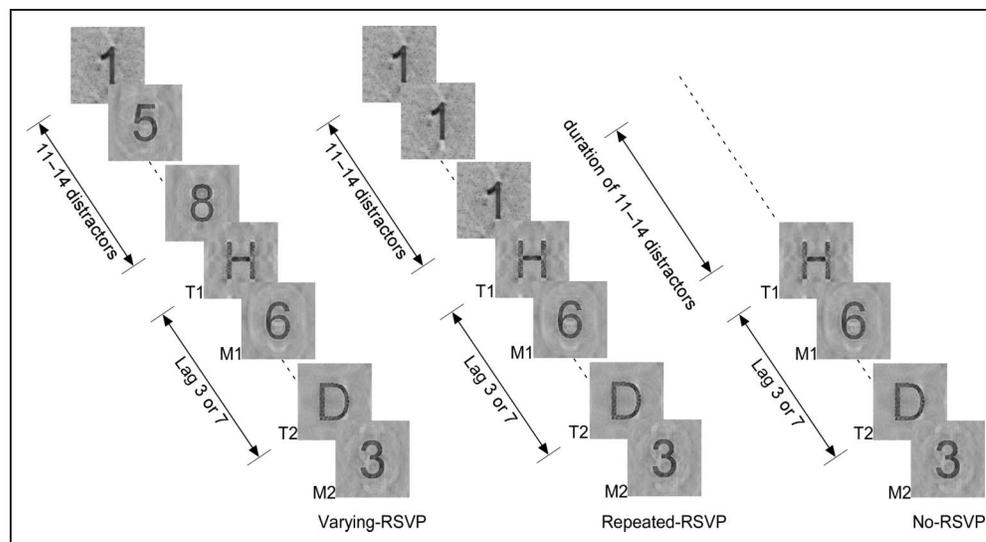
A fourth condition containing only one distracter before T1 presentation was also part of the experiment. This condition, however, is of no relevance for this study and its hypotheses, as it concerned an unrelated research question.² After the T2 mask, the screen remained empty for 1000 msec, after which participants were asked to give their responses by typing the letters they had seen using the corresponding keys on a computer keyboard. Participants had to enter the letters they had seen (max. 2) and were encouraged to guess if they were unsure. Responses were counted as correct irrespective of the order in which they were entered.

Procedure and Setup

Upon arrival in the lab, participants were asked to sign the informed consent sheet. Thereafter, they completed several questionnaires. Following EEG preparation, participants were seated in an electrically shielded, sound-attenuated, dimly lit booth. The computer screen (Samsung Sync Master P2470) for task presentation was placed outside the chamber in front of a shielded glass window. The refresh rate of the screen was 60 Hz. Participants were seated at a distance of 1.70 m from the screen. In front of the participant, a table was placed on which the response keyboard rested.

Participants then received task instructions, were shown a slow motion version of each condition, and received eight practice trials for each condition. Participants were encouraged to ask if they were unsure about the task. After completing the practice trials, the main experiment started. Trials in each condition were presented in blocks of 76 trials (56 Lag 3 and 20 Lag 7 trials). EEG analysis was performed only on Lag 3 trials as the goal of the experiment was to shed light on the neurophysiology of the occurrence of the AB. To obtain a better signal-to-noise ratio for the lag of interest, (i.e., the lag in which the AB often occurs), the experiment was designed to have more

Figure 1. Trial layout of the Varying-RSVP condition, the Repeated-RSVP condition, and the No-RSVP condition. T1 = Target 1; T2 = Target 2; M1 = Mask 1; M2 = Mask 2.



Lag 3 trials compared with Lag 7 trials. Two blocks of each condition were presented totaling 152 trials per condition of which 112 were Lag 3 trials.

The order of condition blocks was randomized, and participants were given 1-min breaks between blocks.

EEG Recordings

The EEG was recorded using an electrode cap on which 96 equidistant Ag-AgCl electrodes were mounted (EasyCap, Herrsching, Germany). Two of these electrodes were placed below the eyes to monitor eye movements. A further electrode was placed on the nose tip as recording reference. Data were recorded using BrainVision, Morrisville, NC, recorder (Version 1.10), together with Brainamp DC Amplifiers (Brain Products GmbH, Gilching, Germany). Electrode impedances were kept below 20 k Ω before data acquisition. Resolution was 0.1 μ V with a range of ± 3.28 mV. Data were recorded with a sampling rate of 1000 Hz with on-line filters of 0.016 Hz for the high-pass filter and 250 Hz for the low-pass filter.

EEG Analysis

Preprocessing

Data analysis was performed using EEGLAB v9.0.4.4b (Delorme & Makeig, 2004), a free open source toolbox running under Matlab version 7.11.0 (R2010b) in combination with custom scripts. Data were filtered off-line with a 100-Hz low-pass filter using sinc FIR filters windowed with a Hann window function (Widmann & Schroger, 2012), downsampled to 500 Hz, and saved for later use. To optimize the data for independent component analysis (ICA) an additional high-pass filter with a cutoff frequency of 1 Hz was applied. Dummy epochs were created of the filtered data with a duration of 2 sec. Data were then semiautomatically screened for nonstereotypical artifacts (Delorme, Sejnowski, & Makeig, 2007), and epochs contaminated by such artifacts were rejected. Extended infomax ICA as implemented in EEGLAB was applied to the pruned data sets. The resulting ICA weights were then imported to the previously saved down-sampled, low-pass filtered raw data. These data were then rereferenced to the average reference and epoched in segments of 4.2-sec duration, corresponding to a time window covering -2.9 to 1.3 sec relative to the presentation of T1. Epochs were derived only for Lag 3 trials. Independent components representing eye blinks, horizontal eye movements, and electrocardiographic artifacts were then semiautomatically identified using CORRMAP (Viola et al., 2009) and removed from all data sets. In the last preprocessing step, the ICA-corrected data were again semiautomatically screened for nonstereotypical artifacts (Delorme et al., 2007) to identify and remove any remaining epochs containing nonstereotyped artifacts.

Time-Frequency Analysis

Time-frequency analysis was performed by convolving the single-trial data ($k(t)$) with a complex Morlet wavelet $w(f_0, t)$ having a Gaussian shape in the time (σ_t) as well as in the frequency (σ_f) domain around the center frequency (f_0 ; Delorme & Makeig, 2004). A wavelet is characterized by a constant ratio $Q = f_0/\sigma_f$. For the analysis of the data in this study, Q was set at 12 to ensure good frequency resolution (see below), and the frequency range was defined from 1 to 20 Hz in steps of 0.2 Hz. The complex result,

$$F_k(f, t) = w(f, t) \times k(t)$$

of the single-trial convolution was then scaled to decibels and normalized by subtracting the mean value of the -200 to -100 msec interval before presentation of the fixation cross for each frequency. Single trials (F_k) were then averaged to obtain a measure of total activity over time.

The frequency resolution (σ_f) of the wavelet at a specific frequency (f) can be approximated by dividing f by the number of cycles (nc) of the wavelet analysis: $\sigma_f = f/\text{nc}$. With $\text{nc} = 12$, a frequency resolution of 0.9 Hz can be obtained at the IAF (10.8 Hz, range = 10.35–11.25 Hz) and a frequency resolution of 1 Hz at the RSVP frequency (12 Hz, range = 11.5–12.5 Hz).

A 500 msec time window of interest was selected, from 700 msec to 200 msec before T1 onset, to allow for potential smearing of post-T1 activity into the pre-T1 activity of interest. The time resolution of the wavelet is given by $\sigma_t = (2\pi\sigma_f)^{-1}$ where σ_f is approximated by dividing the frequency by the number of cycles. A high-frequency resolution typically comes with a low time resolution, and that increases the smearing of activity in time (Herrmann, Grigutsch, & Busch, 2002). This means that for $\text{nc} = 12$, the time resolution for the lowest IAF (9.7 Hz) in this study is 196 msec. Thus, although activity in the time window of interest at this frequency is potentially contaminated by smearing of post-T1 effects, this effect is minimal.³

Intertrial phase coherence (ITC) is often used to obtain more information about the consistency in phase over trials. As ITC values are affected by the number of trials, one would ideally have roughly the same number of trials in all conditions. In this study, data were split into AB trials, that is, trials in which T2 was missed, and noAB trials, which resulted in unequal trial numbers for the three conditions (Repeated-RSVP: AB 39.0 ± 15.1 trials, noAB 48.7 ± 15.97 trials; Varying-RSVP: AB 54.0 ± 12.2 trials, noAB 38.1 ± 12.7 trials; and No-RSVP: AB 42.7 ± 13.6 trials, noAB 54.5 ± 18.5 trials) and thereby potential bias in ITC estimates. Therefore, the pairwise phase consistency (PPC) calculation (Vinck, van Wingerden, Womelsdorf, Fries, & Pennartz, 2010) was used to correct for this bias. The PPC measures the similarity between the relative

phases for all trials. By defining F as the dot product between two unit vectors with phases φ and ω ,

$$F(\varphi, \omega) \equiv \cos(\varphi)\cos(\omega) + \sin(\varphi)\sin(\omega)$$

we can estimate the PPC,

$$\text{EstimatedPPC} \equiv \frac{2}{N(N-1)} \sum_{j=1}^{N-1} \sum_{k=(j+1)}^N F(\theta_j, \theta_k)$$

where θ_j and θ_k refer to the phase estimate of trials j and k . The estimated PPC varies between -1 and 1 where 1 means complete phase consistency and 0 and below means complete absence of phase consistency. The population statistic of the PPC is equal to the population statistic of the squared ITC (Vinck et al., 2010).

Analysis of IAF

The frequency with the highest power and a clear peak between 7 and 14 Hz is defined as the IAF and differs from person to person. To determine the IAF, a fast Fourier transform was performed on the preprocessed data for the 1-sec blank period before the fixation cross in the No-RSVP condition. The IAF values were then used to select data at or closest to (maximal distance = 0.1 Hz) the IAF from the time–frequency analyzed data for each participant. The average IAF over all participants was 10.8 Hz (9.7–12.7 Hz) with a standard deviation of 0.88 Hz (see Figure 2).

Statistical Analysis

Behavior

The statistical analysis of the behavioral data was carried out using a repeated-measures ANOVA with Condition

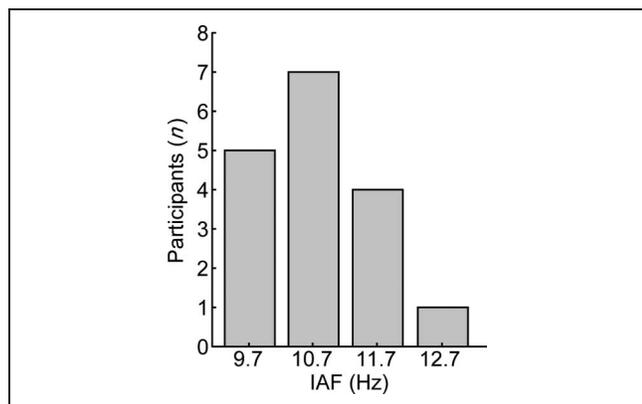


Figure 2. Distribution of the IAF value over participants.

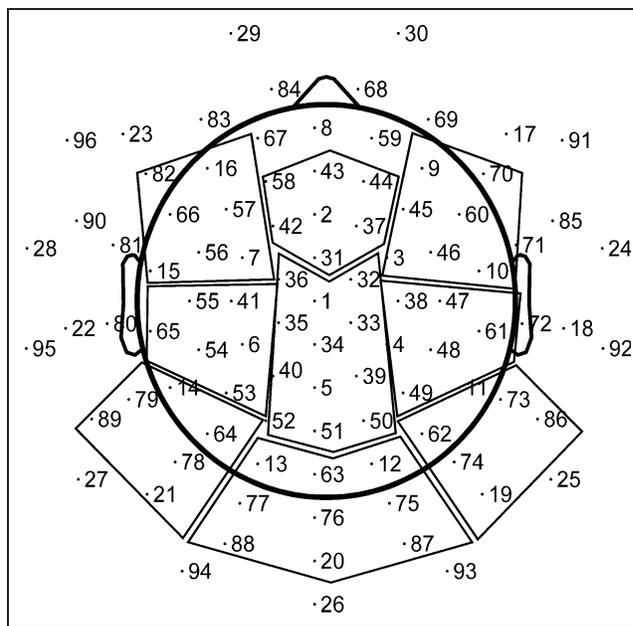


Figure 3. The layout of the 96 electrode EEG cap and the ROIs for statistical analysis. ROIs from left to right and front to back: frontal left, middle frontal, frontal right, parietal left, middle parietal, parietal right, occipital left, middle occipital, occipital right.

(Varying-RSVP, No-RSVP, Repeated-RSVP) and Lag (Lag 3, Lag 7) as independent variables. Analyzed were T1 identification rate and conditional T2 performance, that is, the percentage of trials in which T2 was identified given that T1 had been identified ($T2|T1$). Mauchly's tests of sphericity were not significant in either analysis, so sphericity was assumed and no correction was applied. Main effects and interactions were followed up with t tests.

Electrodes that were in proximity to one another were combined into nine topographical ROIs (see Figure 3). For the RSVP frequency (12 Hz) and the IAF mean amplitudes and PPC values were derived for the time window -700 to -200 msec relative to T1. The time window was chosen based on visual inspection of the time–frequency plots (see Figure 5) and was adjusted such that smearing of post-T1 effects would be largely avoided, as the time resolution of the wavelet (being the standard deviation in the time domain) was below 200 msec at the lowest frequency analyzed. The data were analyzed with four-way repeated-measures ANOVAs with the factors Frequency (IAF and RSVP frequency), Condition (Varying-RSVP, No-RSVP, Repeated-RSVP), AB (AB, noAB), and ROI (frontal left, middle frontal, frontal right, parietal left, middle parietal, parietal right, occipital left, middle occipital, occipital right). When Mauchly's test of sphericity was significant its Sigma score is reported and the Huynh–Feldt correction applied to F and p values. Significant three-way or four-way interactions were followed up by additional repeated-measures ANOVAs. Main effects and two-way interactions of interest were followed up with t tests.

RESULTS

Behavioral Data

The experimental manipulation had a significant effect on the detection of the first target (T1) across conditions ($F(2, 32) = 7.5, p < .01$). t tests revealed that performance in the No-RSVP condition was significantly better compared with both the Varying-RSVP condition ($t(16) = 2.3, p < .05$) and the Repeated-RSVP condition ($t(16) = 3.8, p < .01$; see Figure 4A).

For T2|T1 a clear AB effect was found, as performance was significantly worse at Lag 3 than at Lag 7 ($F(1, 16) = 22.4, p < .001$). Furthermore, a condition effect was present ($F(2, 32) = 24.2, p < .001$) as performance for T2|T1 for the Varying-RSVP condition was significantly worse than performance in the Repeated-RSVP condition ($t(16) = -7.1, p < .001$) and in the No-RSVP condition ($t(16) = -5.6, p < .001$; see Figure 4B). T2|T1 performance did not differ between the Repeated-RSVP condition and No-RSVP condition. The factors condition and lag did not interact significantly.

EEG Data

As illustrated in Figure 5 (left), for the Varying-RSVP and the Repeated-RSVP condition phase consistency in the alpha frequency range was observed. PPC was stronger at the RSVP frequency compared with the IAF for both RSVP conditions. In the No-RSVP condition, no PPC was evident.⁴

All conditions were characterized by a power decrease relative to baseline in the analysis window in both the RSVP and the IAF frequency (see Figure 5, right). The decrease was most pronounced at occipital areas, but also visible at frontal sites. It was most evident in the RSVP conditions.

PPC

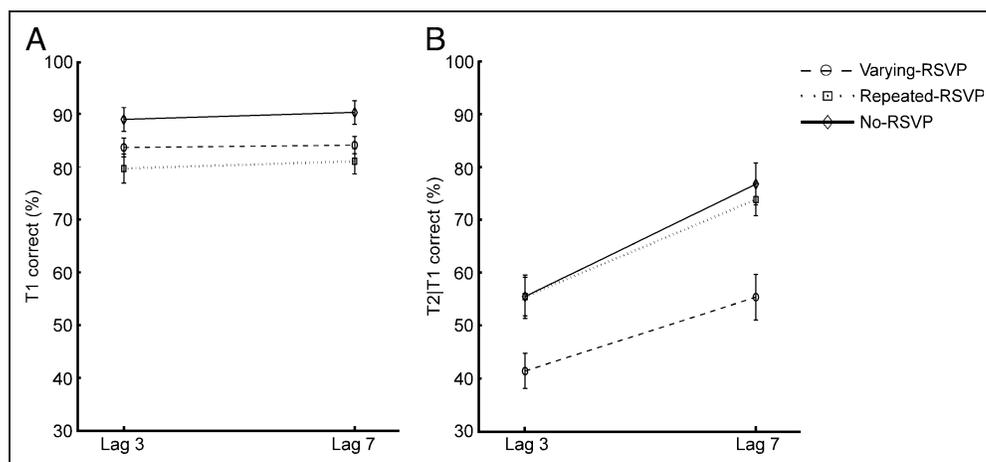
For PPC (see Figure 6A, B), the four-way repeated-measures ANOVA revealed main effects for the factors Frequency ($F(1,$

$16) = 18.3, p < .005$), Condition ($F(2, 32) = 39.6, p < .001$ ($\Sigma = 0.73$)), and ROI ($F(8, 128) = 12.4, p < .001$ ($\Sigma = 0.37$)). Two-way interactions were found for Frequency \times Condition ($F(2, 32) = 18.1, p < .001$ ($\Sigma = 0.56$)), Frequency \times ROI ($F(8, 128) = 9.5, p < .001$ ($\Sigma = 0.338$)), and Condition \times ROI ($F(16, 256) = 12.1, p < .001$ ($\Sigma = 0.25$)). In addition, a three-way interaction was observed between Frequency, Condition, and ROI ($F(16, 256) = 6.8, p < .001$ ($\Sigma = 0.26$)). No main effects or interactions were found involving the factor AB.

PPC condition effects. The three-way interaction between Frequency, Condition, and ROI was followed up with a repeated-measures ANOVA for each ROI with factors Frequency and Condition. A main effect of Frequency was found in all ROIs, indicating that PPC in the IAF was generally smaller than PPC in the RSVP frequency (all $F(1, 16) \geq 6.8$, all $p < .05$). Furthermore a main effect of Condition was found in all ROIs (all $F(1, 16) \geq 9.2$, all $p < .005$ ($\Sigma \geq 0.54$); see Figure 6A). t tests revealed that the Varying-RSVP and the Repeated-RSVP condition showed higher PPC compared with the No-RSVP condition in all ROIs (Varying-RSVP vs. No-RSVP: (all $t(16) \geq 3.9$, all $p < .005$; Repeated-RSVP vs. No-RSVP: all $t(16) \geq 2.2$, all $p < .05$). The Varying-RSVP condition furthermore showed more PPC compared with the Repeated-RSVP condition in all ROIs (all $t(16) \geq 2.8$, all $p < .05$) except for the parietal right ROI in which only a trend in the same direction was found ($t(16) = 1.9, p = .077$; see Figure 6A).

Finally an interaction between Frequency and Condition was found in all ROIs (all $F(2, 32) \geq 5.8$, all $p < .05$ ($\Sigma \geq 0.59$); see Figure 6B). A t test revealed that in the Varying-RSVP condition a higher PPC was present in the RSVP frequency compared with the IAF in all ROIs (all $t(16) \geq 2.9, p < .05$). This was the same in the Repeated-RSVP condition for all ROIs (all $t(16) \geq 2.3, p < .05$) except the frontal left ($t(16) = 1.9, p = .080$)

Figure 4. Behavioral results for the Varying-RSVP, Repeated-RSVP, and No-RSVP conditions in percent correct for Lag 3 and Lag 7. (A) Percentage of correct first target (T1) identification. (B) Percentage of correctly identified second targets (T2) when the first target was also correctly identified.



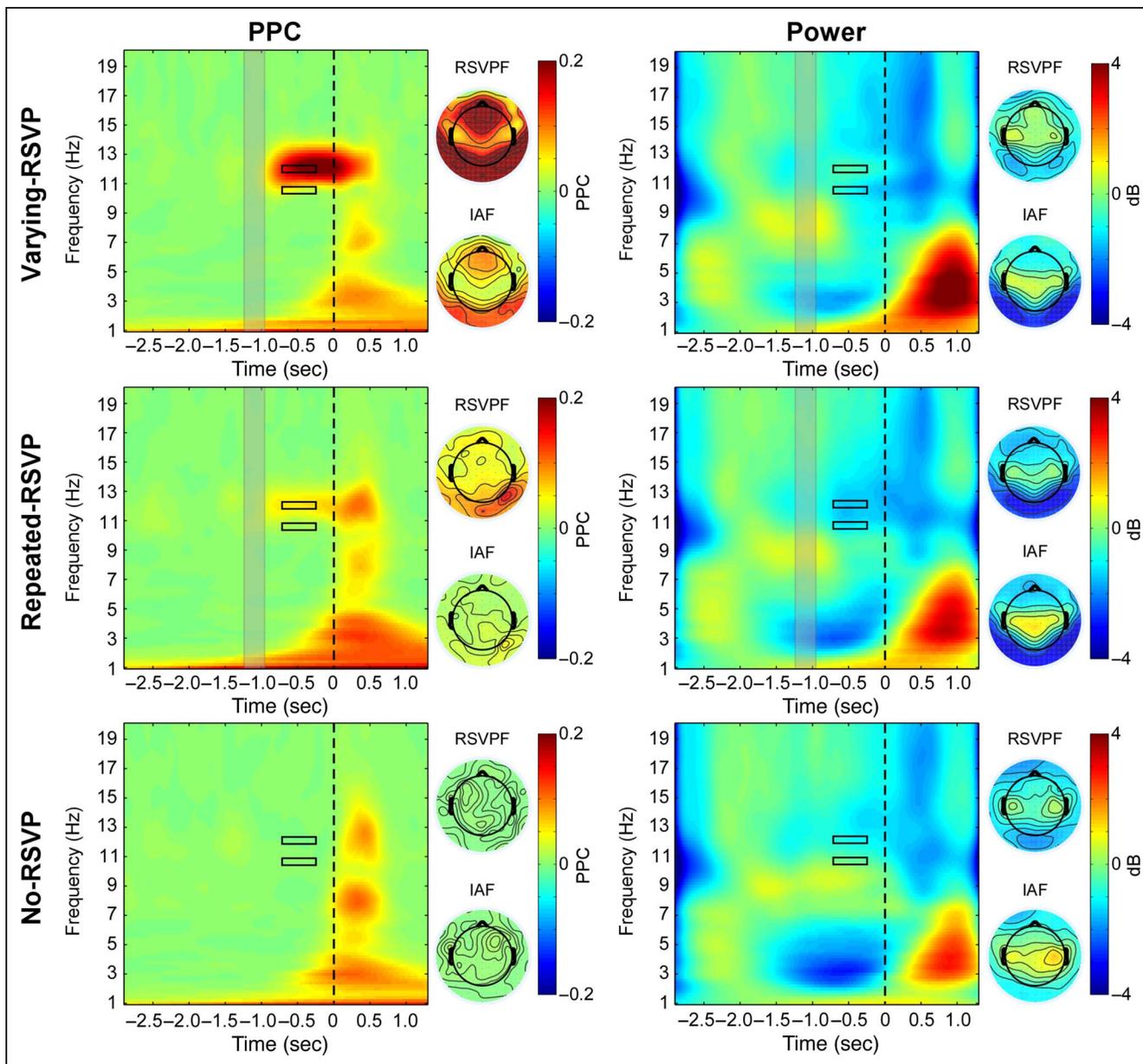


Figure 5. Time–frequency plots for Lag 3 trials for each condition showing activity averaged over all channels for the PPC (left) and power (right). Time zero refers to the presentation of the first target (T1). The onset of the RSVP stream (if present) ranged between -1.18 and -0.92 sec and is represented by a grayed out window. Topographical plots for the PPC and power are based on the time–frequency area indicated by the top black box for the frequency of the RSVP (RSVPF) and in the bottom box for the average IAF over participants.

and frontal right ROI ($t(16) = 1.8, p = .089$), which only showed trends in the same direction. In the No-RSVP condition, there were trends in the opposite direction (ROI middle parietal ($t(16) = 1.8, p = .095$), ROI parietal right ($t(16) = 1.9, p = .080$) and ROI occipital left ROI ($t(16) = 1.9, p = .078$), but no significant effects.

t tests between the conditions for the separate frequencies (IAF, RSVPF) revealed the same pattern as the main condition effect for the PPC; the Varying-RSVP and the Repeated-RSVP condition showed higher PPC compared with the No-RSVP condition and the Varying-RSVP further

showed a higher PPC compared with the Repeated-RSVP condition.

Power

For power (see Figures 6C, D and 7), the four-way repeated-measures ANOVA revealed a main effect of the factor ROI ($F(8, 128) = 17.2, p < .001$ ($\Sigma = 0.46$)). Two-way interactions were found for Frequency \times Condition ($F(2, 32) = 12.8, p < .001$ ($\Sigma = 0.74$)), Frequency \times ROI ($F(8, 128) = 3.4, p < .05$ ($\Sigma = 0.34$)), and Condition \times ROI ($F(16, 256) = 5.3, p < .005$ ($\Sigma = 0.28$)). In addition,

two three-way interactions were observed; Frequency \times AB \times ROI ($F(8, 128) = 3.4, p < .05$ ($\Sigma = 0.47$)) and Frequency \times Condition \times ROI ($F(16, 256) = 3.2, p < .01$ ($\Sigma = 0.42$)).

AB and power. The three-way interaction of Frequency \times AB \times ROI was followed up with repeated-measures ANOVAs for each ROI separately with factors frequency and AB. A main effect of Frequency was found in the middle parietal ROI ($F(1, 16) = 6.1, p < .05$) and a trend in the parietal right ROI ($F(1, 16) = 3.3, p = .089$), reflecting that power in the IAF was higher (i.e., the power reduction was smaller) than in the RSVP frequency in both regions. Furthermore, a Frequency \times AB interaction was found in the middle frontal ROI ($F(1, 16) = 6.1, p < .05$), the frontal right ROI ($F(1, 16) = 7.8, p < .05$), and a trend in the parietal left ROI ($F(1, 16) = 4.4, p = .053$). The

general pattern of this interaction was that in the RSVP frequency power was higher in noAB trials compared with AB trials in the middle frontal, the right frontal, and the left parietal ROI, but that in the IAF power was lower in noAB trials compared with AB trials in the middle frontal and the right frontal ROI (see Figure 7). In spite of the significant interaction, simple comparisons were not significant.

Condition and power. The three-way interaction of Frequency \times Condition \times ROI was also followed up with repeated-measures ANOVAs for each ROI separately, with factors Frequency and Condition. A main effect of Frequency was found in the middle parietal ROI ($F(1, 16) = 6.1, p < .05$) and a trend in the parietal right ROI ($F(1, 16) = 3.3, p = .089$), reflecting that power was larger in the IAF compared with the RSVP frequency

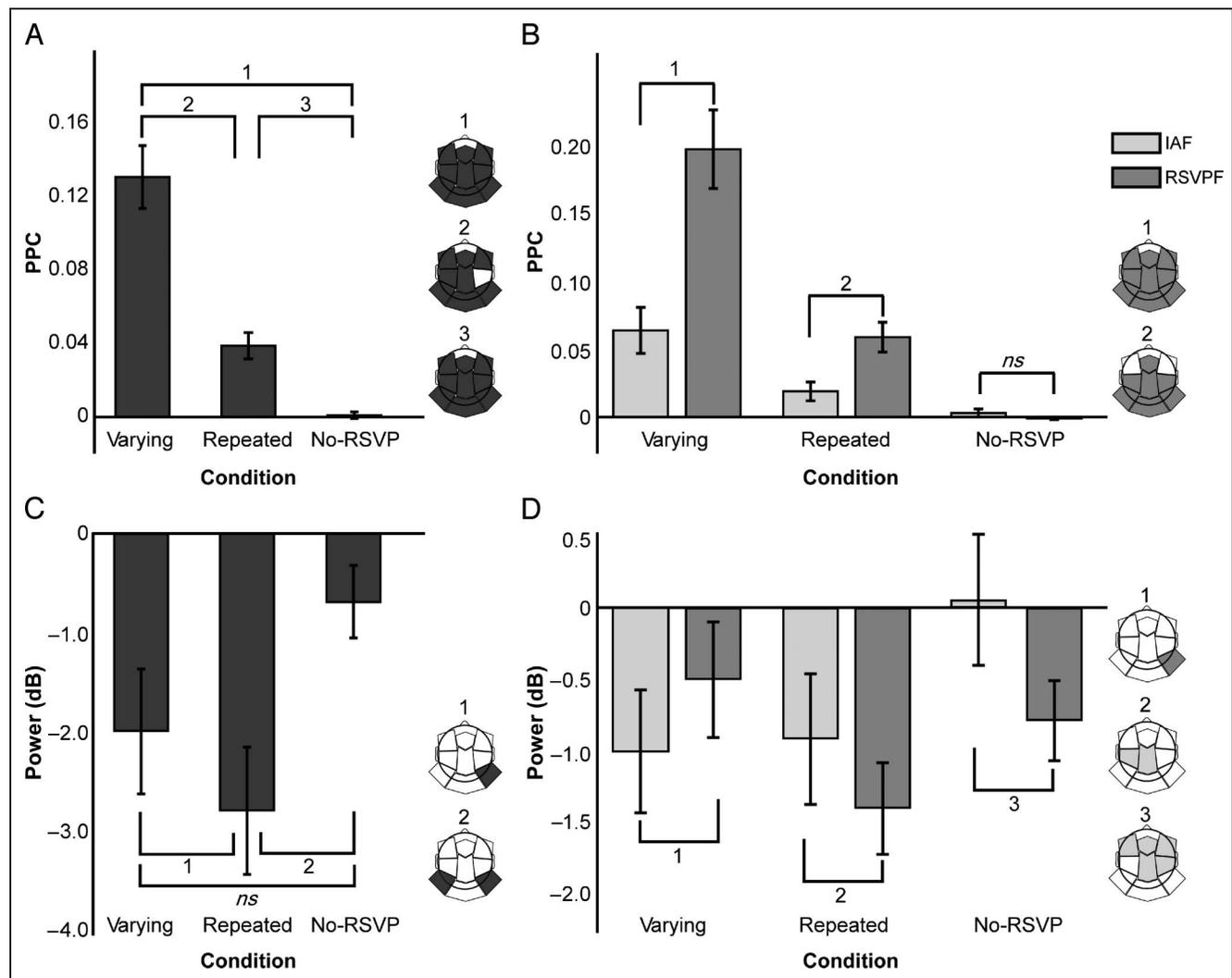


Figure 6. Effects of condition and frequency on PPC and power in Lag 3 trials over all ROIs averaged over the pre-T1 time window of interest from -0.7 to -0.2 sec. Significant main effects of condition are shown in A (PPC) and C (power). The interaction between condition and frequency is shown in B (PPC) and D (power). The head maps illustrate in which ROI a comparison was significant. For the interaction, the color indicates which frequency had the higher value. Numbers assign head maps to the corresponding comparison.

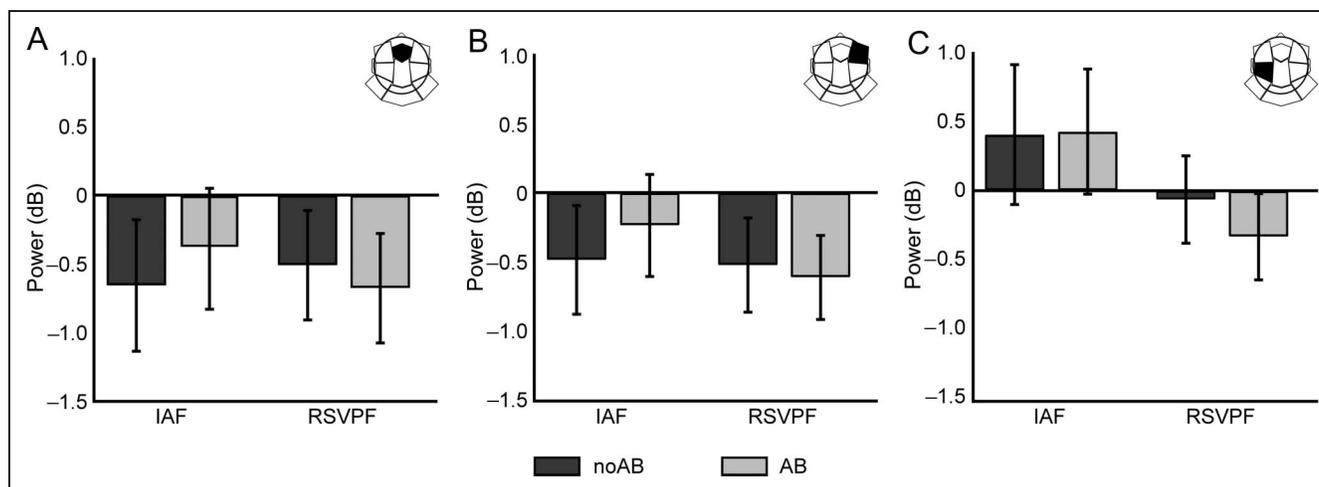


Figure 7. Effects of frequency and presence of an AB on power in Lag 3 trials for separate ROIs over the pre-T1 time window of interest from -0.7 to -0.2 sec. Significant interactions in power between frequency and the AB were found in the middle frontal ROI (A), the frontal right ROI (B), and the parietal left ROI (C). NoAB refers to the detection of both targets, and AB refers to the detection of the first target. RSVPF refers to the frequency of the RSVP (12 Hz).

in both regions. Moreover, a main effect of Condition was found in occipital left ($F(2, 32) = 6.2, p < .05$ ($\Sigma \geq 0.58$)) and occipital right ROIs ($F(2, 32) = 6.6, p < .05$ ($\Sigma \geq 0.71$); see Figure 6C). A trend was found in the frontal left ROI ($F(2, 32) = 2.5, p = .098$) and the middle occipital ROI ($F(2, 32) = 9.3, p = .079$). t tests of the effects revealed that power in the No-RSVP condition was significantly higher compared with the Repeated-RSVP condition ($t(16) \geq 3.7, p < .01$) in the occipital left and the occipital right ROIs. For the comparison between the No-RSVP and the Varying-RSVP condition, a trend in the same direction was observed in both occipital left ($t(16) = 1.8, p = .088$) and occipital right ROIs ($t(16) = 1.8, p = .088$). Power in the Varying-RSVP condition compared with the Repeated-RSVP condition was higher in the occipital right ROI ($t(16) = 2.4, p < .05$) and showed a trend in the same direction in the occipital left ROI ($t(16) = 1.8, p = .095$). Finally, an interaction between frequency and condition was found in all ROIs (all $F(2, 32) \geq 5.1, p < .05$ ($\Sigma \geq 0.66$); see Figure 6D). t tests between IAF and RSVP frequency for each condition revealed higher power for the RSVP frequency compared with the IAF in the Varying-RSVP condition in the occipital right ROI ($t(16) = 2.4, p < .05$). Trends in the same direction were found in the middle frontal ($t(16) = 1.8, p = .085$) and the occipital left ROI ($p = .065$). For the No-RSVP condition, the opposite pattern was found. Here power was higher in the IAF frequency compared with the RSVP frequency in all frontal, the middle parietal, and the parietal right ROIs (all $t(16) \geq 2.2$, all $p < .05$). A trend in the same direction was found in the middle occipital ($t(16) = 1.7, p = .099$) and the occipital right ROI ($t(16) = 2.0, p = .067$). The Repeated-RSVP condition also showed higher power in the IAF compared with the RSVP frequency, but only over the parietal left and

the middle parietal ROI (all $t(16) \geq 2.6, p < .05$). A trend in the same direction was found in the parietal right ROI ($t(16) = 2.0, p = .69$).

t tests between the conditions for the separate frequencies revealed in the IAF that the Varying-RSVP condition showed a larger negativity compared with the No-RSVP condition over parietal right and all occipital ROIs (all $t(16) \geq 2.2, p < .05$). A trend in the same direction was found in the middle frontal ($t(16) = 1.8, p = .089$) and frontal right ROIs ($t(16) = 1.8, p = .087$). The Repeated-RSVP condition also showed a larger negativity compared with the No-RSVP condition in middle frontal, frontal right, and all occipital ROIs (all $t(16) \geq 2.2, p < .05$). Trends in the same direction were found in the frontal left ($t(16) = 1.9, p = .080$) and the parietal right ROI ($t(16) = 2.1, p = .053$). No difference was found in the IAF between the two conditions containing an RSVP.

For the RSVP frequency t tests revealed a larger negativity in the No-RSVP condition compared with the Varying-RSVP condition in the frontal left ROI ($t(16) = 2.3, p < .05$). A similar trend was found in the middle frontal ROI ($t(16) = 1.8, p = .096$). A larger negativity was also found in the Repeated-RSVP condition compared with the Varying-RSVP condition in frontal left, middle frontal, parietal left, and all occipital ROIs (all $t(16) \geq 2.4, p < .05$). The Repeated-RSVP condition furthermore showed more negative power compared with the No-RSVP condition in the occipital left and the occipital right ROI (all $t(16) \geq 2.7, p < .05$). A similar trend was found in the middle occipital ROI ($t(16) = 2.0, p = .064$).

DISCUSSION

With this study we aimed to clarify whether the pre-target modulations in the alpha band previously observed in the

AB paradigm can be ascribed to endogenously generated alpha activity or to ssVEP-related alpha band responses. To this end, we studied three versions of the AB paradigm that varied with regard to the presence and content of a pre-target RSVP stream. Where present, the RSVP stream contained either varying distracters or a single distracter that was repeatedly presented. We observed that the presence of a pre-target RSVP stream negatively affected the identification performance for the first target. Its content, on the other hand, was linked to the identification performance of the second target, with the varying content being detrimental to T2 identification rates. EEG results indicated that pre-target RSVP streams were related to a widespread increase in phase consistency across trials in the time range before T1 presentation. This consistency was overall strongest at the RSVP frequency and relatively stronger for the varying as compared with the Repeated-RSVP stream. Furthermore, in the RSVP frequency for the pre-target interval, a widespread decrease in power was observed. This decrease was strongest in the Repeated-RSVP condition. In the IAF, a pre-target power decrease was also observed, which was limited to the two RSVP conditions. Finally an interaction between frequency and AB was found in which high power in the RSVP frequency was related to noAB trials and high power in the IAF to AB trials.

Behavior

T1 performance was negatively affected by the presence of a RSVP stream, but the content of the RSVP stream made no difference. This detrimental effect did not however spill over to T2 performance, where the content and not the presence of the RSVP stream was associated with the largest impairment. This behavioral pattern fits with earlier results by Visser and Ohan (2007), who found that forward masking, that is, presenting a distracter before T1, makes detection of T1 harder, which in turn negatively affects detection of T2. However, when T1 was again followed by a mask (backward masking), the effect on T2 was shown to be negated.

Although all three conditions were identical from the onset of T1, T2 performance varied across conditions, indicating that the pre-T1 period affects T2 performance. The RSVP stream with varying contents negatively affected T2 performance compared with the Repeated-RSVP and the No-RSVP condition. This suggests that the attentive processing of the RSVP stream and not its mere presence is what is detrimental to T2 processing. Moreover, a lag effect was found for T2 identification for all three conditions, confirming robust AB effects. This is in line with previous research on the AB (Visser & Ohan, 2007; Visser, Bischof, & Di Lollo, 2004; Ward, Duncan, & Shapiro, 1997; Raymond et al., 1992; Broadbent & Broadbent, 1987). In contrast to our expectations, we did not find an interaction between lag and condition. That is, T2 performance in the Varying-RSVP condition was similarly impaired

at both the short and the long T2 lag as compared with the Repeated-RSVP and No-RSVP conditions. The most likely explanation for the absence of this interaction is a higher task difficulty compared with the generally used AB paradigms because of the spatial frequency and luminance manipulation of the visual stimuli and the increased presentation speed. Greater task difficulty has been reported to increase the duration of the AB (Visser et al., 2004). In our study, this would in particular have applied to the Varying-RSVP condition where, as a consequence, the duration of the AB would have been increased, and performance thereby still affected by the AB at Lag 7. The outcome being that T2 performance in the Varying-RSVP condition did not recover to the level of the other two conditions within the covered time range.

Although the observed AB effects were independent of condition, the possibility remains that results are to some degree contaminated by a stimulus confound, that is, the presence versus absence of the RSVP stream. Our approach to control for this potential confound was to include the Repeated-RSVP condition, which introduced a repeated stimulation while at the same time minimizing distraction due to the repeated stimulation. An alternative to this approach could have been to manipulate the rate of the RSVP stream and by so doing keep it close to or away from the IAF. The problem with this approach however is that this would have created its own confound, as target identification is known to become more difficult with the increase of RSVP rate (Keyesers, Xiao, Foldiak, & Perrett, 2001). Moreover, if one were to keep constant the rate of target-mask pairs while manipulating only the rate of the distracter stream, T1 would be presented at different phases of the distracter-induced oscillation, which could affect its perception (Thorne & Debener, 2013; Hanslmayr et al., 2011; Busch, Dubois, & VanRullen, 2009; Mathewson, Gratton, Fabiani, Beck, & Ro, 2009).

Coherence during the Task

A clear increase in PPC in the RSVP frequency was present in both RSVP conditions and absent in the No-RSVP condition. The intensity of the PPC varied with the RSVP content, with the Varying-RSVP condition showing a higher PPC. In the Varying-RSVP condition, the physical features of the visual stimuli change, but so too does their meaning. In the Repeated-RSVP condition, in contrast, both the features and the meaning attached to the features are unchanging. PPC in the RSVP frequency could therefore reflect either physical differences or depth of processing differences. Both RSVP conditions also showed an increase in PPC in the IAF. This increase was however much smaller compared with the increase in the RSVP frequency. As will be discussed in detail in the following, this could be because of the entrainment in the RSVP frequency, for example, either through smearing in the

frequency domain or because of a broadband neuronal entrainment.

We took care to present our stimuli outside the expected mean IAF; however, measured IAF still varied considerably. So although the frequency resolution of the wavelet resulted in only a small overlap between the average IAF of the sample and the RSVP frequency, for the individual IAFs, the overlap could still have been smaller (although, importantly, also larger). In consequence, it cannot be ruled out that some of the ssVEP activity is reflected in the IAF data and vice versa.

Previous research has shown that flickering stimulation in the alpha frequency range tends to entrain activity at the IAF. That is, the ssVEP response is not restricted to the stimulation frequency but may also be evident, sometimes even stronger, in the IAF (Schwab et al., 2006; Gebber, Zhong, Lewis, & Barman, 1999). Zauner et al. (2012), however, take a slightly different view on this. They similarly observed that phase-locking responses in an RSVP task were not restricted to the stimulation frequency. To account for this, they suggested the responsiveness of alpha activity to entrainment to be a broadband phenomenon, rather than the narrowband response of a single frequency.

Coherence and the AB

No changes in PPC were found related to the occurrence or absence of an AB. This is in contrast to a recent publication by Zauner et al. (2012), which reported a relationship between phase entrainment and the occurrence of an AB. Specifically, Zauner and colleagues found a relationship between the occurrence of an AB and a nonuniform distribution of phase at presentation of T2. Furthermore, they found a significantly higher ITC around T2 for AB trials compared with control trials, but not compared with noAB trials. Why in the current study no coherence differences between AB and noAB trials were found could be because of the different time window of interest, as we focused only on the pre-T1 period. Furthermore, the focus in the current study was on investigating the IAF and RSVP frequencies separately, whereas Zauner and colleagues studied the alpha band as a whole. Whether these methodological differences indeed account for the differences in results requires further research.

Power Changes during the Task

Power results did not follow the PPC pattern. This finding is in line with previous research showing that the flickering stimulation increases intertrial phase locking but not single-trial power (Moratti, Clementz, Gao, Ortiz, & Keil, 2007). It also indicates that the two variables reflect different aspects of information processing (Makeig, Debener, Onton, & Delorme, 2004). Moreover, not only did the power effects not follow the pattern of PPC effects, but

they were also different for the IAF as compared with the RSVP frequency. More precisely, a clear decrease in power irrespective of condition was evident for the RSVP frequency, whereas for the IAF a decrease in power was only present in the two RSVP conditions. Additionally, the power difference between the IAF and the RSVP frequency was present in one or more ROIs in all three conditions. This pattern of results strongly suggests that, in this study, activity at the IAF and at the RSVP frequency was successfully separated and, importantly, therefore reflects separate processes (i.e., endogenous and RSVP-induced alpha).

A power decrease (also known as event-related desynchronization or ERD) in the alpha band before stimulus presentation has been suggested to reflect attentional processes. Alpha ERD has also been related to the recruitment of a larger network or more cell assemblies for information processing (Pfurtscheller & Lopes da Silva, 1999). Factors that have been identified to influence the size of the ERD are task complexity, efficiency of task performance (Dujardin et al., 1993; Boiten, Sergeant, & Geuze, 1992), and effort invested in and attention paid to the task (MacLean & Arnell, 2011; Defebvre, Bourriez, Destee, & Guieu, 1996; Derambure et al., 1993; for a review on ERD, see Pfurtscheller & Lopes da Silva, 1999). The decrease found in the current experiment likely reflects a preparatory power decrease in particular in the upper alpha band. This decrease occurs in expectation of the targets but is not entirely independent of the presence of an RSVP stream. According to the interpretation and findings outlined above though, the relatively smaller power reduction in the Varying-RSVP condition as compared with the Repeated-RSVP condition seems contradictory. Another line of research might offer an explanation here. Müller and colleagues reported in a series of studies that attending to flicker stimulation or RSVP streams results in increased ssVEP responses as compared with unattended conditions (Müller et al., 2003; Müller & Hübner, 2002). Given that the stimulus stream in the Varying-RSVP contained relevant information whereas in the Repeated-RSVP condition it did not, the degree of attention to the Varying-RSVP stream needed to be higher than to the Repeated-RSVP stream. In this scenario, the resulting attention-related increase in ssVEP power for the Varying-RSVP condition would have been superimposed on the preparatory upper alpha band ERD, and the net result would be an attenuation of the power decrease in the Varying-RSVP condition.

Power also decreased in the IAF, but here only for the two RSVP conditions. Moreover, in contrast to the RSVP frequency data, the decrease did not differ between RSVP conditions. This likely reflects that in the presence of the pre-target RSVP stream preparation for identifying the targets was intensified. This resulted in a stronger preparatory desynchronization, evident in both the broader frequency range affected and the higher amplitude. The modulation in preparation seems however to depend on the presence and not the content of the pre-target RSVP

stream, as the latter did not affect the power decrease in the IAF.

Power and the AB

There was no indication of a direct relationship between condition and the AB in the power data. However, power in the IAF was lower in noAB trials compared with AB trials in middle frontal, right frontal, and left parietal ROIs. These IAF results are in line with earlier findings of Kranczioch et al. (2007), who found significantly smaller power at 10 Hz for noAB as compared with AB trials in a similar time range before T1. However, because of their choice of a 10-Hz RSVP frequency, the authors were not able to determine if this effect was because of RSVP-induced alpha or endogenous alpha. The present findings now point at an IAF origin for this effect and suggest that being in an attentive state even before the arrival of the targets helps to overcome the AB. They also suggest that the strength of the attentive state varies irrespective of the amount of distraction in the time window before target presentation.

Mechanistically alpha has been described as the inhibiting frequency (Klimesch et al., 2007). In line with this idea, Hanslmayr and colleagues (2011) see alpha as a gating frequency of incoming information. They suggest that a configuration of high alpha amplitude, negative phase, and high cross-electrode phase coupling is the signature of an internal oriented state, in which external information is less likely to be processed well and which should result in an AB. The opposite configuration of amplitude, phase, and cross-electrode phase coupling is seen as characterizing an external state that is optimal for processing incoming information and avoiding an AB. The current result fits in part and adds to this theory, as it points to high amplitude in the alpha range, but in particular at the IAF, as being detrimental to detecting both targets.

The interaction between AB and frequency indicated that for the RSVP frequency, in contrast to the IAF, noAB trials were associated with higher power than AB trials. This apparent contradiction with the theory of Hanslmayr and colleagues (2011) could be solved by assuming that the high externally generated (i.e., RSVP-induced) alpha can occur in parallel to reduced endogenous alpha power. Both would index the proposed external brain state that results in escaping the AB. This scenario would also be in line with the idea that attention to the stimulus stream, that is, externally directed attention, increases the amplitude at the presentation frequency (Müller et al., 2003; Müller & Hübner, 2002).

Higher alpha power (10–12 Hz) in noAB as compared with AB trials was also observed in a study by MacLean and Arnell (2011). MacLean and Arnell suggested this would reflect that less anticipatory attentional investment (i.e., less ERD) is beneficial for detecting both targets. This conclusion is in agreement with overinvestment theories of the AB, which state that when

too much attention (or cognitive resource) is invested in processing distracters, insufficient (attentional) resources remain to process T2 (Olivers & Nieuwenhuis, 2006; Shapiro, Schmitz, Martens, Hommel, & Schnitzler, 2006). However, in contrast to this study, MacLean and Arnell focused on the period before the onset of the RSVP stream, which strongly limits the comparability of the two studies.

As mentioned before, attending to flickering stimuli such as an RSVP stream has been linked to an increase in alpha power at the stream's presentation frequency (Müller & Hübner, 2002). In this study, RSVP-frequency power for the Varying-RSVP stream was found to be higher than for the repetitive RSVP stream. This is consistent with the idea that deployment of attentional resources is dependent on the stream's content. If interpreted along the same line of argument, the pattern of results for the AB effect suggests that when an AB occurs participants tended to have paid less attention to the RSVP stream as compared with when participants escape the AB, that is, when both T1 and T2 are identified.

The conclusion that reduced attention to the RSVP stream is linked to T2 being missed is however an obvious discrepancy with overinvestment theories of the AB and to empirical evidence supporting these theories. These results would be reconciled if the largest influence on the overall amount of attention paid to the RSVP stream is the content of the stream. The condition effects observed for PPC, power, and T2 performance support this assumption. In addition, RSVP power appears to be influenced by another factor, as becomes evident when sorting trials based on T2 detection. We suggest that the effect of this factor is not as strong as the content effect; it might in fact just be an epiphenomenon of what we propose to be reflected in the modulation of the IAF, namely, the strength of a task-oriented, attentive state. That is, although the attentive state helps to keep attention on the task (i.e., detecting T1 and T2 while not being distracted by the RSVP stream), it also leads to an involuntary enhancement of the initial response of the visual system to the RSVP stream. This enhancement however does not seem to affect the overall positive effect of being in a more attentive state. Note that this interpretation also fits with the notion of an internal state in which attention is more focused inward and an external state in which attention is focused outward, for example, on the RSVP stream, as proposed by Hanslmayr and colleagues (2011). We further suggest that, although the modulations of the response of the visual system to the RSVP stream do not affect T2 performance, the amount of attention paid to the stream because of its content does. In detail, the attentive state—reflected in low IAF power—needs to be strong enough to counteract distracters that receive a high amount of attention, which is the case for a Varying-RSVP stream. This assumes that the strength of the IAF-related process varies independently of the presence and content of the RSVP stream. The situation where

the IAF process is strong enough to counteract the distracters will therefore be less likely when more attentional resources are being invested in processing the distracting stream. In consequence, the AB will increase if processing a distracter stream is highly demanding.

Recent research provides evidence of an alpha frequency top-down process, in which the pFC at least partly modulates posterior sensitivity to stimuli (Haegens, Handel, & Jensen, 2011; Rajagovindan & Ding, 2011; Sauseng, Feldheim, Freunberger, & Hummel, 2011). Interestingly, this is not only in line with our interpretation of the relationship between IAF and RSVP frequency findings but also with the observation that on a descriptive level the IAF effect was more pronounced at frontal left and frontal right ROIs whereas the RSVP effect was more pronounced at the parietal left ROI. Taken together, we suggest that the pattern of AB effects in this study is related to the activity of a top-down process and its influence on visual processing areas. Performance is affected by the strength of the top-down process and the amount of attention that needs to be invested in processing the ongoing distracter stream.

Conclusion

Our findings suggest that the mere presence of an RSVP stream does not increase the likelihood of an AB when compared with a condition without an RSVP. The content of the RSVP does however have an influence on the detection of T2. This appears to be because of an increase in attentional resources required to process an ever-changing stream of distracters as compared with a stream where the content repeats itself. Attention to the stimulus stream was reflected in both intertrial phase locking and modulations of power reductions that cover not only the presentation frequency of the RSVP stream but also the IAF.

An interaction between the occurrence of an AB and the frequency at which power was measured indicates a different role for endogenous and RSVP induced alpha in the AB. We suggest that IAF or endogenous alpha power relates to a top-down process that influences whether an AB will occur or not. As a side effect, it also affects the response and excitability of the visual processing areas, although this does not affect the AB. What seems to influence the AB is the balance between the strength of the top-down process and the amount of attention necessary for processing distracting information.

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Notes

1. The minimum criterion was five trials per condition; however, the lowest number of trials for a condition that went into the analysis was nine trials.
2. As to be expected, the results in the -700 to -200 msec time window are similar in this (excluded) fourth condition compared with the No-RSVP condition.
3. On the basis of the properties of the Gaussian curve, the contribution of post-T1 onset activity to the derived signal at time window offset (200 msec before T1 onset) has an upper limit of 15%, and this proportion in reality is much smaller when taking into account, first, the delay between T1 onset and actual neural responses to T1 onset, and second, that the wavelet itself is of lesser size than the full Gaussian envelope with which it is windowed.
4. As the PPC is a fairly new method to control for an imbalance in trial numbers, we performed two parallel analyses with the traditional ITC. In the first analysis, all conditions had an equal number of trials. In the second analysis, only participants with 20 or more trials in all conditions were included. When controlling for an equal number of trials, ITC results were similar to the results with the PPC. When ensuring a minimum of 20 trial numbers in all conditions, we found similar effects for ITC despite the 23% reduction in participants (four participants).

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