In pursuit of visual attention: SSVEP frequency-tagging moving targets

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Abstract

Previous research has shown that visual attention does not always exactly follow gaze direction, leading to the concepts of overt and covert attention. However, it is not yet clear how such covert shifts of visual attention to peripheral regions impact the processing of the targets we directly foveate as they move in our visual field. The current study utilised the co-registration of eye-position and EEG recordings while participants tracked moving targets that were embedded with a 30 Hz frequency tag in a steady-state evoked potentials paradigm. When the task required attention to be divided between the moving target (overt attention) and a peripheral region where a second target might appear (covert attention), the Steady State Visual Evoked Potentials elicited by the tracked car at the 30 Hz frequency band were significantly lower than when participants did not have to covertly monitor for a second target. Our findings suggest that neural responses of overt attention are reduced when attention is divided between covert and overt areas. This neural evidence is in line with theoretical accounts describing attention as a pool of finite resources, such as the perceptual load theory. Altogether, these results have practical implications for many real-world situations where covert shifts of attention may reduce visual processing of objects even when they are directly being tracked with the eyes.

Keywords:

SSVEP

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Attention

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Smooth pursuit

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1. Introduction

In daily life we experience a large variety of situations in which we need to visually track multiple objects at the same time, for instance when crossing a busy street, monitoring the safety of children playing in playgrounds, locating an errant spouse in a bustling shopping centre, etc. In these situations we rely on the division of visual attention as we monitor both moving and stationary objects across time, often rapidly switching between attending to targets through direct eye-movements or through our peripheral visual fields. The need to modulate our attention arises from inherent limitations in our capacity to attend to the broad array of stimuli our senses may provide to us at any one moment (Kahneman, 1973; Lavie et al., 2004). The Perceptual Load Theory advanced by Lavie and others conceptualises attention as a limited pool of resources that we are able to devote to the processing of targets and distractors in various environments. The balance of our attention directed to spatial locations at any given moment is thus related to the perceptual load of the tasks being concurrently performed (Lavie, 1995, 2005, 2010; Lavie & Tsal, 1994). The way in which the brain modulates visual input through attention has additionally been conceptualised as a mechanism that decreases the salience of distractors by reducing the neural sensitivity to unattended stimuli so that attended stimuli experience less competition in terms of processing (Moran & Desimone, 1985; Reynolds et al., 1999; Sundberg et al., 2009).

When applied to contexts and tasks that require the visual analysis of complex scenes that involve both moving and stationary objects, these theories suggest a modulation of attention that depends on the requirement of attention to be either divided or singularly focused.

Part of such a dynamic involves attention directed to what we are directly foveating on (overt attention), as well as attention directed to areas outside our foveal fields in our parafoveal or peripheral visual fields in the form of covert attention (Posner, 1980). While overt visual attention can be indexed through the recording of eye-position during various tasks, covert shifts of attention are by their nature often not accompanied by explicit behavioural measures and must be measured indirectly through analyses of reaction time in paradigms involving cueing to extra-foveal spatial locations compared to either an un-cued or an incorrectly cued location (Posner, Nissen, & Ogden, 1978; Posner, Snyder, & Davidson, 1980).

Aligning with the view of attention to be a limited pool of resources, some studies have suggested that when covert attention is directed to spatial areas in the periphery there is a decrease in overt attention directed towards foveated stimuli (Mishra et al., 2011; Zhou, et al., 2017). However, competing evidence has suggested that both covert and overt visual attention may be deployed simultaneously in parallel in paradigms involving dual tasks without a notable decrease in performance (Heinen et al., 2011; Ludwig, Rhys Davies, & Eckstein, 2014). The nature of the tasks in such paradigms is likely to play a critical role in how attention might be divided between overt and covert monitoring during analysis of objects in the visual environment. In the case of complex scenes this may involve a selection of what targets to monitor overtly with the eyes and which to monitor covertly through the shift of peripheral visual attention. What is yet to be clarified is how overt attention directed to a moving object is influenced by additional requirements to monitor other spatial locations with covert visual attention. This question is the basis of the current study.

While various behavioural tasks have been used to investigate the deployment of both overt and covert visual attention, it is possible to index the relative recruitment of both forms of attention by recording the neural responses in electroencephalographic (EEG) recordings to the flickering of stimuli presented in different spatial locations of the visual field. While

the early occipital lobe responses to this flickering in a systematic way, the strength of this responses is strongly modulated by whether the flickering objects/regions are being attended to or not, with larger responses to attended stimuli compared to unattended stimuli (Andersen & Mueller, 2010; Kim et al., 2007; Morgan, Hansen, & Hillyard, 1996; Mueller, Teder-Sälejärvi, & Hillyard, 1998; Störmer et al., 2013; Toffanin, et al., 2009). Known as Steady-State Evoked Potentials (SSVEP), this technique offers an advantage over the measurement of behavioural responses, as it can capture the time-course of shifts of attention, contrasting with behavioural responses which, while influenced by attention, constitute the end-point of a chain of processes. Indeed, an important benefit of the SSVEP approach is that it does not require a specific behavioural response, making it well-suited to investigate covert shifts of attention that take place without behavioural markers (Norcia et al., 2015; for review). Recent studies investigating attention allocation during smooth-pursuit paradigms have found clear neural responses to flickering stimuli in both peripheral regions (Chen et al., 2017a) and as a general flickering background stimulus (Chen et al., 2017b), with the latter suggesting the neural responses during smooth-pursuit to be larger than when the eye-position is fixed. However, to our knowledge this paradigm has not yet been used to investigate overt visual attention during the tracking of moving objects or how it is affected by task-related shifts of covert attention.

Applied to the question of how visual attention is affected by the need to attend to peripheral areas while simultaneously tracking a moving object, the SSVEP technique offers a means of determining whether such covert shifts of attention decrease the sensitivity to the moving foveal target as might be predicted if a limited pool of visual attention leads to a sacrifice of overt visual attention when deploying covert attention. In order to investigate this question while maintaining systematic control over low-level visual properties, the current study combined eye-position recordings with an SSVEP paradigm, measuring the neural

responses to the flickering of targets as participants followed them with their eyes as they moved across a computer screen. The task consisted of either overtly tracking one target and judging when it entered a specific portion of the screen, or overtly tracking one target while also covertly monitoring for the appearance of another target that might appear in the trial at a specific location. The neural responses to the foveally-tracked target thus formed an index of overt attention, which would be significantly reduced, in the case of shared and limited pool of attentional resources, when the participants covertly monitored for the appearance of second target.

2. Methods

The Human Ethics Committee at the University of Fribourg approved the methods and procedure used in this study.

2.1. Participants

22 participants were tested in the current study. 4 participant datasets were excluded due to insufficient trial numbers to form a meaningful condition average (see section 2.3 for processing details), and one dataset was excluded due to extreme alpha (8-12 Hz) contamination during the trials. Datasets were analysed from the remaining 17 participants (13 females, 17 right-handed), aged between 19 and 44 years (mean age = 26.5 years, SD = 7). All participants had normal or corrected-to-normal vision, and gave their informed consent before participating in the study. Participants were offered 50 CHF for their time or course participation credits.

2.2. Stimuli and procedure

Participants were instructed to follow a moving target as it moved across a computer screen and to press a keyboard button when the target entered a spherical "goal" portion of the screen. The targets consistently travelled along a diagonal path from the top-left part of the screen to bottom-right goal section (see figure 1) at a speed of 3.75 deg/s. The target

stimuli consisted of a black and white rectangle (1.05^0 x 2.10^0 visual angle) checkerboard pattern alternating at a consistent rate of 30 Hz against a white background. The 30 Hz flicker created the frequency tag used for the subsequent EEG analysis of visual attention. Two experimental conditions were created by manipulating what participants expected to see in the trials. In one condition block, participants were instructed that only one target would travel across the screen in each trial, and that they should press the keyboard button when it reached the goal area. In the other condition block, participants were instructed that a second target might appear while the first target was still travelling across the screen (occurring 2100 ms after the onset of the trial, and in 2/3 of the trials in this condition). Participants were instructed that if a second target did appear they were to then track that second target with their eyes and press the button when the second target reached the goal area. This was to provide a task-related division of attention, while balancing all low-level visual properties between the conditions up until the appearance of a second target in the periphery. Participants were informed at the beginning of each condition block whether to expect either only one or more than one target, creating two experimental conditions; an undivided attention condition and a divided attention condition. The time-window leading up to the possible presentation of a second target thus formed the period of interest for our analysis, where shifts of attention relating to participants condition-related expectations were predicted to occur.

There were 204 trials in total, with 102 in each of the divided and undivided attention conditions. The trials were divided into 4 alternating homogenous blocks, and the presentation order of these blocks was counter-balanced to avoid fatigue or order-effects by creating two block-orders presented to two participant groups.

The experimental trials began with a fixation cross in the top left corner of the screen, corresponding to the region where the target would initially appear. When participants fixated

on this cross area (1.3^0 x 1.3^0), the cross would disappear and the target would appear approximately 300 ms later. The trials ended when the participant made their decisions relating to the targets interfering the goal area by making a keypress.

The experimental stimuli were presented on a 24 inch VIEWPixx/3D monitor (1920 x 1080 pixels, 120 Hz refresh rate) at a distance of 75 cm, and presented through Experiment Builder (v1.10.1630) software.
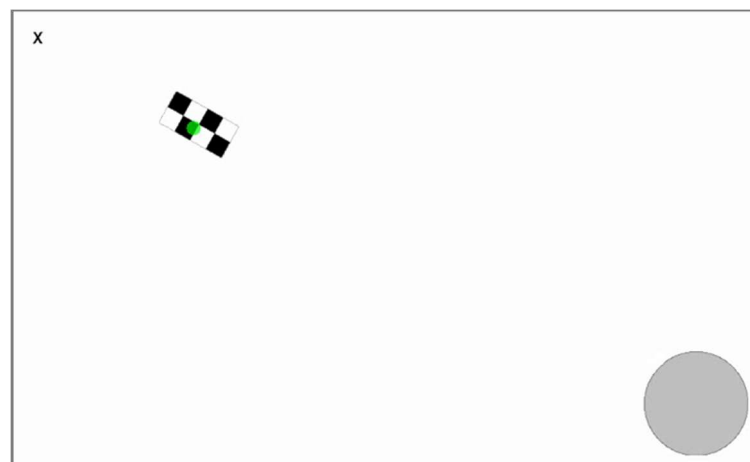
Please insert Figure 1 about here

Figure 1. *Trial example. Targets emerged from the left side of the screen (denoted by "x") and travelled across the screen. Participants pressed a button when they judged the target to be fully within a circular goal region. The green dot denotes the participant gaze-position in the trial sample.*

2.3. Eye-movement recording and processing

Eye-positions were recording through a desktop-mounted Eyelink 1000 monocular (left) eye-tracker sampling at 1000 Hz. Calibrations of the eye-tracker (13-points) were performed at the beginning of the experiment and after breaks in the trials. The onset of a trial was triggered by a fixation in a specified region in the top left part of the screen; if this was not fixated upon within 4 seconds after presentation then a re-calibration sequence was entered, ensuring effective calibration throughout each of the trials.

The trials began with the flickering targets emerging near the upper-left portion of the screen 300 ms after trial onset. The early part of the trials was characterised by the target stimuli approaching and passing the participants' fixated gaze, and the subsequent orienting of their gaze to these moving targets through catch-up saccades. This orienting phase generally took approximately 500 ms before participants were able to align their smooth-pursuit eye movements with the movement of the targets. To allow for this, a time-window of analysis for eye-gaze and EEG was created that excluded the first 700 ms of the trials.

The x and y gaze coordinates of the participants in the trials were exported and analysed to ensure that the flashing target targets were directly foveated by the participants during a 1000 ms period immediately preceding the time at which the onset of a second target would occur. Trials were rejected if the participants were not directly foveating the targets for over 95% of this 1000 ms time period (allowing for transient loss of foveation and eye-blinks). A 1000 ms period of interest was chosen for two reasons: 1. It is preceding the likely appearance of the second target so we expect relevant processes associated with attentional shifts to occur in this period, and 2. This period starts after the catch-up saccade and when the smooth-pursuit is consistently initiated across trials. To ensure a reliable average, a critical threshold of 25 accepted trials was applied, which led to the rejection of 4 participants due to insufficient trials. The SSVEP technique has been found to yield a high signal to noise ratio, with analyses involving known oscillations (frequency tags) reliably measuring visually-entrained EEG responses from as little as 10 artefact-free trials (Miskovic & Keil, 2014), and from 15 trials in a face-detection paradigm using sweep SSVEP (Ales et al., 2012). The average number of accepted trials in the divided and undivided attention conditions in the current study was much higher than this minimum threshold, with 65 and 60 accepted trials, respectively (see supplemental material, figure 1). Because the co-registration of EEG and eye-movements in the current study required rejection of EEG epochs where eye-gaze was

outside of the stimulus regions, the trial rejection rate was considered in the experimental planning, with 102 trials per condition being chosen to allow for a large number of rejected trials, equating to an average rejection of 39% of all trials. Participants' eye-movements were monitored during the testing session by the experimenters to ensure they understood and followed the task instructions. Participants initiated a saccade to the second target within 351 ms (SD=70 ms) of their appearance in relevant trials, suggesting an adherence to the task instructions.

After the trial exclusion process, the remaining trials were analysed to determine whether there were systematic differences in eye-position between the divided and undivided conditions. Repeated measures two-tailed permutation t-tests using a tmax statistic (Blair & Karniski, 1993) were performed at each time point in the period of interest for the X and Y eye-position data, which did not reveal significant patterns of difference between the conditions. This was also performed on data that indexed the absolute distance (in degrees of visual angle) between the participants' eye-positions and the centre of the target at each time point, which similarly yielded no distinct pattern of difference.

The participants' accuracy at tracking the targets can be seen in figures 2a, 2b, and 2c, which depicts the distances at each time point that the participants' eyes were from the target centre in XY co-ordinates and in absolute Euclidean distance, measured in degrees of visual angle. A value of zero would therefore correspond to the centre of the target in either the X or Y plane. The high target-tracking accuracy in the current study is consistent with previous studies utilising targets of predictable speeds and (De Brouwer et al., 2002 for review), and is in line with the results of a previous studying showing that following the centre of a moving target facilitates the allocation of attention to peripheral locations when multiple objects are present (Fehd & Seiffert, 2010).

The average distance from target centre for the undivided and divided attention conditions were -0.05^0 and 0.01^0 respectively for the X positions, and 0.03^0 and 0.02^0 for Y positions. For reference, the length and width of the target stimuli were 2.2^0 and 1.1^0 respectively. The average precision across the critical time-period is illustrated in figure 2d, which represents the average eye-positions on the target throughout the period of interest for the divided and undivided conditions.
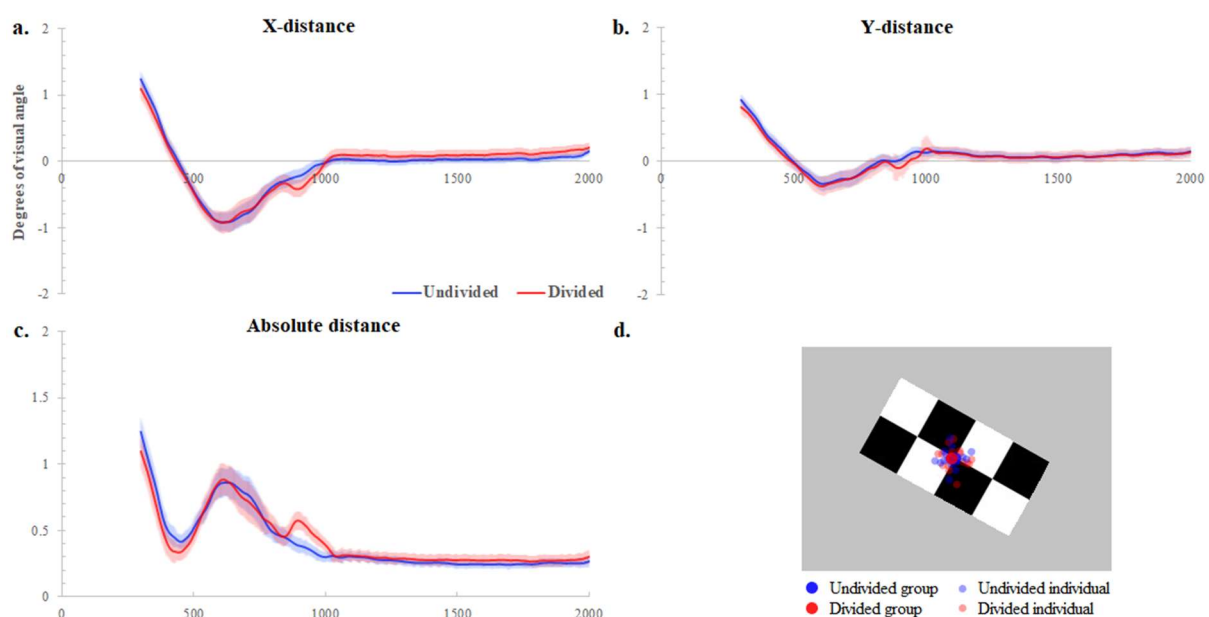
Please insert Figure 2 about here

Figure 2. *Eye-gaze distance from target centre (at 0, measured in degrees of visual angle) for x (a), y (b), and absolute (c) co-ordinate dimensions from the onset of the target target until immediately before the possible appearance of a second target (standard error shaded). Figure 2d depicts the condition average eye-positions (solid large blue/red) relative to the targets throughout the 1000 ms interest period, as well as the individual participant averages (faded small blue/red).*

2.4 EEG recording and processing

Electrophysiological responses were recorded through a Biosemi Active-Two amplifier system, using 128 Ag/AgCl electrodes sampling at 1024 Hz. Additional electrodes were placed at the outer canthi and above of each eye, to register ocular movements and blinks. Electrode impedance was kept in between ±25 kΩ. EEG data was processed offline through EEGLAB (14.1.0b) running in the MATLAB 2016B environment. After an initial bandpass filtering process (0.1-75 Hz), epochs of 5000ms duration were created, beginning at a -1000ms baseline period at the onset of the trial. To isolate and remove blink and eye-movement distortions the epochs were subjected to Independent Component Analysis (ICA) (Delorme & Makeig, 2004). Blink and saccadic distortions were consistently observed and removed from the data, as well as slow drift in EEG corresponding to smooth pursuit activity (see supplementary material, figure 2). However, in a number of datasets this slow drift was not able to be isolated through ICA, even though a clear drift could be observed in the raw data. This was, however, not problematic in the current experimental design, as the slow drift was not related to frequencies overlapping the 30 Hz frequency tag utilised in the study (see supplementary material, figures 2a and 2b for the frequency response of the saccadic and smooth pursuit distortions). This is also true for the blink and saccade artefacts (Perlstein et al., 2003), however they were removed as a matter of convention.

The EEG was subsequently re-referenced to a common-average reference, and epochs noted for rejection in the eye-gaze analysis were removed from statistical analysis, leaving only epochs where the participants were directly foveating the targets more than 95% of the critical 1000 ms period. Frequency values were measured relative to a 1000 ms pre-stimulus onset baseline, and are hereafter discussed in dB units (from baseline). The frequency tag was predicted to lead to a corresponding neural frequency in the central-occipital region, approximately between central Oz and Iz electrodes in a 10-20 system. This was confirmed with a fast-fourier transform of the full 1000 ms critical period, where a 30 Hz signal was

observed in the central occipital region relative to the 1000 ms baseline period (see figure 3a

for a topographical representation of 30 Hz power). The frequency response spectrum at the

posterior occipital cluster indicated a discrete spike in the 30 Hz frequency band (figure 3b).

This was complemented with a time-frequency decomposition using Morlet wavelet

transformations within the range of 3-70 Hz (3-0.5 wavelet cycles) to give insight into the

timing of the 30 Hz signal from the beginning of the trial to the period immediately preceding

the possible onset of a second target (2000 ms window), collapsing across the two conditions.

The 30 Hz signal was observed in both the ERSP and ITC topographs to arise at

approximately 750 ms in the central occipital region and continuing through to the end of the

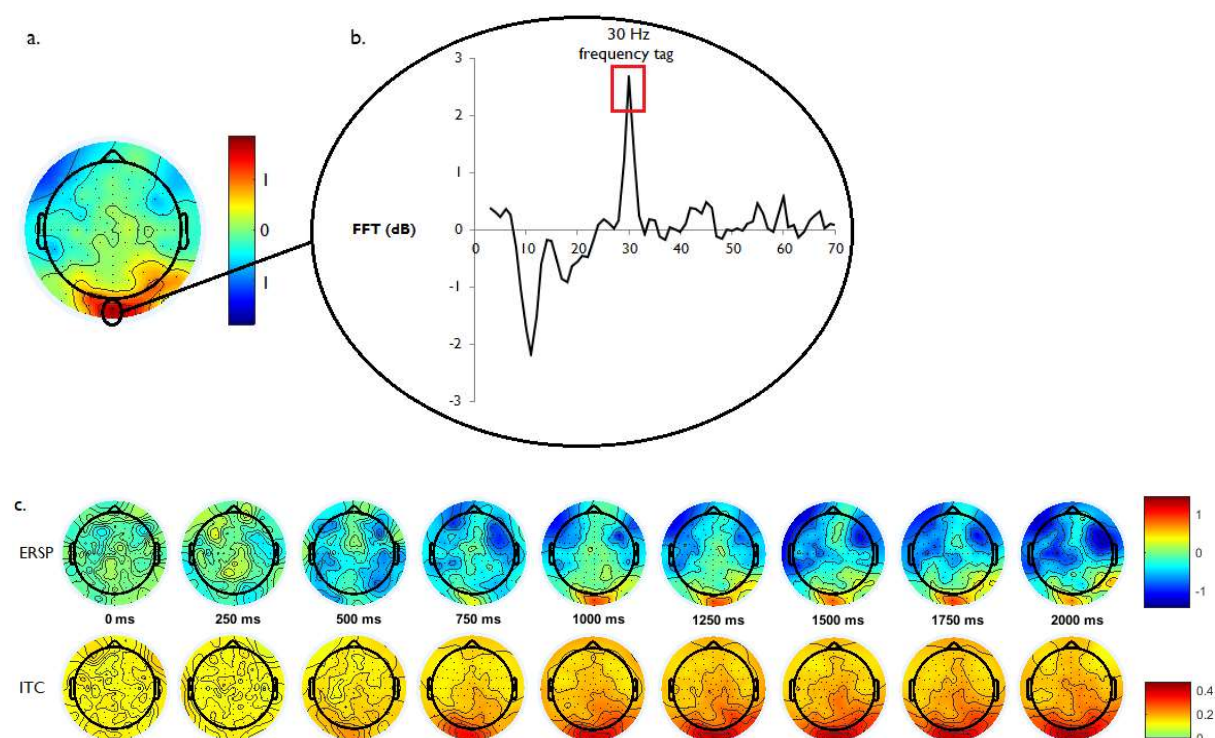2000 ms window.

Please insert Figure 3 about here

Figure 3. *Scalp topography revealed a strong 30 Hz signal in the central-occipital*

region during the 1000 ms critical period (a), with a fast-fourier transform in this area

indicating a distinct 30 Hz spike corresponding to the frequency-tag (b). Event-related

spectral perturbation (c) and inter-trial coherence transforms found reliable 30 Hz

signatures in the central-occipital regions arising at approximately 750 ms into the trial and continuing through the target-tracking period.

Following the confirmation of the 30 Hz frequency tag in the EEG recordings, statistical tests were conducted to compare the effect of divided visual attention on the power of this oscillation in the central occipital region. Event-related spectral perturbations (ERSP) from the Morlet wavelet transformations from this region were computed for the divided and undivided attention conditions, producing ERSP averages of each condition for each participant. Differences between the divided and undivided ERSP data in the critical 1000 ms time window were compared with a repeated measures, two-tailed permutation (50,000 permutations) test using the tmax statistic implemented through R (Blair & Karniski, 1993). This procedure produces distributions for statistical comparison by permuting the observed data to arrive at adjusted p-values. This statistical approach was used to allow for a non-parametric analysis, as measures of brain activity commonly violate assumptions of parametric tests. The permutation process also allows for a conservative correction of the large number of comparisons involved in sample-by-sample t-tests across time periods of interest. To determine whether condition-specific effects were restricted to the predicted occipital region or whether they were more widespread (or localised in other regions), the divided and undivided conditions were further tested at each electrode site through permutation tests (50,000) and corrected spatially through a cluster-based correction, implemented through EEGLAB (Delorme & Makeig, 2004) and Fieldtrip (Oostenveld et al., 2011).

3. Results

3.1.

The statistical analysis of 30 Hz power in the central occipital lobe region across the 1000 ms period preceding the possible onset of a second target revealed a significant decrease in power early in the divided attention condition compared to the undivided attention condition. This effect arose between 1307 ms and 1343 ms after 1st target onset, corrected for multiple comparisons. This corresponded to the period approximately 800 ms before the time that a second target might have occurred in the divided attention condition. This difference can be observed in figure 4 (data), which corresponds in time with an apparent increase in power for the undivided attention and a decrease of power for the divided attention.
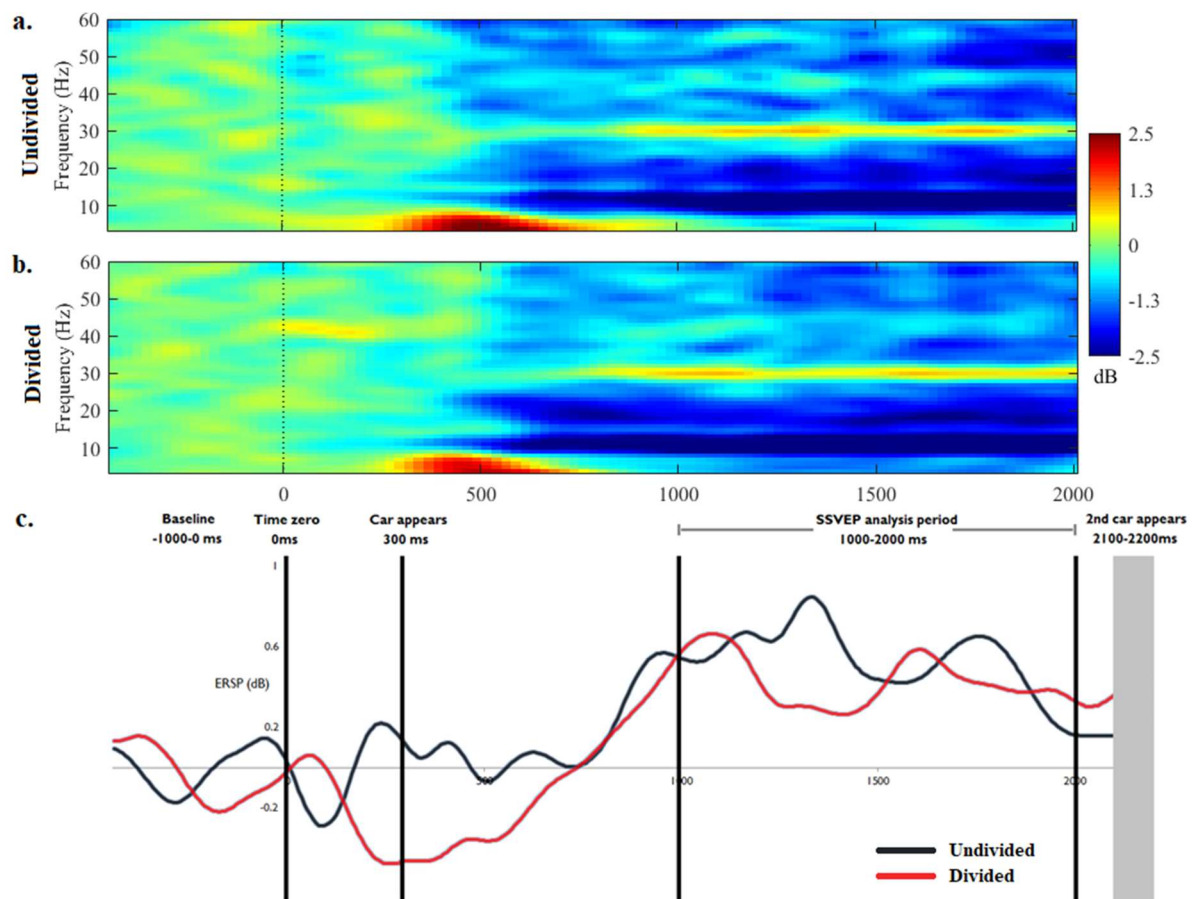
Please insert Figure 4 about here

Figure 4. *30 Hz power (ERSP) across the trial period indicated sustained attention in both the undivided condition and divided attention conditions, with apparent decreases in neural response at discrete periods in the divided attention condition.*

The shaded permutation-corrected 95% confidence intervals in the difference wave in Figure 5a suggests that this was a modest effect. Without multiple comparison correction this period of significant difference extended from 1278 ms to 1387 ms, here reported to give insight into the effect of the permutation correction.

The additional analysis (cluster-based correction) of the location of this effect revealed that the effect of divided attention was restricted to the central occipital region (figure 5b), corresponding to the aforementioned time window but was not apparent at other times.
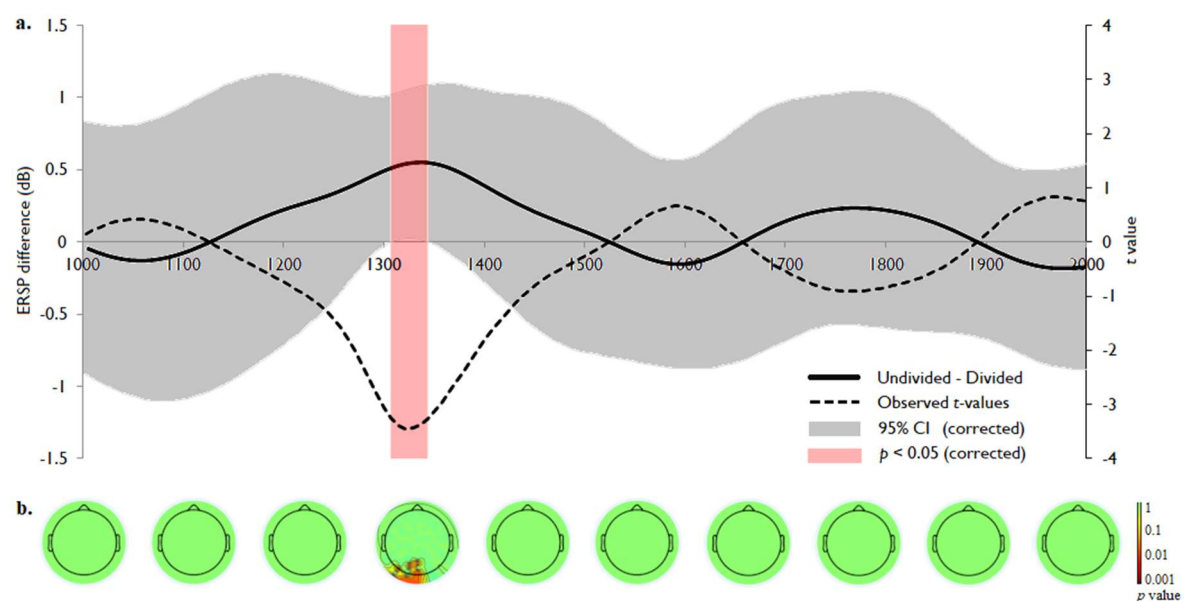
Please insert Figure 5 about here

Figure 5. *The difference waveform of 30 Hz power across the trial (undivided minus divided) revealed a significant dip in 30 Hz power in the divided condition, observed from approximately 1300 ms. 95% confidence intervals not overlapping zero indicate periods of significance. The difference in this 30 Hz power was limited to the central-occipital region of the scalp (b).*

4. Discussion

The current study sought to measure overt visual attention in a smooth-pursuit paradigm, and to determine whether allocation of covert attention to peripheral regions modulated measures of overt attention. The SSVEP power corresponding to the 30 Hz frequency tag of the moving stimuli decreased when the task required participants to attend covertly to where an additional target might appear in the periphery as well as to overtly monitor the moving targets. This finding aligns with the view of covert and overt visual attention as expressions of a pool of attentional resources, where an increase in covert attention can lead to a concomitant reduction in overt attention (Kahneman, 1973; Lavie et al., 2004), similar in nature to the reduction in SSVEP power to foveated static stimuli observed when covert visual attention is recruited (Mishra et al., 2011). Our finding that attention can be deployed covertly while overtly tracking a moving target is also in line with the behavioural results of Seya and Mori (2012), who used saccadic response times to index covert attentional shifts to peripheral spatial regions. Similarly, this finding supports the behavioural findings of Ludwig et al. (2014) suggesting that both covert and overt attention can operate in parallel. A notable difference between our methodology and that of Ludwig et al., however, is that we utilised a passive measure of overt visual attention through SSVEP rather than a behavioural index. Thus, our approach allows us to investigate the fine-grained temporal modulations of overt attention resulting from allocation of covert attention, rather than the end-product. While our SSVEP results indicate that there was a reduction in overt attention to the moving targets when the task required a covert shift of attention to a peripheral location, this does not necessarily mean that a performance decrease would also be observed had an additional behavioural task been employed. This is in line with the perceptual load theory, which suggests that the division of visual attention across covert and overt areas is moderated by the processing load required by the tasks at hand. Accordingly, it is likely that modulating the salience of the moving target may also modulate the degree to which covert shifts of attention

to peripheral locations affect the processing of the moving target. In contexts such as parents tracking moving children in a playground, or security forces monitoring moving threats, one dimension of the task involves accurately following targets with the eyes while an additional task might involve a specific visual analysis of the target itself. In these contexts, the level of overt attention may be higher than when there was no secondary task requiring visual analysis, making it more difficult (or less likely) for covert shifts to occur. It is also likely that additional visual analysis of the moving stimuli would require greater overt attention and thus may limit the amount of covert attention available for monitoring other spatial areas, as suggested by the finding that foveal distractors are harder to ignore than peripheral distractors (Beck & Lavie, 2005). The nature of any such task will likely then influence the relative strength of both central overt and peripheral covert visual attention, as competition between features for visual analysis and their distractors in central vision has been found to lead to an enhancement of neural sensitivity to peripheral regions (Painter, Dux, Travis, & Mattingley, 2014).

There are additional low-level factors that might further be predicted to modulate both overt and covert visual attention during smooth-pursuit, such as the speed of the moving target, and the spatial locations of where covert shifts of attention are directed. Saccade latencies to stimuli presented during smooth-pursuit have been found to increase as target speed increases (Bieg et al., 2015; Seya & Mori, 2012). An SSVEP index of overt attention throughout the overt tracking of a moving target would allow for further clarification of how covert shifts of attention are influenced by target speed, and whether the effects pertain to the strength of covert shifts, the timing of such shifts, or both. Target-speed related modulation of covert peripheral attention is of particular concern in the domain of road-crossing safety, where increased vehicle speed may disproportionately affect individuals who tend to overtly

track moving vehicles rather than covertly monitor them through peripheral vision while overtly monitoring more strategic areas (Biassoni et al., 2018; Nicholls et al., 2018).

From a methodological perspective, the current study supports the use of the co-registration of eye-position recordings with SSVEP paradigms as a means investigating the dynamics of visual processing and attention while people perform tasks involving the tracking of moving objects. The development of this approach has recently shed light on the spread of attention during smooth-pursuit, with Chen et al. (2017) providing electrophysiological evidence that visual attention is directed slightly ahead of targets as they move across the visual field, supporting behavioural results suggesting the same pattern (Khan et al., 2010; for review see Donkelaar & Drew, 2002). A natural convergence of the current study with that of Chen et al. (2017a) would be to investigate the relationship between overt visual attention directed at a moving target and the default spread of attention while visual analysis of the target is taking place. The paradigm is also readily adaptable to investigate both overt and covert attention where multiple moving objects require selection or detection through either overt or covert visual attention (Lappin, Morse, & Seiffert, 2016). The inclusion of a passive neural index of visual attention in such paradigms provides another layer of measurement when determining the timing or intensity or attentional shifts in complex visual environments.

Methodologically speaking, there are a number of technical dimensions that must be addressed in order to obtain reliable SSVEP patterns that can be readily interpreted. The major concern is the control of low-level visual properties. It is imperative that participants' eye-positions are monitored throughout the SSVEP trials, as the relative position of such stimuli in the visual field significantly modulates both the intensity and topography of the recorded signals (Grgič et al., 2016; Müller, Teder-Sälejärvi, &, Hillyard, 1998; Punsawad & Wongsawat, 2017). This process will likely lead to the rejection of a certain number of trials

involving inappropriate gaze-positions, and so the experimental planning needs to account for this reduction either by including a high number of trials, or an online index of gaze-accuracy which can repeat trials when necessary to compensate for rejected trials. In addition, it is likely that some tasks and conditions might involve differences in target-tracking accuracy, where specific conditions or contexts are more likely to elicit saccades that are difficult to inhibit (or in populations where such inhibition might be impaired). An analysis of trial rejection may therefore provide an index of this, as well as more in-depth analysis of gaze-behaviour in the trials. However, experimental conditions with significantly different numbers of accepted trials might further complicate the interpretation of the comparison of SSVEP responses in these conditions as the signal-to-noise ratios in the EEG averages is strongly affected by this factor.

In summary, the application of SSVEPs to index overt visual attention while tracking a moving target provides a useful tool for understanding the effects of task-related covert attentional shifts in terms of both strength and timing. The results of the current study suggests that in contexts where covert attention is likely to be devoted to peripheral regions a concomitant reduction in overt attention to a moving target is likely to occur. The co-registration of EEG and eye-position while using the SSVEP technique would thus be well-suited to exploring this dynamic, and may provide valuable insight into areas where a reduction of overt attention due to covert distractors can lead to a decrease in performance or safety decisions relating to the moving targets.

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