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Sustained division of spatial attention to multiple locations within one hemifield

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Abstract

Attending to a location in space significantly improves stimulus perception at that location. Everyday experience requires the deployment of attention to multiple objects at different locations. Recent empirical evidence suggests that the "beam" of attention can be divided between non-contiguous areas of the visual field. Whether this is only possible when stimuli are presented in different hemifields and harder, if not impossible, when stimuli are in the same hemifield is an ongoing debate. Here we use an electrophysiological measure of sustained attentional resource allocation (the steady-state visual evoked potential, SSVEP) to address this question. In combination with behavioural data we demonstrate that splitting the attentional "beam" is in principle possible within one hemifield. However, results showed that task performance was in general lower for same-hemifield presentation as opposed to our previous study with different-hemifield presentation [M.M. Müller, P. Malinowski, T. Gruber, S.A. Hillyard, Sustained division of the attentional spotlight, Nature 424 (2003) 309–312]. SSVEP amplitude showed a mixed pattern of results for stimuli presented in the upper versus lower quadrant of the left visual hemifield under conditions of attending to two separated locations. Results are discussed in the light of the bilateral distribution advantage hypothesis and differences in stimulus salience between the upper and lower visual field.

Keywords: Steady-state visual evoked potentials; Divided spatial attention; Visual hemisphere; Attention models; Human brain

Natural visual scenes are cluttered with different objects and attention helps to select a particular object for preferred stimulus processing. In recent years empirical evidence was provided that the deployment of attention over space is quite flexible and allows attending to separate locations or objects with irrelevant or to-be-ignored positions or objects in between them [1,4,7,9,15]. In one study we presented four stimuli aligned along the horizontal meridian that flickered with different frequencies for several seconds to elicit the frequency-coded steady-state visual evoked potential (SSVEP) [15]. The SSVEP is the electrophysiological response of the visual cortex to a rapidly repeating (flickering) stimulus and generally has a sinusoidal waveform with the same temporal frequency as the driving stimulus [21]. Previous studies have shown that its amplitude is substantially increased when attention is focused upon the location of the flickering stimulus [14,17] and, thus, serves as a direct neural index of the sustained deployment of attention across space.

In our recent study we found significantly decreased SSVEP amplitudes when the intermittent stimulus was ignored compared to when this stimulus was attended, supporting the view that the attentional spotlight can be split in spatially non-contiguous locations over periods of several seconds [15]. However, given that the stimuli were located in the left and right visual hemifield, the question arises whether splitting the attentional focus was only possible because each hemisphere was able to independently maintain one attentional spotlight or uses independent attentional processing resources. The *bilateral distribution advantage hypothesis* predicts that splitting is much harder or even impossible if stimuli are presented within one hemifield, due to the limited amount of processing resources of only one cortical hemisphere [12,19,23]. In this framework, a bilateral distribution advantage is always present when the

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benefits of the cooperation between the two hemispheres outweigh possible costs [3,24].

Several behavioural studies provide evidence for this assumption. Performance was often found to be superior when stimulus processing required by a certain task could be distributed over the two hemispheres, especially for computationally complex or perceptually demanding tasks [2,10]. Furthermore, in a visual search task neuropsychological patients with surgically transected corpus callosum, resulting in disconnection of the two cerebral hemispheres, were able to scan bilaterally presented stimulus arrays faster than normal control subjects, suggesting that each hemisphere is able to maintain an independent focus of attention [11].

The present study intends to determine whether the ability to maintain two separate foci of attention necessarily requires that the attended locations fall into different hemifields. With other words, are participants still able to split the attentional focus when the separated and to-be attended locations fall into the same visual field? To answer that question we used a similar design as in our previous study [15], but stimuli were presented in the left visual hemifield only. Each stimulus flickered with a different frequency. By mathematically decomposing the electrophysiological brain response into the different stimulation frequencies we studied the deployment of attention to the presented stimuli by testing the amplitude of the respective SSVEP statistically.

All thirteen participants (eight females; mean age 24.3 ± 3.0 years) gave informed consent according to the Declaration of Helsinki. Excessive EEG artefacts resulted in the exclusion of three participants. Thus analysis is based on 10 remaining participants.

The design of the present study was almost identical to the one in our previous study [15], except that stimuli were arranged *vertically* within the left visual hemifield extending the upper and lower quadrant (see Fig. 1).

Stimuli were presented against a dark background on a 17-inch computer monitor (800×600 pixels, vertical refresh rate 59.25 frames/s). Each white rectangle comprised a visual angle

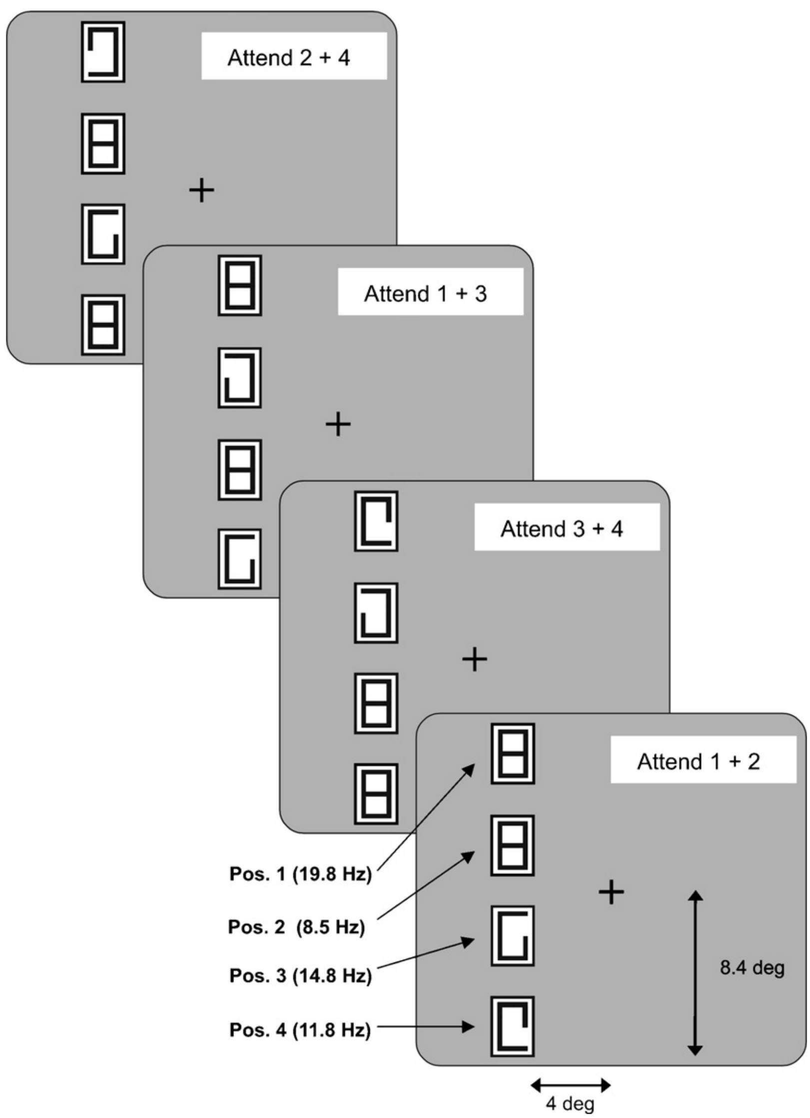

Fig. 1. Schematic diagram of stimulus sequences for all four experimental conditions. Subjects reported a match of the target symbol “8” at the two attended positions (either 1 + 2, 3 + 4, 1 + 3 or 2 + 4) on different blocks of trials.