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Research Report

What determines sustained visual attention? The impact of distracter positions, task difficulty and visual fields compared

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ABSTRACT

We quantified the interference of distracter stimuli on sustained visuo-spatial attention as a function of the distribution of attended positions in the visual fields (bilateral/unilateral, left/right, upper/lower), distracter positions (peripheral, between attended positions, between fixation and attended positions) and task difficulty. Compared to distinct distracter positions, bilateral field and lower field presentation had much stronger influence on the performance. Additionally, interactive effects between task difficulty and distracter position were found. This result was at variance with the previous models of visuo-spatial attention, which attached much more importance to the role of distracter positions compared to visual field effects. In directly comparing the impact of the abovementioned factors, the converse finding is evident—visual field effects, in particular bilateral presentations have a much stronger importance. Moreover, metaphoric concepts of attention like the “zoom lens” are not compatible with these results. The findings are discussed in the light of alternative models of sustained visuo-spatial attention. The visual system architecture and top–down mechanisms are considered.

1. Introduction

What determines the shape of visuo-spatial attention if a task requires to attend on multiple positions in space simultaneously? The most prominent and popular description is the metaphoric concept of visuo-spatial attention as a “zoom lens”. The concept was introduced by Eriksen and St. James in 1986 and physiological evidence in humans was found in our functional magnetic resonance imaging (fMRI) study (Müller et al., 2003b). It was suggested that attention can be aligned like a focus at one circumscribed position in space. Information processing should be enhanced at the attended position. The size of the focus should be adjustable in size like a “zoom lens”, i.e., if multiple positions should be attended simultaneously. Limited attentional resources were strained when the size of the focus was increased (Eriksen and St. James, 1986; Müller et al., 2003b).

Generally, two attentional components were distinguished as transient (exogenous) and sustained (endogenous) attention, depending on the type of the cue (peripheral vs. central,

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respectively) and the timing of the cue-target sequence (short intervals between 50 and 200 ms vs. longer intervals, respectively) (Nakayama and Mackeben, 1989; Weichselgartner and Sperling, 1987; Collie et al., 2000). Regarding the shape, evidence for the "zoom lens" concept was found for both attentional components: for transient attention by Eriksen and St. James (1986) using peripheral cues and short intervals between 50 and 200 ms; for sustained attention by our own study (Müller et al., 2003b) using central cues and long intervals between 4 and 12 s.[1]

However, as appealing and straightforward the "zoom lens" concept is, several psychophysical and physiological studies are incommensurate with the predictions of this model—so are our own recent findings (Kraft et al., 2005a). Consequently, we now want to consider further aspects influencing the distribution of visuo-spatial attention. They are described in greater detail within the next sections.

First, the role of hemifield alignment was investigated in several studies. A bilateral field advantage (BFA) was found when attended targets were processed in distinct hemispheres (e.g., Liederman et al., 1985; Banich, 1998; Sereno and Kosslyn, 1991; Kraft et al., 2005a; Alvarez and Cavanagh, 2005). A model of two independent attentional systems for both hemispheres was suggested (e.g., Liederman et al., 1985; Castiello and Umiltà, 1992; Mangun et al., 1994; Kraft et al., 2005a). Under this model, more attentional resources can be allocated if both systems (i.e., hemispheres) are involved, resulting in better performances in bilateral conditions, especially under high task demands (Banich, 1998; Kraft et al., 2005a).

Second, task difficulty dependencies were examined. A decrease of distracter interference in difficult compared to easy tasks was observed (e.g., Lavie, 1995; Beck and Lavie, 2005; Kraft et al., 2005a). A hybrid resource model was suggested, claiming that exclusion of irrelevant distracter stimuli occurred earlier in information processing with increasing task difficulty (Lavie, 1995). Kraft et al. (2005a) combined the idea of two independent hemispheric attentional systems with the hybrid model of Lavie (1995). Two processing stages were distinguished: the orienting/focusing phase before stimulus presentation, where attention can be aligned like a "zoom lens" within each hemifield.[2] The selection phase begins after stimulus presentation. Here, distracters were discarded at an earlier or later stage depending on task demands.

Third, the shape of the focus of attention was analyzed. Psychophysical measures revealed enhanced detection performance at cued positions, as well as at positions between fixation and cued positions (e.g., Tse et al., 2003). Amplitudes of event-related potentials (ERP) (Slotnick et al., 2002) and amplitudes of visual-evoked potentials (VEP) (Seiple et al., 2002) were also increased within these regions. Furthermore, distracters at fixation revealed larger interference effects than peripheral distracters (Beck and Lavie, 2005). In contrast, neither detection performance nor electrophysiological correlates were enhanced at peripheral, non-attended positions. It was thus proposed that the attentional focus originates from central fixation (e.g., Slotnick et al., 2002; Tse et al., 2003; Seiple et al., 2002). In addition, an inhibition zone surrounding the attended area was discussed in several studies. Psychophysical measures revealed varying interference from distracter stimuli presented in the regions that surround the attended area, depending on their distance to the attended area. Gradient (e.g., LaBerge, 1983; LaBerge et al., 1997) or "Mexican hat" distributions (e.g., Bahcall and Kowler, 1999; Pan and Eriksen, 1993; Müller et al., 2005) of visuo-spatial attention were suggested. Also, ERP (Slotnick et al., 2002) and fMRI studies (Slotnick et al., 2003; Müller and Kleinschmidt, 2004) revealed evidence for inhibitory regions in the periphery of an attended position.

Fourth, visual field differences were investigated. So far, differences between the left and right visual fields were observed in neglect patients (e.g., Mangun et al., 1994; Losier and Klein, 2001; Karnath, 1988), but not in normal subjects (e.g., Mangun et al., 1994; Losier and Klein, 2001; Thiel et al., 2004; Kraft et al., 2005a). In contrast, a lower visual field advantage (LFA) compared to the upper visual field was found in visual search and attention paradigms (e.g., Previc, 1995; Carrasco et al., 2001; Losier and Klein, 2004; Intriligator and Cavanagh, 2001; Kraft et al., 2005a). A higher resolution of attention in the lower visual field was proposed (e.g., Intriligator and Cavanagh, 2001).

What implications do these results have for a model of visuo-spatial attention? Should we retain a single concept of attention like the "zoom lens"? The described aspects, however, have never been analyzed in one experimental setup. In fact, small experimental variations, e.g., distance between targets (Müller et al., 2005), type of cue (Reuter-Lorenz and Fendrich, 1992), type of stimuli (Awh and Pashler, 2000) or temporal distance between cue and target (Collie et al., 2000), resulted in very distinct attentional effects. Moreover, interactive effects between these differential aspects, as well as the relative size of them, could not be quantified.

Here, we ask how these factors influence the distribution of sustained visuo-spatial attention if they are compared under the same experimental conditions. In particular, we ask if a unitary model of sustained visuo-spatial attention (e.g., "zoom lens", "zoom lens" originating from fixation, multiple foci) can be proven as valid when all these factors are considered.[3]

[1] Beside the differentiation between transient and sustained attention, Turatto et al. (2000) distinguished between "orienting" and "focusing" of visuo-spatial attention. Orienting should occur first: Peripheral cues lead to fast, automatic orienting in transient attention. Central cues lead to slower, voluntary orienting in sustained attention. Afterwards, the process of focusing should take place, requiring again processing time. Consequently, also Eriksen and St. James (1986) found stronger size-related changes in conditions with longer stimulus onset asynchronies (SOAs) of 100 and 200 ms compared to a short SOA of 50 ms. Here, the authors suggested that time was too short to adjust the focus in size.

[2] The model had also implications for the "splitting attention debate" (e.g., Awh and Pashler, 2000 vs. Heinze et al., 1994). Kraft et al. (2005a) proposed that attention can only be divided across the hemifields by aligning the two independent foci (i.e., "zoom lenses") separately.

[3] The previously described factors were analyzed either in transient or in sustained attention. However, several studies reported fundamental differences between the two attentional components (e.g., Eimer, 1995, 1997; Ling and Carrasco, 2006). Note that the present study addresses sustained attention only.