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ScienceDirect
Vision Research 48 (2008) 80–95
Vision Research
www.elsevier.com/locate/visres

On the flexibility of sustained attention and its effects on a texture segmentation task

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Received 8 March 2007; received in revised form 27 September 2007

Abstract

Previously we have shown that transient attention—the more automatic, stimulus-driven component of spatial attention—enhances spatial resolution. Specifically, transient attention improves texture segmentation at the periphery, where spatial resolution is too low, but impairs performance at central locations, where spatial resolution is already too high for the task. In the present study we investigated whether sustained attention—the more controlled component of spatial attention—can also affect texture segmentation, and if so whether its effect will be similar to that of transient attention. To that end we combined central, symbolic cues with texture displays in which the target appears at several eccentricities. We found that sustained attention can also affect texture segmentation, but unlike transient attention, sustained attention improved performance at all eccentricities. Comparing the effect of pre-cues and post-cues indicated that the benefit brought about by sustained attention is significantly greater than the effect of location uncertainty reduction. These findings indicate that sustained attention is a more flexible mechanism that can optimize performance at all eccentricities in a task where performance is constrained by spatial resolution.

Keywords: Covert attention; Sustained attention; Texture segmentation; Spatial vision

1. Introduction

Visual attention allows us to select part of the otherwise overwhelming amount of information in our visual field and process it in a privileged way. One way in which this attentional selection occurs is based on the spatial location of visual information. Typically, we foveate the location in space to which we wish to attend, but it is well known that we can direct our attention to a region in our visual field without moving our eyes towards this location (e.g., Eriksen & Hoffman, 1972; Posner, 1980). The selection of information based on its spatial location in the absence of eye movements is referred to as spatial covert attention (Posner, 1980). There are two components of spatial attention, 'sustained' and 'transient'. 'Sustained attention' is a conceptually-driven component that requires conscious effort and is activated in about 300 ms. 'Transient attention' is a stimulus-driven component, and it is activated in an automatic manner in about 100 ms (e.g., Cheal & Lyon, 1991; Jonides, 1981; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989; Posner, 1980; Remington, Johnston, & Yantis, 1992). Transient attention is considered to operate at an earlier stage of visual cortical processing than the sustained component (e.g., Nakayama & Mackeben, 1989). Indeed, neurophysiological studies suggest that whereas sustained attention is cortical in nature, transient attention is mediated by both cortical and subcortical networks (Corbetta & Shulman, 2002; Kastner & Ungerleider, 2000). Previously, we have documented the effects of transient attention on a texture segmentation task constrained

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0042-6989/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.visres.2007.10.015

by spatial resolution (e.g., Carrasco, Loula, & Ho, 2006; Yeshurun & Carrasco, 1998; Yeshurun & Carrasco, 2000). In this study, we investigate the effects of sustained attention on such a texture segmentation task.

A common method to directly manipulate the allocation of spatial attention employs attentional cues, which precede target presentation and induce observers to direct their attention to the target location. Different types of attentional cues are used to manipulate transient and sustained attention: The former is manipulated by a peripheral cue presented adjacent to the target location, and the latter is manipulated by a central cue presented in the center of the visual field. Peripheral cues induce a more rapid shift of attention than central cues, and usually produce larger attentional effects at short intervals. The effects of peripheral cues peak at ~100 ms but then decay rapidly whereas the effects of central cues peak at ~300 ms and then remain for a longer duration (e.g., Carrasco, Ling, & Read, 2004; Cheal & Lyon, 1991; Jonides, 1981; Ling & Carrasco, 2006; Müller & Findlay, 1988; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989). In addition, whereas the shifts of attention by central cues appear to be under conscious control, the effects of peripheral cues are involuntary (but see Ristic, Friesen, & Kingstone, 2002; Tipples 2002, who have shown that there may be a reflexive component for faces and arrows presented at central locations). For instance, peripheral cues cannot be voluntarily interrupted or ignored, even if observers are instructed to do so (Jonides, 1981), and their effect is little influenced by cue validity (i.e., the probability with which the cue predicts the target location). Moreover, shifts of attention induced by peripheral cues have been shown to occur even if the cue is uninformative (e.g., Jonides, 1981; Müller & Rabbitt, 1989 Pestilli & Carrasco, 2005; Pestilli, Viera, & Carrasco, 2007), or if the cue actually impairs performance due to its low validity (e.g., Giordano, McElree, & Carrasco, 2004). In contrast, effects of central cues depend on cue validity and might not occur when the central cues are uninformative (e.g., Giordano et al., 2004; Jonides, 1981; Kinchla, 1969; Kinchla, 1980; Sperling & Melchner, 1978; but see Gibson & Bryant, 2005).

Previously, we have proposed that transient attention can enhance spatial resolution, thus allowing us to resolve finer details at the attended location ('resolution hypothesis'). Several studies have provided evidence supporting the hypothesis that transient attention can enhance spatial resolution. For example, directing transient attention to the target location improves performance in both acuity and hyper-acuity tasks even when a supra-threshold target is presented without distracters (Carrasco, Williams, & Yeshurun, 2002; Golla, Ignashchenkova, Haarmeier, & Their, 2004; Yeshurun & Carrasco, 1999). Similarly, the decrement in visual search performance that occurs as the target is presented at farther peripheral locations is significantly reduced when transient attention is directed to the target location. This finding suggests that attention can reduce resolution differences between the fovea and the periphery (Carrasco & Yeshurun, 1998), much like the effect obtained when the elements of a search display are cortically magnified (Carrasco & Frieder, 1997). Additionally, the hypothesis that transient attention enhances resolution is consistent with neurophysiological studies demonstrating that a neuron's response to its preferred stimulus is greatly reduced when the preferred stimulus is not attended, and an attended, non-preferred stimulus is also presented within the neuron's receptive field. These findings suggest that attention contracts the cell's receptive field around the attended stimulus (e.g., Desimone & Duncan, 1995; Luck, Chelazzi, Hillyard, & Desimone, 1997; Moran & Desimone, 1985; Reynolds & Chelazzi, 2004; Reynolds & Desimone, 1999; Womelsdorf, Anton-Erxleben, Pieper, & Treue, 2006).

In another study we further tested the 'resolution hypothesis' by exploring the effects of transient attention on performance in a basic texture segmentation task (Yeshurun & Carrasco, 1998). We found that transient attention can affect texture segmentation, and that the pattern of this attentional effect depends on the spatial resolution at the attended location. Specifically, we found that transient attention improves performance at locations in which performance is limited by a spatial resolution that is too low (i.e., at peripheral locations), but impairs performance at locations in which performance is limited by a spatial resolution that is too high (i.e., at central locations). The current study was designed to explore whether sustained attention can also affect texture segmentation, and whether the pattern of such an effect would be similar to that of transient attention.

The texture segmentation task we employed in our transient attention study required the detection of a target patch composed of oblique line elements embedded in a larger background of orthogonally oriented line elements (Yeshurun & Carrasco, 1998; Fig. 1). Performance in this task peaks when the target appears at mid-peripheral locations, and drops as the target appears at more central or farther peripheral locations (e.g., Gurnsey, Pearson, & Day, 1996; Joffe & Scialfa, 1995; Kehrer, 1989; Kehrer, 1997; Meinecke & Kehrer, 1994; Morikawa 2000; Potechin & Gurnsey, 2003). It has been hypothesized that performance is suboptimal when there is a mismatch between the specific scale of the texture and the size of spatial linear filters. These linear filters are thought to underlie the visual processing of textures (e.g., Bergen & Landy, 1991; Caelli,

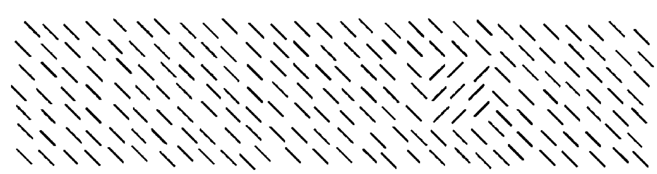

Fig. 1. A schematic example of the texture displays used in Experiments 1 and 2. The texture line elements are oriented ±45° from vertical and the texture display extends along the horizontal meridian. A 3 × 3 target patch is visible in the display on the right.