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SCIENCE DIRECT®
Vision Research 45 (2005) 1129–1137
Vision Research
www.elsevier.com/locate/visres

The attentional field has a Mexican hat distribution

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Received 18 June 2004; received in revised form 23 September 2004

Abstract

We assessed the interference by distracter letters on target discrimination as a function of the distance between incompatible distracters and target. The slope of the response time—distance function supports a Mexican hat pattern of attentional modulation in the visual field. We relate the results to our recent finding of neural activity suppression in primary visual cortex coding locations in the vicinity of an attended region [Müller, N. G., & Kleinschmidt, A. (2004). The attentional 'spotlight's' penumbra: Center-surround modulation in striate cortex. *Neuroreport*, *15*(6), 977–980]. As behavioral performance parallels activity modulation of primary visual cortex but not other areas we propose that perceptual capacities are determined by attentional response properties of V1.
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Keywords: Attention; Perception; Surround inhibition; Mexican hat; Task difficulty

1. Introduction

The existing models of spatial attention, e.g. spotlight (Posner, 1980; Posner, Snyder, & Davidson, 1980), zoom lens (Eriksen & St James, 1986; Eriksen & Yeh, 1985), gradient (LaBerge, 1983; LaBerge & Brown, 1986; LaBerge, Carlson, Williams, & Bunney, 1997) make different assumptions as to the size and boundary of attention-mediated perceptual facilitation (i.e., the 'attentional field'). Yet, most of them agree that this facilitation decreases monotonically with the distance from the focus of attention centered on the target. However, some studies have reported small regions of perceptual suppression surrounding the region of enhanced processing (Bahcall & Kowler, 1999; Caputo & Guerra, 1998; Carr & Dagenbach, 1990; Cutzu & Tsotsos, 2003; Eriksen, Pan, & Botella, 1993; Kim et al., 1999; Krose & Julesz, 1989; Mounts, 2000a, 2000b; Pan & Eriksen, 1993; Slotnick, Hopfinger, Klein, & Sutter, 2002; Steinman, Steinman, & Lehmkuhle, 1995). We have recently provided physiological evidence for surround inhibition in showing that neural activity in early visual areas coding locations in the vicinity of an attended location was suppressed (Müller & Kleinschmidt, 2004). Activity in early visual areas coding more distant locations was relatively enhanced compared to passive viewing but to a lesser extent than in those areas coding the relevant location. We suggested a Mexican hat-like distribution of attentional modulation within early visual cortex.

However, behavioral evidence for a true Mexican hat distribution of attentional modulation is still meager as even the studies which reported a surround inhibition lacked to confirm other predictions of the model. For example, most studies on surround inhibition describe a linear increase of perceptual facilitation with increasing distance from the attentional center (i.e., an inversely oriented gradient model), which would cover only part of a Mexican hat (i.e., the brim). In a Mexican hat model, processing of stimuli very close to the center of

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doi:10.1016/j.visres.2004.11.003

attention should still be enhanced. Further, the behavioral facilitation should level off at large distances. Instead, usually the most remote stimuli, i.e., directly opposite to the cued location in case of a circular array, yield the best performance.

The lack of evidence for a Mexican hat distribution may be related to some shortcomings of former studies with respect to the methods with which they mapped the attentional field (discussed in detail by Intriligator & Cavanagh, 2001). Generally, attentional distribution is addressed in tasks in which a cue or a salient pop-out stimulus first directs attention to a location. Subsequently, a target at this location either has to be compared to a second target at another location (Bahcall & Kowler, 1999; Cutzu & Tsotsos, 2003, Exp 1–3) or the target or a probe stimulus turns up at an uncued location (Cutzu & Tsotsos, 2003, Exp 4; Mounts, 2000a, 2000b). In either case, the distance between the uncued and the cued location is the critical variable. These studies find that stimuli which are presented closer to the cued location are less accurately reported than stimuli further away which is then taken as evidence for surround inhibition. This procedure has two main drawbacks: first, rather than addressing the distribution of attention while it is *focused* on the cued location, these paradigms test perception capabilities when attention has to cover the uncued location and thus depend on the speed and/or accuracy with which attention is either *shifted* to the uncued location or *split* between cued and uncued locations. Therefore, these studies are difficult to interpret with respect to the distribution of the attentional field during continuous focused attention. Their results could also be accounted for by models stating that attention is shifted to more remote instead of nearby locations as soon as the relevant information does not turn up at the primary focus or that splitting of attention in order to cover two targets is more easily accomplished at larger separations (see discussion).

The problem is often aggravated further by the fact that the stimulus at the uncued location has pop-out characteristics (i.e., a probe on a uniform background or a red letter among an array of black letters). Such pop-out stimuli can be detected without the need to focus attention (Treisman & Gelade, 1980), but once they are detected they are known to automatically attract attention thereby pulling away attention from the proposed center.

This raises another crucial point: the usual lack of control of stimulus alignment with respect to the vertical visual field meridian. [1] Several studies have shown a bilateral field advantage for visual processing, i.e., superior processing when stimuli are presented in separate visual hemifields (Brown & Jeeves, 1993; Brown, Jeeves, Dietrich, & Burnison, 1999; Brown, Larson, & Jeeves, 1994; Kraft, Müller, Hagendorf, Villringer, & Brandt, 2002; Larson & Brown, 1997; Sereno & Kosslyn, 1991). Most studies so far have confounded distance with bilateral presentation: cue and target (or the two targets) were more likely to be located in the same hemifield at small separations and in different hemifields at large separations. Thus, the results of these studies cannot distinguish unequivocally distance from hemifield effects.

In order to circumvent these shortcomings of prior studies, we chose to use an adaptation of the classical flanker paradigm (Eriksen & Hoffman, 1973) instead. Subjects had to discriminate target letters that were shown at a fixed location on an imaginary hemicircle centered at fixation. Simultaneously to the target letter, distracter (or flanker) letters were presented at various positions on the hemicircle (see Fig. 1). These letters could either be neutral, compatible or incompatible with respect to the target, i.e., were linked with no, a congruent or a conflicting response with respect to the target letter. Compared to the studies criticized above, this paradigm avoids task relevant stimuli at uncued locations with the risk of unwanted shifts or splitting of attention.

Numerous studies have shown that nearby incompatible flanker stimuli, although irrelevant for the task, interfere with the responses to the target, making them

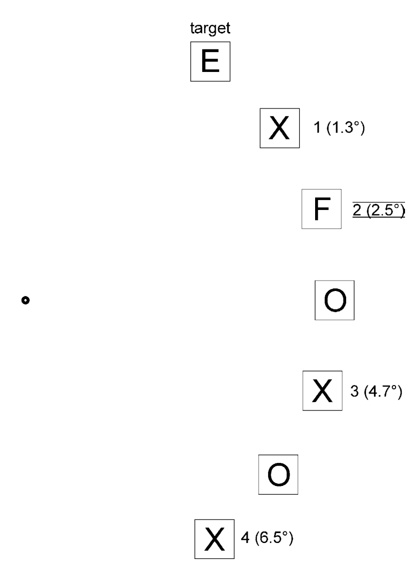

Fig. 1. Experimental stimuli. The figure presents an example for a trial in the difficult version of the task in which the letters E and F had to be discriminated at the uppermost position. An incompatible distracter letter is shown at position 2. Note that all other positions are occupied by neutral letters with respect to the target. The three other positions at which (in)compatible letters could be presented are marked and their distance to the target is provided (visual angle).

[1] Note, that He, Cavanagh, and Intriligator (1996) and Intriligator and Cavanagh (2001) also reported differences of attentional resolution with respect to the horizontal meridian. This, however, is an issue different from the focus of our experiment where the amount of attention—not its resolution—which a stimulus at a given location receives is crucial.

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