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Temporal dissociation between the focal and orientation components of spatial attention in central and peripheral vision

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ABSTRACT

Selective attention, i.e. the ability to concentrate one's limited processing resources on one aspect of the environment, is a multifaceted concept that includes different processes like spatial attention and its subcomponents of orienting and focusing. Several studies, indeed, have shown that visual tasks performance is positively influenced not only by attracting attention to the target location (orientation component), but also by the adjustment of the size of the attentional window according to task demands (focal component). Nevertheless, the relative weight of the two components in central and peripheral vision has never been studied.
We conducted two experiments to explore whether different components of spatial attention have different effects in central and peripheral vision. In order to do so, participants underwent either a detection (Experiment 1) or a discrimination (Experiment 2) task where different types of cues elicited different components of spatial attention: a red dot, a small square and a big square (an optimal stimulus for the orientation component, an optimal and a sub-optimal stimulus for the focal component respectively). Response times and cue-size effects indicated a stronger effect of the small square or of the dot in different conditions, suggesting the existence of a dissociation in terms of mechanisms between the focal and the orientation components of spatial attention. Specifically, we found that the orientation component was stronger in periphery, while the focal component was noticeable only in central vision and characterized by an exogenous nature.

1. Introduction

Selective attention can be defined as the mechanism that selects the most important information from among the many competing stimuli present in the environment; both the internal goals and the salience of the environment determine where and what we attend to (e.g. Hopfinger, Buonocore, & Mangun, 2000; Itti & Koch, 2001). Visual attention selectively enhances the visual information processing of a specific attended location or object, while inhibiting the processing of others (He & Cavanagh, 1996; He, Cavanagh, & Intriligator, 1997; Carrasco, 2011). This selective mechanism is deemed to be necessary, since the limited-cognitive resource capacity doesn't enable the parallel processing of all the available information (Broadbent, 1958).

When the process is involuntary and passive we refer to exogenous attention, while when it is active and voluntary to endogenous attention. Exogenous attention, often linked to abrupt visual changes, is characterized by a short activation time with a minimum use of resources and a relative independence of working memory, whereas endogenous attention takes longer to be activated and it is characterized by more flexibility, central control, and higher cognitive load (e.g. Jonides, 1980; Posner, 1980).

Allocating the attentional resources to a location in space involves two distinct processes. An orientation process shifts the attentional resources to the relevant locations for further processing, and a focusing process acts as a magnifying lens and allows us to concentrate our resources selectively on a limited amount of space within the environment, while ignoring the rest of it (e.g., Chun, Golomb, & Turk-Browne, 2011).

Furthermore, spatial attention can be oriented to a specific location or object both by moving the eyes toward that location (overt attention) or without directing the gaze directly toward it (covert attention). The distinctions "covert vs overt" and "endogenous vs exogenous", have both been extensively studied in terms of behavioural effects and of neuro-functional mechanisms (e.g., Corbetta & Shulman, 2002; Kincade, Abrams, Astafiev, Shulman, & Corbetta, 2005), nevertheless it is still unclear if orienting and focusing are different and independent mechanisms or if the focusing process is just a part of the orienting process. This is the goal of the present study.

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The orienting component was defined by Posner (1980) as the alignment of attention with a source of sensory input or with an internal semantic structure stored in memory. By using his classical cueing paradigm, Posner (1980) showed that detection or discrimination of a target is more accurate and faster when the target appears at a cued location than when the location is uncued. Typically, observers are required to maintain fixation while performing the task with their peripheral vision. Depending on the purpose of the experiment, the type of cue (central and symbolic to involve endogenous attention, peripheral for exogenous attention) and the stimulus onset asynchrony (SOA) between the appearance of the cue and the target are manipulated. Shorter reaction times at cued locations with respect to uncued locations are interpreted as an advantage due to the spatial attentional processing, i.e. the costs and benefits associated with the spatial allocation of selective attention (Posner, 1980; Castiello & Umiltà, 1990a, 1990b).

Because of its simplicity, the Posner paradigm or its variants have been used in several studies to investigate the effect of orienting attention on different performance measures and in different conditions. For example, it has been shown that for attended stimuli the contrast thresholds for target detection (e.g. Carrasco & McElree, 2001; Solomon, 2004; Solomon, Lavie, & Morgan, 1997), as well as the orientation discrimination thresholds (e.g. Lee, Koch, & Braun, 1997) are enhanced. Moreover, orienting attention seems to influence performance in visual search (e.g. Carrasco & Yeshurun, 1998; Morgan, Ward, & Castet, 1998), acuity (e.g. Yeshurun & Carrasco, 1999), texture segmentation (e.g. Yeshurun, Montagna & Carrasco, 2008) and crowding tasks (Huckauf & Heller, 2002; Yeshurun & Rashal, 2010). Taken together these results suggest that attending to the target location enhances detection and discriminability of finer details. According to Carrasco (2011) these results are due to an improvement of spatial resolution. Furthermore it has been shown that the effect of orienting attention increases as eccentricity increases (Carrasco & Yeshurun, 2009).

The focal component of selective attention, instead, increases the efficiency of the processing of specific locations or objects (Intriligator & Cavanagh, 2001), and is in contrast with the ability to equally allocate attention across all possible locations or objects in the visual field, i.e. distributed attention (Jonides, 1981). The attentional focus has been described either as a spotlight (Posner, 1980) or a zoom-lens (Eriksen & Yeh, 1985; Eriksen & St James, 1986), which enhances the processing of visual stimuli within a circumscribed region of the space. According to the spotlight metaphor the attentional focus has a fixed size at each retinal eccentricity (e.g. Klein & McCormick, 1989), whereas the zoom-lens model (Eriksen & Yeh, 1985; Eriksen & St James, 1986) states that the attentional focus is more like a lens varying in size.

Several studies have shown that people adjust the size of the attentional focus voluntarily, in accordance with task demands, and that the processing efficiency increases as size decreases (Castiello & Umiltà, 1990a, 1990b, 1992; Eriksen & St James, 1986; Usai, Umiltà, & Nicoletti, 1995; Benso, Turatto, Mascetti, & Umiltà, 1998; Egeth, 1977). On the other hand, when attention is distributed across the entire visual field there is a corresponding loss in processing efficiency and spatial resolution (Castiello & Umiltà, 1990a, 1990b; Castiello & Umiltà, 1992; Eriksen, 1990; Eriksen & Murphy, 1987; Eriksen & St James, 1986; Eriksen & Yeh, 1985). Typically in focal attention experiments cue dimensions are varied and, usually, participants are faster and more accurate within smaller sized cued regions, suggesting the existence of an inverse relationship between the sizes of the attentional focus and processing efficiency (Castiello & Umiltà, 1990a, 1990b, 1992; Egeth, 1977; Eriksen & St James, 1986). Crucially, Castiello and Umiltà (1990a, 1990b) demonstrated that a gradual drop-off in visual efficiency outside the attentional focus was present only for long SOAs (500 ms), while the gradient was not detectable for very short SOAs (i.e. 40–50 ms). This suggests an independence between the two components of attention, with orienting being fast and focusing arriving later. However, Maringelli and Umiltà (1998) obtained the small-cue advantage in the fovea also with short SOAs (i.e. 100 ms). Other studies have shown a difference in the time course of the attentional advantage between foveal and peripheral target location, with the latter arising at 500 ms SOAs (Benso et al., 1998; Henderson 1991). Finally, Turatto et al. (2000) suggested that the focusing process is composed by two independent mechanisms: one automatic and exogenous, for short intervals (about 100 ms), and one voluntary and endogenous, for longer intervals.

Taken together, the literature about the attentional focus seems to highlight that the temporal trend of the attentional focusing includes a first period during which the attentional focus is automatically triggered by the abrupt onset of the cue (e.g. Maringelli & Umiltà, 1998; Turatto et al., 2000), and a second period during which the focus of attention is maintained actively (e.g. Benso et al., 1998; Turatto et al., 2000). Nevertheless, these studies provided only indirect evidence with regard to this issue, investigating solely on focusing in isolation (Turatto et al., 2000) but they did not compare directly the orienting and the focusing processes in different spatial conditions. Additionally, differences across studies on the distinction of the effects of orienting and focusing of attention may be related to the task choice. Some studies used detection tasks (e.g. Benso et al., 1998; Maringelli & Umiltà, 1998; Posner, 1980), while others used discrimination tasks (e.g. Egeth, 1977; Eriksen & St James, 1986; LaBerge, 1983). Discrimination tasks depend on attention more than detection tasks do (e.g., Bashinski & Bacharach, 1980; Bonnel & Miller, 1994) and this difference may be due to the fact that detection requires the visual system to solve a simpler problem than discrimination (e.g. Egeth, 1977; Eriksen & St James, 1986; Jonides, 1981; LaBerge, 1983; LaBerge & Brown, 1986; Carrasco, 2011). Other authors argued that the use of recognition or discrimination tasks is not optimal in order to study the processing of focusing attention, given that, in addition to visual attention, other processes like expectation (categorization of the stimulus) and intention (selection of the correct response) are involved in these tasks (e.g. Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000; Van der Heijden, 1992). According to these authors the use of a simple detection task is perfectly suitable for studying both orienting and focusing of attention (e.g. Posner, 1980; Benso et al., 1998; Castiello & Umiltà, 1990a, 1990b; Facoetti et al., 2000).

The aim of the present study is to obtain evidence that focusing and orienting attention are independent processes. In particular, here we disentangle the orientation and focal components of spatial attention by comparing the effect of three types of cues in central and peripheral vision as a function of time (short and long SOAs) and task (detection and discrimination). On the basis of the literature, we selected different cue types to elicit the focal and the orientation component of spatial attention differentially (e.g. Castiello & Umiltà, 1990a, 1990b; Maringelli & Umiltà, 1998; Posner, 1980). We compare reaction times across conditions by using: 1) a red dot, as an optimal cue for the orientation component because it directs attention to the target location without conveying any information about the size of the target stimulus; 2) a small square, as an optimal cue for the focal component given that it encloses the target stimulus without masking it, and conveys information about the optimal field of integration to detect or to discriminate the target stimulus; 3) a big square, as a non-optimal cue for the focal component, because it induces the focusing on an area bigger than the target stimulus. We also included a baseline condition in which the target appearance was not pre-cued. SOAs were manipulated to investigate the temporal trend of the two components. Indeed, it have been argued that the most important factor in distinguishing between an automatic (exogenous) and a voluntary (endogenous) allocation of attention is the duration of the SOA, with shorter SOAs evoking an exogenous and automatic orienting process longer SOAs eliciting a more voluntary and endogenous control of orientation component (Epstein, Conners, Erhardt, March, & Swanson, 1997). Results reveal how these two attentional mechanisms operate independently in different viewing conditions, with different temporal trends and different task demands.