Acta Psychologica 150 (2014) 1–13

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Spatial distribution of attentional bias in visuo-spatial working memory following multiple cues

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ARTICLE INFO

Article history:
Received 17 October 2013
Received in revised form 17 March 2014
Accepted 29 March 2014
Available online 8 May 2014

PsycINFO classification:
2346 Attention

Keywords:
Visuo-spatial working memory
Spatial attention
Attentional split
Endogenous attention
Exogenous attention

ABSTRACT

When attention is focused on one location, its spatial distribution depends on many factors, such as the distance between the attended location and the target location, the presence of visual meridians in between them, and the way, endogenous or exogenous, by which attention is oriented. However, it is not well known how attention distributes when more than one location is endogenously or exogenously cued, which was the focus of the current study. Furthermore, the distribution of attention has been manly investigated in perception. In the present study we faced this issue from a different perspective, by examining the spatial distribution of the attentional bias in visuo-spatial working memory (VSWM), when attention is oriented either exogenously or endogenously, i.e., after two peripheral vs. central symbolic cues (also manipulating cue–target predictability). Results indicated a systematic difference between endogenous and exogenous attention regarding the distribution of the attentional bias over VSWM. In fact, attentional bias following endogenous cues was affected by the presence of visual meridians and by the split of the attentional focus, converging in a unipolar attentional distribution, independently of cue–target predictability. On the other hand, when pulled by exogenous cues, attention distributed uni-modally or multi-modally depending on the distance between the cued locations, with larger effects for highly predictive cues. Results are discussed in terms of space-based, object-based and perceptual grouping mechanisms.

1. Introduction

Spatial attention is important to select the most relevant inputs coming from the environment and process them faster and more accurately than irrelevant ones. It is broadly accepted that the control for attentional resources could be exerted, at least, in two different ways (e.g., Klein & Shore, 2000): endogenously and exogenously. Exogenous attention is driven by immediate physical properties of the cue, so by salient stimulation outside the observer, as when sudden changes in the environment attract both oculomotor responses and visual attention. On the contrary, endogenous control originates within the observer and requires development of a spatial expectancy on the basis of an intention usually developed accordingly to the predictability of a to be interpreted central symbolic cue. Most of our knowledge about endogenous and exogenous orienting comes from studies based on the typical Posner's (1980) cost and benefits paradigm. The main finding generally observed using this task is what is known as "facilitation" or "cuing effect", in which stimuli presented at exogenously cued or endogenously indicated locations are responded to faster and/or more accurately than those presented at uncued locations (e.g., Posner, 1980; Prinzmetal, Presti, & Posner, 1986).

Even though cuing effects can be observed with both endogenous and exogenous cues, recent findings converged to the idea that endogenous attention and exogenous attention produce qualitatively different effects on information processing. Interesting examples of dissociation between them have been shown on information processing speed (Carrasco & McElree, 2001; Shore, Spence & Klein, 2001; Schneider & Bavelier, 2003), illusory perceptions (Chica, Charras, & Lupiáñez, 2008), conscious perception (Chica, Botta, Lupiáñez, & Bartolomeo, 2012; Chica et al., 2011), and on conflict resolution (Funes, Lupiáñez, & Milliken, 2007). Particularly, Funes et al. (2007), after showing good evidence for a double dissociation between endogenous and exogenous attentional mechanisms, suggested that a good strategy to investigate the differences between these ways of attentional orienting might be to take into account their differential effects on later stages of information processing. Among these stages, attentional modulation over working memory certainly represents an excellent candidate.

As a matter of fact, in the last fifteen years strong relationships have been both theorized and observed between spatial attention and the encoding, maintenance, and retrieval of selected information in spatial

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http://dx.doi.org/10.1016/j.actpsy.2014.03.013
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working memory (Awh & Jonides, 2001; Awh, Vogel, & Oh, 2006; Bundesen, 1990). Particularly, it has been proposed that attention might act as a “gatekeeper” for information storage in working memory, by controlling the flow of information into working memory, thus biasing the encoding of the objects that are most relevant at the present moment (see Awh et al., 2006, for a review). Botta, Santangelo, Raffone, Lupianez, and Olivetti Belardinelli (2010) explicitly investigated how exogenous orienting and endogenous orienting of spatial attention bias the information encoding into VSWM. Specifically, the presentation of an exogenous (Experiment 1) or endogenous (Experiment 2) cue was followed by a memory array consisting of 8 colored squares, one at each of eight possible locations evenly spaced around an imaginary circle. After a brief delay, the display was presented again with a single probe square in one of the locations, and participants were required to discriminate whether the color of the square presented at that location was the same or different from the one in the preceding memory array (see Luck & Vogel, 1997). The results pointed to a dissociation between the two orienting mechanisms in terms of both meridian and distance effects.[1] Particularly, they found meridian crossing effects only when attention was oriented by endogenous (i.e., central symbolic and predictive) cues, in perfect accordance with the dissociation regarding the meridian effect already observed in the perceptual domain (Rizzolatti, Riggio, Dascola, & Umiltá, 1987; Rizzolatti, Riggio, & Sheliga, 1994). On the other hand, the bias exerted by exogenous (peripheral non predictive) cues on VSWM performance was purely affected by the cue–target distance.

Summarizing, perceptual and VSWM studies indicated that when selective spatial attention is directed to a specific location it produces both an improvement in perceptual processing and an increase in the likelihood that information at this location will be encoded in VSWM. Notwithstanding, it seems that the spatial distribution of the attentional effects on both perception and VSWM changes depending on the way, endogenous or exogenous, by which attentional resources are allocated in the environment.

In the present study we aimed at further exploring the nature of exogenous vs. endogenous attentional modulation over VSWM, by investigating the nature of the distribution of attention, and its modulation over VSWM, when attention is endogenously pushed toward to vs. exogenously pulled by more than one location/object at the same time, i.e., when two cues are simultaneously presented instead of one.

In most cases the objects that capture our attention occupy one single and undivided spatial area. In these cases spatial distribution of attentional effects can be mostly explained by a simple gradient function of attentional facilitation, characterized by a peak over the attended location and by a decrease in the size of the effect as spatial distance from the attended location increases (Henderson & Macquistan, 1993). Consistently, classical models of spatial attention, as the “spotlight” metaphor originally proposed by Posner (1980) and the “zoom lens” model proposed by Eriksen and St. James (1986), both support an interpretation of spatial attention as unitary in nature, excluding the possibility that the attentional focus could be split in two or more disjointed locations.

Notwithstanding, in many daily life circumstances, we need to select together stimuli that are located in noncontiguous regions of the space, as for objects partially occluded or when the to-be-selected stimulus consists of a configuration of objects at separated locations (see Bichot, Cave, & Pashler, 1999). In these cases selection might be better accomplished by other perceptual features than location, such as color or form. However, many studies suggest that selection mechanisms are mediated by spatial location even when the target stimulus is defined by other dimensions than position (see Cave & Bichot, 1999, for a review). This implies that location plays a crucial role in visual selection and somehow indicates that there may be a mechanism by which spatial attention selects noncontiguous locations. Accordingly, in the last twenty years there has been a growing body of evidence claiming that multiple locations can be simultaneously attended (Awh & Pashler, 2000; Baldauf & Deubel, 2008; Bichot et al., 1999; Carlson, VanRullen, Hogendoorn, Verstraten, & Cavanagh, 2007; Gobell, Tseng, & Sperling, 2004; Kraft et al., 2005; Müller, Malinowski, Gruber, & Hillyard, 2003; Scharlau, 2004).

Therefore, at present the question regarding whether attention can be split or not is still unsolved, the reason perhaps being that the truth might lie in the middle, or that it might depend on the nature, endogenous or exogenous, of attentional orienting. In a very recent work, Feng and Spence (2012) intriguingly observed that since both the unitary and multiple-foci models are well supported by empirical and physiological data, it seems unlikely that one of these models is right and the other is wrong. They suggested instead that the occurrence of a single focus or multiple foci is possibly the result of specific experimental conditions. More specifically, Standage, Trappenberg, and Klein (2005) used a neural network simulation to show that attentional split in more than one location is more likely to be observed when the distance between the attended locations is relatively high compared to the spread of each individual attentional distribution. In other words, it seems that the distance between the attended locations is crucial for observing or not effects indicative of attentional split.

Furthermore, we propose that another decisive factor for attention being split in multiple locations might be the presence or absence of frames, objects or, in general, physical stimuli at the to-be-attended locations. Specifically, consistently with many findings suggesting a parallelism between endogenous and exogenous mechanisms on one side and space-based and object-based on the other side (Lauwereyns, 1998; Macquistan, 1997), we hypothesize that it might be possible to split the focus only when attention is automatically captured by objects (exogenous attention), but not when it is voluntarily directed to empty locations (endogenous attention).

1.1. The present study

According to the above-mentioned literature, in the present study we explored how the distance between endogenous and exogenous multiple cued locations affects the spatial distribution of attention, by studying its effects on a further level of information processing than perception. Specifically, following the logic suggested by Funes et al. (2007) to dissociate exogenous from endogenous attention, we analyzed their differential effects on VSWM information encoding.

At this aim we used a task very similar to that of Botta et al. (2010), combining a cuing paradigm with a task involving identification in VSWM. With this new task the presentation of two endogenous (Experiment 1) or exogenous (Experiments 2 and 3) cues was followed by a memory array consisting of eight letters instead of eight colored squares. After a short interval, a location was probed for participants to report the identity of the letter that was presented there in the preceding memory array (see Fig. 1). The stimuli were circularly arranged in such a way that we could precisely control the distance between cued and probed locations. The main reason for this modification of Botta et al.'s paradigm, shifting from recognition to recall, was to increase task difficulty. In fact, according to Jans, Peters, and DeWeerd (2010) setting an appropriate task difficulty is a necessary condition to study divided attention. Nonetheless as this represents an important procedural change of Botta et al.'s study, we firstly replicated their main results in a preliminary study by using a single cue. A description of two experiments with this new procedure, one with a single endogenous and the other with a single exogenous cue is provided in Appendix A. Since the main results of our previous study were perfectly replicated, we used this new procedure in the current double-cue experiments.

[1] Meridian effect consists on an increase of RTs and/or errors when spatial cues and targets are presented on different visual fields (in reference to the vertical and/or horizontal meridians which represent the axes of symmetry of the visual field). Distance effect can be defined as a decrement in performance as a function of the spatial distance between the cue and the target.