



Effects of load on the guidance of visual attention from working memory

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ARTICLE INFO

Article history:

Received 1 November 2010

Received in revised form 14 September 2011

Available online 19 September 2011

Keywords:

Attentional guidance

Memory load

Working memory

Biased-competition

ABSTRACT

An active recent line of research on working memory and attention has shown that the visual attention can be top-down guided by working memory contents. The present study examined whether the guidance effect is modulated by memory load, i.e., the amount of information maintained in working memory. In a set of three experiments, participants were asked to perform a visual search task while maintaining several objects in working memory. The memory-driven attentional guidance effect was observed in all experiments when there were spare working memory resources. When memory load was increased from one item to two items, there was no sign that the guidance effect was attenuated. When load was further increased to four items, the guidance effect disappeared completely, indicating a clear impact of memory load on attentional guidance.

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1. Introduction

When extracting relevant information from a complex visual environment, attentional guidance is often needed as an effective mechanism to optimize target selection (Wolfe, 2007). During visual search, guidance of attention towards a likely target can be achieved in two ways (Buschman & Miller, 2007; Wolfe et al., 2003). In the bottom-up or stimulus-driven way, stimuli with distinctive attributes such as large target–distractor dissimilarity (Müller, Heller, & Ziegler, 1995), novelty or singleton (Johnston et al., 1990) can pop out easily from a visual scene and capture attention. In the top-down or user-driven way, attention is guided by some knowledge or information an observer possesses either implicitly (e.g., contextual cueing, Chun & Jiang, 1998, 2003) or explicitly (e.g., verbal description of the target, Wolfe et al., 2003, 2004).

As a specific case, research has shown that there is attentional guidance by representations in working memory (WM) (Chelazzi et al., 1993; Logan & Gordon, 2001). Soto and colleagues required participants to search for a tilted line target among three vertical lines while holding in WM a colored shape cue (Soto, Humphreys, & Heinke, 2006; Soto et al., 2005). Critically, each item in the search display was enclosed inside a colored shape. Search performance was impaired when the memory item re-appeared surrounding one of the distractor items, compared with when it was absent in the search display. The results were interpreted to suggest that

WM contents, even though not part of the target template to search for, can still guide attention and bias its orientation to items with matching information (see also Olivers, Meijer, & Theeuwes, 2006).

Woodman and Luck (2007), however, found that the attention was directed away from rather than biased towards a memory-matching-distractor in visual search, a result also observed by Downing and Dodds (2004). Soto and Humphreys (2008) suspected that what Woodman and Luck (2007) found may somehow result from loading WM too much with the use of articulatory suppression and the need to maintain three objects. In support of this, Soto and Humphreys (2008) found no change of attentional guidance when load increased from one to two objects, but the effect was eliminated at load 2 combined with articulatory suppression. Although these results are not sufficient to reveal why opposite effects were found across the two abovementioned studies, they at least indicate that WM load is an important factor to be considered when studying attentional guidance. Study of this factor may also help to illuminate the nature of the guidance effect, for example, whether such guidance operates automatically or under voluntary control (Hasher & Zacks, 1979; Schneider & Shiffrin, 1977).

In the present study, we followed Soto and Humphreys (2008) to further examine the impact of memory load on attentional guidance. We would simplify the situation by removing the articulatory suppression component and vary the load factor alone. On the one hand, if both WM load and articulatory suppression compete for cognitive resources, which would then affect the guidance effect per the Soto and Humphreys (2008) study, it would be necessary to assess their impact separately. On the other hand, participants

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in Woodman and Luck (2007) and Soto and Humphreys (2008) were essentially performing three tasks at the same time, articulatory suppression, visual search, and load maintenance. If human frontal functions are limited to pursuing no more than two concurrent goals (Charron & Koechlin, 2010), coordination between three tasks would exceed this limit and lead to performance patterns highly contaminated by strategic factors.

2. Experiment 1

Soto and Humphreys (2008) found that when WM load increased from 1 to 2, attentional guidance was robust and stayed unaffected. We adopted the paradigm in their first experiment and asked whether higher load including a level approaching the WM capacity (Cowan, 2001; Luck & Vogel, 1997; Vogel, Woodman, & Luck, 2001) would affect the guidance effect.

2.1. Methods

2.1.1. Participants

Twenty students (aged between 19 and 23 years old, mean age = 20.1 years) with normal or corrected-to-normal visual acuity and normal color vision participated in this experiment. All were right-handed. Informed consent was obtained at the beginning of the session following a research protocol approved by the Institutional Review Board of the South China Normal University (Guangzhou, China).

2.1.2. Stimuli

All visual stimuli were presented in a gray background on a color CRT monitor (resolution: 1024×768 ; frame rate: 60 Hz) about 57 cm away from the viewer. There were 81 objects constructed by crossing nine colors (red, blue, yellow, cyan, green, orange, pink, black, and white) and nine line drawings of shapes (listed in Fig. 1), each subtending a visual angle of approximately $1.9^\circ \times 1.9^\circ$. The thickness of the border line of the shapes was about 0.5° in visual angle. When there was only one object to hold in memory, the object appeared at the screen center. When there were two objects, they were positioned 2° above and below the screen center. When there were four objects, they were located at the corner of a $4^\circ \times 4^\circ$ imaginary rectangle.

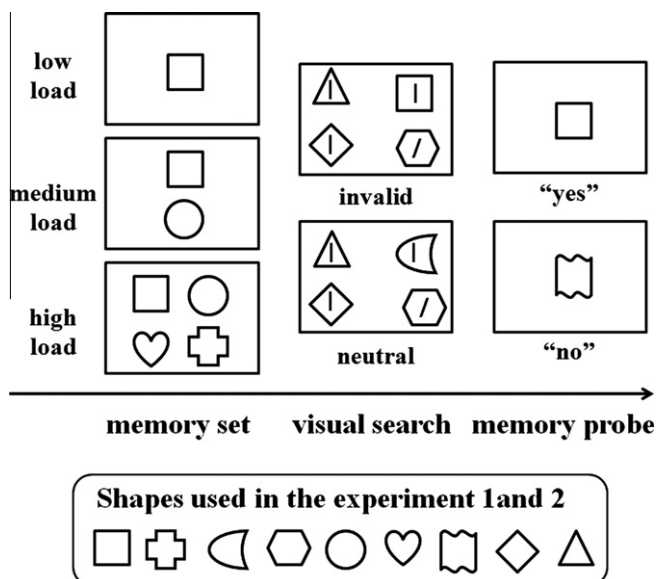


Fig. 1. The sequence of events in a sample trial in Experiment 1. Each shape has a different color.

The search array was composed of four black lines ($0.57^\circ \times 1.2^\circ$) with each embedded inside a colored shape. The three distractor lines were vertical and the one target line was tilted 38° either to the left or right. The search items were arranged around an imaginary circle (radius = 6°), presented at either 1, 4, 7, 10 or 2, 5, 8, 11 o'clock locations.

2.1.3. Procedure

As shown in Fig. 1, each trial started with a $1^\circ \times 1^\circ$ fixation cross for 1000 ms in the center of the screen, followed by the presentation of the memory set. There were three load conditions, low, medium, and high with 1, 2, and 4 objects respectively. The memory set was displayed longer when there were more objects (1000 ms for 1 object, 2000 ms for two objects, and 4000 ms for four objects) to allow adequate encoding. Once the memory set display was turned off, there was a 1000 ms blank screen, followed by the search array till response within 5000 ms. The response was separated by another 1000 ms blank interval from the onset of a memory probe. Participants were asked to study the memory set, searched for the target line, and then responded to the probe. They were required to respond as accurately and fast as possible to judge the orientation of the target line by pressing 'F' for left or 'J' for right. They were to decide whether the probe was the same as or different from any object in the memory set and to press 'F' or 'J' accordingly. The memory probe and one specific object in memory set were matched both in color and shape in half of the trials, and differed in color, shape or both with equal possibility in the other half. Only accuracy was emphasized in the memory probe task. The next trial started 2000 ms after the response to the memory probe.

Other than the load factor, there were two types of trials. In the invalid trials, one of the objects in the memory set re-appeared in the search array to contain a distractor line. In the neutral trials, there was no feature overlap between the memory set objects and colored shapes in the search display. For load higher than 1, each object in the memory set was equally likely to re-appear in the subsequent search array as the object surrounding a distractor.

Each participant did 30 practice trials, and then completed four blocks of 48 trials. Each block included 16 trials for each level of load, 8 for the invalid condition and 8 for the neutral condition.

3. Results

For the load effect on the accuracy measure of the memory probe task, a repeated-measures ANOVA showed a significant main effect of load ($F(2,38) = 15.59, p < .0005$). As the load was increased, memory recognition became less accurate, being

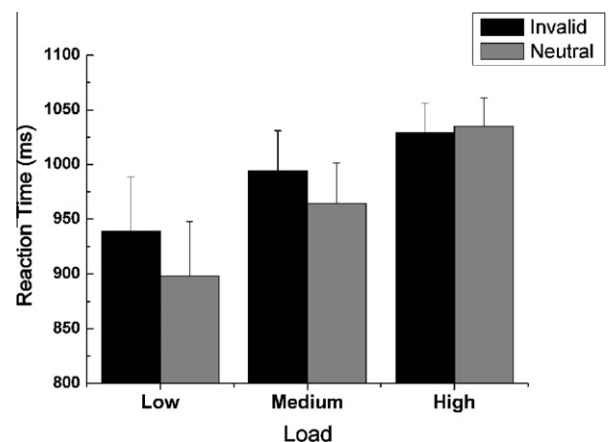


Fig. 2. Mean response time (RT) for all conditions in Experiment 1. Error bars represent standard errors.

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