

THE EFFECTS OF MEMORY LOAD IN VISUAL SEARCH ARE MODULATED BY SIMILARITY BETWEEN THE MATERIALS INVOLVED

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Abstract

The effect of memory load in visual search has shown a high heterogeneity of results: while some researchers have found an impairment of performance under high memory load conditions (eg. Lavie & De Fockert, 2006), others have found no effect of memory load (eg. Woodman, Vogel & Luck, 2001), and even others have found an improvement of performance under high memory load conditions (Smilek, Enns, Eastwood, & Merikle, 2006). In the present research we propose that the relationship between the material retained in working memory (WM) in a secondary memory load task and the target and distractors involved in the visual search task might be a key factor for explaining the discrepancies in the results. We tested our hypothesis manipulating that relationship in four experiments. The results show that the relationships between the material in WM and the target and distractors in the attentional task may be a crucial factor in modulating the effect of memory load in visual search. If the items retained in WM are similar to those presented as targets in the attentional task, visual search performance improves under high memory load conditions. On the contrary, if the items retained in WM are similar to those employed as distractors in the visual search task, there is no modulation of memory load in visual search. Finally, we discuss the theoretical implications in the context of the endogenous and exogenous attentional processes involved in visual search.

The effect of memory load in attention is one key topic in the study of attentional processes. Specifically, in Visual Search (VS) tasks a variety of results have been found. Some of the evidence supports the assumption that as memory load increases, attention to relevant material is impaired (Gil-Gómez de Liaño & Botella, 2010; Lavie & De Fockert, 2006). Other experiments, however, have failed to find the expected effect of memory load (Downing & Dodds, 2004; Logan, 1978; Woodman & Luck, 2007; Woodman, Vogel & Luck, 2001) and even others have found a more efficiency search under high memory load conditions (Smilek, Enns, Eastwood & Merikle, 2006); mostly arguing the flexibility of the cognitive system to sometimes inhibit or facilitate attentional mechanisms. The explanation that Smilek et al. (2006) gave to the results found was based on the idea that improved efficiency can result when reliance on slow executive control processes is replaced with reliance on more rapid automatic processes for directing attention during the search. However, using a very similar task to that used by Smilek et al. (2006), Woodman et al. (2001) did not find any effect of memory load in visual search.

One of the key differences between the studies of Smilek et al. (2006) and Woodman et al. (2001) is based on the information retained in the secondary memory task. Although the relationship between information held in working memory and information in the visual search task has not always modulated effects of memory load in attentional performance (Downing & Dodds, 2004; Woodman & Luck, 2007) there is also strong evidence supporting the effect (Chelazi, Miller, Duncan & Desimone, 1993; Smilek et al., 2006; Soto, Heinke, Humphreys & Blanco, 2005), and it

seems to be the most important difference found between Smilek et al. (2006) and Woodman et al. (2001) experimental procedures. Therefore, the present study pursues the idea that the effects of memory load in visual search could be modulated by the similarity between the material held in working memory and the material playing the roles of target and distractors in the visual search task. We hypothesize that if the information held in working memory is similar to the *target* in the visual search task, it will attract attention faster and, therefore, the slope of the search function will be shallower than in a single visual search task, as supported by many studies (Chelazzi et al., 1993; Downing, 2000; Jha, 2002; Soto & Humphreys, 2006; Soto et al., 2005, 2006). We tested that hypothesis in the first two experiments. Experiments 1 and 2A basically replicate Smilek et al. (2006), changing only the critical differences with the procedure of Woodman et al. (2001); that is, the relationship between material held in working memory and target or distractors in the attentional task. In both experiments, information in memory matches the target for the visual search, so we expect to find shallower slopes in the search function for the high memory load condition than for the single visual search task. We also conducted two more experiments (experiments 2B & 3) where information held in memory matched the distractors of the visual search task. That manipulation was also done by Downing & Dodds (2004) finding no effects of memory load in attentional performance. If the BCM model (Desimone & Duncan, 1995; Duncan & Humphreys, 1989) is right we would expect to find a reversion of the effect; a poorer performance in the visual search task when memory is loaded with distractors of the attentional task, because they automatically may capture attentional demands. However, if Downing & Dodds (2004) are right and there is a fractionated visual working memory system that allows maintenance of critical items not relevant to the task (target), no modulation of memory load is expected in the slope of the search function of the visual search task.

The results found in experiments 1 & 2A, as well as data shown in many other studies (Chelazzi et al., 1993; Smilek et al., 2006; Soto & Humphreys, 2006; Soto et al., 2005, 2006), support the hypothesis suggested: if information retained in working memory is similar to the target in the visual search task, it seems to capture attention and, therefore, the interference from the distractors is smaller than in a single visual search task. As expected in experiments 1 and 2A, we found a significantly shallower slope of the function in the memory load condition than in the single task condition. Apparently, the attentional effect of set size is attenuated by maintaining the target active in working memory. As different attentional capture studies have previously shown (e.g. Downing, 2000; Soto et al., 2005) the exogenous component of attention benefits by having the target items active in working memory and the selection of the target is less impeded by the distractors in the task.

In contrast, in experiments 2B and 3 we have found that the search functions were statistically equivalent in both conditions, as reflected in the lack of a significant interaction between memory load and set size in both experiments 2B and 3. No interaction showing a steeper slope function under the high memory load condition has been found. In fact, other studies have previously reported similar data. When information in working memory fits the distractors in the VS task there is no modulation of memory load in VS efficiency (Downing & Dodds, 2004; Moores & Maxwell, 2008). One of the most plausible explanations for present results has been proposed by Downing & Dodds (2004), suggesting the existence of two general models: one in which a representation of the current task biases the competition between items in a unitary Visual Working Memory (VWM) (results supported in our experiments 1 & 2A and in previous studies manipulating working memory and target information in VS), or one in which VWM is fractionated

to allow for maintenance of critical items that are not immediately relevant to the task. In other words, although the distractors in experiments 2B & 3 may have automatically captured more attention because they were active in working memory (those items that had to be recognized at the end of the trial), that capture is not enough strong as in experiments 1 & 2A to show more interference than in the single task condition because *they are not relevant* to the purpose of the task. In general, when information in working memory is the same as the target in the attentional task (experiments 1 & 2A) the exogenous component of attention is benefited by having the target items active in working memory and the selection of the target is less impeded by the distractors in the task, as proposes by the BCM model. When, however, information in working memory fits the distractors of visual search the exogenous component of attention is not benefited because the distractors are not relevant for the purposes of the task (searching the target) and they just show the same interference as in the single task, in contrast to what may be expected by the BCM model.

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