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The effects of array structure and secondary cognitive task demand on processes of visual search

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ABSTRACT

Many aspects of our everyday behaviour require that we search for objects. However, in real situations search is often conducted while internal and external factors compete for our attention resources.

Cognitive distraction interferes with our ability to search for targets, increasing search times. Here we consider whether effects of cognitive distraction interfere differentially with three distinct phases of search: initiating search, overtly scanning through items in the display, and verifying that the object is indeed the target of search once it has been fixated.

Furthermore, we consider whether strategic components of visual search that emerge when searching items organized into structured arrays are susceptible to cognitive distraction or not. We used Gilchrist & Harvey's (2006) structured and unstructured visual search paradigm with the addition of Savage, Potter, and Tatler's (2013) secondary puzzle task.

Cognitive load influenced two phases of search: 1) scanning times and 2) verification times. Under high load, fixation durations were longer and re-fixations of distracters were more common. In terms of scanning strategy, we replicated Gilchrist and Harvey's (2006) findings of more systematic search for structured arrays than unstructured ones. We also found an effect of cognitive load on this aspect of search but only in structured arrays. Our findings suggest that our eyes, by default, produce an autonomous scanning pattern that is modulated but not completely eliminated by secondary cognitive load.

1. Introduction

How is search disrupted by cognitive distraction? Visual search is at the heart of our visual behaviour: each eye movement we make involves a search of peripheral vision to identify the target of the next saccade, and search for an object in a cluttered scene can take several saccades until the object is correctly located and scrutinised by central vision. While our understanding of visual search in simple arrays and complex scenes is relatively well developed, the conditions under which we search in the lab are often unlike those under which we search in real situations. In particular, when we search in real situations, search is rarely the sole task we are engaged in. Rather search is conducted in situations where internal and external factors compete for our attention resources. Real environments are visually cluttered (unstructured), dynamic and noisy. However, there are also situations where the arrangement of objects in the environment provides structure for our search, for example looking for a specific cereal in a supermarket or your car in a crowded parking lot. Furthermore, we are often preoccupied, thinking about other things. This preoccupation can come from within the task we are engaged in: when searching for a particular object we are likely doing so as part of a larger behavioural goal and the processes of monitoring progress and planning the next steps of the task are themselves cognitively demanding. Preoccupation can also come from distracting secondary tasks such as contemplating previous conversations, rehearsing a shopping list, or listening to the radio. In some real world scenarios such cognitive preoccupation can have a profound effect on our ability to complete attentionally demanding real-world tasks (such as driving). Given the attentional demands of search, which are both low-level and high-level, it is likely that our ability to search effectively might be at risk from cognitive distraction.

Previous work has shown that distraction by secondary tasks can make search slower (Oh & Kim, 2004; Woodman & Luck, 2004), with participants being slower to initiate search, spending longer overtly scanning the items in the display and being slower to verify that the

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target has been found once it is looked at (Solman, Cheyne, & Smilek, 2011). These previous studies have used working memory paradigms based upon memory for recently seen visual displays. However, little is known about the impact of cognitive load coming from less visual sources, such as preoccupation with a previous conversation, upon search. Furthermore, whether secondary cognitive load impacts strategic elements of search is as yet unknown. Here we extend current understanding by studying the effect of cognitive load arising from a non-visual source of preoccupation and by considering whether systematic aspects of search are disrupted by such distraction.

How we search for targets amongst distractors has been studied extensively and much is understood about the underlying mechanisms when searching arrays of targets presented on computer monitors (see Wolfe, 1998). It is clear that search is guided by both low-level visual information and higher-level strategies (Wolfe, 2007). The low-level component is often operationalized as arising from an internal priority map of the scene constructed by combining low-level featural descriptions of the scene (e.g., Treisman, 1988; Treisman & Gelade, 1980; Itti & Koch, 2000; Wolfe, 2003). However, when attempting to extend these models to account for search behavior in more complex scenes, it is clear that purely low-level accounts of attention selection are very limited (see Tatler, Hayhoe, Land, & Ballard, 2011 for a review) because they fail to account for the influence of high-level factors such as strategy and task demands, on search behavior in complex scenes (Buswell, 1935; Yarbus, 1967). More recently Adeli, Vitu, and Zelinsky (2016) have proposed a model which includes high-level processes but core principles of superior colliculus organization. Their MASC (model of attention in the superior colliculus) is capable of predicting fixation locations of individuals when performing categorical and exemplar search tasks. The predictive success of this model relies on the incorporation of saliency and target maps (for prioritizing areas to be fixated based on low level features contrasts and higher level target goals respectively) coupled with the constraints associated with the basic organizing brain principles in the oculomotor system. This demonstrates the importance of considering low level, task specific as well as organizing brain principles when trying to understand the relationship between the visual world and overt visual attention.

In simple search arrays of targets and distractors on a screen, there appear to be clear strategic components to search that arise not from the visual features of the items in the display but from the structure of the array of items. Gilchrist and Harvey (2006) showed that search behavior differed when searching structured (that is, regularly arranged) arrays of items from that when searching unstructured arrays. When searching structured arrays, with items arranged in clearly identifiable rows and columns (see Fig. 1, left), searchers made more horizontal and vertical eye movements than when searching arrays that were less structured (as in Fig. 1, right). However, while disrupting the display structure led to a reduction in this horizontal/vertical bias, it did not eliminate it.

The presence of a preference to make more horizontal and vertical saccades irrespective of display structure suggests a systematic component to visual search. Strategic search has been found in other types of search arrays (e.g., Hooge & Erkelens, 1999) and even when viewing natural scenes, where horizontal and vertical saccades dominate (Tatler & Vincent, 2009). Gilchrist and Harvey (2006) interpreted this systematic component of search, as evidence for a strategic component of visual search behaviour that greatly reduces the need to remember items that have been viewed previously. In a study conducted by Amor, Reis, Campos, Herrmann, and Andrade (2016) the authors found that subjects had a clear preference towards a reading like pattern of eye movements during visual search. Such a preference, it is argued, eliminates the need to remember the location of previously inspected items. Likewise during mindless reading and z-string reading tasks it has been found that we move our eyes across letter strings in the same way regardless of the cognitive demands of the visual information (Luke & Henderson, 2013; Nuthmann, Engbert, & Kliegl, 2007; Rayner & Fischer, 1996). Moreover, Vitu, O'Regan, Inhoff, and Topolski (1995) tested both a letter search task and a z-reading task, and found that the eye-movement behaviour was similar regardless of the linguistic content or the type of task. Although these studies have demonstrated similarities in eye movement behaviour when looking at words and z-strings, it should be stated that we cannot be certain that eye movements in mindless reading are not affected by cognitive task demand.

It is not yet clear whether search strategies such as the systematic scanning identified by Gilchrist and Harvey (2006) and others are affected by distraction stemming from a secondary cognitive task. If systematic scanning were a result of higher-level processes or strategies, one would expect a reduction of this systematic component when secondary cognitive task demand is high. Conversely if systematic scanning requires no effortful top-down control but is a process employed to free up resources and guide visual search when secondary cognitive task demand is high, one might expect an increase in this systematic component. Another alternative would be that the preference to make reading like eye movements (many horizontal and vertical interspersed with a few oblique saccades) is automatic due to decades of reading and is not affected at all by the addition of a cognitive task.

Previous research has found that working memory resources play an important role in visual search processes. These are thought to be in terms of maintaining a template of the search target in working memory throughout search (e.g., Shiffrin & Schneider, 1977; Wolfe, 1994, 2012), and deploying attention (Bundesen, 1990, Desimone & Duncan, 1995; Miller & Cohen, 2001). This is supported by previous reports that secondary visual working memory load slows search (Oh & Kim, 2004; Oliviers, Meijer, & Theeuwes, 2006; Woodman & Luck, 2004; Woodman, Vogel, & Luck, 2001) increases disruption by distractors (Lavie, 2005) and increases the rate of re-fixating previously-

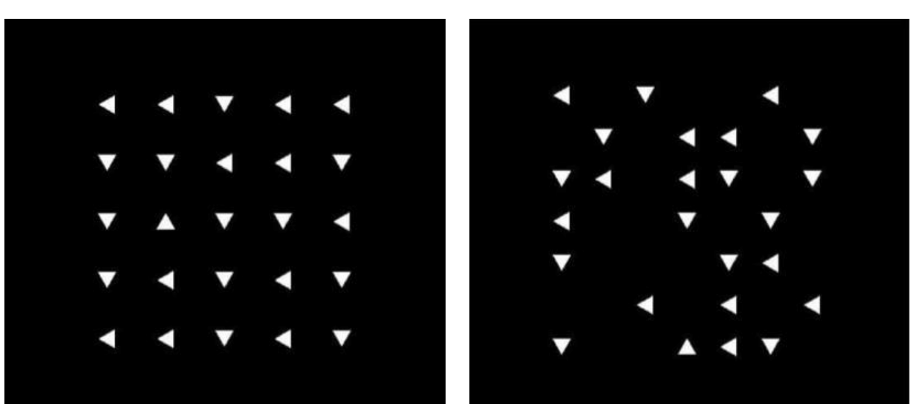

Fig. 1. Example displays of both structured (left panel) and unstructured (right panel) search arrays.