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Simultaneous attentional guidance by working-memory and selection history reveals two distinct sources of attention

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ABSTRACT

Recent theories of attention have proposed that selection history is a separate, dissociable source of information that influences attention. The current study sought to investigate the simultaneous involvement of selection history and working-memory on attention during visual search. Experiments 1 and 2 used target feature probability to manipulate selection history and found significant effects of both working-memory and selection history, although working-memory dominated selection history when they cued different locations. Experiment 3 eliminated the contribution of voluntary refreshing of working-memory and replicated the main effects, although selection history became dominant. Using the same methodology, but with reduced probability cue validity, both effects were present in Experiment 4 and did not significantly differ in their contribution to attention. Effects of selection history and working-memory never interacted. These results suggest that selection history and working-memory are separate influences on attention and have little impact on each other. Theoretical implications for models of attention are discussed.

1. Introduction

Do your eyes scan every shelf of your refrigerator when looking for a milk jug or is your attention directed to a certain area? To make search efficient, you can rely on your past experience with milk jugs in your refrigerator to guide your search. For example, milk jugs may have consistent visual features or probable locations where they have been found in previous searches. Holding a mental representation of a white milk jug while searching might also cause your attention to be directed towards white objects. These methods are indicative of visual search strategies that are informed by repeated experiences performing a task (Chun & Jiang, 1998, 2003; Jiang, Swallow, & Rosenbaum, 2013; Kunar, Flusberg, & Wolfe, 2008) and by representations held in working memory (WM; Desimone & Duncan, 1995; Kiyonaga, Egner, & Soto, 2012; Olivers, Meijer, & Theeuwes, 2006; Soto, Hodsoll, Rotshtein, & Humphreys, 2008). These sources of information work to bias and guide attention in different ways during visual search (Awh, Vogel, & Oh, 2006; Theeuwes, 2010; Woodman, Luck, & Schall, 2007).

The prominent framework used to explain attentional guidance in visual search describes a dichotomy of control: endogenous, top-down sources of attention that are goal-driven, and exogenous, bottom-up sources of attention that are salience-driven (Posner, 1980; Posner & Petersen, 1990; Wolfe, Cave, & Franzel, 1989; Yantis & Jonides, 1990). While this framework has demonstrated success in explaining many perceptual phenomena, like pop-out effects and guided attention, recent studies have challenged the reality of this attentional dichotomy (Awh, Belopolsky, & Theeuwes, 2012). Specifically, criticisms have been directed towards the presumed equality of top-down or goal-driven attention and the apparent conflict in explaining attention driven by rewards and selection history, which can still guide attention when they are not congruent with task goals. Henceforth, we will focus exclusively on the guidance of attention as a result of selection history and its relation to WM.

1.1. Selection history

Certain aspects of a visual search, such as target locations, are incidentally learned when the search is performed repeatedly. This statistical learning, which occurs as a result of contextual or probability cuing, can guide attention to probable target locations in visual search. Studies in contextual cuing have found that familiar spatial contexts can serve to implicitly cue target location in visual search, even if the

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context itself is not meaningful, as long as the association between the context and target location remains constant (Chun & Jiang, 1998; Kristjansson, Mackeben, & Nakayama, 2001). This results in speeded responses toward targets at the location defined by the selection history. Contextual cuing occurs implicitly via repeated exposure to the same associations (Chun, 1999; Torralba, Oliva, Castelhano, & Henderson, 2006) and can occur on both local (near the target) and global (overall) scales (Kunar, Flusberg, & Wolfe, 2006). The mechanism responsible for the speeded responses may be improved guidance of attention (Chun & Jiang, 1998, 2003; Jiang et al., 2013) or simply a lower threshold needed to elicit responses due to repeated displays (Hout & Goldinger, 2012; Kunar, Flusberg, Horowitz, & Wolfe, 2007; Schankin & Schubö, 2009).

Although contextual cuing effects are robust (Brady & Chun, 2007; Olson & Chun, 2002), flexible (Jiang & Wagner, 2004), and long lasting (Chun & Jiang, 2003), the extent of contextual cuing in certain visual search tasks is limited. For example, Kunar and Wolfe (2011) did not find contextual cuing if the cue was predictive of the absence, rather than the presence, of a target. In fact, contextual cuing only occurred when the cue was perfectly predictive of the target on target-present trials. Any disruption in the target-distractor association eliminated contextual cuing effects (Kunar & Wolfe, 2011).

Prior studies have generally investigated selection history in isolation. These studies have found that target detection is speeded when a target appears in a probable location as compared to an improbable location (Geng & Behrmann, 2005; Hoffmann & Kunde, 1999; Shaw & Shaw, 1977). This speeding of target detection not only occurs for probable locations, but for probable target features as well (Schwark & Dolgov, 2013). Several studies have examined the role of selection history in conjunction with other sources of attention. For example, Geng and Behrmann (2005) presented targets in probable locations along with a simultaneously presented cue and found evidence of both top-down and bottom-up contributions to probability cuing. Selection history can also influence the allocation of WM resources (Umemoto, Scolari, Vogel, & Awh, 2010). Umemoto and colleagues found that, in a change-detection task, objects were more likely to be encoded in WM if they occurred in quadrants where changes were most probable. Furthermore, certain types of objet features are also more likely to be encoded based on a higher probability that the feature will change (van Lamsweerde & Beck, 2011).

Recently, investigations into the conflict between selection history and alternative sources of attention have begun to provide a clearer picture of how selection history contributes to bottom-up and top-down direction of attention. The guided search model asserts that selection history, or contextual cuing, functions as a source of top-down attentional guidance (Wolfe, 2007). Alternatively, the biased-competition model states that statistical learning functions in a bottom-up manner to bias top-down control (Desimone & Duncan, 1995). Additionally, it has recently been suggested that, rather than being subsumed by other cognitive processes, selection history functions as a separate, tertiary director of attention (Awh et al., 2012; Jiang et al., 2013).

Jiang et al. (2013) investigated attentional guidance using spatial probability cuing with an endogenous cue, similar to Geng and Behrmann (2005). They found that, while both spatial probability and the endogenous cues impacted attention similarly, endogenous cuing took precedence when presented simultaneously. However, when statistical learning was allowed to develop before the endogenous cue was introduced, an overadditive effect was found, whereby probability cuing was only influential when the endogenous cue validly cued the target location. They concluded that this probability cuing is a distinct source of attentional guidance from top-down control and proposed a tripartite model. However, the authors did note that they could not say that selection history was not biasing attention in a similar way to the bottom-up WM process described by Desimone and Duncan (1995).

Research investigating event-related potentials supports this notion, finding evidence of WM activation while a feature is being learned, but not once the representation has presumably moved into long-term memory after repeated, consistent exposure (Carlisle, Arita, Pardo, & Woodman, 2011). When features of a search remain constant, there is little interference with WM and memory bias results from long-term memory, but when target features fluctuate throughout the experiment, WM is impaired, indicating that constant features are stored in long-term memory (Olivers, 2009; Woodman et al., 2007). Once established, this long-term memory representation can then guide search in a top-down manner (Van der Stigchel et al., 2009).

1.2. Working memory

While selection history takes time to accumulate before it influences visual search, WM representations have an immediate impact. According to the biased-competition model of attention (Desimone & Duncan, 1995), bottom-up processes establish a representation in WM that, in turn, biases top-down attention in search towards objects with features matching the representation. When the target matches this template, successful target identification is speeded (Kiyonaga et al., 2012; Olivers, Peters, Houtkamp, & Roelfsema, 2011; Soto et al., 2008). This WM capture effect has been found for both spatial (Awh & Jonides, 2001; Courtney, Ungerleider, Keil, & Haxby, 1996; Theeuwes, Kramer, & Irwin, 2011) and non-spatial target features (Beck, Hollingworth, & Luck, 2012; Kiyonaga et al., 2012; Olivers et al., 2006; Soto, Heinke, Humphreys, & Blanco, 2005). Typical visual WM paradigms use explicit cues to manipulate WM representations. Cue validity, or how often the cue matches the target or a distractor, has been found to influence visual search performance (Carlisle & Woodman, 2011; Kiyonaga et al., 2012). In general, target identification is faster when given cues are highly valid. Importantly, these explicit cues are only influential when they are committed to memory (Downing, 2000; Olivers et al., 2006; Soto et al., 2005).

While many studies have found search benefits when the WM template matches a target feature and disadvantages when the WM template matches a distractor feature, others have failed to find this effect (Houtkamp & Roelfsema, 2006; Peters, Goebel, & Roelfsema, 2009; Woodman & Luck, 2007). These conflicting results prompted the question of whether the WM capture effect is a controlled or automatic process. Cued representations are attended to, even when they correspond with distractors, and this inability to override attention and ignore the cue when it is predictive of where not to attend seems to provide some support that attention is automatically captured (Soto et al., 2008). However, cued distractors may be intentionally attended to as well, so that the cued WM representation can be refreshed in anticipation of memory recall (Woodman & Luck, 2007). One proposed solution suggests that the immediate capture of attention is automatic, but executive control is used if the search is sufficiently delayed (Han & Kim, 2009). Yet, a recent study failed to find a cost when switching from automatic processing to executive control (Carlisle & Woodman, 2011), leaving the issue largely unresolved.

Different cue attributes also influence the cue's ability to facilitate visual search. For example, visual cues elicit larger search benefits than verbal cues (Wolfe, Horowitz, Kenner, Hyle, & Vasan, 2004). Cues that predict target color offer a stronger benefit than cues that predict target orientation (Anderson, Heinke, & Humphreys, 2010), even when the color cue is not predictive of the target (Anderson, Heinke, & Humphreys, 2011). Anderson et al. (2011) also found that color cues guide early eye movements and are strongest when the cue is presented for a short duration (100–200 ms), which is consistent with the finding that executive control can override automatic attentional capture when search is sufficiently delayed (Han & Kim, 2009).

The role of top-down and bottom-up processes in WM has remained an open area of investigation. Desimone and Duncan (1995) acknowledged that both processes likely contributed to WM capture, with bottom-up neural mechanisms biasing perception towards probable objects and top-down mechanisms determining whether those objects were relevant to the current task goals. Findings such as top-down control being diminished when WM are occupied (Lavie, Hirst, de Fockert,