



# Release of inattentive blindness by high working memory load: Elucidating the relationship between working memory and selective attention

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## ARTICLE INFO

### Article history:

Received 5 May 2009  
Revised 19 July 2011  
Accepted 28 August 2011  
Available online 19 September 2011

### Keywords:

Inattentive blindness  
Selective attention  
Working memory

## ABSTRACT

An unexpected stimulus often remains unnoticed if attention is focused elsewhere. This inattentive blindness has been shown to be increased under conditions of high memory load. Here we show that increasing working memory load can also have the opposite effect of reducing inattentive blindness (i.e., improving stimulus detection) if stimulus detection is competing for attention with a concurrent visual task. Participants were required to judge which of two lines was the longer while holding in working memory either one digit (low load) or six digits (high load). An unexpected visual stimulus was presented once alongside the line judgment task. Detection of the unexpected stimulus was significantly improved under conditions of higher working memory load. This improvement in performance prompts the striking conclusion that an effect of cognitive load is to increase attentional spread, thereby enhancing our ability to detect perceptual stimuli to which we would normally be inattentively blind under less taxing cognitive conditions. We discuss the implications of these findings for our understanding of the relationship between working memory and selective attention.

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## 1. Introduction

Working memory and selective attention have been shown to be closely related systems (e.g., Kane & Engle, 2003; Kim, Kim, & Chun, 2005; Lavie, Hirst, De Fockert, & Viding, 2004). The general finding has been that selective attention depends on the availability of working memory to maintain efficient target processing in the presence of potential distractors. This has led to the proposal that working memory constitutes an important top-down component in the processing of multiple incoming stimuli, to ensure that goal-directed behavior can be successfully based on task-relevant information. According to the “load theory” of selective attention (Lavie et al., 2004), the extent

to which task-irrelevant information is processed depends critically on the level of both perceptual and working memory task demands. The prediction from load theory is that a key role of working memory in selective attention is to keep a clear distinction between relevant, to-be-attended target information and irrelevant, to-be-ignored distractor information. On this view, working memory plays an active and direct role by maintaining processing priorities in order to selectively attend to relevant information.

A question that has received relatively little consideration in the literature concerns the precise relationship between working memory and selective attention. More specifically, although a clear relationship between working memory and selective attention has been established (e.g., Lavie et al., 2004) it remains relatively unclear which sub-component of working memory may be most involved in selective attention. Many studies have used verbal working memory tasks to load working memory during selective attention (e.g., De Fockert, Rees, Frith, & Lavie, 2001; De

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Fockert & Wu, 2009; Kim et al., 2005; Lavie & De Fockert, 2005; Lavie et al., 2004; Rissman, Gazzaley & D'Esposito, 2009). For example, participants maintain a set of digits while trying to ignore distracting flankers in a speeded target identification task (e.g., Lavie et al., 2004). Selective attention is modulated by the size of the to-be-maintained set, rather than merely by the need to (sub-vocally) rehearse the working memory items, as working memory load (WM load) effects on selective attention still occur during articulatory suppression (Lavie et al., 2004, Experiment 2). This suggests that the phonological loop is unlikely to be the working memory component most involved in selective attention. Loading working memory interferes with the ability to separate target and distractor information in visual processing, thereby increasing the likelihood that distractors are attended. Thus, we consider the most plausible candidate working memory component for the process of maintaining attentional priorities is the central executive, and argue that in many selective attention tasks, executive control processes are necessary both to rehearse the items in working memory and to maintain a task-appropriate focus of attention.

An interaction between working memory and selective attention through the central executive points at a domain-general effect of working memory. Some evidence, however, is not in line with this suggestion. In a study of the effects of working memory on selective attention by Kim et al. (2005), the content of the working memory set was manipulated to overlap with either target or distractor processing in a subsequent selective attention task. Distractor effects were greater under WM load when the memory task overlapped with target processing (i.e., having to read the word and ignore the ink color of a Stroop stimulus during a verbal working memory task), but smaller when the memory task overlapped with distractor processing (i.e., having to name the ink color and ignore the word during a verbal working memory task). No such effects were found with a spatial working memory task. These findings imply that the interaction between working memory and selective attention involves dissociable systems for different types of working memory, rather than a general working memory effect on selective attention. Other evidence, however, shows that this specificity does not always apply: greater distractor processing is also found under high load on verbal working memory when the target requires mainly non-verbal processing such as in visual search (Lavie & De Fockert, 2005), or making a size judgement (De Fockert & Wu, 2009). In these cases, the effect of working memory on selective attention has to be more general, as there is little overlap in terms of the nature of target processing, and the contents of the load on working memory. Other work also points at a domain-general role of working memory in maintaining task-appropriate priorities in visual processing (e.g., Rissman, Gazzaley, & D'Esposito, 2009).

The present study uses the inattention blindness paradigm to further investigate the precise role of working memory in selective attention. Inattention blindness refers to the finding that an unexpected visual stimulus often remains undetected when attention is engaged in another task (Mack & Rock, 1998; Rock, Linnett, Grant, & Mack,

1992). Inattention blindness is usually interpreted to mean that attention is sufficiently focused on a relevant task, thereby reducing the ability for processing of the unexpected task-irrelevant stimulus. For example, when observers have to engage in an attentionally demanding task that involves comparing the sizes of two lines (the "line task"), the presence of an unexpected visual stimulus close to the two lines often goes unnoticed (e.g., Downing, Bray, Rogers, & Childs, 2004; Rock et al., 1992). The dependence of inattention blindness on focused attention to another task makes it a suitable measure to test models that make predictions about selective attention under varying conditions of WM load. The current study aims to do so by measuring inattention blindness under varying levels of WM load.

Importantly, in the inattention blindness paradigm, participants perform a task that includes only target information until an unexpected distracting stimulus is presented just once. The inattention blindness paradigm therefore allows to investigate the role of working memory in selective attention in a situation in which attention has to be directed to relevant information without regular competition from irrelevant distractors. All previous evidence on the role of working memory in distractor processing (e.g., Kim et al., 2005; Lavie et al., 2004) have involved tasks in which a distractor was present on every trial, which would promote active suppression of known distractors. We argue that the level of overlap between a working memory task and an inattention blindness task is considerably less than is the case in selective attention tasks in which every trial contains both a target and distractors: whereas maintaining a clear target template (Duncan & Humphreys, 1989) in working memory is critical for successful target selection in the latter, such active maintenance of the target template is less important in the inattention blindness task, as no information other than the relevant target stimuli is present until the unexpected stimulus is presented. In the current study, we therefore measured detection of the unexpected stimulus in an inattention blindness task under varying levels of WM load, in order to determine to what extent working memory is also needed in a situation in which, up to that point, it had not been necessary to prioritize relevant processing and actively guard against distraction.

The load model (Lavie et al., 2004) makes different predictions regarding the level of interference from distractors, depending on the type of load (perceptual load or WM load) that is manipulated in a task. Under high perceptual load, the perceptual processing demands of the relevant task prevent processing of the task-irrelevant unexpected stimulus, thus leading to greater blindness. Confirming this prediction, research shows that inattention blindness is greater when evaluating line length in the line task (high perceptual load), compared to when evaluating line color (low perceptual load; Cartwright-Finch & Lavie, 2007). In contrast to the effect of perceptual load on inattention blindness, load theory predicts that increases in WM load should have the opposite effect, i.e., higher WM load should reduce inattention blindness (and thus, improve detection). If the prevention of processing of task-irrelevant information indeed requires working

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