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The benefits of stimulus-driven attention for working memory encoding

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ABSTRACT

The present study investigates how stimulus-driven attention to relevant information affects working memory performance. In three experiments, we examine whether stimulus-driven attention to items can improve retention of these items in working memory. Lists of phonologically-similar and dissimilar items were presented at expected or unexpected locations in Experiment 1. When stimulus-driven attention was captured by items presented at unexpected locations, similar items were better remembered than similar items that appeared at expected locations. These results were replicated in Experiment 2 using contingent capture to boost stimulus-driven attention to similar items. Experiment 3 demonstrated that stimulus-driven attention was beneficial for both similar and dissimilar items when the latter condition was made more difficult. Together, these experiments demonstrate that stimulus-driven attention to relevant information is one mechanism by which encoding can be facilitated.

Introduction

Working memory (WM) keeps information in an active state for a short period of time so that it can be readily accessed and manipulated in the service of immediate task goals. Given its limited capacity, WM must be used efficiently, maintaining only task-related information. Therefore, a large body of research has examined how the flow of information into WM is controlled in order to understand the limitations it places on human performance.

The benefit of voluntary attention for prioritizing task-related information at encoding is well-established (for reviews, see Awh, Vogel, & Oh, 2006; Gazzaley & Nobre, 2012); that is, WM performance improves when individuals exert control over what information is encoded and maintained in WM. However, the contents of WM are not entirely under voluntary control. This is primarily demonstrated in research examining the detrimental effects on WM performance when stimulus-driven attention is captured by irrelevant distractors (Anticevic, Repovs, Shulman, & Barch, 2009; Majerus et al., 2012; Olesen, Macoveanu, Tegner, & Klingberg, 2007; West, 1999). Stimulus-driven attention is an involuntary mechanism that is engaged by salient or novel properties of the environment. Rather than focusing on the detrimental effects of stimulus-driven attention to distracting information, the present study examines whether stimulus-driven attention can benefit WM performance.

Theories of WM widely embrace the notion that attention serves as a gate to resource-limited maintenance processes; however, there is little empirical work to verify that stimulus-driven attention results in better WM performance. On the theoretical side, the Embedded Process model (Cowan, 1988, 1999) posits that attention directed towards incoming stimuli will increase the activation level of these items in WM, and that attentional selection can be either voluntary or stimulus-driven. In particular, novel, salient, or personally-relevant stimuli will automatically

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recruit stimulus-driven attention compared to stimuli that have been habituated. A similar idea is incorporated in the serial-order-in-a-box (SOB) and the oscillator-based memory for serial order (OSCAR) models in which encoding strength is novelty sensitive in order to avoid the storage of redundant information (Brown, Preece, & Hulme, 2000; Farrell & Lewandowsky, 2002). The critical idea is that habituated or unchanged stimuli that do not capture attention will be strongly represented in WM only if they are voluntarily attended whereas novel stimuli will capture attention automatically and, thus, be encoded in WM (Cowan, 1988, 1999). Attention is assumed to modulate how strongly information is activated in WM. Thus, encoding benefits can be obtained by moving attention voluntarily via the top-down control or through stimulus-driven attention that is automatically directed toward novel or salient stimuli.

On the empirical side, investigations of the interaction between attention and WM have focused on the competition between voluntary and stimulus-driven attention when distraction is present (Anticevic et al., 2009; Majerus et al., 2012). For example, stimulus-driven attention to distracting information during the encoding or maintenance interval of a WM task reduces the accuracy and speed of recall (Anticevic et al., 2009; Majerus et al., 2012; Olesen et al., 2007; West, 1999). Other research has examined how items in WM may induce attentional capture to irrelevant items in a visual search task (see Soto, Hodsoll, Rotshtein, & Humphreys, 2008 for a review). Visual search is slower when stimulus-based attention is captured by distractors that are identical to or match the features of items held in WM (Olivers, Meijer, & Theeuwes, 2006; although see, Woodman & Luck, 2007). While these studies clearly demonstrate that stimulus-driven attention to irrelevant information disrupts performance, the current study investigates the potential benefits of stimulus-driven attention for encoding items into WM.

There is evidence that stimulus-driven and voluntary attention may have distinct consequences. For example, stimulus-driven attention does not appear to enhance perceptual encoding (Prinzmetal, Ha, & Khani, 2010; Prinzmetal, McCool, & Park, 2005). Prinzmetal et al. (2005) proposed that stimulus-driven attention shortens the decision stage through non-perceptual priming rather than an enhancing the quality of the perceptual representation (as when items are voluntarily attended). That is, stimulus-driven attention speeds processing because information is accumulated earlier for stimuli presented at the cued location. When response selection is modeled as a leaky accumulator model (e.g., Usher & McClelland, 2001), this results in faster, but not more accurate, responses to involuntarily attended information than unattended information (see Prinzmetal & Landau, 2008 for a review). Prinzmetal et al. (2005) showed in a series of experiments that just this pattern of results is observed when stimulus-driven attention is directed toward a stimulus whereas - both response accuracy and speed of perceptual identification improve when voluntary attention is directed towards a stimulus (Prinzmetal et al., 2005). Memory performance relies on accurate representations rather than speed of responding, however, and this casts doubt on whether stimulus-driven attention can improve WM recall in a similar manner to voluntary attention.

There is little data to indicate whether stimulus-driven attention affects WM performance. Involuntary cuing improves recognition accuracy in a visual change detection task due to the sudden onset of the cue (Schmidt, Vogel, Woodman, & Luck, 2002). Other studies have shown that visual salience (e.g., discontinuities in line orientation, intensity contrast, color opposition) improved memory for an object's location (Fine & Minnery, 2009; Santangelo & Macaluso, 2012). However, all of these studies presented items at multiple locations, simultaneously, making it unclear whether WM performance improved because the quality of information encoded in the memory trace increased or because environmental cues allowed this information to be entered into WM first. In other words, visual salience (Fine & Minnery, 2009; Santangelo & Macaluso, 2012) or the sudden onsets of involuntary cues (Schmidt et al., 2002) may have provided a starting point at which encoding could begin and so these items were prioritized (for a similar argument in perception, see Prinzmetal et al., 2010). It remains unclear whether stimulus-driven attention will have any effect on WM performance when selection is easy. In the present paper, we assess whether stimulus-driven attention will enhance memory when information is presented serially so there is no competition between items at encoding. In this way, we can assess whether stimulus-driven attention has similar benefits to voluntary attention in increasing the amount or quality of information encoded into WM or whether it merely prioritizes selection in a noisy environment.

The interaction of stimulus-driven and voluntary attention

Our hypothesis is that stimulus-driven and voluntary attention can act cooperatively as well as competitively to enhance memory encoding. Stimulus-driven attention may facilitate the encoding of items into WM by reorienting attention to novel or salient information that is task-relevant. Thus, stimulus-driven attention may be important when information is unlikely to be brought into the focus of attention through voluntary effort. For example, the ability to sustain voluntary attention may diminish as a function of time and memory for items at the end of a list of items might be especially vulnerable. This idea is in line with the claims of several WM models which posit a primacy gradient in which the strength of the memory trace declines for each successive item in a list (Brown et al., 2000; Farrell & Lewandowsky, 2002; Page & Norris, 1998). This primacy gradient may be due to declining voluntary attention to a relatively homogenous lists of items (; Farrell & Lewandowsky, 2002). Brown et al., 2000 argue that this idea is consistent with the lack of a primacy effect in incidental memory tasks in which attention may not be voluntarily deployed at encoding.

If stimuli are novel or salient, stimulus-driven attention may alleviate the attenuation and boost the activation of these items' representations. Critically, the benefit of stimulus-driven attention to memory encoding should only be observed for items that are unlikely to be brought into the focus of attention voluntarily. Items that are brought into