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A bilateral advantage for maintaining objects in visual short term memory

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ABSTRACT

Research has shown that attentional pre-cues can subsequently influence the transfer of information into visual short term memory (VSTM) (Schmidt, B., Vogel, E., Woodman, G., & Luck, S. (2002). Voluntary and automatic attentional control of visual working memory. *Perception & Psychophysics, 64*(5), 754–763). However, studies also suggest that those effects are constrained by the hemifield alignment of the pre-cues (Holt, J. L., & Delvenne, J.-F. (2014). A bilateral advantage in controlling access to visual short-term memory. *Experimental Psychology, 61*(2), 127–133), revealing better recall when distributed across hemifields relative to within a single hemifield (otherwise known as a bilateral field advantage). By manipulating the duration of the retention interval in a colour change detection task (1 s, 3 s), we investigated whether selective pre-cues can also influence how information is later maintained in VSTM. The results revealed that the pre-cues influenced the maintenance of the colours in VSTM, promoting consistent performance across retention intervals (Experiments 1 & 4). However, those effects were only shown when the pre-cues were directed to stimuli displayed across hemifields relative to stimuli within a single hemifield. Importantly, the results were not replicated when participants were required to memorise colours (Experiment 2) or locations (Experiment 3) in the absence of spatial pre-cues. Those findings strongly suggest that attentional pre-cues have a strong influence on both the transfer of information in VSTM and its subsequent maintenance, allowing bilateral items to better survive decay.

1. Introduction

Visual short term memory (VSTM) allows visual information to be maintained across intervals when no longer in view and thus plays a crucial role in many cognitive tasks. However, the capacity of this store is extremely limited, with most studies revealing that only 3–4 objects can be maintained at any one time (Luck & Vogel, 1997; Vogel, Woodman & Luck, 2001). In order to deal with this limited capacity store, humans must therefore prioritise the relevant information to be processed. The process which selects relevant information in the environment and subsequently maintains the information in memory has been recognised to heavily rely on attention. In fact, attention has even been described as a 'gatekeeper' of VSTM due to its ability to determine which information can enter the store (Awh, Vogel & Oh, 2006).

The role of attentional selective processes on VSTM representations has been extensively studied with the use of the cueing paradigm. For instance, a number of studies have demonstrated that directing attention to the location of one stimulus before encoding, with the use of spatial pre-cues, subsequently improves the chance that the item is transferred into VSTM (Botta, Santangelo, Raffone, Lupianez & Belardinelli, 2010; Griffin & Nobre, 2003; Makovski & Jiang, 2007; Murray, Nobre & Stokes, 2011; Schmidt, Vogel, Woodman & Luck, 2002). Indeed, Murray et al. (2011) have recently demonstrated that neural activity associated with preparatory attention at the pre-cueing stage, can predict individual differences in the cue related advantage in VSTM recall. In addition, their findings revealed that the cue related advantage was associated with a specific electrophysiological correlate of VSTM maintenance indicating the number of items within VSTM (otherwise known as contralateral delay activity (CDA)), see Vogel and Machizawa (2004). Research also suggests that directing attention to task relevant stimuli at encoding can subsequently modulate activity in sensory cortices which code those stimuli (for a review see Gazzaley & Nobre, 2012). This top-down modulation has also been shown to directly influence VSTM performance (Rutman, Clapp, Chadick & Gazzaley, 2009; Zanto, Rubens, Thangavel & Gazzaley, 2011).

Furthermore, numerous studies have indicated that attentional directing spatial cues are also effective when presented during the maintenance stage of VSTM tasks. Specifically, those studies have shown that directing attention to the location of one previously encoded stimulus using *retro-cues* subsequently enhances the recall of that stimulus (Berryhill, Richmond, Shay & Olson, 2012; Delvenne, Cleeremans & Laloyaux, 2010; Griffin & Nobre, 2003; Landman, Spekreijse & Lamme, 2003; Lepsien, Griffin, Devlin & Nobre, 2005; Lepsien & Nobre, 2006; Makovski & Jiang, 2007; Makovski, Sussman &

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Jiang, 2008; Matsukura, Luck & Vecera, 2007; Nobre et al., 2004; Tanoue & Berryhill, 2012; Tanoue, Jones, Peterson & Berryhill, 2013, amongst others). Recent electrophysiological evidence suggests that retro-cues promote the selective access of relevant VSTM representations and bias processing in favour of those representations (Kuo, Stokes & Nobre, 2012). Specifically, Kuo et al. (2012) revealed that retro-cues can also modulate the CDA, which in response to retro-cues, reflects the withdrawal of processing resources from irrelevant stimuli and the maintenance of the cued stimuli.

State based models of short-term memory (Cowan, 1995; McElree, 1996; Oberauer, 2002) also propose that attention can play a fundamental role in the short-term retention of information. Specifically, those models reconceptualise the idea of visual short-term memory as active long-term memory, highlighting that attention can influence the representation of items which reside in a common memory store. Indeed, cognitive neuroscience research suggests that memory items inside and outside the focus of attention elicit different neural responses (for a review, see LaRocque, Lewis-Peacock & Postle, 2014).

Recently, we have provided evidence that directing attention simultaneously to the locations of two stimuli, with the use of two separate and non contiguous attentional cues, also improves the chance that those items are transferred into VSTM (Delvenne & Holt, 2012; Holt & Delvenne, 2014). Importantly, the two cues were significantly more effective when they were distributed between the left and right hemifields relative to within the same single hemifield. This supports a number of previous studies that have found that attentional resources are more effectively distributed across hemifields relative to within a single hemifield (Alvarez & Cavanagh, 2005; Awh & Pashler, 2000; Kraft et al., 2005; Malinowski, Fuchs & Müller, 2007). Specifically, those studies suggest that the focus of attention can be split to non contiguous locations more easily when the locations are divided across hemifields relative to within a hemifield. The direct implication of this ability to bilaterally split attention is what is known as the *bilateral field advantage* (BFA), namely an increase of visual processing efficiency when to-be-processed information is divided across the two visual fields relative to when the same information is presented within just one hemifield (e.g. Alvarez & Cavanagh, 2005). This is likely to be an effect of the underlying anatomy of the early visual system which is contralaterally organised (Eviatar & Zaidel, 1994; Gazzaniga, 2000). As the information within each hemifield is initially processed by the contralateral hemisphere, the BFA may be attributed to a processing advantage when stimuli are projected to both cerebral hemispheres rather than one. This advantage in visual processing may be attributed to the interaction of processing resources from each hemisphere (see Banich, 1998) and/or the engagement of independently controlled capacity limited hemispheres (see Alvarez & Cavanagh, 2005) (for a review, see Delvenne, 2012).

Our most recent findings suggest that those hemifield constraints on attentional selection can indeed impact the transfer of information into VSTM (Holt & Delvenne, 2014). By selectively pre-cueing coloured squares in the presence of distracters at encoding, we observed better memory performance when the cued squares were divided across both the left and right hemifields relative to within a single hemifield. Importantly, the BFA was not observed in the absence of those selection requirements, strongly suggesting that the BFA is the result of attentional selection.

Rutman et al. (2009) suggest that better VSTM recall in response to pre-cues may be explained by an increase in the fidelity of memory representations due to the early modulation of sensory activity in response to selection. In relation to our previous findings (Holt & Delvenne, 2014), this suggests that bilateral items which are attentionally selected at encoding, may also better survive decay relative to unilateral items. Therefore, the present study investigated whether selective pre-cues can also influence the retention of information in VSTM within and across hemifields. The effect of selective pre-cueing on VSTM maintenance was directly tested by manipulating the retention interval of a memory task (i.e., 1 s versus 3 s). It was hypothesised that if splitting attention between the left and right hemifields at the encoding stage provides a benefit on the transfer of the cued items into VSTM but also on their retention, then two bilaterally cued items may better survive decay in memory as compared to two unilaterally cued items.

To preview the results, we found that the BFA was influenced by the duration of the retention interval (Experiment 1 & 4). Interesting the BFA emerged as the retention interval was increased suggesting that bilateral items better survived decay in VSTM. Importantly, this was not shown in the absence of the cues (Experiment 2 & 3), suggesting those effects pertain to the selection of information at the encoding stage. As a result, the findings suggest that selection not only affects the transfer of items into VSTM (Schmidt et al., 2002), but also influences VSTM maintenance. This provides a new understanding of the dynamic relationship between attention and VSTM.

2. Experiment 1

2.1. Method

2.1.1. Participants

18 subjects completed the experiment (9 females; mean age = 24.04 years; range = 20–34 years). Participants were neurologically normal with self-reported correct colour vision and normal or corrected-to-normal visual acuity.

2.1.2. Stimuli and procedure

A computer-based change detection task, generated using E-Prime computer software (Psychology Software Tools, Inc., www.pstnet.com) was presented on a 17 inch screen of a 3.20GHz PC. Participants were seated at a viewing distance of 60 cm and a chin-rest was used to reduce movement. All stimuli were presented on a grey screen background (127 of red, blue and green phosphors) which was divided into 4 invisible quadrants (each subtending 4.8° × 4.8°).

On each trial, participants were presented with a black fixation cross (.61° × .61°) at the centre of the screen (500 ms) followed by the presentation of 12 white placeholders (.15° × .15°) which were presented at fixed positions across two vertical (unilateral presentation) or two horizontal (bilateral presentation) quadrants indicating the positions of the stimuli to be displayed (500 ms). As shown in Fig. 1, the placeholders within each quadrant were arranged in pairs. The centre–centre distance between each placeholder within a pair was 1.22°. The furthest stimuli from fixation were presented at an eccentricity of 5.76° (centre–centre) and 6.09° to the furthest stimulus edge in the horizontal and vertical directions. The closest stimuli to the vertical and horizontal

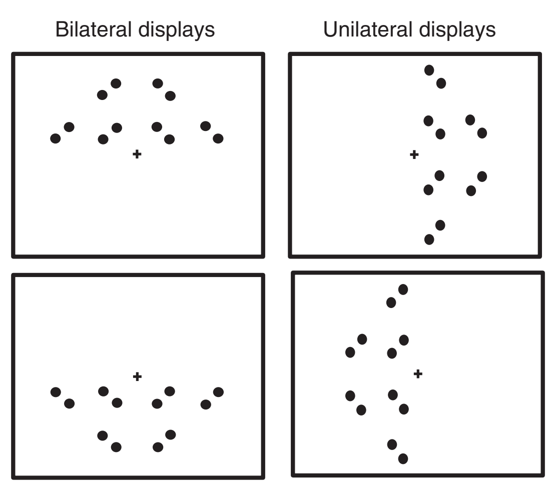

Fig. 1. An illustration of the fixed positions in the bilateral and unilateral displays of Experiment 1. For clarity, the illustration is not drawn to scale.