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Social attention directs working memory maintenance

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ABSTRACT

Visual working memory (vWM) performance is enhanced when a memorized object is cued after encoding. This so-called retro-cue effect is typically observed with a predictive (80% valid), retrospective cue. The current study examined whether a nonpredictive (50% valid) retro-cue can similarly enhance internal memory representations in cases where the cue conveys social signals. To this end, gaze cues were presented during the retention interval of a change-detection task, which are capable to engender a mutual attentional focus of two individuals towards one location. In line with our prediction, Experiment 1 demonstrated that a polygon presented at the gazed-at location was remembered better than that at both non-gazed and gazed-away locations. Experiments 2 and 3 showed that low-level motion cues did not elicit attentional orienting in a comparable manner as the gaze cue, and these differences in cuing were found to be reliable and independent of memory load. Furthermore, the gaze retro-cue effect disappeared when the face was inverted (Experiment 4). In sum, these results clearly show that sharing the focus of another individual establishes a point of reference from which visual information is restored with priority, suggesting that a gaze retro-cue leads to social attention, thus, modulating vWM maintenance in a reflexive, automatic manner.

1. Introduction

Visual working memory (vWM) actively maintains a limited proportion of the total sensory input to serve the needs of ongoing tasks, thus providing critical information for adaptive and efficient human behavior in an ever-changing visual environment (see Luck & Vogel, 2013, for a review). The representation of information in vWM is usually assessed with the change-detection task, in which a memory display containing multiple objects is followed by a blank retention interval, after which a test display is presented (Luck & Vogel, 1997). Studies using such a task have shown that observers are capable of maintaining up to four items in vWM, although the exact nature of this capacity limitation is currently a topic of vigorous debate (Luck & Vogel, 2013; Ma, Husain, & Bays, 2014). The contents in vWM are considered to reflect a stable and enduring representation that renders the structural layout in the environment (Nie, Müller, & Conci, 2017), and which is robust to visual interference (Irwin, 1991; Pinto, Sligte, Shapiro, & Lamme, 2013). Recent efforts incorporating spatial cues during the retention interval of a change-detection task (Myers, Stokes, & Nobre, 2017), however, provide a challenge to this rather static conception of vWM representations.

Growing evidence in fact indicates that objects stored in vWM are not fixed and unmodifiable, but are capable of being transformed, or shaped during maintenance. Such a flexible nature of vWM representations is supported by several studies demonstrating that spatial cues, which are presented after encoding can improve vWM performance even though no new information is provided to the observer (Berryhill, Richmond, Shay, & Olson, 2012; Delvenne, Cleeremans, & Laloyaux, 2010; Griffin & Nobre, 2003; Landman, Spekreijse, & Lamme, 2003; Makovski & Jiang, 2007; Makovski, Sussman, & Jiang, 2008; van Moorselaar, Gunseli, Theeuwes, & Olivers, 2015). These cues retroactively manipulate expectations, i.e., by providing a 70% valid cue that informs which of the memorized items will subsequently be relevant. Previous studies using such a task variant have repeatedly demonstrated that such a predictive retro-cue can substantially improve performance (e.g., by 15% relative to a no-cue condition, see Souza & Oberauer, 2016, for a review), thus, suggesting that contents in vWM can be modulated by retroactive shifts of attention.

The extant studies that investigated mechanisms of selective maintenance in vWM mostly used symbolic, non-social retro-cues (e.g., arrows or word cues). However, in everyday life humans often process information based on social cues such as another person's gaze behavior. Indeed, previous work demonstrated that these types of social cues can trigger visuo-spatial orienting of attention: averted gaze of others can automatically induce the observer to shift attention toward the

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location as signaled by the others' gaze direction (e.g., Driver et al., 1999; Friesen & Kingstone, 1998). Such a mutual attentional focus of two individuals towards one single location is known as "social attention". With these variants of spatial cuing paradigms, a series of studies have shown that the gaze direction of a centrally presented face can trigger automatic spatial orienting even if gaze direction does not predict where a target item may appear (i.e., when presenting only 50% valid cues) and/or when the observer is explicitly asked to ignore the cue (Driver et al., 1999; Friesen & Kingstone, 1998). In a typical gaze cuing task, a face would appear at the screen center, with the eyes looking straight ahead initially, after which the eyes avert to the left or right in a subsequent image frame (Bayliss, Paul, Cannon, & Tipper, 2006; Friesen & Kingstone, 1998). Next, a target letter was displayed at either the gazed-at (validly cued) or at the gazed-away (invalidly cued) location. Participants were instructed to categorize the target letters, which revealed a performance advantage for the valid relative to the invalid gaze cue condition (Deaner & Platt, 2003; Driver et al., 1999; Friesen & Kingstone, 1998; Ricciardelli, Bricolo, Aglioti, & Chelazzi, 2002; but see Sun, Stein, Liu, Ding, & Nie, 2017, for a different type of social cue [i.e., biological motion] in orienting unconscious attention). These findings have been taken to suggest that the gaze cue provides a socially and biologically relevant signal that is very efficient in triggering attention shifts.

Although the orienting effects induced by social stimuli as compared to orienting attention by non-social cues is still debated, a number of studies suggested that visuo-spatial orienting due to social and non-social cues leads to diverging behavioral effects that may rely on different underlying processes (Friesen, Ristic, & Kingstone, 2004; Langdon & Smith, 2005) and distinct neural systems (Callejas, Shulman, & Corbetta, 2014; Kingstone, Tipper, Ristic, & Ngan, 2004; Lockhofen, Gruppe, Ruprecht, Gallhofer, & Sammer, 2014). For example, Friesen et al. (2004) used a counterpredictive spatial cuing task to investigate attentional orienting in response to gaze cues as compared to non-social, arrow cues. The task induced a volitional bias in participants to expect that a target will appear at the location opposite to the gazed-at position (i.e., in 75% of trials when the eyes gazed at one side, the target would appear at the other, opposite side). Results indicated that gaze cues not only triggered reflexive orienting of attention to the gazed-at target location but also induced volitional orienting to a likely (i.e., predicted) target location as compared to two baseline locations (two other orthogonal positions) that were neither cued nor predicted. By contrast, only volitional orienting to predicted target locations (vs. baseline locations) was found in the arrow cue condition. These results suggest that social cues are processed differently from non-social cues, and they may in fact be special as they lead to both reflexive and volitional orienting, which are probably subserved by different attentional subsystems (Friesen et al., 2004). Given that orienting of attention in visual perception and in working memory share analogous mechanisms (Harrison & Tong, 2009; Mayer et al., 2007; Serences, Ester, Vogel, & Awh, 2009), it may be equally plausible that distinct behavioral results emerge for a retro-cue that comprises social as opposed to non-social information.

Recent studies that employed a retro-cue paradigm in vWM presenting non-social arrow cues have reported that cue validity modulates the magnitude of the cuing effect (Gunseli, van Moorselaar, Meeter, & Olivers, 2015; Gözenman, Tanoue, Metoyer, & Berryhill, 2014). For example, Gözenman et al. (2014) found a reliable retro-cue effect when the cue validity was 100%, but this effect disappeared when the cue validity decreased to 80%. This suggests that a decrease in cue validity reduces the informative cue value such that observers do not take full advantage of the information that the cue provides, thus leading to a less effective maintenance of items in vWM. By contrast, in a standard gaze cuing experiment, eye gaze was found to trigger reflexive orienting even though the cue did not predict the location where the target would appear (Friesen & Kingstone, 1998). One might therefore assume that such a social cue could reflexively guide individuals' attention to items in working memory even when the predictive value of the gaze cue is rather low. Gregory and Jackson (2017) investigated how gaze cues modulate vWM encoding, in which a vWM task was employed to compare how gaze cues, arrow cues, or non-social motion cues affect vWM encoding for colored squares. The cues were non-predictive of the location where the memory items would appear, but nevertheless, the results indicated that in particular gaze cues (but not arrow or motion cues) affected the encoding of colored squares into vWM. However, this study displayed the gaze cues *before* or *during* the presentation of colored squares and hence only examined the cues' effect on vWM encoding. It has however, been shown that pre-cues versus retro-cues are qualitatively different in typical vWM tasks such as change detection: predictive (e.g., 70% valid) spatial cues *before* the onset of a memory array facilitate the encoding of external representations at the cued location, thus modulating the access of items into vWM, whereas predictive retro-cues *after* the offset of a memory array rather prioritize internal representations at the cued location, i.e., they modulate already-stored object representations (Griffin & Nobre, 2003). To date, it remains unknown how gaze cues impact vWM when the cues appear *after* the offset of a memory array, that is, during maintenance. The current study therefore aimed to examine whether participants could selectively retain items after a nonpredictive gaze cue was presented during the maintenance interval.

The current study presents four experiments, which in each case required participants to memorize two or four polygons. Subsequently, during a retention interval, in Experiment 1, a nonpredictive (50% valid) gaze cue was presented to test whether the direction of gaze influences the vWM representation of the polygons. Next, in Experiments 2 and 3, we compared gaze and comparable motion cues to explore the contribution of low-level kinetic information to the updating of vWM representations under variable memory load. In Experiment 4, inverted faces were then used as retro-cues to further determine whether cuing is related to the social nature of the cues.

2. Experiment 1: gaze retro-cuing

Experiment 1 employed a retro-cue paradigm to examine whether a social (gaze) cue can affect the maintenance of objects in vWM. In this experiment, two polygons were presented in the left and right hemifield of the screen center (see Fig. 1). Participants were asked to remember the shape of these items. The subsequent retention interval then presented a gaze cue, i.e., a face with a neutral expression. After a short delay of 500 ms, the eyes then gazed left, right, or straight ahead for another 500 ms. Thereafter a polygon was presented on the left or right side of a probe array, 500 ms after the offset of the gaze cue. There were three cuing conditions (see Fig. 1). In the *valid* cue condition, the eyes gazed towards the left or right, that is, to the position where the polygon in the subsequent probe display would be presented. In the *invalid* cue condition, the eyes gazed towards the location opposite to the position where the probe display would present a polygon. In the *neutral* cue condition, the eyes looked straight ahead, and the polygon in the probe display was presented on either the left or right side of the screen. The participants were instructed to indicate whether the probe item was identical to the previous memory item at the same position. We predicted that, given the special status of social cues (see above), valid gaze cues should facilitate the maintenance of polygons in vWM as compared to neutral and invalid gaze cues.

2.1. Methods

2.1.1. Participants

Sixteen (9 female; average age: 21.1 years) undergraduate students of Zhejiang University participated in the current experiment. All participants were unaware of the purpose of the experiment. They were all right-handed, and had normal color vision and normal or corrected-to-normal visual acuity. Participants provided written informed consent to