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Memory-based attentional capture by colour and shape contents in visual working memory

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ABSTRACT
Current theories assume that there is substantial overlap between visual working memory (VWM) and visual attention functioning, such that active representations in VWM automatically act as an attentional set, resulting in attentional biases towards objects that match the mnemonic content. Most evidence for this comes from visual search tasks in which a distractor similar to the memory interferes with the detection of a simultaneous target. Here we provide additional evidence using one of the most popular paradigms in the literature for demonstrating an active attentional set: The contingent spatial orienting paradigm of Folk and colleagues. This paradigm allows memory-based attentional biases to be more directly attributed to spatial orienting. Experiment 1 demonstrated a memory-contingent spatial attention effect for colour but not for shape contents of VWM. Experiment 2 tested the hypothesis that the placeholders used for spatial cueing interfered with the shape processing, and showed that memory-based attentional capture for shape returned when placeholders were removed. The results of the present study are consistent with earlier findings from distractor interference paradigms, and provide additional evidence that biases in spatial orienting contribute to memory-based influences on attention.

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The human cognitive system has a limited perceptual and mnemonic capacity. Mechanisms of attention and working memory enable the system to effectively deal with these limitations (Baddeley & Hitch, 1974; Cowan, 1988; 2001; Neisser, 1969). There is now substantial evidence that attention and working memory closely interact (see Awh & Jonides, 2001; Chun, 2011; Cowan, 2001; Kiyonaga & Egner, 2013; Olivers, 2008; Woodman & Chun, 2006, for reviews).

A large part of this evidence indicates that contents in visual working memory (VWM) modulate competition for attentional processing among objects in the visual field, in accordance with what has been proposed under the biased competition account of Desimone and Duncan (1995). To demonstrate this, a number of studies have used a combination of a VWM task, for which the observers needs to remember a specific visual object, and a visual search task, in which the observer needs to look for s specific target object (Downing & Dodds, 2004; Olivers, 2009; Soto, Heinke, Humphreys, & Blanco, 2005; Woodman & Luck, 2007; see Pashler & Shiu, 1999, for a sequential rather than a spatial search). The crucial manipulation is that the memorized object can return as a distractor in the search display (or sometimes also as a target, e.g., Soto et al., 2005). When it does, it affects search reaction times (RTs), with the often-found result that search is slowed when a distractor matches the memory content (see Downing & Dodds, 2004; Houtkamp & Roelfsema, 2006; Woodman & Luck, 2007, for exceptions). This has led to the conclusion that memory-matching visual objects automatically capture attention. If so, then this would mean that the memory object automatically becomes part of the observer's attentional set, despite its irrelevance to the search task (Olivers, Peters, Houtkamp, & Roelfsema, 2011).

The memory-based attentional capture findings, plus the idea that they reflect changes in the observer's attentional set, are very much reminiscent of the contingent attentional orienting phenomena as uncovered by Folk and colleagues (Anderson & Folk, 2012; Becker, Folk, & Remington, 2010; Folk & Remington, 1998; Folk, Remington, & Johnston, 1992; Irons, Folk, & Remington, 2012; Wyble, Folk, & Potter, 2013). Folk and colleagues developed a widely used

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paradigm in which the observer is instructed to actively look for a target that is defined by a specific feature (e.g., colour). Crucially, spatial cues appear shortly before the onset of the target display, and the target's location may coincide with the cue location (on valid trials), or appear at a different, uncued location (invalid trials). Importantly, these cues are non-predictive, as they provide no information on where the target will appear. Yet, when the cues carry the sought-for feature (e.g., the same colour), the target is responded to faster when it appears at the cued location compared to an uncued location. Such cueing effects are smaller or absent when the cue does not match the sought-for feature. The results of this paradigm have led Folk and colleagues to conclude that observers adopt an attentional set for the defining target feature, and that spatial orienting is at least partly contingent on this attentional set.

Here we use the contingent spatial orienting paradigm to provide converging evidence for the idea that adopting a working memory is at least in part like adopting an attentional set. An advantage of the spatial cueing paradigm is that the cueing effect is inherently *spatial* in nature (Burnham, 2013), and thus provides direct behavioural evidence that attention is directed at the location of the memory-matching object (see Downing, 2000). Paradigms that measure interference from distractors that are presented during search (as above) have had to rely on oculomotor and electroencephalogram (EEG) measures to demonstrate a spatial component (Hollingworth, Matsukura, & Luck, 2013a; Hollingworth, Matsukura, & Luck, 2013b; Kumar, Soto, & Humphreys, 2009; Olivers, Meijer, & Theeuwes, 2006; Silvis & Van der Stigchel, 2014). Furthermore, in the related research area of *bottom-up* attentional capture by salient visual objects, the spatial cueing paradigm and the visual search paradigm have led to different results, different conclusions, and a decade-long controversy on underlying mechanisms of attentional capture (Ansorge, Kiss, & Eimer, 2009; Becker et al., 2010; Belopolsky & Theeuwes, 2010; Belopolsky, Schreij, & Theeuwes, 2010; Folk & Remington, 1998; Irons et al., 2012; Schreij, Owens, & Theeuwes, 2008; Theeuwes, Olivers, & Belopolsky, 2010). It would thus be valuable to know if, in terms of memory-driven capture, the two paradigms converge. Furthermore, the demonstration of spatially specific prioritization of memory-matching stimuli would provide further evidence that the interference caused by memory-matching distractors is not due to some spatially non-specific filtering cost (Folk & Remington, 1998; Folk, Remington, & Wu, 2009).

For this purpose, we combined Folk et al.'s (1992) spatial cueing paradigm with Olivers et al.'s (2006) memory task. Observers first saw a colour which they had to remember for a later memory test. During the retention period between the encoding and the recognition tests, they were to search for an onset target appearing in one of four placeholders. Unlike in the standard spatial cueing paradigm, the colour was never relevant for the search task. Shortly before the onset of the target-search display, one of the four placeholders was cued for 50 ms by a memory-matching or non-matching cue. The cue was completely task-irrelevant because the target was presented at the cued location by chance, so the cue was not predictive of the target location. If the contents of visual working indeed lead to contingent orienting, similar to what an attentional set has been demonstrated to do, a cueing effect should occur for memory-matching cues, but not for non-matching cues.

To provide further converging evidence, we also adopted some of the additional manipulations of Olivers et al. (2006). In one of their experiments, they used both easy and difficult to categorize stimuli for the memory tasks, in an attempt to induce more or less visual memories. In the easy categorization task (presumably tapping into more verbal memory), the memory test consisted of three differently coloured disks (e.g., red, blue, and yellow), making it sufficient to verbally remember the memorized item. In the difficult memory task (presumably tapping into more visual memory), the test colours subtly differed from each other. For example, when the memorized colour was red, participants had to distinguish the memorized colour from disks of very similar shades of red, requiring participants to visually remember the target shade. The memory-based attentional capture effect was obtained for the difficult but not for the easy memory task, suggesting that it is really visual memory that needs to be activated—although we point out other evidence that verbal information is sufficient (e.g., Soto & Humphreys, 2007). Here we tested whether a similar dissociation between easy and difficult to categorize stimuli also occurred for the spatial cueing paradigm. Finally, Olivers et al.

(2006) also found memory-based capture for shape (in addition to colour). We therefore included not only colour cues, but also shape cues. The first experiment showed little capture for shape cues (in contrast to colour cues). Experiment 2 investigated further what might underlie shape-based effects or the lack thereof, and provides evidence that the placeholders as often used in Folk's contingent cueing paradigm may interfere with shape processing.

Experiment 1

The goal of Experiment 1 was to investigate whether the contents of working memory could involuntarily guide attention in a task that was modelled after Folk's classic contingent orienting paradigm. At the beginning of each trial, observers were asked to memorize the colour or the shape of an object. At the end of the trial, they performed a recognition test in which they were to identify the memorized item among an array of three alternatives. During the retention period between encoding and recognition test, participants were asked to search for an onset target appearing in one of four placeholders. Before the onset of the search display, one of the four placeholders was cued by a colour- or shape-defined cue. Importantly, both types of cue were completely independent of the attentional control settings necessary for the search task because the search target was defined by onset, while the cues were defined by colour or shape (Becker et al., 2010; Belopolsky et al., 2010; Folk et al., 1992; Folk & Remington, 1998; Folk, Remington, & Wright, 1994; Lien, Ruthruff, & Johnston, 2010). Here we investigated if the contents of VWM guide visual attention irrespective of attentional control settings. If so, attention would be captured by the memory-matching but not non-matching colour (shape) cue when participants memorized the colour (shape) of the to-be-memorized item.

Furthermore, following Olivers et al. (2006), easy and difficult to categorize stimuli were used for the memory task, to investigate whether memory-based attentional capture operates from visual or from categorical working memory. This manipulation is based on the assumption that the difficult memory task forced participants to memorize a feature more visually, which would then result in stronger visual biases than when the memory could be retained in a presumably more categorical type of representation.

Method

Participants

Thirty-two undergraduate students from Korea University participated as partial fulfilment of a course requirement. Of these participants, 16 participated in the colour memory task and the remainder in the shape memory task. All had normal or corrected-to-normal visual acuity and colour vision.

Apparatus

Stimuli were presented on a CRT monitor (17 in) of a personal computer. The distance between the participants and the monitor was approximately 50 cm. All experiments were programmed and presented using

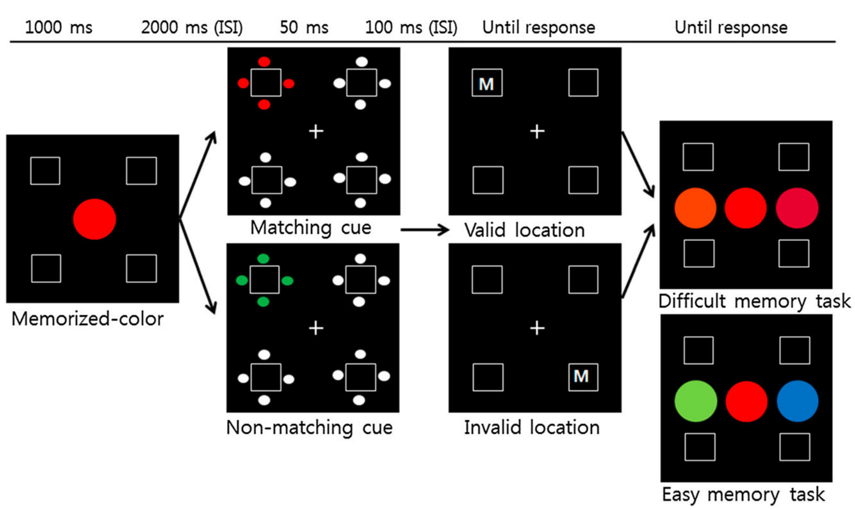

Figure 1. Examples of displays of the colour memory condition in Experiment 1.

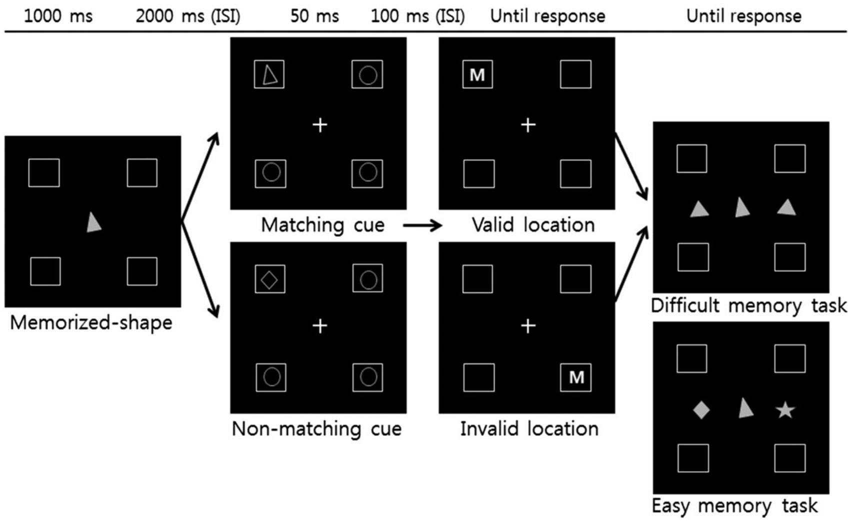

Figure 2. Examples of displays of the shape memory condition in Experiment 1.

MATLAB and Psychophysics Toolbox software. Responses were collected using a standard keyboard.

Stimuli and procedure

All stimuli were presented on a black background. A trial began with a 300 ms presentation of the fixation display. The fixation display consisted of a light grey (*R* = 70, *G* = 70, *B* = 70; 69.3 cd/m^2) fixation cross (0.36° × 0.36°) at the centre, surrounded by four light grey placeholder boxes (1.7° × 1.7°) with centres positioned at 3.7° of the top left, top right, bottom left, and bottom right of fixation. The fixation cross blinked off for 300 ms and on for 300 ms. The memory display was shown for 1000 ms. The memory display consisted of the four placeholder boxes and a to-be-memorized colour (shape) item at the centre of the display in the colour (shape) memory task. Participants were asked to memorize colour or shape of the memory item until the end of each trial. Then, the fixation display was presented for 2000 ms. Subsequently, the cue display was presented for 50 ms and replaced with the fixation display for 100 ms. In the colour memory task, the cue display consisted of the fixation cross, four boxes, and four sets of small circles (0.24° in diameter) so that such each placeholder box was surrounded by four dots. The circles surrounding one of the boxes were coloured the same as the to-be-memorized colour (matching cue) or the different colour (non-matching cue). For example, if the to-be-memorized colour is red, the matching cue was red and the non-matching cue would be blue, green, or purple. The circles surround the other three boxes were

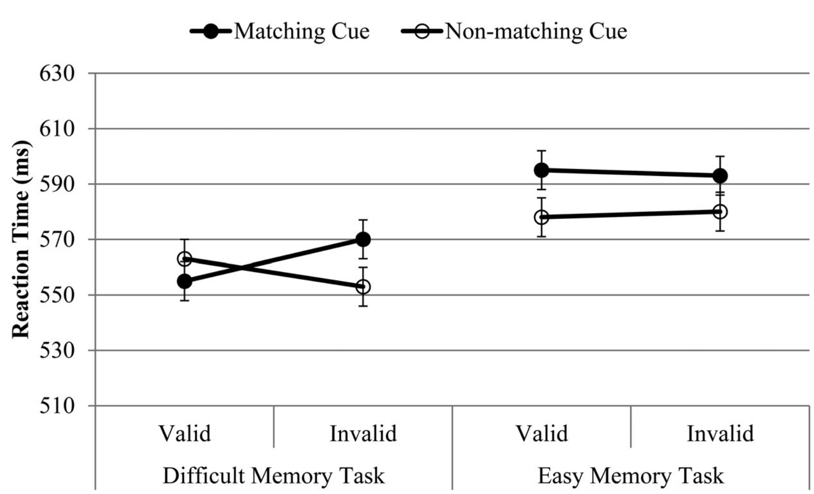

Figure 3. Mean RTs as a function of memory type (difficult or easy), cue type (matching or non-matching cue), and cue validity (valid or invalid) in the colour memory condition in Experiment 1. Error bars represent 95% confidence intervals (Loftus & Masson, 1994).

Table 1. The colours of the memory items used in Experiment 1.

R	G	B	CIE x	y	Y
255	0	0	0.592	0.344	7.7
200	0	0	0.591	0.337	3.9
255	0	50	0.58	0.33	7.8
255	50	50	0.578	0.35	7.9
0	0	255	0.191	0.122	4.8
0	0	200	0.178	0.119	2.2
0	0	150	0.168	0.096	0.8
0	50	255	0.169	0.098	4.9
0	255	0	0.274	0.598	15.3
0	255	50	0.285	0.575	19.3
0	200	0	0.281	0.588	12.9
0	160	0	0.287	0.579	5.1
100	0	153	0.173	0.099	0.9
100	0	204	0.17	0.097	2.4
100	0	255	0.154	0.116	5.1
150	50	255	0.191	0.109	5.8

Note: R, G, and B indicate red, green, and blue, respectively. x, y, and Y are the values of Commission Internationale d'Eclairage (CIE).

coloured in white. In the shape memory task, the cue display consisted of the fixation cross, the four boxes, a to-be-memorized shape (matching cue) or different shape (non-matching cue) in one of the placeholder boxes, and three circles (1.2° in diameter) in the other three placeholders. For example, if the to-be-memorized-shape is triangle, the matching cue is triangle and the non-matching cue would be star, rectangle, or diamond. The box having the matching or non-matching cue was assumed to be a cued location.

The target display consisted of a single letter, "M" or "N", that appeared in one of the four boxes. The letter was grey in colour ($R = 204$, $G = 204$, $B = 204$, 202 cd/m^2). In the colour memory condition (Figure 1), the memory display consisted of the four placeholder boxes with a row of three differently coloured disks presented in random order, including the memorized colour. The four colour categories included red, blue, green, and purple (Table 1). In the shape memory condition (Figure 3), the memory display consisted of a row of different three shapes, including the memorized shape. The four shape categories included star, rectangle, triangle, and diamond. The four placeholder boxes were visible throughout each trial. Cues and targets appeared in the same location in 25% of the trials (valid cue) and in different locations in 75% of the trials (invalid cue). The two target letters (M and N) were used equally often across conditions. Participants were to respond as quickly and accurately to an onset "N" or "M" by pressing the N or M key on the standard keyboard with the left middle and index fingers, respectively. When an incorrect response was made, a 1000 Hz tone sounded for 500 ms.

Table 2. The correct rate (and standard deviation in parentheses) of the memory task as a function of task-difficulty, memory type, cue type, and cue validity in Experiment 1.

		Difficult		Easy	
Memory type	Cue validity	Matching	Non-matching	Matching	Non-matching
Colour memory	Valid	65 (11.7)	66.5 (13.4)	96.9 (3.6)	97.1 (5.2)
	Invalid	64.1 (8.3)	61.1. (10.6)	97.3 (2.4)	95.9 (4.2)
Shape memory	Valid	70.5 (10.1)	71.5 (10.1)	97.9 (4.3)	94.5 (6.4)
	Invalid	71.8 (9.6)	70.9 (10)	96.1 (3.9)	94.5 (4.3)

Table 3. The correct rate (and standard deviation in parentheses) of the memory task as a function of placeholder, cue type, and cue validity in Experiment 2.

	Absent		Present	
Cue validity	Matching	Non-matching	Matching	Non-matching
Valid	72.9 (15.7)	76 (12.1)	74 (16.6)	74.7 (13.3)
Invalid	75 (16.4)	71.9 (16)	76 (13.8)	74 (5.2)

In the difficult memory task, participants were required to identify the memorized item from among three different items belonging to the same category in the memory test display. For example, when the memory colour was red, three different shades of red appeared in the memory test display. When the memory shape was a star, three different shaped stars appeared. In contrast, in the easy memory task, participants were required to indicate the memorized item from among three different items belonging to different categories. For example, when the memory colour was red, two different colours belonging to three different colour categories (e.g., blue, green, and purple) and the to-be-memorized red colour appeared in the memory test display. When the memory shape was a star, two different shapes belonging to different shape categories (e.g., rectangle, triangle, and diamond) and the to-be-memorized star shape appeared. Participants were instructed to visually remember the precise feature in the difficult memory task and to verbally remember the global feature in the easy memory task. Memory difficulty (easy and difficult) was between blocks. The memory test display was then shown until a response was made. Participants were instructed to respond accurately and to indicate the remembered item by pressing the 1, 2, or 3 key on the numeric keyboard with the right index, middle, or ring finger, respectively. When an incorrect response was made, a 1000 Hz tone sounded for 500 ms.

Results

RTs shorter than 125 ms and longer than 1250 ms were excluded as outliers from the analyses (55 out of 6144 trials, 1.31%). Following Olivers et al. (2006), the analyses included the trials in which a memory error occurred because it is assumed that the higher error rate in the difficult memory test condition may be due to task difficulty rather than failure to comply with task instructions. However, the results remained the same with memory errors excluded. Mean correct RT and percent error (PE) were calculated for each participant as a function of task type (colour and shape), cue type (matching and non-matching), memory type (easy and difficult), and cue validity (valid and invalid). Analyses of variance (ANOVAs) were conducted on the mean RT and PE data, with task type entered as a between-subjects variable and the others entered as within-subjects variables (see Table 1).

RT

The overall mean RT was 590 ms. The main effect of cue type was significant, $F(1, 30) = 6.97$, $p = .0130$, $MSe = 423$, $\eta_p^2 = .16$. The mean RT was shorter with non-matching cues ($M = 587$ ms) than matching cues ($M = 594$ ms). A significant memory type effect was obtained, $F(1, 30) = 11.04$, $p < .0001$, $MSe = 2766$, $\eta_p^2 = .04$. Responses were faster with the difficult memory task ($M = 574$ ms) than the easy memory task ($M = 606$ ms). The interaction of cue type and memory type was also significant, $F(1, 30) = 4.87$, $p = .0351$, $MSe = 325$, $\eta_p^2 = .17$. Importantly, the four-way interaction of task type, memory type, cue type, and cue validity was significant, $F(1, 30) = 7.25$, $p = .0115$, $MSe = 155$, $\eta_p^2 = .19$. To explore this interaction, simple interaction comparisons were performed on the effect of cue type on cue validity on memory type at each level of task type.

For the colour memory task (Figure 2), the main effect of cue type was significant, $F(1, 15) = 5.25$, $p = .0369$, $MSe = 573$, $\eta_p^2 = .25$. The mean RT of the difficult memory task ($M = 560$ ms) was shorter than that of the easy memory task ($M = 586$ ms). The main effect of memory type was also significant, $F(1, 15) = 11.04$, $p = .0046$, $MSe = 1980$, $\eta_p^2 = .42$. The mean RT of non-matching cue trials ($M = 568$ ms) was shorter than that of matching cue trials ($M = 578$ ms). The three-way interaction of memory type, cue type, and cue validity was significant, $F(1, 15) = 9.24$, $p = .0083$, $MSe = 182$, $\eta_p^2 = .38$. To investigate the three-way interaction, simple interaction comparisons were performed on the effect of cue type on cue validity at each level of memory type. For the difficult memory task, the interaction of cue type and cue validity was significant, $F(1, 15) = 6.18$, $p = .0252$, $MSe = 384$, $\eta_p^2 = .29$. Simple main effects analyses confirmed that matching cues produced a 15 ms cueing effect, $F(1, 15) = 5.69$, $p = .0307$, $MSe = 275$, $\eta_p^2 = .27$, while non-matching cues did not cause a cueing effect, $F(1, 15) = 2.56$, $p = .1306$, $MSe = 336$. For the easy memory task, there was a significant effect of cue type, $F(1, 15) = 14.88$, $p = .0016$, $MSe = 244$, $\eta_p^2 = .49$, in that the mean RT was shorter with non-matching cues ($M = 579$ ms) than matching cues ($M = 594$ ms). The interaction between cue type and cue validity was non-significant, $F(1, 15) < 1.0$.

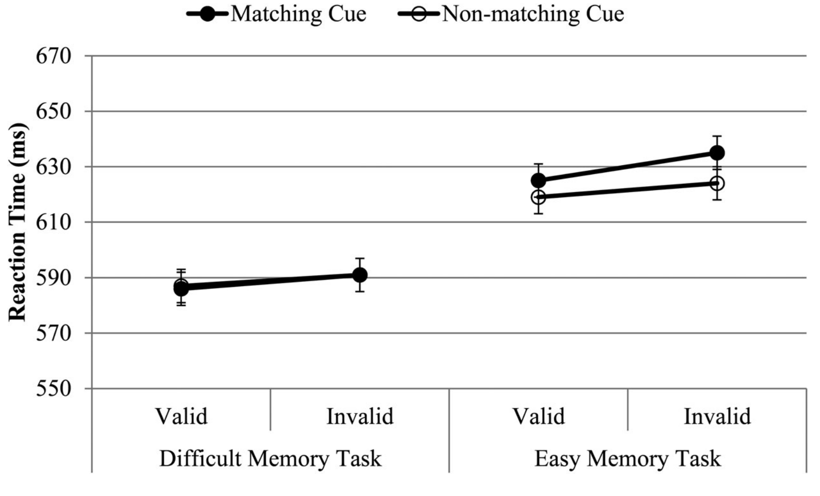

Figure 4. Mean RTs as a function of memory type (difficult or easy), cue type (matching or non-matching cue), and cue validity (valid or invalid) in the shape memory condition in Experiment 1. Error bars represent 95% confidence intervals.

For the shape memory task (Figure 4), the main effect of memory type was significant, $F(1, 15) = 12.38$, $p = .0031$, $MSe = 3551$, $\eta_p^2 = .45$. The mean RT of the difficult memory task ($M = 589$ ms) was shorter than that of the easy memory task ($M = 626$ ms). The three-way interaction of memory type, cue type, and cue validity was not significant, $F(1, 15) < 1.0$.

PE

The overall PE for the search task was 2.54%. There was no significant main effect or interaction. In the memory task, the overall PE was 18.03% and there was a significant main effect of memory type, $F(1, 30) = 325.46$, $p < .0001$, $MSe = .02$, $\eta_p^2 = .91$. Specifically, as expected, the PE was higher for the difficult test (32.36%) than the easy test (3.71%). There were no other significant main or interaction effects.

Discussion

A memory-based attentional capture effect was observed when participants performed the colour memory task, consistent with previous studies (Kumar et al., 2009; Olivers et al., 2006; Soto et al., 2005). The results show that memory-based capture also occurs for the contingent spatial orienting paradigm, providing converging evidence that memory-matching stimuli lead to locally prioritized processing, and are not solely due to general interference. ("filtering costs"; Folk et al., 2009; Folk & Remington, 1998). Furthermore, consistent with Olivers et al. (2006), a memory-based attentional bias was found for the difficult to categorize colours, but not for the easy to categorize colours, supporting the idea that very similar colours force the recruitment of visual memory, hence resulting in visual biases. Clear categorical distinctions may allow for verbal recoding, resulting in weaker visual biases. This distinction also helps in excluding the possibility that the cueing effect obtained was the result of sensory priming rather than active working memory content. If the capture effect in the colour difficult memory task was due to a simple priming effect, the same pattern of results should have been obtained in both easy and difficult colour memory tasks (Olivers et al., 2006).

However, clearly no memory-based attentional capture was found for the shape memory task. This finding supports Soto et al.'s (2005) finding suggesting that shape memory content interacts less strongly with matching input than colour memory. However, Olivers et al. (2006) did find memory-based attentional capture effects for shape. This issue was further investigated in Experiment 2.

Experiment 2

One difference between the two paradigms (the spatial cuing paradigm used here and the visual search paradigm used by Olivers et al., 2006) is the presence of the four placeholders during the inter-stimulus interval (ISI) between the memory item and cue displays in the present study. As these placeholders are themselves shapes, surrounding the cues, we hypothesized that they may have interfered with either the perception of the relevant shapes or the matching process with the memory representation (which did not include placeholders). Experiment 2 tested this possibility by comparing two conditions: one with placeholders and one without. If the placeholders interfere with the memory-matching cue capturing attention, then a memory-based capture effect would be observed in the placeholder absent but not in the placeholder present condition.

Method

Sixteen new undergraduate students from Korea University participated. Experiment 2 consisted of two within-participant blocks. The placeholder-present block was identical to the shape difficult memory task condition of Experiment 2, except that the memory items and cues were larger and fully filled and that the placeholders were absent only for the cue display. The placeholder-absent block was identical to the first block, except that the placeholders were always absent (Figure 5).

Results

The data were analysed in the same way as in Experiment 1. Of the total trials, 0.77% (47 of 6144 trials) were excluded from the analyses. The mean correct RT and PE were calculated for each participant as a function of cue type (matching and non-matching), placeholder (presence and absence), and cue validity (valid and invalid). ANOVAs were conducted on mean RT and PE data, which were used as within-subjects variables (see Table 2).

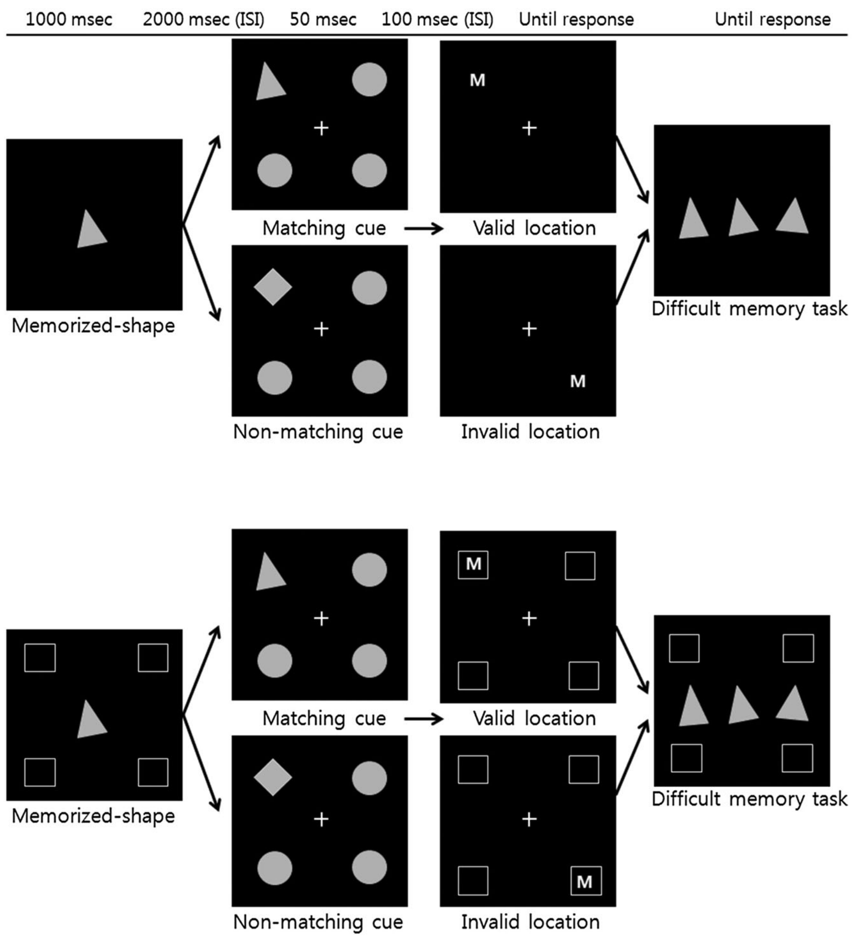

Figure 5. Examples of displays in Experiments 2. Upper is the placeholder absent, lower is the placeholder present.

RT

The overall mean search RT was 573 ms (Figure 6). When the placeholders were present, the interaction of cue type and cue validity was not significant, $F(1, 15) < 1.0$. This replicates Experiment 1 in demonstrating the absence of a contingent spatial cueing effect for shape memory. In contrast, when the placeholders were absent, the interaction of cue type and cue validity was very reliable, $F(1, 15) = 8.97$, $p = .0091$, $MSe = 125$, $\eta_p^2 = .37$. Simple main effects analyses confirmed that matching cues produced an 11 ms cueing effect, $F(1, 15) = 4.05$, $p = .0626$, $MSe = 223$, η_p^2

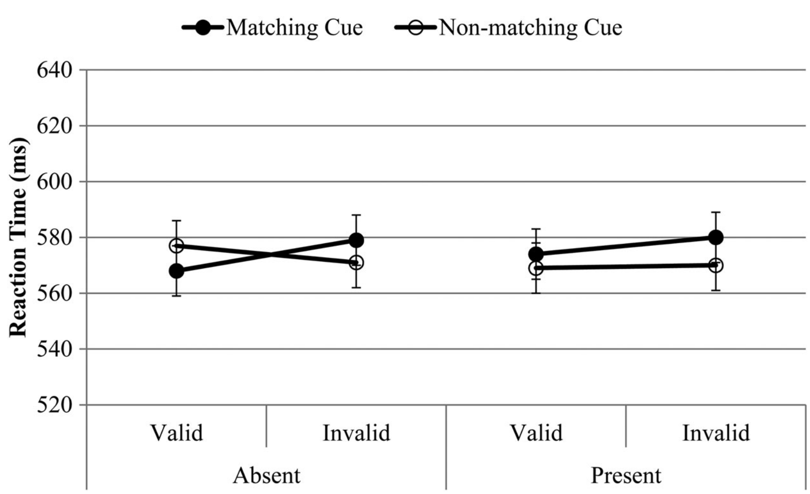

Figure 6. Mean RTs as a function of holder (absent or present), cue type (matching or non-matching cue), and cue validity (valid or invalid) in Experiment 2. Error bars represent 95% confidence intervals.

= .21, while non-matching cues did not result in a cueing effect, $F(1, 15) = 2.46$, $p = .1379$, $MSe = 121$, $\eta_p^2 = .14$. Despite the considerable reliability of a contingent cueing effect in the placeholder absent condition, and no such effect in the placeholder present condition, the three-way interaction of placeholder presence, cue type, and cue validity was not significant, $F(1, 15) = .62$, $p = .4416$, $MSe = 311$, $\eta_p^2 = .04$, probably due to the considerable variability in the placeholder present condition.

PE

The overall PE for the search task was 2.18% and the overall PE for the memory task was 25.71%. There were no significant main or interaction effects for either task.

Discussion

Experiment 2 shows that reliable memory-based attentional capture effects can be observed for shape memory when the placeholders are absent. As in Experiment 1, there was no such effect when the placeholders were present. The results support the idea that the placeholders interfere with perceiving the shape of cues, due to the proximity of contours, as well as a less obvious match with the memory representation. Without such placeholders, the results become more comparable to the shape effects reported by Olivers et al. (2006), but now using the spatial cueing paradigm.

General discussion

The spatial cueing paradigm used in the present study allowed us to verify and generalize the hypothesis that VWM representations bias perceptual processing toward the selection of stimuli that are similar to those representations. In Experiment 1, a memory-based attentional capture effect was observed for colour but not for shape contents of VWM. However, the absence of attentional capture by shape contents probably occurred due to placeholders interfering with perceptions of the shape-matching cue. Experiment 2 showed that when the placeholders were removed, memory-based attentional capture by shape contents occurred.

According to the contingent attention capture hypothesis, attentional capture depends on the match between the cue and the attentional control setting determined by target-defining features (Folk et al., 1992). However, in the present study, the memory-matching cue captured attention although it did not match the target. This implies that adopting a working memory is at least in part like adopting an attentional set.

Given the nature of the contingent spatial orienting task, we can unambiguously attribute the current effects to biases in spatial orienting. This helps to distinguish the memory-based effects from non-specific interference costs that have been associated with having to filter out irrelevant stimuli at a task level (Folk et al., 2009; Folk & Remington, 1998). The results therefore corroborate earlier demonstrations using eye movement and EEG measures that a memory-matching object leads to spatially localized advantages for the matching object (Hollingworth et al., 2013a; Hollingworth et al., 2013b; Kumar et al., 2009; Olivers et al., 2006; Silvis & Van der Stigchel, 2014).

The current paradigm may have some additional advantages for investigating memory-attention interactions. Some studies have failed to find evidence for memory-based attentional capture (Woodman & Luck, 2007). As has been argued by Woodman and colleagues (Carlisle & Woodman, 2011a, 2011b; Woodman & Luck, 2007), many of the studies investigating memory-based attentional capture, including their own, used visual search tasks in which the memory-matching item is in fact *counter*-predictive of the search target (it is never the search target). This may invite the active suppression of the memory-matching object that, under some circumstances, may be stronger than the capture it induces in the first place. Therefore, although the memory-matching item elicits an "attend-to-me" signal, this signal can be offset by the top-down suppression caused by the avoidance (Carlisle & Woodman, 2011b; Kiyonaga, Egner, & Soto, 2012; Sawaki & Luck, 2011). Note that in the paradigm of the present study, the memory-matching cue was not counter-predictive but *non*-predictive of the search target location, as the cue and search target appeared in the same location by chance (Belopolsky et al., 2010; Folk & Remington, 1998; Schreij et al., 2008; Soto et al., 2005). Consequently, the incentive for top-down suppression would be reduced. That said, it should be noted that Sawaki and Luck (2011) showed that top-down suppression can also occur toward memory-matching items when the memory-matching items are non-predictive—however, this may still be reduced relative to when the memory-matching objects are counter-predictive.

Another possible reason for the absence of the memory-based attentional capture effect in previous studies (Carlisle & Woodman, 2011a; Woodman & Luck, 2007) is that the search target and memorized item may have competed more strongly for the status of the search template (Olivers et al., 2011). It has been suggested that only one search template can be active at a given time (Eimer & Kiss, 2010; Folk & Anderson, 2010; Olivers, 2009; Olivers et al., 2011), and that visual attention and VWM compete and influence one another because they share limited cognitive resources (Kiyonaga & Egner, 2013). In the current paradigm, observers merely need to detect the abrupt onset, a single target without distractors, which probably required little in terms of a top-down template. This may allow more resources for the memory item, and therefore stronger interactions between memory and attention.

In the easy memory tasks, the mean RT was longer when a matching cue appeared than when a non-matching cue appeared, regardless of spatial validity. This cue type effect seems to be due to a property of the memory task. In the present study's easy memory tasks, participants were asked to verbally memorize the memory item's feature. Therefore, the stimulus sharing the feature automatically primes its name. For example, when memorizing a red item as the word "red", a red cue primes the word "red". It has also been found that an unattended stimulus can induce this priming effect (Calvo & Nummenmaa, 2007; Heil & Rolke, 2004). Thus, when the matching cue was presented in the easy memory task, the verbal representation of the memorized item was primed. This primed verbal representation probably interfered with search task performance in which participants discriminated between the onset letters ("M" or "N"), which required verbal working memory resources (Baddeley & Hitch, 1974). However, in the difficult memory tasks a visual representation was primed so that it did not interfere with the letter discrimination process. Although the cue type effect was observed even in the shape memory task of Experiment 1, this is not surprising because shape items would be memorized verbally due to easiness of the shape memory task. Moreover, the finding related to the use of a longer search time in the easy than in the difficult memory task indicates that participants used the same memory resource for the search and easy memory tasks (Baddeley & Hitch, 1974).

Conclusion

The present study explored the influence of VWM in the early deployment of attention using the spatial cueing paradigm. Although experimental findings should be obtained through different methods and paradigms in order to maximize the gain from converging operations (Pashler, 1998; Treisman & Gelade, 1980), the most compelling evidence for memory-based attentional capture has emerged from research using the visual search paradigm (Carlisle & Woodman, 2011b; Mazza, Dallabona, Chelazzi, & Turatto, 2011; Olivers, 2009; Olivers et al., 2006; Soto et al., 2005). In conclusion, the present study contributes to a growing body of evidence demonstrating that a currently task-irrelevant stimulus can capture attention when it shares features with contents in VWM like adopting attentional control setting.

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