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Attention on our mind: The role of spatial attention in visual working memory

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ABSTRACT

The current study shows that spatial visual attention is used to retrieve information from visual working memory. Participants had to keep four colored circles in visual working memory. While keeping this information in memory we asked whether one of the colors was present in the array. While retrieving this information, on some trials a probe dot was presented. When this probe dot was presented at the location of the color that had to be retrieved, participants responded faster than when it was presented at another location. Our findings further elaborate the role of visual attention in working memory: not only is attention the mechanism by which information is stored into working memory, it is also the mechanism by which information is retrieved from visual working memory.

Both *visual attention* and *working memory* are crucial to the control of common everyday behavior. Visual attention is the mechanism by which we *select* visual information relevant to everyday behavior. Working memory, on the other hand, is the mechanism by which we temporarily *retain* visual information relevant to everyday behavior (Baddeley & Hitch, 1974). Working memory can be divided into separate subsystems: one for verbal and one for visual spatial information (Baddeley, 1986). The present study focuses on the interaction between visual working memory and visual spatial attention.

Research by Awh and colleagues (Awh & Jonides, 2001; Awh, Jonides, & Reuter-Lorenz, 1998) indicates that for visuo-spatial memory, there is a close link between working memory and visual attention. Awh and colleagues showed that when a location is kept in working memory, processing of stimuli at the memorized location is facilitated relative to other locations, just like attending to a location improves the processing of information at that location (Posner, 1980). Conversely, when attention to memorized locations is interrupted, the ability to remember these locations is impaired (but see Belopolsky & Theeuwes, 2009). Brain imaging studies of working memory confirm the notion that rehearsal of spatial information modulates early sensory areas (Awh & Jonides, 2001; Munneke, Heslenfeld, & Theeuwes, 2010).

Other studies have revealed that attention may not only be needed to maintain information, but may also be necessary to get information into working memory. For instance Vogel, Luck, and Shapiro (1998) showed that for a new object to be stored in working memory, attention needs to be paid to it. Also, Schmidt, Vogel, Woodman and Luck (2002) showed that focusing attention on a spatial location increases the probability that information at that location will be transferred into visual working memory. These findings are in line with earlier findings (e.g., Irwin & Gordon, 1998) suggesting that attention controls the transfer of perceptual representations into visual working memory (see. e.g., Bundesen, 1990; Duncan and Humphreys, 1989).

The current study explores the role of spatial attention in retrieving information from visual working memory. Participants were required to hold four distinctly colored circles in visual working memory. Each circle was positioned at one of the corners of the display. Since the storage capacity for visual working memory is about 3 to 4 items (e.g., Sperling, 1960, Vogel, Woodman & Luck, 2001), we assumed that visual working memory was full. To ensure that the four colored circles were encoded in visual working memory and not recoded into a verbal code, we used a concurrent verbal load task identical to the one used by Schmidt et al. (2002). After storing these four items in visual working memory, we asked observers whether one of the colors was present in the memory array (e.g., "was red present?"). On some trials, a probe dot was presented on the (empty) computer screen at a location that previously was occupied by one of the four circles. The probe dot location could, with chance probability, coincide with the location of the colored circle that had to be retrieved from visual working memory. We wanted to determine whether spatial attention was used to retrieve information from visual working memory. If observers shift spatial attention to the location that previously contained the relevant information one expects faster

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probe RTs when the location of the probe coincides with the location in memory than when the probe does not coincide with that location.

1. Method

1.1. Participants

Eight participants from the University of Illinois ranging in age between 18 and 26 years participated as paid volunteers. All had self-reported normal or corrected-to-normal vision and reported having no color vision defects.

1.2. Stimuli

The visual field consisted of four colored circles (1.9° diameter) equally spaced around a fixation point on an imaginary circle (6.7° radius). The circles were positioned at the corners of the display positioned at 45, 135, 225, and 315° of angle. The color of each circle was selected at random (without replacement) from a set of five easily discriminable colors (red, green, blue yellow and gray). The probe was a white circle of 0.2° diameter. The background was black.

1.3. Procedure

Each trial began with a 500 ms presentation of a two-digit number at fixation that was used for the articulatory suppression task. Participants were required to read this number aloud throughout the duration of the trial. Participants were told that performance was monitored on-line by the experimenter. The two-digit number was replaced by a fixation cross. After 1500 ms a memory array consisting of 4 colors was presented for 100 ms. Participants had to memorize these four colors. After 900 ms the center fixation cross was extinguished and a word was presented for 400 ms in the center of the screen. The word was either "green?", "red?", "blue?", "yellow?" or "gray?". Upon seeing this color question participants were required to determine whether the color referred to was present in the memory array. The words were presented in capital letters (approximate size 2°). The screen remained black for another 1000 ms and then the question appeared in the center of the display "your answer, y or n?". At this point participants had to provide an non-speeded response to the color question and type "Y" if they thought the color was present or "N" when they thought it was not present. If they committed an error participants heard a high tone.

On two-third of the trials, a probe reaction time task was interleaved with the primary memory task. Subjects were asked to respond to the probe as quickly as possible. Three hundred milliseconds after the offset of the color question (e.g., "blue?", "red?", etc.), a small white circle appeared for 100 ms equally often at the center of one of the four locations of the memory array. Note that at the moment the probe was presented the actual memory array was already extinguished for 1600 ms. If participants committed an error (pressed the spacebar when there was no probe, or forget to press when there was a probe) with respect to the probe task, they heard a low tone. Fig. 1 provides an example of the displays.

1.4. Design

Participants performed 480 experimental trials. In 2/3 of these trials a probe was presented with equal probability at one of the four locations that contained the colors. In half of the trials, the color asked by the color question (e.g., "red?", "blue?" etc.) was present and participants were supposed to press Y. In the other half of the trials the color asked was not present in the memory array, and participants had to press N. Of those trials in which the color was present in the memory array and a probe was present, there were 40 valid trials and 120 invalid trials. Valid trials are those in which a probe appeared at the location at which the to be retrieved object had previously been presented. Invalid trials are those in which the probe appeared at a location that did not coincide with the to be retrieved information.

Participants received 120 practice trials. They were told to try to remember all four colors and make a non-speeded response to the question. They were also told that they had to quickly respond to the appearance of the probe dot.

2. Results

Probe RTs lasting longer than 900 ms were counted as errors, which led to a loss of less than 1% of the trials. Only trials in which both color matching and probe detection were correct were analyzed. Overall, participants responded correct to both tasks on 93.3% of the trials. For trials in which the color was present in the memory array, response times were reliably faster to probes at a location that coincided with the color to retrieve (Valid Probe: M = 385 ms) than to probes presented at locations that did not coincide with the retrieved color (Invalid Probe: M = 399 ms), ($F(1, 7) = 10.9$; $MSE = 71.7$; $p < 0.05$). There was no sign of a speed-accuracy trade-off. Error rates were 6.2 and 5.6% for valid and invalid probe locations ($F < 1$).

Whether or not a color was present in the array (answers "Yes" versus "No" in the color matching task) had no effect on probe RT ($F < 1$). Participants made 6.4% false alarm and 4% miss errors. This difference was not reliable.

3. Discussion

The present study shows that when retrieving information from visual working memory observers allocate visual attention to the location in space that contains the information to be retrieved. Even though there was no reason to allocate spatial attention to the location of the previously presented colored objects (i.e., we did not ask to report a color at a particular location), observers did so anyway.

The current results are consistent with research that has shown that working memory plays a role in the control of attention. For example, Downing (2000) showed that observers were more likely to attend to a face matching the one they were required to hold in memory, relative to a novel face. Similarly, Olivers, Meijer, and Theeuwes (2006) showed that an object kept in working memory causes more attentional capture than when the very same object is not stored in working memory. Schmidt et al. (2002) showed that advance focusing of attention on a location increases the probability for the item at that location to enter visual working memory. Overall, the current findings further elaborate the role of visual attention in working memory: not only is attention the vehicle to keep and store information into working memory, it is also the vehicle by which information is retrieved from visual working memory.

The current findings are related to those of Awh et al. (1998) who showed that working memory maintenance of a spatial location generates a shift of attention to that location. In Awh et al. participants had to keep one location in working memory. Participants were faster to discriminate a probe occurring at a location maintained in memory than to probes at other locations. Even though their results are related to ours, it should be noted that unlike in Awh et al. in our experiment participants did not have to memorize any location. They just had to memorize the four colors; the locations of the colors were completely irrelevant to our task.

It should be noted that the current probe benefits seem to depend on the verbal suppression task. A pilot experiment in which no verbal suppression task was applied showed no probe validity effect.[1] Obviously only when visual working memory is utilized does spatial attention play a

[1] In a pilot experiment ($n = 7$) we did not use an articulatory suppression task. We also used different SOAs (a 1200 ms delay after the memory array, a question to probe SOA of 500 ms). In this experiment there was no sign of a probe validity effect ($F < 1$; M = 385 for valid versus M = 386 ms for invalid trials).

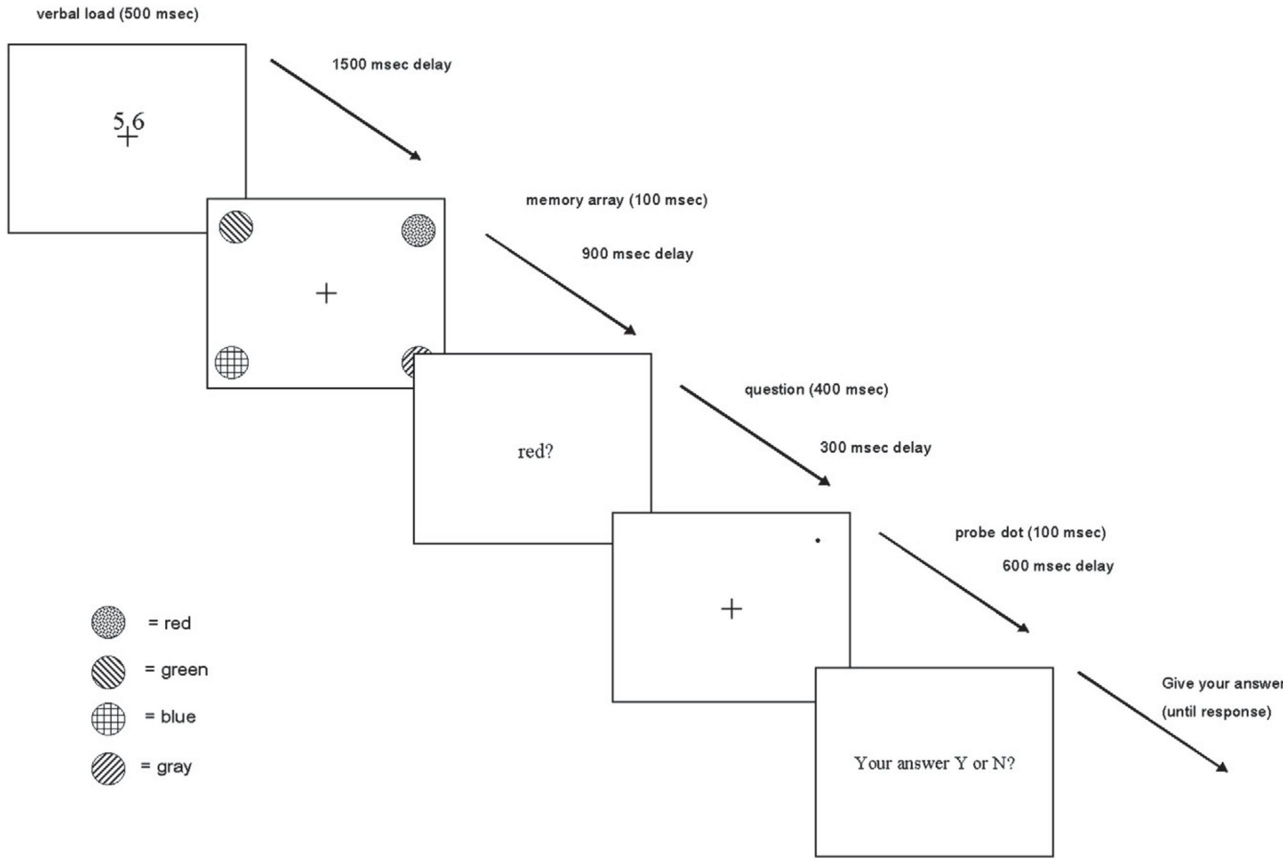

Fig. 1. An example of a probe trial. Participants had to memorize the memory array while saying aloud the number "56". After receiving the question "red?" participants were required to consult the memorized array and determine whether red was present in the array. On probe trials a white probe was presented at any of the four locations in the visual field. Participants had to respond as fast as possible to the presentation of the probe. In this example – a valid probe trial – the location at which the probe is presented coincides with the location containing the 'retrieved' information (i.e., the probe is presented at the same location where the red circle was presented in the memory array). After the probe trial, participants gave a non-speeded response to the question whether "red?" was presented. Note that different fill patterns are used to represent different colors.

role in retrieving information. When opportunity is provided to verbally recode the colors, spatial attention probably plays a minor role.

In our experiment we asked something about a property of one of the objects stored in visual working memory. In order to retrieve this information, the location of the object was apparently used. This demonstrates an important interaction between Ungerleider and Mishkin's (1982) *what* and *where* pathways in the visual system: The "where" system (e.g., the locations of the objects) was used to retrieve the "what" (e.g., the color of one of the objects). A PET study of visual working memory suggests that working memory for object properties activates predominantly inferior prefrontal cortex, whereas working memory for spatial locations activates predominantly superior prefrontal cortex (Smith, Jonides, & Koeppe, 1996). These results suggest the human prefrontal cortex is functionally organized according to what is called 'domain specificity': processing spatial information in working memory is accomplished in one brain area (i.e., the dorsolateral prefrontal area) while processing nonspatial information is accomplished in another area (i.e., the ventrolateral prefrontal areas) [see Ungerleider, Courtney, & Haxby, 1998 for a review]. Even though these areas may be functionally separated, our data show that addressing one system (the "what") can entail the usage of the other system (the "where") to access this information. In fact, it seems that the way we interact with information stored in visual working memory is quite similar to the way we interact with information that is actually present in the outside world. When looking at the outside world different features of objects are processed to a certain extent by different neurons within the visual system. It is generally agreed that location information (i.e., directing attention to a spatial location) provides the key to access and bind different types of information (e.g., Treisman & Gelade, 1980).

The present findings are also consistent with studies that have shown a strong relationship between attention, eye movements and working memory (see for a review Theeuwes, Belopolsky, & Olivers, 2009). For example, Richardson and Spivey (2000) showed that participants systematically fixate specific empty spaces when questioned about the semantic content of a linguistic event that had previously taken place at that location. When participants were asked questions about video clips they previously memorized, they tended to fixate empty locations that were previously associated with information related to the questions (see also, Spivey & Geng, 2001). Interestingly, as in the current study, there were no improvements in memory performance observed due to attending to these specific locations.

The current findings suggest that accessing information from memory is not much different than accessing information from the outside world. In both cases spatial visual attention plays a key role in accessing this information.

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