validity effects, varies systematically as a function of variations in similarity. Importantly, this type of systematic variation also provides the necessary conditions for assessing the presence of a mixture distribution, allowing the opportunity to test whether or not the two-process model of attention allocation applies to instances of attentional capture. A mixture analysis applied to the results of the second experiment found that the obtained variance for the intermediate distributions was significantly less than that predicted by a mixture of capture and no capture trials, disconfirming a two-process model.

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Ensemble statistics of a display influence the representation of items in visual working memory

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In just a glance, observers extract a great deal of perceptual and semantic information from a real-world scene (Oliva, 2005). When later recalling the

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Please address all correspondence to Timothy Brady, Department of Brain and Cognitive Sciences, 46-4078, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA. E-mail: tfbrady@mit.edu details of the scene, they are influenced by this gist, tending to remember objects that are consistent with the scene but were not in fact present (Lampinen, Copeland, & Neuschatz, 2001). Thus, memory for individual items is influenced by memory for the structure of the entire scene: The gist creates expectations about what objects were present and where they were located.

Most studies of visual working memory use randomized displays that are, as best as possible, prevented from having any overarching structure or gist (Luck & Vogel, 1997). Even in displays with simple coloured circles, however, there are ensemble statistics such as the mean size that can be computed quickly and easily by observers (Ariely, 2001). Such information, when task relevant, could allow observers to encode the displays more efficiently by providing expectations that reduce the uncertainty in memory for individual items. In fact, because of their simplicity, these displays provide an interesting test case for examining when and how observers make use of such hierarchical constraints in short-term memory.

We thus sought to examine whether the ensemble statistics of a display would guide memory for individual items in a task involving memory for the size of coloured circles. We hypothesized that on displays with several different colours of circles, observers would be biased in reporting the size of a given circle by the size of the other circles of that colour.

METHOD

Six observers were presented with 400 individual displays consisting of three red, three blue, and three green circles of varying size and told to remember the size of all of the red and blue circles, but to ignore the green circles. Each display appeared for 1.5 s, followed by a 1 s blank, after which a single circle reappeared in black at the location that a red or blue dot had occupied. Observers had to slide the mouse up or down to resize this new black circle to the size of the red or blue dot they had previously seen, and then click to lock in their answer and start the next trial. Green distractor items were present in the display because we believed they would encourage observers to encode the items by colour, rather than selecting all of the items into memory at once (Halberda, Sires, & Feigenson, 2006; Huang, Treisman, & Pashler, 2007).

The sizes of the circles were drawn from separate normal distributions for each colour, each with a mean diameter chosen uniformly on each trial from the interval $[0.625^\circ, 3.125^\circ]$ (degrees visual angle) and with standard deviation equal to one-eighth of their mean. Thus, on a given trial, the three red dots could be sampled from around 1°, the blue dots from 2.5° and the green dots from 0.6°. However, on the next trial it could be the red dots that were largest and the blue dots smallest; thus, long-term memory for the sizes of the dots could not be responsible for any results.

To allow a direct test of the hypothesis of bias towards the mean, the displays were generated in matched pairs: 200 displays were generated as described; another 200 were created by swapping the colour of the to-be-tested item with a dot of the other nondistractor colour (either red or blue). These 400 displays were then randomly interwoven, with the constraint that paired displays could not appear one after the other. This resulted in 200 pairs of displays, each matched in the size of all of the circles present, with a difference only in the colour of the circle that would later be tested. By comparing the size reported by observers when the tested circle was in one colour with the size reported when it was in another, we were able to directly test the hypothesis that observers would be biased towards the mean of the items in the same colour as the tested item.

RESULTS

Observers' performance was quite good, with an error of 0.5° on average (SEM: 0.06°), significantly less than our empirical measure of chance ($p = .00005$; empirical chance: 0.825°; SEM: 0.04°).

Next, we examined whether observers tended to be biased towards the size of the same-coloured dots. For each matched pair of trials, we selected the display in which the mean of all of the other dots of the same colour as the tested item was smallest and used this as a baseline. If observers were not biased, the ratio between the size observers reported on these displays and the size on the other half of the displays should be 1.0; they should be equally likely to report a larger or smaller size. However, if observers are biased toward the mean size of the same coloured dots, this ratio should be greater than 1.0 (Figure 1).

Observers reported a size on average 1.2 times greater (SEM: $+/-$ 0.05) on the half of the displays with larger same-coloured dots (the dots were on average 1.4 times larger in these displays than their matched counterparts). This ratio was significantly greater than 1.0, $t(5) = 3.76$, $p = .01$, indicating that observers reported a larger size on the display in which the other items of the same colour were larger, despite the fact that all of the dots—including the tested item—were exactly the same size.

CONCLUSION

We find that observers are biased by the ensemble statistics of the display when representing items in visual working memory. This suggests that, for displays with higher order structure like real-world scenes, items in visual working memory are not represented in isolation. Instead, observers use the

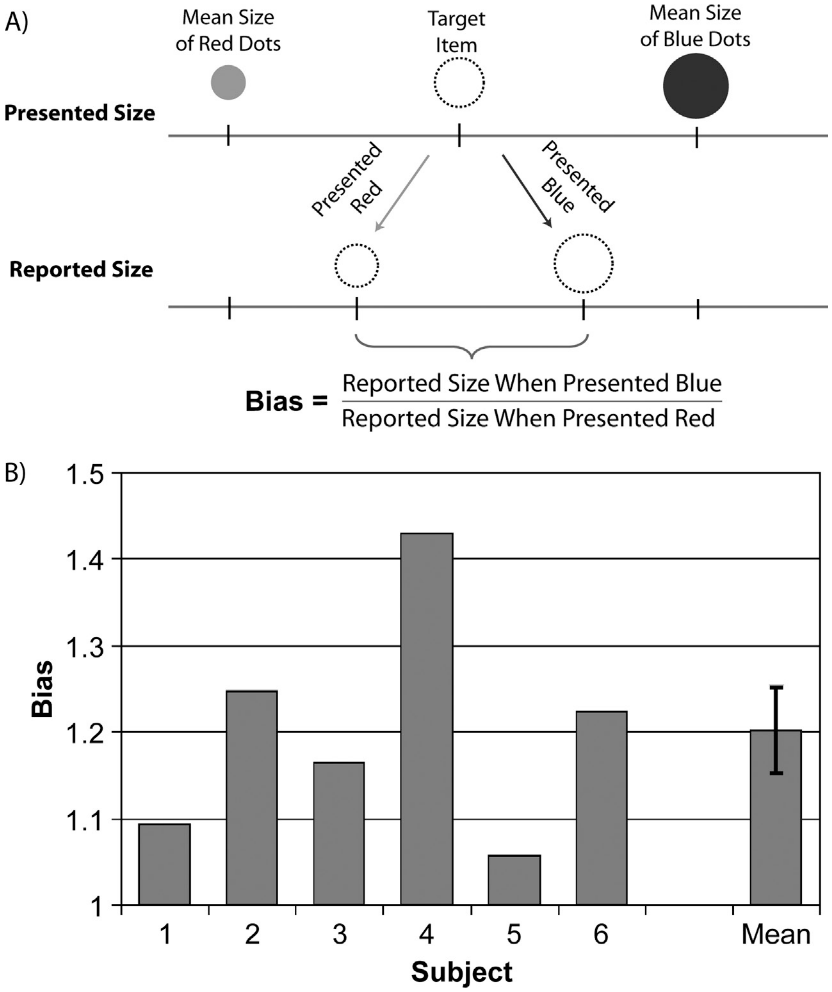

Figure 1. (A) Observers had to remember the size of each red and blue dot. In this example, the blue dots were larger than the red dots. Observers saw each display twice, with the target dot's colour changed for the second presentation. We then measured whether observers reported different sizes for the tested dot when it was red versus when it was blue (the dot was in fact the same size in both presentations). Which colour was larger was counterbalanced across trials in the actual experiment, but bias was always calculated by dividing the size reported for the larger colour by size reported for the smaller colour. (B) The bias for each of our six observers, plus the mean (error bar represents SEM). If observers showed no bias this index would be 1.0; instead, it is significantly greater than 1.0, suggesting a bias to report a larger size when items of the same colour as the tested item were larger in size.

constraints that more abstract information like the gist of the scene or the ensemble size of the set of items provides to reduce their uncertainty about the size of individual items and encode the items more efficiently.

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Action influences figure–ground assignment

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Our ability to segregate objects from one another in a scene is a fundamental perceptual mechanism. Central to this process is figure–ground assignment, or the segregation of candidate objects from their backgrounds. Although hierarchical models of vision (e.g., Julesz, 1984; Pylyshyn, 1999) posit that figure–ground assignment occurs prior to higher level visual processing such as focal attention, a recent study demonstrated that attention can influence which regions of a scene are assigned figural status (Vecera, Flevaris, & Filapek, 2004). As a result, it has been posited that figure–ground segregation is an interactive process, in which both bottom-up and top-down cues compete to bias which items in a scene are perceived as figures and grounds (Vecera et al., 2004; Vecera & O'Reilly, 1998).

Such an interactive account raises the possibility that other high-level factors can influence figure–ground segregation. Specifically, it is possible that *acting* upon an object can increase the likelihood that it will be assigned figural status. In other words, action may act as a cue to figure–ground assignment. Such a possibility is suggested by the presence of populations of bimodal visuotactile neurons that respond exclusively to tactile and visual

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