Systematic Bias in Location Memory Arises from Uncertainty

Mark P. Holden, Temple University
Nora S. Newcombe, Temple University
Thomas F. Shipley, Temple University

When asked to make spatial judgments or to recall locations, participants frequently make non-random errors. Rather, errors tend to be systematically biased toward the central value of the surrounding region (e.g. Fitting, Wedell, & Allen, 2007; Holden, Curby, Newcombe, & Shipley, 2010; Huttenlocher, Hedges, & Duncan, 1991; Plumert & Hund, 2001).

While some researchers have suggested that such errors simply show the schematized, distorted quality of spatial memory representations (e.g., Tversky, 1981), a more recent model – the Category Adjustment (CA) model – suggests that such errors are merely the result of an adaptive process of optimal combination across multiple levels of information about a given location – a process that actually *minimizes* overall error (Huttenlocher et al., 1991).

The key to this model is that it assumes that information about spatial locations is coded at multiple levels of specificity; the metric level is a very fine-grained estimate of location, while the categorical level is a much coarser type of coding. For example, in remembering where one's keys are on a table, one could remember that they are 4 inches from the bottom edge, and 3 inches from the left edge (metric information) or they could simply recall that they are "on the table" (categorical information). Critically, the CA model posits that individuals remembering a given location combine information across these levels. According to the CA model, this combination proceeds in a Bayesian manner; the final estimate is essentially a weighted average of metric and categorical information, with each type of information weighted by its relative reliability (or certainty). For example, one's certainty regarding the metric estimate might be higher immediately after dropping the keys than if the keys were dropped hours ago. Thus, in the latter case, the metric estimate would be relatively less strongly weighted than the categorical information (which is represented by the category center or prototype). This "weighted averaging" results in biased estimates that deviate away from the metric estimate (and correct location), toward the category prototype. However, this process of Bayesian combination is actually an optimal strategy in that it minimizes overall error across multiple estimates.

Empirical evidence for this model has primarily been derived from experiments in which people are asked to recall locations presented within simple geometric spaces, such as a blank circle (e.g., Huttenlocher et al., 1991). Participants used both metric and categorical information (corresponding to the quadrants of the circle) in remembering the locations. Bias was seen toward the category prototype (center of mass) of the surrounding quadrant. However, a recent study in our lab has shown that the same bias in location memory toward category prototypes was also found when individuals were asked to recall locations in color photographs of complex, natural scenes (Figure 1; Holden et al., 2010).

Figure 1. Sample image from Holden et al., 2010. Participants' errors in recalling the yellow dot showed bias toward the center of the surrounding region (the shadow-covered area).

Although the finding of categorical bias is robust, there are at least a few uncertainties. First, it is not entirely clear from recall tasks whether the metric information is lost during the combination process. Sampaio and Wang (2009) had participants perform a recognition task, and found that they preferentially chose the correct location over a biased location, implying that metric information was not lost. However, their task involved simple geometric shapes and only one potential error (the biased location) was available. In our first experiment, we sought to address this question by replicating Sampaio and Wang's findings using much more visually-complex stimuli, and by including other possible errors. This also allowed us to examine, on trials when errors are made, whether those toward the category center were the most likely. In experiment 2, we asked whether individuals were more likely to choose these biased responses under conditions of uncertainty.

For stimuli, we used a subset of the locations used in Holden et al. (2010). These defined the correct location. For all test versions of an image (excluding the correct one), the to-be-recalled dot was moved the same distance from the correct location. This distance was equal to the average error in Holden et al.'s recall task using that same location. The CA bias location was moved that given distance in the direction of the category center. Seven "other error" images were then created by moving the dot the same distance, but in directions that that deviated from the CA bias path by ±45, 90, 135, and 180º. If these manipulations resulted in an image with a dot that was no longer within the same category as the correct location, then that image was discarded. A sample of 4 images is below (Figure 2).

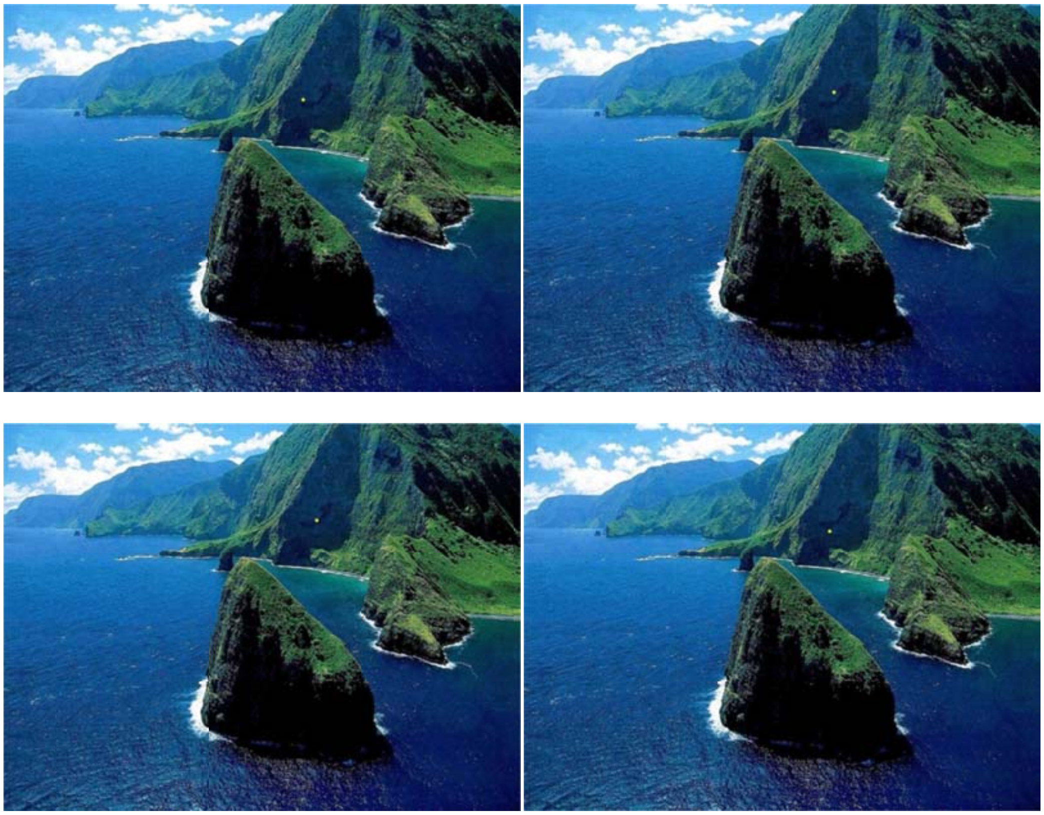

Figure 2. Sample Test Images. Clockwise from top left: Correct, CA bias, Error 1 (45°), Error 2 (90º)

The results of Experiment 1 are shown graphically below (Figure 3). We found that individuals chose the correct answer significantly more often than any other option, $t(29)=15.53$, $p<0.01$. If metric information were lost, we would expect that CA bias errors would be chosen more often than correct. This finding therefore implies that metric information is not lost, and is still available for use in this task. Interestingly, though, CA bias errors were still chosen significantly more often than the other errors, $t(29)=4.96$, $p=0.02$. We explored this in more detail in experiment 2.

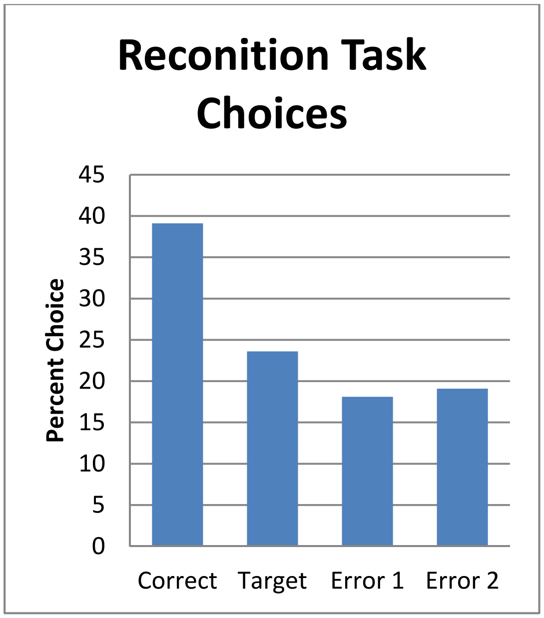

Figure 3. Recognition Test Choices.

In Experiment 1, we showed that CA bias errors were more likely than any other type of error, even in recognition tasks. In Experiment 2, we asked whether these errors arise under conditions of uncertainty. The task was the same as in Experiment 1, except that subjects now had the option of pressing a key to skip a trial, if they were uncertain. Thus, for trials in which a key was not pressed, the participant is relatively certain about their response. However, the key press only worked 75% of the time, randomly. On the remaining trials, when a key press did not work, subjects were required to make a response – even though they were uncertain about the location. The error patterns under these two conditions were then examined.

As in Experiment 1, when subjects were relatively certain of their responses, the correct location was chosen significantly more often than any other choice, $t(34)=3.09$, $p<0.01$ (Figure 4a). However, under these conditions, the CA bias image was not chosen any more often than any other type of error, $t(34)=1.045$, *ns*. Conversely, when subjects were uncertain, but required to respond, the CA bias was chosen significantly more often than any other response, including correct, $t(8)=2.50$, $p=0.04$ (Figure 4b). Comparing across the two conditions, participants were significantly more likely to choose images depicting the CA bias under conditions of uncertainty, $t(8)=2.86$, $p=0.02$.

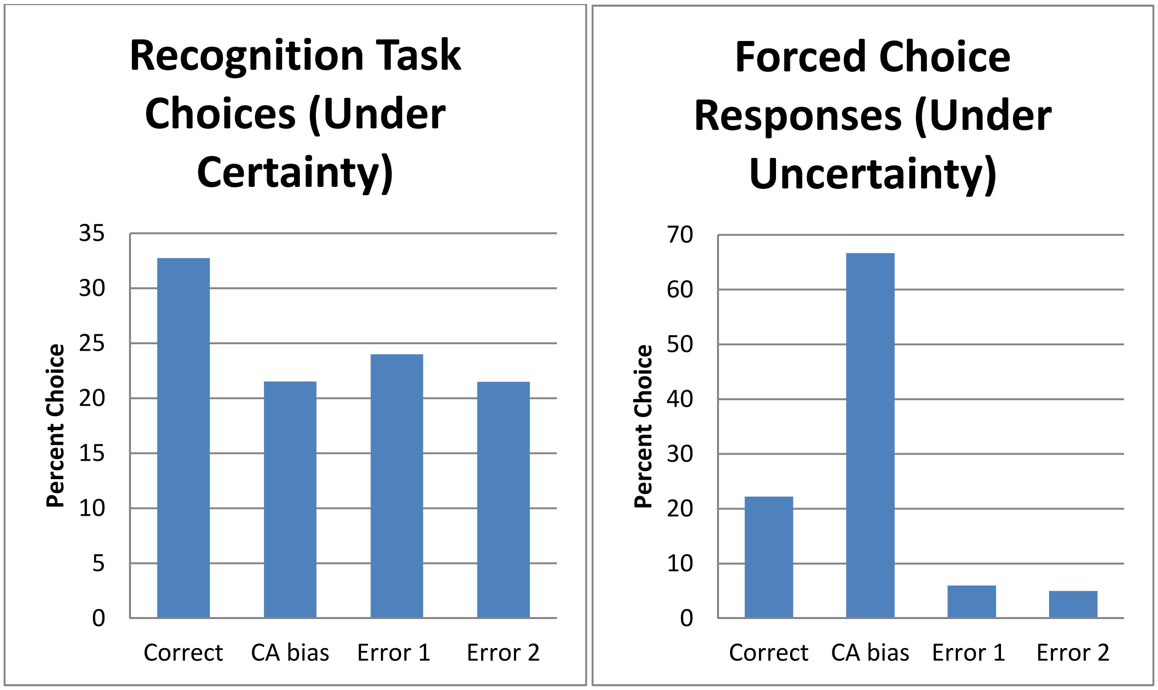

Figure 4. Percent of Choices in Experiment 2. 4a Shows the choices made under conditions of relative certainty (i.e. no key-press), while 4b shows the choices made under uncertainty (i.e. key-press did not work, therefore choice is still required)

Our results therefore suggest that metric information is not lost during the process of combination, because it is used to correctly recognize previously-seen locations (experiment 1). This replicates Sampaio and Wang (2009), using a very different set of stimuli and methodology. Furthermore, we built upon Sampaio and Wang by also showing that, when errors *are* made in a recognition task, participants are still more likely to choose CA bias locations over any other type of error. Finally, in experiment 2, we demonstrate that this effect is due to uncertainty about the metric location; when participants have the ability to opt out of trials in which they are uncertain, any errors made appear to be random, yet, when they are forced to choose under conditions of uncertainty, the CA bias is by far the most common response.

References:

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