Combining Perception and Experience in Spatial Categorization

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Abstract

Two experiments examined how categories derived from experience and those derived from perception affect spatial memory. Four kinds of objects were distributed within a circle and spatially clustered so that all objects of each kind appeared within the same spatial region. These identity-based categories were either aligned with or in opposition to the perceptually-based quadrant categories that are imposed on the circle by default. When remembering only one object location at a time, participants used only the default categories and not the identity-based categories to reconstruct memories. When remembering four objects simultaneously, participants combined inductive experience with the default category structure to organize space.

Keywords: spatial categories; spatial memory; category learning.

Introduction

The categories that people use to organize and retrieve information have a variety of origins. Some stem from the way the human perceptual system imposes structure on experiences with objects. Others are formed inductively out of observations of those objects and may thus reflect the extant statistical structure of items in the world. Here we examine the role of both perception and experience in people's organization of a spatial frame.

It is well known that memories of stimulus locations within an empty frame are biased by the category organization that people impose on space. A common finding is that stimuli (dots) presented within a circular frame are biased away from the circle's horizontal and vertical axes of symmetry and toward diagonal locations (see Figure 1). Huttenlocher, Hedges, and Duncan (1991) described these biases as resulting from a reconstructive memory process in which inexact memory of a particular stimulus location is combined with knowledge about the spatial region, or category, in which that stimulus appeared. Blending these sources of information causes estimates of location to be biased toward category centers (prototypes) and away from category edges (boundaries). Although using categories in reconstructive memory causes bias, Huttenlocher et al. argue that it can also make estimates more accurate than they would have been had the category information not been used.

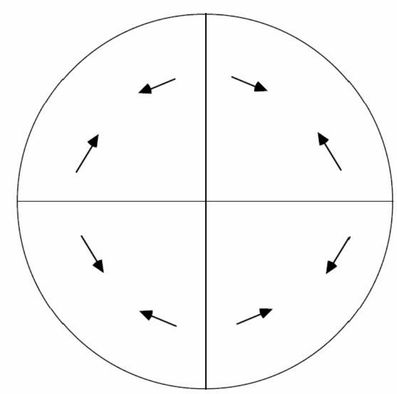

Figure 1: Memory biases for locations within a circular frame.

There are an infinite number of ways to carve an empty space into categories, and yet people consistently default to dividing the circle along its cardinal axes. While other kinds of object categories seem to be derived from experience with the range of presented object attributes (e.g., Crawford, Huttenlocher & Hedges, 2006; Huttenlocher, Hedges and Vevea, 2000), such inductive experience appears to have little impact on how people organize undifferentiated space. Huttenlocher and colleagues (Huttenlocher, Hedges, Corrigan, & Crawford, 2004) had participants view and reproduce the locations of dots within a circle under different distribution conditions. In some cases, the dots were densely clustered around the cardinal axes (the default category boundaries) and very few appeared at diagonal locations (the default category prototypes). They investigated whether people would revise their categories in order to better capture regions of high density in the stimulus space, placing boundaries at diagonal locations and prototypes at the cardinal axes. Several experiments found no evidence that estimates of location took the distribution of stimuli into account: responses exhibited bias away from the cardinal axes even though this meant that estimates landed in locations where stimuli were less likely to have appeared. Even having participants first classify each dot into axes-centered categories (corresponding to up, down, left and right) before reproducing the dot's location did not produce bias toward those axes. Spencer and colleagues (Spencer and Hund, 2002; Schutte & Spencer, 2002) also examined the effect of experience with stimulus distributions on spatial memory. They found that both adults and young children were sensitive to the distribution of presented stimuli, although the default organization still had strong effects.

These studies and others (e.g. Crawford, Regier & Huttenlocher, 2002; Sandberg, 1999; Wedell, Allen & Fitting, in press) have used dots as stimuli, and thus they have not examined how the identity of stimuli may be used to organize spatial categories. Usually when trying to retrieve a location from memory, we seek only a particular object, such as our wallets or key rings. As Hund and Plumert (2003) note, "For the vast and majority of such tasks, people must remember the links between objects and locations." (p. 939). They have shown that such links between location and object identity may be used to organize a spatial array. They had children remember the locations of 20 objects which, in some cases, were spatially grouped by kind. After studying all of the objects, participants reproduced the location of each one. The pattern of bias in responses revealed that those who had studied the clustered objects used that information to estimate locations. Similarly, Crawford & Drake (2005) showed that after viewing 60 positive and negative image stimuli that were (in some conditions) spatially grouped by valence, participants used those groupings to estimate locations during a subsequent memory test. Specifically, their estimates were biased toward the centers of regions defined by the valence of stimuli that appeared there. These studies suggest that at least under certain conditions, participants use the distribution of object kinds to derive categories that affect spatial memory.

A potentially important methodological feature of studies that examined identity-based spatial categories is that stimulus presentations and responses were blocked. Both Hund and Plumert (2003) and Crawford and Drake (2005) had participants view all stimuli in a study block and then reproduce their locations in a subsequent testing block. Thus the identity of an object is necessarily used as a cue to retrieve its location. In contrast, earlier studies of spatial category effects on memory had participants view the same stimulus repeatedly and reproduce its location immediately after each presentation. Object identity was not manipulated and was not important for doing the task.

The present study seeks to combine aspects of prior studies in order to examine whether and how people use identity-based spatial groupings to organize space. In two experiments, we present four kinds of objects within a circular frame. They are spatially clustered by object type in a manner that is congruent or incongruent with the default quadrant categories. Experiment 1 examines whether participants use the identity-based categories to estimate the locations of single objects, a task in which identity information is incidental. Finding that they do not, we then examine whether increasing the number of stimuli to be remembered will lead participants to rely on identity-based categories.

Experiment 1: Single stimulus recall

Method

Participants Twenty-seven undergraduates at the University of Richmond participated in exchange for Psychology course credit.

Stimuli and Procedures After informed consent procedures, each participant was seated at a pc computer with 17" monitor set to a resolution of 38 pixels per cm. It was explained that they would see an object within a circle and then would reproduce the object's location from memory in a comparable circle. There were four different stimulus objects used in the experiment: a pink diamond, a blue square, a red dot, and a yellow hourglass. Each was 13 x 13 pixels. The objects appeared at the same radial location (240 pixels from the circle's center) and at 120 unique angular locations, approximately every 3 degrees around the circle.

Participants were randomly assigned to view stimuli that were grouped so as to be congruent or incongruent with the default quadrant organization. In the congruent condition, the blue squares appeared between 0° and 90°, the red dots between 90° and 180°, the yellow hourglasses between 180° and 270°, and the pink diamonds between 270° and 360°. Thus the prototypical location of each of object type was at the center of one of the four quadrants (45°, 135°, 225°, and 315°). In the incongruent condition, this organization was rotated 45 degrees so that the blue squares appeared between 45° and 135°, the red dots appeared between 135° and 225°, the yellow hourglasses appeared between 225° and 315°, and the pink diamonds appeared between 315° and 45°. In this condition, the prototypical location of each object type was on one of the four quadrant boundaries (0°, 90°, 180°, and 270°). Each location was shown once except for the locations at the object-category boundaries, which were shown twice (once with each possible object), resulting in 124 trials.

On each trial, a 668 pixel diameter circle was displayed for 3000ms and then one of the four stimuli (drawn at random without replacement) appeared within the circle for 600ms. The screen went blank (600ms) and then the circle reappeared, shifted 100 pixels to the right. (This shift was included to prevent participants from relying on unplanned landmarks, such as a smudge on the monitor, to aid their memory). The object then reappeared in the center of the circle and participants used the mouse to move it to the location where it had just been shown, relative to the circle. A response was registered when the participant pressed the mouse button.

Results

One participant was culled for having an average absolute error that was more than 3 standard deviations above the mean error by participant. In addition we culled individual responses that had either an absolute error more than 3 standard deviations above the mean absolute error or an angular bias more than 3 standard deviations above or below the mean angular bias. These culls removed 5.6% of responses.

Angular bias was calculated as the difference in degrees between the angular position of each stimulus and the angular position of the estimate of that stimulus. Positive values indicate counter-clockwise bias and negative values indicate clockwise bias. Thus, if estimates are biased toward the center of the default quadrant categories as in earlier work, plotting angular bias against actual angular location will produce a negatively sloping curve within each quadrant and this pattern will not differ between conditions. Alternatively, if participants used the identity-based categories in estimation, then this negative slope should be attenuated or even reversed for the incongruent condition.

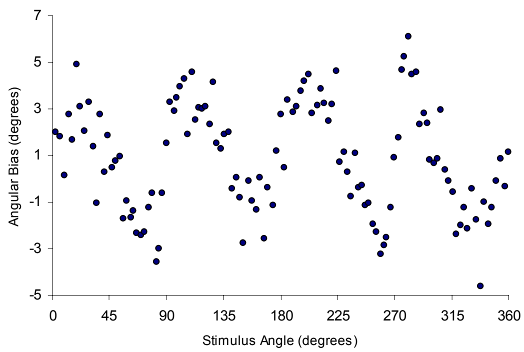

Figure 2a: Experiment 1, congruent condition, bias by stimulus angle.

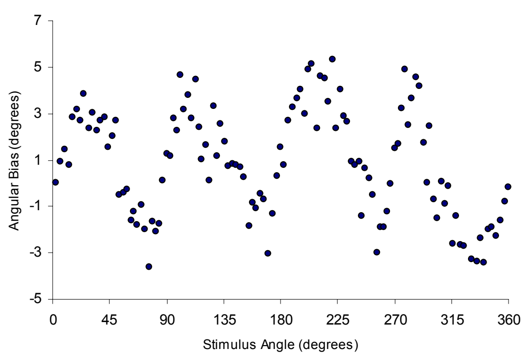

Figure 2b: Experiment 1, incongruent condition, bias by stimulus angle.

The pattern of angular bias in estimates against true angular position is shown in Figure 2a for the quadrant congruent condition and Figure 2b for the incongruent condition. The data mirror the negatively sloping bias curves reported in previous work. Within each quadrant, estimates are biased away from the quadrant boundaries and toward quadrant centers, and there is no apparent difference in this organization between conditions. To test for differences, we collapsed across the four quadrants by coding each stimulus angle relative to its position within the quadrant, thus treating 93°, 183°, and 273° all as comparable to 3°. We then submitted the average biases at each angle (except 0°, the default boundary) to a regression analysis that included a dummy variable for condition. This allowed us to test for differences in the slope of the bias curve between the two conditions. We found no significant difference between the slopes (Congruent condition slope = -.068, incongruent condition slope = -.074, slope difference = .006, $t(54) = 1.24$, *ns*). These results provide no evidence that participants use object identity clusters to reconstruct memories of spatial location.

Discussion

The pattern of bias in estimates indicates that participants relied on the default quadrant categories to organize the circle and used those categories to estimate locations. The results provide no evidence that participants took advantage of available identity-based categories. In the incongruent condition, like stimuli were spatially clustered so that items of each kind appeared in separate regions that were centered on the major axes (0°, 90°, 180°, 270°). If participants had used that information, they would have shifted their responses toward those angular locations, for instance, placing a red dot in the middle of the region where red dots appeared. Instead estimates exhibited bias away from those locations. This means that people shifted memories of stimuli away from regions where stimuli of that kind were more likely to have appeared and toward regions where they were less likely to have appeared.

If participants seek to maximize accuracy in spatial memory, the identity-based clusters would seem to have provided valuable information about object locations, and yet participants do not take advantage of this information. While this may seem to be irrational, another interpretation is suggested by Huttenlocher et al. (2004). They note that cardinal axes are coded very precisely and thus using them as category boundaries may prevent people from making classification errors which in turn lead to huge errors in memory. Given the high cost of miscategorizing a stimulus, it may not be adaptive to abandon such clearly defined categories in order to adopt some with fuzzier boundaries, even if those categories would better capture the extant distribution of objects.

In addition, participants may ignore identity information because the task does not require them to attend to it. Encoding and retrieving the location of one object at a time requires attention only to the object's location and not to its other features. Previous work (Hund & Plumert, 2003; Crawford & Drake, 2005) suggests that when participants must remember locations of several unique objects they do use identity-based categories in estimation. These studies did not compare conditions in which the identity-based categories were either aligned or misaligned with the default categories, and thus they do not address what role the default quadrant organization might play in enabling people to learn identity-based categories. In Experiment 2, we consider this question by having participants view objects that are clustered in a way that is either congruent or incongruent with the default organization and by having them reproduce the locations of multiple items within a trial. It is expected that in the congruent condition, participants will produce estimates that are biased toward the centers of the four quadrants, thus producing the negatively sloping bias pattern found in Experiment 1. The pattern of bias in the incongruent condition will depend on participants' use of the identity-based categories. If participants use the default quadrant organization even when reproducing multiple objects, then the bias in estimates should be comparable to that of the congruent condition. If they abandon the quadrant organization and use identity-based categories, their estimates should be biased toward the cardinal axes and away from diagonal locations, producing a positive bias slope across each quadrant. Alternatively, if they use both kinds of category information, then they should produce an intermediate pattern of bias.

Experiment 2: Multiple stimuli recall

Method

Participants Twenty-four University of Richmond undergraduates participated in exchange for partial course credit.

Stimuli and Procedures The stimulus objects and their possible locations were the same as in Experiment 1. Participants were randomly assigned to view stimuli from either the congruent or incongruent distribution. On each trial, the circle appeared and then four objects (one of each type) appeared successively for 1000ms each. The order of the objects was random and each was presented in a location drawn randomly from the possible locations for that object. After the fourth object was shown, there was a 1000ms blank screen and the circle was shifted 100 pixels to the right. Then participants reproduced the locations of each object one at a time. First, one of the four objects appeared in the center of the circle and participants used the mouse to move it back to the location where it had been seen previously. Participants pressed the mouse button to register the response, the object was removed, and the next object appeared in the center of the circle, to be moved to its prior location. After each of the four objects had been relocated, the circle shifted back to the original position and the next trial began. During the reproduction phase of the trial, the four objects were presented in a random order which did not necessarily correspond to the random order in which they had been presented for study. This is important because it obviates the tendency to focus on the temporal order of stimuli, and thus it was emphasized during the instructions. There were 3 practice trials followed by 42 trials.

Results

We culled individual responses that had either an absolute error more than 3 standard deviations above the mean absolute error or an angular bias more than 3 standard deviations above or below the mean angular bias. These culls removed 4.7% of responses. Angular bias was coded as in Experiment 1.

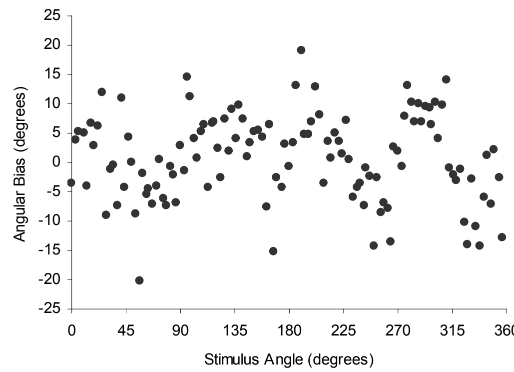

Figure 3a: Experiment 2, congruent condition, bias by stimulus angle

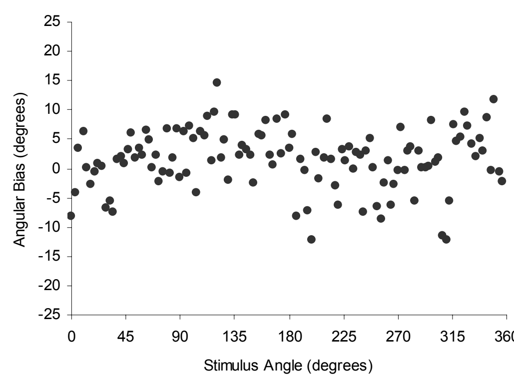

Figure 3b: Experiment 2, incongruent condition, bias by stimulus angle

The average bias by angular position for the congruent and incongruent conditions is presented in Figures 3a and 3b. The graphs make clear that the previously observed sinusoidal pattern with negative bias slopes for each quadrant is replicated in the quadrant congruent condition but not in the incongruent condition. As in Experiment 1, we collapsed angular locations across quadrants and ran a dummy-variable regression of bias on actual stimulus angle. There was a significant difference in the slope of the regression line between the two conditions (congruent condition slope: -.17, incongruent condition slope: +.02, slope difference: 1.9, $t(54) = 6.2$, $p < .001$). In addition, the bias is much more extreme in Experiment 2 than it was in Experiment 1.

Discussion

The results of Experiment 2 show that when participants must remember the locations of four objects during a trial, their estimates are influenced by the identity-based organization of stimuli. As predicted, when stimuli are grouped in a manner congruent with the default quadrant organization, participants use that organization in estimation, producing estimates that are biased toward the centers of the four quadrants. In contrast, when stimulus clusters are incongruent with the default organization, estimates reflect neither the default categories nor the categories suggested by the identity based clusters. The difference in bias patterns indicates that participants utilize information about object identity clusters in their estimates. Thus this experiment shows that under certain conditions, knowledge that objects of a certain kind usually appear in certain regions of space is used to reconstruct memories of object locations. However it also shows that such inductively acquired knowledge does not override participants' a priori default organization of space but rather operates in conjunction with it.

When viewing objects that are organized in opposition to the default categorization, participants do not simply abandon the default organization and adopt the identity-based organization. If they had, the pattern of bias would look like that of the congruent condition only phase shifted by 45 degrees. The bias in this condition does not clearly reflect either that of the two category organizations being examined here and may reflect a blend of the two structures.

General Discussion

Two experiments examined how categories derived from experience and those derived from perception affect spatial memory. Objects were distributed so that each region of space was devoted to only one kind of object. These identity-based regions were either aligned with or opposed to the default perceptually-based categories. When remembering only one object location at a time, participants used only the default categories and not the identity-based categories to reconstruct memories. When remembering four different objects, participants used both categorization schemes to inform their estimates of location.

In this study, the task of remembering multiple objects differed from that of remembering a single object in several ways which may have influenced reliance on identity-based categories. For instance, viewing and then reproducing four objects, as in Experiment 2, requires a longer delay between presentation and response. Longer delays have been shown to increase reliance on the default spatial categories (e.g., Huttenlocher et al., 1991). In addition, Schutte & Spencer (2002) showed that during delays children's memory of spatial location drifted toward previously seen locations. It may be that the long delays of Experiment 2 led our participants to give relatively more weight to identity-based categories.

Another difference between remembering one and four objects may be that, with multiple objects, participants are required to link the identity and location of each object, whereas with a single object, participants may focus solely on location while ignoring identity. Attention is required to bind information about identity and location and participants in Experiment 1 may not have devoted attention in such a way as to learn the links between identity and position. In contrast, Experiment 2 required that participants attend to identity to retrieve location, increasing the likelihood that participants would integrate this information and use the identity-based categories.

In addition, remembering four objects produces substantial memory load and as such is a more difficult task than remembering one. If only one object is to be remembered, participants are likely to know which quadrant it appeared in, and thus additional information about its identity may provide little further benefit. Under the demands of trying to remember four objects within a trial, participants may lose track of which stimulus appeared in which quadrant. This would undermine the key benefit of using the quadrant categories, which Huttenlocher et al. (2004) argue is that they enable people to categorize objects accurately, thus avoiding large memory errors that results from miscategorization. Perhaps only when the quadrant categorization is no longer useful do we find that people use other sources of information to inform their estimates.

It is clearly adaptive for people to keep track of where certain kinds of things are likely to be found, and previous work has shown that people can use such information to remember and infer locations of objects (Crawford & Cacioppo, 2002; Hund & Plumert, 2003). Furthermore it is well documented that people encode spatial information as well as frequency information about objects, even when such information is incidental to the task at hand (e.g., Hasher & Zacks, 1979). Thus it is somewhat surprising that the presented stimulus distribution does not have stronger effects on spatial memory. Even under conditions of long delay, high memory load, and task demands that require the integration of object identity and location, participants do not simply form categories reflecting identity-based clusters. Instead they combine their inductive experience with perceptually derived categories to organize space.

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