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Distortions in location memory

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Memory for the location of a briefly presented target is often distorted in systematic ways. When people remember dot locations within a circular space, they typically show memory biases that appear to reflect a categorical strategy. However, memory for a target location can also be biased toward visible markers or landmarks. In the present study, we investigated the interaction of categorical and landmark effects by providing sectioning lines in a circular space. In the absence of lines, response biases showed categorical effects, whereas in the presence of lines, response biases suggested that participants used a landmark-based scheme. Possible relations between the strategies are discussed.

Memory for location is rarely perfect. Forgetting or misremembering where we parked our car, where we placed our keys, or where our golf ball landed are everyday examples of this imperfection. Researchers have investigated two processes that influence location memory. One is a process in which people subdivide a large space into smaller categories and encode the category along with the specific target location (e.g., Huttenlocher, Hedges, & Duncan, 1991). The second process is to encode the location in relation to nearby landmarks (e.g., Hubbard & Ruppel, 2000). Interestingly, although both of these processes may improve location memory, they can also produce systematic distortions in remembered location.

There is strong evidence that people's memory for a category member can be distorted toward the prototype of its category. This distortion has been demonstrated in various domains: Memory of an artificially colored object will shift toward the usual color of the object (Belli, 1988); when attention is compromised, judgments of people are biased toward stereotypical categories (Neuberg & Fiske, 1987); and spatial memory of a dot's position is affected by spatial category membership (Huttenlocher et al., 1991).

Huttenlocher et al. (1991) developed a categorical adjustment model for spatial memory distortions. They tested it with experiments wherein a dot was presented in a circle and participants attempted to reproduce the dot location in a blank circle. Huttenlocher et al. (1991) theorized that fine-grained information about a position will be lost as one forgets but the spatial category in which the dot was positioned will be remembered. As forgetting occurs, the degraded, fine-grained memory of the position will be averaged with the prototypical value of the category, resulting in a bias toward the center of the category (i.e., toward the prototype). They suggested that use of categorical information reduces variability and, thereby, enhances response accuracy. In Huttenlocher et al.'s (1991) experiments, the dot was remembered as being angularly closer to the oblique axes of the circle, toward the 45º angles of the four Cartesian quadrants. From this, they inferred that the categorical breakdown of the circle is into four quadrants, with the cardinal vertical and horizontal axes serving as boundaries. They also found that dot angular biases roughly followed a linear function of within-category angle, with lower bias near the prototypes and increasing bias with distance from the prototypes. An idealized diagram of this pattern is displayed in Figure 1.

Biases in dot location memory toward category prototypes can be robust and impervious to some seemingly salient manipulations. For example, Huttenlocher, Hedges, Corrigan, and Crawford (2004) tried to influence category formation in the dot and circle task by providing a distribution of dots that was not well captured by the natural quadrant scheme. Dots were clustered toward the cardinal axes, and no dots appeared near the oblique axes. It would seem optimal to form categories of top, bottom, left, and right, rather than the top-right, bottom-right, bottom-left, and top-left categories that people naturally use. In the strongest manipulation, participants were shown the distribution from which sample dots were drawn and were required to categorize each dot into the top, bottom, left, or right category before making their dot position estimate. Even this strong manipulation did not affect response biases, and the evidence indicated that the participants still used their natural categorization scheme.

Several studies, using various procedures, have also shown biases in location memory produced by the presence of nearby landmarks. Although at least one study reported a bias away from landmarks (Schmidt, Werner, & Diedrichsen, 2003), most studies have reported that remembered location is biased toward a nearby landmark. For example, Sheth and Shimojo (2001) found a bias in remembered location toward a visible marker, an effect they referred to as a compression of distance in memory. Using both a mouse click and a sequential judgment task, they found that dots presented on the horizontal meridian of a computer screen were remembered as closer to a cen-

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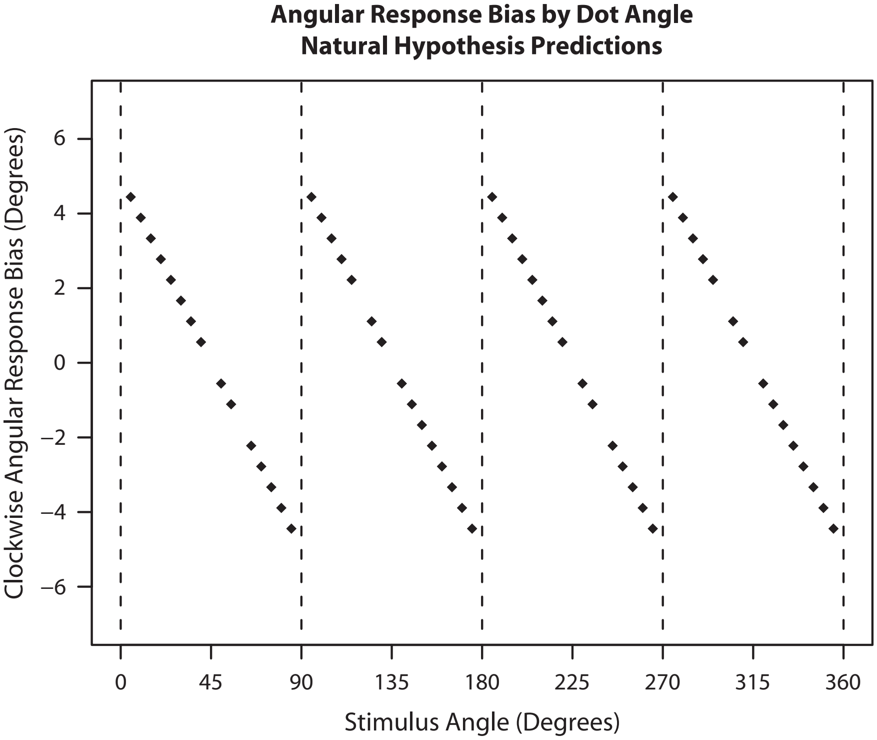

Figure 1. Idealized pattern of angular biases expected to occur according to the categorization scheme proposed by Huttenlocher, Hedges, and Duncan (1991). The dashed vertical lines indicate the hypothesized boundaries of the inferred categories.

ter fixation point even if participants looked away from the center before responding. Participants also showed a bias in dot location memory toward a line presented on the right-hand side of the screen.

Experiments by Hubbard (1998) showed attraction biases in location memory toward large surface areas. Targets moved vertically alongside a filled black area and then vanished at an unpredictable time; participants clicked to indicate where they had last seen it. Hubbard found that responses were biased toward the black area, whether it was on the right or the left side of the target. No biases occurred if the black area was absent or if the target moved between two black regions. Hubbard and Ruppel (2000) also found a landmark attraction bias when a small target was presented for 1 sec above, below, or on either side of a larger square landmark. Participants showed an overall downward bias in remembered location (already documented as a representational gravity bias), as well as a bias toward the landmark; this bias increased with increases in the distance of the landmark from the target.

Our experiments were designed to examine the influence of categorization and landmark processes within the same experiment. Specifically, we examined the effect of providing visible sectioning radial lines in the circular display for a dot reproduction task. These lines provided visual boundaries that the participants could use to form new categories of the circle. If the participants used the lines as category boundaries, their responses should be biased toward the center of our induced categories. Alternatively, people might use the lines as landmarks and, consequently, show a response bias toward the lines.

EXPERIMENT 1

This experiment examined the effect of visible dividing lines in a circular space on people's dot location memory. Either three or four radial lines in one of two configurations produced four possible visible breakdowns of circular space. We tested three hypotheses. The *boundary* hypothesis is that the lines would be treated as category boundaries and responses would be biased toward the center of those categories. The *landmark* hypothesis is that the lines would be used as landmarks and responses would be biased toward the lines. The *natural* hypothesis is that the lines would have no effect and responses would be biased toward the center of the four Cartesian quadrants of the circle, as in previous studies with unsectioned circles.

Method

Participants. The participants were 112 University of Alberta undergraduates enrolled in 1st-year psychology courses. They received course credit for participation.

Design. The participants were assigned in random order to one of four conditions ($n = 28$ per condition): four-section standard, four-section rotated, three-section standard, and three-section rotated (see Figure 2). These four conditions divided the same circular space in different ways, named according to the number of sections and the orientation of the lines (i.e., where standard conditions have a vertical line in the top half of the circle, and rotated conditions have the same line configuration as the standard but rotated by half of a section). The experiment consisted of two phases with 60 trials each. The stimulus circle was sectioned in both phases, but the response circle was sectioned in one phase and blank in the other phase. Phase order was counterbalanced across participants.

Stimuli. The stimuli were presented on either 17-in. CRT or 17-in. LCD monitors; resolution was set to 1,280 × 1,024 pixels. The stimuli

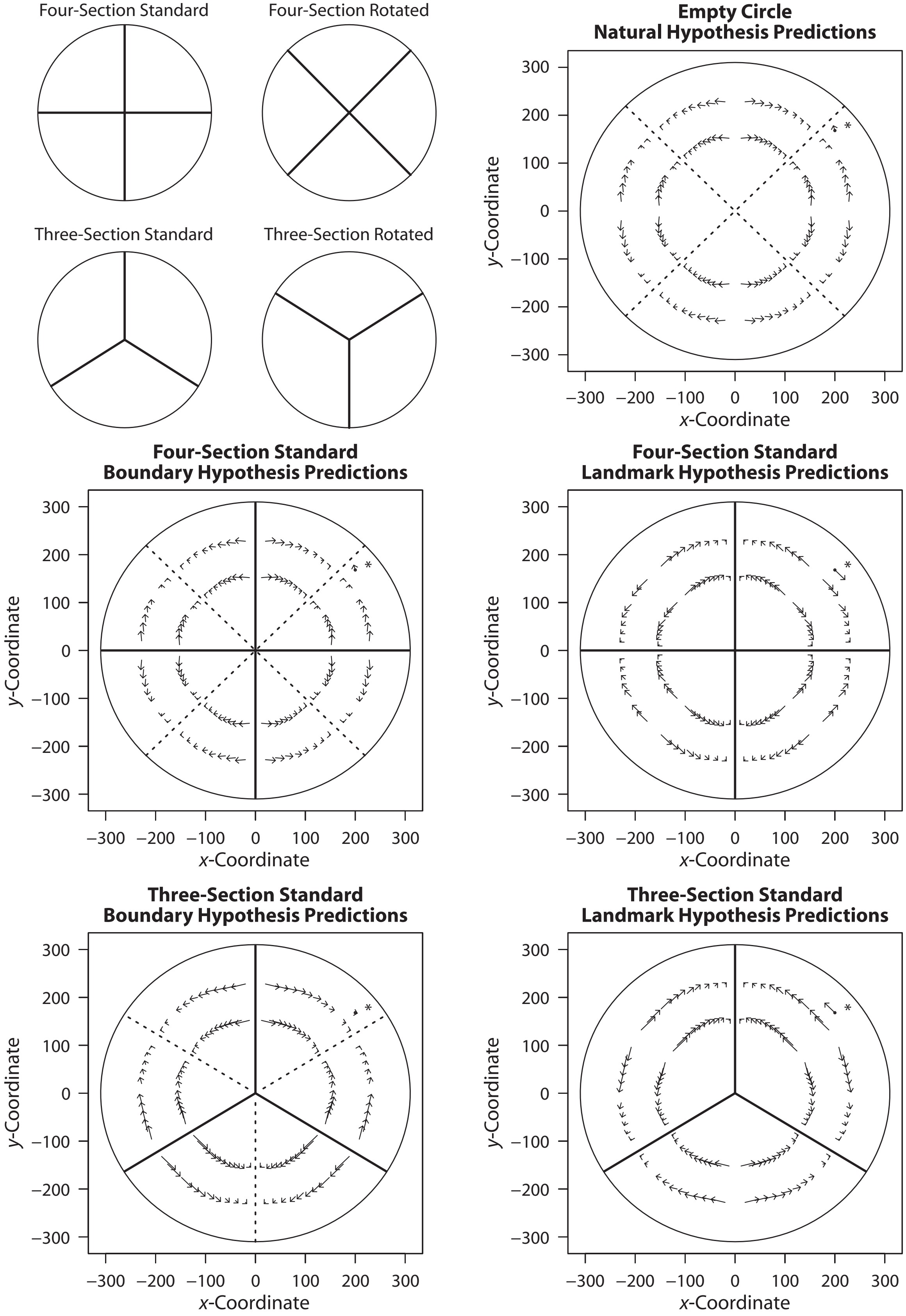

Figure 2. The top-left diagrams indicate the number and orientation of section lines in each of the four conditions. All the remaining panels represent idealized patterns of bias under different situations. The top-right panel corresponds to the natural hypothesis and a condition with no sectioning lines at all. The middle-left and bottom-left panels correspond to the boundary hypothesis, wherein participants treat lines as category boundaries. The resulting biases are away from the visible category boundaries (dark lines) and toward the inferred category prototypes (dashed lines). The middle-right and bottom-right panels correspond to the landmark hypothesis, in which participants use the lines as reference points and bias their responses toward them. The rotated conditions would be simple rotations of the standard patterns and, thus, are excluded for brevity.

were yellow and were displayed on a gray background. Seated participants viewed the screen from a distance of 30–60 cm. The circle and its sections were drawn with a 1-pixel-thick (0.25 mm) line and had a radius of 305 pixels (76 mm). Dots were squares with 6-pixel (1.5-mm) sides. Dot locations had one of two set radius values, approximately 152 or 228 pixels (38 or 57 mm) from the center of the circle. The dot angular locations were kept at least 5º away from any of the possible section lines but, otherwise, occurred every 5º. Combining radius and angles, there were a total of 120 dot locations.

Procedure. Two computer stations were used, and 2 participants were tested concurrently. The experimenter, who remained in the testing room, gave the participants simple verbal instructions, directed them to read the instructions on the screen, then reiterated those instructions and asked whether they had questions. Instructions included the following information. A yellow circle would appear on screen, and soon after a dot would appear in the circle. A short time after the dot appeared, the screen would clear briefly, and then another yellow circle would appear somewhere else on the screen. In this new circle, the participants should click where they remembered the dot to be, relative to the circle, and not relative to anything else, such as the monitor. No mention of categories or sections was made. Halfway through the session, the response section condition was reversed for each participant, and a message screen informed them of the change (i.e., lines in the response circle would be added or removed).

Trials started with a display of the circle and any dividing lines. After 1 sec, the stimulus dot was added for 1.5 sec, and then the entire display was cleared. The response circle was then displayed at a random location, and the participants responded by clicking the mouse. Clicks made within the first 1 sec of response display onset were not registered, to omit accidental or impulsive responses. After a response was recorded, the stimulus dot reappeared briefly in its correct location as visual feedback, followed by a 6-sec intertrial interval with a blank screen. The experiment took approximately 25 min in total and consisted of 120 trials across two phases. Dot radius was randomly determined, with an equal number of short and long radius dots appearing. Each of the 60 dot angles was presented exactly once, for each participant during each phase, in a randomly determined order.

Analysis. Circle categorization is typically demonstrated by linear regression of angular response bias on stimulus dot angle, separately for each of the four Cartesian quadrant categories (Huttenlocher et al., 2004). The angular bias (response angle minus stimulus angle) is calculated so that positive values are clockwise biases and negative values are counterclockwise biases. Significant negative slopes in each category indicate a bias toward the central portion (i.e., the prototype) of each category.

Since the regressor is the angle of the dot within the category, and not relative to the 360º within the circle, category-relative angles are required as regressors. The three hypotheses discussed above lead to different categorization schemes for the different conditions and three possible regressors: a natural regressor, a boundary regressor, and a landmark regressor. General predictions based on each hypothesis are shown in Figure 2. Within each circle, a sample dot is shown at 50º relative to the entire circle, with 0º at the top of the circle. This dot will be in a different category for each section condition and, thus, will have a different category-relative angle per condition. Under the natural hypothesis (which assumes that the section lines are not used), this dot will be in the top-right category and will be given a natural regressor value of 50º in all conditions. Under the boundary hypothesis, the boundary regressor value depends on the section condition: It is 50º in the four-section standard condition, 5º in the four-section rotated condition, 50º in the three-section standard condition, and 55º in the three-section rotated condition. Under the landmark hypothesis, this dot will have landmark regressor values of 5º in the four-section standard condition, 50º in the four-section rotated condition, 55º in the three-section standard condition, and 50º in the three-section rotated condition. Regressor range is between 0º and 44º for the four-section conditions and between 0º and 59º for the three-section conditions.

To illustrate how these hypotheses make different predictions, Figure 3 shows the mean angular bias for each dot angle for two of the conditions. If a given hypothesis is correct, the within-category stimulus dot angle will be a good predictor of the angular bias, resulting in a negative slope within each of the hypothesized sections indicated by the vertical lines. Using a regressor from an incorrect hypothesis will result in inferior predictive power. We can thus distinguish between the three hypotheses by running regressions using each of the three regressors under each category condition. Support for a given hypothesis will be provided if the R^2 values, or model fits, are greater for that regressor than for the other regressors and if the slope is lower than for the other regressors.

We regressed angular bias on each of these three regressors, separately for each participant. The resulting R^2 values were used as the data for inferential analysis, with the understanding that the slope and R^2 indicate the extent to which a participant's response angle was biased in the way specified by the hypothesis. Separate ANOVAs were performed on each section condition to compare the hypotheses, using slopes and R^2 values as dependent measures. Where required, we also performed *t* tests for planned comparisons between the three hypotheses.

Note that there is overlap in the predictions of the three hypotheses in each of the four-section conditions. In the standard four-section condition, the regressor is the same for both the boundary hypothesis and the natural hypothesis, because the induced categories are the same as the natural ones. In the rotated four-section condition, the natural and landmark regressors are the same. Both three-section conditions have distinct regressors for the three hypotheses. Thus, we compared two regressors for the four-section conditions and three regressors for the three-section conditions.

Results and Discussion

Initial analyses for order of exposure to the two phases (sectioned or unsectioned response circles) did not reveal any effects of order, and therefore, the data were collapsed across order for all the subsequent analyses. We first analyzed the results from the phases in which both the stimulus and the response circles were sectioned. To determine which regressor predicts best, we conducted separate within-subjects ANOVAs on the slopes and R^2s for each of the section conditions. For all tests, the results for the slope and R^2 are concordant. As can be seen in Table 1 and Figure 4, the landmark regressor fit the data better than did the natural/boundary regressor for the four-section standard condition, and the natural/landmark regressor fit the data better than did the boundary regressor for the four-section rotated condition. In fact, the natural/landmark regressor in the four-section rotated condition accounts for more variance than does any other regressor. In both three-section conditions, ANOVAs and planned comparisons demonstrated that the landmark regressor was superior to both the natural and the boundary regressors.

When stimulus circles were sectioned but response circles were not, the results were less clear. In two of the conditions (four-section rotated and three-section standard), fits from the landmark and/or natural hypotheses were significantly better than those from the boundary condition. In the remaining two conditions, there were no significant differences between the hypotheses. Fits from the natural and landmark hypotheses did not differ significantly in any of the conditions.

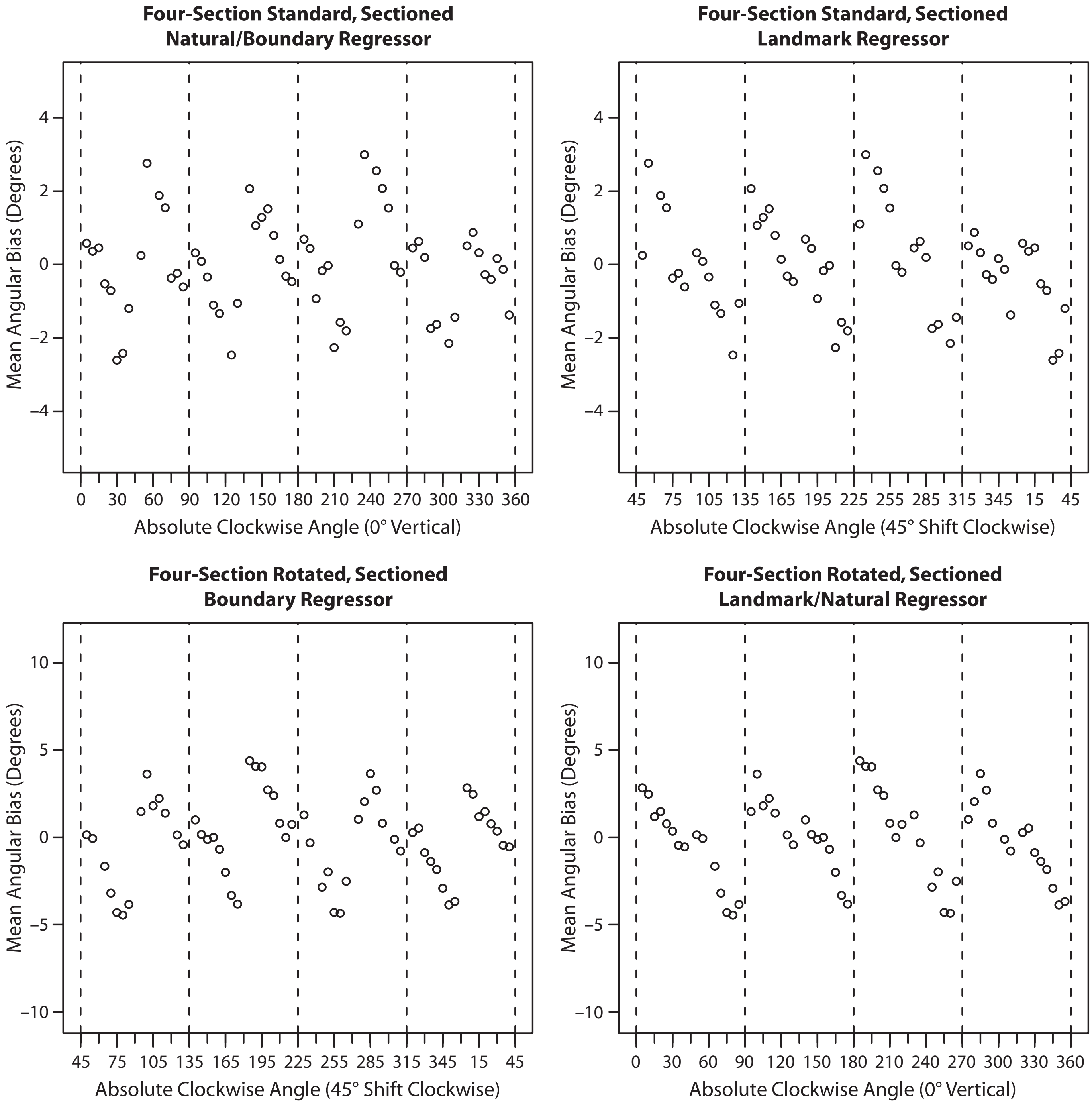

Figure 3. Scatterplots demonstrating a sampling of response patterns under different regressors. The dotted vertical lines represent the boundaries for the hypothesized categories. The predicted pattern of response is a linearly decreasing function between each set of dotted lines.

Overall, these results support the landmark hypothesis. When section lines were present in both the stimulus and the response circles, analyses on both slopes and regressors supported the hypothesis that people use sectioning lines as landmarks. Furthermore, the landmark/natural regressor in the four-section rotated condition explained the greatest variance, presumably because of the complete congruence between the landmark-based induction and the natural categorization scheme. When sections were removed from the response circles, neither the landmark nor the natural scheme appeared to dominate, which is indirect evidence for a mixture of strategies within or across participants.

EXPERIMENT 2

When both the stimulus and the response circles were sectioned in Experiment 1, the participants showed a bias toward the lines, consistent with a landmark strategy. Across the four conditions, the landmark hypothesis provided the best fit and the boundary hypothesis provided the worst fit to the data, with the natural hypothesis falling between the two. When the stimulus circle was sectioned but the section lines were removed in the response circle, the data suggested a mixture of strategies. Although the boundary hypothesis continued to provide the worst fit to

Table 1
Summary of the ANOVAs on R^2s and Slopes for Angular Biases When the Data Were Grouped According to Predictions of the Natural (N), Landmark (L), and Boundary (B) Hypotheses for Each Condition in Experiments 1 and 2 and for Phases in Which the Stimulus Circles (SCs) and Response Circles (RCs) Were Sectioned (S) or Unsectioned (U)

			R^2				Slope		
Sectioning (SC/RC)	Condition	Hypothesis Compared	*df*	*F*	*p*	Hypothesis Supported	*F*	*p*	Hypothesis Supported
			Experiment 1						
S/S	4-section standard	N/B vs. L	1,27	12.58	<.01	L > N/B	25.38	<.01	L > N/B
	4-section rotated	N/L vs. B	1,27	66.51	<.01	L/N > B	98.81	<.01	N/L > B
	3-section standard	N vs. L vs. B	2,54	30.04	<.01	L > N > B	43.34	<.01	L > N > B
	3-section rotated	N vs. L vs. B	2,54	40.23	<.01	L > N > B	51.75	<.01	L > N > B
S/U	4-section standard	N/B vs. L	1,27	0.18	.679	L = N/B	0.92	.347	L = N/B
	4-section rotated	N/L vs. B	1,27	73.05	<.01	L/N > B	232.3	<.01	N/L > B
	3-section standard	N vs. L vs. B	2,54	11.33	<.01	L = N > B	13.56	<.01	L = N > B
	3-section rotated	N vs. L vs. B	2,54	1.62	.214	L = N = B	0.8	.380	L = N = B
			Experiment 2						
S/S	4-section standard	N vs. L	1,15	1.48	.243	L = N	9.76	<.01	L > N
	3-section standard	N vs. L	1,15	21.47	<.01	L > N	33.68	<.01	L > N
	3-section rotated	N vs. L	1,15	29.67	<.01	L > N	2.41	.142	L = N
U/U	4-section standard	N vs. L	1,15	21.28	<.01	N > L	52.76	<.01	N > L
	3-section standard	N vs. L	1,15	15.12	<.01	N > L	47.2	<.01	N > L
	3-section rotated	N vs. L	1,15	21.93	<.01	N > L	45.98	<.01	N > L

Note—The hypotheses supported are based on a significant *F* value in the case of two comparisons and a significant planned *t* test in the case of three comparisons.

the data, fits of the landmark and natural hypotheses were not significantly different. Thus, when the section lines are present at encoding but are removed during responding, participants seem to partially, but not fully revert to the natural categorization scheme.

In Experiment 2, all the participants were first tested in a phase in which both the stimulus and the response circles were sectioned and then were tested in a phase in which both the stimulus and the response circles were unsectioned. If the sectioning lines had only transient effects on responding, participants should fully revert to a natural categorization scheme when the section lines are absent from both the stimulus and the response circles. On the other hand, if the section lines had enduring effects and result in participants' forming a new long-term framework in which to remember dot locations, the natural scheme may not predict biases in responding even in a fully unsectioned phase.

Method

The participants were 64 undergraduate students from the same pool as that in Experiment 1. They were assigned in random order to one of four conditions ($n = 16$). The methods were those used in Experiment 1, with three exceptions. First, all the participants used 17-in. LCD monitors. Second, for all the participants, both the stimulus circle and the response circle were sectioned (according to the participant's sectioning condition) during the first experimental phase, whereas both the stimulus circle and the response circle were unsectioned during the second phase. Third, because the boundary hypothesis was ruled out in Experiment 1, we simplified the analysis to consider only the natural and landmark hypotheses.

Results and Discussion

As in Experiment 1, we conducted separate within-subjects ANOVAs on the slopes and R^2s for each condition. However, we excluded the four-section rotated conditions because of the complete correspondence between the natural and the landmark regressors. In two of the conditions, only one measure produced a significant result, but in all other cases, a significant difference between the landmark and the natural regressors occurred for both measures (see Table 1 and Figure 5). In the sectioned conditions, the landmark regressor had lower slopes and higher R^2s values, whereas in the unsectioned conditions, the natural regressor had lower slopes and higher R^2s. Averaged across the three conditions in which section lines were present in both the stimulus and the response circles, mean R^2 was .215 with the landmark regressor and .103 with the natural regressor. The corresponding means for the unsectioned phases were were .076 and .163. Thus, the participants appeared to have used the section lines as landmarks when they were present, but they reverted to the natural scheme once the lines were removed from both the stimulus and the response circles.

To further check for any potential carryover of the sectioned phase, we compared the natural regressor for the unsectioned phase of the four-section rotated condition (in which the section lines were congruent with the natural categorization scheme) with the natural regressor for the unsectioned phase of the remaining three conditions (in which the sections were incongruent with the natural categorization scheme). If the R^2 of the natural regressor in the four-section rotated case was higher than in the other three conditions, this would indicate that the encoding scheme during the sectioned phase was not immediately eradicated when the sections were removed. Although the natural regressor mean was not significantly higher for the four-section rotated condition (.199) than the average of the other three category conditions (.151) [$t(26.73) = 1.66, p > .05$], the negative slope was significantly steeper for the four-section rotated condition (-0.115) than the average of the three other conditions (-0.086) [$t(31.9) = -2.72, p < .05$], suggesting a small carryover effect.

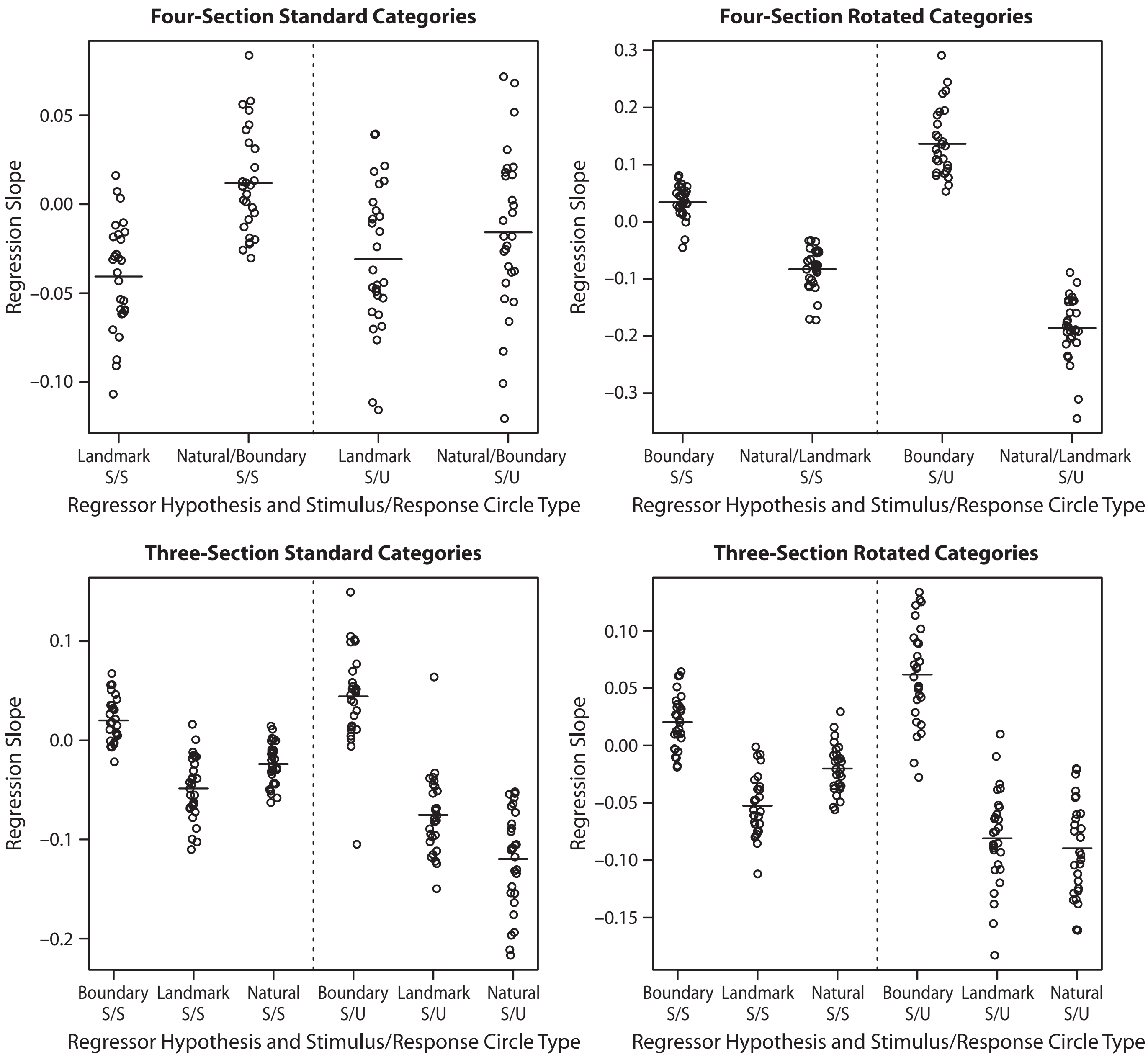

Figure 4. Stripcharts of Experiment 1 slopes under different regressors, per each section condition. Each participant's slope is plotted, and the horizontal line across each cluster designates the mean slope. The expectation was that the best predictor would lead to lower slopes. S, sectioned; U, unsectioned.

Overall, these results suggest that the explicit visual sectioning lines were used as landmarks while they were present but did not produce a strong lasting effect. Once the lines were removed from both the stimulus and the response displays, people returned to their natural categorization scheme and, at best, showed a weak carryover effect from the previous phase.

GENERAL DISCUSSION

Our results show that biases in remembered locations in a circular space can be influenced by visible radial divisions. Interestingly, the participants showed no evidence of using the lines as new category boundaries, even though salient category boundaries should allow for more accurate categorization and, hence, better responding overall (Huttenlocher et al., 1991). Although there was no indication that the lines were used as category boundaries, overall accuracy in responding was enhanced by the lines. In Experiment 1, the average absolute angular error was 3.02º when the response circle was sectioned and 6.28º when it was blank. In Experiment 2, the error was 3.24º for sectioned conditions and 4.86º for unsectioned conditions.

There are at least two plausible interpretations for our results. First, the lines may have resulted in a switch in strategy. Specifically, the participants may have switched from using a category-based strategy with an empty circle to a landmark strategy when section lines were present. Second, it is possible that the participants used the same strategy in both cases but the presence of the sec-

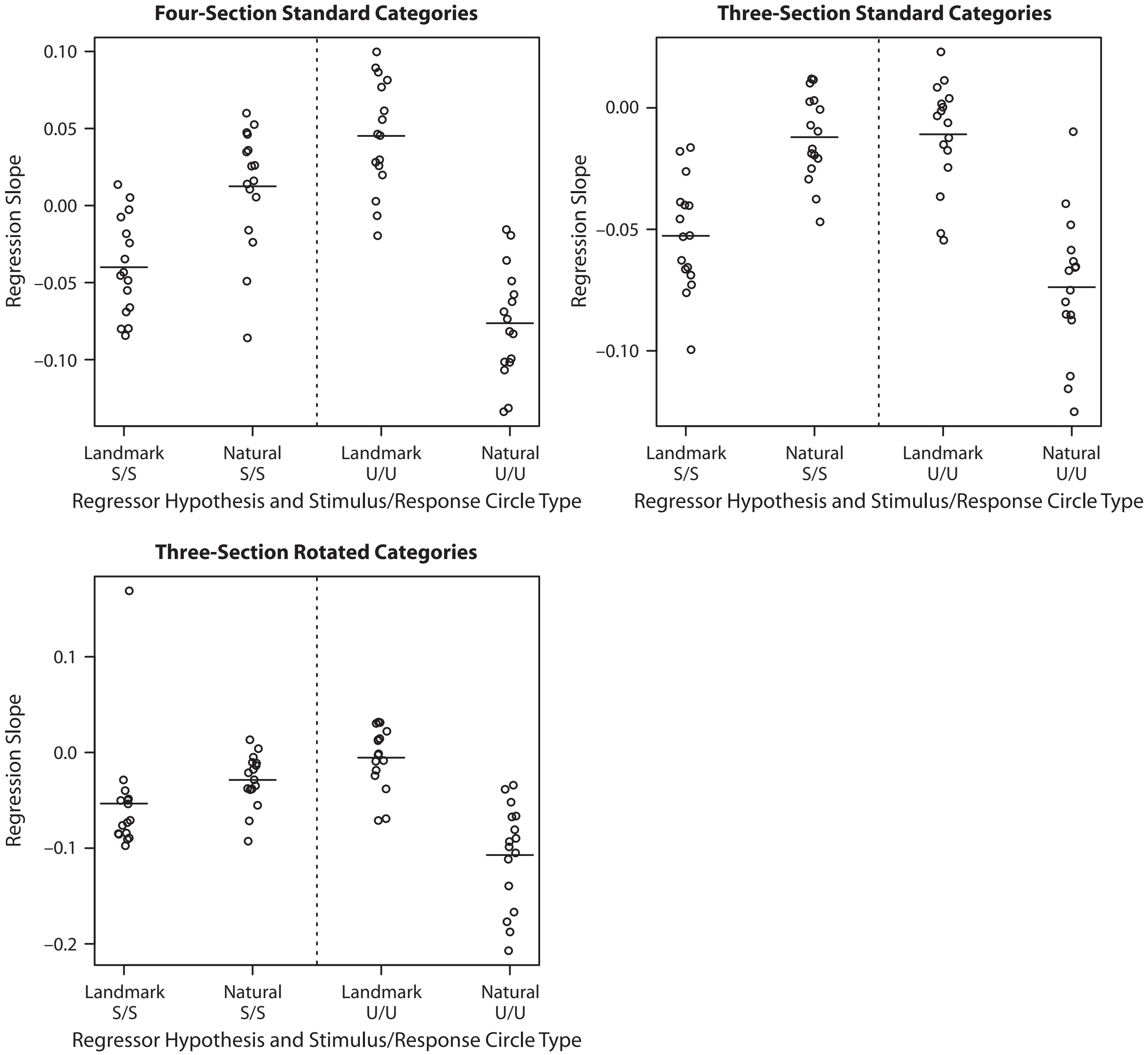

Figure 5. Stripcharts of Experiment 2 slopes under different regressors, per each section condition tested. Each participant's slope is plotted, and the horizontal line across each cluster designates the mean slope. The expectation is that the best predictor will lead to lower slopes. S, sectioned; U, unsectioned.

tion lines altered how the strategy was applied. For example, the participants may have used the sectioning lines not as landmarks, but rather as category prototypes, and then subsequently inferred the category boundaries. This would presumably be a reversal of the process used in the natural categorization scheme but would, nevertheless, be a categorization strategy. Although possible, this approach seems unlikely because it contradicts tenets of the categorical approach (Huttenlocher et al., 1991). For example, it would result in categories with poorly defined boundaries under the four-section standard condition and in both three-section conditions, due to the oblique effect (Appelle, 1972). An alternative possibility is that a landmark strategy could underlie the natural categorical strategy. The category prototype may provide an imagined landmark, its position inferred from the category boundaries selected. The accuracy advantage in using visible landmarks over the natural categorization scheme may arise because it is easier to remember the distance of a dot from a visible landmark line than from the invisible inferred center point of a quadrant.

There is some evidence that people can show biases toward inferred landmarks. Bryant and Subbiah (1994) reported biases toward both visible and "subjective" landmarks. Dot stimuli were presented in a square field with three distance markers on the left and bottom sides of the square that allowed people to form imaginary intersections. They found that people showed an attraction bias toward single visible "+" marks placed on the intersection nearest to the stimulus dot. In the absence of such marks, production accuracy was highest for dots presented on the imaginary intersection of the markers. For dots presented elsewhere, production was biased toward the nearest imaginary intersection point. Notably, verbal instructions regarding mnemonic tactics powerfully influenced whether imagined intersections biased responding.

Tversky and Schiano (1989) also found that instructional frames of reference can alter memory bias. Participants were shown figures labeled either as graphs or as maps. The figures showed a straight line at various angles within an L-frame with tick marks. The participants reproduced the line on a blank L-frame. For the graph condition, the participants showed a bias toward 45º, whereas no such bias was found in the map condition. Thus, higher level conceptual frameworks apparently can override lower-level spatial memory strategies. Our results suggest the opposite possibility, that a simpler landmark-based strategy may override, or underlie, a hierarchical categorical memory strategy.

In future research, it will be important to further explore the theoretical relations between landmarks and categorical prototypes. We might take lead from Hubbard (1998). Just as he investigated the relations among referential gravity, friction, and landmark attraction effects, we can ask how categorization, landmarks, and other frames of reference interact. Although it seems unlikely that all categorical judgment effects can be explained by a landmark account, it seems possible that the categorical strategy is used to produce implicit landmarks. If so, the same mechanisms might underlie the use of explicit visual landmarks and the use of implicit, virtual, subjective, or emergent landmarks (such as category prototypes, frames of reference, or inferred intersections). Perhaps it is the selection of landmarks or frame of reference that differs under various conditions. Personal experience, experimental instructions, and stimulus affordances could each influence frames of reference, and all of these factors may be considered in discovering how people remember locations in space.

AUTHOR NOTE

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