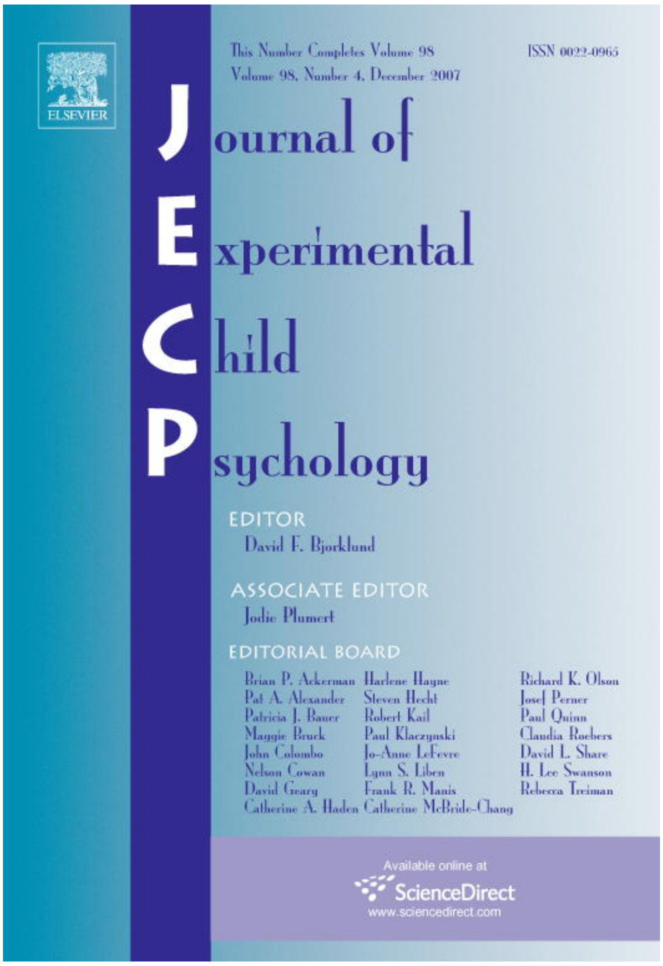
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# How do biases in spatial memory change as children and adults are learning locations?

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**Abstract**

This investigation tracked changes in categorical bias (i.e., placing objects belonging to the same spatial group closer together than they really are) while 7-, 9-, and 11-year-olds and adults were learning a set of locations. Participants learned the locations of 20 objects marked by dots on the floor of an open square box divided into quadrants. At test, participants attempted to place the objects in the correct locations without the dots and boundaries. In Experiment 1, we probed categorical bias during learning by alternating learning and test trials. Categorical bias was high during the first test trial and decreased over the second and third test trials. In Experiment 2, we manipulated opportunities for learning by providing participants with either one, two, three, or four learning trials prior to test. Participants who experienced one or two learning trials exhibited more bias at test than did those who experienced four learning trials. The discussion focuses on how categorical bias emerges through interactions between the cognitive system and task structure.


*Keywords:* Spatial memory; Cognitive development; Spatial cognition; Category learning

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## Introduction

The idea that people (and animals) create and store "cognitive maps" of their environments has a long and venerable history (Tolman, 1948). Many studies conducted over the past 50 years have focused on the nature of these spatial representations. For example, there is considerable controversy over whether people's spatial representations are viewpoint dependent or independent (e.g., Diwadkar & McNamara, 1997; Epstein & Kanwisher, 1998; King, Burgess, Hartley, Vargha-Khadem, & O'Keefe, 2002). Largely, these studies focus on what spatial memory looks like after people have learned a set of locations in an environment. As a consequence, relatively little is known about how spatial memory changes while people are learning a set of locations (for an exception, see Hund & Spencer, 2003). The goal of our investigation was to track changes in memory for location while children and adults were learning a set of locations in a small-scale environment.

Systematic bias in memory for location is an important signature of the underlying processes involved in reproducing previously seen locations. Recent work has shown that both children and adults exhibit systematic bias toward the centers of geometric regions and spatial groups (Huttenlocher, Newcombe, & Sandberg, 1994; Plumert & Hund, 2001; Spencer & Hund, 2002). A key question is where this bias comes from. According to the category adjustment model originally proposed by Huttenlocher, Hedges, and Duncan (1991), retrieval of locations from memory involves the use of both fine-grained and categorical information. When trying to remember a location, people make estimates based on their memory of fine-grained metric information such as distance and direction from an edge. However, because memory for fine-grained information is inexact, people adjust these estimates based on categorical information about the location. This categorical information can be represented by a prototype located at the center of the spatial region (Huttenlocher et al., 1991) or by the associations among locations in a spatial group (Plumert & Hund, 2001). In both cases, adjustments based on categorical information lead to systematic distortions toward the centers of spatial categories. That is, spatial prototypes and spatial groups exert "pull" on estimates of location. More recent work suggests that the magnitude of the pull toward category centers depends on the interaction of memory for fine-grained and categorical information (Plumert, Hund, & Recker, 2007). When memory for the individual locations is strong relative to memory for the spatial categories, people exhibit little or no categorical bias in their placements. Conversely, when memory for the individual locations is weak relative to memory for the spatial categories, people place objects closer to the centers of spatial categories than they really are.

Recent studies have examined how the strength of memory for fine-grained and categorical information influences bias in estimates of location by manipulating the salience of one type of information relative to the other (Hund & Plumert, 2002, 2003, 2005; Hund, Plumert, & Benney, 2002; Hund & Spencer, 2003; Plumert & Hund, 2001). A claim that has been widely supported is that increasing the uncertainty of memory for fine-grained information leads to greater categorical bias (Engebretson & Huttenlocher, 1996; Herman, Cachuela, & Heins, 1987; Hund & Plumert, 2002; Hund & Spencer, 2003). One way to manipulate fine-grained certainty is to impose a delay between learning and reproducing locations. The rationale behind this approach is that memory for fine-grained information should decay with delays between learning and test, leading to increased weighting of categorical information in estimates of location. Consistent with this proposal, Hund and

Plumert (2002) found that children and adults exhibited more categorical bias when there was a delay between learning and reproducing a set of locations. Likewise, Spencer and his colleagues have shown repeatedly that bias in estimates of location increases systematically with delays between seeing and reproducing locations (Hund & Spencer, 2003; Spencer & Hund, 2002). Together, these findings support the idea that certainty about fine-grained information plays an important role in estimates of location.

Clearly, the finding that people exhibit more bias in their placements after a delay than after no delay supports the claim that memory for location is dynamic, undergoing systematic change over time. To this point, this claim has been evaluated mainly based on differences in categorical bias observed after learning is complete (e.g., after participants reach a learning criterion). In other words, we infer changes in memory for location over time when we find that categorical bias varies in response to delays between learning and test. Another way to examine the dynamics of spatial memory is to probe for change in categorical bias *during* the course of learning. As others have noted, tracking change during learning provides a unique window into the processes that give rise to emergent behaviors (Siegler, 1996; Thelen & Smith, 1994). That is, we can better understand how interactions between task structure and the cognitive system give rise to particular patterns of behavior by observing change over time (see Plumert et al., 2007). In the current investigation, we were particularly interested in how increased opportunities for learning a set of locations interacted with memory for fine-grained and categorical information to produce changes in the pattern of categorical bias.

The aims of this investigation were twofold. Our first aim was to test how changes in the certainty of memory for fine-grained information over time affects categorical bias in estimates of location. We did this by manipulating opportunities for learning a set of locations. The basic task involved learning the locations of 20 objects on the floor of an open square box. During learning trials, dots marked the locations of the objects and boundaries divided the box into quadrants (with five objects in each quadrant). Participants attempted to place the objects on the correct dots (incorrect placements were corrected immediately). During test trials, the dots marking the locations and the boundaries subdividing the box were removed. Participants then attempted to place the objects in the correct locations. The primary measure of interest was whether participants placed the objects in each spatial group closer together than they really were. In Experiment 1, participants received a test trial immediately following each learning trial. Thus, we probed categorical bias while children and adults were learning the locations. In Experiment 2, we provided participants with either one, two, three, or four learning trials prior to test. According to the category adjustment model, children and adults should be more uncertain about the locations early in learning, resulting in relatively more categorical bias at the beginning of learning than at the end of learning (Experiment 1) and more categorical bias with few learning trials prior to test than with many learning trials (Experiment 2). In addition, we expected that categorical bias would decrease more quickly in Experiment 1 than in Experiment 2 because repeated testing would lead participants to focus on fine-grained information about the locations after the first test trial.

Our second aim was to examine age differences in categorical bias when the absolute amount of exposure to the locations is held constant. Previous work always has adopted a trials-to-criterion approach in which children and adults were brought up to a learning criterion prior to test in the task described above (Hund & Plumert, 2002, 2003, 2005; Hund et al., 2002; Plumert & Hund, 2001). In these studies, the learning phase continued until participants reached a learning criterion of placing all the objects correctly in a single trial. At test, participants attempted to replace the objects without the dots marking the locations. Under this procedure, adults almost always exhibited categorical bias at test when even a single cue (e.g., boundaries) was available to organize the locations into groups during learning. In contrast, children often did not exhibit categorical bias at test unless two cues were available during learning. Given that children almost always require more learning trials than do adults, we do not know what categorical bias looks like in children and adults when they are given the same exposure to the locations, particularly early in learning. To address this question, we probed categorical bias after children and adults had completed the same absolute number of learning trials. Boundaries were present during learning to organize the locations into groups. Based on previous work suggesting that adults code spatial groups very quickly, we expected that adults would exhibit strong categorical bias at the first test trial. However, we expected that children would exhibit little or no bias across the three test trials given previous work showing that they rarely exhibit categorical bias when only one cue is available for coding spatial groups during learning.

## Experiment 1

### *Method*

#### Participants

Participants were 48 7-, 9-, and 11-year-olds and adults (mean ages = 7 years 4 months, 9 years 6 months, 11 years 9 months, and 19 years 9 months, respectively). There were 12 participants in each age group, with approximately equal numbers of males and females in each group. Children were recruited from a child research participant database maintained by the Department of Psychology at the University of Iowa. Parents received a letter describing the study, followed by a telephone call inviting their children to participate. Of the child participants, 94% were European American, 3% were Hispanic/Latino, and 3% were African American. Of the children's mothers, 6% had completed a high school education or less, 34% had completed some college, and 60% had a 4-year-college education or beyond. Adults participated to fulfill research credit in their introductory psychology course at the University of Iowa. Of the adult participants, 92% were European American and 8% were Asian American.

#### Apparatus

The experimental space was an open square box (91.44 cm long × 91.44 cm wide × 30.48 cm high) placed on the testing room floor. A total of 20 1.91 cm light-emitting diodes (LEDs) beneath a black-tinted Plexiglas floor marked the locations. Lines (0.79 cm wide × 0.79 cm high) divided the floor into quadrants, with five locations in each quadrant (Fig. 1). The following 20 unrelated objects (approximately 1.91 cm long × 1.57 cm wide) were used to help participants learn the locations: basket, carrot, dog, bottle of milk, jack-o'-lantern, hot dog, plate, jar of honey, beverage carton, frog, pot, shirt, box of tissues, measuring cup, shoe, star, teapot, block, toy plastic person, and watering can.

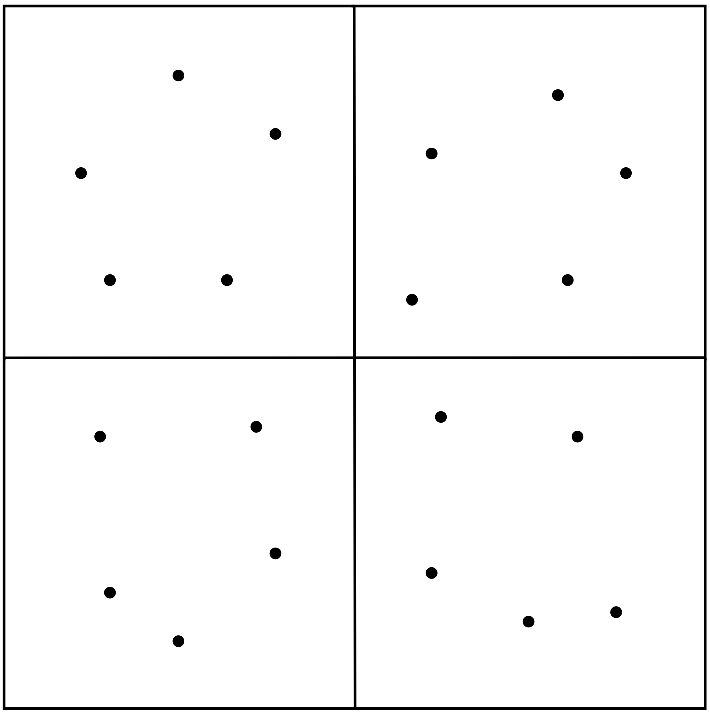

Fig. 1. Diagram of experimental apparatus and locations during learning trials.

An Olympus C-3040 Zoom digital camera mounted on the ceiling was used to record participants' object placements. These digital images, displayed on a 50.80 cm computer monitor covered with a transparent grid of $x$ and $y$ coordinates, were used to code participants' placements.

## Design and procedure

All participants were tested individually in the laboratory in a single session. At the beginning of the experiment, the experimenter stood in front of one side of the box, and participants were seated to the right of the experimenter facing an adjacent side of the box.

The experimental session consisted of alternating learning and test trials. The experimenter first told participants that 20 objects would be placed in the box one at a time and that they should try to remember the locations of the objects because they would be asked to replace them later. The object locations corresponded to the 20 LEDs on the floor of the box. Participants first watched as the experimenter named the objects and placed them on the dots one at a time until all 20 objects were in the box. The order of locations and the pairing of locations with objects were randomized for each participant.

The first learning trial began immediately after the experimenter placed all 20 objects. Participants closed their eyes while the experimenter removed the objects from the box. Then the experimenter gave the objects to participants one at a time and asked them to place them on the correct dots. Participants were allowed to move around the outside of the box to place the objects during learning trials. The experimenter corrected any errors immediately. Participants continued to place the objects until all 20 objects were in the box. A new random order was used for each learning trial.

A test trial immediately followed *each* learning trial. First, participants closed their eyes while the experimenter removed the objects and boundaries from the box. The experimenter also turned off the LEDs marking the locations, leaving a homogeneous black floor. Participants then tried to replace the objects in the correct locations in any order they chose. Next the experimenter asked participants to close their eyes and took a digital picture of the box. The experimenter then removed the objects, replaced the boundaries, and turned on the LEDs. Participants opened their eyes, and a new learning trial began. Participants continued with the alternating learning and test trials until they completed three test trials.

## Coding

We coded the $x$ and $y$ coordinates for each object to the nearest 1.27 cm. We then coded which object corresponded to each actual location. Participants sometimes preserved the overall configuration of the locations in a quadrant but paired some objects and locations incorrectly. For example, participants might mistakenly transpose the objects in two of the five locations in a configuration. As in previous work, we used the $x$ and $y$ coordinates for these substituted locations in all analyses regardless of whether the correct objects were placed in the locations (see Hund & Plumert, 2002, 2003). Participants also sometimes omitted an object from a configuration or placed an object in a totally wrong location in a configuration (e.g., in the center of the configuration, outside of the configuration). The locations corresponding to these objects were omitted from all analyses (Table 1). Intercoder reliability estimates for object–location pairings (i.e., correct, substituted, or omitted) were calculated for eight randomly selected participants (two in each age group). The exact percentage agreement was 93.96% (out of 160 locations).

Table 1
Mean percentages of locations substituted and omitted for each age group and test trial in Experiment 1

| Age and test trial | Locations substituted (%) | Locations omitted (%) |
|---|---|---|
| 7-year-olds | | |
| Test trial 1 | 21.67 | 7.92 |
| Test trial 2 | 17.50 | 6.67 |
| Test trial 3 | 9.58 | 4.17 |
| 9-year-olds | | |
| Test trial 1 | 18.75 | 6.25 |
| Test trial 2 | 8.33 | 5.00 |
| Test trial 3 | 5.42 | 3.75 |
| 11-year-olds | | |
| Test trial 1 | 7.92 | 2.08 |
| Test trial 2 | 3.75 | 0.42 |
| Test trial 3 | 0.83 | 0.00 |
| Adults | | |
| Test trial 1 | 12.08 | 0.42 |
| Test trial 2 | 1.67 | 0.42 |
| Test trial 3 | 0.83 | 0.00 |

## Measures

*Error score*. Participants received a single error score for each test trial (i.e., first, second, and third) reflecting the accuracy of memory for fine-grained information (i.e., how closely they placed objects near their actual locations). This score was calculated by determining the distance between each remembered location and the corresponding actual location and then averaging these distances over all locations.

*Center displacement score.* Center displacement scores reflected the degree to which participants systematically placed objects from the same group closer together than they actually were. For each test trial, we first subtracted the distance between each remembered location and the center of mass of the remembered group of locations from the distance between the corresponding actual location and the center of mass of the actual group of locations. We then averaged these difference scores across all locations to obtain a single center displacement score for each test trial. Higher positive scores reflected greater center displacement.

# *Results*

## Error

Preliminary inspection of the data indicated that younger children placed the objects farther from the correct locations than did older children and adults. In addition, error decreased linearly over test trials. Preliminary analyses revealed no significant effects of gender, so the data were collapsed across this factor in the analyses reported below.

To test for differences in overall error among the age groups and across the test trials, mean error scores were entered into an Age (7 years, 9 years, 11 years, or adult) × Test Trial (first, second, or third) mixed model analysis of variance (ANOVA) with age as a between-participants factor and test trial as a within-participants factor. This analysis yielded significant main effects of age, $F(3,44) = 12.33$, $p < .0001$, $\eta_p^2 = .46$, and test trial, $F(2,88) = 8.90$, $p < .001$, $\eta_p^2 = .17$. Both 7- and 9-year-olds exhibited significantly greater error than did 11-year-olds and adults. The mean error scores were 6.41 cm ($SD = 0.93$), 5.98 cm ($SD = 1.30$), 4.85 cm ($SD = 0.92$), and 4.49 cm ($SD = 1.28$) for 7-, 9-, and 11-year-olds and adults, respectively. Moreover, participants placed the objects significantly less accurately during the first test trial ($M = 5.79$ cm, $SD = 1.47$) than during the second test trial ($M = 5.39$ cm, $SD = 1.34$) and third test trial ($M = 5.12$ cm, $SD = 1.20$). There was no Age × Test Trial interaction, $F(6,88) = 1.08$, *ns*, indicating that the pattern of decreasing error across learning trials held for both children and adults.

## Center displacement

Preliminary analyses revealed no significant effects of gender, so the data again were collapsed across this factor. We first examined whether the pattern of categorical bias across test trials differed by age by entering center displacement scores into an Age (4) × Test Trial (3) mixed model ANOVA. This analysis yielded a significant main effect of test trial, $F(2,88) = 8.71$, $p < .001$, $\eta_p^2 = .17$. There was no main effect of age, $F(3,44) = 0.11$, *ns*, or Age × Test Trial interaction, $F(6,88) = 2.03$, *ns*, indicating that the pattern of categorical bias over learning held for both children and adults.

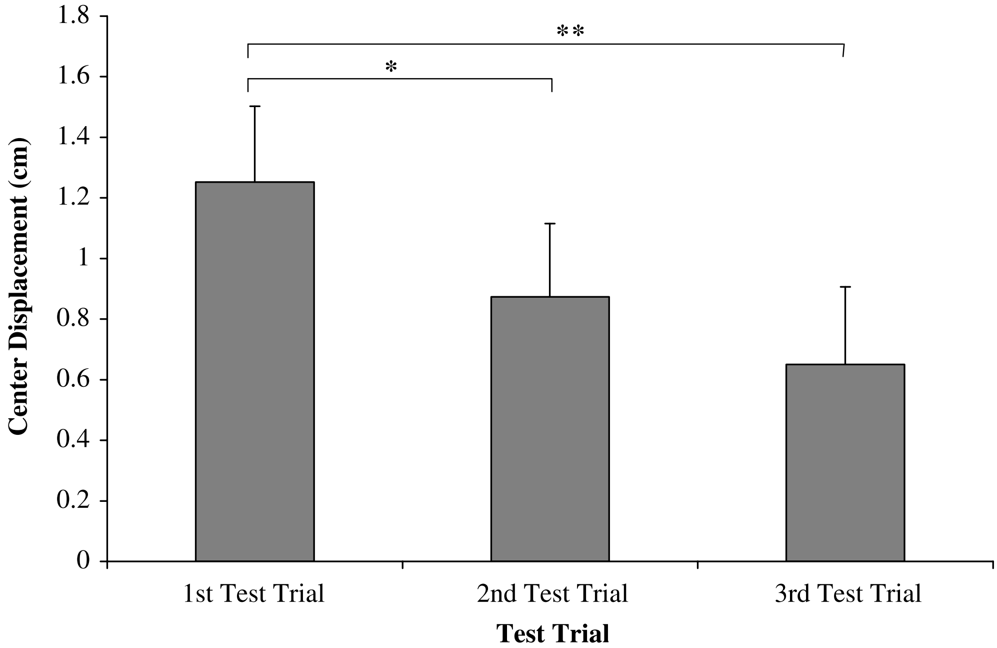


Fig. 2. Center displacement scores on each test trial. *Significant difference between test trials at $p < .05$ level. **Significant difference between test trials at $p < .0001$ level.

We then conducted a set of planned *t* tests comparing center displacement across test trials to test for the predicted pattern of categorical bias with increased opportunities for learning (Fig. 2). As expected, participants placed objects from the same group significantly closer together on the first test trial than on the second test trial, $t(47) = 2.65$, $p < .05$, $d = .22$. Likewise, participants exhibited significantly greater categorical bias on the first test trial than on the third test trial, $t(47) = 3.82$, $p < .001$, $d = .34$. The second and third test trials did not differ significantly.

## *Discussion*

These results clearly show that metric error and categorical bias decreased over the course of learning. Children and adults exhibited significantly greater error on the first test trial than on the second and third test trials, indicating that fine-grained certainty increased over learning. Likewise, participants exhibited significantly greater categorical bias on the first test trial than on the second and third test trials, suggesting that memory for the individual locations was weak relative to memory for the spatial groups early in learning. Hence, memory for the spatial groups exerted a strong pull on memory for the individual locations at the beginning of learning. As learning progressed, memory for the individual locations became stronger, effectively counteracting the pull from memory for the spatial groups. These results support the idea that categorical bias is an emergent property of the cognitive system, arising out of interactions between memory for fine-grained and categorical information during the course of learning (see also Spencer, Simmering, Schutte, & Schöner, 2007).

We conducted a second experiment to examine two issues in greater detail. First, we were surprised to find that children exhibited strong categorical bias at the beginning of learning. This contrasts with earlier work in which children often did not exhibit categorical bias when only boundaries were available for grouping the locations (Hund et al., 2002; Plumert & Hund, 2001). In these studies, however, children and adults were brought up to a learning criterion prior to test. Children typically take three or four learning trials to reach the learning criterion, whereas adults usually take approximately two trials. We sought to further investigate developmental differences in categorical bias by holding constant the number of learning trials prior to test. We were especially interested in the amount of categorical bias exhibited by children after only one or two learning trials than after three or four learning trials.

Second, the within-participants design used to track changes in categorical bias over learning in Experiment 1 necessarily meant that participants knew about the upcoming test after the first test trial. This knowledge of the upcoming test may have played a role in the decline of categorical bias over learning. In particular, once participants knew that they would be asked to place the objects without the aid of the dots and boundaries, they may have quickly begun to focus on the fine-grained detail about the object locations. In Experiment 2, we examined these two issues using a between-participants design in which participants experienced either one, two, three, or four learning trials *before* a single test trial. As in Experiment 1, we expected that children and adults would exhibit less categorical bias with more learning trials prior to test. Moreover, we expected that the decline in categorical bias would be less dramatic than that in Experiment 1 because participants were unaware of the upcoming test trial during the learning phase of the experiment.

## Experiment 2

### *Method*

#### Participants

Participants were 192 7-, 9-, and 11-year-olds and adults (mean ages = 7 years 7 months, 9 years 5 months, 11 years 4 months, and 19 years 6 months, respectively). There were 48 participants in each age group, with approximately equal numbers of males and females in each group. Children and adults were recruited in the same manner as in Experiment 1. Of the child participants, 89% were European American, 8% were Asian American, 1% were Native American, 1% were African American, and 1% were Hispanic/Latino. Of the children's mothers, 3% had completed a high school education or less, 26% had completed some college education, and 71% had a 4-year-college education or beyond. Of the adult participants, 85% were European American, 6% were Hispanic/Latino, 4% were African American, 2% were Asian American, and 2% were Indian.

#### Design and procedure

The experiment was divided into a learning phase and a test phase. Participants were randomly assigned to one of four conditions: one learning trial, two learning trials, three learning trials, or four learning trials. Thus, unlike Experiment 1, participants completed either one, two, three, or four learning trials *before* completing a single test trial. The test procedure was identical to that used during Experiment 1, as were the coding and measures (Table 2 shows the percentages of substituted and omitted locations). Intercoder

Table 2
Mean percentages of locations substituted and omitted for each age group and learning condition in Experiment 2

| Age and condition | Locations substituted (%) | Locations omitted (%) |
|---|---|---|
| 7-year-olds | | |
| One learning trial | 18.75 | 5.42 |
| Two learning trials | 17.50 | 5.00 |
| Three learning trials | 11.25 | 1.25 |
| Four learning trials | 3.75 | 1.67 |
| 9-year-olds | | |
| One learning trial | 12.08 | 2.92 |
| Two learning trials | 11.25 | 3.33 |
| Three learning trials | 5.00 | 1.25 |
| Four learning trials | 1.67 | 0.42 |
| 11-year-olds | | |
| One learning trial | 5.42 | 0.83 |
| Two learning trials | 4.17 | 0.83 |
| Three learning trials | 4.17 | 0.00 |
| Four learning trials | 2.08 | 0.42 |
| Adults | | |
| One learning trial | 10.24 | 0.83 |
| Two learning trials | 0.00 | 0.00 |
| Three learning trials | 0.00 | 0.00 |
| Four learning trials | 5.83 | 0.00 |

reliability estimates were calculated for 32 randomly selected participants (8 in each age group). The exact percentage agreement was 98.59% (out of 640 locations).

## *Results*

### Error

As in Experiment 1, preliminary inspection of the data indicated that younger children exhibited more error in their placements than did older children and adults, and error decreased linearly as the number of learning trials prior to test increased. Preliminary analyses revealed no effects of gender, so the data were collapsed across gender in the analyses below.

Mean error scores were entered into an Age (7 years, 9 years, 11 years, or adult) × Condition (one learning trial, two learning trials, three learning trials, or four learning trials) ANOVA with two between-participants factors. This analysis yielded main effects of age, $F(3,176) = 15.53$, $p < .0001$, $\eta_p^2 = .21$, and condition, $F(3,176) = 3.80$, $p < .05$, $\eta_p^2 = .06$. Both 7- and 9-year-olds exhibited significantly greater error than did 11-year-olds and adults. The mean distances from correct locations were 6.12 cm ($SD = 1.78$), 5.75 cm ($SD = 1.25$), 4.97 cm ($SD = 1.01$), and 4.48 cm ($SD = 1.15$) for 7-, 9-, and 11-year-olds and adults, respectively. In addition, participants placed objects less accurately after one learning trial than after three or four learning trials. The mean error scores were 5.81 cm ($SD = 1.94$), 5.39 cm ($SD = 1.31$), 5.17 cm ($SD = 1.21$), and 4.96 cm

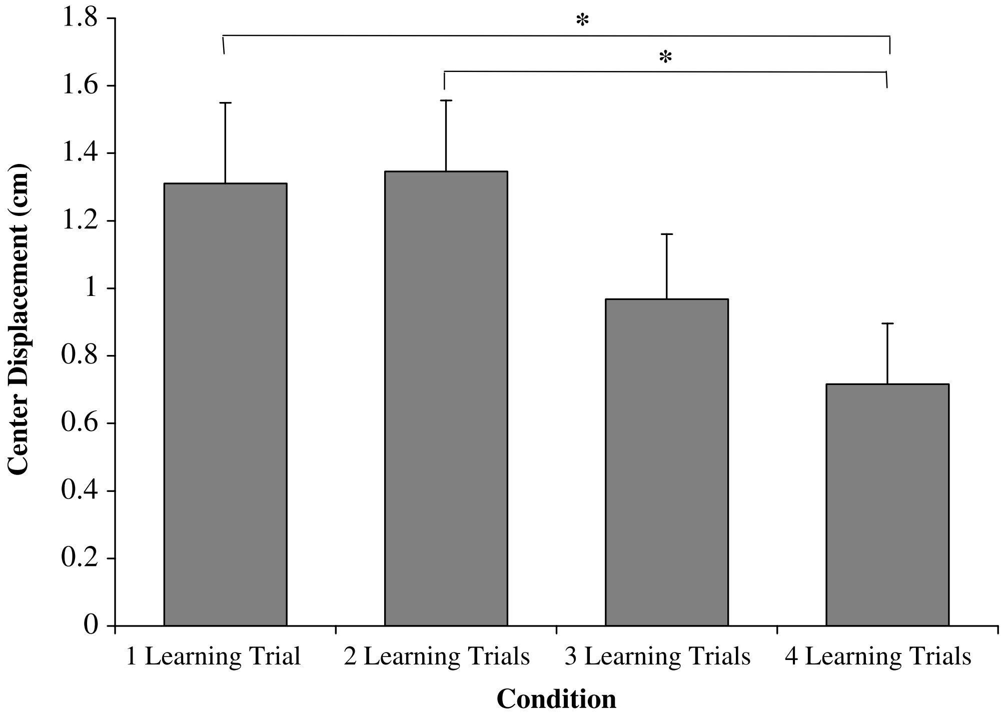


Fig. 3. Center displacement scores for each learning condition. *Significant difference between conditions at $p < .05$ level.

($SD = 1.18$) after one, two, three, and four learning trials, respectively. There was no Age × Condition interaction, $F(9, 176) = 0.83$, *ns*.

## Center displacement

Preliminary analyses revealed no significant effects of gender, so the data again were collapsed across this factor. To examine whether the pattern of center displacement across learning conditions differed by age, we entered center displacement scores into an Age (4) × Condition (4) ANOVA. The effect of condition approached significance, $F(3, 176) = 2.09$, $p = .10$. Again, there was no main effect of age, $F(3, 176) = 1.3$, *ns*, or Age × Condition interaction, $F(9, 176) = 0.73$, *ns*, indicating that the pattern of categorical bias across learning conditions held for both children and adults.

We again conducted a set of planned $t$ tests comparing center displacement across the four learning conditions to test for predicted decreases in center displacement with increased opportunities for learning (Fig. 3). Participants exhibited significantly greater center displacement after one learning trial than after four learning trials, $t(94) = 1.99$, $p < .05$, $d = .41$. Likewise, participants showed significantly greater center displacement after experiencing two learning trials than after experiencing four learning trials, $t(94) = 2.28$, $p < .05$, $d = .46$. None of the other comparisons yielded significant differences.

### *Discussion*

Like Experiment 1, both children and adults exhibited less error and categorical bias during test with more opportunities to learn the locations. Participants exhibited less mean error when reproducing locations after four learning trials than after one learning trial, indicating that fine-grained certainty increased with additional experience with locations. Likewise, participants exhibited significantly less categorical bias after four learning trials than after one and two learning trials. Again, these results support the idea that categorical bias emerges out of the interaction of memory for the spatial groups and memory for the individual locations. With very limited opportunities for learning the locations, memory for fine-grained detail about the locations was weak relative to memory for the spatial groups. Consequently, memory for the individual locations was not able to effectively counteract the pull from the spatial groups. With more extensive opportunities for learning the locations, memory for fine-grained detail about the individual locations strengthened, reducing the pull from the spatial groups on placements.

In Experiment 1, categorical bias decreased significantly from the first test trial to the second test trial. Participants in Experiment 2 did not show a significant decrease in categorical bias until they had experienced four learning trials. What accounts for this difference? We hypothesize that participants are less likely to focus strongly on fine-grained detail about the precise locations during learning when they have no knowledge of the upcoming test. In short, because the dots marking the locations were present throughout learning, children and adults focused more on the group to which each object belonged and where each object was located within each group. Thus, although memory for the individual locations improved with increased opportunities for learning, memory for the spatial groups also continued to strengthen with learning. As a result, participants in Experiment 2 continued to exhibit a relatively high level of categorical bias until they had experienced four learning trials.

## General discussion

The results of this investigation clearly demonstrate that categorical bias undergoes systematic change as children and adults become more familiar with a set of locations. In both experiments, categorical bias decreased with increased opportunities for learning the locations. In Experiment 1, children and adults exhibited significantly more categorical bias after the first learning trial than after the second and third learning trials. In Experiment 2, children and adults exhibited significantly greater categorical bias when given only one or two learning trials prior to test than when given four learning trials prior to test. How might we account for the changes in categorical bias over learning? The finding that children and adults showed significant categorical bias at the beginning of learning indicates that they coded the spatial groups relatively quickly and that memory for the individual locations was relatively weak at the beginning of learning. As learning progressed, memory for the individual locations strengthened, especially when children and adults knew about the upcoming test (i.e., Experiment 1). Stronger memory for the individual locations effectively counteracted the pull from the spatial groups, leading to reduced categorical bias.

Our findings are consistent with those from a study by Spencer and Hund (2003), who examined how directional bias changed over trial blocks in a spatial working memory task. In that investigation, 6- and 11-year-olds saw an image of a spaceship appear on a black homogeneous tabletop for 2 s. The spaceship then disappeared for a delay period of 0, 5, 10, or 15 s. After the delay, children attempted to move their finger to the remembered location of the spaceship. The target locations were composed of three adjacent locations within one spatial region (i.e., the left or right half of the task space). Across two conditions, either the inner or outer target of the layout was presented more frequently than the others. Early in learning (i.e., Trial Blocks 1 and 2) children exhibited large biases toward the frequent targets. For example, when the inner target was presented frequently, children remembered the center and outer targets as being closer to the inner target than they actually were. Likewise, when the outer target was presented frequently, children's responses to the center and inner targets were pulled toward the outward target. As learning progressed (i.e., Trial Blocks 3 and 4), these biases tended to decrease, showing some recovery from the pull toward the frequent targets. These findings indicate that memory for location undergoes systematic change over time. Early in learning, children are more uncertain about the infrequent locations, leading to greater pull from the frequent (and presumably more well-learned) target. Later in learning, children are more certain about the infrequent locations, resulting in less pull from the frequent target.

We were surprised to find that both children and adults showed strong categorical bias early in learning. We expected that children would exhibit relatively low levels of categorical bias throughout learning given that earlier work showed that children often do not exhibit significant categorical bias at test when only boundaries are available to organize the locations into groups during learning (Hund et al., 2002; Plumert & Hund, 2001). In these earlier studies, however, children and adults did not receive the test trial until they reached a learning criterion of placing all objects on the correct dots in a single learning trial. Adults typically reached the learning criterion in approximately two trials, whereas children reached the learning criterion in three or four learning trials (and sometimes more). This necessarily meant that adults often received the test trial after only two learning trials, whereas children rarely received the test trial after fewer than three learning trials. These differences between adults and children in exposure to the locations during learning may in part explain the differences seen in past studies between adults and children in categorical bias at test. More specifically, children's greater familiarity with the locations may have led to a stronger memory for the individual locations relative to the spatial groups, thereby reducing categorical bias in their placements after repeated learning opportunities.

But why did both children and adults show bias early in learning in the current experiments? We hypothesize that even when age differences in memory for fine-grained and categorical information exist, the relative weighting of the two can produce similarity in bias across ages (for similar ideas about list recall, see Brainerd & Reyna, 2004). For children, categorical bias early in learning was likely driven mostly by the weakness in their coding of the individual locations, whereas for adults, categorical bias early in learning was likely driven by the strength of their memory for the spatial groups. The end result for both groups was the same even though it is likely that absolute levels of memory for fine-grained and categorical information differed widely between children and adults. This analysis is supported by consistent age differences in absolute error seen in this study as well as other studies (Hund & Plumert, 2002, 2003, 2005; Hund et al., 2002; Plumert & Hund, 2001).

Together, these findings support the idea that patterns of bias emerge out of the interaction of structure available in the task and the characteristics of the cognitive system (Plumert et al., 2007). Hence, both differences in the cognitive system (e.g., ease of coding of fine-grained vs. categorical information) and differences in the task structure (e.g., amount of exposure to locations or knowledge of the upcoming test) alter the interaction, leading to changes in the pattern of categorical bias. Task structure that highlights the spatial groups (e.g., multiple cues for forming spatial groups) leads to stronger activation of the associations between locations belonging to the same spatial group (Hund & Plumert, 2003, 2005; Hund et al., 2002; Plumert & Hund, 2001). Likewise, task structure that makes it easier to code and maintain fine-grained metric information about the individual locations (e.g., repeated opportunities to learn the locations or information about the upcoming test phase) leads to stronger activation of memory for the individual locations. The relative weighting of memory for the individual locations and memory for the spatial groups determines where people place the objects at test. As illustrated here, the relative weighting of memory for individual locations and spatial groups undergoes systematic change as children and adults become more familiar with locations. These changes undoubtedly affect how people learn the locations of objects and buildings in everyday environments such as learning where supplies and toys are located in a preschool classroom and learning the locations of buildings in a metropolitan area (for findings documenting categorical biases in everyday environments, see Cohen, Baldwin, & Sherman, 1978; Kosslyn, Pick, & Fariello, 1974; McNamara, 1986; Newcombe & Liben, 1982).

More generally, our findings are consistent with other work showing that increased opportunities for studying word lists lead children and adults to rely more on verbatim information than on gist information (Brainerd, 2004; Brainerd & Reyna, 2004). This shift from reliance on coarse-grained information to fine-grained information is also evident in adult category learning (Smith & Minda, 1998). Specifically, people rely on category prototypes at the beginning stages of learning but then shift to category exemplars at later stages of learning. These changes in the cognitive system that result from increased familiarity with stimuli appear to operate across development and cognitive domains. In fact, recent findings suggest that changes in category learning based on familiarity may well be present even during infancy (Horst, Oakes, & Madole, 2005).

Finally, our results underscore the fact that the amount of spatial learning prior to test is a critical factor in studies of spatial cognition, particularly when comparing participants of different ages. In short, seemingly insignificant age differences in exposure to locations during learning can result in large age differences in memory for the locations at test. Given that conclusions about cognitive development are driven largely by performance at test, these results underscore the need to better understand the processes operating during learning or familiarization (for similar ideas about novelty and familiarity preferences in infant habituation studies, see Schöner & Thelen, 2006). Indeed, the fact that categorical bias disappeared over repeated learning trials illustrates why basing conclusions solely on tests performed at the end of learning offers only part of the story. Although probing behaviors of interest over the course of learning presents its own methodological challenges, tracking behavior as it unfolds over time is a powerful tool for understanding cognitive processes over both short and long time scales (see also Siegler, 1996; Smith & Minda, 1998; Thelen & Smith, 1994). By offering a rare glimpse into changes in spatial memory that occur over the course of an experimental session for children and adults, this investigation represents a step forward in understanding these cognitive processes.

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