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Delay-Induced Bias in Children's Memory for Location

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Two experiments examined how imposing a delay between learning and reproducing locations influences children's memory for location. In Experiment 1, ninety-six 7-, 9-, and 11-year-old children and adults learned the locations of 20 objects in an open, square box divided into four regions by opaque walls. During test, participants attempted to place the objects in the correct locations without the aid of the dots that had marked the locations or the boundaries that had divided the space. The test phase began either immediately following learning or following a 12-min delay. As predicted by the Category-Adjustment model, bias toward category centers increased significantly following an intervening delay. Moreover, the magnitude of categorical bias followed a systematic U-shaped developmental pattern. Results from a second study ($N = 72$) replicated this developmental pattern. Discussion focuses on the implications of these results for understanding how children and adults remember locations.

INTRODUCTION

Remembering where things are is central to human functioning. Children and adults must be able to remember information about location to carry out basic tasks such as getting to school or preparing a meal. Much of the research in this area has focused on the types of information that people use to code locations (e.g., Acredolo & Boulter, 1984; Bushnell, McKenzie, Lawrence, & Connell, 1995; Hirtle & Jonides, 1985; Kosslyn, Pick, & Fariello, 1974; Newcombe & Liben, 1982; Presson & Hazelrigg, 1984; Rieser & Heiman, 1982; Stevens & Coupe, 1978). For example, many studies have examined how children and adults use landmarks to remember locations (e.g., Acredolo & Evans, 1980; Holyoak & Mah, 1982; McNamara & Diwadkar, 1997; Sadalla, Burroughs, & Staplin, 1980). Although these studies have revealed important information about the types of cues children and adults use to remember previously learned locations, relatively little is known about the processes that underlie memory for location and how they change over development.

How might people remember information about location? According to the Category-Adjustment (CA) model proposed by Huttenlocher, Hedges, and Duncan (1991), retrieval of locations from memory is a hierarchical process that involves the use of both fine-grained and categorical (i.e., spatial region) information. When trying to remember a previously learned location, people make estimates based on their memory of fine-grained, metric information such as distance and direction from an edge. Because memory for fine-grained information is inexact, however, people adjust these estimates based on categorical information about the location (i.e., region membership). According to the model, this categorical information is represented by a prototype located at the center of the spatial region. Hence, adjustments based on categorical information lead to systematic distortions toward the centers of spatial categories. For example, when children between the ages of 16 months and 10 years searched for a toy they had previously seen hidden in a long, narrow sandbox, their searches were distributed around the actual locations and biased toward the category centers (Hutttenlocher, Newcombe, & Sandberg, 1994). More specifically, 2- and 6-year-olds' searches were biased toward the center of the entire sandbox, whereas 10-year-olds' searches were biased toward the centers of the two halves of the sandbox. Results such as these suggest that children and adults combine fine-grained and categorical information to estimate locations (see also Engebretson & Huttenlocher, 1996; Hund, Plumert, & Benney, in press; Huttenlocher et al., 1991; Laeng, Peters, & McCabe, 1998; Newcombe, Huttenlocher, Sandberg, Lie, & Johnson, 1999; Plumert & Hund, 2001; Sandberg, Huttenlocher, & Newcombe, 1996).

The issue of exactly *how* children and adults combine fine-grained and categorical information to arrive at estimates of location has not been well investigated, however. According to the CA model, the magnitude of distortion toward category centers depends on the certainty of the fine-grained, metric information. When memory for fine-grained information is relatively certain, categorical information receives a low weight, resulting in only small distortions toward category centers. Conversely, when memory for fine-grained information is relatively uncertain, categorical information receives a high weight, resulting in large distortions toward category centers.

Testing this proposal involves manipulating the certainty of fine-grained information and observing the resulting pattern of categorical bias during location estimation. One way to manipulate fine-grained certainty is to change the amount of perceptual information available between learning and remembering a set of locations. Specifically, decreasing the amount of perceptual information available at test should increase the uncertainty of fine-grained information, thereby increasing categorical bias. Recently, Plumert and Hund (2001) tested this proposal by comparing the amount of categorical bias in estimates of location when key perceptual information remained the same or changed from learning to testing. Seven-, nine-, and eleven-year-old children and adults learned the locations of 20 miniature objects in a small model house. The locations were marked by yellow dots on the floor of the house. During learning, opaque boundaries divided the house into four identical regions. Following learning, the dots that had marked the locations were removed and participants attempted to replace the objects in the correct locations. In one situation, the boundaries remained in place during the test phase, and in the other situation, the boundaries were absent during the test phase. When the boundaries were absent, adults and 11-year-olds in the most salient boundary condition significantly displaced objects toward the category centers. When the boundaries remained in place during the test phase, however, neither the adults nor the children displaced objects toward the category centers. Together, these findings suggest that fine-grained certainty affects location estimation: when previously available perceptual information decreases, the uncertainty of fine-grained information increases, thereby increasing bias toward category centers.

Another way to manipulate fine-grained certainty is to alter the delay between learning and remembering a set of locations. That is, increasing the delay between learning and remembering locations should increase fine-grained uncertainty, resulting in greater categorical bias. In two investigations, Huttenlocher and colleagues examined whether imposing a brief interference task between seeing and reproducing a location led to more categorical bias in adults' estimates of location (Engebretson & Huttenlocher, 1996; Huttenlocher et al., 1991). In the first investigation, people saw a dot located inside a small circle on each trial (Huttenlocher et al., 1991). Then the circle with the dot was removed and people were asked to reproduce the dot's location inside a blank circle. During half of the trials (i.e., standard trials), people completed the dot-marking task immediately following the removal of the original circle and dot. On the remaining trials (i.e., interference trials), people completed an interference task during the delay between the removal of the circle and dot and the dot-marking response. This interference task involved viewing and remembering a pattern of 16 black-and-white grid units inside a square. In total, the interference portion of each trial lasted approximately 5 to 8 s. As predicted by the CA model, people exhibited significantly greater biases toward category centers during the interference trials than during the standard trials.

In the second investigation, adults saw a V frame with a line inside it on each trial (Engebretson & Huttenlocher, 1996). Following the removal of the V frame and line, people were asked to reproduce the line's location inside a blank frame. Adults in the control condition estimated the line's location immediately following the removal of the V frame. Adults in the interference condition remembered and reproduced a second line between the removal of the original stimulus and its estimation (i.e., an 8- to 12-s interference task). As predicted by the CA model, people's location estimates were biased toward an angular prototype in the center of each category. More importantly, this categorical bias was significantly greater in the interference condition than in the control condition, suggesting that the weighting of categorical information increases as fine-grained uncertainty increases.

Although these findings provide preliminary support for the claim that fine-grained certainty influences the amount of categorical bias, the Huttenlocher et al. (1991) and Engebretson and Huttenlocher (1996) studies only examined how imposing an interference task between seeing and reproducing a location influenced adults' estimates of location. With the exception of the Plumert and Hund (2001) study, little is known about how manipulations of fine-grained certainty influence the amount of categorical bias in children's estimates of location. Given claims that the CA model accounts for even very young children's memory for location (e.g., Huttenlocher et al., 1994), it is particularly important to test whether the proposal concerning the relative weighting of fine-grained and categorical information holds for children as well as adults.

The present study addressed this issue by examining whether imposing a relatively long delay between learning and reproducing locations would lead to significant increases in distortion toward category centers for both children and adults. As in our previous studies, children and adults learned the locations of 20 objects marked by yellow dots on the floor of an open, square box (Hund et al., in press; Plumert & Hund, 2001). A small-scale space was chosen in this investigation to be consistent with previous work in this area (e.g., Engebretson & Huttenlocher, 1996; Hund et al., in press; Huttenlocher et al., 1991, 1994; Laeng et al., 1998; Newcombe et al., 1999; Plumert & Hund, 2001; Sandberg et al., 1996). During learning, opaque boundaries divided the house into four identical regions. Following learning, participants attempted to replace the objects after the dots that had marked the locations and the boundaries that had divided the house into regions had been removed. In Experiment 1, participants either completed the test phase immediately following learning or after a 12-min intervening delay. Based on the CA model, we expected that children and adults in the delay condition would exhibit significantly greater distortions toward category centers than would participants in the no-delay condition.

EXPERIMENT 1

Method

Participants

Ninety-six 7-, 9-, and 11-year-olds and adults participated. There were 24 participants in each age group. Fifty-one percent of the participants were female. The mean ages were 7,9 (*range* = 7,1–7,11), 9,8 (*range* = 9,6–9,9), 11,1 (*range* = 10,10–11,8), and 18,9 (*range* = 18,2–22,11), respectively. Three additional 11-year-olds and one additional adult were excluded from the experiment because of experimenter error. Children were recruited from a child research participant database maintained by the Department of Psychology at the University of Iowa. Adults participated to fulfill research credit for an introductory psychology course. The majority of participants were White and from middle- to upper middle-class families.

Apparatus and Materials

A 32-inch (81.28 cm) long × 32-inch (81.28 cm) wide × 13-inch (33.02 cm) high model house was used as the experimental space. The model house was an open square box with white exterior walls. The house had two identical windows evenly spaced on each of its four exterior walls. The floor consisted of a layer of Plexiglas™ and a layer of plywood separated by a ½-inch (1.27 cm) space. Removable boards could be inserted between the plywood and the Plexiglas to change the appearance of the floor. Three floors were used in this experiment: (1) a blue carpeted floor with yellow dots on it, (2) a blue carpeted floor with no dots, and (3) a grid of x- and y-coordinates at ½-inch (1.27 cm) intervals.

The model house could be divided into four identical 16 inch × 16 inch (40.64 cm × 40.64 cm) regions by placing opaque walls inside the house. The white plywood walls were 13 inches (33.02 cm) tall and 5/16 inches (.79 cm) wide. Each region contained five locations marked by ¾-inch (1.91 cm) yellow dots (see Figure 1) . The locations were arranged so that all were at least 2½ inches (6.35 cm) from the exterior walls and interior boundaries. Twenty miniature objects were used to help participants learn the locations in the house: a pot, a bear, a birdhouse, a pie, an iron, a paint can, a picture, a book, a purse, a flower pot, a present, a fishbowl, an apple, a trashcan, a hat, a pail, a toy person, a bag of chips, a jar of honey, and a soda carton. The average length and width of the objects were .70 inches (1.78 cm) and .64 inches (1.63 cm), respectively.

Design and Procedure

Participants were tested individually in the laboratory. The model house was placed on the floor of the experimental room. The experimenter stood directly in front of the house, whereas participants were seated to the right of the experimenter facing an adjacent side of the house. Participants were randomly assigned to one of two experimental conditions: no-delay or delay. Participants in both conditions completed a learning phase followed by a test phase. In the no-delay condition, the test phase followed immediately after learning. In the delay condition, there was a 12-min intervening delay between learning and test.

During the learning phase, participants learned the locations of 20 objects in the model house. The ex-

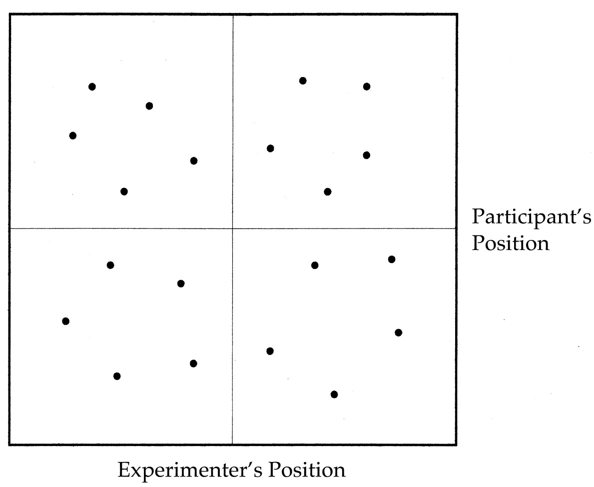

Figure 1 Diagram of model house and locations used in Experiments 1 and 2.

perimenter first told participants that she would place 20 objects in the model house 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 yellow dots on the floor of the house (see Figure 1). Participants then watched as the experimenter named the objects and placed them in the house one at a time in a random order. The pairings of objects and locations were randomized for each participant.

After the experimenter had placed all 20 objects, she asked participants to turn around while she removed the objects from the house. The experimenter then gave the objects to the participants one at a time and asked them to place them in the house. Incorrect placements were recorded and corrected. The learning trials continued until participants could correctly replace all 20 objects in a single trial. Objects were presented in a new random order for each learning trial. The mean number of trials to criterion for 7-, 9-, and 11-year-olds and adults was 4.25 (SD = 1.42), 3.33 (SD = .96), 3.67 (SD = 1.58), and 2.50 (SD = 1.32), respectively.

The test phase began either immediately following the learning phase (no-delay condition) or following a 12-min intervening delay (delay condition). Participants in the delay condition completed an unrelated direction-giving task during the intervening delay. While participants were not watching, the experimenter removed the objects and the walls that divided the house into regions. She also removed the floor with the yellow dots and replaced it with the plain blue floor. The experimenter then asked participants to try to replace the objects in the correct locations. Thus, participants attempted to place the objects in the correct locations without the aid of the yellow dots that had marked the locations and the boundaries that had divided the house into regions. Participants were allowed to replace the objects in any order they chose. After participants replaced all 20 objects, the experimenter thanked them for their participation. The experimenter then removed the blue floor and replaced it with the grid and recorded the x- and y-coordinates for each object to the nearest 1/2 inch (1.27 cm).

Coding

A placement was coded as "correct" if it was in the correct region and in the correct position relative to the other objects. Occasionally, participants preserved the overall configurations, but incorrectly paired objects and locations. As in previous studies (Plumert & Hund, 2001), the x- and y-coordinates were used for the locations regardless of whether the correct objects were placed in those locations. We used substituted x- and y-coordinates for 5.21% of the locations for 7-year-olds (25 out of 480), 1.04% for 9-year-olds (5 out of 480), 1.04% for 11-year-olds (5 out of 480), and .42% for adults (2 out of 480). These substituted locations were used in all analyses. As in previous studies (Plumert & Hund, 2001), objects placed in the wrong region or in a completely wrong configuration were omitted from analyses. We omitted x- and y-coordinates for 1.25% of the locations for 7-year-olds (6 out of 480), .83% for 9-year-olds (4 out of 480), .83% for 11-year-olds (4 out of 480), and .21% for adults (1 out of 480).

Intercoder reliability estimates of object placement were calculated for 16 randomly selected participants using exact percentage agreement. For each of these participants, two coders judged which object was placed in each of the 20 locations. Coders agreed on 100% of the 320 locations coded.

Measures

Metric accuracy score. A metric accuracy score was calculated to determine how accurately participants placed the objects relative to the true locations. Participants received a single metric accuracy score that represented the distance between the remembered location and the true location averaged over all locations.

Center displacement score. A center displacement score was calculated to determine whether participants displaced locations toward the centers of the spatial categories (i.e., the groups of objects within each region). Center displacement scores were calculated for each participant by subtracting the distance between each remembered location and the center of mass of the remembered spatial category from the distance between the corresponding actual location and the center of mass of the actual spatial category. (The center of mass of the spatial category—remembered or actual—represented the average location of the objects in each region.) These differences were averaged across all 20 locations to obtain a single center displacement score for each participant. Thus, center displacement scores represented the average displacement toward the category centers after removing effects due to translation of categories. Effects due to translation of categories were eliminated so that bias toward category centers could be examined more precisely.

Results and Discussion

Metric Accuracy

Figure 2 shows where children and adults in each condition placed the objects relative to the actual lo-

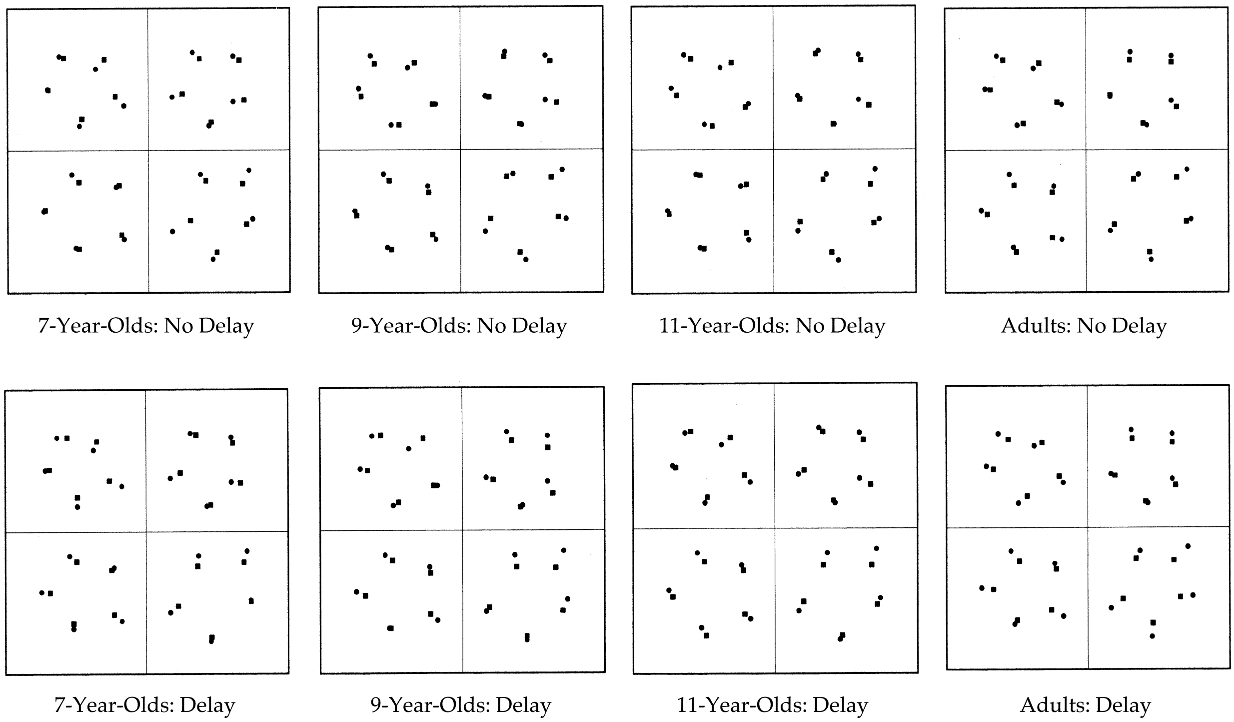

Figure 2 **Diagram of actual locations (circles) and remembered locations (squares) for participants in each age group and experimental condition in Experiment 1.**

cations. In general, children and adults placed the objects fairly accurately, suggesting that they used fine-grained, metric information to estimate the locations. To investigate possible differences in metric accuracy among the age groups and experimental conditions, metric accuracy scores were entered into an Age (7 years versus 9 years versus 11 years versus adult) × Condition (delay versus no-delay) analysis of variance (ANOVA). This yielded a significant main effect of age, $F(3, 88) = 5.94, p < .01$. Fisher's Protected Least Significant Difference (PLSD) follow-up tests indicated that 7-year-olds were significantly less accurate than were the other age groups. The mean displacement from correct locations was 2.10 inches (5.33 cm; SD = .43 inches or 1.09 cm) for 7-year-olds, 1.78 inches (4.52 cm; SD = .37 inches or .94 cm) for 9-year-olds, 1.78 inches (4.52 cm; SD = .43 inches or 1.09 cm) for 11-year-olds, and 1.62 inches (4.11 cm; SD = .40 inches or 1.02 cm) for adults.

Center Displacement

Figure 3 shows center displacement scores for the 7-, 9-, and 11-year-olds and adults in the two experimental conditions. Two things are striking about the pattern of results depicted in this figure: first, participants exhibited greater categorical bias when there was a delay between learning and test than when there was no delay; and second, the magnitude of categorical bias followed a very systematic U-shaped

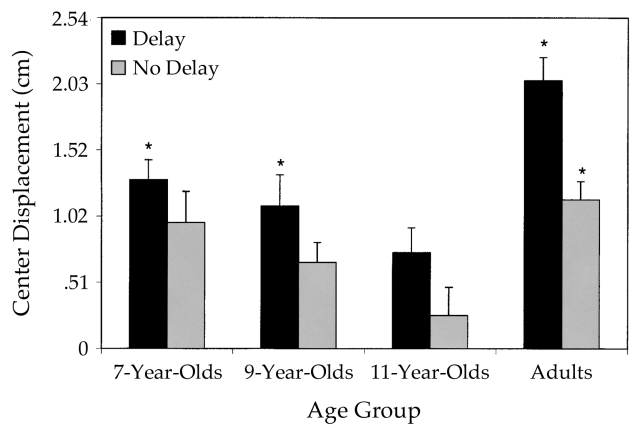

Figure 3 **Center displacement scores for participants in each age group and experimental condition in Experiment 1. Positive values represent displacement toward the category centers. *Significant results, $p < .05$, of one-sample t tests ($df = 11$) comparing the observed displacement value to the expected value with no displacement (i.e., 0 cm).**

developmental pattern. That is, categorical bias decreased systematically between 7 and 11 years and increased for adults.

Statistical analyses confirmed these observations. In the first analysis, center displacement scores were entered into an Age (4) × Condition (2) ANOVA. As expected, this analysis yielded significant main effects of condition, $F(1, 88) = 4.09$, $p < .05$, and of age, $F(3, 88) = 2.95$, $p < .05$. As predicted by the CA model, participants in the delay condition placed objects significantly closer to the centers of the spatial categories (M = .51 inches or 1.30 cm; SD = .54 inches or 1.37 cm) than did participants in the no-delay condition (M = .40 inches or 1.02 cm; SD = .54 inches or 1.37 cm). Fisher's PLSD follow-up tests also indicated that adults placed objects significantly closer to the category centers than did 11-year-olds. The mean displacement scores were .44 inches (1.12 cm; SD = .53 inches or 1.35 cm) for 7-year-olds, .35 inches (.89 cm; SD = .55 inches or 1.40 cm) for 9-year-olds, .20 inches (.51 cm; SD = .54 inches or 1.37 cm) for 11-year-olds, and .63 inches (1.60 cm; SD = .46 inches or 1.17 cm) for adults.

In the second analysis, separate one-sample t tests were conducted for each age group and condition to determine whether center displacement scores differed significantly from the expected score of 0. If participants displaced objects toward the centers of the spatial categories, then the mean difference between the actual location to actual category center distance and the remembered location to remembered category center distance should be greater than 0. As can be seen in Figure 3, 7- and 9-year-olds in the delay condition and adults in both conditions placed the objects significantly closer to the category centers than they actually were, suggesting that they used categorical information to estimate the locations.

What might account for the U-shaped developmental pattern depicted in Figure 3? According to the CA model, the magnitude of distortion toward category centers depends on the certainty of fine-grained information. When fine-grained information is certain, categorical information receives a low weight, resulting in small distortions toward category centers. Conversely, when fine-grained information is uncertain, categorical information receives a high weight, resulting in large distortions toward category centers. Thus, according to the CA model, 11-year-olds showed little categorical bias because they were relatively certain about fine-grained location information. Conversely, younger children and adults exhibited larger distortions toward category centers because they were less certain about fine-grained location information. This proposal is a reasonable explanation for the child findings; however, although it is possible that adults exhibited large categorical biases because they were uncertain about fine-grained information, this is not a very probable explanation for the adult findings. (A detailed discussion of the adult findings and the implications for the CA model are included in the General Discussion.)

Based on the relation between fine-grained certainty and bias toward category centers outlined in the CA model, we would expect participants to exhibit larger categorical biases if task factors increased metric uncertainty more than in the present experiment. Thus, one goal of Experiment 2 was to examine whether imposing a relatively demanding interference task during the 12-min delay increased distortions toward category centers. A second goal was to determine whether the U-shaped developmental pattern revealed in Experiment 1 would be replicated. Because of the relatively demanding nature of the interference task, only 9- and 11-year-old children and adults participated in this study.

As in Experiment 1, 9- and 11-year-olds and adults learned the locations of 20 objects in the model house. Following learning, participants completed either an unrelated task (replicating the delay condition from Experiment 1) or a second location-learning task (i.e., an interference task) during the 12-min intervening delay. Following the delay, participants attempted to replace the original 20 objects without the aid of the dots that had marked the locations and the boundaries that had divided the space. If the location-learning interference condition was more demanding than the standard-delay condition, then we would expect fine-grained memory to be less certain for participants in the interference condition, resulting in greater distortions toward category centers.

EXPERIMENT 2

Method

Participants

Seventy-two 9- and 11-year-olds and adults participated. None had participated in the previous experiment. There were 24 participants in each age group. Fifty-six percent of the participants were female. The mean ages were 9,3 (*range* = 9,2–9,9), 11,2 (*range* = 10,11–11,5), and 19,2 (*range* = 18,2–20,6), respectively. One additional 11-year-old and four additional 9-year-olds who failed to reach criterion during learning were excluded from the experiment. Two additional 9-year-olds were excluded because of experimenter error. Children and adults were recruited in the same manner as in Experiment 1. The majority of participants were White and from middle- to upper middle-class families.

Apparatus and Materials

The model house and the locations were identical to those used in Experiment 1. The same 20 miniature objects were used to help participants learn the locations. In addition, a pink carpeted floor with blue dots on it and 12 additional miniature objects were used to help participants in one condition learn another set of locations. These additional objects were a watering can, a cat, a pillow, a rabbit, a soccer ball, a shoe, a jack-o'-lantern, a basket, a bag of popcorn, a paper bag, a bunch of grapes, and an alien. The average length and width of these objects were .93 inches (2.36 cm) and .67 inches (1.70 cm), respectively.

Design and Procedure

Participants were tested individually in the laboratory. Participants were randomly assigned to one of two experimental conditions: delay or delay + interference. As in Experiment 1, participants in both conditions completed a learning phase and a test phase. A 12-min intervening delay separated the learning and test phases. As in Experiment 1, participants in the delay condition completed an unrelated direction-giving task during the delay. Participants in the delay + interference condition completed a second location-learning task during the 12-minute intervening delay.

All aspects of the learning phase were identical to those of Experiment 1. Participants again learned the locations of 20 objects in the model house. The locations to be learned corresponded to yellow dots on the floor of the house. Opaque walls divided the house into four identical regions. The mean number of trials to criterion for 9- and 11-year-olds and adults was 3.08 ($SD = 1.28$), 3.96 ($SD = 1.57$), and 2.92 ($SD = 1.06$), respectively.

As in Experiment 1, participants in the delay condition completed an unrelated direction-giving task during the delay that followed the learning phase. Participants in the delay + interference condition learned a second set of locations in the model house during the 12-min intervening delay between learning and test. This location-learning task was identical to the learning phase described previously, except that 12 different objects and locations were used. The experimenter first told participants that 12 new objects would be placed in the model house and that they should try to remember their locations. While participants were not watching, the experimenter removed the blue floor with the yellow dots and replaced it with a pink floor with blue dots. The object locations corresponded to the 12 blue dots on the floor of the house. Participants watched as the experimenter named the objects and placed them in the house one at a time in a random order. The pairings of objects and locations were randomized for each participant. After the experimenter had placed all 12 objects, participants were asked to turn around while the objects were removed from the house. The experimenter then gave the objects to the participants one at a time and asked them to place them in the house. Incorrect placements were recorded and corrected. Learning trials continued until the 12-min delay was complete.

The test phase began following the 12-min intervening delay. The procedure for the test phase was the same as in Experiment 1. While participants were not watching, the experimenter removed the objects and the walls that had divided the house into regions. The experimenter also removed the floor with the dots and replaced it with the plain blue floor. Participants then were asked to try to replace the (original 20) objects in the correct locations. Thus, participants attempted to place the objects in the correct locations without the aid of the yellow dots that had marked the locations and the boundaries that had divided the house into regions. Participants were allowed to replace the objects in any order they chose. After participants replaced all 20 objects, the experimenter thanked them for their participation. The experimenter then removed the blue floor and replaced it with the grid and recorded the x- and y-coordinates for each object to the nearest 1/2 inch (1.27 cm).

Coding and Measures

Coding was identical to that used in Experiment 1. We substituted x- and y-coordinates for 4.58% of the locations for 9-year-olds (22 out of 480), 1.04% for 11-year-olds (5 out of 480), and 1.88% for adults (9 out of 480). These substituted locations were used in all analyses. We omitted x- and y-coordinates for 1.46% of the locations for 9-year-olds (7 out of 480), 2.29% for 11-year-olds (11 out of 480), and .63% for adults (3 out of 480).

Intercoder reliability estimates of object placement were calculated for 12 randomly selected participants using exact percentage agreement. As in Experiment 1, two coders judged which object was placed in each of the 20 locations for these participants. Coders agreed on 100% of the 240 locations coded.

All scores were calculated in the same manner as in Experiment 1. Again, each participant received a metric accuracy score and a center displacement score.

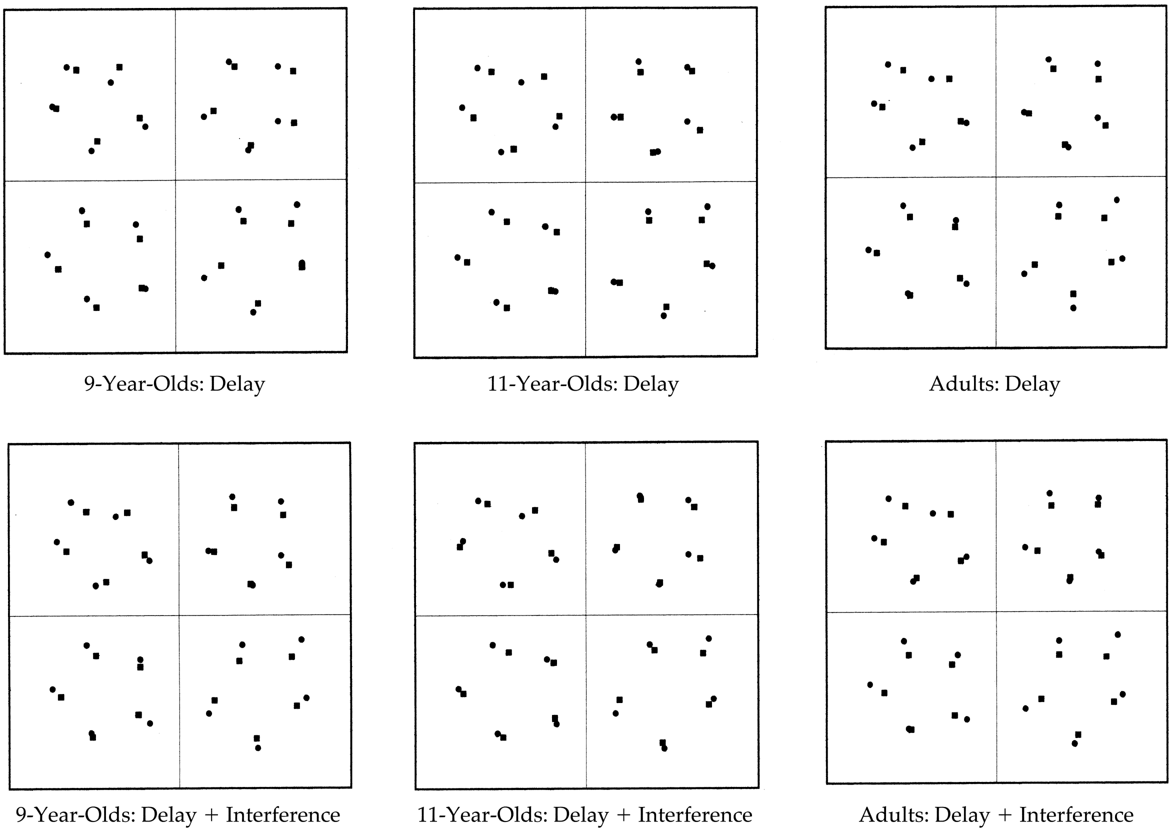

Figure 4 Diagram of actual locations (circles) and remembered locations (squares) for participants in each age group and experimental condition in Experiment 2.

Results and Discussion

Metric Accuracy

Figure 4 shows where children and adults in each condition placed the objects relative to the actual locations. As in Experiment 1, both children and adults placed the objects fairly accurately. To investigate possible differences in accuracy across age groups and experimental conditions, metric accuracy scores were entered into an Age (9 years versus 11 years versus adult) × Condition (delay versus interference) ANOVA. There were no significant age or condition effects. As before, there were no significant differences in metric accuracy among the 9- and 11-year-olds and adults.

Center Displacement

Figure 5 shows mean center displacement scores for the 9- and 11-year-olds and adults in the two experimental conditions. Again, the magnitude of categorical bias followed a U-shaped developmental pattern, with 9-year-olds and adults exhibiting far more categorical bias than 11-year-olds.

Statistical analyses confirmed this observation. First, center displacement scores were entered into an Age (3) × Condition (2) ANOVA to determine whether the magnitude of categorical bias differed across ages or conditions. As expected, this analysis yielded a significant main effect of age, $F(2, 66) = 6.64$, $p < .005$. Fisher's PLSD follow-up tests indicated that 9-year-olds ($M = .54$ inches or 1.37 cm; $SD = .62$ inches or 1.57 cm) and adults ($M = .72$ inches or 1.83 cm; $SD = .49$ inches or 1.24 cm) placed objects significantly closer to the category centers than did the 11-year-olds ($M = .19$ inches or .48 cm; $SD = .37$ inches or .94 cm).

Second, separate one-sample t tests were conducted for each age group and condition to investigate whether center displacement scores differed significantly from the expected score of 0. As shown in Figure 2, 9-year-olds in both conditions, 11-year-olds in the delay condition, and adults in both conditions placed the objects significantly closer to the category centers than they actually were, suggesting that they used categorical information to estimate the locations.

As in Experiment 1, bias toward the category cen-

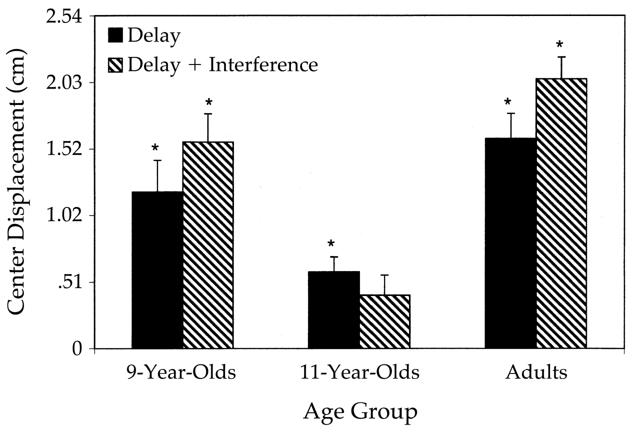

Figure 5 **Center displacement scores for participants in each age group and experimental condition in Experiment 2. Positive values represent displacement toward the category centers. * Significant results, $p < .05$, of one-sample t tests ($df = 11$) comparing the observed displacement value to the expected value with no displacement (i.e., 0 cm).**

ters followed a clear U-shaped developmental pattern. Both 9-year-olds and adults exhibited large distortions toward category centers, whereas 11-year-olds exhibited relatively small distortions toward category centers. Moreover, although adding an interference task during the delay resulted in somewhat more categorical bias for 9-year-olds and adults, it did not result in more categorical bias for 11-year-olds.

It is noteworthy that the performance of the 11-year-old children in this experiment differed slightly from the 11-year-olds' performance in Experiment 1. That is, 11-year-olds in the delay condition showed significant categorical bias in the present experiment, but not in Experiment 1. Closer inspection of the means, however, revealed that the center displacement scores were very similar in magnitude across studies (Experiment 1: $M = .29$ inches or .74 cm; $SD = .52$ inches or 1.32 cm; Experiment 2: $M = .23$ inches or .58 cm; $SD = .32$ inches or .81 cm), suggesting that differences in variability led to inconsistencies in the results. Together, these findings suggest that although there was some variability across studies in whether 11-year-olds' displacement scores reached significance, both studies consistently showed that the magnitude of categorical bias exhibited by 11-year-olds was relatively small.

GENERAL DISCUSSION

The results from the present investigation clearly showed that imposing a delay between learning and reproducing locations led to increases in categorical bias for both children and adults. These findings indicate that children and adults rely more on categorical information to estimate location as memory degrades over time. This reliance on categorical information was not constant across development, however. Rather, the magnitude of categorical bias was greatest for the youngest children and the adults and decreased across the range of child ages studied here.

What accounts for this U-shaped developmental pattern? According to the CA model, the magnitude of categorical bias depends on the certainty of fine-grained information. As mentioned before, this would suggest that the 11-year-olds exhibited little distortion toward category centers because they were relatively certain about fine-grained information, whereas the 7-year-olds exhibited large distortions toward category centers because they were less certain about fine-grained location information. Analyses of metric accuracy support these suggestions. In Experiment 1, 7-year-olds placed the objects significantly less accurately than did the other age groups. Numerous other studies also suggest that the precision of location memory increases throughout childhood (e.g., Acredolo & Boulter, 1984; Cohen, Weatherford, Lomenick, & Koeller, 1979; Sandberg et al., 1996; Siegel, Herman, Allen, & Kirasic, 1979). Thus, it is possible that increases in the precision of metric coding across middle childhood led to decreases in categorical bias.

Although this explanation seems to account for why categorical bias decreased across childhood, it does not explain why adults exhibited large distortions toward category centers. The CA model suggests that these large biases resulted from uncertainty regarding fine-grained information. Thus, to account for the observed pattern of results, the CA model would assume that the precision of metric coding decreases between 11 years and adulthood. This assumption does not fit the metric accuracy findings reported in this investigation. Moreover, it does not fit general ideas regarding changes in memory abilities across development. Thus, the CA model's dependent weighting of categorical information does not account fully for the data obtained in the present investigation.

Instead, the present results suggest that people weight fine-grained and categorical information independently when remembering locations. From this perspective, estimates of location depend on the weights given to fine-grained and categorical information at learning and on the rate of decay of fine-grained and categorical information over time. This perspective raises two key questions: (1) What factors influence the weights given to fine-grained and categorical information at learning?, and (2) How do fine-grained and categorical information decay over delays? Results from our previous studies in which there was a minimal delay between learning and reproducing the locations suggest that there are age-related changes in the weight given to both fine-grained and categorical information (Hund et al., in press; Plumert & Hund, 2001). More specifically, we have consistently found that adults exhibit larger biases toward category centers than do children, suggesting that adults assign higher weights to categorical information than do children. Likewise, we have consistently found that 7-year-olds are significantly less accurate than are older children and adults, suggesting that the precision of metric coding changes with development.

The results of the present investigation also suggest that there may be age-related changes in how rapidly fine-grained and categorical information decays over time. That is, younger children may experience greater decay in memory for fine-grained information than do older children and adults, resulting in a fairly low weight given to fine-grained information by the end of a long delay such as that used in the present investigation. Moreover, the results of the present investigation suggest that categorical information may decay very little over delay. That is, even younger children may be quite good at remembering groups of locations or the region to which a location belongs over relatively long delays. This may be particularly true in cases such as the present investigation, in which the structure of the task space provides support for these spatial categories (e.g., a small-scale space with visible boundaries that demarcate regions).

How might this modification of the CA model apply to the results of the present investigation? Seven-year-olds may have given approximately equal weights to fine-grained and categorical information at the end of learning. Because their memory for fine-grained information decayed more than their memory for the categorical information over the delay, however, categorical information was weighted relatively more strongly than fine-grained information at test. Conversely, 11-year-olds may have given a stronger weight to fine-grained than categorical information at the end of learning. Moreover, their memory for fine-grained information may have decayed relatively little over the course of the delay. As a result, they exhibited relatively little bias toward category centers at test. Finally, it appears that adults assigned a stronger weight to categorical than to fine-grained information at learning. Although their memory for each type of information may have decayed very little over delay, the much higher initial weight given to categorical information may have resulted in large biases toward category centers at test.

The idea that children and adults assign different weights to categorical information at learning is consistent with other research showing that adults are much more likely than children to use spatial clustering strategies to recall objects (Plumert, 1994). In one study, 10-, 12-, 14-, and 16-year-old children and adults were asked to recall the furniture in their homes. Recall orders were examined to determine whether children and adults used semantic category membership (e.g., tables, chairs) or spatial category membership (e.g., kitchen items, living room items) to organize their recall. Unlike the younger children, 16-year-olds and adults relied on spatial category membership to organize their recall, suggesting that the spontaneous use of spatial organizational strategies emerges quite late in development. Although this furniture recall task differs from the current task in which participants learned and reproduced object locations, the late emergence of spatial category effects is consistent across tasks. Thus, a developmental increase in reliance on spatial categories across childhood and adolescence may underlie differences in categorical weighting during location estimation.

What leads to this increase in reliance on spatial category information across development? One possibility is that this increase results from an increase in sensitivity to cues that delineate spatial categories. That is, adults might be more sensitive to subtle cues than are children, allowing adults to delineate many possible spatial categories. Future research could explore this possibility by examining the types of cues that children and adults use to form spatial categories. Another possibility is that the developmental increase in reliance on spatial category information results from an increase in the precision with which people remember categorical information. Although both children and adults appear able to use categorical information to estimate locations quite effectively, adults may be able to remember the spatial category information with a higher degree of precision, possibly leading to larger categorical biases. Additional research could examine this possibility by investigating the fidelity of spatial categorical information and how that fidelity might change across delays.

What are the implications of the present findings for the CA model? Our findings provide additional support for the CA model's claim that children and adults use fine-grained and categorical information to estimate locations. They also suggest, however, that people weight fine-grained and categorical information independently. As such, the CA model should be modified to include factors that influence the weighting of fine-grained information and factors that influence the weighting of categorical information. This modification is needed because according to our framework, it is possible for factors to influence the weighting of categorical information without influencing the weighting of fine-grained information. One way to test this prediction is to explore whether factors that do not influence metric certainty affect bias toward spatial category centers. To this end, we are currently examining how information about the identity of the objects used in our memory task might influence people's memory for where the objects belong. Specifically, we are investigating whether children and adults remember categorically related objects as closer together than they really are. Although the CA model does not make specific predictions about how identity information might influence location estimation, there is no reason to suspect that identity information should affect the certainty of fine-grained information. Thus, the CA model would predict no effects based on object identity. Conversely, according to our framework, identity information might influence the weighting of categorical information, thereby leading to changes in biases toward category centers.

The results of the present investigation provide further evidence that children and adults use fine-grained and categorical information to estimate locations. Moreover, imposing a delay between learning and reproducing locations leads to increases in categorical bias for both children and adults. That is, children and adults relied more on categorical information to estimate location as their memory degraded over time. The magnitude of categorical bias, however, was greatest for the youngest children and the adults and decreased across the range of child ages studied here. Importantly, these findings suggest that fine-grained and categorical information receive independent weights and show different patterns of decay.

Additional research is needed to test this explanation and to explore the factors that influence how children and adults weight fine-grained and categorical information. Moreover, further research is needed to determine whether these findings generalize to other types of tasks and spaces, including large-scale spaces in which not all locations are visible from a single vantage point. The results of this investigation and others like it (e.g., Hund et al., in press; Huttenlocher et al., 1991; 1994; McNamara & Diwadkar, 1997; Plumert & Hund, 2001; Sandberg et al., 1996), however, represent a valuable starting point for understanding the processes underlying memory for location and how they change over development.

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