ACADEMIC PRESS

J. Experimental Child Psychology 82 (2002) 200–225

Journal of Experimental Child Psychology

www.academicpress.com

Experiencing nearby locations together in time: the role of spatiotemporal contiguity in children's memory for location[☆]

Alycia M. Hund,[*] Jodie M. Plumert, and Christina J. Benney

Department of Psychology, 11 SSH East, University of Iowa, Iowa City, IA 52242, USA

Received 7 February 2001; revised 8 February 2002

Abstract

Three studies investigated how experiencing nearby locations together in time influences memory for location. Seven-, 9-, and 11-year-old children and adults learned 20 object locations in a small-scale space. The space was divided into regions by lines or walls. In Study 1, participants learned the locations either region by region or in a random order. Following learning, participants replaced the objects without the aid of the dots marking the locations and the boundaries subdividing the space. They replaced the objects in any order they chose. After experiencing the locations in random orders during learning, only adults underestimated distances between locations belonging to the same group (i.e., region). Conversely, 9- and 11-year-old children and adults who had experienced the locations region by region during learning underestimated these distances. These findings suggest that experiencing nearby locations together in time increases the weight children assign to categorical information in their estimates of location. Results from Studies 2 and 3 in which participants learned the locations region by region and then replaced the objects region by region

[☆] We thank Rachel Howell, Peter Lovegrove, Bethany Moore, and Kim Schroeder for their help with data collection and coding. We also thank the teachers and staff from the College Community Schools in Cedar Rapids, Iowa, for their cooperation and the children and parents for their participation. This research was supported by a grant awarded to Jodie M. Plumert from the National Institutes of Health (R03-HD36761).

[*] Corresponding author. Fax: +319-335-0191.
E-mail addresses: alycia-hund@uiowa.edu (A.M. Hund), jodie-plumert@uiowa.edu (J.M. Plumert).

PII: S0022-0965(02)00004-8

(Study 2) or in a random order (Study 3) were similar, highlighting the importance of spatiotemporal cues in memory for location.

Keywords: Spatial cognition; Location memory; Spatial cognitive development; Spatial organization; Spatiotemporal contiguity

---

The ability to organize objects and locations into groups plays a central role in everyday functioning. Without this ability, remembering the countless objects and locations encountered each day would be an insurmountable task. Over the past 2 decades, a great deal of research has been aimed at understanding how children form and use object categories (e.g., Bauer & Mandler, 1989; Gelman & Markman, 1987; Mandler & McDonough, 1993; Mervis, 1985; Moely, Olson, Halwes, & Flavell, 1969; Oakes, Madole, & Cohen, 1991; Ornstein, Naus, & Liberty, 1975; Quinn, Eimas, & Rosenkrantz, 1993). For example, numerous studies have examined developmental changes in children's use of object categories to organize their recall (e.g., Cole, Frankel, & Sharp, 1971; Frankel & Rollins, 1985; Lange, 1973; Moely et al., 1969; Ornstein et al., 1975; Schneider, 1986). In contrast, we know relatively little about developmental changes in children's ability to form and use spatial categories. The goal of this investigation was to examine the role of spatial categories in children's memory for location.

How might people use spatial categories to remember locations? According to the category adjustment model proposed by Huttenlocher, Hedges, and Duncan (1991), people estimate locations based on their memory of fine-grained, metric information such as distance and direction from a landmark. However, because memory for fine-grained information is inexact, people adjust these estimates based on coarse-grained, categorical information about the location (i.e., region membership). As a result, people tend to think that things are closer to the centers of spatial categories than they really are. Importantly, 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.

We recently proposed a more general framework to explain how children and adults combine fine-grained and categorical information in their estimates of location (Hund & Plumert, in press). According to our framework, people weight fine-grained and categorical information independently when remembering locations. Thus, 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. One critical question this raises is what "factors influence the weighting of categorical information in estimates of location?"

One factor that may increase the weight children and adults assign to categorical information is the presence of visible boundaries that divide locations into clearly marked groups or categories. For example, children might remember playground equipment on one side of a fence as belonging together or rooms on one floor of a house as belonging together. In fact, recent research has shown that visible boundaries play an important role in infants' ability to group locations together (e.g., Quinn, 1994; Quinn, Cummins, Kase, Martin, & Weissman, 1996). In these studies, infants in one condition were familiarized with a dot that appeared in several locations above (or below) a horizontal bar. During test, infants were shown a dot in a novel location above (or below) the bar and a dot below (or above) the bar. Infants in the other condition were presented with the same stimuli, except that the horizontal bar was absent during both habituation and test. Results indicated that infants only responded categorically when the horizontal bar organized the locations into groups, suggesting that visible boundaries facilitate young infants' ability to form spatial categories.

Research also suggests that visible boundaries influence older children's reliance on categorical information in estimates of location (e.g., Cohen, Baldwin, & Sherman, 1978; Kosslyn, Pick, & Fariello, 1974; Newcombe & Liben, 1982; Plumert & Hund, 2001). Plumert and Hund (2001), for example, recently demonstrated that boundaries influence categorical bias in people's estimates of location. Seven-, 9-, and 11-year-old children and adults were asked to learn the locations of 20 objects marked by yellow dots on a blue floor in an open, square box. The box was divided into four identical regions by boundaries that varied in salience (i.e., either opaque walls or lines on the floor). Five objects were located in each region. Unlike previous studies with adults (e.g., McNamara, 1986; McNamara, Altarriba, Bendele, Johnson, & Clayton, 1989), participants learned the locations in random orders. During the test phase, the experimenter removed the yellow dots marking the locations and the boundaries dividing the house into regions. Participants then attempted to place all of the objects in the correct locations. They could place the objects in any order they chose. Eleven-year-olds and adults in the most salient boundary condition (i.e., walls) placed the objects belonging to the same region closer together than they actually were, suggesting that the boundaries increased the weighting of categorical information in their estimates of location. Conversely, 7- and 9-year-olds did not underestimate distances between locations in the same group in either boundary condition. Another investigation in which lines divided the house into regions revealed that adults, but not children, placed objects belonging to the same region closer together than they actually were following random experience with the locations during learning (Hund & Plumert, in press). Together, these findings suggest that visible boundaries increase the weighting of categorical information during location estimation, especially for older children and adults.

Another cue that might affect the weighting of categorical information is spatiotemporal experience. Specifically, experiencing several nearby locations together in time may increase the weighting of categorical information in estimates of location. For example, suppose a child and her parent spend Saturday morning shopping at several downtown businesses and stop for lunch at a nearby restaurant. This spatiotemporal experience (and similar experiences on other days) may strengthen the relations among the downtown businesses and restaurants. Thus, everyday spatiotemporal experience may serve as an important cue for highlighting categorical information. It is important to note that although spatial and temporal contiguity can operate independently, the two are often highly correlated in our everyday experiences: we typically visit nearby locations close in time. Moreover, temporal contiguity may be influenced by visible boundaries: physical boundaries may guide locomotion so that people usually visit sites on one side of a boundary before visiting sites on the opposite side.

Several researchers have investigated whether spatiotemporal contiguity influences how adults remember locations (e.g., Clayton & Habibi, 1991; Curiel & Radvansky, 1998; McNamara, Halpin, & Hardy, 1992; Sherman & Lim, 1991). Clayton and Habibi (1991), for example, asked adults to learn the locations of several cities on a fictitious map. City names were presented on a computer monitor so that both spatial and temporal contiguity could be controlled. In the correlated condition, spatially contiguous locations (i.e., locations nearby each other) were presented contiguously in time, whereas spatially distant locations were separated in time. In the uncorrelated condition, nearby and distant locations were presented contiguously in time. Following learning, people completed a recognition task that involved judging whether city names had appeared during learning. Recognition lists included city names that were preceded by near or far city names or by foils. Participants in the correlated condition were faster to recognize a city name when it was preceded by a nearby city than when it was preceded by a distant city (i.e., a spatial priming effect). Thus, when adults learned the locations of nearby cities close together in time, they treated them as if they belonged to the same category. At present, however, little is known about how spatiotemporal contiguity influences children's memory for location.

The goal of this investigation was to examine how visible boundaries and spatiotemporal experience affect the weighting of categorical information during location estimation. In other words, when children and adults experience locations from the same region close together in time, do they remember those locations as closer together than they really are? In a series of three studies, we asked 7-, 9-, and 11-year-old children and adults to remember several locations in a small-scale, homogeneous space.[1] First, participants learned the locations of 20 objects in a model house. Opaque walls or lines divided the house into four identical regions during learning. These boundary conditions allowed us to examine how boundary salience interacts with spatiotemporal experience to produce categorical bias in estimates of location. The locations were marked by 20 yellow dots on the floor of the house. There were five locations in each region. To examine how spatiotemporal contiguity influences the weighting of categorical information, participants experienced nearby locations (i.e., locations from the same region) together in time during learning. Study 1 also included a random learning condition in which participants experienced the locations in random orders during learning. During test, participants attempted to place the objects in the correct locations without the aid of the yellow dots marking the locations and the boundaries dividing the house into regions. In Study 1, participants placed the objects in any order they chose during the test phase.

Based on previous work in which participants learned the locations in random orders (Hund & Plumert, in press; Plumert & Hund, 2001), we expected that 11-year-olds in the walls condition and adults in both boundary conditions would underestimate distances between locations belonging to the same group regardless of learning condition. That is, we expected 11-year-olds in the walls condition and adults in the walls and lines conditions to place objects belonging to the same group closer together than they actually were. In addition, we expected that 11-year-olds in the less salient boundary condition (i.e., the lines condition) and younger children in the more salient boundary condition (i.e., the walls condition) might also underestimate distances between locations in the same group following spatiotemporally contiguous experience (i.e., in the contiguous learning condition), but not following random learning experience. These findings would suggest that experiencing nearby locations together in time increases the weighting of categorical information during location estimation.

[1] We chose to use a small-scale space in this investigation to be consistent with previous work in this area (e.g., Engebretson & Huttenlocher, 1996; Huttenlocher et al., 1991; Huttenlocher, Newcombe, & Sandberg, 1994; Laeng, Peters, & McCabe, 1998; Newcombe, Huttenlocher, Sandberg, Lie, & Johnson, 1999; Plumert & Hund, 2001; Sandberg, 1999; Sandberg, Huttenlocher, & Newcombe, 1996). Further research is needed to determine whether findings concerning how children and adults estimate locations in small-scale spaces generalize to large-scale spaces in which not all locations are visible from a single vantage point.

Study 1

Method

Participants

One hundred ninety-two 7-, 9-, and 11-year-olds, and adults participated. There were 48 participants in each age group, with approximately equal numbers of males and females in each group. The mean ages were 7 years and 7 months (range = 6;9 to 8;0), 9 years and 4 months (range = 8;10 to 9;11), 11 years and 4 months (range = 10;8 to 11;10), and 19 years and 8 months (range = 17;2 to 27;11), respectively. One additional 11-year-old was excluded because 10 of 20 remembered locations were incorrect. One additional 7-year-old and one adult were excluded because of experimenter error. One additional 7-, 9-, and 11-year-old, who did not reach our learning criterion, were excluded. Children were recruited from a local public school district and from a child research participant database maintained by the Department of Psychology at the University of Iowa. Most children were from middle- to upper middle-class Caucasian families. Adults participated to fulfill research credit for an introductory psychology course.

Apparatus and materials

A 32-in. long × 32-in. wide × 13-in. 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 1/2-in. 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 study: (a) a blue-carpeted floor with yellow dots marking the locations, (b) a blue-carpeted floor with no dots, and (c) a grid of x and y coordinates at 1/2-in. intervals.

The model house could be divided into four identical regions (16 in. × 16 in.) by placing walls or lines inside the house. The white plywood walls were 13-in. tall and 5/16-in. wide. The white lines were 1/4-in. tall and 5/16-in. wide. Each region contained five locations marked by 3/4-in. yellow dots. Twenty miniature objects were used during the study to help participants learn the locations in the house: a pot, bear, birdhouse, pie, iron, paint can, picture, book, purse, flower pot, present, fishbowl, apple, trash can, hat, pail, legoman, bag of chips, jar of honey, and a beverage carton. The average length and width of the objects were .70 and .64 in., respectively.

Design and procedure

Children were tested individually in a quiet room at their elementary school or in the laboratory. Adults were tested individually in the laboratory. The model house was placed on the floor of the room. The experimenter stood directly in front of the house, while participants were seated to the right of the experimenter facing an adjacent side of the house.

Participants were assigned to one of two learning conditions: *contiguous learning* or *random learning*.[2] In the contiguous learning condition, participants experienced the locations belonging to each region together in time during learning. In the random learning condition, participants experienced the locations in random orders during learning. Half of the participants in each learning condition were randomly assigned to each boundary condition: *walls* or *lines*. In the walls condition, opaque walls divided the house into four equal regions. In the lines condition, lines on the floor divided the house into four equal regions.

The experimental session included a learning phase followed by a test phase. During the learning phase, participants learned the locations of 20 objects in the house. At the beginning of the session, the experimenter told participants that 20 objects would be placed 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. Participants watched as the experimenter named the objects and placed them in the house one at a time. In the contiguous learning condition, the experimenter placed all five objects in one region before moving to another region. This ensured that spatially contiguous locations (i.e., locations in the same region) were experienced contiguously in time. Both the order of regions and the order of locations within each region were randomized for each participant. The pairings of locations and objects also were randomized for each participant. In the random learning condition, the experimenter placed the objects in a random order. The order of locations and the pairings of locations and objects were randomized for each participant.

After the experimenter had placed all 20 objects, participants were asked to turn around while the experimenter removed the objects from the model house. The experimenter then gave the objects to the participants one at a time and asked them to place them on the correct dots in the model house. In the contiguous learning condition, the experimenter gave participants all of the objects from one region before moving to another region. Hence, spatial and temporal contiguity were perfectly correlated during learning. The order of regions and the order of locations within regions were randomized for each learning trial. In the random learning condition, the experimenter

[2] Random assignment to learning condition was not possible because the random learning condition was added following the completion of the contiguous learning condition. The apparatus, task, and procedure were identical across conditions, and the participant populations were highly similar. Thus, we have no reason to believe that the sequential collection of data in these conditions affected our results. We have chosen to present these conditions together to maintain clarity and brevity.

gave participants the objects in a random order. The order of locations was randomized for each learning trial. The participant's task was to try to place each object in its correct location. Incorrect placements were recorded and corrected by the experimenter. Participants were allowed to move around the outside of the model house to replace the objects during learning trials. Participants continued with the learning trials until they could correctly replace all 20 objects in a single trial. The mean number of trials to criterion for 7-, 9-, and 11-year-olds and adults were 4.90 ($SD = 1.96$), 3.79 ($SD = 1.43$), 3.10 ($SD = 1.24$), and 2.73 ($SD = 1.27$), respectively.

The test phase began immediately following the learning phase. First, the experimenter asked the participants to turn away from the model house while the objects were removed. The experimenter removed the floor with the yellow dots and replaced it with a plain blue floor. The boundaries that divided the house into regions also were removed. The experimenter then asked participants to face the house and 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 marking the locations and the boundaries subdividing the space. The experimenter gave participants all 20 objects and asked them to replace them in the correct locations. Thus, participants were allowed to replace the objects in any order they chose. The experimenter recorded the order of replacement for each participant. After participants replaced all 20 objects, the experimenter thanked them for participating. The experimenter then removed the blue floor and replaced it with the grid of x and y coordinates and recorded the x and y coordinates for each object to the nearest 1/2 in.

Coding and measures

A placement was considered "correct" if it was in the correct region and in the correct position within the configuration relative to the other objects. Occasionally, participants preserved the overall configuration within a region, but incorrectly paired objects and locations. For example, participants might correctly preserve the overall shape of the configuration involving locations 1–5, but mistakenly transpose the objects in locations 3 and 4. As in previous research (Hund & Plumert, in press; Plumert & Hund, 2001), we used the x and y coordinates for these locations, regardless of whether the correct objects were placed in the locations. We substituted 3.23% of the locations for 7-year-olds (31 of 960), 1.88% for 9-year-olds (18 of 960), 2.19% for 11-year-olds (21 of 960), and .83% for adults (8 of 960). These substituted locations were used in all analyses. Objects placed in the wrong region or in a completely wrong configuration were omitted from analyses. We omitted 2.40% of the locations for 7-year-olds (23 of 960), .42% for 9-year-olds (4 of 960), .94% for 11-year-olds (9 of 960), and 0% for adults (0 of 960).

Intercoder reliability estimates of object placement were calculated for 32 randomly selected participants (15% of the sample) using exact percentage agreement. For each of these participants, two coders judged which object was placed at each of the 20 locations. Coders agreed on 99.38% of the 640 locations coded.

Measures

Metric error score. Participants received a single metric error score reflecting the degree to which they placed objects near their actual locations. This score was calculated by determining the distance between each remembered and actual location. We then averaged these distances over all locations to obtain a single error score, reflecting the precision of memory for fine-grained information.

Spatial clustering score. Participants received a spatial clustering score reflecting the degree to which they replaced the objects region by region during test. The clustering measure used was the adjusted ratio of clustering (ARC) score (Roenker, Thompson, & Brown, 1971). This score represents the proportion of observed number of region repetitions relative to the total possible number of repetitions corrected for chance. A score of 1.00 represents perfect clustering, whereas a score of 0.00 represents no above-chance clustering. Negative ARC scores were set to zero because they represent below-chance levels of clustering and are difficult to interpret. Thus, ARC scores in this study ranged from 0.00 to 1.00.

Center displacement score. Participants also received a center displacement score reflecting the degree to which they systematically placed objects belonging to the same group closer together than they actually were. To calculate this score, 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 differences across all 20 locations to obtain a single center displacement score for each participant. Thus, center displacement scores reflected the degree to which participants displaced locations toward the centers of the spatial groups, after removing effects due to translation of groups. This score provided an index of categorical weighting during location estimation.

Results

Metric error

Inspection of object placements revealed that, in general, children and adults in both learning conditions placed the objects quite accurately, suggesting that they used fine-grained, metric information to estimate the locations. To investigate possible differences in metric error during test among the age groups, learning conditions, and boundary conditions, metric error scores were entered into an Age (7 years vs 9 years vs 11 years vs adult) × Learning Condition (contiguous vs random) × Boundary Condition (lines vs walls) analysis of variance (ANOVA). This analysis yielded a significant effect of age [$F(3, 176) = 7.95$, $p < .001$]. No other effects were significant. Follow-up tests of the age effect indicated that 7-year-olds exhibited significantly greater metric error than did the other age groups.[3] In addition, 9-year-olds exhibited significantly greater error than did the adults. The mean distance from correct locations was 2.07 in. ($SD = .40$) for 7-year-olds, 1.88 in. ($SD = .40$) for 9-year-olds, 1.83 in. ($SD = .43$) for 11-year-olds, and 1.69 in. ($SD = .30$) for adults.

Spatial clustering

During learning, the experimenter determined the object placement orders for the participants. That is, participants either experienced all the objects in one region before experiencing those in the next region or they experienced the objects in a random order. During test, however, participants were allowed to replace the objects in any order they chose. One question this raises is whether the degree to which participants replaced all of the objects belonging to one region before replacing those belonging to another region during the test phase was affected by learning condition. Spatial clustering (ARC) scores can be seen in Table 1. To determine whether the magnitude of spatial clustering differed across age groups, learning conditions, and boundary conditions, ARC scores were entered into an age (7 years vs 9 years vs 11 years vs adult) × Learning Condition (contiguous vs random) × Boundary Condition (lines vs walls) ANOVA. This analysis revealed significant main effects of age [$F(3, 176) = 8.20$, $p < .001$] and of learning condition [$F(1, 176) = 31.91$, $p < .001$].

Follow-up tests indicated that 7-year-olds' replacement orders were significantly less organized than were those of the other age groups. In addition, 9-year-olds' replacement orders were significantly less organized than were those of the adults. The mean spatial clustering score was .39 ($SD = .33$) for 7-year-olds, .56 ($SD = .38$) for 9-year-olds, .60 ($SD = .33$) for 11-year-olds, and .72 ($SD = .36$) for adults. Thus, spatial organization of replacement orders increased across development. Moreover, participants in the contiguous learning condition had significantly higher spatial organization scores ($M = .70$; $SD = .33$) than did participants in the random learning condition ($M = .43$; $SD = .36$). In other words, children and adults who experienced the objects region by region during learning were more likely to replace the objects region by region during the test phase than were participants who experienced the objects in random orders during learning.

---

[3] All post hoc comparisons reported in this article were conducted using Fisher's protected least significant difference (PLSD) test ($\alpha = .05$).

Table 1
Adjusted ratio of clustering (ARC) scores for children and adults in each learning and boundary condition in Study 1

Age and condition	ARC score	
	Contiguous learning	Random learning
7-year-olds		
Walls	0.58 (.39)**	0.25 (.28)***
Lines	0.52 (.33)***	0.20 (.16)***
9-year-olds		
Walls	0.60 (.38)**	0.49 (.36)***
Lines	0.82 (.29)+	0.34 (.35)***
11-year-olds		
Walls	0.72 (.33)*	0.42 (.28)***
Lines	0.74 (.28)**	0.52 (.34)***
Adults		
Walls	0.72 (.33)*	0.70 (.41)*
Lines	0.89 (.20)+	0.56 (.41)**

Note. Standard deviations are listed in parentheses. Asterisks denote results of one-sample t tests ($df = 11$) comparing the observed ARC score to a perfect clustering score (i.e., 1.0).
+ $p < .08$.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

Center displacement

The primary question of interest was whether children and adults in each learning and boundary condition placed the objects belonging to each group closer together than they actually were. We addressed this question by conducting two sets of analyses. First, we used separate one-sample t tests for each age, learning condition, and boundary condition to compare center displacement scores to an expected value of 0. No difference in distance would be expected if participants neither underestimated nor overestimated the distances between locations belonging to each group. Positive difference scores would reflect underestimation of distances, whereas negative difference scores would reflect overestimation of distances. As shown in Fig. 1, in the random learning condition, only the adults (in both boundary conditions) significantly underestimated distances between locations [ts$(11) > 4.75$, $p < .001$], suggesting that the adults weighted categorical information relatively heavily in their estimates of location. In contrast, none of the child age groups placed the objects significantly closer together than they actually were following random experience with the locations during learning [ts$(11) < 1.85$, $p > .085$]. In the contiguous learning condition, however, adults and 11-year-olds in both boundary conditions and 9-year-olds in the lines condition significantly underestimated distances between locations [ts$(11) > 2.20$, $p < .05$], suggesting that they also weighted categorical information relatively heavily in their estimates of location. However, 7-year-olds in both boundary conditions

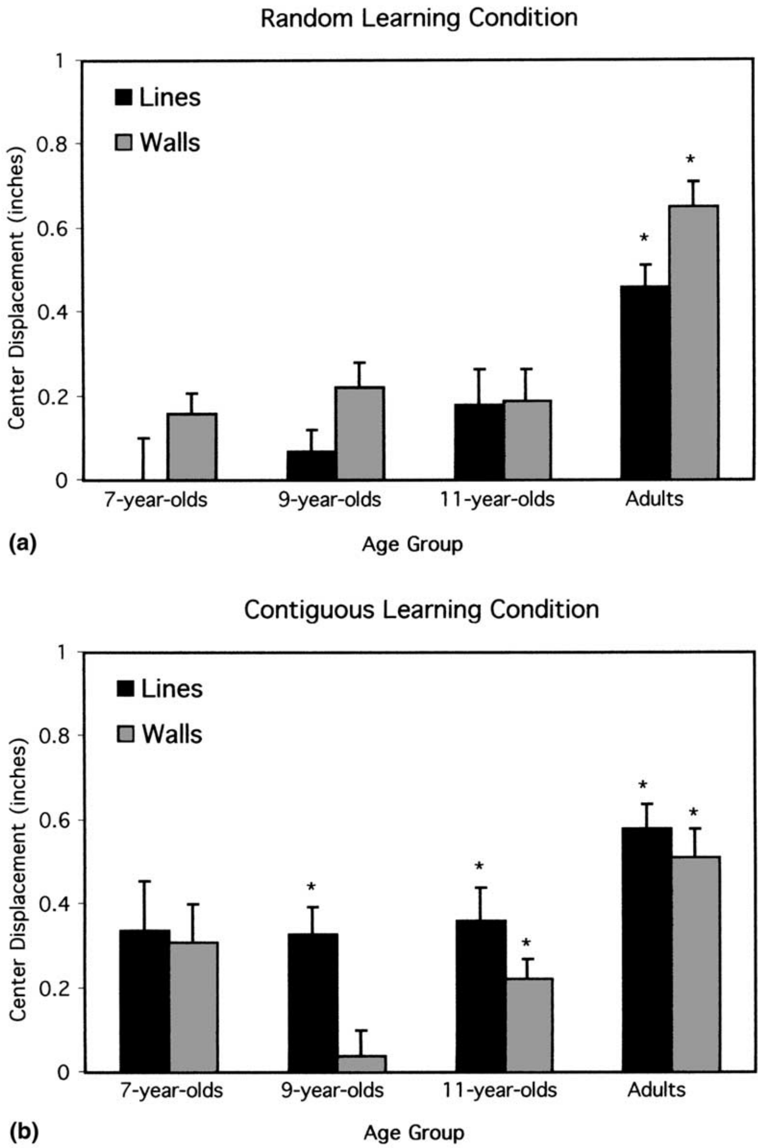

Fig. 1. Center displacement scores for each age group, learning condition, and boundary condition in Study 1. Asterisks denote significant results of one-sample t tests ($df = 11$) comparing the displacement score to the expected score with no displacement (i.e., 0 in.).

and 9-year-olds in the walls condition did not place the objects significantly closer together than they really were following contiguous experience during learning [ts$(11) < 1.72$, $p > .10$]. Together, these findings suggest that experiencing nearby locations together in time during learning increases the weight given to categorical information in estimates of location.

In addition to these analyses, center displacement scores were entered into an Age (7 years vs 9 years vs 11 years vs adult) $\times$ Learning Condition (contiguous vs random) $\times$ Boundary Condition (lines vs walls) ANOVA to compare the magnitude of center displacement across ages and conditions. This analysis revealed a significant main effect of age [$F(3, 176) = 5.92$, $p < .001$]. Follow-up tests indicated that the adults placed the objects significantly closer together than did the other age groups. The mean center displacement score was .20 in. ($SD = .63$) for 7-year-olds, .17 in. ($SD = .41$) for 9-year-olds, .24 in. ($SD = .50$) for 11-year-olds, and .55 in. ($SD = .41$) for adults. Results also revealed a marginally significant Learning Condition $\times$ Boundary Condition interaction [$F(1, 176) = 3.15$, $p < .08$]. Simple effects tests revealed that center displacement scores were significantly greater in the contiguous learning condition than in the random learning condition for participants in the lines condition [$F(1, 94) = 4.08$, $p < .05$], but not for participants in the walls condition [$F(1, 94) = .11$, *ns*].

Discussion

Our primary goal was to investigate whether experiencing nearby locations together in time during learning influenced the weighting of categorical information in estimates of location. In the random learning condition, only the adults placed the objects significantly closer to the centers of the groups than they really were. In the contiguous learning condition, however, adults and 11-year-olds in both boundary conditions and 9-year-olds in the lines condition significantly underestimated distances between locations in the same spatial group, suggesting that they relied heavily on categorical information to remember the locations. Seven-year-olds did not underestimate distances between locations in the same spatial group in either boundary condition or learning condition. Together, these differences across conditions indicate that spatiotemporal contiguity among locations increases the weighting of categorical information in 9- and 11-year-old children's estimates of location.

In general, results from the random learning condition replicated findings from our previous studies (Hund & Plumert, in press; Plumert & Hund, 2001). As before, adults underestimated distances between locations in the same region (Hund & Plumert, in press; Plumert & Hund, 2001). However, unlike our previous findings (Plumert & Hund, 2001), 11-year-olds in the walls condition did not place the objects in the same region significantly closer together than they really were. This slight difference in 11-year-olds' performance across studies could reflect differences in the scores used to assess center displacement. That is, center displacement was measured using displacement toward the geometric center of the region in Plumert and Hund (2001). In the present investigation and in Hund and Plumert (in press), however, displacement toward the centers of the spatial groups (after removing effects of translation of groups) was used to assess categorical bias. Despite the slight differences across studies, the overall pattern of results reveals systematic differences between the random and contiguous learning conditions, suggesting that spatiotemporal contiguity influences the weighting of categorical information in estimates of location.

As noted above, results from the contiguous learning condition generally confirmed our predictions. One exception was the performance of the 9-year-olds. We expected that the combination of spatiotemporal contiguity and salient boundaries (i.e., walls) would increase the weighting of categorical information more than would the combination of spatiotemporal contiguity and less salient boundaries (i.e., lines). However, in the contiguous learning condition, 9-year-olds in the lines condition, but not in the walls condition, significantly underestimated distances between locations belonging to the same spatial group. Possibly, 9-year-olds are transitional with respect to their sensitivity to spatiotemporal cues. If so, children in this age range may exhibit more variability in their performance. Additional work is needed to clarify the nature of these effects.

Overall, results from this study demonstrate that experiencing the locations region by region during learning increased the weighting of categorical information for the 9- and 11-year-olds; however, it did not increase the weighting of categorical information as much for 7-year-olds. One question this raises is whether providing spatiotemporal contiguity during both learning and test would increase the weighting of categorical information, especially for the 7-year-olds. The goal of Study 2 was to test this possibility. The learning procedure was identical to the contiguous learning condition in Study 1. That is, participants experienced locations from the same region together in time during learning. However, participants replaced objects from the same region together in time during the test phase. Thus, the learning and test phases were highly similar: spatiotemporal contiguity cues were present in both phases. As in Study 1, we expected that adults and 11-year-olds in both boundary conditions would significantly underestimate distances among locations within groupings. Moreover, we expected that 7- and 9-year-olds in both boundary conditions might significantly underestimate distances among locations belong to the same group.

Study 2

Method

Participants

Ninety-six 7-, 9-, and 11-year-olds, and adults participated. There were 24 participants in each age group, with approximately equal numbers of males and females in each group. The mean ages were 7 years and 9 months (range = 7;0 to 8;0), 9 years and 9 months (range = 9;6 to 9;11), 11 years and 5 months (range = 10;11 to 11;11), and 19 years and 3 months (range = 17;3 to 23;0), respectively. One additional 7-year-old and one additional 9-year-old were excluded because their experimental sessions were interrupted. In addition, one 7-year-old, one 9-year-old, and one adult were excluded because of experimenter error. Children were recruited from a child research participant database maintained by the Department of Psychology at the University of Iowa. Most children were from middle- to upper middle-class Caucasian families. Adults were recruited in the same manner as in Study 1.

Apparatus and materials

The same model house and miniature objects were used as in Study 1. Again, walls or lines divided the model house into four identical regions. The locations also were the same as those used in Study 1.

Design and procedure

Participants were tested individually in the laboratory. Participants again were randomly assigned to one of two boundary conditions: walls or lines. As in the contiguous learning condition in Study 1, participants learned the locations region by region. The mean number of trials to criterion for 7-, 9-, and 11-year-olds, and adults were 3.25 ($SD = 1.03$), 3.13 ($SD = 1.87$), 3.33 ($SD = 1.47$), and 2.58 ($SD = 1.18$), respectively.

The test phase began immediately following the learning phase. All aspects of the testing procedure were the same as before except that participants replaced the objects region by region during test. That is, the experimenter gave participants five objects from one region and asked them to replace them in the correct locations. When they finished replacing those, she gave them five more objects from another region, and so on. Placing the objects region by region ensured that spatial and temporal contiguity were perfectly correlated during both learning and test. The order of presentation of regions during the test phase was randomized for each participant. After participants replaced the last five objects, the experimenter thanked them for participating and recorded the x and y coordinates for each object to the nearest 1/2 in.

Coding and measures

Coding was identical to Study 1. We substituted 0.42% of the locations for 7-year-olds (2 of 480), 0.42% for 9-year-olds (2 of 480), 1.67% for 11-year-olds (8 of 480), and 0% for adults (0 of 480). These substituted locations were used in all analyses. Objects placed in the wrong region or in a completely wrong configuration were omitted from analyses. We omitted 1.88% of the locations for 7-year-olds (9 of 480), 0.83% for 9-year-olds (4 of 480), 0.63% for 11-year-olds (3 of 480) and 0% for adults (0 of 480).

Intercoder reliability estimates of object placement were calculated for 16 randomly selected participants (15% of the sample) using exact percentage agreement. For each of these participants, two coders judged which object was placed at each of the 20 locations. Coders agreed on 100% of the 320 locations coded.

Participants again received a metric error score and a center displacement score. These scores were calculated in the same manner as in Study 1.

Results

Metric error

As in Study 1, metric error scores were entered into an Age (7 years vs 9 years vs 11 years vs adult) × Boundary Condition (lines vs walls) ANOVA. As in Study 1, this analysis yielded a significant effect of age [$F(3, 88) = 6.20$, $p < .001$]. Follow-up tests indicated that adults exhibited significantly less error than did the other age groups. The mean displacement from correct locations was 1.98 in. ($SD = .44$) for 7-year-olds, 1.94 in. ($SD = .32$) for 9-year-olds, 1.88 in. ($SD = .44$) for 11-year-olds, and 1.55 in. ($SD = .33$) for adults.

Center displacement

The primary question of interest was whether participants placed the objects belonging to each group closer together than they actually were when they experienced the objects region by region during both learning and test. As in Study 1, we conducted two sets of analyses. First, we used separate one-sample *t* tests for each age and boundary condition to compare center displacement scores to an expected value of 0. As shown in Fig. 2, 9- and 11-year-olds and adults in both boundary conditions significantly underestimated distances between locations [$ts(11) > 2.40$, $p < .05$], suggesting that they weighted categorical information relatively heavily in their estimates of location. Conversely, the 7-year-olds did not place the objects significantly closer together than they actually were [$ts(11) < 1.30$, $p > .20$].

In addition to these analyses, center displacement scores were entered into an Age (7 years vs 9 years vs 11 years vs adult) × Boundary Condition (lines vs walls) ANOVA to compare the magnitude of center displacement across ages and conditions. As in Study 1, this analysis revealed a significant main effect of age [$F(3, 88) = 3.73$, $p < .05$]. Follow-up tests indicated that the 11-year-olds and adults placed the objects significantly closer together than did the 7-year-olds. The mean center displacement score was .13 in. ($SD = .52$) for 7-year-olds, .34 in. ($SD = .37$) for 9-year-olds, .49 in. ($SD = .52$) for 11-year-olds, and .53 in. ($SD = .35$) for adults.

Comparison of Studies 1 and 2. The overall goal of Study 2 was to explore whether providing spatiotemporal contiguity during both learning and test

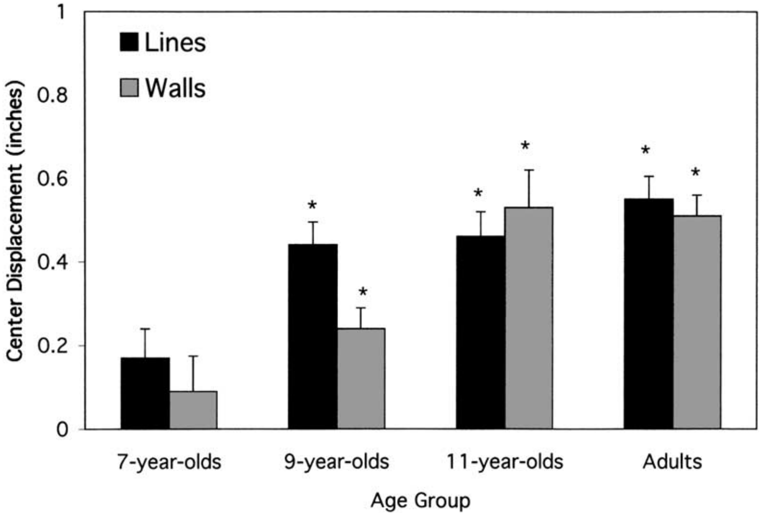

Fig. 2. Center displacement scores for each age group and boundary condition in Study 2. Asterisks denote significant results of one-sample t tests ($df = 11$) comparing the displacement score to the expected score with no displacement (i.e., 0 in.).

would increase the weighting of categorical information, especially for the 7-year-olds. To examine this issue in greater detail, center displacement scores from the present study were compared with center displacement scores from participants in the completely contiguous learning condition in Study 1. Participants in both studies experienced the objects that belonged to the same region together in time during learning. However, in Study 1, participants placed the objects in any order during the test phase, whereas in Study 2, they placed the objects that belonged to the same region together in time during test. Center displacement scores for participants in the completely contiguous learning condition were entered into an Age (7 years vs 9 years vs 11 years vs adult) × Boundary Condition (lines vs walls) × Study (1 vs 2) ANOVA to compare the magnitude of center displacement across ages, boundary conditions, and studies. As in the individual analyses, this analysis yielded a significant main effect of age [$F(3, 176) = 3.82$, $p < .05$]. Follow-up tests indicated that the adults placed the objects significantly closer together than did the 7- and 9-year-olds. The mean center displacement score was .23 in. ($SD = .62$) for 7-year-olds, .26 in. ($SD = .41$) for 9-year-olds, .39 in. ($SD = .50$) for 11-year-olds, and .54 in. ($SD = .40$) for adults. There were no other significant effects, indicating that for participants who experienced the objects region by region during learning, the magnitude of categorical bias was similar regardless of the nature of the test phase.

Discussion

Our primary goal was to investigate whether experiencing nearby locations together in time during learning and test increased the weight children and adults gave to categorical information. We expected to see significant categorical bias in estimates of location because the spatiotemporal component of the learning and test phases was identical. As in the contiguous learning condition in Study 1, adults and 11-year-olds in both boundary conditions and 9-year-olds in the lines condition significantly underestimated distances between locations in the same spatial group, suggesting that they used categorical information to adjust their estimates of location. Unlike Study 1, however, 9-year-olds in the walls condition also underestimated distances between locations in the same group. Again, experiencing nearby locations together in time during learning and test did not lead 7-year-olds in either boundary condition to significantly underestimate distances between locations belonging to the same spatial group. Thus, correlating spatial and temporal contiguity during learning and test increased the weighting of categorical information for 9-year-olds, but not for the 7-year-olds.

Together, the results of Studies 1 and 2 suggest that experiencing locations from the same region close together in time increases the weight given to categorical information in estimates of location, especially for 9- and 11-year-old children and adults. However, these findings leave unanswered the question of whether spatiotemporal experience during learning alone is sufficient to produce categorical bias. That is, because spatial and temporal contiguity were partially correlated during test in Study 1 and perfectly correlated during test in Study 2, it is not clear how categorical weighting is affected when spatial and temporal contiguity are correlated during learning but not during test.

To answer this question, we conducted a third study to strictly control the order in which participants placed objects during test. We used the same apparatus and learning procedure as in the previous studies. Thus, participants again experienced nearby locations together in time during learning. During test, however, participants replaced the objects in a random order. This design allowed us to determine whether spatiotemporally organized experience during learning alone is sufficient to produce underestimation of distances within spatial groups at test. Given that the 11-year-olds and adults in the contiguous learning condition in the previous studies exhibited clear categorical bias in their estimates of location, only 7- and 9-year-old children participated in this study. As in previous studies, we predicted that 9-year-olds might significantly underestimate distances among locations in the same group, suggesting that spatiotemporally organized experience during learning alone is sufficient to increase the weighting of categorical information. Conversely, we expected that

7-year-olds would not significantly underestimate distances among locations.

Study 3

Method

Participants

Forty-eight 7- and 9-year-olds participated. There were 24 participants in each age group, with approximately equal numbers of males and females in each group. The mean ages were 7 years and 9 months (range = 7;0 to 8;0) and 9 years and 4 months (range = 9;2 to 9;8). One additional 7-year-old, who did not reach our learning criterion, was excluded. Children were recruited in the same manner as in Study 2. Most children were from middle- to upper middle-class Caucasian families.

Apparatus and materials

The same model house and miniature objects were used as in the previous studies. Again, walls or lines divided the model house into four identical regions. The locations also were identical to those used in the previous studies.

Design and procedure

Participants were tested individually in the laboratory. Again, they were randomly assigned to one of two boundary conditions: walls or lines. As in the previous studies, participants learned the locations region by region. The mean number of trials to criterion for 7- and 9-year-olds was 4.1 ($SD = 1.7$) and 3.2 ($SD = 2.1$), respectively.

The test phase began immediately following the learning phase. All aspects of the testing procedure were the same as before except that the experimenter gave the objects to the participants one at a time in a random order. A different random order was used for each participant. After participants replaced the last object, the experimenter thanked them for participating and recorded the x and y coordinates for each object to the nearest 1/2 in.

Coding and measures

Coding was identical to the previous studies. Again, we used the x and y coordinates for locations regardless of whether the correct objects were placed in the locations. We substituted 3.54% of the locations for 7-year-olds (17 of 480) and 2.08% for 9-year-olds (10 of 480). These substituted locations were used in all analyses. Objects placed in the wrong region or in a completely wrong configuration were omitted from analyses. We omitted 2.29% of the locations for 7-year-olds (11 of 480) and 2.50% for 9-year-olds (12 of 480).

Intercoder reliability estimates of object placement were calculated for eight randomly selected participants (15% of the sample) using exact percentage agreement. For each of these participants, two coders judged which object was placed at each of the 20 locations. Coders agreed on 100% of the 160 locations coded.

Participants again received a metric error score and a center displacement score. These scores were calculated in the same manner as in the previous studies.

Results

Metric error

Metric error scores were entered into an Age (7 years vs 9 years) $\times$ Boundary Condition (lines vs walls) ANOVA. This analysis yielded a significant Age $\times$ Boundary Condition interaction [$F(1,44) = 4.09,\ p < .05$]. Follow-up tests indicated that 7-year-olds in the walls condition ($M = 2.18$ in., $SD = .50$) exhibited less error than did 9-year-olds in the walls condition ($M = 1.78$ in., $SD = .20$) [$F(1,22) = 6.74,\ p < .05$]. Metric error scores for 7-year-olds ($M = 1.81$ in., $SD = .41$) and 9-year-olds ($M = 1.84$ in., $SD = .29$) in the lines condition differed nonsignificantly [$F(1,22) = .03$, *ns*].

Center displacement

Did children in both boundary conditions place the objects within each group closer together than they actually were when the test phase involved placing the objects in a random order? As in the previous studies, we first conducted separate one-sample t tests for each age group and boundary condition to compare center displacement scores to an expected value of 0. As shown in Fig. 3, 9-year-olds in both boundary conditions significantly underestimated distances among locations. Unexpectedly, 7-year-olds in the walls condition also underestimated distances among locations [$ts(11) > 2.45,\ p < .05$]. Seven-year-olds in the lines condition did not place the objects significantly closer together than they actually were [$t(11) = .50$, *ns*].

In addition to these analyses, center displacement scores were entered into an Age (7 years vs 9 years) $\times$ Boundary Condition (lines vs walls) ANOVA to compare the magnitude of center displacement across ages and conditions. This analysis revealed a significant Age $\times$ Boundary Condition interaction [$F(1,44) = 6.43,\ p < .05$]. Simple effects tests indicated that center displacement scores were significantly greater in the walls condition than in the lines condition for the 7-year-olds [$F(1,22) = 6.61,\ p < .05$], but not for the 9-year-olds [$F(1,22) = .62$, *ns*]. The mean center displacement score was .06 in. ($SD = .45$) for 7-year-olds in the lines condition, .53 in. ($SD = .44$) for 7-year-olds in the walls condition, .37 in. ($SD = .29$) for 9-year-olds in the lines condition, and .26 in. ($SD = .37$) for 9-year-olds in the walls condition.

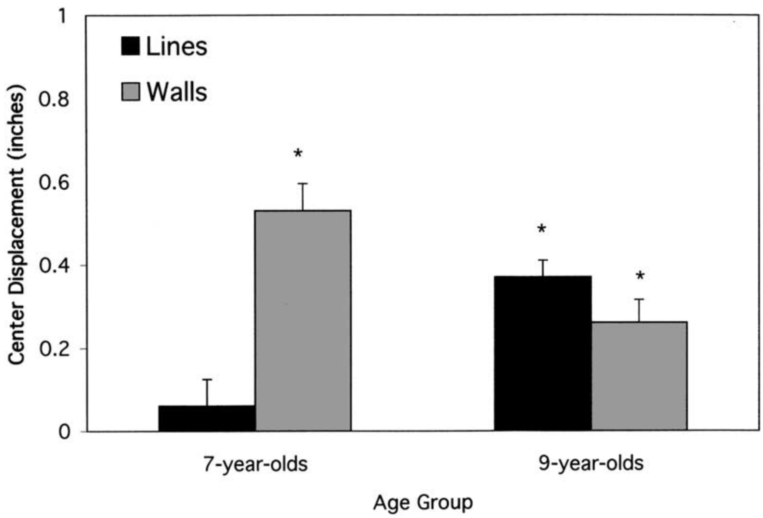

Fig. 3. Center displacement scores for each age group and boundary condition in Study 3. Asterisks denote significant results of one-sample t tests ($df = 11$) comparing the displacement score to the expected score with no displacement (i.e., 0 in.).

Comparison of Studies 1, 2, and 3. To investigate whether the magnitude of categorical bias differed depending on the nature of the test phase, center displacement scores from the present study were compared with scores from the previous studies. In particular, center displacement scores from 7- and 9-year-olds in the completely contiguous condition were entered into an Age (7 years vs 9 years) × Boundary Condition (lines vs walls) × Study (1 vs 2 vs 3) ANOVA to compare the magnitude of center displacement across ages, boundary conditions, and studies. There were no significant effects, indicating that for participants who experienced the objects group by group during learning, the magnitude of categorical bias was similar regardless of the nature of the test phase.

Discussion

The goal of the present study was to investigate whether experiencing nearby locations together in time during learning alone led to categorical bias in estimates of location. The results revealed that 9-year-olds in both boundary conditions and 7-year-olds in the walls condition significantly underestimated distances between locations in the same spatial group. These results clearly demonstrate that experiencing nearby locations together in time *during learning* increases the weight given to categorical information regardless of spatiotemporal experience with locations during test.

One question these findings raise involves the unexpected performance of the 7-year-olds in the walls condition. Unlike the 7-year-olds in the previous studies, 7-year-olds in the walls condition in the present study underestimated the distances between locations in the same group, suggesting that they assigned a relatively high weight to the categorical information. Although it is not clear why we obtained this difference, it is possible that 7-year-olds are transitional with respect to their sensitivity to spatiotemporal cues. It is interesting to note that the difference across studies was most pronounced in the walls condition, suggesting that 7-year-olds are sometimes sensitive to the combination of spatiotemporal cues and *highly salient* visible boundaries. As noted previously, future work is needed to clarify how children and adults use boundaries of varying salience to organize locations into groups.

General discussion

The goal of the present investigation was to determine whether experiencing locations from the same region together in time increases the weight children and adults give to categorical information in their estimates of location. In Study 1, participants experienced the locations either in random orders or region by region during the learning phase. During test, they placed the objects in any order they chose. In the contiguous learning condition, 9-year-olds in the lines condition and 11-year-olds and adults in both boundary conditions thought that locations belonging to the same group were closer together than they really were, suggesting that they weighted categorical information relatively heavily in their estimates of location. In contrast, only the adults in the random learning condition (in both boundary conditions) placed the objects belonging to the same region closer together than they really were. These findings indicate that experiencing nearby locations together in time increases the weight given to categorical information during location estimation for 9- and 11-year-old children. In Study 2, participants experienced the locations region by region during learning. In addition, they replaced all the objects belonging to one region before those belonging to another region during test. Nine- and 11-year-olds and adults in both boundary conditions significantly underestimated distances between locations in the same group. Finally, in Study 3, 7- and 9-year-old children experienced the locations region by region during learning. This time, they replaced the objects in a random order during the test phase. Nine-year-olds in both boundary conditions and 7-year-olds in the walls condition significantly underestimated distances between locations in the same spatial group. Together, these results clearly demonstrate that experiencing nearby locations together in time during learning exerts an important influence on the weighting of categorical information in estimates of location for children and adults.

Why might experiencing locations from the same region close together in time increase the weight given to categorical information? As noted above, spatial and temporal contiguity typically are correlated in our everyday experience with locations. Locations that are near each other are much more likely to be experienced close together in time than are locations that are distant from each other. For example, children are much more likely to consecutively visit locations in the same room than they are to consecutively visit locations in two adjacent rooms. Through these everyday experiences with locations, children may form expectations about relations between spatial and temporal contiguity. Thus, spatiotemporally organized experience may increase the weighting of categorical information because this organization is consistent with their everyday experiences with locations.

Another reason why children may have relied on categorical information in the present investigation is that multiple cues were available to highlight the groups of locations. That is, in the contiguous learning condition, spatial groups were defined by both visible boundaries and spatiotemporal experience. In contrast, in the random learning condition in Study 1, only visible boundaries divided the locations into groupings. Unlike results from the random learning condition in which only adults underestimated distances between locations in the same group, results from the contiguous learning condition demonstrate that the presence of visible boundaries and spatiotemporal experience highlighted the groups of locations for 9- and 11-year-old children, leading them to underestimate distances between nearby locations. One key question that remains unanswered is whether the combination of cues or the nature of the cues themselves influences the weighting of categorical information. In other words, do people rely on categorical information because multiple cues are available regardless of what those cues are, or do some cues highlight categorical information more than others? Further research separating the effects of visible boundaries and spatiotemporal experience may provide additional information about how these cues influence the weighting of categorical information during location estimation.

The results of the present investigation and others like it support the proposal that both fine-grained metric and coarse-grained categorical information influence people's estimates of location (e.g., Hund & Plumert, in press; Huttenlocher et al., 1991, 1994; Plumert & Hund, 2001; Sandberg et al., 1996). For example, previous findings suggest that degrading fine-grained information through a delay between learning and reproducing locations or through the addition of an interference task leads to a significant increase in bias toward category centers (e.g., Engebretson & Huttenlocher, 1996; Huttenlocher et al., 1991; Spencer & Hund, 2002). However, the present results also have important implications for the category adjustment model. According to this model, the amount of categorical bias depends on the certainty of the fine-grained metric information. When metric certainty is high, categorical information receives a low weighting, and biases are minimal. As metric certainty decreases, the weighting of categorical information increases, and biases toward category centers also increase. Based on this model, experiencing nearby locations together in time influences location estimation by decreasing the precision of metric information, thereby increasing the weighting of categorical information. However, it is not clear why experiencing nearby locations together in time during learning would decrease the certainty of metric information. In fact, one might expect that a spatiotemporally organized experience during learning would increase the precision of metric information, resulting in less, not more, categorical bias.

Rather, 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. How might this proposal apply to the results of the present investigation? We propose that experiencing locations region by region during the learning phase leads people to assign higher weights to categorical information than does experiencing the locations in a random order during learning. As mentioned above, we have little reason to believe that experiencing the locations region by region influenced the weight assigned to metric information. Thus, it appears that differences in the initial weighting of categorical information resulted in greater categorical bias in the contiguous learning condition than in the random learning condition. Furthermore, comparisons across studies revealed that the magnitude of categorical bias for participants in the contiguous condition did not differ significantly depending on the nature of the test phase. This finding provides further support for the notion that people assigned a relatively high weight to categorical information at learning. In addition, it suggests that the weighting of categorical information does not decay very dramatically, regardless of the amount of contextual support for category assignment during the test phase. These findings are consistent with our previous results suggesting that categorical information decays relatively slowly (Hund & Plumert, in press).

Clearly, the present findings highlight the importance of spatiotemporal cues for location memory. Children and adults use their experience with nearby locations to remember the locations. As such, our findings are similar to the results from numerous studies from the cognitive psychology literature showing that adults use spatiotemporal cues to organize their memory for locations (e.g., Clayton & Habibi, 1991; Curiel & Radvansky, 1998; McNamara et al., 1992; Sherman & Lim, 1991). More generally, the present findings suggest that spatiotemporal cues provide a useful means of organizing information to be remembered. This is consistent with other findings from the event memory literature suggesting that children use information about when and where routine events occur to rapidly learn about events. For example, Fivush (1984) found that after only 2 days of school, kindergartners exhibited scriptlike knowledge of school-day occurrences. Their school-day scripts were organized temporally and spatially. Thus, they tended to recall activities in the correct temporal order: arrival, playtime, snack, meeting, lunch, gym class, and so on. Moreover, they tended to discriminate events based on changes in locations. For example, the most common events mentioned (e.g., "coming in" and "playtime") were marked by clear spatial transitions (e.g., from the hallway to the classroom and from one area of the classroom to another area). Thus, even young children use spatiotemporal information to organize information in memory (for related ideas, see Schank & Abelson, 1977), suggesting that spatiotemporal cues play an important role in the development of memory skills.

In conclusion, the results of this investigation underscore the importance of experience in the acquisition of spatial knowledge. Clearly, experiencing nearby locations together in time during learning affects the weighting of categorical information during location estimation for children and adults. Thus, the present results provide an important step toward understanding the processes by which children and adults use categorical information to facilitate memory for location.

References

Bauer, P. J., & Mandler, J. M. (1989). Taxonomies and triads: conceptual organization in one- to two-year-olds. *Cognitive Psychology, 21*, 156–184.

Clayton, K., & Habibi, A. (1991). Contribution of temporal contiguity to the spatial priming effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*, 263–271.

Cohen, R., Baldwin, L. M., & Sherman, R. C. (1978). Cognitive maps of a naturalistic setting. *Child Development, 49*, 1216–1218.

Cole, M., Frankel, F., & Sharp, D. (1971). Development of free recall learning in children. *Developmental Psychology, 4*, 109–123.

Curiel, J. M., & Radvansky, G. A. (1998). Mental organization of maps. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*, 202–214.

Engebretson, P. H., & Huttenlocher, J. (1996). Bias in spatial location due to categorization: comment on Tversky and Schiano. *Journal of Experimental Psychology: General, 125*, 96–108.

Fivush, R. (1984). Learning about school: the development of kindergartners' school scripts. *Child Development, 55*, 1697–1709.

Frankel, M. T., & Rollins, H. A., Jr. (1985). Associative and categorical hypotheses of organization in the free recall of adults and children. *Journal of Experimental Child Psychology, 40*, 304–318.

Gelman, R., & Markman, E. M. (1987). Young children's inductions from natural kinds: the role of categories and appearances. *Child Development, 58*, 1532–1541.

Hund, A. M., & Plumert, J. M. (in press). Delay-induced bias in children's memory for location. *Child Development*.

Huttenlocher, J., Hedges, L. V., & Duncan, S. (1991). Categories and particulars: prototype effects in estimating spatial location. *Psychological Review, 98*, 352–376.

Huttenlocher, J., Newcombe, N., & Sandberg, E. H. (1994). The coding of spatial location in young children. *Cognitive Psychology, 27*, 115–147.

Kosslyn, S. M., Pick, H. L., & Fariello, G. R. (1974). Cognitive maps in children and men. *Child Development, 45*, 707–716.

Laeng, B., Peters, M., & McCabe, B. (1998). Memory for locations within regions: spatial biases and visual hemifield differences. *Memory & Cognition, 26*, 97–107.

Lange, G. (1973). The development of conceptual and rote recall skills among school age children. *Journal of Experimental Child Psychology, 15*, 394–406.

Mandler, J. M., & McDonough, L. (1993). Concept formation in infancy. *Cognitive Development, 8*, 291–318.

McNamara, T. P. (1986). Mental representation of spatial relations. *Cognitive Psychology, 18*, 87–121.

McNamara, T. P., Altarriba, J., Bendele, M., Johnson, S. C., & Clayton, K. N. (1989). Constraints on priming in spatial memory: naturally learned versus experimentally learned environments. *Memory & Cognition, 17*, 444–453.

McNamara, T. P., Halpin, J. A., & Hardy, J. K. (1992). Spatial and temporal contributions to the structure of spatial memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*, 555–564.

Mervis, C. B. (1985). On the existence of prelinguistic categories: a case study. *Infant Behavior and Development, 8*, 293–300.

Moely, B. E., Olson, F. A., Halwes, T. G., & Flavell, J. H. (1969). Production deficiency in young children's clustered recall. *Developmental Psychology, 1*, 26–34.

Newcombe, N., Huttenlocher, J., Sandberg, E. H., Lie, E., & Johnson, S. (1999). What do misestimations and asymmetries in spatial judgment indicate about spatial representation? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*, 986–996.

Newcombe, N., & Liben, L. S. (1982). Barrier effects in the cognitive maps of children and adults. *Journal of Experimental Child Psychology, 34*, 46–58.

Oakes, L. M., Madole, K. L., & Cohen, L. B. (1991). Infants' object examining: habituation and categorization. *Cognitive Development, 6*, 377–392.

Ornstein, P. A., Naus, M. J., & Liberty, C. (1975). Rehearsal and organizational processes in children's memory. *Child Development, 46*, 818–830.

Plumert, J. M., & Hund, A. M. (2001). The development of memory for location: what role do spatial prototypes play? *Child Development, 72*, 370–384.

Quinn, P. C. (1994). The categorization of above and below spatial relations by young infants. *Child Development, 65*, 58–69.

Quinn, P. C., Cummins, M., Kase, J., Martin, E., & Weissman, S. (1996). Development of categorical representations for above and below spatial relations in 3- to 7-month-old infants. *Developmental Psychology, 32*, 942–950.

Quinn, P. C., Eimas, P. D., & Rosenkrantz, S. L. (1993). Evidence for representations of perceptually similar natural categories by 3-month-old and 4-month-old infants. *Perception, 22*, 463–475.

Roenker, D. L., Thompson, C. P., & Brown, S. C. (1971). Comparison of measures for the estimation of clustering in free recall. *Psychological Bulletin, 76*, 45–48.

Sandberg, E. H. (1999). Cognitive constraints on the development of hierarchical spatial organization skills. *Cognitive Development, 14*, 597–619.

Sandberg, E. H., Huttenlocher, J., & Newcombe, N. (1996). The development of hierarchical representation of two-dimensional space. *Child Development, 67*, 721–739.

Schank, R., & Abelson, R. (1977). *Scripts, plans, goals and understanding*. Hillsdale, NJ: Erlbaum.

Schneider, W. (1986). The role of conceptual knowledge and metamemory in the development of organizational processes in memory. *Journal of Experimental Child Psychology, 42*, 218–236.

Sherman, R. C., & Lim, K. M. (1991). Determinants of spatial priming in environmental memory. *Memory & Cognition, 19*, 283–292.

Spencer, J. P., & Hund, A. M. (2002). Prototypes and particulars: Geometric and experience-dependent spatial categories. *Journal of Experimental Psychology*: *General, 131*, 16–37.