How Do Opportunities to View Objects Together in Time Influence Children’s Memory for Location?

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We conducted three experiments to investigate how opportunities to view objects together in time influence memory for location. Children and adults learned the locations of 20 objects marked by dots on the floor of an open, square box. During learning, participants viewed the objects either simultaneously or in isolation. At test, participants replaced the objects without the aid of the dots. Experiment 1 showed that when the box was divided into quadrants and the objects in each quadrant were categorically related, 7-, 9-, and 11-year-olds and adults in the simultaneous viewing condition exhibited categorical bias, but only 11-year-olds and adults in the isolated viewing condition exhibited categorical bias. Experiment 2 showed that when the objects were categorically related but no boundaries were present, 11-year-olds and adults in the simultaneous viewing condition exhibited categorical bias, but only adults showed bias in the isolated viewing condition. Experiment 3 revealed that adults exhibited bias in both simultaneous and isolated viewing conditions when boundaries were present but the objects were not related. These findings suggest that opportunities to see objects together in time interact with cues available for grouping objects to help children form spatial groups.

The ability to form spatial groups is an important aspect of everyday life for children and adults alike. Specifically, remembering the group to which a location belongs is useful for reducing the demands of keeping track of a large number of locations. One apparent cost of forming spatial groups is
that people tend to think that objects belonging to the same spatial group are closer together than they really are. Plumert and her colleagues, for example, have repeatedly shown that both children and adults exhibit systematic bias toward the centers of spatial groups (Hund & Plumert, 2002, 2003; Hund, Plumert, & Benney, 2002; Plumert & Hund, 2001). In these studies, children and adults place objects belonging to the same spatial group closer together than they really are, particularly when multiple cues are available for organizing the locations into spatial groups during learning. In the present study, we examined developmental changes in children’s ability to form and use spatial groups when opportunities to view objects together in time varied during learning.

THEORETICAL BACKGROUND

Systematic bias in memory for location is seen as an important signature of the underlying processes involved in reproducing previously seen locations (Huttenlocher, Hedges, & Duncan, 1991; Huttenlocher, Newcombe, & Sandberg, 1994; Plumert, Hund, & Recker, 2007; Sandberg, Huttenlocher, & Newcombe, 1996; Spencer, Simmering, Schutte, & Schöner, 2007). A key question is where does this bias come from? According to the Category-Adjustment (CA) model originally proposed by Huttenlocher et al. (1991), retrieval of locations from memory involves the use of both fine-grained and categorical information. When trying to remember a previously learned location, children and adults make estimates based on their memory of fine-grained, metric information, such as distance and direction from an edge. However, because memory for fine-grained information is inexact, children and adults adjust these estimates based on categorical information about the location represented by a prototype located at the center of the spatial region or group. Hence, adjustments based on categorical information lead to systematic bias toward the centers of spatial categories. The end result of such systematic bias is that responses are less variable, leading to greater overall accuracy in estimates of location.

Recent empirical tests of the CA model support the notion that children and adults combine memory for fine-grained and categorical information to estimate location (Engebretson & Huttenlocher, 1996; Hund & Plumert, 2002, 2005; Huttenlocher et al., 1991; Laeng, Peters, & McCabe, 1998; Sandberg et al., 1996). However, these studies also suggest that fine-grained and categorical information represent independent inputs that can vary in strength. From this view, categorical bias reflects the “push” and “pull” of memory for fine-grained detail about individual locations and memory for the group to which a location belongs (Hund & Plumert, 2002, 2005;
Plumert et al., 2007). When memory for the spatial groups (i.e., associations among locations in the spatial groups) is strong relative to memory for the individual locations, spatial groups exert “pull” on estimates of locations, and people place objects closer together than they really are. Conversely, when memory for the individual locations is strong relative to memory for the spatial groups, people exhibit little or no categorical bias in their placements.

A key question is: how do we account for developmental differences in categorical bias? From a traditional perspective on development, age differences in patterns of bias depend solely on age-related changes in how the cognitive system codes, maintains, and retrieves fine-grained and categorical information. From an interactionist perspective, however, patterns of bias emerge in the moment out of the interaction of structure available in the task and the characteristics of the cognitive system (Plumert, 2008; Plumert et al., 2007). Hence, both differences in the cognitive system and differences in the available task structure can alter the interaction, leading to changes in the pattern of categorical bias. This means that patterns of categorical bias cannot be explained by referring only to task structure (e.g., presence or absence of boundaries) or by referring only to developmental differences in the cognitive system (e.g., strategic encoding of spatial groups). Below, we elaborate on these ideas to motivate specific predictions about how developmental differences in categorical bias emerge out of interactions between the cognitive system and the task structure.

FORMING SPATIAL GROUPS

The ability to organize locations within some kind of spatial structure is fundamental to the process of learning and remembering locations. One way to organize space is by grouping objects or locations on the basis of common membership within a spatial region. Typically, spatial regions are defined by physical or perceptual boundaries or by proximity to salient landmarks (McNamara, 1986; Huttenlocher & Lourenco, 2007). For example, one might think of a table, stool, and refrigerator as belonging together because they are all located in the kitchen, or one might think of a couch, rug, and rocking chair as belonging together because they are all located near the fireplace. We might also think of a region as a cluster of nearby objects or places such as pieces of play equipment on a schoolyard or a group of university buildings on campus. In the real world, cues for forming spatial groups typically overlap. For example, a spatial group might be defined by perceptual boundaries, salient landmarks, and close proximity of objects.
To form and use spatial groups, children must focus on the spatial relations among the locations. The ease with which children represent and access spatial relational information and the extent to which tasks cue spatial relations among locations impact the likelihood that children will form and use connections among locations based on common membership in a spatial group. We hypothesize that two complementary processes are at work in forming spatial groups: differentiation of the stimulus array into distinct sets of locations and association of individual locations within sets of locations. We view these as complementary processes, because drawing distinctions between sets of locations makes it easier to form associations among locations within a set and forming associations among locations makes it easier to draw distinctions between sets of locations. Engaging these cognitive processes depends on structure available in the physical or task environment, however. When no obvious physical or task structure is available for forming spatial groups, even adults should have great difficulty differentiating sets of locations or forming associations among locations. Conversely, when multiple cues are available for forming spatial groups, both children and adults should find it easier to form strong spatial groups. Developmentally, we would also expect that younger children would require more converging cues to form strong spatial groups than would older children or adults.

Perhaps the most obvious cue for forming spatial groups is visible boundaries (Acredolo & Boulter, 1984; Huttenlocher et al., 1991; Kosslyn, Pick, & Fariello, 1974; McNamara, 1986; Newcombe & Liben, 1982; Plumert & Hund, 2001; Rossano & Hodgson, 1994; Stevens & Coupe, 1978). Plumert and Hund (2001), for example, showed that having boundaries present during learning influenced categorical bias at test. Seven-, 9-, 11-year-old children and adults learned the locations of 20 objects marked by dots on the floor of a box. The box was divided into quadrants by either walls or lines, with five objects in each quadrant. There was also a control condition in which no boundaries were present. After participants learned the locations of all 20 objects, they attempted to replace the objects in their correct locations without the aid of the dots or the boundaries subdividing the space. When no boundaries were present during learning, neither children nor adults exhibited significant categorical bias. In contrast, 11-year-olds and adults showed significant categorical bias when walls subdivided the space during learning. Adults also exhibited significant categorical bias when lines subdivided the space during learning. These findings suggest that salient boundaries help older children and adults form strong connections among groups of objects during learning, leading to categorical bias at test. In contrast, when only a single cue (boundaries) was available for coding spatial groups during learning,
younger children had great difficulty differentiating sets of locations or forming connections among locations.

Another cue that influences people's ability to form spatial groups is object relatedness. In everyday experience, related objects often occupy nearby locations. For example, similar items are usually located together in one's kitchen (e.g., canned goods, silverware, dishes, pots and pans, etc.). These kinds of categorical or thematic links among objects may make it easier for people to remember which locations go together. A study by Hund and Plumert (2003) addressed the question of whether children and adults exhibit more categorical bias when the objects within a spatial group (i.e., a set of nearby locations) were related than were unrelated. Seven-, 9-, 11-year-old children and adults learned the locations of 20 objects marked by dots on the floor of a box. These objects belonged to four object categories (i.e., vehicles, clothing, food, and animals). In the related condition, the objects in each quadrant were categorically related (e.g., all the animals were located in one quadrant). In the unrelated condition, the same objects were used but the object-location pairings were completely randomized. After participants learned the locations of all 20 objects, they attempted to replace the objects in their correct locations without the aid of the dots. Both children and adults showed significantly more categorical bias when the objects belonging to each group were related, rather than unrelated. A follow-up experiment in which two coincident cues (i.e., visible boundaries and object relatedness) defined the spatial groups during learning led to even stronger categorical bias at test, particularly for children.

One important factor that may interact with the availability of cues for forming spatial groups is the opportunity to view groups of objects simultaneously. For example, it may be much easier to notice that objects in a group are categorically related (e.g., animals or vehicles) when they can be seen together, rather than when they are seen in isolation. Previous research by Plumert and Hund has consistently provided children and adults with many opportunities to simultaneously view the objects during learning. That is, participants cumulatively place the 20 objects on the floor of the box until they are all fully visible. Therefore, it is not known to what extent participants (especially children) use information gained from viewing groups of objects together in time to form spatial categories. In particular, can children use cues such as visible boundaries and object relatedness to form spatial groups if they never see the objects together in time?

Previous research clearly shows that adults can integrate isolated information to form coherent spatial representations (Allen, 1988; Allen, Siegel, & Rosinski, 1978; Fields & Shelton, 2006; Hanley & Levine, 1983; Moar & Carleton, 1982; Montello & Pick, 1993; Shelton & McNamara, 2004; Yamamoto & Shelton, in press; Zimmer, 2004). For example, Zimmer
(2004) found that adults were able to integrate spatial information to form an accurate representation of an island when shown a fragmented map depicting the space that was as accurate as viewing a complete map. Likewise, Allen (1988) found that adults were able to integrate isolated scenes from a route to form a coherent representation of the entire route. Together, these findings illustrate that adults are able to integrate spatial information presented over time to form accurate spatial relations. This ability to represent and access spatial relational information over time becomes especially important in tasks that require learning large-scale spatial layouts. For example, when groups of locations cannot be viewed from a single vantage point, integrating spatial information over time is necessary in forming accurate spatial representations.

The results of studies examining whether or not children can integrate isolated spatial information to form a coherent representation are mixed. On the one hand, Schumann-Hengsteler and her colleagues found that 6-, 8-, and 10-year-old children are able to integrate spatial information over time (Schumann-Hengsteler, Strobl, & Zoelch, 2004). Other research, however, has shown that children have difficulty integrating isolated pieces of spatial information (Ondracek & Allen, 2000; Taylor & Tversky, 1992; Uttal, Fisher, & Taylor, 2006). Uttal et al. (2006), for example, found that children’s memory for spatial relations was more accurate when they learned a layout of objects simultaneously (i.e., by viewing a map) than when they learned the layout sequentially (i.e., by listening to verbal descriptions).

THE PRESENT INVESTIGATION

Taken together, the studies reviewed above suggest that children have more difficulty than adults with integrating spatial information presented in isolation to form coherent spatial representations. However, virtually nothing is known about how opportunities to view objects together in time affect children’s ability to form spatial groups. More generally, very little is known about the development of the ability to integrate spatial information over time. To examine these issues, the present investigation manipulated both opportunities to view groups of objects together in time during learning and the availability of cues for forming spatial groups (i.e., visible boundaries and object relatedness).

We have chosen to study 7-, 9-, 11-year-old children and adults in the present investigation because we hypothesize that important developmental changes are occurring in the cognitive system during late childhood and early adulthood. Specifically, we hypothesize that the precision of fine-grained, metric coding is improving between the ages of 7 and 11 years.
(and possibly between 11 years and adulthood). Recent work has consistently shown that younger children exhibit greater mean and variable error than do older children and adults (Hund & Plumert, 2003, 2005; Hund et al., 2002; Recker, Plumert, Hund, & Reimer, 2007; Schutte & Spencer, 2002; Schutte, Spencer, & Schöner, 2003; Spencer & Hund, 2002, 2003). In addition, the use of spatial clustering strategies is also increasing across this age range. Adults readily use spatial clustering strategies to help them recall both objects and locations (Plumert, 1994). Children’s use of spatial clustering undergoes significant change across childhood, not reaching adult performance until early to mid adolescence. As a result, adults may form much stronger associations among the locations within a spatial group than do children. These stronger associations increase the “pull” from the spatial groups, thereby increasing the likelihood of systematic bias in placements. An important question that remains is how cues for organizing locations into groups (i.e., visible boundaries and object relatedness) and opportunities to view objects together in time interact with these changes in the cognitive system, leading to differences in how children and adults form spatial groups.

In Experiment 1, we provided 7-, 9-, 11-year-old children and adults with two coincident cues for forming spatial groups (i.e., visible boundaries and object relatedness). Participants learned the locations of 20 miniature objects marked by dots on the floor of a box. Half of the participants viewed the objects in the box simultaneously, whereas the other half viewed the objects in isolation. For both conditions, the dots marking the locations remained visible at all times during learning. Thus, opportunities to view locations together in time remained constant across conditions, but opportunities to view objects together in time varied across conditions. At test, participants were asked to replace the objects without the aid of the dots marking the locations. Of particular interest was the degree to which children and adults placed the objects belonging to the same group closer together than they really were (i.e., exhibited categorical bias). As in Hund and Plumert (2003), we expected that 7-, 9-, 11-year-olds and adults would exhibit significant categorical bias when they viewed the objects simultaneously. In contrast, we expected that only adults and older children would show significant categorical bias when they viewed the objects in isolation. In other words, we expected that younger children’s ability to form spatial groups would be disrupted when they only saw one object at a time, even though multiple cues highlighted the spatial groups. Experiments 2 and 3 were designed to further explore how the salience of cues for organizing locations into groups and opportunities to view objects together in time interact to produce age differences in categorical bias.
EXPERIMENT 1

Method

Participants

Ninety-six 7-, 9-, and 11-year-old children and adults participated in this study (mean ages = 7 years 7 months, 9 years 2 months, 11 years 3 months, and 19 years 6 months, respectively). There were 24 participants in each age group, with approximately equal numbers of males and females in each group. Three additional 7-year-olds and one additional 11-year-old were excluded because they did not complete the task. Children were recruited from a child research participant database. Eighty-five percent of children were European American, 6% were Asian American, 4.5% were Hispanic/Latino, 3% were African American, and 1.5% were Moroccan. Seven percent of the mothers had completed their high school education or less, 26% had completed some college education, and 67% had a 4-year-college education or beyond. Adults participated to fulfill research credit for an introductory psychology course. Ninety-two percent of the adult participants were European American, 4% were Native American, and 4% were Asian American.

Apparatus and Materials

A 36-inch long x 36-inch wide x 12-inch high open, square box with black exterior walls and a black tinted plexiglas floor was used as the experimental space. Twenty 3/4-inch, light-emitting diodes (LEDs) beneath the plexiglas were used to mark the locations of the objects. When the LEDs were on, participants saw the 20 locations on the floor of the box. When the LEDs were off, participants saw a homogeneous, black floor.

Two 5/16-inch wide x 5/16-inch high strips of gray wood placed at right angles to each other were used to divide the floor of the box into four identical regions (18 in. x 18 in.). There were five locations in each quadrant of the box (see Figure 1). Twenty miniature objects (approximately .96 in. long x .61 in. wide) were used to help participants learn the locations: a car, dump truck, plane, van, cement mixer, shirt, shoe, hat, skirt, pair of gloves, apple, bag of candy, pie, can of soup, box of popcorn, horse, dog, pig, cow, and a cat. These objects were grouped into four object categories (i.e., vehicles, clothing, food, and animals).

An Olympus C-3040 Zoom Digital Camera was mounted on the ceiling above the box to record participants' placements of the objects. These digital images were fed into a computer and displayed on a 20-inch computer monitor that was covered with a transparent grid of x- and y-coordinates used for later coding.
Design and Procedure

Participants were tested individually in the laboratory. At the beginning of the experiment, the experimenter stood facing one side of the box, and participants were seated to the right of the experimenter facing an adjacent side of the box. The experimental session consisted of a learning phase followed by a test phase. During the learning phase, participants learned the locations of 20 objects in the box. At the beginning of the session, the experimenter told participants that 20 objects would be placed one at a time in the box and that they should try to remember the locations of the objects because they would be asked to replace them later. The object locations corresponded to the 20 LEDs on the floor of the box (see Figure 1). Participants first watched as the experimenter named the objects and placed them in the box one at a time in a random order. Participants were randomly assigned to one of two experimental conditions: simultaneous viewing or isolated viewing. In the simultaneous viewing condition, the objects were cumulatively placed on the floor of the box until all 20 objects were in their correct locations. Thus, after all objects had been placed, participants were able to simultaneously view the objects on the floor of the box. In the isolated viewing condition, participants were shown
only one object in its correct location at a time. An object was placed in its location for approximately five seconds and was then removed by the experimenter. Thus, the objects were never seen together in time. The overall amount of viewing time for each learning trial was similar in both the simultaneous and isolated viewing conditions. The LEDs marking the locations of the objects and the boundaries dividing the floor of the box were visible throughout all learning trials for both conditions. The only difference between the two conditions was how participants viewed the objects during learning. The pairings of the locations and objects were randomized for each participant, but these pairings were constrained such that objects belonging to the same category were located in the same quadrant of the box. The pairings of object categories and spatial quadrants were also randomized for each participant.

The first learning trial began after the experimenter had placed all 20 objects. Participants in the simultaneous viewing condition were asked to close their eyes while the experimenter removed the objects from the box, and participants in the isolated viewing condition were notified that all 20 objects had been placed. Then, the experimenter gave the objects to the participants one at a time in a random order and asked them to place them in the correct locations. Participants were allowed to move around the outside of the box to place the objects. The experimenter immediately corrected any placement errors. In the simultaneous viewing condition, the objects remained on the dots until the participant had placed all 20 objects. In the isolated viewing condition, the experimenter removed each object from the box before giving the next object to the participant. Participants continued with the learning trials until they correctly replaced all 20 objects in a single trial. The mean number of trials to criterion for the 7-, 9-, 11-year-old children and adults were 2.96 (SD = 1.20), 3.67 (SD = 1.83), 2.54 (SD = 1.22), and 1.67 (SD = .92), respectively. Not surprisingly, the mean number of learning trials differed significantly across condition, F(1,88) = 12.55, p < .001. Participants required significantly fewer learning trials to reach criterion in the simultaneous viewing condition (M = 2.27, SD = 1.09) than in the isolated viewing condition (M = 3.15, SD = 1.73), indicating that participants required more experience to learn the location of each object when the objects were presented in isolation.

The test phase began immediately following the learning phase. The experimenter removed the objects and boundaries from the box and turned off the LEDs marking the locations. Participants then attempted to replace the objects in the correct locations in any order they chose. After participants replaced the objects, the experimenter took a digital photograph of the box for later coding and thanked them for participating.
Coding

We coded the x- and y-coordinates for each object to the nearest 1/2-in. We then coded which object corresponded to each actual location. Participants sometimes preserved the overall configuration of the locations in a quadrant, but paired some objects and locations incorrectly (e.g., they placed the apple where the pie should have gone and vice-versa). As in previous work (e.g., Hund & Plumert, 2002, 2003, 2005; Hund et al., 2002; Plumert and Hund, 2001; Recker et al., 2007), we used the x- and y-coordinates for these substituted locations in all analyses regardless of whether the correct objects were placed in the locations. We substituted 3.13% of the locations for the 7-year-olds (15 out of 480), .63% for 9-year-olds (3 out of 480), .42% for 11-year-olds (2 out of 480), and 1.46% for adults (7 out of 480). Participants also sometimes omitted an object from a configuration or placed an object in a totally wrong location in a configuration (e.g., in the center of the configuration, outside of the configuration). The locations corresponding to these objects were omitted from all analyses. We omitted .63% of the locations for the 7-year-olds (3 out of 480), .83% for 9-year-olds (4 out of 480), 0% for 11-year-olds (0 out of 480), and .21% for adults (1 out of 480).

Intercoder reliability estimates of object placements were calculated for 16 randomly selected participants (two in each age group and condition). Coders agreed 100% of the time on which object was placed in each of the 320 locations. For both the x- and y-coordinates, the correlation between coders was r = 1.0, with a mean difference between coders of 0 inches.

Measures

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

We also calculated a variable error score for each participant, reflecting variability in the degree to which they placed objects near the actual locations. This score was calculated by first determining the distance between each remembered location and actual location. We then calculated the standard deviation of these distances for all locations to obtain a single variable error score, reflecting the precision of memory for fine-grained information.
Center displacement score. Participants received a center displacement score reflecting the degree to which they systematically placed objects belonging to the same spatial group (i.e., in each quadrant) closer together than they actually were (i.e., exhibited categorical bias). 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, the center displacement score reflected the degree to which participants displaced locations towards the center of spatial groups, after removing effects due to translation of groups.

Results
Mean and Variable Error

How accurately did children and adults in the two conditions place the objects relative to their true locations? Preliminary analyses revealed no significant effects of gender, so the data were collapsed across this factor in the analyses reported below. To test for differences in overall error among the age groups and across conditions, mean error scores were entered into an age (7 years, 9 years, 11 years, adult) × condition (simultaneous viewing, isolated viewing) Analysis of Variance (ANOVA), with two between-subjects factors. There was a significant main effect of age, $F(3, 88) = 11.74, p < .0001$. Fisher’s PLSD follow-up tests indicated that 7- and 9-year-olds exhibited significantly greater error than did 11-year-olds and adults. In addition, 11-year-olds exhibited significantly greater error than adults. The mean distance from correct locations was 2.16 in. (SD = .33) for 7-year-olds, 2.16 in. (SD = .50) for 9-year-olds, 1.85 in. (SD = .22) for 11-year-olds, and 1.63 in. (SD = .35) for adults. There was no significant effect of condition, $F(1, 88) = .01, ns$. The mean error scores were 1.95 in. (SD = .45) for the simultaneous viewing condition and 1.95 in. (SD = .40) for the isolated viewing condition.

An age (4) × condition (2) ANOVA on variable error scores also yielded a significant main effect of age, $F(3, 88) = 8.89, p < .0001$. Fisher’s PLSD follow-up tests indicated that 7- and 9-year-olds exhibited significantly greater variability than did 11-year-olds and adults. Mean variable error scores were 1.14 in. (SD = .27) for 7-year-olds, 1.18 in. (SD = .30) for 9-year-olds, .96 in. (SD = .20) for 11-year-olds, and .86 in. (SD = .17) for adults. Variable error scores did not differ significantly across the two conditions.
conditions, $F(1, 88) = .06$, ns. Mean variable error scores were 1.03 in. ($SD = .29$) for the simultaneous viewing condition and 1.04 in. ($SD = .25$) for the isolated viewing condition.

**Center Displacement**

Did children and adults in the two conditions place the objects belonging to each group closer together than they actually were? We used two sets of analyses to address this question. One set examined the differences in magnitude of center displacement across age groups and conditions. The second set examined whether the magnitude of center displacement was significantly greater than 0 for each age group and condition. Preliminary analyses revealed no significant effects of gender, so the data again were collapsed across this factor. In the first analysis, we entered center displacement scores into an age ($4$) × condition ($2$) ANOVA. This analysis yielded a significant main effect of condition, $F(1, 88) = 6.90, p < .05$, indicating that participants in the simultaneous viewing condition placed objects significantly closer to the centers of the spatial groups ($M = .60$ in.; $SD = .57$) than did participants in the isolated viewing condition ($M = .32$ in.; $SD = .48$). There was also a significant age × condition interaction, $F(3, 88) = 3.57, p < .05$ (see Figure 2). Simple effects tests indicated that center displacement scores were significantly greater in the simultaneous viewing condition than in the isolated viewing condition for the 7-year-olds, $F(1, 22) = 9.48, p < .01$ and 9-year-olds, $F(1, 22) = 4.95, p < .05$, but not for the 11-year-olds and adults, all $Fs(1, 22) < .90$, ns.

In the second analysis, we conducted separate one-sample t-tests for each age group and condition to compare center displacement scores to an expected value of 0. No difference in distance would be expected if participants neither compressed nor expanded the distances between locations belonging to each spatial group. However, positive displacement scores would be expected if participants displaced objects toward the centers of the spatial groups. As shown in Figure 2, all age groups in the simultaneous viewing condition and 11-year-olds and adults in the isolated viewing condition placed the objects significantly closer to the category centers than they actually were, all $ts(11) > 2.35, p < .05$. Displacement scores for the 7- and 9-year-olds in the isolated viewing condition did not reach significance, all $ts(11) < 1.34$, ns.

**Discussion**

The results of this study clearly demonstrate that opportunities to view objects together in time affected young children’s ability to form
associations among groups of objects. Specifically, all age groups exhibited significant categorical bias when they viewed the objects simultaneously during learning. In contrast, only the 11-year-olds and adults exhibited significant categorical bias when they viewed the objects one at a time during learning. Importantly, mean and variable error did not differ significantly depending on the viewing condition. The fact that mean and variable error were similar across viewing conditions suggests that children and adults coded fine-grained information about location similarly, regardless of whether or not they could simultaneously view the objects. The difference in center displacement scores across viewing conditions for the two younger age groups illustrates the importance of seeing groups of objects together in time for coding categorical information in this task.

What accounts for this pattern of results? The 20 dots marking the locations of the objects were present for all participants on all learning trials. That is, the fine-grained, metric information was available to all

FIGURE 2 Mean center displacement for each age group and viewing condition.
participants throughout the learning phase of the experiment. On the other hand, the categorical information experienced by the participants differed depending on the viewing condition. When objects were simultaneously present on the marked locations, the spatial groups were easily visible to participants. In particular, it was easy to see that the objects in each quadrant were organized by category (i.e., vehicles, food, clothing, and animals). Consequently, children and adults formed strong connections among the objects in the spatial groups, leading to a strong "pull" from the spatial groups at test. On the other hand, when objects were viewed in isolation, younger children found it more difficult to form strong connections among the objects in the spatial groups, particularly given the fact that the objects were always placed in a random order (i.e., not quadrant by quadrant). As a result, their memory for the spatial groups exerted less "pull" on their estimates of location. Note, however, that although the younger children exhibited less categorical bias than the older children and adults, they also exhibited greater error and variability in their placements.

The fact that learning a set of locations in isolation led older children and adults to think that the locations were closer together than they really were indicates they were able to integrate information about object locations presented over space and time. In particular, older children and adults used both the visible boundaries and object relatedness to form strong associations among groups of objects when they learned the objects in a random order and viewed the objects in isolation. One question this raises is whether or not 11-year-olds and adults are also able to form strong associations among the objects in the spatial groups when the salience of the cues for forming spatial groups is decreased. In a second experiment, we examined whether 11-year-old children and adults in the isolated viewing condition would continue to show significant categorical bias when only one cue was present (i.e., object relatedness). Thus, Experiment 2 was designed to investigate whether decreasing the salience of the spatial groups would reduce the "pull" of memory for categorical information for older children and adults when they viewed the objects in isolation during learning.

All aspects of Experiment 2 were the same, except that visible boundaries no longer divided the box into quadrants during learning. We reasoned that 7- and 9-year-old children would not show significant categorical bias in the isolated viewing condition with only one cue, because they did not show significant bias in the presence of both cues. Therefore, we only included 11-year-olds and adults in Experiment 2.
EXPERIMENT 2

Method

Participants

Forty-eight 11-year-old children and adults participated (mean ages = 11 years 4 months and 19 years 6 months, respectively). There were 24 participants in each age group, with approximately equal numbers of males and females in each group. Children and adults were recruited in the same manner as in Experiment 1. Eighty-three percent of children were European American, 9% were Hispanic American, 4% were Native American, and 4% were Asian American. Eight percent of mothers had completed their high school education or less, 29% had completed some college, and 63% had a 4-year-college education or beyond. Ninety-six percent of the adult participants were European American and 4% were African American.

Apparatus and Materials

The apparatus, locations, and miniature objects were the same as those used in Experiment 1. Boundaries subdividing the box were not included in the present experiment, however.

Design and Procedure

As in Experiment 1, participants were randomly assigned to either the simultaneous viewing or isolated viewing condition. The learning and test phases were identical to those used in Experiment 1. The mean number of trials to criterion for the 11-year-olds and adults were 2.17 (SD = 1.01), and 2.38 (SD = 1.44), respectively. The mean number of learning trials differed significantly across condition, F (1,44) = 4.15, p < .05. Participants required significantly fewer learning trials to reach criterion in the simultaneous viewing condition (M = 1.92, SD = 1.28) than in the isolated viewing condition (M = 2.63, SD = 1.44), indicating that participants required more experience to learn the location of each object when objects were presented in isolation. Again, the LEDs marking the locations of the objects were visible throughout all learning trials for both conditions.

Coding and Measures

The coding and measures were identical to those used in Experiment 1. We substituted 1.25% of the locations for the 11-year-olds (6 out of 480) and .83% for the adults (4 out of 480). These substituted locations were used
in all analyses. We omitted 1.88% of the locations for the 11-year-olds (9 out of 480) and .21% for the adults (1 out of 480).

Intercoder reliability estimates of object placements were calculated for eight randomly selected participants (two in each age group and condition). Coders agreed 100% of the time on which object was placed in each of the 160 locations. For both the x- and y-coordinates, the correlation between coders was \( r = 1.00 \), with a mean difference between coders of 0 inches.

**Results**

**Mean and Variable Error**

As in Experiment 1, preliminary analyses revealed no significant effects of gender, so the data were collapsed across gender in the analyses below. To examine possible differences in overall error among the age groups and experimental conditions, mean and variable error scores were entered into separate age (11 years, adult) \( \times \) condition (simultaneous viewing, isolated viewing) ANOVAs. There was a significant main effect of age for mean error scores, \( F (1, 44) = 9.64, p < .005 \). The mean distance from correct locations was 2.05 in. (SD = .32) for 11-year-olds and 1.74 in. (SD = .38) for adults. There was no significant effect of condition, \( F (1, 44) = .001, \) ns. The mean error scores were 1.90 in. (SD = .37) for the simultaneous viewing condition and 1.89 (SD = .41) for the isolated viewing condition.

Likewise, there was a significant main effect of age for variable error scores, \( F (1, 44) = 8.41, p < .01 \). Mean variable error scores were 1.09 in. (SD = .18) for 11-year-olds and .92 in. (SD = .22) for adults. Variable error scores did not differ significantly across condition, \( F (1, 44) = .37, \) ns. Mean variable error scores were .98 in. (SD = .23) for the simultaneous viewing condition and 1.02 in. (SD = .20) for the isolated viewing condition.

**Center Displacement**

Preliminary analyses revealed no significant effects of gender, so the data again were collapsed across this factor. As in Experiment 1, center displacement scores were entered into an age (2) \( \times \) condition (2) ANOVA to examine possible differences in the magnitude of categorical bias across age groups and conditions. There was a significant main effect of condition, \( F (1, 44) = 4.20, p < .05 \), indicating that participants in the simultaneous viewing condition placed objects significantly closer to the centers of the spatial groups (M = .59 in., SD = .37) than did participants in the isolated viewing condition (M = .32 in., SD = .51).

Separate one-sample t-tests for each age group and condition comparing center displacement scores to an expected value of 0 showed that both
11-year-olds and adults in the simultaneous viewing condition placed the objects significantly closer to the category centers than they actually were, \( t(11) > 4.86, p < .001 \) (see Figure 3). In the isolated viewing condition, however, the adults placed the objects significantly closer to the category centers than they actually were, \( t(11) = 3.10, p < .05 \), but the 11-year-olds did not exhibit significant categorical bias, \( t(11) < 1.48, \text{ns} \).

**Discussion**

The results of this experiment again show that opportunities to view groups of objects simultaneously during learning affects categorical bias in estimates of location at test. Specifically, when the objects in the groups were related, but boundaries subdividing the space were not present, 11-year-olds exhibited significant categorical bias at test only when they viewed the objects simultaneously during learning. In contrast, adults continued to show significant categorical bias in both the simultaneous and isolated viewing conditions.
The fact that 11-year-olds did not place related objects from the same quadrant closer together than they really were in the isolated viewing condition suggests that even older children have difficulty forming associations among groups of objects when they view objects in isolation. The finding that adults exhibited categorical bias in both the isolated and simultaneous viewing condition suggests that they are able to integrate information over space and time to form spatial groups even when only one cue (i.e., object relatedness) defines the spatial groups. One question this raises is whether adults are also able to form associations among groups of objects when only lines divide the locations into groups. In Experiment 3, boundaries divided the objects into groups, but the objects in each quadrant were not related. Again, participants either viewed the objects simultaneously or in isolation. Because previous research under simultaneous viewing conditions has shown that children rarely exhibit categorical bias when only boundaries divide the locations into groups (Hund & Plumert, 2002, 2003; Hund et al., 2002), only adults were included in this study.

**EXPERIMENT 3**

**Method**

**Participants**

Twenty-four adults participated in this study (mean age = 19 years 6 months). Participants were recruited in the same manner as in the previous experiments. Seventy-nine percent of the participants were European American, 17% were Asian American, and 4% were Hispanic.

**Apparatus and Materials**

The apparatus, locations, and miniature objects were the same as those used in the previous studies. Boundaries divided the box into quadrants.

**Design and Procedure**

All aspects of the design and procedure were the same as before, except that the pairings of the locations and the objects were fully randomized so that objects belonging to the same category were not located in the same quadrant of the box. The mean number of trials to criterion was 3.17 (SD = 1.66). The mean number of learning trials did not differ significantly across condition, F (1, 22) = 2.94, ns (isolated viewing: M = 3.75, SD = 1.60; simultaneous viewing: M = 2.58, SD = 1.56).
Coding and Measures

The coding and measures were identical to those used in the previous studies. There were no substituted locations. We omitted .42% of the locations (2 out of 480).

Intercoder reliability estimates of object placements were calculated for four randomly selected participants (two in each condition). Coders agreed 100% of the time on which object was placed in each of the 80 locations. For both the x- and y-coordinates the correlation between coders was $r = 1.00$, with a mean difference between coders of 0 inches.

Results

Mean and Variable Error

Preliminary analyses revealed no effects of gender, so the data were collapsed across gender in the analyses below. Mean and variable error scores were entered into separate ANOVAs with condition (simultaneous viewing, isolated viewing) as a between-subjects factor. There was no significant effect of condition for either the mean error scores, $F (1, 22) = 2.84$, ns or the variable error scores, $F (1, 22) = 3.11$, ns. The mean error scores were 1.80 in. ($SD = .48$) for the simultaneous viewing condition and 1.50 ($SD = .40$) for the isolated viewing condition. The mean variable error scores were .91 in. ($SD = .23$) for the simultaneous viewing condition and .77 in. ($SD = .13$) for the isolated viewing condition.

Center Displacement

Preliminary analyses revealed no significant effects of gender, so the data were collapsed across this factor. Center displacement scores were entered into an ANOVA with condition (2) as a between-subjects factor. Although categorical bias was twice as high in the simultaneous viewing condition ($M = .48$ in.; $SD = .36$) than in the isolated viewing condition ($M = .24$ in.; $SD = .35$), there was no significant effect of condition, $F (1, 22) = 2.86$, ns.

One-sample t-tests comparing center displacement scores to an expected value of 0 revealed that adults in both the simultaneous viewing condition, $t (11) = 4.58$, $p < .001$, and in the isolated viewing condition, $t (11) = 2.35$, $p < .05$, placed objects belonging to the same spatial group significantly closer together than they actually were.

Discussion

The goal of this experiment was to investigate whether adults could use boundaries during learning to organize locations into groups even when
objects were presented in isolation. Adults exhibited significant categorical bias under both viewing conditions, illustrating that they form strong associations among the objects in a spatial group when only one cue defines the spatial groups and the objects are presented in a random order and viewed in isolation during learning.

**GENERAL DISCUSSION**

The results of this investigation clearly demonstrate that opportunities to view groups of objects together in time plays an important role in forming spatial groups, particularly for younger children. When two cues for forming spatial groups were present (i.e., object relatedness and visible boundaries), 7- and 9-year-olds only exhibited significant categorical bias when they viewed the objects simultaneously. In contrast, 11-year-olds and adults exhibited categorical bias when they viewed the objects simultaneously or in isolation. When only object relatedness was available for organizing the objects into groups, 11-year-olds exhibited significant categorical bias only when they viewed the objects simultaneously. Adults exhibited significant categorical bias when they viewed the objects simultaneously or in isolation. Finally, when only visible boundaries were available for forming spatial groups, adults exhibited significant categorical bias in both the simultaneous and isolated viewing conditions. Importantly, although there were age differences in categorical bias depending on viewing condition, mean and variable error did not vary by condition. As in other studies, mean and variable error decreased between 7 years and adulthood, suggesting changes over development in the precision of spatial coding. Together, these results indicate that the ability to integrate information about objects and their locations over time is undergoing significant change over late childhood and early adolescence.

A central question these findings raise is why it is difficult to form associations among groups of objects when objects are viewed in isolation? There are at least three possibilities. One of these is that viewing objects in isolation puts greater demands on memory than does viewing objects simultaneously. When the objects were viewed simultaneously, the group to which each object belonged was quite obvious, particularly when related objects were divided by visible boundaries (Experiment 1). When the objects were viewed in isolation, however, children and adults had to hold in mind the group to which each object belonged. For children, the demands of doing so may have left few processing resources for noticing or using the available cues for forming associations among objects. This is consistent with a large body of research showing that processing capabilities are
undergoing significant change during childhood (Case, Kurland, & Goldberg, 1982; Dempster, 1981; Kail, 1991). Moreover, studies of utilization deficiencies have shown that limited processing capabilities are related to ineffective strategy use (Bjorklund & Harnishfeger, 1987; Miller, 1994; Miller, Seier, Probert, & Aloise, 1991; Woody-Dorning & Miller, 2001).

A second possible reason why viewing the objects in isolation interfered with younger children’s ability to form associations among groups of objects is that the learning task focused their attention on the individual locations rather than on the spatial groups. Although children in both conditions were instructed at the start of the session that they would be learning the locations of 20 objects, the experience of viewing the objects one at a time may have led younger children in the isolated viewing condition to focus exclusively on learning the individual object locations, not on learning the relations among the locations. This hypothesis is consistent with other work showing that younger children are less flexible in their deployment of clustering strategies than are older children (Bjorklund & Jacobs, 1985; Frankel & Rollins, 1985; Plumert, 1994; Plumert & Strahan, 1997). More generally, younger children may be more likely to focus on one salient aspect of the task than are older children.

A third possible reason why children in the isolated condition had more difficulty forming associations among groups of objects is that viewing the objects in isolation may have interfered with their ability to process configural information. Although the dots marking the locations were present in both conditions, recent research suggests that the objects making up a configuration play an important role in memory for object locations. In particular, Hollingworth (2006, 2007) found that adults’ memory for a given object location depends on the specific object-location pairings in the surrounding configuration, not just on the configuration itself. That is, when probed for the locations of individual objects presented within a configuration of other objects, memory for the location of an individual object was better if the surrounding objects were in the same relative locations at test. These findings suggest that the context of surrounding objects plays an important role in how people remember object locations. In the present study, the isolated viewing condition limited the ability of children and adults to use the surrounding context when remembering object locations. This limited context may be one reason why younger children had difficulty forming spatial groups when objects were presented in isolation. That is, when objects can be seen together in time, configural information is often salient and can be used to remember locations. For example, Uttal et al. (2001) have shown that young children are better at remembering object locations when they are presented within a systematic figure (i.e., configuration with lines outlining a dog), than when they are presented within an
unsystematic figure (i.e., same configuration without lines). This again illustrates the important role that context plays in memory for location.

It is important to note that the task used in the present investigation required children and adults in the isolated viewing condition to integrate spatial information over both time and space. Specifically, the 20 objects were viewed one at a time and presented in a random order. Clearly, this differs from everyday experience in which children often experience locations close together in time and space. One question this raises is whether or not younger children could integrate locations presented in isolation if the locations were presented close together in time and space. Previous work has shown that under simultaneous viewing conditions, children exhibit significant categorical bias when visible boundaries divide locations into quadrants and children learn the locations quadrant by quadrant (i.e., close together in time and space), but not when children learn the locations in a random order (Hund et al., 2002). Other work has shown that spatiotemporal contiguity also plays an important role in adults’ memory for objects and their locations (Clayton & Habibi, 1991; Curiel & Radvansky, 1998; McNamara, Halpin, & Hardy, 1992; Sherman & Lim, 1991). At present, it is not known whether children can integrate object locations presented in isolation if they are learned close together in time and space.

Another important question is how the results of the present study relate to children’s ability to integrate spatial information in large-scale environments. As suggested earlier, the ability to integrate spatial information over time becomes especially important in large-scale space. For example, when viewing the contents of a classroom from a single vantage point, it is likely that some objects will be out of view (e.g., occluded by other objects). The inability to simultaneously view the contents of a large-scale room may influence how children represent the layout of the space. Given the difficulty that 7- and 9-year-olds had in integrating spatial information presented in isolation in our small-scale task, one could assume that children would have even more difficulty integrating spatial information presented in isolation in large-scale environments. Clearly, further research is needed to explore the differences between small- and large-scale spaces. One potentially fruitful way of doing so is to use large-scale virtual environments (e.g., Plumert, Kearney, Cremer, & Recker, 2005; Waller & Richardson, 2008).

More generally, the results of this investigation provide additional support for the idea that categorical bias emerges out of the interaction of the cognitive system and the task structure (Plumert, 2008; Plumert et al., 2007). Two sets of results are particularly revealing. First, 11-year-olds in the isolated viewing condition, but not 7- and 9-year-olds, exhibited significant categorical bias when both visible boundaries and object relatedness were available for organizing the objects into groups. Second, adults in
the isolated viewing condition, but not 11-year-olds, exhibited significant categorical bias when only object relatedness was available for organizing the objects into groups. The fact that different age groups (7-, 9-, and 11-year-olds) responded differently to the same task structure (i.e., visible boundaries and object relatedness) and that the same age group (i.e., 11-year-olds) responded differently to different task structure (i.e., object relatedness with visible boundaries vs. object relatedness without visible boundaries) indicates that both the cognitive system and the task structure work together to produce biases in memory for location. That is, characteristics of the cognitive system (e.g., age-related differences in the coding of fine-grained and categorical information) and structure available in the task (e.g., types of cues available for coding spatial groups) jointly determine patterns of categorical bias.

Finally, the results from the present investigation add to a small but growing body of research, which shows that object information plays a critical role in how people process spatial information (Carlson-Radvansky, Covey, & Lattanzi, 1999; Hirtle & Kallman, 1988; Hirtle & Mascolo, 1986; Hollingworth, 2007; Hund & Plumert, 2003; Uttal et al., 2001). In particular, findings from the present investigation and others like it suggest that information about the objects occupying particular locations influences how those locations are processed and remembered. Further work is needed to understand exactly how children and adults integrate location and object information when remembering object locations.

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