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Linking “What” and “Where” Information:

How the Strength of Object Categories Influences Children’s Memory for Object Locations

Word count: 9,594

Abstract

We conducted three experiments to examine how the degree of category relatedness among objects in a group affects the magnitude of spatial bias in memory for their locations. Seven-, 9-, 11-year-olds and adults learned the locations of 20 objects marked by dots on a touchscreen monitor. After learning the object locations, participants attempted to place the objects without the aid of the dots. We compared spatial bias at test (i.e., placing objects in the same quadrant closer together than they really were) when objects within the same quadrant were strongly related vs. unrelated (Experiment 1), or weakly related vs. unrelated (Experiment 2). Nine-year-olds, 11-year-olds, and adults exhibited significant spatial bias when groups of objects were comprised of either strongly or weakly related exemplars, but 7-year-olds exhibited significant spatial bias only when the objects were strongly related. A third experiment revealed that 7-year-olds exhibited only marginally significant spatial bias when objects within the same quadrant were weakly related and we cued them about the category labels beforehand. The Discussion focuses on developmental changes in bottom-up associative processes and top-down strategic processes in memory for object locations.

Keywords: spatial memory, object categories, cognitive development, strategies, spatial biases

Linking “what” and “where” information is critical for everyday functioning for both children and adults. For example, finding a car in a crowded parking lot requires linking memory for object features, such as the size and color of the car, with memory for object position, such as the distance and direction from a landmark. Traditional approaches to understanding the development of spatial thinking have typically treated objects and locations independently (e.g., Piaget & Inhelder, 1967). The separation of “what” and “where” information is evident in neural processing as well, with information about objects processed via the ventral stream and information about location processed via the dorsal stream (Ungerleider & Haxby, 1994). Nonetheless, other work suggests that information about objects can influence thinking about locations (Carlson-Radvansky, Covey, & Lattanzi, 1999; Hirtle & Kallman, 1988; Hirtle & Mascolo, 1986; Hund & Foster, 2008; Hund & Plumert, 2003). For example, Carlson-Radvansky et al. (1999) found that people’s interpretations of spatial terms such as “above” were biased by the functional relations between objects (e.g., toothpaste and toothbrush), suggesting that the meaning of spatial terms like “above” varies depending on the objects involved. The goal of the present investigation was to further examine how the nature of “what” information influences memory for “where” information in children and adults. In particular, how does the strength of object categories influence memory for object locations?

Organizing locations into meaningful groups is critical for remembering the countless locations around us. One obvious source of structure for forming spatial groups is visible boundaries that divide locations into groups (Friedman & Brown, 2000a; Kosslyn, Pick, & Fariello, 1974; Montello, 2003; Newcombe & Liben 1982; Plumert & Hund, 2001; Stevens & Coupe, 1978). For example, an elementary school child might learn the locations of major U.S. cities by grouping them into states and regions based on map boundaries. Another type of

structure for forming spatial groups is spatiotemporal experience, or experience with repeatedly visiting nearby locations close together in time (e.g., Clayton & Habibi, 1991; Curiel & Radvansky, 1998; Hund & Plumert, 2005; Hund, Plumert, & Benney, 2002; McNamara, Halpin, & Hardy, 1992). A delivery driver for example might group together a set of locations based on repeated experience with dropping off packages close together in time at those locations. A third type of structure for forming spatial groups is categorical relations among the objects that occupy a set of locations (Hirtle & Kallman, 1988; Hirtle & Mascolo, 1986; Hund & Foster, 2008; Hund & Plumert, 2003). For example, a shelf stocker might mentally organize locations in a grocery store based on the categories of objects occupying those locations (e.g., dairy, meat, and produce sections). Importantly, in many cases these three sources of structure for forming spatial groups overlap in the real world, thereby providing redundant cues for forming spatial groups.

Previous work has shown that object categories play an important role not only in the organization of recall (i.e., the order in which objects are recalled), but also in memory for location (i.e., memory for the positions of objects). Hund and Plumert (2003), for example, examined whether children and adults exhibit more spatial bias when the objects within a spatial group (i.e., a set of nearby locations) are related versus unrelated. In other words, do children and adults remember categorically related objects as closer together than they really are? 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 learning the locations of the objects, participants attempted to place the objects in their correct locations without the aid of

the dots. Participants in the related condition placed objects belonging to the same quadrant significantly closer together than did participants in the unrelated condition, indicating that information about what objects are influences memory for where objects are located. Further work by Hund and Foster (2008) showed that 7-, 9-, 11-year-olds and adults retain spatial groupings of related objects over relatively long delays (7 days) and that 11-year-olds and adults can use object relatedness as a cue for flexibly shifting between different organizations of object locations.

This kind of 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; Spencer, Simmering, Schutte, & Schöner, 2007). A key question is what governs the strength of the bias? The Dynamic Field Theory developed by Spencer, Schöner, and colleagues is a neural network model that captures how object- and location-related activation in a network of neurons can be sustained from moment-to-moment and drift over short time periods. (Spencer et al., 2007; Ziemer, Buss, Plumert, and Spencer, 2009). The model consists of several interconnected layers (i.e., fields), including 1) a perceptual field that encodes the visual position of each object, 2) a spatial working memory field that actively maintains the position of each object during short-term delays, 3) a shared inhibitory layer that mediates neural excitation in both the perceptual field and spatial working memory field, 4) a long-term spatial memory field that retains the positions of the objects over a trial-to-trial timescale, 5) a feature-space working memory field that binds the features of an object to its spatial position, and 6) an associated long-term feature-space field that retains this information from trial-to-trial. Importantly, when the objects in a spatial group are related (i.e., share features), the peaks of

activation representing those objects overlap in the long-term feature-space field. As a result, the feature-space working memory field drives peaks of activation in the spatial working memory field at biased locations, leading to biased responses. Hence, greater overlap in long-term feature-space peaks leads to greater bias in spatial memory.

The Category-Adjustment Model developed by Huttenlocher et al. (1991, 1994) proposes that memory for a location depends on memory for fine-grained metric information (e.g., distance and direction from an edge) and on categorical information about the location (e.g., region membership). Categorical information is represented by a prototype located at the center of the spatial region. The magnitude of spatial bias depends on the certainty of the fine-grained, metric information about the location. When memory for fine-grained information is relatively certain, categorical information receives a low weight, resulting in only small distortions (i.e., bias) toward the centers of spatial categories. Conversely, when memory for fine-grained information is relatively uncertain, categorical information receives a high weight, resulting in large distortions toward category centers. The end result of this process for combining fine-grained and categorical information is that responses are less variable, leading to greater overall accuracy.

Both the Category Adjustment Model and the Dynamic Field Theory were developed to account for bias in tasks that require participants to remember one location at a time (i.e., participants see a location and then reproduce that location after some delay). In the work on memory for the locations of categorically-related objects described above (Hund & Plumert, 2003; Hund & Foster, 2008), participants were asked to remember the locations of 20 objects at a time. Clearly, this task requires that participants remember fine-grained, metric information about the individual object locations. In addition, coding information about the spatial group to

which each location belongs is useful for reducing the demands of remembering 20 individual locations. This likely involves noticing and forming associations among the members of the spatial groups, leading to a “pull” between members of a spatial group. The relative weighting of these sources of metric and spatial group information determines the degree of bias in placements at test. When memory for the spatial groups (i.e., associations among locations in the spatial groups) is strong relative to memory for the individual locations, people place the 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. Note that this framework borrows from both the Dynamic Field Theory (i.e., forming associations among locations) and the Category Adjustment Model (i.e., relative weighting of metric and categorical information). However, unlike the Dynamic Field Theory, forming associations among locations likely involves top-down strategic processes, and unlike the Category Adjustment Model, metric and categorical information represent independent inputs (i.e., categorical information can be weighted heavily even when metric certainty is high).

One question this raises is how the strength of category relatedness among a group of objects might affect bias in children’s memory for the locations of those objects. Numerous studies by Plumert and Hund have shown that younger children often require multiple cues (e.g., both visible boundaries and spatiotemporal contiguity) or more salient cues (e.g., walls rather than lines subdividing a space) to form spatial groups (Hund et al., 2002; Hund & Plumert, 2003, Plumert & Hund, 2001; Plumert, 2008 for a review). This suggests that younger children may be more likely to exhibit spatial bias in their placements when categorically-related groups of objects are strongly than weakly related. This hypothesis is also consistent with older work on the development of children’s use of categorical organizational strategies in free recall, which

shows that prior to about age 10, children rarely spontaneously use category membership to organize their free recall (Bjorklund, & de Marchena, 1984; Bjorklund, 1980; Corsale & Ornstein, 1980; Lange, 1973; Moely, Olson, Halwes, & Flavell, 1969; Nida & Lange, 1995). However, children as young as seven or eight years of age will use category membership to organize their recall if the items are highly related (Bjorklund, & de Marchena, 1984; Bjorklund & Jacobs, 1985; Frankel & Rollins, 1985, Schneider, 1986). For example, Bjorklund and Jacobs (1985) presented 8-year-old children with a randomized list of object names. For half of the children, the list contained pairs of objects that were strongly related (e.g., dog and cat). For the other half, the list contained pairs of objects that were weakly related (e.g., bear and monkey). They found that children were significantly more likely to recall pairs of objects together when they were strongly than weakly related. Similarly, Schneider (1986) found that 7-year-olds exhibited significantly more categorical clustering in their recall when the items were strongly than weakly related, whereas 10-year-olds’ recall organization was unaffected by item associations.

The goal of the present investigation was to test how the categorical relatedness of the objects forming a spatial group influences memory for the locations of those objects in 7-, 9-, and 11-year-old children and adults. These ages were chosen because of the developmental change that occurs in both the use of cues to form spatial groups and use of categorical organizational strategies from middle to late childhood (e.g., Bjorklund & de Marchena, 1984; Corsale & Ornstein, 1980; Plumert, 1994, 2008; Schneider, 1986). The adults served as a comparison group. Children and adults learned the locations of 20 objects marked by dots on a large touchscreen monitor. After learning the object locations (i.e., placing all objects correctly in a single trial), participants attempted to place the objects without the aid of the dots. We

measured placement accuracy (mean and variable error), spatial bias (the degree to which participants placed objects within the same quadrant closer together than they really were), and spatial clustering (the degree to which participants placed all of the objects quadrant-by-quadrant). We also explored whether the amount of spatial clustering in children’s placement orders was related to the amount of spatial bias in their object placements. Other work has shown that at transitional ages, children recall more items when they use a spatial clustering strategy (Plumert, 1994). Given that the Category Adjustment Model hypothesizes that spatial bias benefits spatial memory, we reasoned that spatial clustering might also be positively correlated with spatial bias at transitional ages.

The first two experiments manipulated the strength of associations among category exemplars by comparing spatial bias when the objects within the same quadrant were strongly related vs. unrelated (Experiment 1) or weakly related vs. unrelated (Experiment 2). A third experiment examined spatial bias in 7-year-olds’ placements when objects within the same quadrant were weakly related, and children were either cued or not cued about the category labels beforehand. Given their more well-developed category knowledge, we expected that older children and adults would exhibit significant spatial bias regardless of whether the objects in the same quadrant were strongly or weakly related. In contrast, we expected that 7-year-olds would be more likely to exhibit spatial bias when the objects in the same quadrant were strongly than weakly related, and that they would be more likely to exhibit spatial bias when the objects in the same quadrant were weakly related if they were cued about the category labels beforehand.

EXPERIMENT 1

Method

Participants

Ninety- six 7-, 9-, and 11-year-old children and adults participated. There were 24 participants in each age group, with equal numbers of males and females in each group. The mean ages of the groups were 7 years 8 months (range = 7 years 4 months to 7 years 11 months), 9 years 7 months (range = 9 years 4 months to 9 years 10 months), 11 years 4 months (range = 11 years 0 months to 11 years 10 months), and 19 years 5 months (range = 18 years 0 months to 20 years 11 months). One additional 7-year-old was excluded because he did not complete the experiment. Children were recruited from a research participant database maintained by the Department of Psychological and Brain Sciences at the University of Iowa. Parents received a letter describing the study, followed by a telephone call inviting children to participate. Children received a small gift for participating. Eighty-nine percent of the children were European American, 1% were African American, 4% were Asian American, 3% were Hispanic/Latino, and 3% did not fit in these categories. Adults participated to fulfill research credit for an introductory psychology course.

Apparatus and Materials

The stimuli were presented on a 46-in. (116.8-cm) NEC MultiSynch P461LCD touchscreen monitor with integrated 3M Dispersive Signal Technology (DST) placed on a 42 in. high table. Participants sat 15 inches away from the touchscreen in an office chair, which could be raised or lowered depending on the height of the participant. For each participant, the chair was adjusted so the participant was comfortably seated at eye-level with the center of the screen. The experimenter sat behind and to the left of each participant. The touchscreen monitor was controlled by an Apple iMAC. The experiments were programmed in Matlab, using the Psych Toolbox extensions.

The touchscreen displayed twenty .75 in. (1.91cm) red dots in a center-aligned 22.5 in. (57.2-cm) square box with a .25 in. (1.91 cm) white border. There were 20 icons of objects to help participants learn the locations in the box: a cat, dog, cow, horse, pig, pants, shorts, skirt, shoes, socks, bed, chair, table, lamp, sofa, bowl, cup, spoon, pot, and a pan. These objects belonged to four categories (animals, clothing, furniture, and kitchenware) and had high category relatedness based on the Battig and Montague (1969) norms (average frequency ranking = 4.9, range across categories = 3.2 – 6.6). All icons were edited in Adobe Photoshop CS2 as Portable Network Graphics images on transparent backgrounds. The average length and width of the objects were 0.66 in. (1.68 cm) and 0.72 in. (1.83 cm), respectively.

Design and Procedure

Participants were randomly assigned to one of two experimental conditions: high grouped or high random. In the high grouped condition, the pairings of objects with locations were constrained so that all objects belonging to an object category occupied locations in the same quadrant of the box. Both the pairings of categories and quadrants and the pairings of objects and locations within quadrants were randomized across participants. In the high random condition, the same objects and locations were used, but the pairing of objects and locations were randomized across participants so that any object could occupy any location.

The experimental session started with practice using the touchscreen, followed by a learning and a test phase. Participants first practiced using a 4 in. stylus to manipulate the icons on the screen. A cat image appeared at a random x- and y- coordinate on the touchscreen, and participants dragged the image onto a red square positioned in the center point of the screen. Participants completed five practice trials.

Learning phase. During the learning phase, participants learned the locations of the 20 objects. The experimenter told participants that 20 objects would be placed 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 participants first watched all the objects being placed onto their correct dots. The objects appeared one at a time, all on either the right or left side of the box (counterbalanced across participants). An object appeared outside of the box for 3 s while the experimenter named the object. Then participants watched as the computer moved the object onto a red dot inside of the box. After all 20 objects were placed, the participants closed their eyes while the objects disappeared from the box. The participants then attempted to place the objects in their correct locations. Objects appeared one at a time outside of the box for an unlimited time. Participants attempted to move each object onto the correct dot. Incorrect placements were corrected by the computer (i.e., the object automatically moved to the correct location). Objects remained on the dots until all 20 had been placed. Participants received the objects in a new random order for each learning trial. The learning trials ended when all 20 objects were correctly placed on the corresponding red dots in a single trial. Table 1 shows the mean number of learning trials required to reach criterion for participants of each age and condition. An Age (7 years, 9 years, 11 years, adults) x Condition (high grouped, high random) Analysis of Variance (ANOVA) on the number of learning trials to reach criterion revealed a main effect of condition, $F(1, 88) = 12.33, p < .01$. Participants in the high grouped condition ($M = 4.46, SD = 2.32$) required fewer learning trials than participants in the high random condition ($M = 6.15, SD = 2.38$).

Table 1. *Mean Number of Learning Trials in Experiments 1 and 2 by Age Group and Condition*

	Experiment 1		Experiment 2	
Age Group	High Grouped	High Random	Low Grouped	Low Random

7-year-olds	5.33 (1.92)	6.58 (2.88)	7.75 (3.98)	5.83 (2.25)
9-year-olds	3.92 (1.38)	6.42 (2.07)	4.50 (3.34)	6.25 (3.79)
11-year-olds	4.92 (3.48)	6.00 (2.34)	5.08 (2.35)	7.75 (4.65)
Adults	3.67 (1.78)	5.58 (2.35)	3.83 (3.34)	6.08 (2.61)

Note. Standard deviations are listed in parentheses.

Test phase. The test phase began immediately following the learning phase. First, the experimenter asked participants to close their eyes while the objects were removed from the dots. When participants opened their eyes, they saw the white box outline and the objects clustered together in a group on either the left or right side of the box (corresponding to the side used for the learning trials). Participants then were asked to put the objects in their correct locations without the aid of the red dots marking the locations. Participants replaced the objects in any order they chose. After the participants replaced the objects, the experimenter thanked them for participating.

Coding and Measures

The same coding and measures were used as in previous studies (Hund & Plumert, 2002, 2003; Hund et al., 2002; Plumert & Hund, 2001). A placement was considered correct if it was in the correct quadrant of the box and in the correct position relative to the other objects. Occasionally, participants preserved the overall configuration of locations, but incorrectly paired objects and locations. For example, they might preserve the overall configuration of the set of animals, but mistakenly transpose the location of the cat and pig. We used the x- and y-coordinates for these locations regardless of whether the correct objects were placed in the locations. We substituted 2.5% of the locations for 7-year-olds (12 out of 480), 2.7% for 9-year-olds (13 out of 480), 3.1% for 11-year-olds (15 out of 480), and 2.3% for adults (11 out of 480).

These substituted locations were used in all analyses. As in previous experiments, objects placed in the wrong quadrant or in a completely wrong configuration were omitted from analyses. We omitted 4.4% of the locations for 7-year-olds (21 out of 480), 1.7% for 9-year-olds (8 out of 480), 1.7% for 11-year-olds (8 out of 480), and 0.42% for adults (2 out of 480).

We calculated intercoder reliability estimates of object placement for 15 randomly selected participants (16% 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 98.8% of the 300 locations coded.

Mean and Variable Error Scores

Participants received a single mean error score reflecting the degree to which they placed objects near their actual locations. This score was calculated by first determining the distance between each remembered and actual location and then averaging these distances over all locations to obtain a single mean error score that reflected the accuracy of memory for location information. Participants also received a single variable error score reflecting the variability of remembered placements relative to actual locations. This score was calculated by first determining the distance between each remembered and actual location and then calculating the standard deviation of these distances to obtain a single variable error score that reflected the precision of memory for location information (i.e., the consistency of the error).

Center Displacement Score

Participants also 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. 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 toward the centers of the spatial groups after we removed effects due to translation of groups. This score provided a sensitive index of spatial bias in estimates of location.

Spatial Clustering Score

Participants also received a spatial clustering score reflecting the degree to which they replaced objects quadrant-by-quadrant during test. The clustering measure used was the adjusted ratio of clustering (ARC) score (Roenker, Thompson, & Brown, 1971). This score represents the proportion of the observed number of quadrant 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. ARC scores in this study ranged from 0.00 to 1.00 (negative ARC scores were set to 0). This score provided an index of spatial organization in participants' replacement orders during test.

Results

In Experiments 1 and 2, all dependent measures were analyzed in Age (7 years, 9 years, 11 years, adults) x Condition (grouped, random) Analyses of Variance (ANOVA) with $\alpha = .05$. Fisher's PLSD tests were used in all post-hoc follow-up analyses. In all experiments, non-significant effects are not reported.

Mean and Variable Error

The analyses of mean error scores and variable error scores yielded no significant effects. Thus, when the objects were strongly related category members, there were no age or condition

differences in the accuracy or precision of placements. On average, participants placed the objects 3.49 cm ($SD = .86$) from the true locations.

Center Displacement

Were children and adults more likely to place the objects closer together than they actually were when strongly related category members were grouped together in the same quadrant of the box? We used two sets of statistical analyses to address this question. In the first analysis, we used an ANOVA on center displacement scores to examine whether there were differences in the magnitude of center displacement scores across ages and conditions. This analysis yielded a significant main effect of condition, $F(3, 88) = 22.54, p < .001, \eta_p^2 = .20$. Participants in the high grouped condition placed the objects significantly closer to the centers of the spatial groups ($M = 1.04$ cm, $SD = .99$) than did participants in the high random condition ($M = .16$ cm, $SD = .79$).

Figure 1. Mean center displacement (cm) by age in the high grouped and high random conditions. Asterisks denote scores significantly greater than 0. Error bars indicate standard error.

In the second analysis, we conducted separate one-sample t tests to determine whether the magnitude of displacement was significantly greater than 0 for participants in each age group and condition (Figure 1). No difference in distance would be expected if participants neither underestimated nor overestimated the distances between locations belonging to each spatial group. Positive scores would reflect displacement toward the centers of the spatial groups, whereas negative scores would reflect displacement away from the centers of the groups. All age groups in the high grouped condition placed the objects significantly closer to the centers of the spatial groups than they actually were, all t 's (11) > 2.30 , $p < .05$. In contrast, none of the age groups in the high random condition exhibited significant spatial bias, all t 's (11) < 1.17 , ns .

Spatial Clustering

To investigate whether the order in which participants placed the objects during the test phase differed by age or condition, we conducted an ANOVA on spatial clustering (ARC) scores (Table 2). This analysis yielded significant main effects of age, $F(3, 88) = 4.32$, $p < .007$, $\eta_p^2 = .13$, and condition, $F(3, 88) = 45.98$, $p < .0001$, $\eta_p^2 = .34$. Participants were more likely to place the objects belonging to one quadrant together in time during replacement in the high grouped condition ($M = .66$, $SD = .28$) than in the high random condition ($M = .33$, $SD = .22$). There was also a marginal Age x Condition interaction, $F(3, 88) = 2.48$, $p = .067$, $\eta_p^2 = .08$. Simple effects tests revealed a significant effect of condition for the 9-year-olds, $F(1, 22) = 18.96$, $p < .0001$, $\eta_p^2 = .46$, 11-year-olds, $F(1, 22) = 12.45$, $p < .002$, $\eta_p^2 = .36$, and adults, $F(1, 22) = 28.23$, $p < .0001$, $\eta_p^2 = .56$, but not for the 7-year-olds, $F(1, 22) = 1.12$, ns . With the exception of the 7-year-olds, participants in the high grouped condition had significantly higher ARC scores than did participants in the high random condition.

We also explored whether the amount of spatial clustering participants exhibited in their replacement orders was related to the amount of spatial bias they exhibited in their placements. We limited this analysis to participants in the high grouped condition because spatial bias and spatial clustering were quite low in the high random condition, thereby limiting variation in scores.

Table 2. *Mean Adjusted Ratio of Clustering (ARC) Scores by Age Group and Condition*

Age Group	Condition	
	High Grouped	High Random
7-year-olds	.47 (.29)	.36 (.22)
9-year-olds	.69 (.30)	.23 (.21)
11-year-olds	.65 (.29)	.29 (.19)
Adults	.84 (.10)	.45 (.23)

Note. Standard deviations are listed in parentheses.

Interestingly, the relationship between center displacement and spatial clustering was very high for 7-year-olds, $r = .69$, $p = .012$. The correlation between center displacement and spatial clustering did not reach significance for the 9-year-olds, $r = .06$, or 11-year-olds, $r = .29$, and was marginally significant for adults, $r = .57$, $p = .055$.

Discussion

As expected, all age groups exhibited significant spatial bias when strongly related exemplars were located in the same quadrant of the box, but not when the same objects were randomly paired with locations. This work replicates previous research by Hund and Plumert (2003) showing that children and adults remember categorically related objects as closer together than they really are. Although there were no age differences in the magnitude of spatial bias in

participants’ object placements, there were age differences in the magnitude of spatial clustering in participants’ replacement orders. For the 9- and 11-year-olds and adults, spatial clustering was much higher in the high grouped than in the high random condition. Seven-year-olds exhibited a relatively low amount of spatial clustering in both conditions, an indication that they were less strategic in their placements than the older age groups. However, the strong correlation between spatial clustering and center displacement for 7-year-olds in the high grouped condition suggests reciprocal relationships between the two, particularly for children at transitional ages. This is consistent with work showing children at transitional ages receive more benefit from using spatial organizational strategies than do younger children (Plumert, 1994).

The next question we addressed was whether 7-, 9-, 11-year-olds and adults exhibit significant spatial bias when the category exemplars are weakly related. Past work suggests that children younger than 7 or 8 years of age do not spontaneously use categorical organizational strategies to organize their verbal recall unless the exemplars are strongly related (Bjorklund & Jacobs, 1985; Lange, 1973). This suggests that 7-year-olds may have difficulty forming spatial groups when the groups of objects are weakly related. The design of the experiment was identical to that used in Experiment 1 with the exception that the exemplars used for the four categories were weakly related.

EXPERIMENT 2

Method

Participants

Ninety-six 7-, 9-, and 11-year-old children and adults participated. There were 24 participants in each age group, with equal numbers of males and females in each group. The mean ages of the groups were 7 years 8 months (range = 7 years 3 months to 7 years 11 months),

9 years 7 months (range = 9 years 1 month to 9 years 10 months), 11 years 6 months (range = 11 years 2 months to 11 years 11 months), and 20 years 7 months (range = 18 years 0 months to 47 years 11 months). Three additional 7-year-olds were excluded because they incorrectly placed more than 12 of the 20 locations during test. Children and adults were recruited in the same manner as in Experiment 1. Eighty-six percent of the children were European American, 2% were African American, 5% were Asian American, 4% were Hispanic/Latino, and 2% identified as multi-racial.

Apparatus and Materials

The touchscreen display was the same as in Experiment 1. The object categories (animals, clothing, furniture, and kitchenware) remained the same as in Experiment 1. However, the objects used in this experiment had low category relatedness based on the Battig and Montague (1969) norms (average frequency ranking = 24.6, range across categories = 19.6 – 34.0). The items included a baboon, beaver, camel, hippo, turtle, gloves, hat, swimsuit, tie, vest, bookshelf, clock, desk, TV, stool, rolling pin, teapot, toaster, whisk, and a (wine) glass. The average length and width of the objects was 0.64 in. (1.6 cm) and 0.73 in. (1.9 cm), respectively.

Design and Procedure

Participants were randomly assigned to one of two experimental conditions: low grouped or low random. With the exception of the exemplars, these conditions were structured identically to the high grouped and high random conditions in Experiment 1. The learning and test phases were also identical to those in Experiment 1. Table 1 shows the mean number of learning trials required to reach criterion for participants of each age and condition. An Age (4) x Condition (2) ANOVA on the number of learning trials to reach criterion revealed no significant effects. The mean number of trials to reach the learning criterion was 5.89 ($SD = 3.42$).

Coding and Measures

The coding and measures were identical to those used in Experiment 1. We substituted 2.5% of the locations for 7-year-olds (12 out of 480), 5% for 9-year-olds (24 out of 480), 1.9% for 11-year-olds (9 out of 480), and 1.9% for adults (9 out of 480). These substituted locations were used in all analyses. We omitted 1% of the locations for 7-year-olds (5 out of 480), 3.3% for 9-year-olds (16 out of 480), 1% for 11-year-olds (5 out of 480), and 0.42% for adults (2 out of 480). We calculated intercoder reliability estimates of which object was placed at each of the locations for 19 randomly selected participants (20% of the sample). Coders agreed on 98.9% of the 380 locations coded. Scores for mean error, variable error, center displacement, and spatial clustering were calculated in the same manner as in Experiment 1.

Results

Mean and Variable Error

The ANOVA on mean error scores yielded a main effect of age, $F(3, 88) = 4.67$, $p < .004$, $\eta_p^2 = .14$. Follow-up tests revealed that adults ($M = 2.99$ cm, $SD = .54$) exhibited significantly less error than 7-year-olds ($M = 3.74$ cm, $SD = .82$) and 9-year-olds ($M = 3.79$ cm, $SD = .94$), but not 11-year olds ($M = 3.37$ cm, $SD = .98$).

An ANOVA on variable error scores also yielded a main effect of age, $F(3, 88) = 5.51$, $p < .05$, $\eta_p^2 = .16$. Follow-up tests showed that adults ($M = 1.54$, $SD = .32$) exhibited significantly lower variable error scores than 7-year-olds ($M = 1.89$, $SD = .44$), 9-year-olds ($M = 2.16$, $SD = .71$), and 11-year-olds ($M = 1.88$, $SD = .63$).

Center Displacement

As in Experiment 1, we first conducted an ANOVA on center displacement scores to explore differences in the magnitude of spatial bias across ages and conditions. This analysis

yielded significant effects of age, $F(3, 88) = 3.96, p = .01, \eta_p^2 = .12$, and condition, $F(3, 88) = 23.15, p < .001, \eta_p^2 = .21$. Overall, participants in the low grouped condition ($M = 1.02$ cm, $SD = 1.12$) exhibited significantly higher center displacement than participants in the low random condition, ($M = .08$ cm, $SD = .88$). Follow-up tests of the age effect indicated that center displacement increased significantly across development, with the 7-year-olds ($M = .06$ cm, $SD = .81$) demonstrating significantly less center displacement overall than 11-year-olds ($M = .88$ cm, $SD = 1.32$) and adults ($M = .84$ cm, $SD = .90$). There was no significant difference between 9-year-olds ($M = .38$ cm, $SD = 1.14$) and the other age groups, or between 11-year-olds and adults.

We also conducted separate one-sample t -tests for each age group and condition to determine whether center displacement scores differed significantly from the expected score of 0 (Figure 2). Nine- and 11-year-olds and adults in the low grouped condition placed the objects significantly closer to the category centers than they actually were, all t 's (11) $> 3.39, p < .01$,

Figure 2. Mean center displacement (cm) by age in the low grouped and low random conditions. Asterisks denote displacement scores significantly greater than 0. Error bars indicate standard error.

but the 7-year-olds did not, $t(11) = 1.25$, ns . In the low random condition, center displacement scores of the 7-, 9-, and 11-year-olds were not significantly different from 0, t 's $(11) < .56$, ns . However, adults in the low random condition did place the objects significantly closer to the category centers than they actually were, $t(11) = 2.60$, $p < .05$, suggesting that they formed spatial groups even when the objects were unrelated.

Spatial Clustering

To investigate whether the order in which participants placed the objects differed by age or condition, we conducted an ANOVA on spatial clustering (ARC) scores (Table 3). This analysis yielded significant main effects of age, $F(3, 88) = 10.84$, $p < .0001$, $\eta_p^2 = .27$, and condition, $F(1, 88) = 31.20$, $p < .0001$, $\eta_p^2 = .26$. These effects were subsumed under a significant Age x Condition interaction, $F(3, 88) = 3.28$, $p < .05$, $\eta_p^2 = .10$. Simple effects tests revealed no significant effect of condition for 7-year-olds, $F(1, 22) = .36$, ns , a marginally significant effect of condition for the 9-year-olds, $F(1, 22) = 3.91$, $p < .06$, $\eta_p^2 = .15$, and a significant effect of condition for the 11-year-olds, $F(1, 22) = 20.71$, $p < .001$, $\eta_p^2 = .49$, and adults, $F(1, 22) = 15.63$, $p < .001$, $\eta_p^2 = .42$. With the exception of 7-year-olds, all age groups exhibited more spatial clustering in their replacement orders in the low grouped versus random condition. We again explored whether the amount of spatial clustering participants exhibited in

Table 3. *Mean Adjusted Ratio of Clustering (ARC) Scores by Age Group and Condition*

Age Group	Condition	
	Low Grouped	Low Random
7-year-olds	.33 (.16)	.29 (.18)
9-year-olds	.51 (.34)	.25 (.30)
11-year-olds	.81 (.19)	.33 (.31)

Adults	.85 (.14)	.49 (.28)
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Note. Standard deviations are listed in parentheses.

the low grouped condition was related to the amount of spatial bias they exhibited in their placements. The relationship between spatial clustering and center displacement was not significant for any age group.

Discussion

The results of this experiment show that 9- and 11-year-olds and adults exhibited significant spatial bias when weakly related exemplars were located in the same quadrant of the box, but with the exception of the adults, not when the same objects were randomly paired with locations. In contrast, the 7-year-olds did not exhibit significant spatial bias in their placements in either the low grouped or the low random condition. Likewise, 7-year-olds did not exhibit more spatial clustering in their replacement orders in the low grouped versus the low random condition. Unlike older participants, it appears that the 7-year-olds had difficulty noticing the spatial groups when the objects within the group were weakly related. This is consistent with previous research on younger children’s difficulty with using categorical organizational strategies when items are weakly related (Bjorklund & Jacobs, 1985; Schneider, 1986).

A large body of research on the development of children’s recall organization has shown that younger children often fail to produce categorical organizational strategies spontaneously (e.g., Lange & Griffith, 1977; Moely, Olson, Halves, & Flavell, 1969). However, they will use categorical organizational strategies if provided with task support (e.g., Sodian, Schneider, & Perlmutter, 1986). One source of task support is category labels for organizing the objects into groups. For example, previous recall memory research has shown that children in middle childhood exhibit greater categorical organization in their recall when category labels are present

than absent during learning (Kobasigawa & Middleton, 1972), and that they benefit more when category labels are provided during learning than at test (Bjorklund & Hock, 1982). This work suggests that category labels can help younger children organize sets of categorically-related items. In an attempt to facilitate 7-year-olds’ spatial clustering of groups of weakly related objects, we conducted a follow-up experiment in which we explicitly provided the four object category labels to a group of 7-year-olds before they started the learning phase. A control group of 7-year-olds received the same instructions as in Experiment 2. We hypothesized that knowing the category labels beforehand would help 7-year-olds notice the spatial groups of weakly related objects, thus leading to higher center displacement scores.

EXPERIMENT 3

Method

Participants

Twenty-four 7-year-old children participated. There were 12 participants in each condition with an equal number of males and females in each group. The mean age of the children was 7 years, 9 months (range = 7 years 7 months to 7 years 11 months). Two additional 7-year-olds were excluded because they either did not follow instructions or complete the experiment. Children were recruited in the same manner as participants in Experiments 1 and 2. Ninety-six percent of the children were European American and 4% identified as multi-racial.

Apparatus and Materials

The touchscreen display and objects (i.e., low related animals, clothing, furniture, and kitchenware) were the same as those used in Experiment 2.

Design and Procedure

Participants were randomly assigned to one of two experimental conditions: explicit or

non-explicit. For both conditions, all objects belonging to the same category occupied locations in the same quadrant of the box. The learning and test phase procedures were identical to those used in Experiment 1 and 2 with one exception. In the explicit condition, the experimenter informed participants immediately prior to the learning phase that the 20 objects were organized into four groups: animals, clothing, furniture, and kitchenware. The instructions about the category labels were as follows: *“You’ll see four groups of objects. In one there will be animals, in another group there will be pieces of furniture, in another group there will be kitchen things and in another group there will be pieces of clothing.”* In the non-explicit condition, the instructions were identical to those used in the previous experiments. The mean number of trials to reach the learning criterion did not differ in the explicit ($M = 6.75$, $SD = 1.91$) and ($M = 7.67$, $SD = 2.81$) non-explicit conditions, $F(1, 22) = .874$, ns .

Coding and Measures

The coding of placements at test was identical to that in Experiments 1 and 2. We substituted 1.9% of the locations (9 out of 480) and omitted 3.1% (15 out of 480). The substituted locations were used in all analyses. Intercoder reliability estimates of object placement for five randomly selected participants (20% of the sample) indicated that coders agreed on 98.5% of the 100 locations coded. Mean and variable error scores and center displacement scores were calculated in the same manner as Experiments 1 and 2.

Results

Mean and Variable Error

Separate one-way ANOVAs on mean and variable error scores with condition (explicit vs. non-explicit) as a factor produced no significant results. The mean and variable error was

3.77 cm ($SD = 1.05$) and 1.89 ($SD = .64$) in the explicit condition and 3.82 cm ($SD = 1.14$) and 2.17 ($SD = .85$) in the non-explicit condition.

Center Displacement

We first entered center displacement scores into a one-way ANOVA with condition as a factor to measure differences in the degree to which participants exhibited spatial bias in the explicit and non-explicit conditions. Although center displacement scores were higher in the explicit ($M = .78$ cm, $SD = 1.39$) than in the non-explicit ($M = .42$ cm, $SD = .93$) condition, the difference was not significant, $F(1, 23) = .54$, ns . Separate one-sample t -tests comparing center displacement scores to the expected score of 0 showed that scores in the explicit condition differed only marginally from 0, $t(11) = 1.95$, $p = .08$, whereas those in the non-explicit condition did not differ significantly from 0, $t(11) = 1.57$, $p = .14$.

Spatial Clustering

To investigate whether the order in which 7-year-olds placed the objects differed by condition, we entered spatial clustering (ARC) scores into a one-way ANOVA with condition as a factor. This analysis also yielded no significant difference between the explicit ($M = .25$, $SD = .26$) and non-explicit ($M = .27$, $SD = .26$) conditions, $F(1, 23) = .03$, ns .

Discussion

The goal of this experiment was to determine whether 7-year-olds would be more likely to exhibit spatial bias in their placements of groups of weakly related exemplars if they were told the category labels beforehand. There was no significant difference between the explicit and non-explicit condition, and spatial bias scores were only marginally different from the expected score of 0 in the explicit condition. Further, spatial clustering was relatively low in both the explicit and non-explicit condition, and there was no significant difference in spatial clustering scores

between the two conditions. Thus, providing 7-year-olds with category labels had only a very modest effect on their ability to notice the groups of weakly related exemplars. This is consistent with other work showing that younger children require substantial cues in order to use categorical clustering strategies, and that they often fail to persist in using categorical clustering strategies when the experimenter-imposed requirement to cluster items is removed (Lange, 1973).

GENERAL DISCUSSION

The goal of our investigation was to examine developmental changes in how information about what objects are influences memory for where they are located. In particular, we explored how the degree of category relatedness among objects in a group affects the magnitude of spatial bias in memory for their locations. In Experiments 1 and 2, we found that regardless of whether groups of category exemplars were strongly or weakly related, 9- and 11-year-olds and adults exhibited significant spatial bias in their placements at test. However, 7-year-olds only exhibited significant spatial bias at test when the groups of category exemplars were strongly related. Further, 9- and 11-year-olds and adults in Experiments 1 and 2 exhibited more spatial clustering in their replacement orders in the grouped than random conditions, whereas 7-year-olds in the two conditions exhibited no significant difference. In Experiment 3, we found that cuing 7-year-olds beforehand about the names of the categories when the exemplars were weakly related only resulted in marginally significant spatial bias.

The findings from Experiments 1 and 2 indicate that exemplar relatedness affected the 7-year-olds differently than the older children and adults. This is remarkably consistent with previous work on children’s use of categorical organizational strategies in recall, showing that 7- and 8-year-olds use categorical organizational strategies when items are strongly related, but not

weakly related even though all other aspects of the task are the same (Bjorklund & de Marchena, 1984; Bjorklund & Jacobs, 1985; Frankel & Rollins, 1985; Schneider, 1986). This suggests that developmental advances in category knowledge play a role in whether children can use object categories to form spatial groups. Previous research has shown that a more richly elaborated knowledge base supports memory and strategies involving information that is part of the knowledge base. A classic study by Chi (1978), for example, showed that child chess experts had better memory for meaningful chess arrangements than did adult chess novices.

How might a stronger knowledge base give rise to the pattern of age differences observed here? One possible explanation is that the strength of the connections among exemplars automatically drives the strength of the connections among locations via bottom-up associative processes. A critical component of the Dynamic Field Theory model outlined earlier is the degree of overlap between the objects in the long-term feature-space field. As the system learns the links between objects and locations, groups of objects with overlapping peaks of activation in the long-term feature-space field drive corresponding overlapping peaks of activation in the long-term spatial memory field, leading to systematic spatial bias. For the 7-year-olds, a less developed knowledge base would result in overlapping peaks of activation for strongly related exemplars, but not for weakly related exemplars. For the older children and adults, a more developed knowledge base would result in overlapping peaks of activation for both strongly and weakly related exemplars. The Category Adjustment Model would also predict that differences in the category knowledge base would impact category prototype effects, with stronger prototypes leading to greater pull toward the centers of spatial groups.

Another possible explanation for the pattern of age differences we observed is that stronger connections among the exemplars may also help younger children form spatial groups

via top-down strategic processes. Specifically, younger children may be more likely to explicitly notice that groups of nearby objects are from the same category when the objects are strongly versus weakly related. Once they notice there are groups of objects, they may explicitly use spatial organizational strategies to help them learn the object locations. That is, children may try to learn the location of each object by first remembering the spatial group containing the object and then its location within the group. This top-down attention to the spatial groups makes it more likely that children will form strong connections among the objects belonging to the same spatial group. This may lead to more organized placements and more spatial bias at test, the dominant pattern exhibited by adults regardless of relatedness among category members. Indeed, the high correlation between 7-year-olds’ ARC scores and spatial bias scores when the objects were strongly related (Experiment 1) indicates that children who were more strategic in their replacement orders were also more biased in their placements. This explanation is consistent with Bjorklund’s (1987) hypothesis that strongly related items (e.g., dog and cat) cue younger children’s use of categorical organizational strategies in recall. That is, they begin to notice the categorical relationships between items as they recall progressively more items, leading them to explicitly adopt a categorical organizational strategy as they recall the remaining items.

The bottom-up and top-down processes outlined above are not mutually exclusive. On the one hand, the overlapping peaks of activation or stronger category prototypes that characterize representations of strongly related objects may be necessary for younger children to notice the groups of objects in our task. On the other hand, explicitly noticing and strategically remembering the groups may serve to further strengthen and stabilize existing connections between the objects, leading to the formation of stronger spatial groups. This is consistent with other work showing that 7- and 9-year-old children are unable to take advantage of categorical

relations among nearby objects to form spatial groups unless they are able to see the groups simultaneously during learning (Recker & Plumert, 2008). In this study, participants either saw all the objects cumulatively placed in the box or saw each object placed individually and then removed from the box. Without the experience of seeing the objects in a group together during learning, younger children had more difficulty forming spatial groups of categorically-related objects. Although neither the Dynamic Field Theory nor the Category Adjustment Model incorporate top-down strategic processes into their accounts of spatial bias, it seems likely that associative and strategic processes work together to produce spatial bias in this task.

In conclusion, this investigation shows there are developmental changes over middle to late childhood in how the strength of object categories influences memory for locations. This work also underscores the tight links between memory for what objects are and where they are located. In particular, 7-year-olds had difficulty forming spatial groups when objects occupying the same quadrant of the box were weakly related, whereas 9- and 11-year-olds and adults formed spatial groups regardless of whether the objects were strongly or weakly related. We hypothesize that these developmental differences are the result of both changes in the strength of connections between category members in memory and changes in the ability to strategically organize and retrieve information about object locations. Further research is needed to better understand how associative and strategic processes work together to produce changes in children’s memory for object locations.

References

- Battig, W., & Montague, W. (1969). Category names for verbal items in 56 categories. *Journal of Experimental Psychology Monographs*, 80, 1–45.
- Bjorklund, D.F. (1987). How age changes in knowledge base contribute to the development of children's memory: An interpretive review. *Developmental Review*, 7(2), 93-130.
- Bjorklund, D.F. (1980). Children's identification of category relations in lists presented for recall. *The Journal of Genetic Psychology*, 136(1), 45-53.
- Bjorklund, D. F., & de Marchena, M. R. (1984). Developmental shifts in the basis of organization in memory: The role of associative versus categorical relatedness in children’s free recall. *Child Development*, 55, 952-962.
- Bjorklund, D. F., & Hock, H. S. (1982). Age differences in the temporal locus of memory organization in children’s recall. *Journal of Experimental Child Psychology*, 33, 347-362.
- Bjorklund, D.F., & Jacobs, J.W. (1984). A developmental examination of ratings of associative strength. *Behavior Research Methods, Instruments, & Computers*, 16 (6), 568-569.
- Bjorklund, D.F., & Jacobs, J.W. (1985). Associative and categorical processes in children's memory: The role of automaticity in the development of organization in free recall. *Journal of Experimental Child Psychology*, 39(3), 599-617.
- Carlson-Radvansky, L. A., Covey, E. S., & Lattanzi, K. M. (1999). “What” effects on “where”: Functional influences on spatial relations. *Psychological Science*, 10, 516-521.
- Chi, M. T. H. (1978). Knowledge structure and memory development. In R. Siegler (Ed.), *Children’s thinking: What develops?* (pp. 73-96). Hillsdale, NJ: Erlbaum.
- 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.

Corsale, K., & Ornstein, P. A. (1980). Developmental changes in children’s use of semantic information in recall. *Journal of Experimental Child Psychology*, 30, 231-245.

Curiel, J. M., & Radvansky, G. A. (1998). Mental organization of maps. Journal of Experimental Psychology: Learning, Memory, and Cognition, 24(1), 202-214.

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.

Friedman, A., & Brown, N. (2000a). Reasoning about geography. *Journal of Experimental Psychology: General*, 129, 193-219.

Hirtle, S. C., & Kallman, H. J. (1988). Memory for the locations of pictures: Evidence for hierarchical clustering. *American Journal of Psychology*, 101, 159-170.

Hirtle, S. C., & Mascolo, M. F. (1986). Effect of semantic clustering on the memory of spatial locations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 12, 182-189.

Hund, A. M., & Foster, E. K. (2008). The stability and flexibility of spatial categories based on object relatedness. *Developmental Psychology*, 44, 218-232.

Hund, A. M., & Plumert, J. M. (2002). Delay-induced bias in children’s memory for location. *Child Development*, 73, 829–840.

Hund, A. M., & Plumert, J. M. (2003). Does information about what objects are influence children’s memory for where objects are? *Developmental Psychology*, 39, 939-948.

Hund, A. M., & Plumert, J. M. (2005). The stability and flexibility of spatial categories. *Cognitive Psychology*, 50, 1-44.

Hund, A. M., Plumert, J. M., & Benney, C. J. (2002). Experiencing nearby locations together in time: The role of spatiotemporal contiguity in children’s memory for location.

Journal of Experimental Child Psychology, 82, 200–225.

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.

Kobasigawa, A., & Middleton, D. B. (1972). Free recall of categorized items by children at three grade levels. *Child Development*, 43, 1067-1072.

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

Lange, G. (1973) The development of conceptual and rote recall skills among school age children. *Journal of Experimental Child Psychology*, 15(3), 394-406.

Lange, G., & Griffith, S. B. (1977). The locus of organization failures in children’s recall. *Child Development*, 48, 1498-1502.

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(3), 555-564.

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.

Montello, D. R. (2003). Regions in geography: Process and content. In M. Duckham, M. F. Goodchild, & M. F. Worboys (Eds.), *Foundations of geographic information science* (pp. 173-189). London: Taylor & Francis.

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

Nida, R. E., & Lange, G. (1995). The effects of category distinctiveness and stimulus relations on young children’s use of retrieval clustering strategies. *The Journal of General Psychology*, 122, 345-355.

Piaget, J., & Inhelder, B. (1967). *The child’s conception of space*. New York: W. W. Norton & Company.

Plumert, J. M. (1994). Flexibility in children’s use of spatial and categorical organizational strategies in recall. *Developmental Psychology*, 30, 738–747.

Plumert, J. M. (2008). Children’s thinking is not just about what’s in the head: Understanding the organism and environment as a unified system. In R. V. Kail (Ed.), *Advances in Child Development and Behavior*, pp. 373- 417. San Diego, CA: Academic Press.

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

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.

Recker, K. M., & Plumert, J. M. (2008). How do opportunities to view objects together in time influence children’s memory for location? *Journal of Cognition and Development*, 9, 434-460.

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.

Sodian, B., Schneider, W., & Perlmutter, M. (1986). Recall, clustering, and metamemory in young children. *Journal of Experimental Child Psychology*, 41, 395-410.

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

Spencer, J. P., & Hund, A. M. (2003). Developmental continuity in the processes that underlie spatial recall. *Cognitive Psychology*, 47, 432-480.

Spencer, J. P., Simmering, V. R., Schutte, A. R., & Schöner, G. (2007). What does theoretical neuroscience have to offer the study of behavioral development? Insights from a dynamic field theory of spatial cognition. In J. M. Plumert & J. P. Spencer (Eds.), *The emerging spatial mind* (pp. 320-361). New York: Oxford University Press.

Stevens, A., & Coupe, P. (1978). Distortions in judged spatial relations. *Cognitive Psychology*, 10, 422-437.

Ungerleider, L. G., & Haxby, J. V. (1994). ‘What’ and ‘where’ in the human brain. *Current Opinion in Neurobiology*, 4, 157-165.

Ziemer, C. J., Buss, A. T., Spencer, J. P., & Plumert J. M. (April, 2009). *Recall of “where” is affected by “what”: Capturing categorical biases with Dynamic Field Theory*. Poster presented at the 34th Biennial Meeting of the Society for Research in Child Development, Denver, CO.