JOURNAL OF COGNITION AND DEVELOPMENT, 9(3):310–339

ISSN: 1524-8372 print/1532-7647 online
DOI: 10.1080/15248370802247988

Developmental Changes in Young Children's Spatial Memory and Language in Relation to Landmarks

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Two experiments investigated how young children and adults understand whether objects are *by* a landmark and remember their locations. Three- and 4-year-old children and adults were asked to judge whether several blocks were *by* a landmark. The blocks were arranged so that their absolute and relative distances from the landmark varied. Later, the blocks were removed, and participants were asked to place them in their original locations. All ages relied on relative distance between objects and a landmark when making *by* judgments; however, older children and adults showed systematic judgments. Relative distance also affected block placement, and systematicity increased across development. Children's understanding of the relative nature of *by* and their ability to remember locations precisely increased during the preschool years, indicating developmental changes in the adaptive combination of location cues for spatial language and memory.

The ability to remember and communicate about locations is central to human functioning. Children and adults need to remember the locations of many objects, such as shoes, mittens, and car keys, and communicate successfully regarding these locations to avoid long and tedious searches. Despite years of research demonstrating intriguing changes in location memory and communication abilities across age (Dromi, 1979; Hund & Plumert, 2005; Huttenlocher, Newcombe, & Sandberg, 1994; Johnston & Slobin, 1979; Meints, Plunkett, Harris, & Dimmock, 2002; Newcombe, Huttenlocher, Drummey, & Wiley, 1998; Plumert, Ewert, & Spear, 1995;

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Plumert & Hawkins, 2001; Sandberg, Huttenlocher, & Newcombe, 1996; Schutte & Spencer, 2002; Weist, Lymburner, Piortowski, & Stoddard, 2000), we know very little about the processes underlying these developmental changes. The purpose of this investigation was to examine how young children remember and communicate about locations in relation to landmarks.

How does memory for locations change during the preschool years? Early research focused on young children's use of egocentric and allocentric cues (e.g., Acredolo, 1977, 1978; McKenzie, Day, & Ihsen, 1984). For example, Acredolo and Evans (1980) showed that egocentric responding declined during the first year of life. Moreover, they noted that allocentric coding increased during the first two years, emerging first when using proximal landmarks and later when using more distal landmarks to remember locations. Likewise, Bushnell, McKenzie, Lawrence, and Connell (1995) found that 12-month-olds could find an object when it was hidden under a distinctive landmark but had difficulty finding the object when it was hidden *next to* a distinctive landmark. Other studies have show that even 5-year-olds are more likely to rely on proximal than distal landmarks to remember a location (Acredolo, 1976; Craton, Elicker, Plumert, & Pick, 1990; Overman, Pate, Moore, & Peuster, 1996). Together, these studies suggest that young children tend to rely on egocentric coding to remember locations. Later, they show increased reliance on landmarks that are very close to target objects to remember their locations. With development, children show increasing tendencies to use distal landmarks, indicating changes in the adaptive combination of location cues (Acredolo, 1990; Allen & Kirasic, 1988).

Research with adults has confirmed that they use landmarks to remember locations (e.g., Sadalla, Burroughs, & Staplin, 1980). In fact, much work has documented biases toward salient landmarks (Briggs, 1973; Bryant & Subbiah, 1994; Burroughs & Sadalla, 1979; Hubbard & Ruppel, 2000; McNamara & Diwadkar, 1997; Nelson & Chaiklin, 1980; Newcombe, Huttenlocher, Sandberg, Lie, & Johnson, 1999). For example, Sadalla et al. (1980) asked participants to estimate the distances between campus locations by placing one location marker in relation to an anchored location marker (i.e., at the origin of a semi-circular grid). Sometimes, landmarks served as the anchored locations, whereas other times, nonlandmarks served as the anchored locations. Participants tended to place nonlandmarks closer to anchored landmarks than vice versa, indicating that they think that nonlandmarks are closer to landmarks.

Do children show similar patterns of bias in relation to landmarks? In one study, first- and fifth-grade children learned the locations of several objects in a model town or farm and then estimated distances between pairs of locations (Presson, 1987). As expected, children tended to underestimate distances involving landmarks more than distances not involving landmarks. Despite the robustness of biases involving landmarks, their developmental emergence remains unclear. Thus, one goal of the present investigation was to examine the nature of location memory biases in relation to landmarks during the preschool years. To our knowledge, this was the first study to investigate such biases among preschool-aged children. As such, the present study would provide details regarding how young children use landmarks to remember locations.

A second goal of this investigation was to specify how young children communicate about locations in relation to landmarks. In English, we use prepositions or prepositional phrases to convey spatial information (e.g., The shoe is *by* the chair.). Early research focused on the order of acquisition of spatial terms, revealing striking similarities across languages. Children first produce terms such as *in*, *on*, and *under* and only later produce terms such as *beside*, *by*, *near*, and *next to* (e.g., Clark, 1973, 1980; Dromi, 1979; Johnston & Slobin, 1979). This investigation focused on young children's understanding of the spatial term *by* to describe the relation between nonlandmark locations and a landmark.

According to Herskovits (1986), people's conception of the spatial term *by* is based on the notion of relative proximity to a reference object (see also Landau & Jackendoff, 1993). As such, relative distance affects people's notions of *by*. When deciding whether a target object is *by* a reference object, people consider not only how far the target object is from the reference object (i.e., absolute distance), but also how far the target is from the reference object in relation to the distances between other nontarget objects and the reference object (i.e., relative distance). For example, assume that City Park is 5 blocks from one's house, and University Park is 2 blocks from home. The absolute distances between the parks and home are 5 blocks and 2 blocks, respectively. Based on these distances, we might judge that the parks are *by* the house. However, we might judge that City Park is *not by* the house because it is relatively further than University Park. Clearly, understanding the relative nature of proximity judgments involves complex cognitive skills. In fact, the ability to consider multiple, relative comparisons undergoes dramatic change during the preschool years (e.g., Huttenlocher, Newcombe, & Vasilyeva, 1999; Plumert et al., 1995; Plumert & Hawkins, 2001; Vasilyeva & Huttenlocher, 2004). For example, Gentner & Ratterman (1991) showed that children become increasingly able to use relative information during the preschool years. Thus, it is possible that young children's understanding of the proximity term *by* evolves as their understanding of relative distance increases, revealing a tight relation between linguistic and conceptual development.

To specify how young children's conception of *by* might change as a function of their understanding of relative distance, Hund and Plumert (2007) asked 3- and 4-year-old children and adults to judge whether or not several blocks were *by* a landmark. The blocks were arranged so that their absolute and relative distance from the landmark varied. All three age groups were more likely to judge blocks at an intermediate distance as *by* the landmark when intervening blocks were absent than when they were present. Nonetheless, reliance on relative distance became more systematic and applicable to larger spatial extents across development. These findings suggest that relative distance affects children and adult's communicative judgments, though it is unclear whether these factors also affect location coding.

One goal of the present study was to examine the nature of location memory biases in relation to landmarks. A second goal was to further specify how children's *by* judgments change during the preschool years. Together, these goals allowed us to probe the links between spatial memory and language during childhood. We expected to find developmental differences in young children's *by* judgments. In particular, we expected that, when making *by* judgments, 3-year-olds would use relative distance less systematically and across a narrower range of distances than would 4-year-olds. These findings would provide important insights regarding preschool children's changing conceptions of *by*. We also expected that memory for locations in relation to landmarks would become more precise over development. We speculated that bias toward landmarks might be evident by 3 years, though its magnitude might change over development. These findings would provide details about the development of memory processes. We included adult participants to provide details regarding mature memory and communication.

EXPERIMENT 1

Three- and 4-year-old children and adults were asked to judge whether several small blocks surrounding a larger box (i.e., a landmark) were *by* the box. We focused on participants' responses to target blocks that were the same absolute distance from the landmark but were different relative distances from the landmark. We expected that children and adults would judge the target blocks as *by* the landmark when other blocks did not intervene but would not judge the target blocks as *by* the landmark when other blocks intervened. In addition, we expected that fewer 3-year-olds would use relative distance systematically. We predicted that the precision of memory for locations would increase across development. Moreover, we expected that responses would be biased toward the landmark for all three ages, though the magnitude of bias might change over development (Huttenlocher, Hedges, & Duncan, 1991; Presson, 1987).

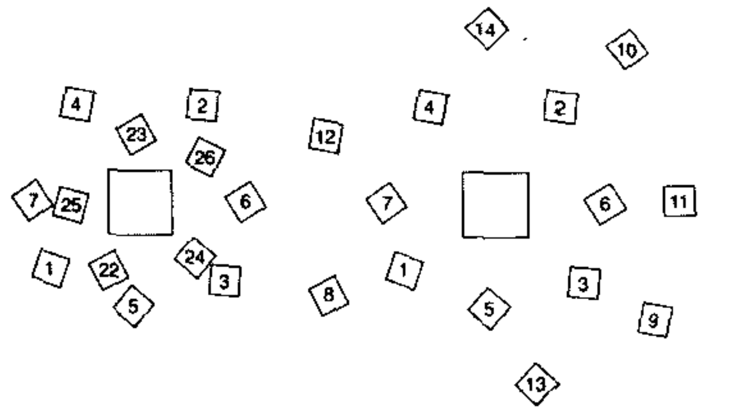
Method

Participants. Twenty-four 3-year-olds (mean age = 3:7, range = 3:0 to 3:11; 16 girls, 8 boys), 24 4-year-olds (mean age = 4:6, range = 4:3 to 4:11; 12 girls, 12 boys), and 24 adults (mean age = 21:7, range = 18:2 to 34:3; 12 women, 12 men) participated. Data from two additional 3-year-olds and two additional 4-year-olds were omitted because they did not complete the task. Children were from primarily middle- to upper-middle class Caucasian families. They were recruited from area preschools and day care centers, as well as from the community at large. Children received a small gift. Adults were recruited from undergraduate psychology courses at a Midwestern, public university and received extra credit.

Apparatus and materials. Nineteen identical small, brown blocks (1.13 in. tall × 2.5 in. wide × 2.5 in. deep; 2.87 cm × 6.35 cm × 6.35 cm) were arranged on a 78 in. long × 48 in. wide (198.1 cm × 122 cm) piece of white vinyl on the floor of the testing room. A larger, blue box (5 in. on all sides; 12.7 cm) at the center of the blocks served as a landmark. The blocks were arranged so that five blocks were 3 in. (7.62 cm) from the blue box in the center, seven blocks were 6 in. (15.24 cm) from the blue box, and seven blocks were 12 in. (30.48 cm) from the blue box. These blocks were classified as the inner, target, and outer blocks, respectively. The blocks were oriented to minimize the appearance that they created concentric circles around the landmark (see Figure 1).

A blank piece of white vinyl (78 in. long × 48 in. wide; 198.1 cm × 122 cm) was set down on top of the original vinyl for the memory portion of the experiment to cover the markings indicating the block locations. A 60 in. long × 45 in. wide (152.4 cm × 114.3 cm) transparent plastic mat (marked using 1-inch increments; 2.45 cm) served as a coding grid.

Design and procedure. Participants were randomly assigned to one of two conditions: intervening or nonintervening. In the intervening condition, the five inner blocks (7.62 cm from the box) and the seven target blocks (15.24 cm from the box) were present. In the nonintervening condition, the seven target blocks and the seven outer blocks (30.48 cm from the box) were present (see Figure 1). Participants were tested individually in a quiet room at their preschool or in the laboratory. They were seated on a chair approximately 28 in. (70 cm) from the edge of the vinyl. While seated,



(a) (b)

FIGURE 1 Panel A is a diagram of the block layout used in the intervening condition in Experiment 1. Panel B is a diagram of the block layout used in the nonintervening condition in Experiment 1. Block numbers are for illustration only.

participants were asked to make judgments about the proximity of the blocks to the landmark. The experimenter first marked the location by placing a small (1.25 in. diameter; 3.18 cm) marker on one of the blocks. Participants then were asked, "Do you think this block is *by* the blue box or *not by* the blue box?" for each of the blocks. The order of blocks was randomized for each participant. The participants also were told to pay attention to the block locations because they would be asked to put the blocks back in their correct locations later.

During the memory portion of the study, participants were asked to turn around while the experimenters set up the remaining portion. The blocks were removed and the unmarked piece of white vinyl was laid down. The landmark then was placed in the center of the vinyl. Participants were asked to place the blocks back in their previous locations. They were given as much time as necessary, and they were encouraged to move around if needed to place the blocks.

Coding and measures. For the communication task, the experimenter recorded the participants' *by* judgments for each block. For each participant, we then calculated the proportion of blocks at each distance (e.g., inner, target, outer) that were judged to be *by* the landmark. For the memory task, the experimenter laid the coding grid over the blocks and measured their x- and y-coordinates to the nearest inch (2.54 cm) after participants left. The coordinates for the five closest and seven furthest blocks were used to calculate displacement scores in the intervening condition, whereas coordinates for the seven closest and seven furthest blocks were used in the nonintervening condition. Displacement scores were calculated by subtracting the actual distances between the blocks and the landmark from the remembered distances between the blocks and the landmark. Positive scores reflected displacement toward the landmark, whereas negative scores reflected displacement away from the landmark.

Results

Communication: Individual patterns of responding. We examined individual patterns of responding to provide detailed information about the systematicity of children's *by* judgments. We were particularly interested in how many children and adults exhibited highly differentiated patterns of responding based on relative distance. We classified participants in the intervening condition as systematic users of relative distance if they said yes to at least 4 out of 5 inner blocks and no to at least 6 out of 7 target blocks. Likewise, we classified participants in the nonintervening condition as systematic users of relative distance if they said yes to at least 6 out of 7 target blocks and no to at least 6 out of 7 outer blocks. We also classified participants as having a yes (or no) bias if they said yes (or no) to at least all but one blocks. Responses not fitting one of these patterns were classified as mixed. Results are shown in Table 1. Only seven 3-year-old children were systematic users of relative distance, whereas twelve 4-year-olds and 21 adults used relative

TABLE 1
Individual Patterns of Responding in Experiment 1

Age and Condition	Number of Participants Exhibiting Each Response Pattern			
	Systematic	*Mixed*	*Yes Bias*	*No Bias*
3-year-olds				
Intervening	3	2	1	6
Nonintervening	4	5	1	2
4-year-olds				
Intervening	4	7	1	0
Nonintervening	8	4	0	0
Adults				
Intervening	9	3	0	0
Nonintervening	12	0	0	0

Note. The classification of individual participants is based on the proportion of yes (*by*) responses (see text for details).

distance systematically, indicating that systematic use of relative distance when making by judgments increases during the preschool years.

By responses. Did the systematicity with which children and adults responded to the blocks differ as a function of age, distance, or condition? To answer this question, the mean proportion of by responses was entered into an Age (3 years vs. 4 years vs. adult) × Condition (intervening vs. nonintervening) × Distance (closer vs. farther) mixed model analysis of variance (ANOVA) with the first two factors as between-subjects factors and the third as a within-subjects factor. There were significant main effects of age, $F(2, 66) = 3.31$, $p < .05$, and of distance, $F(1, 66) = 382.35$, $p < .001$. These main effects were subsumed by a significant Age × Distance interaction, $F(2, 66) = 22.45$, $p < .001$. Simple effects tests yielded a significant difference across distance for 3-year-olds, $F(1, 23) = 23.59$, $p < .001$; for 4-year-olds, $F(1, 23) = 130.47$, $p < .001$; and for adults, $F(1, 23) = 663.82$, $p < .001$. As expected, the proportion of *by* responses to the closer blocks (3 years: $M = .56$, $SD = .40$; 4 years: $M = .81$, $SD = .21$; Adults: $M = .99$, $SD = .05$) was significantly greater than the proportion for the farther blocks (3 years: $M = .19$, $SD = .32$; 4 years: $M = .10$, $SD = .23$; Adults: $M = .06$, $SD = .15$) for all three age groups. Additional tests of simple effects revealed a significant effect of age for responses to the closer blocks, $F(2, 69) = 16.08$, $p < .001$, but not for the farther blocks, $F(2, 69) = 1.66$, *ns*. Follow-up tests revealed that 3-year-olds were significantly less likely to judge that the closer blocks were by the landmark than were the 4-year-olds and adults. Similarly, the 4-year-olds were significantly less likely to judge that the closer blocks were by the landmark than were the adults. These findings indicate that systematicity increases across development.

The analysis also revealed a significant Condition × Distance interaction, $F(1, 66) = 5.42$, $p < .05$. Simple effects tests yielded a significant difference across distance in the intervening condition, $F(1, 35) = 79.33$, $p < .001$, and in the nonintervening condition $F(1, 35) = 182.56$, $p < .001$. As expected, the proportion of *by* responses was significantly greater for the closer blocks than for the farther blocks in both conditions (intervening close: $M = .75$; $SD = .35$; intervening far: $M = .16$; $SD = .28$; nonintervening close: $M = .81$; $SD = .28$; nonintervening far: $M = .07$, $SD = .19$). Additional tests of simple effects revealed a marginally significant effect of condition for responses to the farther blocks, $F(1, 70) = 2.81$, $p < .10$, but not for the closer blocks, $F(1, 70) = .73$, *ns*. Follow-up tests revealed that the proportion of *by* responses for the farther blocks was lower in the nonintervening condition than in the intervening condition, indicating that *by* responses decline as the distance from the landmark increases.

By responses for the target blocks. One specific question of interest was whether children and adults were more likely to judge the target blocks (15.24 cm from the box) as *by* the landmark when no intervening blocks were present than when intervening blocks were present. To address this issue, the proportion of *by* responses for the target blocks was entered into an Age (3 years vs. 4 years vs. adult) × Condition (intervening vs. nonintervening) ANOVA. As expected, the analysis yielded a significant main effect of condition, $F(1, 66) = 105.36$, $p < .001$, and a significant Age × Condition interaction, $F(2, 66) = 3.72$, $p < .05$. Simple effects tests yielded a significant effect of condition for 3-year-olds, $F(1, 22) = 9.73$, $p < .01$; for 4-year-olds, $F(1, 22) = 35.28$, $p < .001$; and for adults, $F(1, 22) = 216.68$, $p < .001$. All ages were significantly more likely to judge the target blocks as *by* the landmark when no blocks intervened than when other blocks intervened (see Figure 2), suggesting that they used relative distance to make *by* judgments. Additional simple effects tests revealed that *by* responses differed significantly across age groups for participants in the nonintervening condition, $F(2, 33) = 5.87$, $p < .01$, but not for participants in the intervening condition, $F(2, 33) = .35$, *ns*. Follow-up tests showed that, in the nonintervening condition, 3-year-olds were significantly less likely than were the adults to judge that the target blocks were *by* the landmark. The other

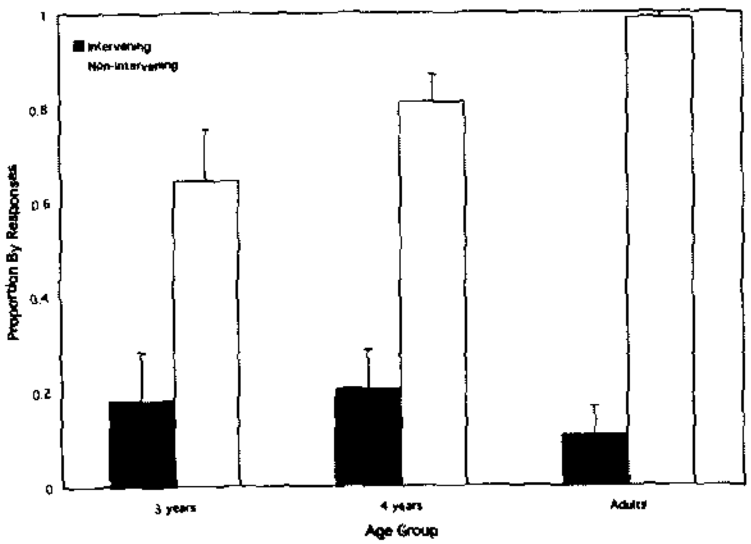


FIGURE 2 Mean proportion of *by* responses to the target blocks for each age group and condition in Experiment 1.

pair-wise differences among age groups did not reach statistical significance (see Figure 2).

Memory: Individual patterns of block placement. Another primary goal of the study was to examine the precision with which children and adults remembered the block locations, particularly whether they displaced the blocks toward the landmark. We examined individual patterns of block placement to provide detailed information about the systematicity of children's memory for locations. We were particularly interested in how many children and adults exhibited patterns that were akin to the actual locations (i.e., blocks form two concentric circles surrounding the central landmark) versus other types of patterns, including central clumping (i.e., blocks within 8 inches of the central landmark), edge clumping (i.e., blocks within 8 inches of the outer edge of the white vinyl), linear (i.e., blocks form a continuous line), or pretend play (i.e., blocks form a recognizable shape or are stacked on top of each other). We classified participants as exhibiting one of these patterns if at least all but two of the blocks met the criterion for that pattern. Participants not meeting these criteria were classified as other. The results are shown in Table 2. No 3-year-old children placed the blocks in two concentric circles. In contrast, six 4-year-old children and 22 adults placed the blocks in two concentric circles, exhibiting highly systematic placements. Four 3-year-olds exhibited central clumping, whereas nine 4-year-olds and one adult exhibited this pattern. Sixteen 3-year-olds, eight 4-year-olds,

TABLE 2
Individual Patterns of Block Placement in Experiment 1

	Number of Participants Exhibiting Each Pattern of Block Placement					
Age & Condition	*Concentric Circles*	*Central Clumping*	*Edge Clumping*	*Linear*	*Pretend Play*	*Other*
3-year-olds						
Intervening	0	4	0	0	2	6
Nonintervening	0	0	0	2	0	10
4-year-olds						
Intervening	2	9	0	0	1	0
Nonintervening	4	0	0	0	0	8
Adults						
Intervening	10	1	0	0	1	1
Nonintervening	12	0	0	0	1	0

Note. The classification of individual participants is based on the pattern of block placements (see text for details).

and one adult exhibited other patterns. Together, these findings indicate a dramatic shift from less systematic to more systematic block placements over development.

Block displacement. To determine whether displacement toward or away from the landmark differed across ages, conditions, and distances, block displacement was entered into an Age (3 years vs. 4 years vs. adult) × Condition (intervening vs. nonintervening) × Distance (closer vs. farther) mixed model ANOVA. There were significant main effects of age, $F(2, 66) = 13.79$, $p < .001$, and of distance, $F(1, 66) = 20.96$, $p < .001$, and a significant Age × Distance interaction, $F(2, 66) = 15.78$, $p < .001$. Simple effects tests yielded a significant difference across distance for 3-year-olds, $F(1, 23) = 20.43$, $p < .001$, and for adults, $F(1, 23) = 5.76$, $p < .05$, but not for 4-year-olds, $F(1, 23) = .14$, ns. For 3-year-olds and adults, outward displacement for the farther blocks was significantly greater than was outward displacement for the closer blocks (see Figure 3). In contrast, inward displacement did not differ across distances for the 4-year-olds (see Figure 3). Additional tests of simple effects revealed a significant effect of age for placements of the closer blocks, $F(2, 69) = 7.81$, $p < .001$, and of the farther blocks, $F(2, 69) = 17.06$, $p < .001$. Follow-up tests revealed that 4-year-olds placed the closer blocks closer to the landmark than did the 3-year-olds and adults. Placements did not differ significantly for 3-year-olds and adults. Moreover, 3-year-olds placed the farther blocks significantly further from the landmark than did the 4-year-olds and adults. Placements did not differ significantly for the 4-year-olds and adults.

Displacement of the target blocks. To determine the effect of relative distance on block displacement, displacement scores for the target blocks were entered into an Age (3 years vs. 4 years vs. adult) × Condition (intervening vs. nonintervening) ANOVA. A significant main effect of age was found, $F(2, 66) = 12.86$, $p < .001$. Follow-up tests indicated that the 3-year-olds ($M = -4.39$ in., $SD = 6.29$ in.) placed the target blocks significantly further from the landmark than did the 4-year-olds ($M = 1.07$ in., $SD = 1.47$ in.) and adults ($M = -.94$ in., $SD = 1.26$ in.). Placements for 4-year-olds and adults did not differ. No other effects reached statistical significance.

Discussion

One goal of this experiment was to investigate how 3- and 4-year-olds make *by* judgments, particularly the extent to which they rely on relative distance.

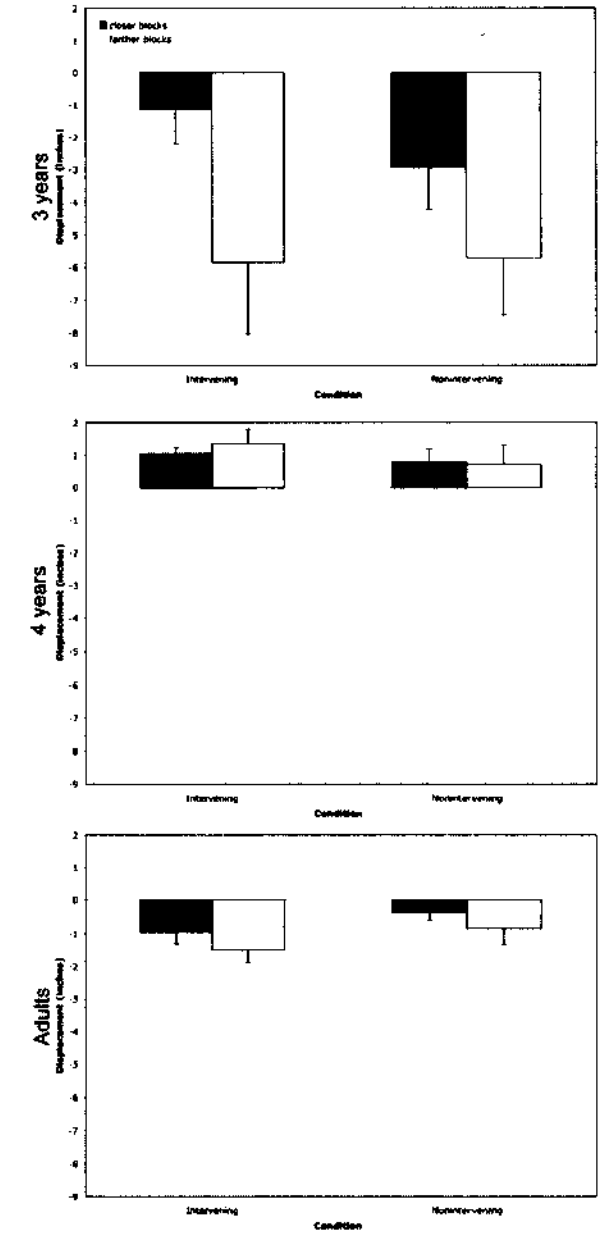


FIGURE 3 Mean block displacement for each age group, condition, and distance in Experiment 1. Positive scores reflect displacement toward the landmark, whereas negative scores reflect displacement away from the landmark.

We compared judgments for a target set of blocks across two conditions in which other blocks were present in intervening locations or in nonintervening locations. All three age groups were significantly more likely to judge the target blocks as *by* the landmark when no other blocks intervened than when other blocks intervened, indicating that they relied on relative distance when communicating about locations. Across all three age groups, *by* responses declined as the distance from the landmark increased. Nonetheless, response differentiation increased across development. In particular, the 3-year-olds were significantly less likely than the older ages to judge the closer blocks as *by* the landmark. Similarly, the 4-year-olds were less likely than the adults to judge the closer blocks as *by* the landmark. These findings suggest that systematicity increased from 3 years to 4 years to adulthood. Inspection of individual patterns of response confirmed this notion: seven 3-year-old children were systematic users of relative distance, whereas twelve 4-year-olds and 21 adults used relative distance systematically.

Another primary goal was to examine how memory for locations in relation to a landmark changes across development. In particular, we investigated whether young children and adults displaced blocks toward or away from a landmark. Interestingly, 3-year-olds and adults tended to displace the blocks away from the landmark. In fact, the magnitude of displacement away from the landmark increased as the distance from the landmark increased. In contrast, 4-year-olds tended to displace the blocks toward the landmark, and the magnitude of this displacement did not change across distance. These results offer an intriguing U-shaped developmental pattern of displacement in which the 3-year-olds and adults exhibit displacement away from the landmark and the 4-year-olds exhibit displacement toward the landmark.

What might account for this U-shaped developmental pattern? Adults' placements were highly systematic and fairly accurate overall, though their placements were repelled slightly from the landmark. In contrast, 4-year-olds' placements clearly were attracted toward the landmark. Three-year-olds' placements were highly variable and generally not attracted toward the landmark. It is possible that this change in the nature of memory biases involving landmarks during the preschool years parallels a developmental shift from attraction toward the midline axis (at 3 years) to repulsion from the midline axis (at 6 years) observed in spatial recall tasks (Hund & Spencer, 2003; Huttenlocher et al., 1994; Schutte & Spencer, 2002). Schutte, Spencer, and Schöner (2003) maintain that this change results from increases in the spatial precision of working memory over development. Importantly, the present findings indicate that location distortions change not only across development but also across tasks (i.e., 3-year-olds show biases toward the middle of a space in a spaceship task reported by Schutte & Spencer (2002) and away from the middle of a space in the block replacement task reported here). Thus, it is possible that working memory precision varies as a function of complex interactions among perceiving and remembering in the context of specific social and physical environments (see also Plumert, Hund, & Recker, 2007). Clearly, additional research is needed to specify the complex dynamics underlying distortions in location estimates toward or away from reference points in different situations, perhaps focusing on the interaction between task difficulty and memory precision.

Toward that end, our second experiment was designed to examine young children's memory and communication regarding locations in relation to landmarks under different task demands. In particular, we tested whether patterns of *by* judgments and block displacement depend on the overall distances between the blocks and the landmark. The design was identical to Experiment 1, except that blocks were presented at 6 and 12 inches (15.24 and 30.48 cm) or 12 and 18 inches (30.48 and 45.72 cm). We predicted that 3-year-olds' *by* judgments would be less systematic than would the older ages. Moreover, we expected that systematicity would be lower here than in the previous experiment, given the more challenging nature of the task involving greater spatial extents. Given the unexpected U-shaped pattern of displacement revealed in the first experiment, we sought to extend the findings regarding memory for locations relative to landmarks over larger distances. We predicted that the 3-year-olds would displace the blocks away from the landmark, whereas the other ages would displace the blocks toward the landmark. Nonetheless, we anticipated that the magnitude of displacement toward the landmark might decline as distance from the landmark increased.

EXPERIMENT 2

Method

Participants. Twenty-four 3-year-olds (mean age = 3:8, range = 3:1 to 3:11; 13 girls, 11 boys), 24 4-year-olds (mean age = 4:8, range = 4:1 to 4:12; 11 girls, 13 boys), and 24 adults (mean age = 20:11, range = 18:10 to 29:11; 14 women, 10 men) participated. Data from three additional 3-year-olds were omitted because they did not complete the task. Children and adults were recruited and compensated in the same manner as in Experiment 1.

Apparatus and materials. The same blocks, landmark, vinyl surfaces, and coding grid were used as in the previous experiment. This time, the blocks were arranged so that seven blocks were 6 in. (15.24 cm) from the blue

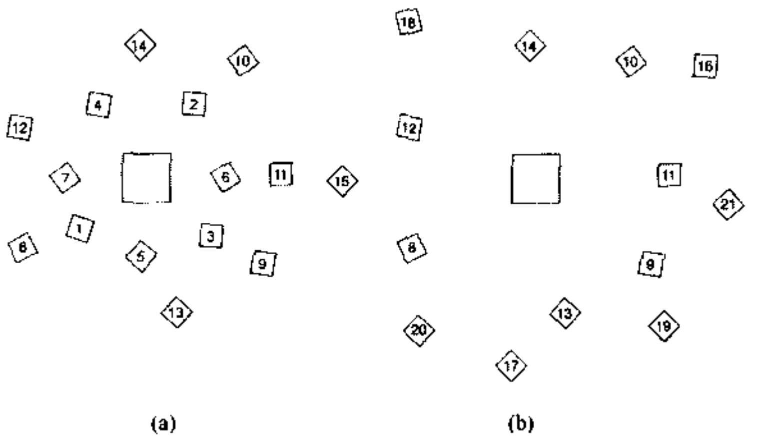


FIGURE 4 Panel A is a diagram of the block layout used in the intervening condition in Experiment 2. Panel B is a diagram of the block layout used in the nonintervening condition in Experiment 2. Block numbers are for illustration only.

box in the center, seven blocks were 12 in. (30.48 cm) from the blue box, and seven blocks were 18 in. (45.72 cm) from the blue box. These blocks were classified as the inner, target, and outer blocks, respectively (see Figure 4).

Design, procedure, coding, and measures. Participants were randomly assigned to one of two conditions: intervening or nonintervening. In the intervening condition, the seven inner blocks (15.24 cm from the box) and the seven target blocks (30.48 cm from the box) were present. In the nonintervening condition, the seven target blocks and the seven outer blocks (45.72 cm from the box) were present (see Figure 4). As in Experiment 1, participants were asked whether each block was *by* the blue box or *not by* the blue box. Then, they were asked to replace the blocks in their locations. The coding and measures were identical to those used in Experiment 1.[1]

Results

Communication: Individual patterns of responding. As in Experiment 1, we examined individual patterns of responding to provide information

[1]Note that the coordinates for the seven closest and seven furthest blocks were used to calculate displacement scores in both conditions.

TABLE 3
Individual Patterns of Responding in Experiment 2

Age and Condition	*Number of Participants Exhibiting Each Response Pattern*			
	Systematic	*Mixed*	*Yes Bias*	*No Bias*
3-year-olds				
Intervening	2	8	0	2
Nonintervening	1	10	0	1
4-year-olds				
Intervening	9	3	0	0
Nonintervening	2	8	1	1
Adults				
Intervening	11	0	1	0
Nonintervening	10	1	1	0

Note. The classification of individual participants is based on the proportion of yes (*by*) responses (see text for details).

about the systematicity of children's by judgments. We were particularly interested in how many children and adults exhibited highly differentiated patterns of responding based on relative distance. The classifications for systematic use of relative distance, mixed responding, and yes/no bias were identical to those used in Experiment 1.[2] The results are shown in Table 3. Only three 3-year-old children were systematic users of relative distance, whereas eleven 4-year-olds and 21 adults used relative distance systematically. Note that the individual response patterns were fairly consistent across the two experiments for the older two age groups, whereas the number of systematic responders declined between Experiments 1 and 2 for the 3-year-olds.

By responses. Did the systematicity with which children and adults responded to the blocks differ as a function of age, distance, or condition? We expected that participants' *by* responses would decrease as the distance between the blocks and the landmark increased for all ages, though systematicity would increase over development. The mean proportion of *by* responses was entered into an Age (3 years vs. 4 years vs. adult) × Condition (intervening vs. nonintervening) × Distance (closer vs. farther) mixed model ANOVA. There were significant main effects of age, $F(2, 66) = 4.38$, $p < .05$, and of distance, $F(1, 66) = 266.17$, $p < .001$. These main effects were subsumed by a significant Age × Distance interaction,

[2] Note that participants in the intervening condition needed to respond yes to at least 6 out of 7 blocks to be considered systematic.

F (2, 66) = 15.32, p < .001. Simple effects tests yielded a significant difference across distance for 3-year-olds, F (1, 23) = 25.28, p < .001; for 4-year-olds, F (1, 23) = 98.41, p < .001; and for adults, F (1, 23) = 157.71, p < .001. As expected, the proportion of *by* responses was significantly greater for the closer blocks (3 years: M = .55, SD = .34; 4 years: M = .77, SD = .26; Adults: M = .98, SD = .10) than for the farther blocks (3 years: M = .20, SD = .22; 4 years: M = .16, SD = .25; Adults: M = .12, SD = .30) for all three age groups. Additional tests of simple effects revealed a significant effect of age for responses to the closer blocks, F (2, 69) = 17.12, p < .001, but not for the farther blocks, F (2, 69) = .62, ns. Follow-up tests revealed that 3-year-olds were significantly less likely to judge that the closer blocks were by the landmark than were the 4-year-olds and adults. Similarly, the 4-year-olds were significantly less likely to judge that the closer blocks were by the landmark than were the adults. These findings indicate that systematicity increases across development.

The analysis also revealed a significant Condition × Distance interaction, $F(1, 66) = 5.72$, $p < .05$. Simple effects tests yielded a significant difference across distance in the intervening condition, $F(1, 35) = 134.71$, $p < .001$, and in the nonintervening condition, $F(1, 35) = 63.61$, $p < .001$. As expected, the proportion of *by* responses to the closer blocks was significantly greater than the proportion for the farther blocks in both conditions (intervening close: $M = .81$; $SD = .27$; intervening far: $M = .11$; $SD = .23$; nonintervening close: $M = .73$; $SD = .33$; nonintervening far: $M = .21$, $SD = .28$). Additional tests of simple effects revealed no effect of condition for responses to the closer blocks, $F(1, 70) = 1.13$, *ns*, or for the farther blocks, $F(1, 70) = 2.96$, *ns*.

By responses for the target blocks. To determine whether children and adults were more likely to judge the target blocks (30.48 cm from the box) as *by* the box when no intervening blocks were present than when intervening blocks were present, the proportion of *by* responses for the target blocks was entered into an Age (3 years vs. 4 years vs. adult) × Condition (intervening vs. nonintervening blocks) ANOVA. Results revealed significant main effects of condition, $F(1, 66) = 111.08$, $p < .001$, and of age, $F(2, 66) = 3.25$, $p < .05$, as well as a significant Age × Condition interaction, $F(2, 66) = 7.60$, $p < .01$. Simple effects tests revealed a significant effect of condition for 3-year-olds, $F(1, 22) = 7.30$, $p < .05$; for 4-year-olds, $F(1, 22) = 49.00$, $p < .001$; and for adults, $F(1, 22) = 94.41$, $p < .001$. As in Experiment 1, all ages were significantly more likely to judge the target blocks as *by* the landmark when no blocks intervened than when other blocks intervened (see Figure 5), suggesting that all three ages used relative distance to make *by* judgments. Additional tests of simple effects revealed

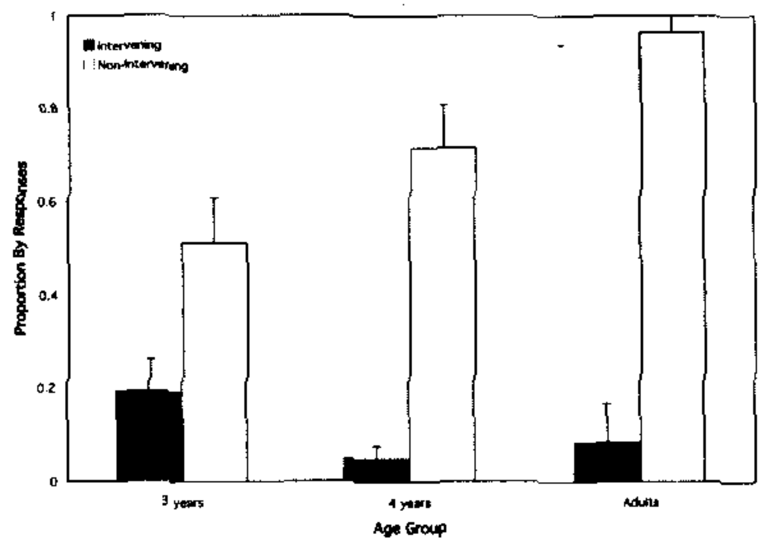


FIGURE 5 Mean proportion of *by* responses to the target blocks for each age group and condition in Experiment 2.

that *by* judgments differed across age groups in the nonintervening condition, $F(2, 33) = 8.09$, $p < .005$, but not in the intervening condition, $F(2, 33) = 1.34$, *ns*. Follow-up tests showed that, in the nonintervening condition, adults were more likely to judge that the target blocks were *by* the landmark than were the 3- and 4-year-olds. Responses from the two child ages did not differ significantly.

Memory: Individual patterns of block placement. Another primary goal of the study was to investigate differences in block displacement based on age and condition. As in Experiment 1, we examined individual patterns of block placement to provide detailed information about the systematicity of children's memory for locations. The classification system was identical to that used in Experiment 1, and the results are shown in Table 4. Two 3-year-old children placed the blocks in two concentric circles. In contrast, eight 4-year-old children and all 24 adults placed the blocks in two concentric circles. These findings generally parallel those from the first experiment, indicating a dramatic shift from less systematic to more systematic block placements over development. It is interesting to note that edge clumping was more common and central clumping was less common here than in

TABLE 4
Individual Patterns of Block Placement in Experiment 2

	Number of Participants Exhibiting Each Pattern of Block Placement					
Age & Condition	*Concentric Circles*	*Central Clumping*	*Edge Clumping*	*Linear*	*Pretend Play*	*Other*
3-year-olds						
Intervening	1	2	0	2	4	3
Nonintervening	1	0	5	0	1	5
4-year-olds						
Intervening	5	0	0	0	3	4
Nonintervening	3	0	2	0	1	6
Adults						
Intervening	12	0	0	0	0	0
Nonintervening	12	0	0	0	0	0

Note. The classification of individual participants is based on the pattern of block placements (see text for details).

the first experiment among the child participants, confirming the influence of increasing spatial extent on children's patterns of block placement. Five 3-year-olds and two 4-year-olds exhibited edge clumping here, whereas none exhibited this pattern in the previous experiment. In addition, pretend play was more common here than in Experiment 1. Five 3-year-olds and four 4-year-olds exhibited pretend play in the present experiment (versus two 3-year-olds and one 4-year-old in the previous experiment). These differences across experiments may be due to the challenging nature of the task in Experiment 2 in which the block layouts covered larger spatial extents than did the layouts used in the first experiment.

Block displacement. To determine whether displacement toward or away from the landmark differed across ages, conditions, and distances, block displacement was entered into an Age (3 years vs. 4 years vs. adult) × Condition (intervening vs. nonintervening) × Distance (closer vs. farther) mixed model ANOVA. There was a significant main effect of distance, F (1, 66) = 31.31, $p < .001$; a significant Age × Distance interaction, F (2, 66) = 8.22, $p < .001$; and a significant Condition × Distance interaction, F (1, 66) = 9.67, $p < .01$. These effects were subsumed by a significant Age × Distance × Condition interaction, F (2, 66) = 5.83, $p < .01$. Simple effects tests yielded a significant difference across distance for 3-year-olds in the nonintervening condition, F (1, 11) = 17.99, $p < .01$, and 4-year-olds in the nonintervening condition, F (1, 11) = 50.91, $p < .001$, and a marginally significant difference across distance for 4-year-olds in the intervening

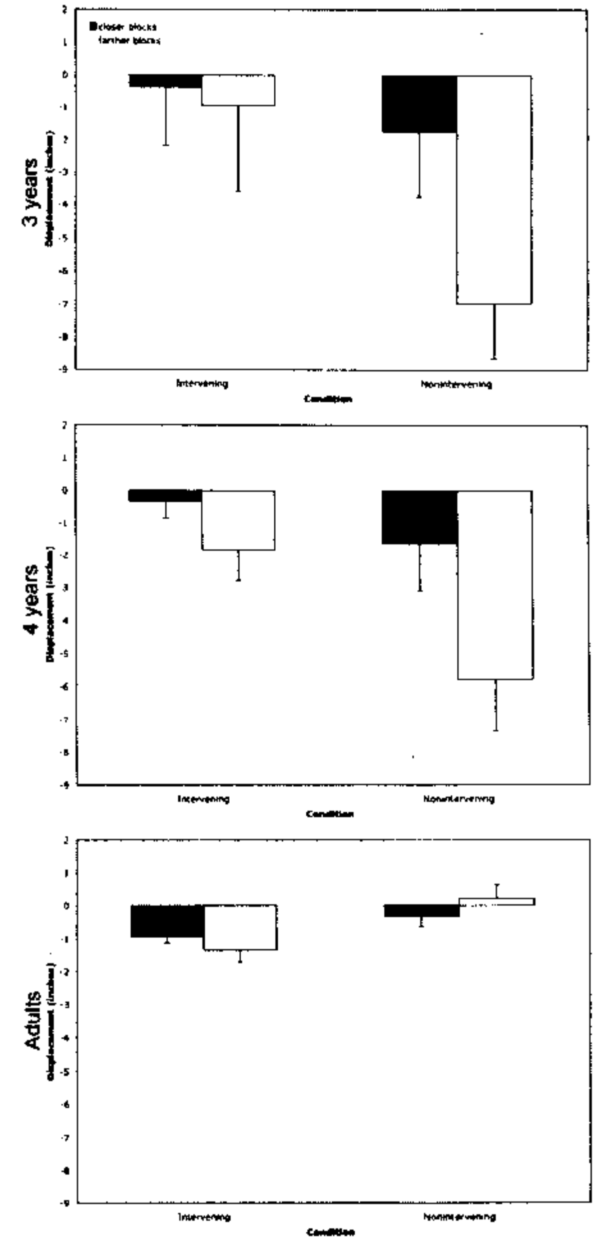


FIGURE 6 Mean block displacement for each age group, condition, and distance in Experiment 2. Positive scores reflect displacement toward the landmark, whereas negative scores reflect displacement away from the landmark.

condition, $F(1, 11) = 3.43$, $p < .10$, but not for the remaining ages and conditions, $Fs(1, 11) < 1.76$, ns. For 3-year-olds in the nonintervening condition and 4-year-olds in both conditions, outward displacement was significantly greater for the farther blocks than for the closer blocks (see Figure 6). Additional tests of simple effects revealed a significant effect of age for placements of the farther blocks in the nonintervening condition, $F(2, 33) = 7.85$, $p < .01$, but not for the other conditions and distances, $Fs(2, 33) < .31$, ns. Follow-up tests revealed that 3- and 4-year-olds' placements of the farther blocks (in the nonintervening condition) were significantly further from the landmark than were the adults' placements. Placements did not differ significantly for 3- and 4-year-olds. Together, these findings indicate that the magnitude of bias away from the landmark was particularly large for 3- and 4-year-olds and somewhat smaller for adults. These biases away from the landmark for the 3-year-olds and adults generally are consistent with the findings from Experiment 1. In contrast, the 4-year-olds' placements were biased away from the landmark here, but toward the landmark in Experiment 1. Implications of these findings are discussed in greater detail in the General Discussion.

Displacement of the target blocks. To examine the influence of relative distance on block displacement, displacement scores for the target blocks were entered into an Age (3 years vs. 4 years vs. adult) × Condition (intervening vs. nonintervening) ANOVA, revealing no significant effects. Participants in all age groups and conditions tended to displace the target blocks away from the landmark.

DISCUSSION

The goal of Experiment 2 was to examine the influence of spatial extent on *by* judgments and memory for locations. In particular, we hypothesized that 3-year-olds would have greater difficulty using relative distance in a systematic fashion when the distances involved were larger than in the previous study. As in Experiment 1, we compared *by* judgments for blocks at a given distance across two conditions in which other blocks were present in intervening locations or in nonintervening locations. *By* judgments for the target blocks differed significantly across conditions for all three age groups, suggesting that the relative distance between the target blocks and the landmark affected *by* judgments. Thus, contrary to our predictions, 3-year-olds' responses differed across layouts even when the overall distances involved were quite large. Nonetheless, only three 3-year-old children (in comparison to eleven 4-year-old children and 21 adults in the present study and seven 3-year-olds in the first experiment) systematically used relative distance when making *by* judgments, indicating that 3-year-olds' judgments were less systematic than were the judgments of the 4-year-olds and adults. In addition, the 3-year-olds were less willing to say that the inner blocks were *by* the landmark than were the older age groups, suggesting that young children's *by* judgments rely increasingly on relative distance with development. Comparison of individual patterns of responses across experiments suggests that systematic use of relative distance depends on the overall spatial extent involved, particularly for 3-year-olds. Three-year-olds were more likely to respond systematically when the blocks covered a smaller spatial extent (Experiment 1) than when they covered a larger spatial extend (Experiment 2). Responses among 4-year-olds and adults were nearly identical across experiments. Thus, spatial extent appears to influence young children's patterns of responding.

A second primary goal was to examine how memory for locations in relation to a landmark changes across development as a function of spatial extent. In particular, we investigated whether young children and adults displaced the blocks toward or away from the landmark. As in the first experiment, 3-year-olds tended to displace the blocks away from the landmark (though several patterns of block placement were observed across individuals). In fact, the magnitude of displacement away from the landmark increased as the distance from the landmark increased. In contrast to the previous experiment, the 4-year-olds also tended to displace the blocks away from the landmark. Adults tended to displace the blocks away from the landmark. The magnitude of outward displacement was particularly large for the closer blocks and decreased across distance. In fact, adults displaced the farthest blocks slightly toward the landmark. Inspection of individual patterns of block placement generally confirmed these findings. Three- and 4-year-olds tended to place the blocks near the edges of the vinyl, in a linear pattern, or in other shapes or small stacks (rather than in two concentric circles, as the adults did). These findings underscore young children's responses to the more challenging nature of the task. Moreover, they suggest a shift from less to more systematic responding over development.

General Discussion

This investigation was one of the first to examine young children's memory for multiple locations, thereby providing detailed information about children's memory processes (Kosslyn, Pick, & Fariello, 1974). In particular, we focused on the emergence of bias toward or away from a central landmark. In both experiments, 3-year-olds tended to displace the blocks away from the landmark for all distances tested. Interestingly, the magnitude of displacement away from the landmark increased as the distance from the landmark increased. These findings reveal strong biases in location coding for young children (Uttal 1994, 1996).

Block placement patterns for the 4-year-olds differed dramatically across experiments. In Experiment 1, in which the blocks were fairly close to the landmark overall, the 4-year-old children tended to displace the blocks toward the landmark, and the magnitude of this displacement did not change in magnitude across distance. In Experiment 2, in which the blocks were more distant from the landmark overall, the 4-year-olds tended to displace the blocks away from the landmark. The magnitude of this displacement was particularly large for the largest distance. We believe that this difference in responding across experiments reveals that 4-year-olds' coding of block locations is transitional in nature. In particular, when the task is challenging (i.e., when the layout of blocks is spread over a greater distance), 4-year-olds rely on the edges of the space to code the block locations. As a result, their placements are biased away from the landmark. This pattern of outward bias is evident at both distances for the 3-year-olds. In contrast, when the task is less challenging (i.e., when the layout of blocks is more compact), 4-year-olds rely on the central landmark to code the block locations. As a result, their placements are biased toward the landmark. Inspection of individual patterns of block placement generally confirms these observations. Specifically, nine 4-year-olds in the intervening condition in Experiment 1 placed all of the blocks near the central landmark, whereas two 4-year-olds in the nonintervening condition in Experiment 2 placed all of the blocks near the edges of the vinyl. Overall, the observed pattern of bias toward a landmark is similar to previous findings with school-aged children and adults (e.g., McNamara & Diwadkar, 1997; Newcombe et al., 1999; Presson, 1987; Sadalla et al., 1980).

In the present study, adults tended to displace the blocks away from the landmark. In Experiment 1, the magnitude of displacement increased over distance. In Experiment 2, however, the magnitude of outward displacement was particularly large for the closest blocks and decreased across distance. In fact, adults displaced the furthest blocks slightly toward the landmark. These findings were unexpected, given the reports of displacement toward landmarks noted in the literature (e.g., e.g., Hubbard, & Ruppel, 2000; McNamara & Diwadkar, 1997; Nelson & Chaiklin, 1980; Newcombe et al., 1999; Sadalla et al., 1980). Nonetheless, closer inspection of previous findings revealed biases away from landmarks in perceptual studies (Gourtzelidis, Smyrnis, Evdokimidis, & Balogh, 2001; Schmidt, 2005; Schmidt, Werner, & Diedrichsen, 2003; Suzuki & Cavanaugh, 1997; Werner & Diedrichsen, 2002). For example, Werner and Diedrichsen (2002) asked adults to view two landmarks and a dot on a computer screen. At test, the landmarks reappeared, and participants were asked to move the cursor to the remembered dot location. Dot reproductions were repelled from the landmarks in both conditions. Thus, it appears as if adults tend to remember locations as closer to landmarks in some experiments and as further from landmarks in other experiments. In fact, previous developmental findings have yielded similarly mixed results regarding distance estimation. Initially, Piaget, Inhelder, and Szeminska (1960) suggested that the perception of distance between two objects is underestimated, or shortened, when an intervening object is introduced. More recently, researchers have suggested that the presence of an intervening object or barrier leads to overestimation, or lengthening, of distance (e.g., Kosslyn et al., 1974; Newcombe & Liben, 1982). Although it is not clear why responses in some experiments are biased toward landmarks and in other experiments are biased away from landmarks, recent findings from Schmidt (2005) offer intriguing possibilities. In that work, adults viewed a dot among three landmarks (i.e., three open circles forming a triangle) on a computer display and reproduced the dot location after a short delay. Responses very near the landmarks were distorted away from the landmarks. In contrast, responses further away were biased toward the landmarks. Thus, it is possible that differences in response biases result from changes in repulsion and attraction as the distance between the target locations and landmarks increases (for related theoretical ideas, see Spencer & Schöner, 2003). It is also possible that the present pattern of findings resulted from a tight linkage between spatial language and memory. That is, perhaps thinking about whether or not blocks are *by* the landmark changed the way the participants remembered their locations (for related ideas, see Levinson, Kita, Haun, & Rasch, 2002; Majid, Bowerman, Kita, & Haun, 2004). These possibilities deserve further systematic study.

What do the present findings suggest regarding the developmental emergence of memory bias involving landmarks and nonlandmarks? First, 3-year-old children tend to think that blocks are further from landmarks than they really are. Four-year-old children tend to think that blocks are further from the landmark when the distances involved are large, but they think that the blocks are closer to the landmark than they really are when the distances involved are smaller. Adults are more accurate overall. Their smaller biases reveal tendencies to think that blocks are further from the landmark than they really are. Together, these findings suggest that location memory biases are evident from a young age, confirming that young children rely on relational information to code locations (Huttenlocher et al., 1994; Schutte &

Spencer, 2002; Sluzenski, Newcombe, & Satlow, 2004; Spencer, Smith, & Thelen, 2001; Uttal, et al., 2006). Nonetheless, there are dramatic changes in bias across development.

The present results also show that both young children and adults use relative distance to make *by* judgments. Nonetheless, the systematicity of *by* judgments increases across development. Four-year-olds and adults systematically used relative distance when making *by* judgments. Thus, they almost always judged blocks as *by* the landmark when no intervening blocks were present and almost never judged blocks as *by* the landmark when intervening blocks were present. In contrast, 3-year-olds were less systematic in their use of relative distance to make *by* judgments. They were less likely to judge that the closest blocks were *by* the landmark than were the other two ages. Moreover, they were much less likely to be classified as systematic users of relative distance than were the older ages. These patterns of responding underscore two points about the developmental trajectory of *by* judgments. First, both children and adults use relative distance to make *by* judgments. Second, *by* judgments based on relative distance become more differentiated over development (Hund & Plumert, 2007).

Why might young children's proximity judgments and location estimates rely increasingly on relative distance over development? One possibility is that these changes parallel changes in young children's understanding of relative information more generally. Although Piaget and Inhelder (1948/1967) proposed that children's understanding of relative information (i.e., proportional reasoning) emerges during the formal operational stage, contemporary researchers have challenged this notion, suggesting instead that young children can use relative coding in rudimentary ways but that this ability becomes more sophisticated with age (Huttenlocher, Duffy, & Levine, 2002; Huttenlocher et al., 1999; MacDonald, Spetch, Kelly, & Cheng, 2004; Vasilyeva & Huttenlocher, 2004). For example, Huttenlocher et al. (1999) asked 3- and 4-year-old children to use a dot marked on a map to find a disk hidden in a long, narrow sandbox. Overall, the 4-year-olds were quite successful in finding the hidden disk. In contrast, only about half of the 3-year-olds were successful. The remaining 3-year-olds were unable to find the disk, instead responding randomly or perseveratively. It is possible that increases in young children's systematic use of relative distance are related to changes in analogical reasoning abilities. According to Gentner (1988), children between the ages of 3 and 5 years become increasingly likely to use relational similarity to solve analogical reasoning tasks in a variety of domains (Andrews & Halford, 2002; Gentner & Ratterman, 1991; Goswami, 1989; Ratterman & Gentner, 1998). These findings suggest that developmental increases in relational thinking may underlie

the increased systematicity in *by* judgments and block placements observed here, revealing a tight link between conceptual, language, and memory development.[3]

A second possibility is that the developmental differences observed here result from differences in the way children and adults interpret the overall task demands. For example, it is possible that the younger children respond differently to the precise task demands than do the older children. Perhaps the younger children see no reason to consider multiple blocks when answering a question about a single block. For them, the task is to answer whether or not one block is *by* the landmark, without considering whether it belongs to the closest set of blocks. Moreover, perhaps they view the location memory task as a block building game. A related third possibility is that there are differences in how participants respond to the verbal question (i.e., a complex counterfactual) employed. Perhaps the younger children have difficulty processing the complex question we used, particularly because doing so requires holding in mind both *by* and *not by* (for related ideas, see de Villiers & de Villiers, 2000). We present these three possibilities not as competing mechanisms but, rather, as factors that work together to shape children's performance. Indeed, we contend that conceptual details (i.e., understanding relative information), the social pragmatics of the task, and linguistic factors interact to shape the language and memory skills children exhibit in a given situation (see also Majid et al., 2004).

In conclusion, the present results highlight important differences in block displacement in relation to landmarks across age groups and distances. Moreover, they show that young children and adults use relative distance to make *by* judgments. Nonetheless, their judgments based on relative distance become increasingly systematic across development. These findings are broadly consistent with recent theoretical claims that reweighting mechanisms underlie developmental changes in location coding (Newcombe & Huttenlocher, 2000; Newcombe et al., 1998; Sluzenski et al., 2004; Uttal et al., 2006). As such, the present findings add to a growing body of research specifying when children can use particular cues and how the adaptive combination of such cues might change across age and experience. More importantly, they offer rich details about the dynamics of spatial memory and language during early childhood.

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[3]It is also possible that young children understand relative distance but do not link it to the spatial term *by*. Here, development involves children gaining experience linking conceptual and linguistic understanding in precise ways.

ACKNOWLEDGEMENTS

We thank Nicole Bush, Lindsey DeRose, Elizabeth Ellison, Emily Foster, and Devin Gill for assistance with data collection and coding; Corinne Zimmerman for comments on an earlier version of the paper; Blooming Grove Academy, Calvary United Methodist Church Preschool, Debra T. Thomas Learning Centers, Discovery World Child Care Center, Hilltop Preschool, Illinois State University Child Care Center, Kiddie Korner Preschool, and Shining Star Learning Center in Bloomington-Normal, IL, for assistance with the project; and all of the children and adults for their participation. Experiment 2 was completed in partial fulfillment of the requirements for undergraduate departmental honors in psychology by the second author.

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