Angles and Distances: Children's and Adults' Reconstruction and Scaling of Spatial Configurations

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Uttal, David H. Angles and Distances: Children's and Adults' Reconstruction and Scaling of Spatial Configurations. Child Development, 1996, 67, 2763-2779. Young children have performed poorly in spatial tasks that require the scaling and reconstruction of a configuration. The present research investigated whether or not children's reconstructions nevertheless preserved the relative positions of objects within the configuration. In Experiment 1, preschoolers (ages 4 and 5), young elementary school children (ages 6 and 7), and adults were asked to reconstruct symmetric configurations of six objects that were depicted on simple maps of an empty room. Most subjects preserved the overall configuration of objects, but preschoolers placed the objects far from the correct locations. Many of the preschoolers' reconstructions contained systematic transformations; many reconstructions were off-center and too small or too large. In Experiment 2, the configurations were asymmetric, and preschoolers performed substantially worse than in Experiment 1. Experiment 3 demonstrated that preschoolers could reconstruct the asymmetric configurations when scaling was not required. Taken together, the results reveal that even young children can represent and transform an entire configuration of objects. At the same time, the results reveal important developmental differences.

Researchers interested in the development of spatial cognition often ask children to learn and then reconstruct a configuration of objects. The reconstructions can provide important insights into how children mentally represent spatial relations and can highlight possible sources of developmental change.

The focus of this manuscript is on children's performance in reconstruction tasks that require scale compensation. Typically, subjects learn a spatial layout in a space of one size (the original space) and then reconstruct the information in a larger (or smaller) space. Young children seem to have difficulty with scale compensation. Liben, Moore, and Golbeck (1982) found that kindergartners performed poorly when asked to place a set of objects in a room after they had learned the locations from a small-scale model of the room. However, children could place the objects in the correct locations in the model (direct reconstruction) (see also Herman & Siegel, 1978).

The purpose of the present studies was to investigate children's and adults' performance in scale-compensation tasks. The approach taken here involved a fine-grained analysis of the spatial characteristics of the reconstructions, with a particular focus on discriminating types of errors. New analyses were developed to gain a more detailed understanding of the relation between what children memorize and what they reconstruct.

Two sets of issues were addressed. The first concerns the kinds of spatial information that children do, and do not, preserve in their reconstructions. Previous research has focused primarily on absolute accuracy, that is, whether children place the objects close to the correct (i.e., target) locations. The researcher calculates the target locations by multiplying appropriate distances

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(e.g., from individual objects to the walls of a model) by the scale factor. He or she then measures the distance from the location at which a child placed a given object and the corresponding target location. Young children typically place the objects much farther from the target locations than do older children or adults.

It is possible, however, that children's reconstructions could nevertheless preserve the relative relations among the objects, even if their reconstructions were inaccurate in an absolute sense. In this case, the reconstructions might contain systematic transformations, in which the relative positions of objects are preserved but the absolute positions differ systematically from the target locations. In a translation, all of the objects are shifted off-center relative to the target configuration. Similarly, in a size difference, the distances between objects within the reconstruction are proportionally smaller or larger than the corresponding distances in the target configuration. In a rotation, the entire configuration is systematically rotated relative to the target configuration.

In addition to indicating that children had preserved the relative relations, the presence of systematic transformations could help to shed light on potential sources of difficulty. These kinds of errors might stem from difficulty compensating for the differences in size between the two spaces. For example, systematic transformations might arise if children failed to scale the configuration correctly or did not realize that the locations of objects in the original space could provide information about the absolute locations of objects in the other space.

For these reasons, the present research investigated whether children's reconstructions preserved the relative relations and contained systematic transformations. Preschoolers, elementary school children, and adults first memorized simple maps that showed the locations of six objects in an otherwise empty room. Subjects then attempted to reconstruct the configurations in the room. Analyses were designed to compare the absolute and relative accuracy of the reconstructions and to detect systematic transformations.

The second set of issues that was addressed concerns the effects of the spatial characteristics of the configurations that children are asked to reconstruct. Two specific questions were addressed. The first was symmetry; the configurations were symmetric in Study 1 and asymmetric in Studies 2 and 3. It was hypothesized that reconstructions of the symmetric configurations would be more accurate, at least in a relative sense, than reconstructions of the asymmetric configurations. Several lines of research have shown that symmetric configurations are easier to remember than asymmetric configurations (Attneave, 1955; Bornstein & Stiles-Davis, 1984; Markman & Gentner, 1993). In addition, symmetric configurations might be easier for children to think about and mentally manipulate than asymmetric configurations. In a symmetric configuration, the locations of individual objects may be systematically related to the locations of other objects. An object on the left side of a room, for example, might be located in a position that corresponds to another object on the right side of the room. Placing an object on the right side of the room therefore might help a child decide where to place another object on the left side of the room.

In addition to symmetry, the influences of configuration size were also investigated. This refers to the distances between objects within the configuration; individual objects are relatively close in a small configuration and relatively far apart in a large configuration. Configuration size might influence how children remembered the locations of the objects by making certain kinds of relations more or less salient. In a large configuration, the individual objects would be relatively far from each other and hence relatively close to the surrounding edges (e.g., the walls of a room or edges of a map). Subjects might therefore remember the locations of individual objects in terms of proximity to the walls or edges (e.g., object X is close to the upper, right wall). Conversely, in a small configuration, the individual objects would be relatively close to each other and relatively far from the walls of the room or edges of a map. The relations among objects therefore might be highlighted. To investigate the influences of configuration size, subjects reconstructed two configurations in each experiment that differed only in size.

**Experiment 1**

**Method**

**Subjects.**—Subjects were 20 4- to 5-year-olds (M = 60 months, range = 48 to 71 months), 19 6- and 7-year-olds (M = 82 months, range = 72 to 94 months), and 20 adults (M = 244 months, range = 223 and 280 months), approximately equally divided between the two sexes. The children were
healthy patients of a physician who informed parents of the research. The adults were university students fulfilling a course requirement. Most of the subjects were white and middle class.

Apparatus.—The room was 16 feet (4.88 m) × 12 feet (3.66 m) and was located within a larger, 24 (7.32 m) × 24 foot area. Figure 1 provides labels for the walls of the reconstruction room and shows where subjects sat or stood during different phases of the experiment. Subjects were asked to memorize and reconstruct two maps of the room (see Fig. 1). The overall pattern of objects was the same on the two maps, but the distance between any pair of objects was 2.2 times shorter in the small configuration than in the large configuration. The maps themselves were identical in size; only the sizes of the configurations on the maps differed. The maps were constructed on white posterboard that was 20 inches (50.8 cm) long and 16 inches (40.7 cm) wide. A frame was drawn in black ink 2 inches (5.1 cm) from the edges of the posterboard to represent the walls of the room. The frame was 16 inches (40.7 cm) long and 12 inches (30.5 cm) wide. The scale relating the area within the frame on the map to the area of the room was 1 to 12.

The individual objects were different for children and adults, but all subjects memorized and reconstructed the same configurations of objects. The objects for children were banks made to look like the following characters: Ms. Piggy, Big Bird, Donald Duck, Kermit, Oscar, and Mickey Mouse. The locations of the banks were represented on the maps with small cutouts of photographs of the banks. The objects for

![Diagram of room and configurations]

Fig. 1.—The layout of the room (top panel) and the symmetric configurations (bottom panel). The X in the top panel represents the location at which subjects learned the maps, and the circle represents the position at which they stood before receiving an object to place. The letters in the bottom panel represent the locations of photographs of the following characters: Ms. Piggy (P), Big Bird (B), Donald Duck (D), Kermit the Frog (K), Oscar the Grouch (O), and Mickey Mouse (M).
adults were household items: iron, toaster, flower pot, lamp, telephone, and book. The positions of these objects were represented on the maps with simple line drawings. Different objects and representational formats (i.e., photographs vs. line drawings) were chosen for children and for adults to make the task appropriate and comprehensible for both age groups. The photographs and line drawings were similar in size (approximately 1.5 × 2.5 cm).

**Procedures.**—Procedures were similar for children and adults, but the task was not presented as a game to the adults. The procedures for children are described. There were four phases: familiarization, map learning, reconstruction, and second testing.

**Familiarization.**—Each child was brought to the testing site by a parent and was tested individually. First, the child was shown the toys. The experimenter said, “We’re going to play a game with these toys and a map. First I want to make sure you know what the toys are.” The child was asked to name each toy as the experimenter picked it up. If the child did not know the name of a toy, the experimenter said it. The child was asked about the toys in random order until he or she could name each without error.

Next, the experimenter walked with the child to the position represented by the X in Figure 1. The experimenter pointed to the bottom wall of the reconstruction room and said, “All of the toys live in this room right here. You’re going to learn a map that shows you where all the toys go, so that when we go into the room, you can put all the toys where they go.” The experimenter then led the child into the reconstruction room and said, “Here’s the room. You’re going to learn the map now, so you can put all the toys in this room where they go.” The experimenter and child left the room.

**Map learning.**—The experimenter then began the map-learning phase, which was similar to that used in previous studies (Uttal, 1994; Uttal & Wellman, 1989). First, the child was seated with the experimenter at a small table (see Fig. 1). The experimenter said, “This is the map. See, it’s a big picture, and it shows you where all the toys should go. And these lines here are the walls of the room.” The experimenter also pointed to the bottom wall of the room and the corresponding line on the map. Then the experimenter pointed in random order to each of the photographs of the toys and asked the child to name each one. Next, the experimenter covered all of the photographs with small cards and asked the child to say which toy was under each card; the experimenter pointed to the cards in random order and removed cards when the child answered correctly. The experimenter returned to the photographs that the child had named incorrectly until all cards were removed.

The experimenter then covered all of the photographs again, and the child was asked to name all of the toys as the experimenter pointed to the cards in random order. After the child responded, the experimenter removed the appropriate card and then replaced it immediately. This procedure was repeated until the child could name all of the toys twice in succession without error. Finally, the child was asked to point to the covered photographs as the experimenter named each one in random order. This was also repeated until the child could point to each of the toys twice in succession without error. The experimenter then said, “Good, now we’re ready to go to the room, and you can put all the toys where they go.”

**Reconstruction.**—The experimenter led the child into the room and positioned him or her at the starting location (see Fig. 1). The experimenter then gave the child the first toy and said, “Think about the map and put where she [or he] goes.” No other instructions were given.

The child was asked to return to the starting position after he or she placed the first (and each subsequent) toy. The experimenter gave the child another toy and asked him or her to place it in the correct location. This was repeated until all toys were placed. Order of placement was random. The experimenter then asked the child to wait outside the room with his or her parents.

The experimenter and an assistant returned to the room and recorded the locations of the objects using X and Y coordinates. Placements were recorded in inches from the left wall (X coordinates) and the bottom wall (Y coordinates). To assess the reliability of the recordings, two assistants independently recorded the placements of six children and six adults. The average absolute difference between the two recordings was small (M = 2.1 cm, SD = .31).

**Second Testing.**—After the positions were recorded, the objects were picked up. The child was told, “Now we’re going to play the game again, but we’re going to use
a different map.” The child was led back into the room, and the experimenter said, “We picked up all the toys. Now you’re going to learn a different map, so that you can put all the toys where they go again for the different map.” The experimenter then led the child out of the room and returned to the table to show him or her the second map. Configuration order (small or large first) was counterbalanced.

The experimenter said, “This is the different map. We’re going to learn it now, so that when we go back into the room, you can put all of the toys where they go.” The learning procedures for the second map were identical to those used for the first map, except that the first two steps were deleted. The experimenter immediately covered all of the animals with the cards and asked the child to say which toys were under which cards. This was repeated until the child could name all of the toys two times successively without error. The experimenter then covered all of the toys and asked the child to point to them as the experimenter named them in random order. This was also repeated until the child could point to all toys twice successively without error. Thereafter the procedures were identical to those described above.

One preschooler asked to leave after reconstructing the first configuration. He seemed distracted, and his data were not included in the analyses.

**Assessing the accuracy of the reconstructions.**—*Relative accuracy* was the measure of whether the reconstructions preserved the relative relations in the configuration. The measure was based on the *angular relations* among objects within the configuration (see Fig. 2 and Appendixes A and B). The relative-accuracy score describes how much, on average, the relative relations in the reconstruction deviated (in degrees) from the correct relations. *Absolute accuracy* was the median of the distances of each object from its target. The target locations were determined by multiplying the coordinates of objects on the maps by 12.

**Results**

Overview.—The analyses addressed four issues: relative accuracy, absolute accuracy, systematic transformations, and differences between reconstructions of the small and large configurations.

![Fig. 2.](image) — The nine angular relations that were calculated to determine relative accuracy. Each line represents an imaginary ray projected from (or parallel to) the bottom wall of the room through two objects in the reconstruction. All angles were computed relative to the bottom wall of the room. The letters represent the locations of individual objects described in Figure 1. The $\theta$ represents a single angular relation.
The analyses often involved comparing the reconstructions to a model of chance performance, which was derived from 1,000 computer-generated, random reconstructions. To ensure that objects were not located on top of or unrealistically close to each other, the minimum distance between any two objects in a random reconstruction was constrained to 6 inches. This is a reasonable estimate of minimum distance because the objects subtended approximately 6 inches. Each random reconstruction was then compared independently to both the small and large target configurations. For example, the location of Oscar within each random reconstruction was compared in separate analyses to the location of Oscar in the small target configuration and in the large target configuration.

The comparisons to chance allow an assessment of subjects’ performance that takes into account the size and shape of the room and of the configurations (i.e., small and large). This obviates the need for arbitrary criteria, such as within 1 foot or within 30 degrees. Reconstructions were considered better than chance only if they were more accurate than 95% of the random reconstructions. The comparisons to chance also provide estimates of the likelihood of systematic transformations occurring by chance.

Relative accuracy.—As shown in Figure 3 and Table 1, most of the reconstructions preserved the relative relations. Only .8% of the random reconstructions were as accurate or more accurate than the mean level of preschoolers’ performance. However, a few of the subjects’ reconstructions were less accurate than the ninety-fifth percentile of random scores (40.7 degrees). This was true of three preschoolers’ (15%) and one adult’s (5%) reconstructions of both configurations; the average relative-accuracy scores of these reconstructions was 106.8 degrees. One preschooler’s and one elementary school child’s reconstructions of the large, but not the small, configuration were also not better than chance.

The next step in assessing the relative accuracy of the configurations was an analysis of systematic rotations. The measure of relative accuracy assumes that subjects reconstructed the configuration relative to the bottom wall of the room (see Fig. 2). If a subject chose a different orientation, then his or her relative-accuracy score might be affected substantially. Therefore, a check for rotation was conducted before proceeding with the analysis of relative accuracy (see Appendix B).

Only 5.0%, 5.0%, and 20.0% of preschoolers’, elementary school children’s, and adults’ small-configuration reconstructions and 15.0%, 0%, and 5.0% of their large-configuration reconstructions were systematically rotated. The magnitude of most of the rotations was small; the relative-accuracy scores were quite good even with the systematic rotation. Most of the adults’ rotations were small in magnitude, usually less than 20 degrees. These adults may not have stood with their backs flush against the bottom wall; they may have turned slightly to the left or right. However, one adult rotated both reconstructions 90 degrees to the left. In other words, this subject reconstructed the configurations relative to the right wall of the room. Correcting this subject’s rotations led to a dramatic improvement in relative accuracy, from 90 to 3 degrees. In the remaining reconstructions, however, correcting the rotation did not improve relative accuracy substantially. In most of these cases, the objects were placed in one or two lines, usually against a wall or two of the room.

Thus far, the analyses have revealed that (a) most of the subjects preserved the overall configuration, but (b) that a few of the reconstructions were inaccurate. The next analysis of relative accuracy focused only on the subjects who did preserve the overall configuration.

Figure 4 shows average relative accuracy after correcting for rotation. The plots are separated by order because order affected the results. In this and all subsequent analyses, sex was also included as an independent variable, but interactions involving sex and order were not considered. Main effects or interactions involving sex are discussed only if they were significant. Tukey contrasts were used to determine the source of main effects.

A 3 (age) × 2 (order) × 2 (configuration size) ANOVA with configuration size as a within-subjects factor revealed a significant three-way interaction, $F(2, 48) = 4.80$, $p < .05$. To follow up the three-way interaction, separate 2 (order) × 2 (configuration size) ANOVAs were conducted for each of the age groups. The interaction was significant only in the analysis of preschoolers’ reconstructions, $F(1, 14) = 11.58$, $p < .01$. Tests of simple main effects on this interaction revealed that the large-configuration recon-
Small Configuration

**Preschool**

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<th>Median (6.3)</th>
<th>Worst (133.7)</th>
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**Adult**

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Fig. 3.—Plots of the best, median, and worst reconstructions of the small configuration. Relative-accuracy scores are shown in parentheses. Plots of the target configuration are also included. Results were similar for reconstructions of the large configuration.

...structions of preschoolers who reconstructed the large configuration first (M = 10.96, SD = 3.67) were less accurate than their small-configuration reconstructions (M = 6.31, SD = 2.78), F(1, 14) = 15.08, p < .01. In contrast, the large- (M = 6.63, SD = 3.74) and small- (M = 7.41, SD = 4.2) configuration reconstructions of preschoolers who reconstructed the small configuration did not differ significantly. Significant two-way interactions between age and configuration size and order and configuration size and the main effect of age were subsumed by the three-way interaction.

**Absolute accuracy.**—The results replicated previous studies; preschoolers placed the objects relatively far from the target locations. The objects were 1.14 m (SD = .67) and 1.34 m (SD = .69) from the targets in preschoolers’ reconstructions of the small and large configurations, respectively. The objects were .71 m (SD = .61) and .74 m (SD = .55) from the targets in elementary school children’s reconstructions and .62 m (SD = .40) and .46 m (SD = .39) from the targets in adults’ reconstructions of the small and large configurations, respectively. A 3 (age) × 2 (order) × 2 (configuration size)
ANOV A revealed a significant interaction between age and configuration size, \( F(1, 53) = 4.05, p < .05 \). Simple effects test indicated that preschoolers’ large-configuration reconstructions (\( M = 1.34, SD = .69 \)) were less accurate than their small-configuration reconstructions (\( M = 1.14, SD = .66 \)), \( t(19) = -.321, p < .05 \). In contrast, adults’ large-configuration reconstructions (\( M = .46, SD = .39 \)) were less accurate than their small configuration reconstructions (\( M = .62, SD = .40 \)), but this difference did not reach statistical significance. The interaction between order and configuration size was also significant, \( F(1, 53) = 4.14, p < .05 \). This interaction probably represents a practice effect. The small-configuration reconstructions of subjects who reconstructed the large configuration first (\( M = .67, SD = .49 \)) were more accurate than their large-configuration reconstructions (\( M = .60, SD = .65 \)). Conversely, the small-configuration reconstructions of subjects who reconstructed the small configuration first (\( M = .97, SD = .66 \)) were less accurate than their large-configuration reconstructions (\( M = .89, SD = .69 \)). Finally, the main effect of age was significant, \( F(2, 53) = 8.92, p < .001 \), but this effect was subsumed by the interaction between age and configuration size.

Systematic transformations.—The next set of analyses assessed whether the reconstructions contained translations or size differences that might account for the difference between relative and absolute accuracy. There were many translations, and there were developmental differences in both magnitude and direction of translation.

To detect translations, the centroid of each reconstruction was calculated. (The centroid is the location represented by the mean of the X and the mean of the Y coordinates.) Comparisons of the locations of the centroids to the midpoint of the room (i.e., the centroid of the target configurations) revealed two developmental differences, as shown in Figure 5. The more obvious one concerns the magnitude of translation. On average, the centroids of preschoolers’, elementary school children’s, and adults’ reconstructions were .92 (SD = .52), .47 (SD = ...
.52), and .27 (SD = .13) m from the centroid of the target configurations. A 3 (age) × 2 (order) × 2 (configuration size) revealed a significant main effect of age, $F(2, 53) = 11.63, p < .001$. Preschoolers’ reconstructions were translated significantly more than both elementary school children’s and adults’ reconstructions. The interaction between sex and configuration size was also significant, $F(1, 53) = 5.21, p < .05$. Males’ large-configuration reconstructions ($M = .57, SD = .48$) were translated more than their small-configuration reconstructions ($M = .48, SD = .43$). In contrast, females’ small-configuration reconstructions ($M = .62, SD = .48$) were translated more than their large-configuration reconstructions ($M = .53, SD = .58$).

The second developmental difference concerns the direction of translation. The most obvious difference was in the vertical dimension; most of the preschoolers’ reconstructions were centered below the midpoint of the room. Eighty percent and 70.0% of preschoolers’ reconstructions of the small configuration and large configuration, respectively, were centered below the midpoint of the room. The corresponding percentages for elementary school children were 78.9 and 42.1; for adults the percentages were 55.0 and 30.0, $\chi^2$'s ($2, N = 59) > 7.2, ps < .05$. In addition, 80.0% and 85.0% of adults’ reconstructions of the small and large configurations, respectively, were translated to the right (although the magnitude of these displacements was quite small). Only 35.0% and 30.0% of preschoolers and 36.8% and 26.3% of elementary school children reconstructed the configurations to the right of center, $\chi^2$'s ($2, N = 59), > 6.7, ps < .05$.

Many of the reconstructions also differed in size from the target configurations, and there were developmental differences in the magnitude and direction of size differences. The size of a reconstruction was defined as the sum of the nine distances represented by the lines between objects in Figure 2. The sizes of the small and large target configurations were 8.4 m and 18.1 m, respectively. Size differences were expressed as ratios (size ratios) of the target configuration. A given reconstruction might be, for example, twice as large as the target configuration (size ratio equals 2.0) or twice as small (size ratio equals 1/2). The size ratio of each reconstruction was converted to a base 10 logarithm to allow direct comparison of ratios greater and less than 1. Many of the size differences were quite large; some dif-
2772 Child Development

fered from the target by more than a factor of 3.

On average, preschoolers’, elementary school children’s, and adults’ reconstruction of the small configuration differed in size from the target by factors of 1.8 (SD = .52), 1.6 (SD = .57) and 1.5 (SD = .48), respectively. The corresponding means for reconstructions of the large configuration were 2.1 (SD = .98), 1.47 (SD = .65), and 1.15 (SD = .16). A 3 (age) × 2 (order) × 2 (configuration size) ANOVA revealed only a main effect of age, F(2, 53) = 8.51, p < .01. The size-difference magnitude was significantly greater in preschoolers’ reconstructions than in elementary school children’s or adults’ reconstructions; no other comparisons were significant.

Regarding direction, 60% of preschoolers’, but only 31.6% and 25.0% of elementary school children’s and adults’ reconstructions of both configurations were smaller than the target, χ²(1, N = 30) = 5.01, p < .05; no other comparisons were significant. Note that the sizes of the target configurations constrained the possible direction of the errors. The comparisons to chance indicated that the probability of a reconstruction being smaller than the small target configuration by chance alone was less than .001. Yet many preschoolers’ reconstructions were substantially smaller than the small target configuration.

Did subjects differentiate the two configurations?—On average, preschoolers’, elementary school children’s, and adults’ large-configuration reconstructions were 1.57 (SD = 1.02), 1.61 (SD = .52), and 1.69 (SD = .59), respectively, times larger than their small-configuration reconstructions. The large target configuration was approximately 2.2 times larger than the small target configuration. A 3 (age) × 2 (order) × 2 (configuration size) ANOVA on the sizes of the reconstructions revealed only the expected main effect of configuration size, F(1, 53) = 43.54, p < .001. All age groups distinguished the two configurations, but the magnitude of difference was smaller than in the target configurations.

Discussion

The results provide strong evidence that preschoolers’ reconstructions can preserve important spatial characteristics, even when scale compensation is required. Almost all of the preschoolers preserved the relative relations of the configurations. At the same time, the results replicated the main finding of previous studies: young children’s reconstructions were inaccurate in an absolute sense.

The analysis of systematic transformations helps to explain the discrepancy between relative and absolute accuracy. The preschoolers reconstructed the configurations close to the starting location, near the bottom wall of the room (see Fig. 1). Consequently, the centroids of their reconstructions were below and relatively far from the midpoint of the room. For the same reason, the distances between objects in their reconstructions were too small. The systematic transformations suggest that the preschoolers either did not acquire or did not use information that specified the locations of the objects in an absolute sense.

That preschoolers’ reconstructions of both configurations were, on average, smaller than the target configurations supports the analysis of their performance. In the large configuration, the photographs on the map were relatively close to the drawn border and the individual objects were relatively far apart. Nevertheless, children still placed the objects quite close together in the room, although their reconstructions of the large configuration were somewhat larger than their reconstructions of the small configuration. Thus, even though information about the relations among objects was perhaps less salient in the large configuration, children nevertheless acquired and reconstructed this information.

Although preschoolers performed quite well overall, adults’ reconstructions were still more accurate. In addition, a few children failed to reconstruct the configuration in any discernible way. This result is consistent with many previous studies of reconstructions (e.g., Hazen, Lockman, & Pick, 1978; Siegel, Herman, Allen, & Kirasic, 1979); even in tasks that do not require scale compensation, a few children almost always fail to preserve the configurations. In interpreting the results, it is important to note that the comparisons of relative accuracy did not include the few subjects whose reconstructions did not preserve the relative relations.

The remainder of this article is devoted to investigating the influences of symmetry on the reconstructions.

Experiment 2

The configurations were asymmetric in Experiment 2. Children might have more difficulty remembering or thinking about
these configurations as an integrated set of spatial relations. This, in turn, would make it more difficult for them to reconstruct the configurations. Thus, relative-accuracy scores would be worse than in Experiment 1. However, if children continued not to use the relation between the map and the room, then absolute-accuracy scores would be similar in the two experiments.

**Method**

**Subjects.**—There were 19 4- to 5-year-olds ($M = 62$ months, range = 51 to 71 months), 20 6- to 7-year-olds ($M = 85$ months, range = 74 to 96 months, and 21 adults ($M = 255$ months, range = 226 and 277 months), approximately evenly divided between the two sexes. Subjects were recruited from the same population that was used in Experiment 1, and the demographic characteristics of the samples were similar.

**Apparatus and procedures.**—The only difference from Experiment 1 was that the configurations were asymmetric (see Fig. 6). The size of the small configuration was nearly identical to that of the small configuration used in Experiment 1. However, the large configuration was slightly smaller than that in Experiment 1.

**Results**

**Relative accuracy.**—In contrast to Experiment 1, most of the preschoolers’ reconstructions did not preserve the relative relations. Figure 7 shows representative plots of small-configuration reconstructions, and Table 2 provides the average relative-accuracy scores. Only 47.3% and 42.1% of preschoolers’ reconstructions of the small and large configurations, respectively, were more accurate than the ninety-fifth percentile of chance performance (39.3 degrees). In contrast, 80% and 85% of preschoolers’ reconstructions in Experiment 1 were more accurate than chance, $\chi^2$’s (1, $N_s = 39$) > 4.50, $p < .05$.

Rotation was not the cause of the poor relative-accuracy scores of preschoolers’ reconstructions. Only 15.8%, 20.0%, and 19.0% of preschoolers’, elementary school children’s and adults’ reconstructions, respectively, were systematically rotated. The corresponding percentages for reconstructions of the large configuration were 21.1, 30.0, and 0. One preschooler rotated both configurations approximately 180 degrees, reconstructing the configuration relative to the top, rather than the bottom, wall of the room. Another preschooler rotated the large configuration approximately 45 degrees to the left. In addition, two elementary school children rotated the large configuration approximately 90 degrees to the left. Correcting these large rotations improved the relative-accuracy scores to a better-than-chance level, but the improvement in the other inaccurate reconstructions was small.

**Absolute accuracy.**—In contrast to the relative-accuracy results, the absolute-accuracy results were very similar to those of Experiment 1. In both experiments, preschoolers placed the objects relatively far from the target locations. A 2 (experiment) $\times$ 3 (age) $\times$ 2 (order) $\times$ 2 (configuration size) ANOVA revealed only one significant effect involving experiment, a three-way interac-

![Small Configuration](image)

![Large Configuration](image)

**Fig. 6.**—The small and large asymmetric configurations
Fig. 7.—Plots of the best, median, and worst reconstruction of the small asymmetric configuration. Results were similar for reconstructions of the large configuration.

<table>
<thead>
<tr>
<th>TABLE 2</th>
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<tbody>
<tr>
<td>Raw Relative-Accuracy Scores</td>
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</table>

<table>
<thead>
<tr>
<th>CONFIGURATION SIZE</th>
<th>AGE</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>4–5</td>
</tr>
<tr>
<td>Small:</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>59.5</td>
</tr>
<tr>
<td>Mdn</td>
<td>34.4</td>
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<td>SD</td>
<td>47.9</td>
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<tr>
<td>Large:</td>
<td></td>
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<td>M</td>
<td>57.4</td>
</tr>
<tr>
<td>Mdn</td>
<td>46.6</td>
</tr>
<tr>
<td>SD</td>
<td>46.0</td>
</tr>
</tbody>
</table>

significant between experiment, age, and configuration size, $F(2, 107) = 4.42, p < .05$. As reported above, the interaction between age and configuration size was significant in Experiment 1, but this interaction was not significant in Experiment 2. Only the main effect of age was significant in Experiment 2, $F(2, 54) = 22.06, p < .001$. Preschoolers ($M = 1.3, SD = .55$) placed the objects significantly farther from the target than did elementary school children ($M = .69, SD = .40$) and adults ($M = .44, SD = .16$). The latter two groups did not differ significantly.

Systematic transformations.—The results were similar to those of Experiment 1. Many reconstructions were transformed, and
there were developmental differences in magnitude and direction. Preschoolers’ reconstructions \((M = .85 \text{ m}, \text{SD} = .57)\) were again translated more than elementary school children’s \((M = .50, \text{SD} = .41)\) and adults’ \((M = .29, \text{SD} = .16)\) reconstructions. A 3 (age) \(\times 2\) (order) \(\times 2\) (configuration size) ANOVA revealed a main effect of age, \(F(2, 54) = 10.04, p < .001\). Preschoolers differed from both elementary school children and adults; the latter two groups did not differ significantly. The main effect of configuration size was also significant, \(F(1, 54) = 4.66, p < .05\). Small-configuration reconstructions \((M = .55, \text{SD} = .50)\) were translated more than large-configuration reconstructions \((M = .50, \text{SD} = .47)\). No other effects were significant.

Most of the preschoolers’ reconstructions again were centered below the midpoint of the room; 73.6%, 80.0%, and 28.6% of preschoolers’, elementary school children’s, and adults’ reconstructions, respectively, of the small configuration were centered below the midpoint of the room. Similarly, 68.4%, 90.0%, and 38.1% of the large-configuration reconstructions were centered below the center for the room, \(\chi^2(2, N = 59) > 12.27, p < .01\). There were no significant differences in the horizontal dimension.

Size differences.—As in Experiment 1, there were many size differences. Preschoolers’, elementary school children’s, and adults’ reconstructions differed from the targets by factors of 1.78 (SD = 1.39), 1.44 (SD = 1.28), and 1.20 (SD = 1.18), respectively. A 3 (age) \(\times 2\) (order) \(\times 2\) (configuration size) ANOVA revealed a main effect of age, \(F(2, 54) = 14.2, p < .001\). The magnitude of size difference was significantly greater in preschoolers’ reconstructions than in elementary school children’s and adults’ reconstructions; the latter two groups did not differ. The main effect of configuration size was also significant, \(F(1, 54) = 5.54, p < .05\). The magnitude of size difference was greater in small-configuration reconstructions \((M = 1.55, \text{SD} = 1.35)\) than in large-configuration reconstructions \((M = 1.35, \text{SD} = 1.48)\). Because of the differences in size between the large configurations used in Experiments 1 and 2, cross-experiment comparisons are not reported.

Regarding the direction of size differences, 63.2%, 60.0%, and 95.2% of preschoolers’, elementary school children’s, and adults’ reconstructions of the small configuration were larger than the target configuration, \(\chi^2(2, N = 60) = 7.98, p < .05\). There were no developmental differences in the direction of size differences in large-configuration reconstructions.

Did subjects differentiate the large and small configurations? On average, preschoolers’, elementary school children’s, and adults’ reconstructions of the large configuration were 1.23 (SD = .62), 1.48 (SD = .57) and 1.43 (SD = .37) times larger than their reconstructions of the small configuration. The corresponding ratio of the large to small target configuration was 1.8. A 3 (age) \(\times 2\) (order) \(\times 2\) (configuration size) ANOVA on the sizes of the reconstructions revealed, a significant interaction between age and configuration size, \(F(2, 54) = 5.30, p < .05\). Preschoolers’ reconstructions of the two configurations differed less than those of the other two groups.

Discussion

Overall, preschoolers had much more difficulty reconstructing the asymmetric configurations than elementary school children or adults did. More than half of the preschoolers did not preserve the overall configuration. In contrast, almost all of the preschoolers in Experiment 1 preserved the configuration.

The other results of Experiment 2 were similar to those of Experiment 1. In both experiments, the preschoolers simply placed the objects down in front of where they stood. Hence, the absolute-accuracy scores of preschoolers’ reconstructions were similar in the two experiments. Children again appear not to have used the relation between the map and the room to determine the absolute locations of the objects.

Why did young children, but not elementary school children and adults, have more difficulty with the asymmetric than with the symmetric configurations? Asymmetric configurations might be more difficult than symmetric configurations for young children to remember, scale, or both. Experiment 3 was designed to help untangle these possibilities.

Experiment 3

In Experiment 3, preschoolers memorized and reconstructed the asymmetric configurations, but scaling was not required. One group of preschoolers (the map group) learned the maps and then reconstructed the configurations on an empty board that was
the same size as the maps. A second group of preschoolers (the *room* group) saw the objects in the target locations in the room and then attempted to place the objects back in the target locations. Hence, both groups reconstructed the configurations in a space that was the same size as the space in which they learned the configurations.

**Method**

**Subjects.**—Seventeen preschoolers participated. The ages of the children were comparable to the preschoolers in Experiments 1 and 2 (*M* = 58.9 months, range = 52.6 to 63.8 months). The children were recruited from a list of parents who had participated in previous studies. Most of the children were white, and all of the children were middle class.

**Apparatus and procedures.**—Subjects were assigned randomly to either the map or the room group. The map group learned the two maps that were used in Experiment 2. However, the children were not informed that the maps represented the room; they were asked instead to learn the locations so that they could place the photograph cutouts back in the correct places. After learning the locations, the map group was asked to reconstruct the configurations on a board that was identical in size and shape to the maps. When children began the reconstruction phase, the board was empty except for the black frame. Children placed copies of the cutout photographs of the toy animals on the empty board. The cutouts were attached to several laminated cards (which were trimmed to the edges of the photographs) so that children could pick up and place them easily. A non-permanent adhesive was applied to the back of the laminate to prevent accidental displacement. The reconstruction board was cleaned between subjects to ensure that no marks remained. As in the previous experiments, children learned and reconstructed small and large configurations on two successive trials, in counterbalanced order.

The room group learned the locations by viewing them in the correct locations. A slightly larger room was used because the original room was no longer available. Masking tape was placed on the floor to define a 16 × 12 foot area, the dimensions of the room used in the previous experiments. No children placed objects outside the tape borders. Before a child assigned to the room group arrived, the objects were placed in the correct positions for the first configuration that the child would learn (either large or small asymmetric configuration). To teach children the locations, an assistant covered the objects with small, brown boxes and asked the child to guess (or point to) the animal that was under each box. The delay between learning and reconstruction was similar to that of the previous experiments (about 30 sec). Like the map group, the room group learned and reconstructed both the small and the large configuration, in counterbalanced order.

In sum, the design of the experiment was 2 (group, i.e., map or room) × 2 (configuration size, i.e., small or large), with configuration size as a within-subjects factor. Order (small or large configuration first) was counterbalanced but not included in the analyses due to the small number of subjects.

**Results and Discussion**

Children in both groups performed much better than preschoolers in Experiment 2. To permit direct comparison of the groups, the coordinates of the placements of the children in the map group were multiplied by the scale factor (12). In terms of relative accuracy, preschoolers performed much better in Experiment 3 (*M* = 10.5 degrees, SD = 3.2) than in Experiment 2 (*M* = 32.1, SD = 22.6), *F*(1, 34) = 15.11, *p* < .001.

The map and room groups performed comparably; a 3 (age) × 2 (configuration size) ANOVA on the angular-accuracy scores from Experiment 3 revealed no significant effects or interactions. Boys (*M* = 8.9, SD = 2.4) were more accurate than girls (*M* = 12.9, SD = 2.7), *F*(1, 15) = 10.94, *p* < .01.

Results were similar for absolute accuracy; children who participated in Experiment 3 (*M* = .54 m, SD = .17) performed much better than the preschoolers who participated in Experiment 2 (*M* = 1.3, SD = .55), *F*(1, 34) = 25.93, *p* < .001. Absolute accuracy scores were similar for the map (*M* = .53, SD = .21) and room (*M* = .55, SD = .15) groups.

In sum, the results of Experiment 3 revealed that children could remember the locations of the objects. When scaling was not required, children performed quite well.

**General Discussion**

The first goal of this research was to investigate whether children’s spatial reconstructions could preserve the overall con-
figuration of objects. In Experiment 1, most of the preschoolers’ reconstructions were systematically related to the target configurations. The relative relations in the reconstructions and in the target configurations were very similar. At the same time, the results replicated the main finding of previous studies; young children placed the objects substantially farther from the target locations than older children and adults. Children’s reconstructions contained systematic transformations; the reconstructions were often too small and off-center.

The second goal of this research was to investigate how characteristics of the configurations could affect the accuracy of children’s reconstructions. Symmetry had a substantial effect on the accuracy of preschoolers, but not elementary school children’s and adults’, reconstructions. Most of the younger children preserved the overall configuration of objects when they reconstructed symmetric (Experiment 1) but not asymmetric (Experiment 2) configurations. However, when scale compensation was not required (Experiment 3), children’s reconstructions of the asymmetric configurations were quite accurate.

Why did symmetry have such a large effect on preschoolers’ reconstructions? Although further research is needed to provide a definitive answer, the present results suggest that a key factor may be the information that children did, and did not, acquire from the maps. Consider first children’s performance with the symmetric configurations in Experiment 1. It seems likely that children in Experiment 1 acquired information about the relative relations among the objects, and hence they were able to reproduce the relative relations in the room. The symmetry of the configurations may have helped children substantially, specifically because symmetric configurations are easier than asymmetric configurations to represent and think about in terms of an organized, integrated configuration or pattern. The symmetry of the configurations also may have helped in another, related way: as the children reconstructed the configuration, their placements of some objects could have reminded them of the locations of to-be-placed objects that shared the same X or Y coordinates. As each object was placed, the children received more information about where to place the next object.

The results of Study 1 also indicate that children may not have acquired or did not use information that specified the absolute locations of the objects in the room. Consequently, even though their reconstructions preserved the relative relations, the reconstructions often were inaccurate in an absolute sense and contained systematic transformations.

Next consider what information children may have acquired when they learned the asymmetric configurations in Studies 2 and 3. Children may not have acquired information about the relative relations among the objects in the asymmetric configurations. Instead, their knowledge may have been limited to the positions of the objects in terms of individual relations to the edges of the map (see Huttenlocher & Newcombe, 1984). For example, the children may have known that Ms. Piggy was close to the lower portion of the map, and that Mickey Mouse was relatively close to the upper portion. Knowing the location of the objects in this way would be sufficient to allow the children to reconstruct the configurations accurately when scale-compensation was not required, and hence they performed well in Study 3.

When scale compensation was required, however, children might have substantially more difficulty if they knew the locations primarily in terms of relations to the edges of the map. To perform well, they would have to use the relation between the map and the room. For example, if children knew that Mickey Mouse was close to the top of the map, then they would need to know that the top of the map corresponded to the top of the room. The systematic transformations in Study 1 suggest that children may not have known or used this correspondence. If the same were true in Study 2, then the information that children had learned from the maps (proximities to the edges) would not be available or useful in the room.

Further studies are needed to test and extend the explanation of children’s and adults’ performance. For example, it is important to investigate how children mentally represented the asymmetric configurations to confirm that they knew the location primarily in terms of proximity to the surrounding edges. In addition, because children’s comprehension or use of the relation between the map and the room appears to influence performance substantially, it is important to investigate this issue in more detail. For example, children’s comprehension and use of the map-room relation might be
improved by giving more detailed instructions or by making the map and room look more alike. In addition, the present explanation does not account for the observed sex differences. These were not common in the present work, but when they did occur, boys usually performed better than girls. Interpreting the sex differences requires replication and an account of how sex could influence the results.

Finally, the results demonstrate the importance of differentiating sources of error in children’s reconstructions. In addition to future studies of reconstruction, the methods developed here may be relevant to research in other domains in which scale plays an important issue, such as drawing. Reconstruction tasks continue to be a very informative method for investigating the development of spatial cognition.

Appendix A
Calculation of Relative Accuracy

An angular relation was defined as the angle that would be formed by projecting a ray from the bottom wall of the room, or from an imaginary extension of the bottom wall of the room. The measure assumes that subjects reconstructed the configuration relative to the bottom wall of the room. For example, $\Theta$ is the angular relation between objects p and d in Figure 2. Angular relations were calculated as follows:

$$\Theta = \arctan\left( \frac{Y_b - Y_p}{X_b - X_p} \right)$$

where X and Y refer to the X and Y coordinates of objects p and b.

The nine angular relations shown in Figure 2 were calculated, and the absolute deviation between each angular relation in the reconstruction and the corresponding relation in the target configuration was calculated. For example, in the target configuration, the angle relating Ms. Piggy to Donald Duck is approximately 45 degrees (see Fig. 2). If the corresponding angle in a reconstruction was 40 degrees, then the absolute deviation would be 5 degrees. The direction of the deviation was not important for determining the magnitude of the overall difference; only the absolute deviation was considered. The median of these nine relations was the overall measure of relative accuracy (see Brown & Siegler, 1993).

Appendix B
Detection and Correction of Rotations

If the assumption that subjects reconstructed the configurations relative to the bottom wall of the room was wrong, then the relative-accuracy score could be substantially affected. For example, if a subject reconstructed the configuration relative to the right wall of the room, the relative-accuracy score will be poor even if the reconstruction did preserve the relative relations among the objects. The raw relative-accuracy score would only show that the reconstruction was inaccurate—off by 90 degrees. The next section describes how these rotations were detected and corrected.

**Detection**

Patterns in the deviations of individual angular relations in the reconstructions from the comparable relations in the target configurations were used as evidence of systematic rotation. If a reconstruction is rotated, then all (or almost all) of the angular relations in the reconstruction will differ systematically from the target direction in the same direction. For example, if the angular relation between Ms. Piggy and Kermit is rotated to the left relative to the target configuration, then all (or at least most) of the remaining angular relations should likewise be rotated to the left. If a reconstruction is not systematically rotated, then discrepancies between angular relations in the target and in a given reconstruction should not show a consistent pattern. On average, about half of the angular deviations from the targets should be negative, and about half should be positive. Comparisons to the random reconstructions confirmed this assumption. Almost exactly half ($M = 4.48, SD = 1.66$) of the nine angular relations that were assessed in each chance reconstruction deviated from their targets in the negative direction (i.e., to the left), and half deviated in the positive direction (i.e., to the right). A reconstruction was considered systematically rotated if at least eight of the nine individual angular relations differed from the target in the same direction. Only 4.2% of the random reconstructions met this criterion.

Rotations of 180 degrees are a special case, and a separate analysis was required to detect them. A 180-degree rotation would involve reconstructing the configuration relative to the top, rather than the bottom, wall of the room. In this case, there would not be a consistent pattern in the deviations of the angular relations from the target configuration. Instead, each of the angular relations would differ from the target configuration in the opposite direction. Therefore, in addition to the criterion discussed above, a reconstruction was also considered systematically rotated if at least eight of the nine angular relations were in the direction opposite that of the target configuration.

**Correction**

The relative-accuracy score was the measure of the magnitude of rotation. For example, if a reconstruction received a relative-accuracy score of 90 degrees, it was assumed to be rotated 90 degrees. The direction in which to rotate the reconstruction was determined by calculating the number of angular relations that differed from the target in one direction versus the other. The reconstruction was assumed to be rotated in the direction of the greatest number of differences. Cor-
rection involved rotating the reconstruction in the opposite direction. For example, if eight of the nine individual relations in a reconstruction were rotated to the left, then the correction would involve rotating the reconstruction to the right.

Corrected x (x') and y (y') coordinates were calculated as follows (Smart, 1988):

\[
\begin{align*}
x' &= (x - h) \times \cos(\theta) (y - k) \times \sin(\theta) + h \\
y' &= (x - h) \times \sin(\theta) (y - k) \times \cos(\theta) + k \\
x &= \text{raw x coordinates of a given object} \\
y &= \text{raw y coordinate of a given object} \\
h &= \text{x coordinate of the centroid of the reconstruction} \\
k &= \text{y coordinate of the centroid of the reconstruction} \\
\theta &= \text{relative-accuracy score. (If the reconstruction was rotated to the left, then this value was multiplied by -1.)}
\end{align*}
\]

References


