Preschoolers' and adults' scale translation and reconstruction of spatial information acquired from maps

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This research investigated the ability of preschoolers (ages 4 and 5) and adults to memorize the configuration of objects depicted on simple maps and to reconstruct the configurations from memory, in a room. Successful performance required that subjects both mentally represent the spatial relations on the maps and coordinate the scale relation between the maps and the room. The task therefore provided information about children's representational skills and understanding and use of scale relations. The reconstructions of most subjects were systematically related to the specific configurations that were depicted on the maps; subjects demonstrated knowledge of the angular relations among objects in the configurations. However, children were significantly more likely than adults to commit scale errors, which involved systematically reconstructing a configuration at a size that was larger or smaller than the target configuration. Taken together, the results suggest that preschoolers' reconstructions can preserve important elements of the original configuration, but that knowledge and use of scale relations may develop later than the ability to represent the relations among a set of objects in a configuration.

Small-scale representations of space play a critical role in the manipulation and communication of spatial information. We draw upon our ability to understand and use small-scale representations whenever we read a map, look at a blueprint, or study a model of a room or other space. Because adults know, for example, that a map is a small-scale representation of a particular place in the world, they can plan a trip and know something about the area they will visit long before they embark. Small-scale representations thus free us from the bounds of our own direct experience and allow us to learn about the world from others (Robinson & Petchenik, 1976; Wilford, 1981).

How do children develop an understanding of small-scale spatial representations? Addressing this question has provided important windows on to several topics of classic and current interest to developmental psychologists (DeLoache, 1989; Liben & Downs, 1992). Two properties of maps or models make them particularly relevant to research in cognitive development. First, in a general sense, all models or maps are symbols; the small-scale representation stands for something or some place in the world. To use a map or model, children therefore must be able to understand the basic relation between a symbol and its referent. Investigating the development of children's use of this symbolic

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relation has provided substantial and very important information about the development of their understanding of symbols (DeLoache, 1987, 1989, 1991). Second, in a more specific sense, models and maps are also spatial representations; they are used to communicate the location of places in the world, and the specific relations among these locations. Consequently, maps and models have also proved to be useful tools for studying basic issues in the development of spatial cognition, such as how children encode spatial configurations (e.g. Blades & Spencer, 1987; Landau, 1986; Scholnick, Fein & Campbell, 1990; Uttal & Wellman, 1989).

Research has established that young preschoolers can understand and use the basic symbolic relation between a model or map and a space (DeLoache, 1987, 1989; Marzolf & DeLoache, 1992; Uttal, DeLoache & Schreiber, 1992; Uttal & Wellman, 1989). Consider, for example 3-year-olds’ excellent performance in DeLoache’s (1987) model task. Children watch as an attractive miniature toy is hidden behind or near an item of furniture in a small-scale model of a room. They then attempt to find the corresponding larger toy in the room. Most 3-year-olds succeed in most versions of this task, but children only 6 months younger fail.

To succeed in the model task, children must use a symbolic relation: they must realize that the model stands for the room. However, successful performance does not necessarily indicate that children can use the spatial relations between the model and the room. The challenge for young children is to understand that the model is a symbol of the room. If they are able to gain this insight, then the spatial aspects of finding the toy are quite simple (DeLoache, 1989). For example, when children witness the miniature toy being hidden behind the couch in the model, they can find the toy by remembering that it is located behind the couch in the room. There is no need to acquire from the model (or remember) more detailed spatial information, such as whether the couch is to the right or left of the chair, or how far the couch is from other items of furniture. Children can thus succeed without a full understanding that the model can be used to gain information about the particular spatial relations among items in the room.

Other tasks, however, do require that subjects take advantage of the spatial correspondence between a map or model and its referent. This paper investigates children’s performance on one such task, scale translation and reconstruction. Typically, subjects first learn, from a small-scale model or map, the spatial relations among a set of objects. They are then asked to reconstruct the configuration of objects in the space that the model or map represents. In previous studies, children have learned the arrangement of furniture in a room from a small model and then attempted to place the actual furniture in the appropriate places in the room (Liben, Moore & Golbeck, 1982; Siegel & Schadler, 1976). Similarly, children have been asked to memorize a small-scale version of a model town and then reconstruct a larger version in a gymnasium (Herman & Siegel, 1978). To perform well, children must understand and use the spatial correspondence between the model or map and its referent in several ways. For example, children must know that the spatial relations depicted on the map or in the model correspond to the relations that should exist in the room when the configuration is reconstructed. Moreover, they must be able to encode the represented configuration in a form that will allow them to reconstruct it at a different scale (see Harris, 1984).

Preschoolers have usually performed abysmally in previous studies of scale translation and reconstruction. For example, Liben et al. (1982) found that kindergarten children
who learned the layout of furniture in a classroom from a small-scale model placed only 25 per cent of the furniture within one foot of the correct locations in the room. Liben & Downs (1989, 1992; see also Liben, 1988) concluded that children’s poor performance stems from a general developmental limit to their understanding, mental representation and manipulation of spatial relations. This interpretation is grounded in a Piagetian perspective (Piaget & Inhelder, 1956; Piaget, Inhelder & Szeminska, 1960) on the development of spatial cognition, which suggests that preschoolers cannot reason about the projective or Euclidean relations in a spatial configuration. In short, Liben & Downs suggest that using anything but the simplest spatial relations in maps or models requires cognitive abilities that are beyond the developmental level of preschoolers.

This paper offers an alternative perspective on young children’s performance in scale translation and reconstruction tasks: the reconstructions may preserve important spatial characteristics of the original configurations, even if children place the objects far from the correct or target locations. Previous studies may have underestimated children’s abilities because reconstructions have been analysed only in terms of absolute criteria: the critical measure is how close subjects place each object to the correct or target location. The present work provides evidence that alternative scoring criteria can reveal substantial accuracies in young children’s reconstructions. Thus, preschoolers may know substantially more about the spatial relations between maps or models and their referents than the results of previous studies of scale translation and reconstruction would seem to suggest.

Specifically, this paper presents evidence that children’s reconstructions of scaled configurations can demonstrate sensitivity to angular relations. This refers to a systematic correspondence between the angular (e.g. 30 degrees) or directional (e.g. northwest) relations in the original configuration and the reconstruction. As used here, systematic means that the individual positions of objects in the reconstruction reflect the angular characteristics of the overall original configuration. The reconstruction provides evidence that the subject was thinking about the specific configuration that was depicted on the map or in the model and that s/he had represented information about the relations among the various objects in the configuration.

It is important to note that a reconstruction that demonstrates sensitivity to angular relations could still be inaccurate in an absolute sense. This could happen if a reconstruction differed systematically in size from the original configuration, that is, if the reconstruction contained a scale error. Figure 1 provides a hypothetical example: it depicts a configuration and a reconstruction that demonstrates sensitivity to angular relations but is inaccurate in an absolute sense. Note that the position of each object in the reconstruction reflects the position that it occupied in the original, and that the overall configuration of objects is preserved. However, also note that the reconstruction differs in an important way from the original; as a whole, the configuration is systematically smaller than the target configuration. That is, the distances between individual objects in the reconstruction are shorter than in the original configuration. Consequently, the reconstruction is not accurate in an absolute sense. The absolute metric accuracy of the reconstruction could be improved substantially by systematically stretching the entire configuration and hence enlarging the distances between individual objects. A scale error could also involve reconstructing a configuration at a size that was systematically larger than the original configuration.
Figure 1. An example of a scale error in a reconstruction. Assume that subjects were asked to construct the configuration of objects labelled 'original'. The configuration labelled 'reconstruction' differs from the original only in terms of size. The angular relations in the reconstruction are systematically related to those in the original configuration.

The presence of systematic scale errors in children’s reconstructions would provide evidence that children were sensitive to the angular relations in the original configurations. Moreover, it would reveal that children understood that the map communicated specific spatial information about a configuration and that they mentally represented information about the angular relations among the objects. Hence, the present research investigated whether young children's reconstructions of scale-translated configurations contained systematic scale errors.

The results of at least one previous study are consistent with the claim that children's reconstructions might demonstrate sensitivity to angular relations. Landau (1986) has found that preschoolers can perform well on search tasks that seem to demand knowledge of the angular or directional relations on a map. After studying a map of a room, children were asked to use the knowledge they gained to travel to specific locations in the room. The relation between the position or orientation of the map and the space that it represented was varied in different conditions. For example, children sometimes studied the map with their backs turned to the room that it represented. To succeed, children had to encode the relations on the map in a form that could be used in the room despite the change in direction or orientation that occurred between studying the map and entering the room. In most cases children performed very well, often travelling directly to the target even though they had studied a map that was not aligned with the space that it represented.

Based on these results, Landau (1986, 1988) claimed that 4-year-olds understood that the map represented a specific set of spatial relations among the objects in the room and that children accurately encoded these relations. Furthermore, she argued that children understood, at an implicit level, the similarity transformation that related the map to the
space. This is a geometric transformation in which angular relations are preserved but specific metric distances are not. As an example, consider a common road map of the US. Most road maps preserve the angular or directional relations between cities; New York is north of Washington, both on the map and in the world. However, distances on the map and in the world are very different. In the world, these cities are approximately 300 kilometres apart; on the map, the corresponding distance is probably only a few inches. To make the metric distances between locations on the map meaningful, the map user must know the scale relation between the map and the world and must multiply a given map-depicted distance by the scale factor. Put simply, obtaining information directly from a map about the angular relations between places or landmarks in the world is much easier than obtaining information about specific metric distances.

This analysis leads to the suggestion that children’s reconstructions of scale-translated configurations might demonstrate sensitivity to the angular or directional relations of the original configurations. If, as Landau has suggested, preschoolers can understand a similarity transformation, then they should be able to reconstruct the relations that remain constant regardless of scale translation, namely, the angular or directional relations. However, children might experience much more difficulty with the relations that change dramatically across scale translation, namely, the metric distances between objects. The presence of systematic scale errors in children’s reconstructions would thus suggest that they were sensitive to the angular or directional relations in the original configurations, but that they had more difficulty taking into account or using the metric scale relation between the small-scale representation and the larger space.

In sum, the primary goal of the present work was to determine whether preschoolers' reconstructions of scale-translated configurations could demonstrate sensitivity to the angular relations in the original configurations. Preschoolers and adults were asked to reconstruct in a room configurations consisting of six objects. Subjects learned the configurations from studying simple maps. Analyses focused on uncovering scale errors and hence sensitivity to angular or directional relations.

A second, more general goal was to use children's performance in scale translation and reconstruction tasks as an index of their ability to represent spatial relations. The configurations on the maps were designed so that children’s reconstructions of them would reveal how specifically the configurations were represented. Analyses of the reconstructions thus provided information about the characteristics of children’s mental representations of the map-depicted configurations.

Method

Subjects

Thirty-eight preschoolers (M = 5.0 years, range = 4.1 to 5.9 years) and 25 adults (M = 19.2 years, range = 18.4 to 21.3 years) participated, including approximately equal numbers of males and females. About two-thirds of the children attended a university preschool serving a predominantly white, middle- to upper-middle-class community. The other third attended another preschool serving an integrated middle-class community. The adults were university students who participated to fulfill a course requirement.

Because the research involved a comparison between two quite different age groups, special effort was devoted to making the tasks appropriate and interesting for both preschoolers and adults. This required that the materials that were used with children differed from those that were used with adults. However,
the spatial characteristics of the configurations that children and adults learned and reconstructed, which were the focus of this research, were identical.

Materials and apparatus

Objects used in the reconstructions. Subjects were asked to memorize maps and then reconstruct the map-depicted configurations in a room. The objects that made up the spatial configurations were different for children and adults. For children, the objects were toy animals (pig, dog, cat, frog, rabbit and bear); for adults, the objects were household items (phone, toaster, lamp, book, cup and flower pot). The toy animals and household items were approximately the same size (diameters of the bases ranged approximately from 5 to 12 cm) and thus subtended approximately the same area in the room. Both the animals and the household items will be referred to as objects.

The configurations. Subjects were asked to reconstruct two different configurations of the objects, labelled Configuration 1 and Configuration 2. Both configurations were derived from a common prototype, a rectangle. Figure 2 shows the prototype rectangle and the arrangement of the toys in the two configurations; Fig. 3 shows the comparable arrangement of the household items in the configurations. Note that the configurations depicted in Figs 2 and 3 were spatially identical. The position of each household item corresponded to the position of a particular toy. For example, the frog (see Fig. 2) and book (see Fig. 3) occupied identical positions within their respective configurations.

An important characteristic of the configurations was that they contained two deviations from the symmetry of the prototype rectangle. For example, in Configuration 1, the bear was located to the right of its position in the prototype, and the cat was located above the position that it occupied in the prototype (see Fig. 2). In Configuration 2, the deviations from symmetry were the opposite of those in Configuration 1: the bear was located to the left of the position that it occupied in the prototype, and the cat was located below the position it occupied in the prototype.

The design of the configuration was influenced by two factors. The first was the need to make the configurations relatively easy for young children to memorize and encode. Consequently, the configurations were nearly (but not completely) symmetrical. A symmetrical configuration might facilitate children’s performance because the number of unique relations that must be encoded is less than in an asymmetric configuration with the same number of objects. For example, in both Configuration 1 and Configuration 2, the dog and pig occupied the same vertical position in the prototype rectangle (see Fig. 2). Hence, knowing the correct position of one of these two animals could help children encode the position of the other animal.

The second factor that influenced the design of the configurations was an attempt to determine whether children could notice, encode, and reproduce in their reconstructions information that specified unique characteristics of the configurations. The deviations from symmetry were included to reveal whether children represented the configurations simply as rectangles, or whether they acquired more specific information about the configurations. It is possible that subjects could encode the locations of objects simply by noting the position of each object relative to an overall rectangular shape. For example, subjects might encode the position of the dog as, ‘In the lower right-hand corner of the rectangle’ or the position of the rabbit as, ‘In the upper left-hand corner of the rectangle’. If this was all that subjects encoded, however, they might fail in their reconstructions to maintain the deviations from symmetry. They might reconstruct the configurations in a completely rectangular shape.

The maps. The configurations were presented on maps that represented the positions of the objects in an otherwise empty room. The only information on the maps was the depiction of the locations of the objects in the room. No other information, such as the walls, door or window, was included on the maps. The maps were constructed on white posterboard that was 51 cm long × 41 cm wide.

Two sets of maps were constructed, one for children and one for adults. Each set contained two maps; one map represented Configuration 1, and the other represented Configuration 2. The maps for children represented the locations of the toys in the room, and the maps for adults represented the locations of the household objects in the room. On the maps for children, small photographs of the appropriate animals were attached to the posterboard in the positions depicted in Fig. 2. Photographs were used to represent the locations of the animals to facilitate children’s comprehension of the relation between the depictions of the animals and...
Figure 2. The symmetrical prototype and the two configurations that children were asked to reconstruct. The letters represent the locations of the following animals: pig (P), dog (D), cat (C), frog (F), rabbit (R), and bear (B). Note that the positions of the cat and the bear (underlined and printed in bold face) deviated from the symmetry of the rectangular prototype.

The room. Figure 4 shows the layout and dimensions (in metres) of the room in which subjects were asked to reconstruct the configurations. Before a child arrived, the frog (or the book, for adult subjects) was placed at the correct location. To determine the correct location, the edges of the map were assumed to represent the walls of the room. The distances of the photograph of the frog (or the line drawing of the book) from the edges were then multiplied by the scale factor, which was approximately one to nine. The remaining objects were placed in a line (in random order) along the windowsill.
Figure 3. The symmetrical prototype and the two configurations that adults were asked to reconstruct. The letters represent the locations of the following household items: phone (P), toaster (T), lamp (L), book (B), cup (C) and flower pot (F). Note that the spatial configurations that adults learned and reconstructed were identical to those that children learned and reconstructed.

Procedures

Attempts were made to have each subject participate twice. Thirty-three preschoolers and 23 adults did participate twice1. The second test data for two of the children were lost due to experimenter error. Thus, complete data were available for 31 preschoolers and 23 adults. Approximately one half of the subjects were asked to reconstruct Configuration 1 at the first testing and Configuration 2 at the second testing; the order was reversed for the other subjects. Testings were conducted at least 10 days apart.

Procedures used with child subjects are described. Similar procedures were followed with adults, but the task was not presented as a game. The experiment consisted of three phases: initial familiarization, map learning and reconstruction.

Initial familiarization. The child was first told that s/he would play a game with some toy animals and a map. The child was then taken into the room. The experimenter pointed to the frog and said, ‘The frog is already in

1The five preschoolers who were not tested twice either refused to participate in the second session or their parents were unable to bring them to the laboratory twice. The two adults who were not tested twice failed to come to two successive appointments for the second testing.
its place. The experimenter then pointed to the remaining animals on the windowsill and told the subject, `All of these other animals have a place in this room. Now you're going to learn a map that shows you where all the animals go, so that when you come back into this room, you can put all of the animals in their places.' The experimenter then led the child out of the room and into a hallway. The door to the room was closed, and the child was seated at a small table in the hallway. The table and chair were positioned so that the child was oriented in the same direction as s/he would stand when reconstructing the configuration in the room.

Learning the maps. To teach children the positions of the animals in the configurations, the experimenter followed a procedure similar to that used by Uttal & Wellman (1989). First, the experimenter pointed (in random order) to the photographs on the map and asked the child to identify each animal. After the child identified all animals, the photographs were covered with small blank cards. The child was then asked to name the animal under each card as the experimenter pointed to each in random order. The appropriate card was removed when the animal was correctly named. The experimenter continued to probe misnamed animals until all cards were removed. The cards were then replaced and the procedure was repeated, except that the cards were removed and then replaced immediately after the child named the animal. The procedure was repeated until all the animals had been named correctly on two successive trials.

Next, the experimenter replaced the cards and asked the child to point to the card that covered the photograph of the appropriate animal as the experimenter named each. When the child pointed correctly, the card was removed briefly for the child to see that his or her point was correct. The photograph was then covered again with the card. The child was tested until s/he could point to the correct location of each animal on two successive trials.

Reconstruction. After the child had learned the map, s/he was taken back into the testing room and was told, 'Now you can put the animals in the room like they were on the map.' The map was not brought into the room; the child had to reconstruct the configuration from memory. The child was asked to stand against the lower short wall of the room, at the position represented by the X in Fig. 4. The experimenter removed the animals from the windowwall and walked to a position immediately beside the child. The experimenter gave the child one of the animals (order of presentation was determined randomly) and told him or her, 'Put the ... in its place.' The experimenter asked the child to return to the starting point after placing the animal and then gave him or her another animal to place. The child was allowed to move any animal except the frog after it was placed, but the experimenter did not encourage this.
Recording of placements

Subjects' placements of the animals were recorded in terms of an X and Y coordinate system. The lower, left-hand corner of the room (see Fig. 4) was assigned the coordinates 0.0. Placements were recorded in terms of inches from this origin. A simple measuring tape was attached to the baseboards of the room, and small marks were drawn to indicate every 3 inches (7.6 cm). The experimenter used these marks to record the location of the objects.

To determine whether the method of recording subjects' placements was reliable, two assistants were asked to assess independently the reconstructions of 12 subjects. One assistant recorded the placement of the objects and then left the room. A second assistant then entered the room and recorded the placements. The mean difference between the measurements of the two assistants was very small, approximately 3 cm.

Results

The primary goal of this research was to determine whether children's reconstructions contained scale errors and hence demonstrated sensitivity to angular or directional relations. The research also investigated how specifically children represented the configurations, that is, whether their reconstructions preserved the deviations from symmetry. These questions were addressed in two sets of analyses.

Sensitivity to angular or directional relations

Did children's reconstructions demonstrate sensitivity to the map-depicted angular relations? Evidence for this would come in the form of systematic scale errors. The analyses were based on a procedure developed by Schönemann & Carroll (1970). The procedure, which is commonly referred to as MOTION, systematically shrinks or expands and rotates a configuration to find a mathematical best fit with the target configuration. As used here, the term systematic means that all objects in the configuration are affected, and the transformation preserves the angular relations between the objects in the reconstruction. A least squares solution is obtained, and the accuracy of the placement of each object can be assessed by comparing the location (both X and Y coordinates) at which the subject actually placed a given object to the procedure-determined location in the best fitting solution. Then, the amount of error that is left over (i.e., the residual error that cannot be attributed to systematic rotation or scale error) is determined for each object in the reconstruction. An overall goodness of fit measure, the Root Mean Square Distance (RMSD), can be derived from the residual matrix (Institute for Social Research, 1981). The RMSD can be construed as the average amount of distance between a subjects' placements and the target locations that cannot be explained by scale adjustment and rotation. Hence, the RMSD will be referred to as the average error. A reconstruction that preserved the exact angular relations that were depicted on the map thus would have an average error of zero because all of the error in the subject's reconstruction could be eliminated by systematically stretching (or shrinking) the reconstruction to best match the target.

An important feature of MOTION is that the scale adjustment is optional. That is, a best-fitting solution can be obtained both with and without a scale adjustment. Obtaining both kinds of solutions provided the means of assessing how much of the error in subjects' reconstructions could be attributed to systematic scale errors: the
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Configuration 1

![Graph showing the effect of scale adjustment on average error.]

Configuration 2

![Graph showing the effect of scale adjustment on average error.]

Figure 5. The effect of scale adjustment on the average error in subjects' reconstructions. The bars represent one standard error of the mean.

difference between solutions obtained with and without a scale adjustment represented the error that was due to systematic scale errors.

The MOTION analyses revealed that a substantial and statistically significant portion of the overall error in children's reconstructions could be attributed to systematic scale errors, and hence children were sensitive to the angular or directional relations in the configurations. As shown in Fig. 5, including a scale adjustment reduced the average error in children's reconstructions of both configurations. However, the scale adjustment had little effect on the accuracy of adults' reconstructions.

The average errors obtained in the MOTION analyses were entered into a 2 (age) by 2 (configuration, i.e. Configuration 1 or Configuration 2) by 2 (scale adjustment: present or absent) ANOVA, with configuration and scale adjustment as within-subject factors.

All the inferential statistics reported below were also conducted with the inclusion of gender as an additional independent variable. There were no main significant effects of, nor interactions with, gender.

Because these analyses compared directly the accuracy of subjects' reconstructions of Configurations 1 and 2, it was necessary to delete those subjects who participated once or whose data for one reconstruction were lost. Thus, these analyses are based on the reconstructions of 31 preschoolers and 23 adults. The regression approach to ANOVA was used. The relevant means and standard errors are shown in Fig. 5.
The main effect of age was significant \( F(1, 52) = 52.99, p < .001 \); adults' reconstructions were more accurate overall than children's reconstructions. The main effect of map configuration was also significant \( F(1, 52) = 5.22, p < .05 \). Surprisingly, reconstructions of Configuration 2 were more accurate than reconstructions of Configuration 1. The main effect of scale adjustment was also significant \( F(1, 52) = 72.22, p < .001 \); overall, reconstructions were more accurate when the scale adjustment was added.

MOTION also rotates the reconstruction in an attempt to find a best-fit solution. This manipulation is statistically independent of the scale adjustment; rotation of the entire configuration has no effect on the degree of sensitivity to angular relations. Examination of the rotation results revealed that three children rotated Configuration 1 approximately 180 degrees relative to the orientation in which they learned the map. That is, these children reconstructed the configuration as if the X in Fig. 4 represented a position that was in the top, rather than the bottom, of the room. The mean degree of rotation for these three reconstructions was 177.1 (SD = 1.9); this mean approaches the 180 degrees that would be expected if subjects rotated the configuration perfectly. In contrast, the mean best-fit rotation statistic for children who did not rotate the configuration was 6.6 (SD = 5.4), which is very close to the 0 degrees that would be expected if children reconstructed the configuration in the same orientation as the map-depicted configuration.

Of particular interest were effects involving scale adjustment because these indicated that a portion of the overall error in children’s reconstructions could be attributed to systematic scale errors. The interaction between age and scale adjustment was significant \( F(1, 52) = 22.52, p < .001 \). Simple effects tests indicated that the scale adjustment has a significant effect on the accuracy of children’s reconstructions \( F(1, 51) = 50.18 \). However, the comparable effect in the analysis of adults’ reconstructions was not significant \( F(1, 51) = 3.01, p > .05 \). Thus, children's reconstructions were improved significantly more by scale adjustment than adults’ reconstructions. This result reveals that a portion of the error in children's reconstructions can be attributed to systematic scale errors.

Reconstruction of the deviations from symmetry

Both configurations that subjects reconstructed contained two deviations from the symmetry of the rectangular prototype (see Figs 2 and 3). The deviations were included to determine whether subjects represented the configurations simply as symmetrical rectangles, or whether they encoded more specific information about the configurations. To determine whether the subjects preserved the deviations from symmetry, their placements of the bear (or flower pot) and cat (or lamp) were analysed. Placements were scored in relation to the frog (or book). For example, in children’s reconstructions of Configuration 1, the bear should be located to the right of the frog, and the cat should be located above the frog. Placements that were equal to the frog were scored as incorrect.

Both children and adults preserved the deviations from symmetry. In their reconstructions of Configuration 1, 73 per cent of the children placed the bear in the correct relation to the frog; 76 per cent of the children placed the cat in the correct relation to the frog. The results for reconstructions of Configuration 2 were similar; the
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corresponding percentages were 74 and 85 for placements of the bear and cat, respectively. Adults performed slightly better, but chi-square comparisons of the number of children and adults who preserved the deviations revealed no significant differences².

Discussion

The most important result of this research was that preschoolers’ reconstructions preserved spatial characteristics of the configurations that were depicted on the maps. Children’s reconstructions were related in a systematic and geometric way to the map-depicted configurations: the reconstructions demonstrated sensitivity to the angular relations in the configurations. This finding provides new information about children’s understanding of small-scale representations and their mental representation of spatial information. In addition, the results provide a new perspective on children’s performance in scale translation and reconstruction tasks. These contributions are discussed in turn.

Understanding maps and representing spatial information

To perform as well as they did, children had to know that the map-depicted configurations were systematically related to the configurations that should exist when the objects were placed in the room. The results reveal that young children can understand and use a particularly important feature of maps: communication of information about spatial configurations. Previous studies have provided evidence that young children can acquire information about landmarks or routes from maps (e.g. Blades & Spencer, 1987), but there has been disagreement about whether young children can take advantage of the specific spatial characteristics of maps (see Liben & Downs, 1989, 1992; Mandler, 1988). The results demonstrate in a new way that young children can take advantage of some of the unique spatial properties of maps.

To perform as well as they did, children also had to represent the information on the map in a form that allowed them to transform the configuration systematically as they reconstructed the configurations in the room. Moreover, most children encoded the information that specified unique characteristics of the configurations, that is, the deviations from symmetry. The ability to encode an integrated systematic set of relations is substantially more than would be predicted by theories that view preschoolers’ representations as fundamentally limited. In particular, the results are difficult to explain in terms of a topological geometry, which Piaget & Inhelder (1956) suggested characterized pre-operational children’s mental representation of space. Topological geometry does not include concepts such as angular relations or distance; the locations of objects are described in terms of surrounding, enclosure, etc. Many configurations that differ in terms of the angular or distance relations between objects are thus topologically identical. In the present research, children’s reconstructions were systematically related

² Because the analyses of whether subjects preserved the deviations from symmetry did not involve a direct comparison between reconstructions of Configurations 1 and 2, all available data were used. In other words, no subjects were deleted from the analysis.
to the map-depicted configurations in a way that cannot be specified in topological geometry. Thus, the characteristics of children’s reconstructions cannot be described adequately in terms of topology. Children clearly represented more than the topological characteristics of the configurations.

Despite the impressive characteristics of children’s reconstructions, it is important to note that scale errors did not explain all errors in the reconstructions. Children’s reconstructions were still less accurate than adults’, even after scale adjustment and rotation. Children were sensitive to the angular relations in the map-depicted configurations, but they did not preserve these relations perfectly in their reconstructions. What accounts for the errors in children’s reconstructions that cannot be attributed to scale errors? One likely possibility is that children may have had more difficulty remembering all the relations in the configurations. Even though children and adults were trained to the same criteria, it is possible that children may have experienced more difficulty rehearsing or maintaining the relations in memory. In addition, adults may have understood more clearly that the accuracy of their reconstructions would be evaluated and thus may have devoted more effort than children to reconstructing the configurations accurately.

One surprising result also merits attention: reconstructions of Configuration 2 were more accurate than reconstructions of Configuration 1. A likely explanation for this finding is that the relations among the objects in Configuration 2 might be easier to perceive or represent as an integrated configuration than the relations among the objects in Configuration 1. Recall that the two configurations differed only in terms of the location of the bear and cat. In Configuration 2, both of these animals were closer to the subject, during both the map-learning and reconstruction phase, than in Configuration 1 (see Fig. 2). Consequently, it may have been easier for children to view and conceive of Configuration 2 as an integrated whole. In other words, more of the objects in Configuration 2 were closer to the subject than in Configuration 1, and subjects consequently may have represented the relations among the objects in Configuration 2 more accurately.

A new perspective on performance in scale translation and reconstruction tasks

The results shed new light on children’s performance in scale translation and reconstruction tasks. In particular, the results help to identify different components of success: to perform well according to an absolute standard, children must encode the relations correctly and take into account the specific scale relation between the map or model and its referent. It is important to consider both components of success in interpreting children’s success or failure. Moreover, it is critical to analyze children’s reconstruction in a way that will distinguish different kinds of errors: difficulty with one component of success may lead to different kinds of errors than difficulty with the other component.

The results are consistent with Landau’s (1986) claim that young children can understand the similarity transformation that relates the angular relations on a map to those that exist in the larger room. Children generally were sensitive to the critical element that stayed constant across scale translation, that is, the angular relations among the different objects. However, as predicted, children’s reconstructions were less
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accurate in an absolute metric sense than adults’ reconstructions. Children’s reconstructions contained significantly more scale errors than adults’ reconstructions. To
reconstruct the metric distances between objects correctly, a person would need to do
more than encode the angular relations accurately; s/he would also need to relate the
distances between objects on the map to the distances that should exist in the room. The
results suggest that adults were more likely than children to perform the extra steps that
were needed to reconstruct the configuration at the correct size.

What were the extra steps that adults performed to allow them to reconstruct the
configuration accurately in terms of size? At some level, a person would need to consider
the scale relation between the map and the room. This does not mean that s/he would
need to know explicitly that the map was nine times smaller than the room. Rather, a
correspondence had to be established between the map-depicted distances and the
distances that should exist in the room. There were two cues available that could have
provided the necessary information. One was the distances on the map from the edges to
the depictions of the objects. If subjects assumed that the edges of the maps represented
the walls of the room, then they could have tried to make the distances between the
objects and the walls in the room proportional to the map-depicted distances. The only
way to do this and preserve the angular relations between the objects would be to
reconstruct the configuration at the correct size. The second possible cue to the size of
the configuration was the fixed object (the frog or the book) in the room. Subjects could
have used the distances from the fixed object to the walls as a scale cue and reconstructed
their configurations accordingly.

An important question for future research is whether, under different circumstances,
young children could translate and reconstruct a configuration of the correct size. It is
possible that children in the present research thought that the size of their
reconstructions was not important and hence did not consider the specific distances
between the animals in the room. Adults’ greater experience with maps may have led
them to consider the size of their reconstruction more systematically than children.
Children may also have been unaware of the cues that were available to help them
reconstruct the configuration at the correct size. Perhaps the magnitude of children’s
scale errors could be reduced substantially if children were encouraged to consider the
sizes of their reconstructions or if the necessary scale cues were made more salient.

In sum, the present research has identified both early competency as well as aspects of
spatial cognition that may continue to develop throughout the elementary school years.
In one sense, the results are consistent with the claims of researchers and theorists (e.g.,
Landau, 1986, 1988; Landau & Spelke, 1985; Mandler, 1988; Miller & Baillargeon, 1990)
who have argued that preschoolers’ understanding of space and spatial relations is quite
rich and sophisticated. Children’s reconstructions demonstrated a systematic geometric
correspondence to the map-depicted configurations that would not be predicted by
theories (e.g., Piaget & Inhelder, 1956) that view children’s understanding of space as
fundamentally limited. At the same time, however, the results point to important
differences between children and adults: children were much less likely than adults to
consider or use the specific scale relation between the map and the space that it
represented. Knowledge of scale relations and their use in maps may continue to develop
throughout the preschool and early elementary school years (see Liben & Downs, 1989,
1992). The present work has provided a theoretical framework and a set of analysis
techniques to help identify both similarities and differences in children’s and adults’ representation and reconstruction of spatial configurations.

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References


Reconstructions of maps


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