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How toddlers represent enclosed spaces

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Abstract

Recent findings indicate that toddlers can use geometric cues to locate an object hidden in a corner of a rectangular room after being disoriented [Cognition 61 (1996) 195]. It has been suggested that locating the object involves reestablishing one's initial heading. The present experiments examine search behavior after disorientation. We find that toddlers go directly to a particular corner, indicating that they do not have to reestablish their original heading. It also has been suggested that toddlers ability to use geometric cues is limited to surrounding spaces. We find that toddlers can locate an object from outside as well as from inside a space, although the task is harder from outside. Based on these results, we argue that while toddlers do not represent their position relative to a particular portion of a space, they nevertheless may represent their position relative to the entire space (i.e., outside vs. inside).

Keywords: Space; Cognition; Representation; Children

1. Introduction

The ability to retain information about the spatial environment is critically important to all mobile creatures. However, there is currently no consensus about how either human or non-human species maintain information about their spatial surroundings after movement to new locations. Nor is there agreement as to how spatial representation may change over development in an individual organism. Recent notions concerning human spatial cognition have varied from claims that spatial representations capture metric and relational information available in the environment (e.g., Landau, Spelke, & Gleitman, 1984), to claims that spatial representations are highly fragmented (e.g., McNamara, 1986; Scholl & Nolin, 1997). No-

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tions also have varied with respect to whether spatial representations are viewer independent ("object-centered," e.g., Biederman & Bar, 1999) or viewpoint specific (e.g., Tarr, Williams, Hayward, & Gauthier, 1998). In the present paper we attempt to clarify the nature of spatial representation in very young children.

The most influential theory of spatial development in human beings has been that of Piaget (Piaget and Inhelder (1948/1967)). He believed that early representations of space are not conceptualized independently of the observer. In his view, distance and length are not initially coded as features of stimuli themselves, but rather are specified in terms of reach. Further, information about location is only preserved from an initial viewing position. If these claims were accurate, young children's spatial representations would indeed be impoverished. Information about length and distance is critical for specifying the shapes of objects and of enclosed spaces (e.g., distinguishing between squares and rectangles), for locating objects that are not adjacent to landmarks, etc. Further, the ability to retain information about location after changes in spatial position is essential, since humans are mobile.

In the present paper we explore certain recent findings that have called Piaget's views into question—namely, findings indicating that even toddlers represent geometric properties of a space. Huttenlocher, Newcombe and colleagues have shown that young children use information about distance/length to code object location in an enclosed space (Huttenlocher, Newcombe, & Sandberg, 1994; Newcombe, Huttenlocher, Drummey, & Wiley, 1998). For example, Huttenlocher et al. (1994) presented toddlers with a task where they had to find an object hidden in a narrow sandbox 5 ft long. In one condition, the children were turned away after the hiding, and then had to point to the location where the object was hidden. They were successful, indicating that they used distance/length information in coding location. In the other condition, the children were moved from their original position in the middle of the box to an end of the box before pointing to the location of the hidden object. Again, they were successful. Newcombe et al. (1998) found that toddlers also could find a hidden object when they moved to the opposite side of the box. The fact that children were successful after moving to a new location indicates that coding was not tied to their initial viewing position.

Spelke and colleagues have shown that young children code the lengths of the walls of a rectangular space in which they are enclosed. Such coding can be seen in the ability to differentiate corners on the basis of geometric features of the space (Hermer & Spelke, 1994, 1996; see also Gouteux & Spelke, 2001; Wang & Spelke, 2002). Hermer and Spelke (1996) presented toddlers with a task where they had to find an object hidden in the corner of a small rectangular room. Before looking for the object, children were disoriented by being turned around several times with their eyes covered. The disorientation procedure prevents children from tracking the change in their relation to the hiding corner as they move. The results indicated that the disorientation procedure worked. That is, toddlers were equally likely to select either the correct corner or the geometrically identical corner diagonally opposite from it, showing that they did not update their relation to the hiding corner. Toddlers' performance indicated that they code distance/length, since what distinguishes the geometrically distinct corners is the difference in the lengths of the walls relative to a viewer; one pair has the longer wall to the right and the shorter wall to the left, and the other pair has the longer wall to the left and the shorter wall to the right.

The work with toddlers on retention of geometric information after disorientation was modeled on earlier research with animals. That research showed that animals also use geometric information to locate objects in their environment. One of the first studies investigating this ability was done by Cheng (1986). In this study, rats were placed in a rectangular box with food hidden in a particular location. The rats searched for the food after they had been disoriented. On most trials, they looked for the food at either the correct location or at a geometrically equivalent location diagonally opposite from it. Similar findings indicating the use of geometric information have been obtained with many other species including chickens (Vallortigara, Zanforlin, & Pasti, 1990), pigeons (Kelly, Spetch, & Heth, 1998), monkeys (Gouteux, Thinus-Blanc, & Vauclair, 2001), and fish (Sovrano, Bisazza, & Vallortigara, 2002).

While accumulating evidence from research on humans as well as animals shows an impressive ability to use geometric information about a space in locating objects, the representations that underlie this ability are not well understood. Currently there is more than one way to interpret success on search tasks involving disorientation. One possibility is that the space is represented as seen from the original heading (viewing perspective). In this case, finding the object after disorientation would involve reestablishing the starting orientation relative to the space. This would seem to be the position of Hermer and Spelke (1996), who propose that toddlers reorient themselves, "aligning the currently perceived environment with a representation of its geometric and sense properties" (p. 208). Another possibility is that the shape of the space is represented independently of the original heading of the viewer. That is, the space might be conceptualized in terms of internal relations among its parts. Such a "space-centered" conceptualization[1] might involve constituent side lengths, or angles, or both. Then no matter what portion of the space the viewer faces after being disoriented, the relation to the hiding corner would be known.

In the present work we explore the nature of children's spatial representations by systematically examining the behaviors they engage in when finding a hidden object following disorientation. If the space is represented from the original viewing perspective, toddlers would have to move or look around after disorientation to view various potential hiding locations and find the one that matches their original view of the space. On the other hand, if the space is represented in terms of internal relations among its parts, independent of viewer heading, toddlers would be able to find the hidden object without having to recover the perspective that matches their original view. Existing studies have reported levels of children's success but have not looked at how children go about locating the hidden object. That is, the studies have not explored whether, after disorientation, children survey the space until they encounter a corner that looks like the hiding location viewed from their initial position, or whether they go directly to that corner. Such information could be important to understanding the representation underlying children's ability to use geometric information in locating objects. Thus, in the three studies reported in the present paper we examine children's search patterns after disorientation.

Even if children's search behavior were to reveal that their representation of an enclosed space is independent of the heading towards a particular portion of that space, their relation to the entire space might be represented (i.e., inside vs. outside the space). This issue is important because it has implications for the nature of spatial representation (addressed in Section 3). In the original Hermer and Spelke study (1994), toddlers were tested only inside an enclosed space. The investigators argued that toddlers' ability to represent geometric features of a space was modular and narrow in scope, restricted to information about spaces that surround the viewer. As Wang and Spelke describe it, "the reorientation system represents only the shape of the permanent surrounding surface layout" (Wang & Spelke, 2002, p. 378).

To determine whether early sensitivity to geometric information actually is restricted to spaces that surround the viewer, we examine children's performance both inside and outside of a spatial layout. Support for the claim that the reorientation mechanism operates only when an organism is inside a space was presented by Gouteux, Vauclair, and Thinus-Blanc (2001). They found that 3-year-olds were unable to use geometric information to locate an object in the corner of a rectangular layout when they were outside of that layout. However, there were certain differences between the procedures used inside versus outside the space which may have contributed to the differential difficulty of the tasks.

First, the Gouteux et al. task involved movement of the spatial layout relative to a stationary child rather than disorientation of the child through movement relative to a stationary space. It is well known that movement of a spatial layout versus movement of the viewer are not of equivalent difficulty (cf. Huttenlocher & Presson, 1979; Simons & Wang, 1998). Second, rather than using a constant location for the hidden object over trials as in the Hermer and Spelke (1996) study, the object in the Gouteux et al study was hidden in different locations on different trials. As Hermer and Spelke pointed out, changes in the object's hiding location may produce perseverative errors. Here we explore children's performance both inside and outside of a space using a task where the child moves relative to the layout and where the object is hidden in a constant location.

To examine the generality of children's ability to use geometric cues in locating objects, we test them with triangular as well as rectangular spaces.[2] These two kinds of shapes differ from one another with respect to the cues that are available for identifying the target location. A rectangular shape has four equal angles and is bilaterally symmetrical; there are two pairs of opposite corners that are geometrically identical. In contrast, the isosceles triangle used in the present study has three corners that can be distinguished from one another, as indicated below.

An isosceles triangle has one unique corner that differs from the others both in angular size, and also in that the two sides forming the corner are of equal length. The two other corners cannot be distinguished by angle (because the angles are equal in size), but *can* be distinguished on the same basis as the two types of corners in the rectangle. That is, for one of the corners the longer wall is on the left and the shorter wall is on the right and for the other corner this relation is reversed. In addition, the two corners are distinguishable because their relation to the unique corner differs, e.g., moving in a clock-wise direction, one of the corners is one step removed and the other is two steps removed from the unique corner. It is always possible to define the shape of an enclosed form in terms of the lengths of its sides. Here we examine what geometric cues children use in searching for a hidden object after disorientation in a triangle—whether shape is characterized in terms of side lengths alone, or also in terms of angle.

The inclusion of a triangular space is also useful in distinguishing among different patterns of search behavior during the recovery of the hidden object. As we have indicated, examination of children's search patterns may provide information critical to understanding the nature of their spatial representation. In a rectangular room, one of the two identical corners can be seen from a single position within the room by glancing along a single wall. In a triangular room, the three distinguishable corners are not simultaneously visible. Hence, one can more reliably determine whether the child surveys the different corners in searching for an object.

2. Present experiments

In the experiments below, we extend the recent findings indicating that toddlers can maintain information about the location of a hidden object after moving to a new position. We wish to obtain further information about their representation of a space. In the first study we examine toddlers' behavior in seeking the hidden object in a triangular space. In the second and third studies we examine the behavior in seeking the hidden object from outside a triangular and a rectangular space, respectively.

2.1. Experiment 1: search in a triangular room

In this experiment we examine children's performance levels and their search behavior in obtaining a hidden object in a triangular space. Our experimental task involves hiding a toy in a corner of a triangular room, twirling the child around, and then having the child find the toy. Children's performance is examined in two experiments (1A and 1B). In Experiment 1A, the toy is hidden in the same location on each trial as in the Hermer and Spelke (1996) study; this allows us to compare our results to the results obtained with a rectangular space. In Experiment 1B, the toy is hidden in a different corner on each trial, providing a test of whether children can use geometric cues to identify a particular corner, updating the location of a hidden object in a space after disorientation. As noted above, using variable hiding locations may lead to a chance level performance because of perseveration errors. In Experiment 1 we examine children's performance on the two finding tasks that differ only with respect to whether the hiding location is constant or variable. This should allow us to investigate directly the role of this factor in children's ability to find an object following disorientation.

2.1.1. Experiment 1A: constant hiding location

2.1.1.1. Participants. There were 26 children (16 boys and 10 girls) who participated in the study. The participants were between 20 and 24 months of age. The average age was 22.5 months. The participating families were from different ethnic backgrounds, largely middle-class. Parents were compensated for taking part in the study.

2.1.1.2. Materials. Children were tested in a triangular room (shown in Fig. 1) located within a larger area. The room was constructed from a wooden frame covered with non-transparent canvas. The walls were 6.5 ft high and formed an isosceles triangle (7 ft × 11 ft × 11 ft). The three corners of the triangular room served as entrance points: the walls were connected to each other by metal hinges that could be opened and closed from outside. Three identical cylinders (3 in. in diameter, 2 ft high) were located inside the room, each in a different corner. Small containers (3 in. deep) placed inside each cylinder served as potential hiding places. The containers were covered so that the child could not see what is inside them unless he/she removed the cover. A small plastic toy (Barney) was used as an object of search. A video camera was attached to the ceiling above the triangular room to provide a view of the experimental procedure.

2.1.1.3. Procedure. The experimenter described the procedure to the parent while the child played with the toys in the larger room. When the child felt comfortable in the new environment,

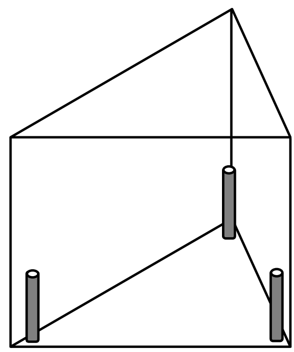

Fig. 1. Triangular room used in Experiment 1.

the experimenter, the child and the parent entered the triangular room. The entrance points were predetermined and counterbalanced across children. The participants stood in the middle of the room while the experimenter introduced the game to the child by saying: "We are going to play Hide and Seek with Barney. Watch where I am hiding Barney." The parent covered her eyes following a signal from the experimenter (which was done to prevent the parent from seeing where the toy was hidden). The experimenter took the toy to a predetermined corner and hid it in the container while the child watched.

After the toy was placed in the container, the experimenter returned to the center of the room and said: "OK, now Barney is hidden." This served as a prompt for the parent to uncover her eyes, pick up the child, and then cover the child's eyes. The parent and the child rotated inside the room. To make the procedure more interesting, everybody sang "Ring around the rosy." After three rotations, the experimenter showed the parent where to stop. The parent put the child with his/her back against the indicated wall. The position of the child at the end of rotation was determined randomly with the restriction that each wall should be faced twice in the course of six trials.

Finally, the child's eyes were uncovered and the child was asked to find the hidden toy. If the child found Barney on the first try, the experimenter proceeded with the next trial. If the child went to the wrong container and did not find the toy there, the experimenter said: "Oh, Barney isn't hiding there. Go find Barney." If the child pointed to a corner rather than walking there, he/she was encouraged to retrieve the toy. If the child made three unsuccessful attempts, the experimenter retrieved the toy and proceeded with the next trial. This procedure was repeated throughout six experimental trials. The toy was hidden in the same corner for a particular child. The location of the hiding corner was counterbalanced across children.

2.1.1.4. Results. When the experiment was completed, the videotapes were transcribed by recording the corner(s) in which the child searched for a hidden object on each trial. Comparing children's first responses with the true locations where the toy was hidden, we calculated accuracy scores (percent of correct responses) for each child.

The average accuracy of the group of participants was 70% which is significantly above chance, $p < .001$ (one-tailed t-test). The performance level in Experiment 1A is roughly comparable to the performance level reported by Hermer and Spelke for children's behavior in a rectangular room. In the rectangular room the accuracy was 78% and the chance level was 50%, whereas in the triangular room the accuracy was 70% and the chance was 33%. Analysis of individual performance showed that 25 out of 26 children had accuracy scores that were above the chance level (33%).

There was no significant difference in children's accuracy when the object was hidden in the unique corner versus when it was hidden in one of the equal-sized corners (two-tailed *t*-test: $t(24) = 1.05$, $p = .30$). To explore whether children confused the two equal-sized corners, we examined the error pattern on those trials where the object was hidden in one of these corners. We found that 44% of errors on such trials resulted from children going to the other corner of the same angular size while 56% of errors resulted from children going to the unique corner of the different angular size. These results indicate that children are not more likely to confuse equal-sized corners with one another than with the unique corner.

We carried out an analysis of variance to determine whether performance varied depending on the hiding corner and on the child's gender. This analysis showed that neither hiding corner nor gender had a significant effect on the accuracy of children's responses (gender: $F(1, 20) = 1.57$, $p = .22$; hiding corner: $F(2, 20) = 2.20$, $p = .14$); the interaction between the two factors was not significant: $F(2, 20) = 2.14$, $p = .14$. In addition, we examined if children's performance changed in the course of experiment. For this analysis, six trials were divided into three categories (first two trials, middle two trials and last two trials) and the resulting "trial position" variable was added to the ANOVA. The analysis revealed that the position of a trial within the experiment did not have a significant effect on the accuracy of scores ($F(2, 40) = 0.01$, $p = .99$) and did not produce any significant interactions (in all interactions, $p > .1$).

To explore children's behavior in finding a hidden object following disorientation, we examined our videotapes. Children's behavior was classified into three categories. One category included responses in which children surveyed different corners by turning their heads or moving around the room. Another category included cases where children went directly to a particular corner. Finally, there were cases that were impossible to classify (for example, when the child could not be seen because of being obstructed by the parent).

The scoring was done initially by two independent observers; the agreement between their scores was 0.88. In cases where there was a disagreement, a third person watched the videotape in question and the three judges together arrived at a final score. This analysis was done on the total of 156 trials. On 36 trials (23%) the responses were unclassifiable. On 12 trials (8%), children moved or turned around and were judged to have surveyed the space. On 108 trials (69%), children went directly to one particular corner. We compared the accuracy of responses in cases where children surveyed the space versus those where they did not. This analysis showed that accuracy level was not related to whether or not children surveyed the space following disorientation (67% vs. 72% correct).

2.1.2. Experiment 1B: variable hiding location

2.1.2.1. Participants. There were 24 children (14 boys and 10 girls) who participated in the study. One more child was eliminated from the sample because he refused to complete more than two trials. The participants were between 20 and 24 months of age, with the average age of 21.5 months. The participating families were from a variety of ethnic backgrounds, largely middle-class. Parents were compensated for taking part in the study.

2.1.2.2. Materials. The materials used in this experiment were the same as in Experiment 1A.

2.1.2.3. Procedure. The procedure was the same as the one used in the previous experiment, with the following exception. Instead of using a constant hiding location with a particular child, the experimenter varied the hiding location across trials. The toy was hidden twice in each corner. The hiding location on each trial was chosen randomly among the three corners, with the restriction that no corner should be used twice in a row.

2.1.2.4. Results. As in Experiment 1A, an ANOVA was conducted with the accuracy score as a dependent variable and with sex and hiding corner as independent variables. The ANOVA showed that neither sex nor hiding corner had a significant effect on the accuracy of children's responses (sex: $F(1, 22) = 2.03$, $p = .17$; hiding corner: $F(2, 44) = 0.59$, $p = .56$). The interaction between the two factors also was not significant: $F(2, 44) = 2.32$, $p = .11$. Post-test contrasts were conducted to compare children's accuracy in locating an object in the unique corner versus locating an object in one of the two corners with the same angular size. This analysis showed no significant difference in performance (two-tailed *t*-test: $t(23) = 0.03$, $p = .97$). We examined whether children tended to confuse the two equal-size corners. The results indicate that when the object was hidden in one of the two equal-size corners, children were no more likely to commit errors by going to the other corner of the same size (42% of errors) than by going to the unique corner (58% of errors).

The analysis of individual performance revealed that 17 out of 24 participants had accuracy scores above the chance level (33%). The analysis of group performance showed that the average accuracy was 58%. This level of performance is significantly higher than chance, $p < .05$ (one-tailed *t*-test). However, it is worse that the level of performance with a constant hiding location, $p < .05$ (one-tailed *t*-test). Examination of the errors revealed that most of them (65%) were perseveration errors, where the child searched for a toy in the corner where it had been hidden on the previous trial. In fact, the percent of perseveration errors accounts for the difference in difficulty between the results with a constant hiding location and the results with a variable hiding location. These findings suggest that the extra difficulty of the task in Experiment 1B as compared to Experiment 1A is due to the interference from information concerning the location of the toy on the previous trial.

We also examined children's behavior in finding the hidden object following disorientation. This analysis was done on the total of 144 trials. On 39 trials (27%), the responses were unclassifiable. On 19 trials (13%), children moved or turned around and were judged to have surveyed the space. On 86 trials (60%), children went directly to one particular corner. We compared the accuracy of responses in cases where children surveyed the space versus those where they did not. This analysis showed that accuracy level was not related to whether or not children surveyed the space following disorientation (58% vs. 60% correct).

2.1.2.5. Conclusions of Experiments 1A and 1B. Clearly, children can use geometric cues to identify different locations in the triangular space as well as in the rectangular space used by

Hermer and Spelke. In a rectangle, the cues that distinguish the corners consist of the differences in the lengths of adjacent walls since all four angles are equal. In the isosceles triangle used in this study, there is an additional cue—one of the corners is unique in angular size. If children used angular information in the triangular space, one would expect the accuracy at the unique corner to be greatest. Further, when the object is hidden in one of the two equal-size corners, children might be more likely to confuse these corners with one another than with the unique corner. Our findings, however, provide no such evidence. This suggests that the representation of the different corners is in terms of the relative lengths of adjacent walls, as in a rectangular space.

With respect to the overall accuracy, when the object is hidden in a constant location, children show comparable levels of performance in rectangular and in triangular spaces. When the object is hidden in variable locations, their performance is worse, due to perseveration, but is nevertheless substantially above chance. Considering this finding relative to that of Gouteux, it is clear that perseveration errors due to change in hiding location do not alone make the task too difficult to perform.

Examination of children's search behavior in both experiments provides suggestive information about their representation of the triangular space. We found that on most trials children go directly to a particular corner rather than moving or looking around as though attempting to recover their original perspective. This pattern of behavior indicates that the toddlers do not have to search for their original heading to determine the hiding corner. Rather, they often go directly to a particular corner, suggesting that they have represented the entire space in terms of information concerning the relations among its parts.

2.2. Experiment 2: search from outside a triangular space

In this study we examine whether children can locate an object in a space when they are outside of that space. As noted above, it has been suggested that toddlers' ability to use geometric cues depends on a spatial module that operates only on spaces that surround the child. Here we test if toddlers can find the hiding corner after being disoriented outside of a space of the same shape as in Experiment 1. We examine children's search behavior in locating the object in order to determine whether they have to recover their original perspective on the hiding corner. When children are outside rather than inside a space, it should be easier to examine their behavior because reestablishing their original heading would involve moving around the perimeter of the space.

Children might find it difficult to locate an object hidden in a corner when they are outside of a space because the appearance of particular corners depends on where along the perimeter of the space the child is located. Fig. 2 shows the appearance of a target corner of a triangle viewed from opposite positions. In Fig. 2A the target is farthest from the child. The long side is to the left and the short side is to the right, joined by an angle of 70°. In Fig. 2B, the target corner is nearest the child; the short side is to the left and the long side to the right, joined by an angle of 290°.

2.2.1. Participants

Participants included 25 children (13 boys and 12 girls) between 21 and 24 months of age. Their average age was 22.5 months. Additionally, two children were excluded; one child refused

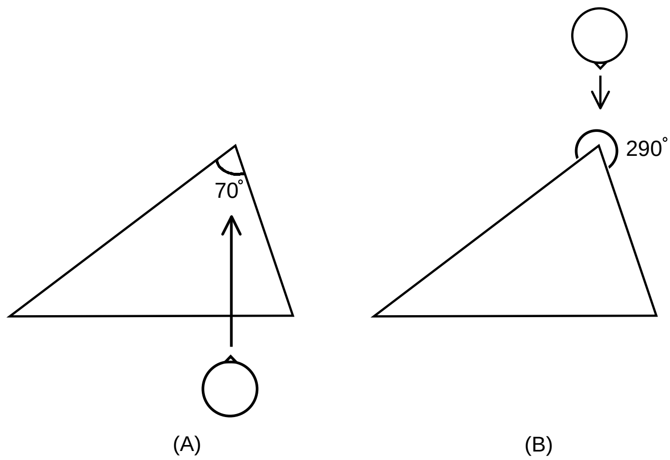

Fig. 2. Alternative views of a corner of the triangular box from two different perspectives.

to complete the trials and another child was excluded because of an experimental error. The participating families were from different ethnic backgrounds, largely middle-class. Parents were compensated for taking part in the study.

2.2.2. Materials

The entire experimental space consisted of a white fabric round enclosure (9 ft in diameter, 6.5 ft high). This enclosure was constructed from a metal frame, as shown in Fig. 3. Four sheets of non-transparent fabric were hung from the upper rim of the frame. The sheets were attached to one another by velcro, thus creating four possible entrances into the enclosure. A triangular box made out of plywood was placed in the center of the enclosure. The box had the same proportional relation of side lengths as the triangular room in Experiment 1 (7:11:11). The box was 6 in. deep and was shaped like an isosceles triangle (14 in. × 22 in. × 22 in.). Three legs attached to the bottom of the box raised it to the waist level of a 2-year-old child.

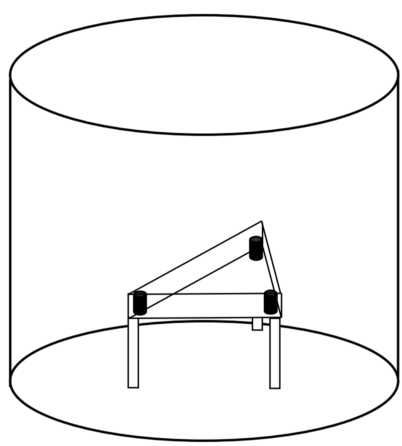

Fig. 3. Triangular box in a round enclosure used in Experiment 2.

Plastic containers (1.5 in. in diameter, 5 in. tall) were put in each corner of the box and used as potential hiding places. A small plastic toy (Barney) was used in the experiment. A video camera attached to the ceiling above the enclosure recorded the course of the experiment.

2.2.3. Procedure

First the child played in the larger room outside of the round enclosure while the experimenter described the study to the parent. Then the experimenter, the parent and the child entered the round enclosure. The entrance points were predetermined and counterbalanced across participants. Once in the room, the experimenter showed a Barney toy to the child and said: "We are going to play Hide and Seek with Barney. Barney is going to hide in this box (pointing to the triangular box). Watch where I am hiding Barney." The experimenter signaled the parent to cover her eyes. After the toy was placed in the container, the experimenter said "OK, it's hidden" and the parent uncovered her eyes. The parent picked up the child and covering the child's eyes, slowly walked around the box (making two to three circles). As in the previous experiments, to make this procedure more interesting, everybody sang "Ring around the rosy."

The experimenter showed the parent where to stop at the end of the rotation. When the participants stood against the wall of the enclosure in the predetermined location, the parent uncovered the child's eyes and asked the child to find Barney. If the child just looked at a container or pointed to it, the experimenter and the parent encouraged the child to physically retrieve the toy. This procedure was repeated six times. The toy was placed in the same corner for any given child. The location of the hidden toy was counterbalanced across participants.

2.2.4. Results and conclusions

An ANOVA was conducted with the accuracy score as a dependent variable and with gender, hiding corner, and trial position (first, middle, last) as independent variables. None of these factors had a significant effect on accuracy or produced significant interactions (gender: $F(1, 19) = 0.05$, $p = .82$; hiding location: $F(2, 19) = 1.98$, $p = .17$; trial position: $F(2, 38) = 2.15$, $p = .13$; in all interactions, $p > .1$). Post-test contrasts showed that there was no significant difference in locating an object in the unique corner versus locating an object in one of the two corners that had the same angular size (two-tailed *t*-test: $t(23) = 1.10$, $p = .28$). As in the previous two studies, we compared the accuracy of children's responses to chance level, 33%. The analysis of individual performance showed that 19 out of 26 children had accuracy scores that were above chance. The average accuracy of the group of participants was 56% which is significantly above chance, $p < .001$ (one-tailed *t*-test).

These results indicate that children can use geometric cues to identify location, not only in a space that surrounds them but also in a smaller scale space presented in front of them. Children's performance (56% correct) was not as good as their performance (70% correct) in the task when they were inside the surrounding space of similar shape in Experiment 1. However, our purpose here has been to establish if children can use geometric cues to locate objects when they are outside of the enclosed space, or if they can do so only when they are surrounded by the space. The findings indicate that children indeed can do the task regardless of their position relative the space.

We examined children's behavior to determine if they went directly to a particular corner or moved around the sandbox, surveying it from different vantage points, as would be expected if they had to recover their original vantage point. We analyzed children's behavior on each of the 150 trials in the experiment. It was much easier to categorize responses on this task compared to that in Experiment 1. In fact, it was possible to determine the strategy children were following on all trials. The results show that on only 16 trials (11%) did children move around the box surveying its corners. These 16 responses were produced by 10 children, many of whom made only one such response. Thus toddlers did not rely on such a strategy. On the remaining 134 trials (89%), children went directly to the corner of the box at which they responded. Clearly, the children were not systematically recovering their original perspective on the hiding corner. The success across the total set of trials was 56%, whereas that on the trials where children did not search for the original view was 55%.

In conclusion, these results indicate that children are able to find an object hidden in a space when they are outside that space. Further, the data show that children do not survey the space, recovering their original perspective to find the object. The ability to do the task without reestablishing the original perspective suggests that toddlers represent the entire space in terms of internal relations among its parts. Further, children can do the task even though the appearance of particular corners varies with viewer position; hence in finding the hiding corner, they do not rely on the particular look of that corner. There is a difference in difficulty between this task and the one where children are inside the space. This result could potentially be due to the fact that the experimental spaces used for the inside and the outside task differed in size (in the present experiment, the space had to be lower and somewhat smaller so that the child could see it). Alternatively, the results may reflect an inherent difference in the difficulty of tasks where the viewer is inside versus outside the space, an issue addressed in Section 3.

2.3. Experiment 3: search from outside a rectangular space

In this experiment we explore children's ability to code the location of a hiding corner from outside of a space of another shape. We present a rectangular box shaped like the room in the original Hermer and Spelke study. As discussed above, finding a hiding corner from outside the space may be difficult because the same corner will be seen in different ways depending on the child's orientation. We want to determine if children would nevertheless be above chance on this task, as in the case of a triangular space. Here too the sizes and heights of the spaces must differ for the task where children are outside from that when they are inside.

2.3.1. Participants

There were 23 children (12 boys and 11 girls) in the study. Additionally, three children refused to complete the trials and thus were excluded from the analysis. The participants were between 21 and 24 months of age. The average age was 22.1 months. The participating families were from different ethnic backgrounds, largely middle-class. Parents were compensated for taking part in the study.

2.3.2. Materials

Children were tested inside the same round enclosure (9 ft in diameter, 6.5 ft high) that was used in the previous experiment. A rectangular box made out of plywood was placed in the center of the enclosure (Fig. 4). The box was 18 in. long, 27 in. wide and 6 in. deep. Four

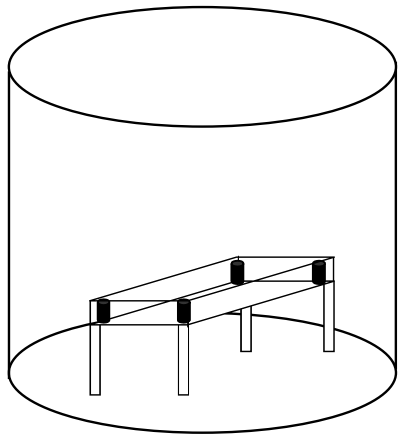

Fig. 4. Rectangular box in a round enclosure used in Experiment 3.

stool legs attached to the bottom of the box raised it to the waist level of a 2-year-old child. Plastic containers (1.5 in. in diameter, 5 in. tall) were put in each corner of the box and used as potential hiding places. A small plastic toy (Barney) was used in the experiment. A video camera attached to the ceiling above the enclosure recorded the course of the experiment.

2.3.3. Procedure

The procedure was identical to that used in the previous experiment.

2.3.4. Results and conclusions

Children's responses were scored as correct if the child searched in the target corner indicated by the experimenter or in the diagonally opposite corner (these two locations in a rectangular space are geometrically equivalent and cannot be distinguished in the absence of landmarks). An ANOVA was conducted with the accuracy score as a dependent variable and with gender, hiding corner, and trial position (first, middle, last) as independent variables. None of these factors had a significant effect on accuracy or produced significant interactions (gender: $F(1, 15) = 0.10$, $p = .75$; hiding location: $F(1, 19) = 0.10$, $p = .75$; trial position: $F(2, 38) = 2.79$, $p = .08$; in all interactions, $p > .1$).

The accuracy of children's responses was compared to chance level, 50%. The average accuracy of the group of participants was 69% which is significantly above chance, $p < .001$ (one-tailed t-test); 16 out of 23 children had accuracy scores that were above the chance level. Children's correct responses were about equally distributed between the two geometrically equivalent corners: 37% of responses were to the target corner and 32% of the responses were to the diagonally opposite corner, $t(22) = 0.53$, $p = .60$.

These results confirm and extend the findings of Experiment 2, indicating that children can use geometric cues to identify a location in a space when they are outside of that space. The comparison of the results obtained in the present study with the results obtained by Hermer and Spelke (who investigated children's performance in a similar task with a rectangular space that surrounded them) shows that the accuracy is somewhat lower when children are outside of the space (69%) than when they are surrounded by the space (78%), an issue addressed in Section 3.

We examined whether children went directly to a particular corner or moved around the sandbox, surveying it from different points, as if they were recovering their original vantage point. We analyzed children's behavior in locating the hidden object on each of the 138 trials in the experiment. As in the previous experiment, it was possible to determine which strategy children were following on all trials. On 19 trials (14%) children moved around the box, surveying its corners. These 19 responses were produced by nine children, most of whom made response only on minority of their six trials. Thus they were not systematically relying on such a strategy. On the remaining 119 trials (86%) children went directly to the corner of the box that constituted their response. Clearly, the children were not systematically searching for the hiding corner as they had originally seen it. Yet the performance on the 119 trials where they did not search for the original view was 69% correct.

Again, the results indicate that children can find a hidden object when they are outside of an enclosed space. As in the other two experiments, we sought to determine whether children have to survey different corners to recover their original perspective in finding a hidden object. Since children searched for the object from outside, as in Experiment 2, reestablishing the original perspective had to involve moving around the perimeter of the space. Thus, it was easy to determine whether children engaged in this behavior. We found that in seeking an object after disorientation, children go directly to a particular corner rather than moving around and surveying different corners.

3. Discussion

In the experiments in this paper we have examined children's ability to use geometric cues in locating an object in an enclosed space. Recent findings had indicated that toddlers can use such cues to find a hidden object in a rectangular room after being disoriented. The present studies provide information concerning the extent of this early skill and the nature of the underlying spatial representation. To examine the generality of the ability to use geometric cues, we varied both the shapes of the spaces presented and the locations of the child relative to the space. We found that toddlers can locate a hidden object after disorientation in a triangular as well as in a rectangular space. We also found that rather than being restricted to dealing only with spaces that surround them, toddlers can locate a hidden object when they are outside as well as when they are inside a space. Our results have extended existing findings concerning toddlers' ability to use geometric cues by showing that this ability is more general than had been previously demonstrated.

As we noted at the start, prior findings were consistent with more than one interpretation of the nature of children's spatial representations. One possibility was that young children's success is based on a representation of their original heading—of the appearance of the hiding corner as seen from the initial viewing position. To identify the hiding location after disorientation, children would have to survey the space until they recover their initial heading. Another possibility was that the space is represented in terms of internal relations among its parts that define its shape independent of the initial heading. In this case children would be able to go directly to the hiding corner no matter what part of the space they face after disorientation.

To obtain information relevant to evaluating these alternative forms of spatial representation, we examined children's behavior in finding the hidden object in enclosures of different shapes, both when toddlers were inside and when they were outside the space. It was not always possible to delineate children's search behavior when they were inside a space, as in Experiment 1, because recovering their initial perspective often required only head movements that were not always classifiable from our tapes. However, even in Experiment 1, it *was* possible to determine children's strategy on a majority of trials, and we found that they did not survey the space but rather went directly to a particular corner. It was much easier to determine children's search pattern when they were outside the space, as in Experiments 2 and 3, since recovering their perspective would involve moving around the perimeter of the space. The results of these two experiments also showed that children rarely surveyed the various locations before going to the corner where they believed the object was hidden. Toddlers' behavior in all three experiments suggests that they do not represent their own perspective relative to a particular portion of the space. Rather, it seems that they represent the entire space so that, no matter where they face after disorientation, they know their relation to the hiding corner.

While there is no reason to believe that children represent their initial orientation relative to a particular portion of the space, we have noted that viewer position relative to the entire space may be included in the representation (as being inside vs. outside). We found a difference in performance levels depending on whether children are inside or outside of the space. Such a finding could potentially be explained by positing that children represent viewer position relative to the entire space. Before elaborating this notion, however, let us consider certain alternative explanations for the observed difference.

One possibility is that there are differences in the level of representation for an inside versus an outside task. That is, when the space is viewed from inside it may be conceptualized in a more abstract way, one which is more consistent with maintaining information after disorientation. In particular, when encoding is done from inside, the entire space is not seen all at once and hence must be "constructed" by the viewer. In contrast, when encoding was done from outside in our study, the entire space could be seen at one time and hence the representation could be more "iconic" and not adequate for maintaining information about the hiding location after disorientation. There are also other possible reasons for the observed differences in the performance from outside versus inside. For example, as discussed in Experiment 2, the task where children are outside the space may be more difficult because there are multiple perspectives on particular corners. Finally, there are differences in the sizes of the experimental spaces in inside versus outside tasks and these might affect the task difficulty.

Earlier findings by Huttenlocher and Presson (1979) indicate that the above explanations are not plausible. A parallel difference was found in the difficulty of inside and outside tasks in a study with older children. The children were presented with the task of locating an object when they were inside versus outside of an enclosed four-sided space 6 ft high. Contrary to the present study, the space used in that study could not be seen all at once from outside. It had to be constructed, and yet the tasks still differed in difficulty. Further, a difference in task difficulty was observed even though there was no problem of multiple perspectives in the outside condition (since the space was 6 ft high, children who were outside could not see a particular corner from across the inside of the space). Finally, the task was easier when the viewer was inside even though the very same space was involved in both tasks.

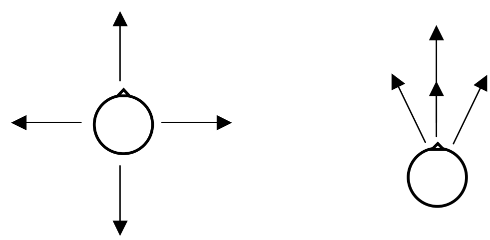

Fig. 5. Schematic representation of alternative positions relative to a space (inside vs. outside).

Since none of the possibilities described above seem compatible with the findings, let us consider an alternative—that the viewer's position relative to the entire space is represented, and that the difference in difficulty when that viewer is inside versus outside the space is due to this factor. The explanation might be that there are differences in the distinctiveness of the critical information about the enclosed space in the inside and outside tasks. For a viewer who faces the space from outside, all potential hiding corners lie in a frontal plane; these positions are similar and hence potentially confusable. In contrast, for a viewer who is inside, the potential hiding corners are not all in the frontal plane; these positions are more differentiated than in the outside condition. Fig. 5 shows that the different paths the viewer would follow in obtaining the object are more distinct when the viewer is inside rather than outside.

The notion of viewer perspective in the existing literature is that of a stationary individual facing a space in a particular direction so that the representation involves the heading towards a portion of the space. For example, Tarr and colleagues argue that spatial representation is viewer specific in the sense that recognition is disrupted by rotation relative to a stationary viewer (Hayward & Tarr, 2000; Tarr et al., 1998). Here we invoke another sense of viewer perspective, one that has not been discussed in the literature. That sense is of a viewer who represents the entire space without particular heading, but incorporates in the representation a viewer who can assume a set of possible positions relative to that space (e.g., inside the space or outside the space).

The model we are proposing holds that there are various levels at which the viewer may be included in the representation of a space. The way the viewer is incorporated may vary with the task. If a viewer is stationary relative to a space, the representation might capture the heading towards a particular portion of the space. If a viewer moves, but only inside or only outside the space (as in the present study), the representation may include the range of positions that the viewer could assume from either inside or outside the space. It remains to be investigated whether or how the viewer would be represented if his or her position were to vary even more widely than in our experiments (e.g., if a viewer watches the hiding of an object from inside and retrieves it from outside or vice versa).

In conclusion, what is especially remarkable about our findings is that the participants in our experiments are only toddlers. At the start of the present experiments, the nature of children's representations of enclosed spaces was not clear. Only recently has it become clear that toddlers can code geometric properties of spaces at all, a finding that requires revision of earlier notions of spatial coding. Our findings indicate an even greater early competence—toddlers' geometric abilities are very general, applying to differently shaped spaces and to different viewer positions. Since such highly developed abilities are exhibited by very young children, it would be of interest to determine if these abilities are found in animals as well. As we noted in the introduction, animal research indicates that a variety of species show sensitivity to geometric properties of space. In fact, at the time we began this study, it seemed that animals and toddlers might exhibit similar abilities. By examining animals' behavior in searching for hidden objects we may be able to determine if their spatial representations are parallel to those of young children.

Notes

1. Biederman and colleagues describe "object-centered" representations, in which an object is characterized in terms of its parts and their interrelations (e.g., Biederman & Bar, 1999; Cooper, Biederman, & Hummel, 1992). In a parallel fashion, we use the term "space-centered" to describe the representation of enclosed spaces.
2. Most existing studies investigating children's sensitivity to geometric information used rectangular spaces. However, Gouteux and Spelke (2001) examined children's performance using a triangular configuration of objects in one of their experiments. It should be noted though that the configuration was formed by single landmarks that could be joined by imaginary lines, so children were not actually tested inside an enclosed triangular space.

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