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REPORT

Coding location in enclosed spaces: is geometry the principle?

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Abstract

Both animals and human toddlers can find an object in a rectangular enclosure after they have been disoriented. They use geometric cues (relative lengths of walls) to discriminate among different corners (e.g. long wall to the left, short to the right). It has been claimed that this ability is 'modular', i.e. exclusively geometric. The present study demonstrates that the ability toddlers exhibit is a more general one, namely, an ability to discriminate relative quantity. Using a square enclosure, we show that toddlers use the relative sizes of the figures on different walls to characterize different corners. We also show that they do not use simple non-relative features to distinguish different corners. Possible reasons for differences in the ability to use relative versus non-relative cues are discussed.

Introduction

Recent research has shown that animals and human toddlers possess a remarkable ability to use geometric features of enclosed spaces to obtain information about the locations of objects. In this work, children (or animals) watch an object being hidden in a corner of a rectangular space. After the object is hidden and before search, a disorientation procedure is introduced in which the viewers are rotated several times so they cannot keep track of the target's relation to themselves. However, the target's relation to the enclosure is not disrupted by the disorientation procedure. Hence it is possible for viewers to maintain information about the position of the target in the space (e.g. that it is in a corner with a longer wall to the right and a shorter wall to the left). This information indicates that the hidden object is in one of two geometrically identical corners diagonally opposite one another, and eliminates the other two corners as possible hiding places. Both animals and young children can choose a geometrically appropriate corner on this task (e.g. Cheng, 1986; Cheng & Gallistel, 1984; Hermer & Spelke, 1994, 1996; Huttenlocher & Vasilyeva, 2003; Kelly, Spetch & Heth, 1998; Lourenco, Huttenlocher & Vasilyeva, 2005; Vallortigara, Zanforlin & Pasti, 1990; Vargas, Lopez, Salas & Thinus-Blanc, 2004).

It has been claimed that the ability to choose an appropriate corner reflects a 'module' specialized for processing geometric information. A finding that has been taken as support for modularity is that children ignore non-geometric information, such as wall color, that is available to distinguish the two geometrically identical corners, for example, that one corner has a short wall that is blue to the left whereas the diagonally opposite corner has a short unpainted wall to the left (Cheng, 1986; Hermer & Spelke, 1996; Wang & Spelke, 2002). It would be reasonable that animate creatures might be specialized to process geometric information since it provides enduring cues about location that are adaptively important (Gallistel, 1990).

However, further issues must be explored to evaluate the claim of a geometric module. First, non-geometric cues are not always ignored, suggesting that children's ability may not be strictly modular (e.g. Learmonth, Nadel & Newcombe, 2002; Learmonth, Newcombe & Huttenlocher, 2001; for review, see Cheng & Newcombe, 2005). Second, it is not obvious what processes involved in the disorientation task might be 'modular'. Shape discrimination does not seem to be specialized; it is seen in various contexts in toddlers, and even infants can distinguish different shapes (Schwartz & Day, 1979; Slater, Morison, Town & Rose, 1985). Nor is the ability to discriminate relative length specialized; when pairs of lines are presented together, toddlers can discriminate the longer from the shorter line, and even infants can determine the length of a dowel relative to a container (e.g. Bryant, 1974; Duffy, Huttenlocher & Levine, 2005; Huttenlocher, Duffy & Levine, 2002). What *might* be specialized is the ability to map wall length (long vs. short) onto spatial orientation (left vs. right). We consider this possibility in the discussion.

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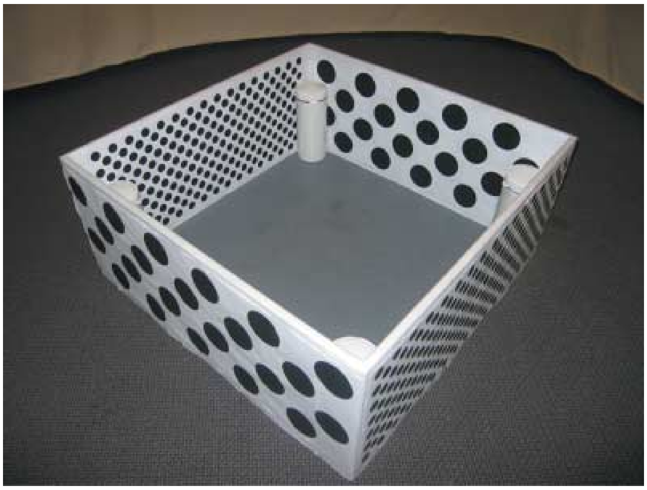

Figure 1 *Photograph of square enclosure used in Experiment 1.*

Finally, to establish modularity it is not enough to show that children can succeed on tasks that require geometric information; it is also necessary to show that they fail on parallel tasks where information is *not* geometric. Otherwise, one might wrongly conclude that children rely on a geometric module when, instead, they are guided by a more general principle. That principle might be an ability to use relative cues to differentiate adjoining walls. In Experiment 1 we explore this possibility. We present a square enclosure where all the walls are equal in length. The adjoining walls have patterns of circles that contrast in size (see Figure 1).

Pattern size does not pertain to the geometry of a space. Hence if young children rely on geometric information, they should fail on this version of the disorientation task. Success on the task would indicate a more general ability. However, further work would be needed to determine the principles used. As noted, one possibility would be that toddlers require relative cues. To assess this possibility requires further experiments with non-relative cues such as the colors or patterns on walls. If toddlers fail on these tasks, it would suggest that they require relative cues. In the discussion, we consider the issue of relative and non-relative cues in more detail, and consider why they might differ in difficulty.

The experiments

In the experiments below we examine what differences in adjoining walls young children can use to differentiate corners of a square enclosure where no geometric information is available. In Experiment 1, we examine if children can differentiate corners when different size circles are shown on adjoining walls. Since children succeed on this task, we carry out two further experiments involving other perceptual contrasts. In Experiment 2, we use a square with adjoining walls of contrasting colors (red vs. blue), and in Experiment 3, we examine whether children can use a patterned versus a plain wall.

Experiment 1: Enclosure with walls that have big vs. small circles

In this experiment, the enclosure was square and thus provided no geometric cues for differentiating corners. Adjoining walls had circles of different sizes, as shown in Figure 1. Just as for rectangular enclosures, success was assessed by determining if children searched either at the corner containing the hidden object or at the equivalent corner diagonally opposite to it. Our purpose is to determine if toddlers can use relative information that is not geometric to eliminate two of the four corners as possible hiding locations. This would indicate that children possess an underlying ability that is not narrowly specialized to deal with the geometry of a space.

A variety of rectangular enclosures have been used in existing disorientation studies. In the original experiment by Hermer and Spelke (1994, 1996), the enclosure was 4 by 6 feet (1.22 m by 1.83 m) with walls 6 feet high. In Learmonth *et al.* (2001), the enclosure was an actual room 8 by 12 feet (2.44 m by 3.66 m). In an experiment by Lourenco, Huttenlocher and Vasilyeva (2005), the enclosure was smaller, 2.5 by 3.75 feet (76.2 cm by 114.3 cm) with walls only 18 inches high (45.72 cm); it was surrounded by a homogeneous circular space of 12.5 feet (3.8 m) in diameter and 7.5 feet (2.3 m) in height. A similar pattern of results was found using these different enclosures. The only factor that was the same across experiments was that the adjoining walls differed in length, providing geometric cues concerning possible hiding corners.

Method

Participants

The sample consisted of 24 children (12 boys and 12 girls). An additional five children were excluded from the analyses because they did not keep their eyes covered during the disorientation procedure (two) or because of parental interference (three). Participants were between 18 and 24 months of age ($M = 20.84$, SD = 2.03). Parents were compensated for their children's participation.

Materials

The experiment took place inside a circular surrounding space (3.8 m in diameter, 2.3 m high), which was housed within a larger testing room. The enclosure was made of beige, non-transparent fabric, which was attached to a circular metal frame and suspended from the ceiling by four chains, evenly spaced. An opening in the fabric permitted entry into the enclosure; when closed, this opening was indiscriminable. Fluorescent lights, centered over the enclosure, hung from the ceiling. The floor was covered in a homogeneous grey carpet. The square enclosure (99.1 cm long, 45.7 cm high) was made of plywood and was placed in the center of the circular space. The area and height of the enclosure were similar to that in Lourenco *et al.* (2005).

The bottom of the enclosure was painted grey and the walls were covered in wallpaper, which was white with black circles. The circles were 8.76 cm in diameter on two opposing walls and 2.77 cm in diameter on the other two opposing walls. The ratio of black to white was equal for all walls. Both sets of circles (big and small) were arranged in the same pattern, as shown in Figure 1. Four identical opaque containers (11.4 cm in diameter, 27.9 cm high) served as potential hiding locations; one container was placed in each corner. A small toy dog was used as the hiding object. A video camera was attached to the center of the ceiling and used to record the experiment.

Procedure

Children were tested individually by a parent and an experimenter. As the child played with toys in the larger testing room, the experimenter explained to the parent the task proper. Once the child seemed comfortable with the experimenter, the child, parent, and experimenter entered the enclosure through an opening in the fabric. Once inside, the experimenter closed the opening and told the child that they were going to play a 'hide-and-seek game'.

The 'game' began with the parent placing the child inside the box. At this point, the experimenter (who stood outside) pointed to each of the box's walls, drawing the child's attention to the different-sized circles. The experimenter then hid the toy in one of the pre-selected containers. The parent, who also stood outside the box, moved around to avoid serving as a landmark. Following the hiding event, the parent stepped inside the box, picked up the child, covered his or her eyes, and rotated four to five times. During this disorientation procedure, the experimenter walked around the box and reminded the child to keep his or her eyes covered. After completing the required rotations, the parent uncovered the child's eyes and placed him or her in front of one of the walls. The wall faced by the child was randomly determined prior to the start of the experiment with the restriction that each wall would be faced only once. The parent then stepped outside the box and stood next to the experimenter, who always stood in front of the same wall as the child. The child then searched for the hidden toy from inside the space. The box was sufficiently high that the child could not move out of the space.

If the toy was retrieved on the first attempt, the experimenter proceeded to the next trial. If it was not retrieved, the child was encouraged to try another corner. There were a total of four trials, and for a given child, the toy was hidden in the same corner across all trials. The location of the hiding corner (four possibilities) was counterbalanced across children.

Results

Accuracy scores were calculated for each child. On each trial, the first response was scored as correct if children searched at the hiding corner or the corner diagonally opposite to it (since both of these corners either had the bigger dots to the left of the smaller dots, or the smaller dots to the left of the bigger dots). The mean accuracy score for children on this task was 70.8% (SE = 4.9%). A comparison to the chance level of 50% revealed that accuracy was significantly above chance, $t(23) = 4.24$, $p < .001$, two-tailed. An examination of the individual children's performance revealed that the majority of children performed above chance, 18 out of 24 (75%). Additional analyses of variance (ANOVA) were conducted to determine whether performance varied as a function of other variables, such as sex, or corner (i.e. bigger dots left of smaller circles or vice versa). The ANOVA revealed no significant main effects of sex, $F(1, 23) = 0.66$, $p = .43$, or corner, $F(1, 23) = 0.16$, $p = .69$; nor was there a significant interaction between sex and corner ($p > .1$).

As indicated above, children performed significantly above chance. To ensure that children were indeed disoriented and did not simply track their changing relation to the hiding corner, we examined search at each of the corners. If children were not fully disoriented, search would occur more frequently at the hiding corner than at the diagonally equivalent one. This was not the case. Responses were evenly distributed across both of these corners (34.4% and 36.5%, respectively). Similarly, responses to the two incorrect corners were evenly distributed (17.7% and 11.5%). Clearly, these children were able to use cues that were not geometric to distinguish among corners on the basis of a relative contrast.

Experiment 2: Enclosure with different colored walls

Experiment 1 showed that young children can use differences in the relative size of circles on the walls of a square enclosure to differentiate corners. Indeed, they did as well on this task as on a task involving relative lengths of walls in a rectangular enclosure. The next step is to determine whether children also can use simple contrasts where the information on the different walls is not relative. In Experiment 2, we present a square with walls of different colors. The task is parallel to that in Experiment 1, except that adjoining sides are red and blue, and opposite sides are the same in color. Clearly, toddlers would have to be able to discriminate the colors we present in order to use those colors to differentiate the corners. It is known that even infants can discriminate color in habituation tasks (for review, see Teller, 1998). Thus, we can present different colors to examine whether children can succeed on a disorientation task with non-relative cues.

Method

Participants

As in the previous experiment, the sample consisted of 24 children (12 boys and 12 girls). An additional three children were excluded from the analyses because they refused to keep their eyes covered during the disorientation procedure (one) or to stay inside the square box (two). Participants were between 18 and 24 months of age ($M = 20.93$, SD = 2.07). All parents were compensated for their children's participation.

Materials and procedure

The experiment took place in the same enclosure as the previous experiment. The materials were identical except that the square box (each wall 99.1 cm long and 43.2 cm high) had two opposing red walls and two opposing blue walls; the bottom was painted white. The procedure also was identical. The experimenter began by telling children that they were going to play a 'hide-and-seek game', and then the experimenter drew the child's attention to the colored walls by pointing to each, before hiding the toy in one of the containers. Following the hiding event, the parent disoriented the child by picking him/her up, covering the child's eyes, and spinning around four to five times. The child then was placed in front of one of the walls, a different one on each trial, and encouraged to find the hidden toy. There were a total of four trials, with the toy hidden in the same corner on all trials.

Results

Accuracy scores were calculated for each child, with the first response scored as correct if children searched at the hiding corner or the corner diagonally opposite to it (e.g. the two corners with the red wall to the left of the blue wall). All but two children completed all the test trials; these two contributed data for three trials. The mean accuracy score for children on this task was 43.75% ($SE = 4.82\%$). A comparison to the chance level of 50% revealed that accuracy did not differ significantly from chance, $t(23) = -1.29$, $p = .21$, two-tailed. An examination of the individual children's performance revealed that only a minority of children performed above chance, four out of 24 (16.7%). In fact, children searched equally often at all of the corners: 23.4% at the hiding corner and 20.2% at the diagonally equivalent corner, and 30.9% and 25.5% at the other two corners, respectively.

An ANOVA was conducted to determine whether performance varied as a function of sex or corner. This analysis revealed no significant main effects of either sex, $F(1, 23) = 0.71$, $p = .41$, or corner, $F(1, 23) = 0.71$, $p = .41$; nor was there a significant interaction between sex and corner ($p > .1$). In short, the children were not able to distinguish corners by the colors of their walls.

Experiment 3: Enclosure with plain vs. patterned walls

Experiment 2 showed that toddlers did not use contrasting colors to differentiate the walls of a square enclosure. Experiment 3 provides a further test of whether toddlers can distinguish among corners of a square enclosure on the basis of a simple non-relative contrast. We use a contrast involving plain versus patterned walls. The two plain walls were grey, and the two patterned walls included one of the two circle patterns (small or large black circles on white walls) from the first experiment. At first glance, this contrast may seem to be a relative one – parallel to the use of small and large circles, or long and short walls. However, absence of pattern is not a value on a specific dimension, and hence zero is not a relative value with respect to that dimension.

Method

Participants

As in the other experiments, the final sample consisted of 24 children (equal numbers of boys and girls). An additional four children were excluded from the analyses because they would not keep their eyes covered during the disorientation procedure (one) or stay inside the box (three). Participants were between 18 and 24 months of age ($M = 19.52$, $SD = 1.45$). In all cases, parents were compensated for their children's participation.

Materials and procedure

The materials and procedure were identical to those in the previous experiments. The one exception was that the square box (99.1 cm in length and 43.2 cm high), with the bottom painted white, consisted of two opposing walls painted grey and two opposing walls painted white with black dots (either 8.76 or 2.77 cm in diameter). As in Experiment 1, the ratio of black to white on the dotted walls was equal in both groups. Equal numbers of children were randomly assigned to either the small or big dots group, counterbalancing for sex.

Results

Accuracy scores were calculated for each child; the first response was scored as correct if children searched at the hiding corner or the corner diagonally opposite to it. All but two children completed all the test trials; these two contributed data for three trials. The mean accuracy score for children on this task was 49.7% ($SE = 5.6\%$). A comparison to the chance level of 50% revealed that accuracy did not differ significantly from chance, $t(23) = -0.06$, $p = .95$, two-tailed. An examination of the individual children's performance revealed that only a minority of children performed above chance, eight out of 24 (33.3%). In fact, the responses were distributed similarly across all of the corners: 24.5% at the hiding corner and 25.5% at the diagonally equivalent corner, and 22.3% and 27.7% at the other two corners, respectively.

Importantly, the results did not differ for children in the small dots group ($M = 47.3\%$, $SE = 9.1\%$) and the big dots group ($M = 52.1\%$, $SE = 7.8\%$), $t(11) = 0.41$, $p = .69$, two-tailed.; and, in neither case did performance differ from chance – i.e. small dots, $t(11) = -0.33$, $p = .74$, and big dots, $t(11) = 0.27$, $p = .79$. An ANOVA conducted across all children (since performance did not differ by group) was conducted to determine whether performance varied as a function of sex or corner. The ANOVA revealed no significant main effects of either sex, $F(1, 23) = 1.99$, $p = .17$, or corner, $F(1, 23) = 0.18$, $p = .67$; nor was there a significant interaction between sex and corner ($p > .1$). Children did not distinguish different corners of a square when contrasting walls were plain versus patterned.

Discussion

We have conducted three studies exploring what cues young children can use in discriminating among the walls in an enclosure. Earlier, it was found that toddlers can use the relative lengths of adjacent sides of a rectangular enclosure. It has been argued that this ability reflects a 'module' specialized for geometric information. In three experiments we examined whether this early ability is indeed specifically geometric, by using a square enclosure where geometric information was not available.

In Experiment 1, the enclosure had circles of different sizes on adjacent sides. Toddlers succeeded on this task, indicating that they could use non-geometric information to locate an object hidden at a particular corner of an enclosed space. Circle size, like wall length, provides relative information but, contrary to wall length, is *not* relevant to the shape of the space. Size is a composite dimension; it can be broken down into component dimensions such as the area of the circles, their spatial density, total number of circles, etc. The fact that these cues co-occur for size may contribute to the ease of discriminating size. However, the critical point is that, regardless of whether children are using a composite dimension like size or a constituent dimension like spatial density, the scale is a relative one. What we have been interested in here is whether children may be able to deal with relative cues, even when they are unrelated to shape, but not with non-relative cues. While one cannot be certain that the relativity of cues is the critical factor from these studies, the findings strongly support such a conclusion.

Since children could use non-geometric relative cues to distinguish among corners, the next step was to determine if they also could use non-relative cues. In Experiment 2, the walls were of two different colors, and in Experiment 3, the walls were plain versus patterned. In both cases, toddlers failed to use the cues to distinguish potential hiding corners. Thus while Experiment 1 showed that geometry is not privileged, Experiments 2 and 3 suggest that relative cues may be privileged. Let us consider why this could be the case.

The cues for discriminating adjoining walls could be binary and unrelated (e.g. pictures of flowers versus dogs on adjoining walls), binary and related (e.g. roses versus daffodils), or could involve values along a common dimension. In Experiment 1, the cues varied along the dimension of size. Size forms a magnitude scale that starts at zero and increases without limit. Anywhere on the scale, a pair of stimuli can be compared; for unequal pairs, one is 'bigger' and the other 'smaller'. These ordered pairs specify direction (order) along the scale. Other discriminative cues do not form such ordered pairs but, rather, encode two distinct properties (e.g. red vs. blue).

In disorientation tasks, the wall cues are mapped onto directions in space (e.g. long is to the left, and short to the right). Earlier research has shown that when items from one set are mapped onto items from another set, task difficulty is affected by the nature of the mapping, i.e. by 'S-R compatibility' (e.g. Fitts & Deininger, 1954; Fitts & Seeger, 1953). We hypothesize that cues which specify order along a magnitude scale (more, less) may be more easily mapped onto spatial position (left, right) than two distinct unordered properties (e.g. red, blue) which are mapped separately onto spatial position. Clearly, this hypothesis must be explored further in later research. The conclusion that can be drawn from the present study is that the toddlers can deal with relative dimensions even when not pertinent to the shape of the enclosure. However, the non-relative cues we investigated (color and presence of a pattern) could not be used to discriminate the different sides of the square enclosure. Hence the conclusion that had been drawn from earlier studies that toddlers code the shape of enclosures seems instead to rest on a more general ability to code relative dimensions on these tasks.

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