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How do young children determine location? Evidence from disorientation tasks

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Abstract

Previous studies show that following disorientation children use the geometry of an enclosed space to locate an object hidden in one of the corners [e.g. (Hermer, L., & Spelke, E. (1996). Modularity and development: A case of spatial reorientation. *Cognition, 61,* 195–232)]. These studies have used a disorientation procedure that involves rotating the viewer (with eyes closed). Here, we examine 18- to 25-month-olds' spatial coding in two disorientation tasks—involving either *viewer* or *space* rotation. Importantly, the rotational movements in both tasks could not be visually tracked. Children were tested in either task (viewer- or space-movement) from either inside or outside a triangular (isosceles) space (with one unique and two equivalent corners). In the viewer-movement task, performance was above chance, regardless of which corner contained the object. In the space-movement task, performance was above chance at only the unique corner. On both tasks, performance was better from inside the space than from outside. The implications for how children determine location are discussed.

Keywords: Spatial cognition; disorientation tasks; viewer vs. space rotation

The present paper concerns spatial coding in young children. The ability to code the locations of objects and to maintain information about those locations following movement is essential for human (and other mobile) beings. Yet specifying how location information is processed poses a challenging empirical problem. Here, we discuss two approaches, which have had profound implications for understanding these processes. One

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approach considers how location is coded in the context of different transformations—namely, movements of the viewer vs. movements of a spatial layout. This approach has been used to show that although both transformations have the same effect (i.e. changing the relation between the viewer and the spatial layout) they may not invoke the same processes for determining location (e.g. Huttenlocher & Presson, 1973, 1979; Simons & Wang, 1998; Wraga, Creem, & Proffitt, 2000). Furthermore, these processes may be influenced by task-related factors, such as whether viewers are questioned about their relation to a single object or to an array of objects (e.g. Huttenlocher & Presson, 1979; Presson, 1982; Wraga et al., 2000).

The other informative approach involves the use of a disorientation procedure. This procedure was originally used by Cheng (1986; Cheng & Gallistel 1984) with rats to show that, when prevented from tracking their movements, rats relied on the geometric cues of a rectangular space (i.e. the relative length of the walls) to locate a target hidden in one of the corners (see also Margules & Gallistel, 1988). It has since been used with a variety of mobile animals, including human children and adults, all of whom code the geometry of enclosed spaces (e.g. *humans:* Hermer & Spelke, 1994; 1996; Huttenlocher & Vasilyeva, 2003; *fish:* Sovrano, Bisazza, & Vallortigara, 2002; Vargas, Lopez, Salas, & Thinus-Blanc, 2004; *pigeons:* Kelly, Spetch, & Heth, 1998; *rhesus monkeys*: Gouteux, Thinus-Blanc, & Vauclair, 2001; *chicks:* Tommasi & Polli, 2004; Vallortigara, Zanforlin, & Pasti, 1990; for review, see Cheng & Newcombe, 2005).

The present study borrows from both approaches. We examine how young children determine the location of an object hidden in an enclosed space following one of two disorientation procedures— Cheng's (1986) version, which involves rotating the viewer, and an alternative version, which involves rotating the space. Importantly, in both versions, viewers are prevented from visually tracking their changing relation to the hidden object, ensuring that geometric information about the space must be used to locate the object (see Gallistel, 1990; Newcombe, in press). Although these tasks are formally equivalent, they may not be psychologically equivalent. As noted above, the processes for determining location may depend on who or what is moved.

1. Viewer- vs. space-movement tasks

Empirical evidence for a psychological dissociation between viewer- and space-movement tasks was first reported by Huttenlocher and Presson (1973). They presented third and fourth grade children with an array of objects and instructed them to remember the locations of the objects. The array was then covered over and the child was told to imagine moving either him- or herself along the edge of the array or the array along its central axis to a particular position. Following these instructions, children were asked about the objects' locations. They made fewer errors and exhibited fewer egocentric responses in the array-than the viewer-movement task (for another example, see Hardwick, McIntyre, & Pick, 1976). However, tasks involving movement of a spatial layout are not invariably easier than those involving movement of the viewer. In fact, performance may be modified by task-related variables, such as the types of location questions and spatial layouts (Huttenlocher & Presson, 1979; Presson, 1982; Wraga et al., 2000). Huttenlocher and Presson (1979) found that when children were asked item questions (e.g. "If you/the array were rotated 90°, what object would be on the right?") they performed better in the viewer- than the array-movement task. However, if a single object (e.g. a telephone) served as the spatial layout, instead of an array, their performance was comparable on the two tasks. Similarly, children performed comparably on the tasks if, instead of item questions, they were asked position questions (e.g. "If you/the array were rotated 90 degrees, where would the drum be?").

Accumulating evidence indicates that, like children, adults' performance on object location tasks may depend on whether movements of the viewer or of the spatial layout are involved (e.g., Amorim & Stucchi, 1997; Hegarty & Waller, 2004; Presson, 1982; Rock, Wheeler, & Tudor, 1989; Wraga et al., 2000). Furthermore, like children, their performance may be influenced by task-related factors (Presson, 1982; Wraga et al., 2000). Following Huttenlocher and Presson (1979; Presson 1982), Wraga et al. presented adult participants with a spatial layout, which participants were instructed to memorize. Each participant was then blindfolded and told to imagine moving either him- or herself, or the layout to a particular position. Two types of spatial layouts were used—either an array with several objects or a single spatially connected object (e.g. a toy car or a block with different colored sides). In the array conditions, performance varied with the type of question. That is, with position questions, the speed and accuracy of participants' responses were comparable across the viewer- and array-movement tasks. However, with item questions, they were faster and more accurate following viewer movement. When a single object was used, performance in the space-movement condition improved in some, but not all, cases—namely, with the toy car but not with the block of different colors.

The finding that processing location information may depend on whether the task involves viewer or space movement has proven robust, occurring under several conditions of imagined rotation—for example, whether viewers are positioned inside or outside an array (Wraga et al., 2000), when movements of the viewer defy gravity (Creem, Wraga, & Proffitt, 2001), with complex virtual displays (Wraga, Creem-Regehr, & Proffitt, 2004) and with translational movement (Creem-Regehr, 2003). Differences in performance have also been reported in tasks involving physical (real not imagined) movements—of the viewer vs. of the spatial layout (Simons & Wang, 1998; Vasilyeva, 2002; Wang & Simons, 1999; Wraga et al., 2004). There have also been neuropsychological studies showing that viewer and space movement may be subserved by different neural regions (e.g. Creem, Downs, Wraga, Proffitt, & Downs, 2001; Zacks, Ollinger, Sheridan, & Tversky, 2002; Zacks, Rypma, Gabrieli, Tversky, & Glover, 1999; Zacks, Vettel, & Michelon, 2003). Using fMRI technology, Zacks et al. (2003) showed that imagined rotations of the viewer led to selective increases in the left temporal cortex, whereas imagined rotations of a spatial layout led to selective increases and decreases in the right and left parietal cortices, respectively.

To account for how location information is processed, several explanations have been proposed (e.g. Huttenlocher & Newcombe, 1984; Huttenlocher & Presson, 1979; Newcombe, 2002; Presson, 1982; Simons & Wang, 1998; Wang & Simons, 1999; Wraga, Creem, & Proffitt, 1999, 2000; Wraga et al., 2004). Here, we consider two accounts—that of Huttenlocher and colleagues and that of Wraga and colleagues. Huttenlocher and Presson proposed that viewers may code spatial layouts on an "item-by-item" basis, for example, coding an array in terms of each of the objects.

They also suggested that coding the individual items in an array might allow for the use of different strategies when solving a problem that involves movement of the array. The strategy that is used depends on whether the locations of all the items must be known or whether it is sufficient to know the location of only one of them. Item questions (e.g. "What object is on the right?") involve the first alternative. In this case, viewers must transform the entire array by moving each of the items while maintaining the relations among them. Position questions (e.g. "Where is the drum?") involve the second alternative. In this case, viewers only need to move the object in question, not the entire array. This is similar to the case involving viewer movement where the array itself need not be transformed.

In another account, Wraga et al. (1999, 2000) argue that tasks involving movement of the viewer vs. of a spatial layout invoke different frames of reference, egocentric vs. object-relative, respectively. They argue that the egocentric reference frame, which specifies the up/down, front/back, and left/right axes of the body, can be transformed cohesively and efficiently; in contrast, the object-relative reference frame, which specifies the relations among the objects in an array, is transformed piecemeal. On their account, egocentric transformations are easier than object-relative ones because of evolutionary and biological restrictions. That is, not only have people evolved to move in a mostly rigid environment, but also it is biologically impossible to separate the individual axes of the body. Furthermore, they argue that the object-relative reference frame is difficult to transform because it lacks internal cohesion. In sum, they suggest that there is a "viewer advantage" when processing location information.

As described above, however, there is not always a viewer advantage. Indeed, with position questions, performance in the viewer-movement task is equivalent to performance in the space-movement task. Furthermore, when a single object is used as the spatial layout, performance on the space-movement task improves, in some cases to the level of the viewer-movement task. Yet Wraga et al. (1999, 2000) have argued that these findings are not inconsistent with their account. First, they suggest that position questions change the nature of the task such that the target object need not be rotated. That is, unlike an array that is rotated along its central axis and a viewer that moves in a rotational path around an array, the target object can be translated to a particular position, which is considered an easier transformation (see Easton & Sholl, 1995; Presson & Montello, 1994; Rieser, 1989). Second, they argue that because a single object is spatially connected it increases the internal cohesion of the object-relative reference frame, which leads to better performance on space-movement tasks. However, the question remains as to why spatial-connectedness is only beneficial with highly familiar objects, such as a telephone or a toy car. Let us consider an alternative explanation. As described above, Huttenlocher and Presson (1979) suggested that arrays of objects might be coded on an item-by-item basis. They also suggested that a single, highly familiar object might be coded as an integrated unit. Yet it is possible that less familiar objects (e.g. a block of different colors) are not coded as units. Indeed, they may be coded in terms of their constituent parts (cf., Biederman & Bar, 1999; Just & Carpenter, 1985). If an object were represented in terms of its parts, rather than as an integrated unit, a task involving object movement would be more difficult than one involving viewer movement since it would require maintaining information about each of the object's parts as well as the internal relations among those parts.

2. A disorientation task

Using the disorientation task originally developed by Cheng (1986), it has been shown that the geometric parts of enclosed spaces (e.g. rectangular rooms) are coded by children as young as 18–24 months of age. In the canonical version of the task, the child watches an experimenter hide an object in one of the identical containers at one of the corners of an all-white rectangular room. Following the hiding event, the child is disoriented by his or her parent—i.e. the child is picked up, his or her eyes are covered, and he or she is rotated several times. The child is then placed in front of one of the walls of the room and asked to retrieve the hidden object. Several studies (e.g. Hermer & Spelke, 1994, 1996; Hupbach & Nadel, 2005; Huttenlocher & Vasilyeva, 2003; Learmonth, Nadel, & Newcombe, 2002; Learmonth, Newcombe, & Huttenlocher, 2001; Lourenco, Huttenlocher, & Vasilyeva, 2005) have shown that children search reliably at one of the two geometrically appropriate corners (i.e. the hiding corner and the corner diagonally opposite to it), indicating that they use information about the geometric properties of the space (e.g. side length) to locate a hidden object.

Recently, some research has been concerned with examining the nature of geometric coding (i.e. how and what information is represented) on the disorientation task described above (e.g. Huttenlocher, Lourenco, & Vasilyeva, in press; Huttenlocher & Vasilyeva, 2003; Lourenco et al., 2005; for research on animals, see Cheng & Gallistel, 2005; Pearce, Good, Jones, & McGregor, 2004; Tommasi & Polli, 2004; Vallortigara, Pagni, & Sovrano, 2004). Huttenlocher and colleagues examined this issue in young children by coding their search behaviors and testing them from different positions, either inside or outside enclosed spaces. In examining children's search behaviors, we found that following disorientation children rarely surveyed the space (by looking or walking around it). Instead, they went directly to a particular corner regardless of which wall they faced. Given that children could infer their relation to the hiding corner without having to survey the space, we concluded that they had coded information about the entire space in terms of its constituent parts. Furthermore, in testing children from different positions, we found that they were more accurate from inside a space than from outside, although performance was above chance for both positions. The difference in accuracy suggested that the distinctiveness of the critical information about the enclosed space was important for determining the location of a hidden object. Consider how this might affect performance. From outside the space, the critical component parts (i.e. the corners) all lie in front of the viewer, whereas from inside the space, they are not all in the frontal plane; see Fig. 1 for an illustration. Thus, for a viewer who stands outside the space, the corners appear less differentiated, making them more confusable and the task more difficult.

To date, many of the studies using disorientation to examine children's coding of enclosed spaces have adopted Cheng's (1986) procedure of rotating the viewer (e.g. Hermer & Spelke, 1994, 1996; Huttenlocher & Vasilyeva, 2003; Learmonth, Nadel, & Newcombe, 2002; Learmonth, Newcombe, & Huttenlocher, 2001; Lourenco et al., 2005;

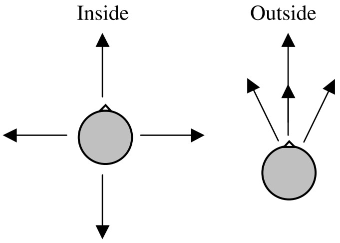

Fig. 1. Schematic representation of inside and outside perspectives.

Wang, Hermer, & Spelke, 1999). However, in a recent study designed to examine children's (3–5 years) coding of small spaces, Gouteux et al. (2001) used a space-movement disorientation procedure, which involved rotating a rectangular box (80× 20 cm^2, and 15 cm deep) while children's eyes were covered. In contrast to the research with toddlers (18–24 months), 3-year-olds searched randomly at each of the corners. The authors concluded that this task was more difficult because small (non-navigable) spaces invoke "secondary" representations, which are orientation-specific; in contrast, large (navigable) spaces invoke "primary" representations, which are independent of orientation (see also Presson & Hazelrigg, 1984). However, there is another possibility. The difficulty may have been due to differences in the disorientation procedures; that is, Gouteux et al.'s task involved rotating the space rather than the viewer. This alternative possibility is supported by the fact that, using a viewer-movement disorientation procedure, Huttenlocher and Vasilyeva found that toddlers could use the geometry of small enclosed spaces, shaped like a rectangle (68.6×45.7 cm^2, and 15.2 cm deep) or an isosceles triangle (55.9×35.6×55.9 cm^3, and 15.2 cm deep), to locate a hidden object.

3. Present experiment

In the present experiment, we compared children's ability to locate an object hidden in an enclosed space following one of two disorientation procedures— Cheng's (1986) version of rotating the viewer or the alternative version of rotating the space. In both versions, children's eyes were covered to ensure that they could not keep track of their changing relation to the hidden object. Thus, in both tasks, children would have to use the geometric features of the space to determine the object's location. Except for whether the disorientation procedure involved rotating the viewer or the space, the tasks were identical; both began with the hiding phase, were followed by a disorientation procedure, and then the retrieval phase. Like Huttenlocher and Vasilyeva (2003), children were tested from either inside or outside the enclosed space. We also used a space shaped like an isosceles triangle with corners that vary in their distinctiveness. That is, one of the corners is unique in that it is distinguishable from the other two corners with respect to side length (i.e. both sides are equal vs. one side being shorter/longer than the other) and angular size (40° vs. 70°). For ease of discussion, this corner will hereafter be referred to as the "unique" corner. In contrast, the other two corners are only distinguishable by the relative length of the sides; they are equivalent in the size of the angles. These corners will hereafter be referred to as the "equivalent" corners.

3.1. Predictions

Like the tasks described above involving movements of the viewer or the spatial layout (e.g. Huttenlocher & Presson, 1979; Wraga et al., 2000), we expected that children would approach the problem of object location differently on our viewer- and space-movement disorientation tasks. For the space-movement version, we reasoned that because the change in the relation between the viewer and the space is not consistent with viewers having remained stationary, children would attempt to transform the space so as to re-establish their original relation to it. We also reasoned that because children have difficulty with the transformation of spatial information (e.g. Dean & Harvey, 1979; Dean & Scherzer, 1982; Levine, Huttenlocher, Taylor, & Langrock, 1999) they should do better at locating the hidden object if, like the position questions described above, they focused on transforming one of the parts of the space—namely, the hiding corner. We predicted that such transformations would be easier with the unique corner since it is not necessary to keep track of the left–right relations of the sides and since the smaller size of the angle would make it less likely to be confused with the equivalent corners. Accordingly, we predicted that, in the space-movement task, performance would be better when the unique corner served as the hiding location. In contrast, for the viewer-movement version, we reasoned that because the change in the relation between the viewer and the space is consistent with viewers having themselves been rotated, the space would not have to be transformed. Accordingly, we predicted that performance would not vary by corner; in the viewer-movement task, children should find the hidden object regardless of which corner served as the hiding location.

We also predicted that, in both tasks, performance would depend on the testing position (inside vs. outside). Recall that in our previous work using the viewer-movement disorientation procedure we showed that performance was better for the inside position than for the outside position (Huttenlocher & Vasilyeva, 2003; Lourenco et al., 2005). We reasoned that the inside advantage would hold for the space-movement task. That is, the spatial information may be easier to transform if the parts of the space appear more distinctive. As described above and shown in Fig. 1, the corners are more distinct to a viewer standing inside than outside the space. Hence, for both the viewer and space movement tasks, performance should be better from the inside, than the outside, position.

4. Method

4.1. Participants

The sample consisted of 72 children (36 boys and 36 girls). An additional 13 children were excluded from the analyses because they either failed to complete all of the test trials (10) or refused to keep their eyes covered during the disorientation procedure (3).

Participants were between 18 and 25 months of age ($M = 22.1$ months, SD = 2.0 months). All parents were compensated for their children's participation.

4.2. Materials

The experiment took place inside a round enclosure (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 evenly spaced chains. An opening in the fabric permitted entry into the enclosure; this opening was sealed together with Velcro during the experiment. Fluorescent lights, centered over the enclosure, hung from the ceiling. The floor was covered in a homogenous gray carpet. A brown bottomless structure shaped like an isosceles triangle (132.1 cm by 91.4 cm by 132.1 cm, and 44.5 cm high) and made of plywood was placed in the center of the enclosure. Small shelves were affixed to each corner. Three identical opaque containers (22.9 cm high, 7.6 cm in diameter), which served as potential hiding locations, were placed in the corners, one on each shelf. Ball bearings with brakes were attached to the underside of each shelf, allowing the space both to be rotated and to remain stationary. A small toy cow was used as the hiding object. A video camera was attached to the center of the ceiling and used to record the experiment.

4.3. Design

Equal numbers of boys and girls were randomly assigned to one of two disorientation tasks: viewer- or space-movement. The tasks were identical except that, in the viewer-movement version, the child was rotated while the space remained stationary, and in the space-movement version, the space was rotated while the viewer remained stationary. In both tasks, children were tested from either inside or outside the space, with equal numbers of boys and girls in each group. The location of the hiding corner (three possibilities: the unique corner, or one of the two equivalent corners) was counterbalanced across children.

4.4. Procedure

The experiment was introduced in the same way for both tasks. The experimenter explained the procedure to the parent while the child played in the waiting area. When the child seemed comfortable with the environment, he or she, the parent, and the experimenter entered the enclosure through an opening in the fabric. Once inside the enclosure, the experimenter closed the opening and told the child that they were going to play a "hide-and-seek game". The remainder of the procedure is described below for the viewer- and space-movement tasks.

4.4.1. Viewer-movement task

As described above, in each task children were tested in either the inside or outside condition. In the *inside* condition, the child stood inside the triangular structure and watched as the experimenter (who stood outside) hid the toy in one of the pre-selected containers. The parent also stood outside the structure but moved around so as not to serve as a potential landmark cue. Following the hiding event, the parent stepped inside the structure, picked up the child, covered the child's eyes, and rotated 4–5 times. During the rotation, the experimenter walked around the outside of the structure 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 of the structure. The wall that the child faced was randomly determined prior to the start of the experiment with the restriction that each wall would be faced twice. The child was then asked to find the hidden toy. If the toy was retrieved on the first attempt, the experimenter proceeded to the next trial. If it was not retrieved on the first attempt, the child was encouraged to try another corner. There were a total of six trials, and for a given child, the toy was hidden in the same corner across all trials.

In the *outside* condition, the child stood outside the triangular structure next to the experimenter and watched as the toy was hidden in one of the pre-selected containers. As in the inside condition, the parent, who stood outside the structure, moved around so as not to serve as a landmark. Following the hiding event, the parent picked up the child and remained outside the space. The parent then covered the child's eyes and walked around the structure 2–3 times. (In both conditions, the movement took approximately 20 s.) During the movement, the experimenter also walked around the outside of the structure, reminding 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 outside the triangular structure in front of one of the randomly predetermined walls with each wall being faced twice in the course of the six trials. As in the inside condition, the child was then asked to find the hidden toy and to continue searching if it was not retrieved on the first attempt; there were a total of six trials with the toy hidden in the same corner on all trials for each child.

4.4.2. Space-movement task

The space-movement task was identical to the viewer-movement task except that, instead of the parent rotating the child following the hiding event, the experimenter rotated the space while the child remained stationary. In the *inside* condition, the parent and the child (whose eyes were covered) stood in the center of the structure during the rotation of the space. In the *outside* condition, the parent and the child (whose eyes were covered) stood outside the structure near the surrounding circular enclosure during the space's rotation. On each trial, the experimenter rotated the structure one full circle (i.e. 360°) before stopping at the 90°, 180°, or 270° orientation (see Fig. 2). (As in the viewer-movement task, the total time during the movement phase was approximately 20 s.) Each orientation (90°, 180°, or 270°) was repeated twice in the course of the six test trials with the order randomly predetermined. After the space was rotated, the parent uncovered the child's eyes and placed him or her in front of one of the walls of the structure. The wall the child faced was determined by where the space stopped rotating; as in the viewer-movement task, each wall was faced twice during the test trials.

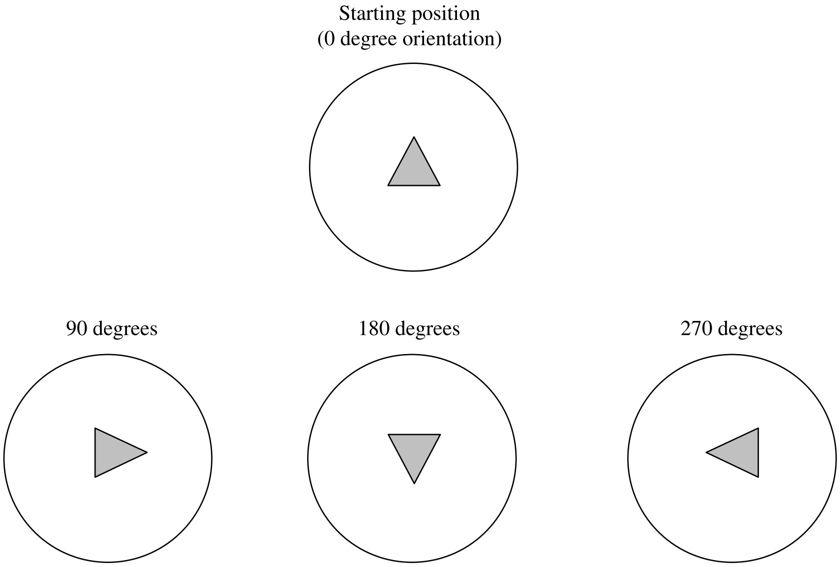

Fig. 2. An overhead view of the possible positions of the triangular structure (and the surrounding enclosure) during the space-movement disorientation task.

5. Results

To test the predictions described above, we conducted an Analysis of Variance (ANOVA) with the following between-subjects independent variables—task (viewer- vs. space-movement), hiding corner (unique vs. two equivalent corners), and position (inside vs. outside). We also included sex in the analysis, although no specific predictions were made regarding this variable. The dependent variable in the ANOVA was accuracy score (out of six trials), calculated for each child; on each trial, the first response was scored as correct if the child searched at the corner where the object was hidden.

As predicted, the ANOVA revealed significant main effects of task, $F(1, 48) = 80.43$, $P < .0001$, and corner $F(2, 48) = 7.49$, $P < .01$, as well as a significant interaction between task and corner, $F(2, 48) = 9.34$, $P < .001$. Fig. 3 depicts the task by corner interaction; in the space-movement task, performance varied by corner, whereas in viewer-movement task, it did not. As predicted, there was also a significant main effect of position, $F(1, 48) = 8.31$, $P < .01$, but no interactions with any other variables (all Ps $> .1$). Fig. 4 depicts the position effect; in both the viewer- and space-movement tasks, performance was better from inside the space than from outside. There was no main effect of sex, nor any interactions between sex and the other variables (all Ps $> .1$).

5.1. Task by corner interaction

As indicated above and shown in Fig. 3, there was a significant interaction between task and corner. An analysis of effect size using Cohen's f revealed that the interaction accounted for a substantial portion of the variance, $f = .48$.

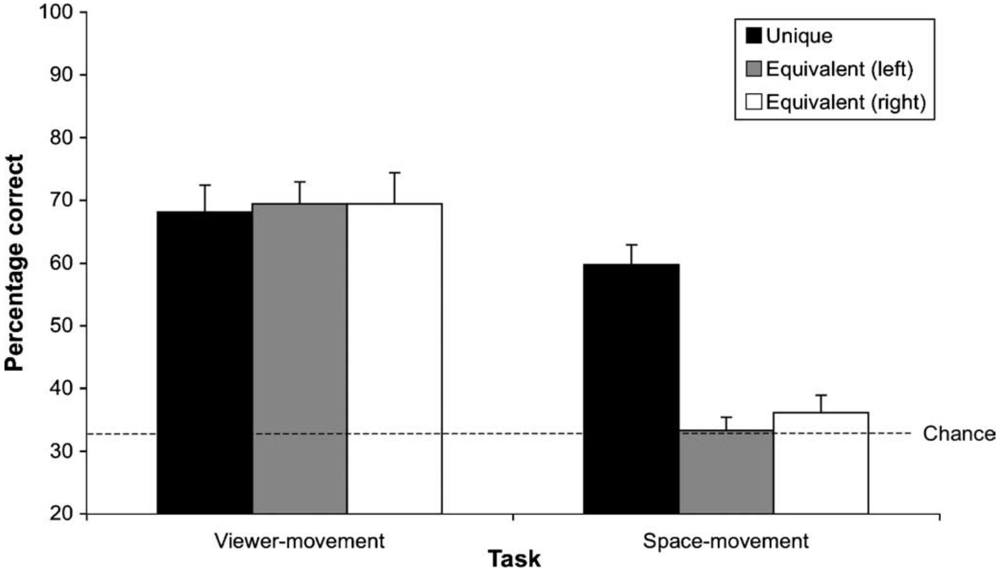

Fig. 3. Mean accuracy scores (and standard errors) as a function of task and corner. The left and right equivalent corners correspond to the left and right position of these corners when the triangular structure was positioned in the 0° orientation (see Fig. 2).

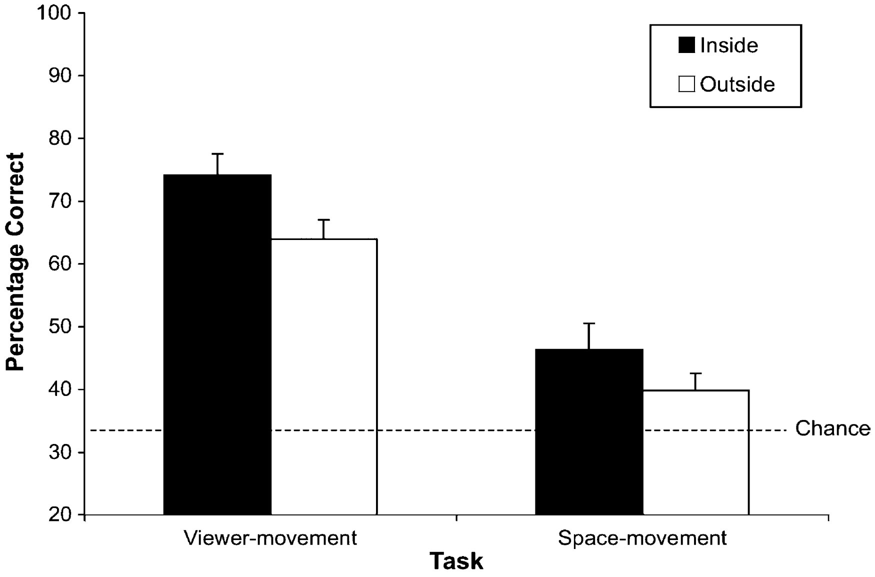

Fig. 4. Mean accuracy scores (and standard errors) as a function of task and testing position (inside vs. outside).

We also conducted post hoc comparisons using Tukey's *HSD* to determine whether there were differences between each of the groups. The analysis revealed that, in the viewer-movement task, performance did not differ as a function of corner (all *P*s > .05). However, in the space-movement task, performance at the unique corner was significantly better than performance at either of the equivalent corners (*P*s < .05); at the equivalent corners, performance did not differ ($P > .05$). The analysis also revealed that when the object was hidden at the unique corner, performance on the viewer-movement task did not differ from performance on the space-movement task ($P > .05$), whereas when the object was hidden at either of the equivalent corners, performance in the viewer-movement task was significantly better than performance in the space-movement task ($P < .05$).

We also conducted analyses comparing performance in each of the groups to the chance level of 33.3%. For this analysis, we used two-tailed *t*-tests and, to control for Type I errors, a Bonferroni-adjusted alpha of .001. The analyses revealed that, in the viewer-movement task, performance was significantly above chance at all of the corners—the unique corner ($M = 68.1\%$, SE = 4.3%), $t(11) = 8.02$, and the equivalent corners ($M =$ 69.4% for each corner, SE = 3.5% and 5.0%), $t(11) = 10.46$ and 7.29, respectively, all *p*s < .001. In the space-movement task, performance was significantly above chance at the unique corner ($M = 59.7\%$, SE = 3.2%), $t(11) = 8.20$, $P < .001$, but not at the equivalent corners ($M = 33.3$ and 36.1%, SE = 2.1 and 2.8%), $t(11) = 0$ and 1.0, respectively.

5.2. *Effect of position (inside vs. outside)*

As indicated above and shown in Fig. 4, there was a significant main effect of position. The effect size was large, $d = .68$. Although performance was better when children were tested from inside the space ($M = 60.2\%$, $SE = 5.0\%$) than from outside the space ($M = 51.9\%$, $SE = 4.1\%$), comparisons to chance, using two-tailed *t*-tests and a Bonferroni-adjusted alpha of .025, revealed that performance was significantly better than chance for both positions—inside, $t(35) = 7.60$, and outside, $t(35) = 6.44$, $P < .001$.

5.3. Analyses on test trials

In addition to the analyses described above, we examined whether performance in the viewer- and space-movement tasks varied across the six test trials (see Fig. 5). Using Mantel–Haenszel chi-square analysis, we found that in the viewer-movement task the number of children who choose the correct corner was consistent across trials, $\chi^2(1, N = 216) = 0.02$, $P > .1$. In contrast, in the space-movement task, the number of children choosing correctly increased over the six trials, $\chi^2(1, N = 216) = 5.61$, $P < .05$.

6. Discussion

Several studies have shown that following disorientation young children use the geometric properties of an enclosed space to locate an object hidden in one of its corners (e.g. Hermer & Spelke, 1994, 1996; Huttenlocher & Vasilyeva, 2003; Learmonth et al., 2001; Lourenco et al., 2005; Wang, Hermer, & Spelke, 1999). Although these studies have used Cheng's (1986) disorientation procedure of rotating the viewer, it has been tacitly assumed that—as long as tracking is prevented—the procedure could involve rotating either the viewer or the space (for examples of space rotation, see Gouteux et al., 2001; Hupbach & Nadel, 2005). After all, with both procedures, viewers would have to use the geometry of the space to locate the hidden object. Yet there is reason to believe that these procedures may evoke different processes for determining location. Indeed, several studies using tasks that involve trackable movements (real or imagined) show that the processing of location information may depend on a number of factors, including whether the viewer or the spatial layout is moved (e.g. Huttenlocher & Presson, 1979; Presson, 1982; Simons & Wang, 1998; ">Wraga et al., 2000, 2004). In the present study, we examined whether the ability to locate a hidden object following disorientation also depends on whether the viewer or the space is rotated. We tested 18- to 25-month-olds in either a viewer- or a space-movement disorientation task from either inside or outside an enclosed space shaped like an isosceles triangle (with one unique and two equivalent corners).

We found that in the viewer-movement disorientation task children performed above chance at all of the potential hiding corners. That is, whether the unique corner or one of the equivalent corners served as the hiding location, children could find the hidden object. Furthermore, performance was consistent across the test trials. In contrast, we found that in the space-movement disorientation task, performance depended on which corner contained the hidden object. When the object was hidden at the unique corner, children performed like their counterparts in the viewer-movement task, locating the object more often than the chance level. Yet, when the object was hidden at either of the equivalent corners, performance did not differ from chance. Furthermore, unlike the viewer-movement condition, performance improved across the test trials. Finally, we also found

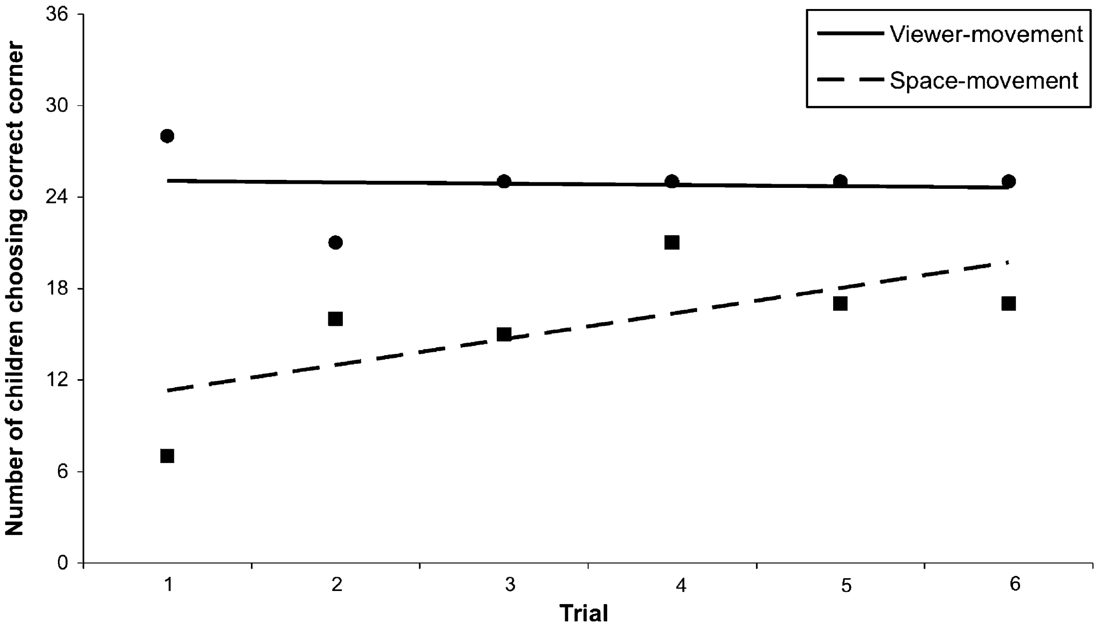

Fig. 5. The total number of children choosing the correct corner as a function of task and trial number (1–6).

that in both movement conditions children were more accurate when tested from inside, than from outside, the space.

The findings from the present study suggest that the viewer- and space-movement disorientation tasks may have been treated differently by children. Indeed, we would propose that how children solved the problem of object location was determined by whether the disorientation procedure involved viewer or space rotation. While both procedures prevent viewers from tracking their changing relation to the hidden object such that they must use geometric information to locate the object, the nature of the problem may change depending on who or what is moved. Take the task involving rotation of the space; following disorientation, children are confronted with the unusual situation of seeing the space in a different position when they have not themselves been rotated. This situation clearly contrasts with the one involving movement of the viewers where the change in their relation to the space is consistent with having themselves been moved. Indeed, mobile beings normally experience such changes in this way; viewers, not large spaces, move to different positions, altering their relations to objects and places in the environment.

Let us then consider how children may have approached the problem of locating the hidden object on each task, beginning with the space-movement condition where children could neither see nor track the movements of the triangular space. Because the change in the viewer's relation to the space is inconsistent with the viewer having remained stationary, children may have attempted to transform the space so as to re-establish their original relation to it (i.e. re-aligning the space with themselves). The transformation of spatial information in this case may be akin to visualizing an object undergoing rotational movement, which, even for adults, can be difficult. The difficulty may depend on factors such as familiarity. As discussed earlier, it may be easier to mentally rotate familiar objects (e.g. a toy car), which are coded as units, than unfamiliar objects (e.g. a block with different colored sides), which may be coded in terms of their constituent parts. Older children too have been shown to be better at mentally rotating familiar objects (e.g. a telephone). For young children, the mental transformation of spatial information is, generally, a difficult task. Indeed, they do not typically succeed on more traditional mental rotation tasks until the age of 4.5 years (Levine et al., 1999). Yet there is evidence that, in some cases, young children can transform spatial information. For example, they find it easier to mentally rotate objects that contain distinctive cues (Rosser, Ensing, Gilder, & Lane, 1984; Rosser, Ensing, & Mazzeo, 1985) and even infants, in habituation tasks, can predict the orientation of an object that moves in a rotational path behind an occluder (Hespos & Rochat, 1997; Rochat & Hespos, 1996).

Here, the transformation of spatial information may have been easier for children in two cases—when the object was hidden at the unique corner and when they were positioned inside the space. Recall that Huttenlocher and Presson (1979; Presson, 1982) proposed that there are different strategies for dealing with a task involving movement of an array. For example, when item questions (e.g. "What object would be on the right?") are asked, viewers rotate the entire array because answering the questions requires knowledge of all the items' locations. In contrast, when position questions (e.g. "Where would the drum be?") are asked, viewers only move the target item because the locations of the other items are not relevant to the questions. That is, with position questions, viewers can simplify the task by focusing on the critical element—the target object (see also Wraga et al., 2000). In the present study, children may have engaged in a similar strategy. That is, they may have simplified the space-movement task by focusing on the critical part of the space—the hiding corner. Such a strategy is possible because enclosed spaces, like arrays and unfamiliar objects, may be coded in terms of their constituent parts (see Huttenlocher, Lourenco, & Vasilyeva, in press; Huttenlocher & Vasilyeva, 2003). Our results suggest that this strategy was most effective when the object was hidden at the unique corner, which is distinct from the other two corners both with respect to the lengths of the sides and to the size of the subtended angle. Accordingly, the unique corner may have been easier to transform not only because it is unnecessary to maintain the left–right relations of the sides, but also because the smaller angle makes it less likely that it will be confused with the other corners.

As indicated above, the other case when the transformation of spatial information might have been easier for children was when they were tested from inside the space. As described in the introduction, the distinctiveness of the critical elements of the space (i.e. the corners) depends on the viewer's position in relation to the enclosed space (i.e. inside vs. outside). For a viewer who stands outside the space, all of the corners lie in a frontal plane. However, for a viewer who stands inside the space, the corners are not all in the frontal plane—they may be in front, behind, to the left or to the right. Accordingly, from the inside position, the locations of the corners are more distinguishable from one another, making them less confusable and perhaps easier for children to transform.

The finding that performance on the space-movement disorientation task improved across the test trials provides further support for the proposal that, on this task, children may attempt to re-establish their original relation to the space by transforming the critical spatial information. Because the improvement in performance occurred in the context of a corner by task interaction, it is not likely that children simply learned that their relation to the space could change when they remained stationary. Instead, we would suggest that children's ability to transform the spatial information improved with experience, which is consistent with research showing that practice leads to better performance on mental rotation tasks even when no explicit instruction is provided (e.g. Levine et al., 1999; Platt & Cohen, 1981).

Let us now consider how children may have approached the problem of object location on the viewer-movement disorientation task, which involves non-trackable movements of the viewer. Unlike the space-movement task, the change in the viewer's relation to the space is not an unusual situation. Indeed, it is entirely consistent with children having themselves been rotated several times. Accordingly, children would not need to transform their representation of the triangular space, which would explain why they could find the hidden object regardless of the corner serving as the hiding location. As in previous studies, our results show that when the task involves a viewer-movement disorientation procedure children can easily use information about the shape of the space to locate a hidden object. It also shows that when the spatial information is more distinct with respect to the viewer, as in the inside position, children are better at locating the hidden object.

Taken together, our findings may account for why, in the Gouteux et al. (2001) study, children had difficulty locating the hidden object. Recall that they used a space-movement disorientation procedure, which creates a situation that people are not generally accustomed to dealing with—namely, a change in their relation to the spatial environment when they have not been moved. As a result, children may have attempted to re-establish their original relation to the space following disorientation by transforming the space. However, unlike the present study where there were two cases (i.e. a unique corner and the inside position) when such rotational transformations could be made easier, neither case existed in the Gouteux et al. study. In their study, children were tested with a rectangular space and were always positioned outside that space.

In conclusion, our findings have important implications for understanding the processing of location information. As in previous studies involving trackable movements, we show that how the problem of object location is approached following disorientation is determined by whether the viewer or the space has been rotated. In space-movement disorientation tasks, children may attempt to transform the space, whereas in viewer-movement disorientation tasks, the space need not be transformed. Importantly, in only some cases does having to transform spatial information make the task of locating a target object more difficult for young children.

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