Research Report

Reorientation and Landmark-Guided Search by Young Children

Evidence for Two Systems

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ABSTRACT—***Disoriented 4-year-old children use a distinctive container to locate a hidden object, but do they reorient by this information? We addressed this question by testing children's search for objects in a circular room containing one distinctive and two identical containers. Children's search patterns provided evidence that the distinctive container served as a direct cue to a hidden object's location, but not as a directional signal guiding reorientation. The findings suggest that disoriented children's search behavior depends on two distinct processes: a modular reorientation process attuned to the geometry of the surface layout and an associative process linking landmarks to specific locations.***

Disoriented humans and animals tend to reorient by relying on the geometry of the surrounding environment. When rats see food buried in a rectangular arena and then are disoriented, for example, they search primarily, and equally, in the correct and rotationally symmetrical locations (Cheng, 1986). Geometrically guided reorientation has been observed in various species, including fish, monkeys, chicks, pigeons, and humans (Gouteux, Thinus-Blanc, & Vauclair, 2001; Hermer & Spelke, 1994; Kelly, Spetch, & Heth, 1998; Sovrano, Bisazza, & Vallortigara, 2002; Vallortigara, Zanforlin, & Pasti, 1990), and the prevalence of reliance on geometric information is now widely acknowledged (Cheng & Newcombe, 2005).

In contrast, there are mixed findings on the use of landmarks for reorientation. Disoriented animals and human children often ignore featural cues that break an arena's symmetry (Cheng, 1986; Hermer & Spelke, 1994, 1996; Margules & Gallistel, 1988), but they use such landmarks reliably in tasks that elicit higher motivation (Dudchenko, Goodridge, Seiterle, & Taube, 1997), after multiple training trials (Cheng, 1986; Gouteux et al., 2001; Sovrano, Bisazza, & Vallortigara, 2003), or when tested in larger rooms (Learmonth, Nadel, & Newcombe, 2002; Learmonth, Newcombe, & Huttenlocher, 2001). What accounts for these findings?

Cheng (1986) and Gallistel (1990) proposed that reorientation depends on a modular system (Fodor, 1983) sensitive only to geometry, but that disoriented animals locate hidden objects by using direct landmarks. In this view, search depends on two processes: a modular reorientation process that operates only on the geometry of the surface layout and an associative learning process that relates landmarks directly to goal locations (Wang & Spelke, 2002). Other investigators propose that the reorientation mechanism is not modular and accepts information about both geometry and landmarks under certain conditions (Cheng & Newcombe, 2005; Learmonth et al., 2002; O'Keefe & Nadel, 1978).

The present experiments tested these contrasting accounts by building on studies by Gouteux and Spelke (2001). These studies were conducted in a circular arena with three containers; children watched an object placed in one container, were disoriented, and then searched for the object. They performed at chance when the containers were identical, but successfully found the object when the containers were distinctive. These results provide evidence for landmark use during disorientation.

Here we ask whether landmarks serve as cues to reorientation or as direct markers of object location. In the critical experiments, children were tested with one distinctive and two identical containers. If children use landmarks to reorient, under

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such conditions they should find an object after disorientation, regardless of where it is hidden. In contrast, if they directly associate landmarks to locations, then they should search correctly only at the distinctive container.

GENERAL METHOD

Children were tested in a circular chamber (diameter = 3.8 m) equipped with soundproof walls, symmetrically positioned lights, a camera, and a hidden door. Three containers were centrally placed, 2 m apart, to form an equilateral triangle. In Experiments 1, 2, 4, and 5, we used one red cylindrical container (diameter = 25 cm, height = 40 cm) and two blue boxes (50 × 24 × 18 cm), so that only the cylinder broke the room's symmetry. In Experiment 3, a green bowl (diameter = 28 cm, height = 12 cm) replaced one blue box, so that all three landmarks were distinct.

The procedures followed those of Gouteux and Spelke (2001). After walking the child around the room, providing a view of the three containers from all directions, the experimenter administered three consecutive search trials per container (or container pair in Experiments 3–5). At the start of each trial, the experimenter hid a sticker under a container (or two stickers under two containers) and pointed out the door panel. In Experiments 1 through 4, the child was blindfolded and turned in place several times until disorientation was confirmed by his or her inability to point correctly to the door. Finally, the experimenter stood behind the child, removed the blindfold, and encouraged the child to find the sticker (or stickers). The order of hiding places was counterbalanced across subjects, and the child's facing direction at the onset of search was counterbalanced and varied across trials.

EXPERIMENT 1

In this experiment, children searched for a single object hidden either under a red cylinder, A, or under one of two identical blue boxes, B and C (Fig. 1). They began their search at the center of the room, facing midway between two of the containers (Fig. 1). Facing direction was varied across trials such that each container was initially out of view behind the child on three of the nine search trials. Participants were 6 boys and 6 girls, 48 to 50 months old. One additional child refused to be tested.

The children's search accuracy differed reliably across the containers, $F(2, 20) = 15.69, p < .001$ ($\eta_p^2 = .61, p_{\text{rep}} = .99$). They found the sticker on their first try when it was hidden at the cylinder (94.4% vs. 33.3% chance), $t(11) = 16.32, p < .001$, both when it was in view at the start of search (91.7%) and when it was not (100%). Because searches at the cylinder (A) were highly accurate, performance at the two boxes (B and C) was compared against a chance value of 50%; success at the boxes did not differ from chance (38.9% for B, 44.4% for C; both ts < 1.4, n.s.; Fig. 2). The children performed at chance both when the cylinder was initially in view (38%) and when it was not (42%). They chose the correct (41.7%) and incorrect (50%) boxes equally often ($t < 1$, n.s.) and searched less accurately than at the cylinder, $t(11) = 9.84, p < .001$.

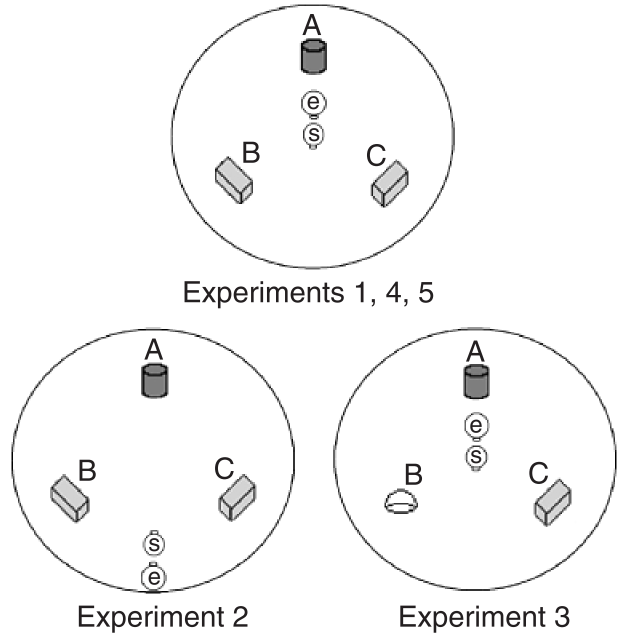

Fig. 1. The experimental room and setup in the five experiments. The positions of the subject (s), the experimenter (e), and the three containers (A, B, and C) are indicated.

Disoriented children searched correctly at a distinctive container, even when it was initially out of view. When an object was hidden in one of two identical containers, in contrast, children searched primarily those two containers but chose randomly between them. These findings suggest that the children used the distinctive container only as a direct cue to the object's location. It is possible, however, that they had difficulty recalling the spatial relations among the three containers from the central viewing position. If all three containers were visible at once, perhaps children would use the distinctive cylinder to reorient themselves and locate the object wherever it was hidden. Experiment 2 tested that possibility.

EXPERIMENT 2

Experiment 2 followed the same method as Experiment 1, except that before the blindfold was removed, the disoriented children were brought to a position at the edge of the room, such that they were equidistant from two of the containers and all three containers were in view (Fig. 1). Participants were 6 boys and 6 girls, ages 47 to 51 months.

Search accuracy differed reliably across hiding locations, $F(2, 20) = 12.79, p < .001$ ($\eta_p^2 = .56, p_{\text{rep}} = .99$). The children

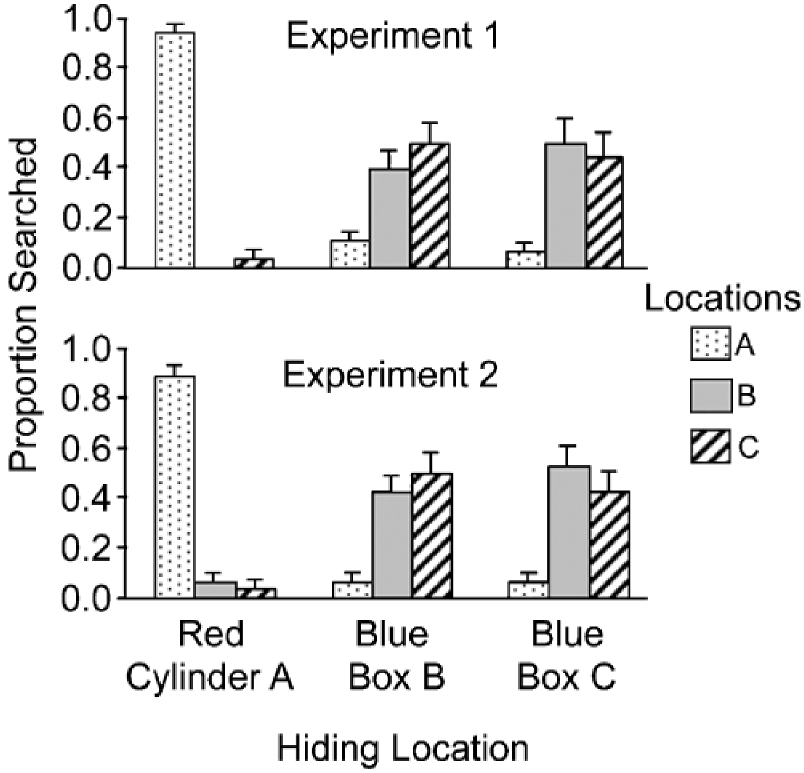

Fig. 2. Mean search rates at each container in Experiments 1 and 2. Each graph shows the proportion of trials on which each location was searched as a function of the hiding location.

successfully located the sticker in the cylinder (88.9% accuracy vs. 33.3% chance), $t(11) = 8.86, p < .001$, but searched the two boxes at random (41.7% for both boxes vs. 50% chance, both ts < 1.2, n.s.; Fig. 2). Children chose the correct (41.7%) and incorrect (51.4%) boxes equally often ($t < 1$), searching less accurately than at the cylinder, $t(11) = 5.17, p < .001$.

Children again successfully located an object hidden at a distinctive container but failed to use the container to differentiate between two identical boxes, even when all three containers were in full view. The children's indiscriminate search of the two boxes suggests a failure to reorient by the available landmark. However, the possibility remains that the children encoded and reoriented by the container where the sticker was hidden, but ignored the other containers. According to this interpretation, when the critical container was distinctive, reorientation was successful; when it was not, the children misoriented themselves half the time.

These two possibilities can be distinguished in this paradigm by hiding two objects on each trial, one in the red cylinder and the other in a blue box. If children reorient only by landmarks that serve as the hiding place in a given trial, they should reorient correctly, distinguish between the two boxes, and successfully locate both objects. In contrast, if children use landmarks only as direct cues, then they should find the object in the cylinder but search the two boxes at random. Such a test requires, however, that children remember and find two hidden objects. In Experiment 3, we used three distinct containers to determine whether children can remember two object locations within one trial, and to prepare for the critical test of landmark-based reorientation in Experiment 4.

EXPERIMENT 3

In Experiment 3, children were presented with three distinctive containers (Fig. 1). On three search trials, two objects were hidden at two different containers; the same pair of containers was used for all three trials, with order of hiding alternating between trials. Participants were 5 boys and 5 girls, ages 47 to 50 months.

The children found both objects without error 96.7% of the time (vs. 33.3% chance), $t(9) = 19.0, p < .001$. Any one object was correctly retrieved within the first two search attempts of a trial 98.3% of the time (vs. 66.7% chance),[1] $t(9) = 19.0, p < .001$ (Fig. 3). Thus, a two-object search task does not overtax disoriented children's memory and can serve to test whether children use landmarks for reorientation.

[1]Chance level of locating both objects in the first two searches is 33.3%, and chance level of locating any one object is 66.7%.

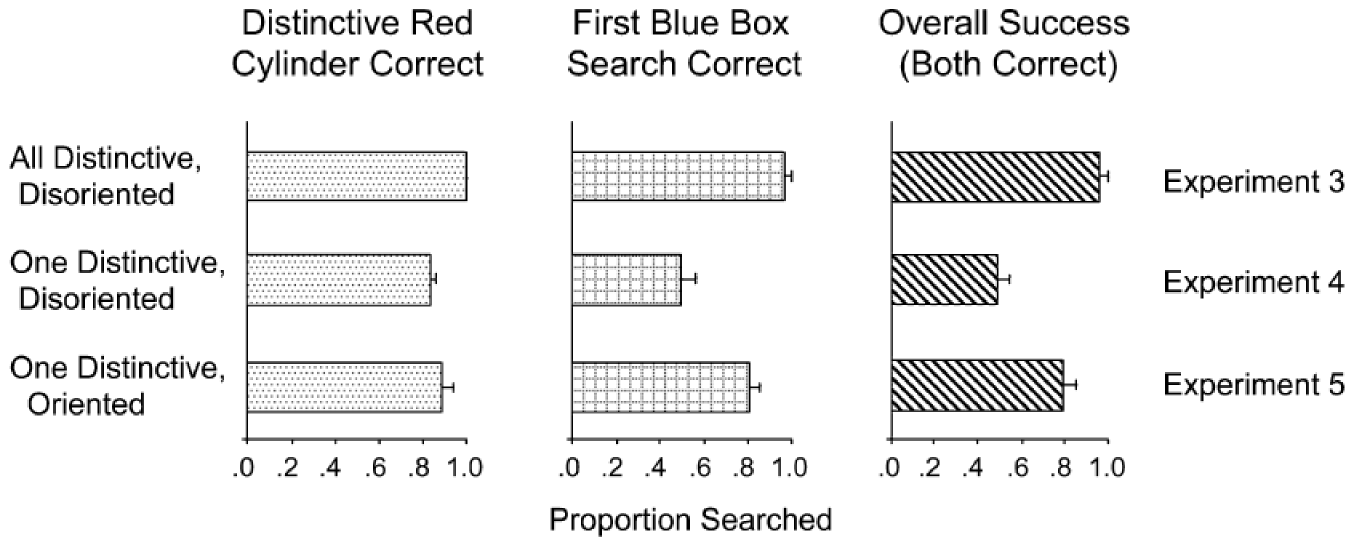

Fig. 3. Mean search rates in Experiments 3, 4, and 5. The first set of bars shows the proportion of trials on which the distinctive red cylinder was searched in the first two search attempts; the red cylinder always contained a hidden object. The second set of bars shows the proportion of trials on which the first blue box chosen to be searched contained a hidden object. The third set of bars shows the proportion of trials on which children found both hidden objects without error (i.e., in the first two search attempts). The experiments differed in whether one or all three containers were distinctive and whether the children were or were not disoriented before they began their search for the hidden objects.

EXPERIMENT 4

In this experiment, children viewed one distinctive and two identical containers, as in Experiments 1 and 2, and received six search trials with two hidden objects. On each trial, one object was hidden at the distinctive cylinder, and another object was hidden at one of the blue boxes. Participants were 6 boys and 6 girls, ages 47 to 50 months. Ten of these children had participated in Experiment 3 immediately before this experiment.

The children successfully located both hidden objects without error about half the time (48.6% accuracy vs. 33.3%), $t(11) = 2.56, p = .026$. Within children's first two search attempts, they searched correctly at the cylinder (83.3% vs. 66.7% chance), $t(11) = 5.75, p < .001$, but not at the boxes (63.9% vs. 66.7% chance, $t < 1$). The difference between search rates at the cylinder and the correct box was marginally significant, $t(11) = 2.03, p = .067$. This measure of search performance at the boxes is inflated, however, by 11 trials in which a child searched the incorrect box and then the correct box before proceeding to the cylinder (Table 1). Because the first box searched was as often incorrect (50%) as correct (50%), success at retrieving both stickers was entirely predicted by accuracy selecting the first box to be searched (Pearson's $r = .974, p < .001$; see Fig. 3). Therefore, although children succeeded at searching the cylinder, they did not distinguish between the two blue boxes.

Because 10 children participated in both Experiments 3 and 4, we conducted a repeated measures analysis of variance with sex as the between-subjects variable and landmark condition (Experiment 3: three distinctive landmarks, Experiment 4: one distinctive and two identical landmarks) and container as the within-subjects variables. There was a main effect of container, $F(2, 16) = 85.30, p < .001$ ($\eta_p^2 = .91, p_{\mathrm{rep}} = .99$), and an interaction between landmark condition and container, $F(2, 16) = 49.81, p < .001$ ($\eta_p^2 = .86, p_{\mathrm{rep}} = .99$). Children searched with high accuracy at the containers when they were distinctive and unique within a given array and searched less accurately at the nondistinctive containers.

The findings of Experiment 4 provide evidence that children do not reorient by landmarks. The children's overall accuracy of 48.6% can be attributed to success using container features and failure to reorient by the cylinder to locate the correct box. Although the relation of the cylinder to the correct box was highlighted as the experimenter hid the two stickers successively, the children continued to search the two boxes indiscriminately.

Nevertheless, an alternative interpretation of the findings remains.[2] Children's errors in Experiment 4 may have stemmed not from a failure to reorient, but rather from a failure to remember the location of an object when it was hidden in a nondistinctive container. The final experiment tested this possibility by investigating oriented children's memory for locations of hidden objects.

EXPERIMENT 5

Experiment 5 followed the method of Experiment 4, except that the children were not disoriented. For the first three trials, the experimenter hid two stickers, then held the child's hands and counted out loud to 10 while maintaining eye contact. For the next three trials, the experimenter hid two stickers, blindfolded

[2]We are grateful to James Cutting and to an anonymous reviewer for this suggestion.

TABLE 1

Children's Search Patterns in Experiment 4 (One Distinctive Red Cylinder and Two Identical Blue Boxes)

Order in which objects were searched	Number of trials
Cylinder–correct box	27
Cylinder–incorrect box–correct box	18
Correct box–cylinder	8
Correct box–incorrect box–cylinder	1
Incorrect box–cylinder–correct box	7
Incorrect box–correct box–cylinder	11
Total	72 trials (6 per subject)

the child, and counted to 10. For all trials, the child was asked to point to the door and then to find the stickers. Counting to 10 ensured that the delay between hiding and search was as long as in the previous experiments. Participants were 6 boys and 6 girls, 45 to 53 months old.

The children found both objects without error both on the open-eyes trials (80.6%) and on the closed-eyes trials (77.8%), a success rate significantly above the chance level of 33.3% (both ts > 5, ps $< .001$). Because performance on the two types of trials did not differ ($t < 1$), we collapsed across all trials in the following analyses. The children successfully located both the sticker hidden in the distinctive cylinder (88.9% vs. 66.7% chance), $t(11) = 4.30, p = .001$, and the sticker hidden in one of the two boxes (90.3% vs. 66.7% chance), $t(11) = 7.34, p < .001$ (Fig. 3). Accuracy at searching the cylinder and the boxes did not differ ($t < 1$). The first blue box searched was the correct one on 80.6% of the trials (vs. 50% chance), $t(11) = 5.70, p < .001$.

A further analysis compared children's search in Experiments 5 and 4. An analysis of variance with container as the within-subjects measure and sex and orientation (oriented vs. disoriented) as the between-subjects factors revealed a main effect of container, $F(2, 40) = 33.18, p < .001$ ($\eta_p^2 = .624, p_{\text{rep}} = .99$), and a significant interaction between container and orientation, $F(2, 40) = 9.48, p < .001$ ($\eta_p^2 = .32, p_{\text{rep}} = .99$). Children searched correctly at all the containers when oriented, but only at the distinctive container when disoriented.

Therefore, children are able to remember the locations of two objects hidden in an array with two identical containers, provided that the children are oriented. Together, Experiments 3 through 5 provide evidence that although children remember the locations of objects and use landmarks as direct cues to location, they fail to use those landmarks as cues to reorientation.

GENERAL DISCUSSION

Preschool children, like other animals, can use landmarks as direct cues to the positions of hidden objects, but they fail to reorient by this information, even as they adeptly use it as a direct guide to their search. These findings suggest that search behavior following disorientation depends on two distinct processes: a modular reorientation process that is sensitive only to the geometry of the surrounding surface layout and an associative process that directly links landmarks to locations.

The present findings may help bring order to the large and complex literature on landmark use in reorientation, accounting for the three conditions under which disoriented children and animals have been found to use landmarks. They suggest that landmarks serve as associative cues for disoriented children and animals, who use those cues even as they remain disoriented. Disoriented rats may use landmarks in tasks that elicit high motivation because such tasks lead them to encode goal locations in multiple ways. Trained rats and fish may find food in relation to a colored wall by selectively using the room's shape to reorient and then, in a separate step, using associated features to identify the correct location. Finally, disoriented children may use landmarks in large rooms because a landmark that is particularly large or distant may be more salient and easier to associate with a hidden object's location than a small, unstable, and nearby landmark. The interplay of modular and associative systems may help to explain both the reliability and the flexibility of human and animal navigation.

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