Penetrating the Geometric Module: Catalyzing Children's Use of Landmarks

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Abstract

We examined whether 4-5 year old children could be trained to use landmark features to relocate goals after disorientation. In Experiment 1, half of the children were pretrained in a small equilateral triangle shaped room with different colored walls. These children and a control group were tested in a small rectangular room with a feature wall. Children with pretraining responded more frequently to the correct corner than to the diagonally congruent corner on their first set of four trials in the rectangular room whereas the children in the control group used geometric cues exclusively. Three additional groups of children (Experiment 2) showed that the use of landmark features – both salient and subtle – can be learned in as few as four practice trials in a small rectangular room. The data support the view that both geometry and landmark features are combined in the same representation.

Key Words: children; feature; learning; single representation

Introduction

The ability to orient oneself in space is a fundamental skill that has evolutionary and ecological significance for all mobile organisms. Virtually all species tested encode geometric properties of the environment (see Cheng & Newcombe, 2005, for review). While children under 6 years of age (Hermer-Vasquez, Moffet, & Munkholm, 2001; Hermer & Spelke, 1996) appear to use geometric cues exclusively, many species are able to conjoin geometric and feature cues, including pigeons, (Kelly, Spetch, & Heth, 1998) rhesus monkeys (Gouteux, Thinus-Blanc, & Vauclair, 2001) chicks, (Vallortigara, Zanforlin, & Pasti, 1990) and fish (Sovrano, Bisazza, & Vallortigara, 2002).

Cheng (1986) first proposed the existence of an encapsulated geometric module devoted to the task of orienting (and reorienting) in space. In a working memory task, rats used geometric information exclusively even when the corners of the space were completely disambiguated by various non-geometric landmarks. In a reference memory task, the rats learned to use featural information to locate the target within 30 trials. However, when the featural information was removed from the target corner, the rats were unable to use the remaining cues and reverted to using geometric cues exclusively. Cheng hypothesized that rats reoriented by using representations encoded in a geometric module, which essentially records metric information about the shape of the environment. Information about landmarks near the target was hypothesized to be "glued" onto the metric frame provided by the geometric module. Subsequent researchers have assumed that such nongeometric features are encoded and represented in separate modules (see Cheng & Newcombe, 2005, for review).

Hermer and Spelke (1994, 1996) extended Cheng's (1986) work to human children and found that younger children (between 2 and 4 years of age) behaved identically to the rats. Choices were divided evenly between the rotationally equivalent corners of a small rectangular room, even though a blue wall – a landmark – could have been used to improve accuracy. Hermer-Vasquez, Moffet, and Munkholm (2001) demonstrated that children are able to integrate landmark information with geometric information at about the same age as they are mastering spatial language, particularly "left" and "right".

However, Learmonth, Nadel, and Newcombe (2002) challenged the modular view by contrasting performance of 5-year-old children in small (4 x 6ft.) and large (8 x 12ft.) rooms. The children in the small room replicated Hermer and Spelke's (1996) findings: they failed to use the blue feature wall. In contrast, children were able to integrate both feature and landmark information successfully in the large room. Thus, children are able to use feature information before the mastery of spatial language in some cases. By age 6, children were able to succeed regardless of room size. Learmounth et al. (2002) proposed three explanations for why room size would matter. First, younger children may fail to generalize what they know about navigation in large spaces to the small experimental space. With more experience, older children may learn that color can be a useful cue regardless of the size of the search space. Second, the task demands of the two spaces may have been different. The last, and related, possibility is that the blue wall was used as a heading cue in the large room, but may not have been perceived as a useful heading cue in the small room. The fragility and variability of landmark use with room size argues against an encapsulated representation of geometric information. It is difficult to understand how such a module could be active under one circumstance but not another.

The main goal of the present study was to challenge the modularity hypothesis further by examining whether 4- and 5-year-olds can learn to use landmark features in a small space. If children can generalize navigational skills to the experimental space after a relatively small amount of training, it would argue against the existence of an encapsulated geometric module. The influence of such a module should not be rapidly overshadowed. In addition, if 4-year-olds can learn to use landmark features in a reorientation task, spatial language should not be necessary for a flexible integration of geometric and non-geometric cues (Hermer-Vasquez, Moffet, & Munkholm, 2001; Hermer-Vasquez, Spelke, & Katsnelson, 1999). If the task is fundamentally different in the two room sizes, then training should not alter the use of landmark features.

Experiment 1

To examine the malleability of children's search choices, half of the children practiced the task in a room shaped like an equilateral triangle. This shape prevents geometric cues from being used to solve the relocation task. However each wall of the triangular room was a different color to provide unique landmarks and the target is presented in the center of one wall. If the children trained in the triangular room learn to use the yellow wall to solve the task, they should choose the correct corner more often than the geometrically congruent corner when transferred to the rectangular room with the yellow wall, and more often than the group who was not trained.

If children can learn to attend to and encode landmark features, then the training should help in two ways. The importance of color is emphasized, both in general and to the particular reinforced color (yellow). As the target is in the middle of the wall, left-right sense relations are irrelevant. This ensures that training does not merely teach children the correct answer (i.e., left of the yellow wall). If children are learning only the correct color, they should respond equally often to both yellow corners in the rectangular room. Alternatively, if geometry is compulsory, then children should revert to geometry when they are transferred to the rectangular layout. But if the training merely "reminds" children that color can be used as a heading cue or as a means of reorienting, then this should transfer to the rectangular room instantly. When children in the training group are tested in the absence of features, they should revert to responding on the basis of geometry.

Method

Participants. Twenty-nine children were recruited from daycare centers and YMCA facilities. Parents were given an honorarium. Equal numbers of 4- and 5-year old girls and boys were randomly assigned to either the control group or to the triangle pretraining condition. The data from 5 were discarded because they either did not spin, count out loud, keep their eyes closed, or want to continue playing. The remaining 24 participants had an average age of 58 months. There were twelve 4-year-olds (average = 52 months; range = 49 -59 months) and twelve 5-year-olds (average = 65 months; range = 61 - 71 months).

Apparatus and materials. The triangular and rectangular rooms were located in adjacent rooms. Both rooms were constructed out of 180 cm tall office dividers stabilized with a wooden frame and exterior brackets. Vapor barrier sheets provided a ceiling that allows light in without external cues. The interior of the dividers were covered with cotton fabric. The equilateral triangle walls were 224 cm in length, creating a 2.17 m^2 search space. Each wall was completely covered with red, yellow, or blue fabric. The entrance between the blue and yellow wall was a flap of fabric 120 cm high that could be secured with Velcro.

The rectangular room was 180 cm long and 122 cm wide, creating a search space of 2.20m^2. Three of the walls (two long and one short) were covered with off-white fabric. The remaining short wall was covered with either off-white or yellow fabric hung from a rectangular plank. The door was again a fabric flap located between two white walls and could also be fastened with Velcro. The search stimuli were 21.5 cm white squares of laminated paper placed on the floor in both rooms. All of the squares looked identical from the back. The front of one card had a picture of one the characters from the movie Madagascar (DreamWorks Animation LLC, 2005), including a hippopotamus, a lion, a zebra, a penguin, and a giraffe.

Design and Procedures. Children were tested with a reference memory paradigm. All children received eight trials in the rectangular room. The first four trials were with a yellow wall where the correct corner was one of the two adjacent to the feature. The second four trials were tested with all white walls. The correct corner was the same for each child, and counterbalanced across children within groups. Half the children received pretraining in the equilateral triangle room with an area approximately equal to that of the rectangular room. The correct choice was in the centre of the yellow wall. The criterion for mastering the triangular room was three correct choices in a row. All children reached the criterion (mean = 6.2 trials; range = 3 – 12 trials). The cards were placed in the middle of the walls of the triangular room and in the corners of the rectangular room. After obtaining consent, children were familiarized to the surroundings and the experimenter. It was emphasized at the start and after the first trial that the child could stop participating at any time. Once in the room, children were shown the cards on the floor and were told that one was hiding an animal. The cover story was based on the movie Madagascar. In essence, the children were told that one of the animals had escaped from the zoo and they could try to find the animal with the help of a special fort.

For each trial, the experimenter turned over the card with the character and the children were asked to remember where the character was hiding. Then they were asked to close their eyes, spin in a circle, and count their footsteps audibly. While the child was rotating, the experimenter circled in the opposite direction. After rotating at least four times, the child was asked to stop, facing the middle of a different wall for each trial. The child was then allowed one choice to find the character. If incorrect, the experimenter flipped over the correct card.

When the children in the pretraining group had reached the criterion of three correct in a row, they were told that they were "getting so good at finding the animals that we are going to go to a new fort." Then they were taken to the rectangular room. After the first four trials, the child was led out of the room and the yellow wall was changed to a white wall. The target corner remained in the same location for all eight trials in the rectangular shaped room.

Results

Figures 1 and 2 show the proportion of responses made at each corner for the pretraining group and the control group. The participants trained in the triangular room successfully used the yellow wall as a landmark feature from the beginning of their transfer trials, whereas the untrained group used geometric cues exclusively during the initial four trials. Planned comparisons showed that for the first set of four trials the pretrained group went to the correct corner 71% of the time and to the diagonally opposite corner 16% of the time; $F(1, 11) = 10.75$, $p < 0.01$. In contrast, during the second four trials, which had all white walls, they went to these corners 38% and 35% of the time, respectively, $F(1, 11) < 1.00$. The group that received no pretraining went to the correct corner 44% of the time and to the diagonally opposite corner 33% of the time, $F(1, 11) < 1.00$ during their first four trials with the yellow wall. Curiously, during the second set of trials with all white walls, this group went to the correct corner 56% of the time and to the congruent corner 15% of the time, $F(1, 11) = 10.58$, $p < 0.01$.

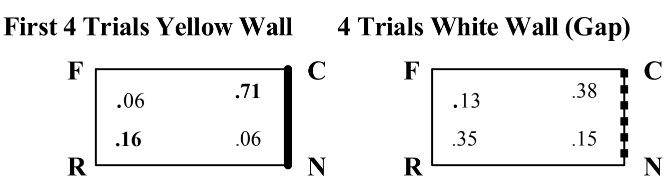

Figure 1: Mean number of searches at each corner for the triangle pretraining group (C= correct corner, R= reversal corner, N= near error, F= far error). Bolded numbers indicate a significant difference between the correct and reversal corner, indicative of landmark use.

An analysis of variance (ANOVA) with group (training vs. no training) and age (4 and 5) as the between-subjects factors and corner (correct vs. diagonally opposite) and half (first vs. second four trials) as within-subject factors yielded the expected group by corner by half interaction, $F(1, 20) = 14.98$, $p < 0.01$, as well main effects of corner, $F(1, 20) = 12.64$, $p < 0.01$ and age, $F(1, 20) = 4.74$, $p = 0.04$. Across the control and pretraining groups the 4-year-olds showed a greater tendency than the 5-year-olds to choose the correct corner over the diagonally opposite corner during both the first and second set of four trials: For the 4-year-olds the difference between corners was 42% on the first set of trials and 29% on the second set, and for the 5-year-olds the differences were 23% and 15%, respectively. No effects interacted with age and no other effects were significant.

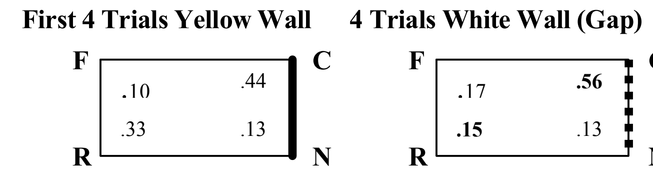

Figure 2: Mean number of searches at each corner for the control group. One of the white walls had a small (4 cm) gap between the carpet and the edge of the fabric.

Experiment 2

The first experiment provided evidence that a small amount of training in an enclosure lacking geometric cues facilitated the immediate use of features during a transfer test. But, there was one aspect of the procedure and one aspect of the data that warranted caution. From the procedural standpoint, the pretraining group received more trials overall than the control group (from as few as 3 to as many as 12 pretraining trials). Consequently, the fact that children in the control group did not use the yellow wall during their first four trials in the rectangular enclosure might reflect a general lack of practice rather than a lack of specific training with the feature wall. To examine the possibility that practice alone might facilitate the use of features to reorient, we tested a group of children in the rectangular room with the yellow wall present for all eight trials and analyzed the data separately for the first and second set of four trials. We will refer to this group as the "yellow-wall" group. From the results of Experiment 1, we anticipate that the data for the second set of four trials in the yellow-wall group should replicate the data from the first set of four trials for the group pretrained in the triangular room in Experiment 1. The second issue was raised by the data themselves. The children in the control group of Experiment 1 appeared to use some sort of feature during the second set of four trials when, ostensibly, there should have been none. Inspection of the rectangular room showed that the fabric on the removable white wall that replaced the removable yellow wall had a gap of approximately four cm between the bottom of the fabric and the floor, leaving visible the grey fabric on the room divider. It was possible that this was treated as a feature. If so, the children in the control group may have started to learn to use the yellow wall as a landmark feature by the end of the first four trials and then, when the yellow wall was switched to the white wall with the gap, they noticed and were able to use the gap. The triangle group, on the other hand, may have been overtrained with the yellow wall. This may have prevented them from immediately noticing the gap in the white wall on their second four trials in the rectangular room.

To test this idea, we ran two additional groups of children. For the "white-wall-gap" group we tested the children for eight trials in the original rectangular room with the white wall that contained the 4 cm gap between the fabric and the floor. If they were able to use this gap as a feature, then they should respond to the correct corner more frequently than to the geometrically congruent corner during the second set of four trials, and thus replicate the data for the second set of trials in the original control group (Figure 1b). For the "white-wall" group we constructed a new rectangular room that was identical in size to the original, except that all four white walls were covered with fabric that abutted the floor. Thus, there was no unique feature that could be used to respond and we expected that this group would use geometry exclusively during both the first and second set of four trials.

Method

Participants. For the yellow wall group, 7 girls and 6 boys participated. The data from one girl were discarded because she did not count aloud. The remaining 12 participants were eight 4-year-olds (average age = 54 months; range = 51-58 months) and four 5-year-olds (average age = 66 months, range = 61 - 70 months). There were 3 girls and 5 boys in the white-wall-gap group. The average age of the three 4-year-olds was 54 months (range = 50 - 59 months), and the average age of the five 5-year-olds was 64 months (range = 61 - 72 months). There were 4 girls and 4 boys in the white-wall group. The average age of the three 4-year-olds was 52 months (range = 49 – 54 months), and the average age of the five 5-year-olds was 66 months (range = 61-70 months).

Apparatus and materials. The apparatus for the yellow-wall group and the gap group was the same as Experiment 1. The apparatus for the new white-wall group was identical in size to the original rectangular room.

Design and procedures. The procedure for all participants was identical to the control condition of the first experiment. This included a 3 min break between the trials 4 and 5.

Results

Figure 3 confirms that participants learned to attend to a feature during the first four trials in the yellow-wall and white-wall-gap groups but not in the white-wall group. Planned contrasts showed that for the yellow-wall group, there was no difference in proportion of responses to the correct or diagonally opposite corner on the first set of four trials (50% vs. 40%, respectively, $F(1, 11) < 1.00$), but there was a large effect of corner during the second set of four trials (73% vs. 20%, respectively, $F(1, 11) = 12.21$, $p < 0.01$). In fact, the data for the second set of four trials in the yellow wall room were nearly identical to the data for the first set of trials in that room for children in the pretraining group of Experiment 1.

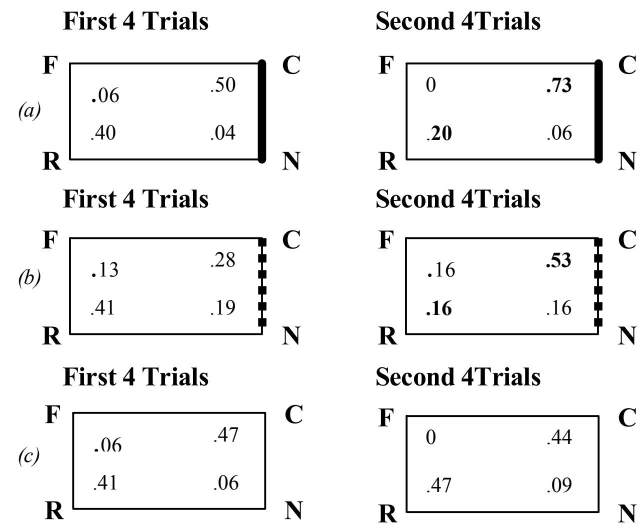

Figure 3: Mean number of searches in the small space for the (a) yellow wall group, (b) white wall gap group and (c) white room group. Numbers in bold indicate a significant difference between the correct and reversal corner.

An ANOVA with age as the between subjects factor and corner and half as the within subjects factors showed no main effect or interactions with age, but the expected half by corner interaction approached significance, $F(1, 10) = 4.14$, $p = 0.07$. Similar to the results for the yellow-wall group, for the white-wall–gap group, there was no difference in proportion of responses to the correct or diagonally opposite corner on the first set of four trials (28% vs 41%, respectively, $F(1, 7) = 1.17$, $p = .32$), but there was a difference on the second set of trials (53% vs. 16%, respectively, $F(1, 7) = 9.00$, $p < 0.02$). The data on the second set of trials for this group nicely replicated the data for the second set of trials for the control group of Experiment 1 (Figure 1b), as predicted. The ANOVA with age as a factor yielded only the expected half by corner interaction, $F(1, 6) = 8.95$, $p < 0.02$. In contrast to the data for the children in the yellow wall and white wall-gap groups, the children in the white wall group responded solely on the basis of geometry for both the first and second set of trials, $F(1, 7) < 1.00$ in both cases.

Discussion

Remarkably, four out of five groups of young children rapidly learned to use landmarks to relocate a hidden object in a small room. One group was trained to find the object in the middle of a yellow wall of a small room shaped like an equilateral triangle and then transferred this strategy to a small rectangular room in which the landmark was still a yellow wall, but the object was in a corner. The remaining three groups received no specific training outside of the environment they were to perform in, yet each was able to use landmark information – either the yellow wall *or a even a 4 cm gap*– to respond correctly after only four practice trials.

The sole group that did not use landmark cues was the group that had none to use.

In some ways, the most interesting data are from the original control group. The children in this group received four trials in the small rectangular room with a yellow wall as a landmark and then four trials in the same room with a white wall that, inadvertently, had a gap between the bottom of the fabric and the floor. Eight of the 12 children responded more frequently to the correct corner than to the diagonally opposite corner during the second set of four trials. Thus, not only were these children able to use landmarks after four practice trials, they generalized what they had learned during the first four trials to a completely new type of landmark cue which, arguably, was a much more subtle one. The similarity between the data from the second set of four trials in the original control group and the second set of four trials in the new gap group is striking: 7 of the 8 children in the gap group responded more frequently to the correct corner than to the congruent corner during the second set of trials.

Equally striking is the similarity between the data from the group who received pretraining in the triangular room and the group who started out in the rectangular room immediately and had 8 trials with the yellow wall present. The data for the first four trials of the pretrained group are nearly identical to the data for the second four trials of the "untrained" control: Nine of the 12 children in the pretraining group and 8 of the 12 children in the yellow-wall control group responded significantly more to the correct corner (86.1% and 87.5%, respectively) than to the geometrically opposite corner (3.1% vs. 6.3%, respectively). For children trained in the triangular room this performance implies that they not only learned that color was important, but were able to make immediate use of sense (left-right) information to find the correct corner when they were transferred to the rectangular room. Notably, these children could not have been using the yellow wall merely as a beacon. For the children who started out in the rectangular room, it took a mere four trials for them to achieve this level of performance. Further, all of the children were young enough to preclude spatial terms of "left" and "right" to have played a major role in their success.

Given how readily the original control group and the gap group learned to use the gap as a landmark, it may appear odd that the group trained in the triangular room, who so successfully and immediately transferred to using the yellow wall as a landmark in the rectangular room reverted to geometry when the yellow wall was changed to the white wall with the gap. However, the group trained in the triangular room had an average of 6 training trials (range = 3 to 12) in which the yellow wall cued the correct response, and then four more trials in the rectangular room with the yellow wall. Assuming that color is a reasonably salient landmark, it may be that color overshadowed the more subtle gap cue after the yellow wall was removed. In addition, the children trained in the triangular room still had to learn to use sense cues when they were transferred to the rectangular room; perhaps separating these two aspects of landmark use (the "value" of the landmark itself and its relation to other features of the environment) during training actually worked against the children in the experimental group when they were transferred. Distinguishing between these theoretical possibilities – the role of overshadowing, the relative salience of landmarks, and the functional traits for a landmark – is an area for future research.

Learmonth et al.'s (2002) participants successfully used a colored wall as a landmark in a large room but did not transfer this behavior to a small room with the same landmark. One important difference between their study and ours is that the participants in our study who successfully switched from one kind of situation or landmark to another (the triangle training group, the original control group, the yellow-wall group, and the white-wall-gap group) were all either trained or practiced in small rooms that were almost identical in *area* to begin with. We have already hypothesized that training in the triangular room emphasized the importance of color which was then easy to transfer to the rectangular room (and difficult to "unbind" when the yellow wall disappeared). The other three groups began in a small rectangular room; effectively, we gave them four practice trials in this room and then four additional test trials. As hypothesized by Learmonth et al., (2002), it may be that there is something about a small room that is at least initially unique. For example, Newcombe (2005) recently hypothesized that it may be difficult to engage spatial orientation mechanisms when motion is limited; also, landmarks are more likely to be used when they are far from an observer. Nevertheless, as children in our study rapidly became accustomed to the small space; we presume that had Learmonth et al. (2002) continued testing their children in the small space they would have found similar results.

In a recent review of the spatial orientation literature, Cheng and Newcombe (2005) noted that (a) all vertebrate species tested thus far used geometry to respond when continuous surfaces form the geometric properties, (b) all species tested used feature information under some circumstances, and (c) all mammals made systematic rotational (geometric) errors under some circumstances, so all mammals occasionally fail to use feature information. They proposed three possible process models to account for the way in which geometric and featural information are used to orient, and to reorient, in any environment. In two of these models geometric information is presumed to be represented modularly (Fodor, 1983); in the third both types of information are combined in the same representation.

Our data support the third type of model. This model assumes that there is no reason to believe that geometric information is encapsulated; rather, there is much support for the idea that geometric and landmark information are combined (and bound to) the same representation of space. Indeed, once processed at input, this model assumes that geometric and featural information are always put together in the same representation. The representation can be used for spatial orientation and reorientation, and in principle, for other tasks as well. Newcombe (2005) and Newcombe and Ratliff (2006) have called this type of process "adaptive combination" (see also Newcombe & Huttenlocher, 2006), and our data support the idea that many types of information are combined into a single representation. In real-world navigation, all kinds of information are used to orient and to reorient if needed, including geometry, landmarks, proximal and distal cues, and so on. Although these different types of information might have different developmental trajectories, from a functional standpoint it makes sense that they should bind to the same representation. A child's learning history would naturally affect the weighting given to different sorts of information; indeed from an adaptive combination viewpoint it is natural to suppose that experience will influence the weightings in some sort of integrative process.

Because the children in the present study learned to combine geometric and landmark cues in only four trials, it seems likely that their abilities to attend, encode, remember, and successfully use landmark features are not being learned "from scratch." Similarly, because Cheng's (1986) rats learned to use landmark features in a reference memory task in 30 trials, they, too, were unlikely to have been learning the constellation of cognitive functions underlying this behavior from scratch. Rather, the ability to use landmarks and combine them with geometric cues must be extant in the organism(s), needing only a little practice to become functional. It would benefit the organism to have as many representations of a food location as possible to augment the chances of finding the location at a future date. That this is so should not be surprising; from an ecological standpoint, the type of landmarks that are functional for navigation or used to signal a food supply would rarely change locations with respect to the geometry of the environment.

Our results add to evidence suggesting that children as young as four years are fully capable of combining featural and geometric information. They do so even in a small room, within a few trials. Nevertheless, our results are also consistent with the notion that for young children, the use of features is not as automatic as, the use of geometry. Using geometry to reorient appears to occur instantly whereas use of features needs to be catalyzed by experience.

Acknowledgments

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