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PAPER

Why size counts: children's spatial reorientation in large and small enclosures

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Abstract

When mobile organisms are spatially disoriented, for instance by rapid repetitive movement, they must re-establish orientation. Past research has shown that the geometry of enclosing spaces is consistently used for reorientation by a wide variety of species, but that non-geometric features are not always used. Based on these findings, some investigators have postulated a species-universal 'geometric module' that is transcended by the acquisition of spatial language at 6 years. This conclusion has been challenged, however, by findings that children as young as 18 months actually do use features to reorient in larger enclosures than those used in the original experiments. The reason for the room size effect is explored here in five experiments. Collectively, the data on age at which features are first used point to the importance of both restriction of movement in the small space and the fact that features are closer in the small space. In addition, success is seen at younger ages when the target object is adjacent to the feature. These results favor an adaptive combination model of spatial reorientation over a 'module-plus-language' view.

Introduction

The importance of the ability to reorient in an unfamiliar place is familiar to anyone who has emerged from the subway in an unfamiliar city to wonder which direction is uptown. Recently, the ability of young children and non-human animals to reorient has been the subject of a great deal of attention from researchers, with debate centering on cognitive modularity and the role of language in cognitive development. In studies of reorientation, experimenters typically hide a desirable object in one corner of a regular enclosure, often a rectangular one, disorient the child or non-human animal, and then allow search for the target. Reorientation in these paradigms can be accomplished in two major ways. First, the geometric information in the environment (i.e. the relative length of the walls in a rectangular room) allows for focus on corners with particular shape characteristics (e.g. a long wall to the left of a short wall). All species tested have proved capable of using the geometric features of the environment to reorient (for review, see Cheng & Newcombe, 2005). Often, however, more than one location fits the same geometric description. For example, in a rectangle, pairs of diagonally opposite corners are congruent. When available, a second kind of information, often called non-geometric or featural information, can be used to disambiguate the geometrically congruent corners and find the target. For example, if one of the walls in a rectangular room is a distinctive color, the congruent corners are visually distinctive even though geometrically the same.

Initial research using this paradigm with rats had found an exclusive reliance on geometric information (Cheng, 1984), and this conclusion has been widely cited. Recent research, however, has found successful reorientation using a combination of geometric and non-geometric (or featural) information in a large number of non-human animal species ranging from chickens and fish to monkeys (e.g. Vallortigara, Zanforlin & Pasti, 1990; Sovrano, Bisazza & Vallortigara, 2002, 2003; Kelly, Spetch & Heth, 1998; Gouteux, Thenus-Blanc & Vauclair, 2001; for review, see Cheng & Newcombe, 2005).

Research with human children has yielded a mixed picture. Initial experiments found results that mirrored those obtained with rats (Hermer & Spelke, 1996). Children saw a toy hidden in a small (4′ × 6′) rectangular space, were disoriented and were then encouraged to search for the toy. Their searches were concentrated in the two corners that were geometrically appropriate, but with no preference for the correct corner even when

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distinctive featural information was available. Further research showed that use of features appeared between the ages of 5 and 6 years (Hermer-Vazquez, Moffet & Munkholm, 2001). Hermer-Vazquez *et al.* suggested that the language ability of the older children, specifically accurate use of the terms *right* and *left*, allows them to combine the geometric and featural information in ways unavailable to younger children. They bolstered this argument with a demonstration that a linguistic interference task eliminated the ability of adults to use features (Hermer-Vazquez, Spelke & Katsnelson, 1999).

Subsequent research has, however, called this view into question. Children as young as 18 months can sometimes use features to reorient (Learmonth, Newcombe & Huttenlocher, 2001). Learmonth *et al.* failed to replicate Hermer and Spelke's initial experiments. The 18- to 24-month-old children in the Learmonth *et al.* study used the landmark to guide their search and thus were successful in their search. The contrast between the Hermer-Spelke and Learmonth *et al.* results was subsequently shown to be due to the size of the enclosure (Learmonth, Nadel & Newcombe, 2002). The space used by Hermer and Spelke was only 4 by 6 feet, whereas Learmonth *et al.* used a similarly proportioned space four times as large (8 by 12 feet). Although both of these spaces are quite small, larger spaces are clearly closer to ecological validity, and an $8' \times 12'$ space is large enough to be reasonably considered a room. In the smaller space the children did not use the featural information, while in the larger space those same children used the featural information. Second, the idea that language is crucial to developmental change has several flaws. The hypothesis cannot explain why children as young as 18 months can combine the two sources of information when the space is larger. Additionally, recent research shows that spatial as well as linguistic interference tasks disrupt the ability of adults to use features, showing that language is not the exclusive means of combining information useful for reorientation (Ratliff & Newcombe, 2008). In addition, Ratliff and Newcombe found that interference effects are obtained only in incidental learning conditions, showing that people can utilize both geometric and featural information for reorientation in cases where they know ahead of time that reorientation will be required.

An alternative explanation of the development of reorientation ability is an adaptive combination view, in which geometric and non-geometric information are weighted differently in different situations, depending on factors such as cue salience, encoding certainty, and cue validity (Newcombe & Huttenlocher, 2006; Newcombe & Ratliff, 2007). An adaptive combination view suggests the possibility that geometric and featural information are utilized in varying degrees at varying points in development. The weighting of each element reflects the certainty and variance with which the two kinds of information are encoded, along with their salience and perceived usefulness. One reason for the predominance of geometry in reorientation studies may be the fact that a fully enclosed room formed by uninterrupted walls unambiguously defines a geometric shape. When shape is suggested in a more ambiguous fashion by separated points, leading to uncertainty, geometry is used with more difficulty in a mapping task and success in using it is only observed at older ages (Vasilyeva & Bowers, 2006).

A challenge for any approach to spatial reorientation, including the adaptive combination framework, is to provide an answer to the question of why the size of the enclosure makes such a large difference to the age at which children are able to use features as well as geometry successfully. There are several possible explanations for the room size effect. First, it is possible that younger children do not combine the two sources of information in a small space because the small space restricts their movement, interfering with their normal navigation ability. Restrained rats do not seem to learn the same information about a maze that rats allowed to actually move around the maze do (Foster, Castro & McNaughton, 1989). Several studies indicate that children perform more accurately when they are actively moving, rather than passively moved (Acredolo, 1978; Acredolo & Evans, 1980). For example, children who move actively to find puzzle pieces are more likely to find them than children pushed in a wheelchair while searching (McComas & Dulberg, 1997). Second, the location of the wall itself, and its distance from the child, could be important. Most animals rely more heavily on distal rather than proximal location cues when they navigate a space, perhaps because such cues provide more precise information about location as movement occurs (Gallistel, 1990; Nadel & Hupbach, 2006; Vlasak, 2006). In the large room, the walls are more distant from one another and thus the blue wall is (often) farther away and could be a sufficiently distal cue to be weighted more heavily by the reorientation system.

The adaptive combination model predicts that the use of different available cues will depend on the weighting of those cues in the situation. Therefore it predicts that there are a number of different featural and configurational factors that could be important to the ability of the children to reorient. Simply, the developmental pattern seen in the small and large spaces could depend on the demands of the task. There are several factors that could be important to the young children's failure to use the landmark in the small space, and it is possible that each of these factors has a different developmental trajectory. Three factors that could be important are restriction of movement, the distal or proximal location of the landmark and the relationship between the target and the feature.

The current set of experiments was designed to evaluate the role of restricted movement and landmark distance as well as the relationship between the goal and the landmark in whether young children between the ages of 3 and 6 years use features to reorient. The basic principle of these experiments was to restrict children's activity to an area the size of the smaller space used in the

Hermer-Spelke experiments, within an area the size of the larger space used in the experiments by Learmonth *et al.* Although the children's motion was restricted to the smaller space, they had visual access to a larger space, containing a distal feature. Thus, if activity is important, children might perform poorly in this situation until 6 years, whereas if access to a distal feature is important, children might successfully use the feature quite early. The room within a room design of this study allowed us to put the goal box in the smaller internal space, away from the distal landmark, or in the outer room proximal to the landmark but away from the children. This allows us to look at the relationship of the target to the landmark and the subject. We continued to use the same room sizes as used in previous work, in order to explore the room size effect as it exists in the current literature, despite the fact that such an approach is inherently conservative. Given our analysis, features are ever more likely to be used as size increases, thus allowing for more movement and/or increasingly distal landmarks.

Experiment 1

This experiment was designed to determine at what age children might use features as well as geometry to reorient in a situation in which they could only move within a portion of the space that was the same extent as it had been in the small room used by Hermer and Spelke (1996) but in which the feature was the larger and more distal one available in the Learmonth *et al.* (2001, 2002) experiments. If restriction of action is important, young children should fail to use the feature, but if distal features are more relevant, they should succeed. Because both factors might be important, another possible outcome is that success in using features as well as geometry will first be observed at an age later than the 18 months at which children succeeded in the Learmonth *et al.* (2001) experiments, but prior to the 6 years at which children first succeeded in the Hermer and Spelke (1996) experiments.

Method

Participants

There were 20 3-year-old children, 20 5-year-old children and 16 6-year-old children participating in this experiment. Two additional 3-year-old subjects refused to complete the task, and data from two more 3-year-old subjects were discarded due to experimenter error. The average age of the 20 remaining 3-year-old participants was 39.68 months (range 36.13–46.89 months). The average age of the 20 5-year-old participants was 65.31 months (range 60.36–71.23 months). The average age of the 16 6-year-old participants was 78.04 months (range 72.50–83.56 months). Participants were obtained from a commercially available list.

Apparatus

The experiment was conducted in an 8′ by 11′ space[1] defined by sheets suspended from the ceiling, creating a uniform look on all sides. Three walls were white, and one of the short walls was red. The ceiling was covered with navy fabric. Identical floor lamps were positioned in each of the corners and radios tuned to the same station and set to the same volume were placed behind the curtain in each corner. The floor was covered with industrial carpet without any distinctive markings. A 4′ by 6′ inner enclosure, the size of Hermer and Spelke's (1996) room, was placed in the center of the room. The walls of the enclosure were all covered with white sheets. The height of the enclosure was 18 inches. Four opaque, yellow plastic boxes were placed in the four corners of the inner enclosure. The boxes were positioned at a 45° angle from the wall such that the front of each box faced the center of the room. A small toy duck was used as the search object. The lamps and the goal boxes were the same in each corner, therefore not providing any information that might differentiate the corners.

Procedure

The children came into the playroom waiting area and played with toys provided while the parent signed the consent forms and the experimenter explained the experimental procedure. Participants were randomly assigned to an experimental order. When the child was comfortable, the experimenter led the child into the experimental space, which was located in a separate room. If a child was apprehensive, the parent was asked to come with the child into the experimental room. If the child was comfortable after the parent had approved of the room, the parent returned to the waiting area. The experimenter explained to the child that the toy duck would be hidden in only one box and that all other boxes were empty and then asked the child to hide the toy in the predetermined box and shut the lid. The experimenter then explained that the child would close his or her eyes while she turned him or her in a circle, and then the child would be required to indicate which box contained the duck. Once the experimenter received oral consent from the child, she began the disorientation procedure. The experimenter ensured the child's eyes were closed and turned him or her by the shoulders until the child had made a minimum of four full rotations. The experimenter stood behind the child at the end of the disorientation procedure and stopped the child's rotation such that the child faced a different wall on each of the four trials. The child

[1] We did not have access to a room large enough to allow use of an 8 by 12 foot space, as used in previous studies. However, this difference seems unimportant. The reduction in the ratio of long to short walls, if it has any effect at all, would be expected to reduce the power of geometric information, and yet the data indicate that geometric information still exerted a powerful influence on children's performance.

was then immediately encouraged to search for the toy duck. The child was either congratulated if he/she succeeded or immediately shown which box was correct if he/she did not succeed on the first attempt. The process was then repeated three more times with the child ending the disorientation procedure facing a different wall on each trial.

Results

In this experiment as well as in the subsequent ones, the analysis used the number of correct choices, reversal errors, far errors, and near errors for each trial (there were four trials so the possible range was 0 to 4 for any of the available response categories with the total for each child of four responses across all categories). We began in each case by analyzing for gender differences or interactions, age differences within the age groups (using a median split) or interactions, and trial effects or interactions. No such effects were ever observed. We then proceeded to examine key contrasts using one-tailed *t*-tests, as there were directional expectations for the results. (However, the results are not materially altered by the use of two-tailed tests.) Figure 1 shows the data for Experiment 1 expressed as percentages.

The 3-year-olds in this experiment went to the correct corner or the opposite (rotationally equivalent) corner the majority of the time, 39% and 36%, respectively. The 5-year-olds were similarly unsuccessful at using features in this task, choosing the correct and rotationally equivalent corners 50% and 40% of the time, respectively. By contrast, 6-year-olds were successful at using features in this task, choosing the correct corner in 74% of trials. They selected the rotationally equivalent corner 14% of the time, and the near and far corners each 6% of the time.

A 3 (age) × 2 (correct or reverse) ANOVA was conducted to examine the relationship between the likelihood of making a correct or reversed choice and age. There was a significant age by correct or reverse interaction ($p < .01$). In addition there was a main effect of age ($p < .05$), and a main effect for reverse or correct response ($p < .01$). Post-hoc tests using Fishers LSD revealed that responding to the correct corner was not different from responding to the reverse corner in the 3-year-olds ($p = .8$) or the 5-year-olds ($p = .34$); however, the 6-year-olds responding to the correct corner was significantly different from their responding to the reverse corner ($p < .01$). Responding to the correct corner was significantly different between the 5- and 3-year-olds ($p < .05$) and both groups and the 6-year-olds (all *p*-values < .01). Responding to the reverse corner was not different for the 3- and 5-year-olds ($p = .41$), but both groups were different from the 6-year-olds (all *p*-values < .01).

Even the 3-year-olds made relatively few responses to the corners that were not geometrically correct, and the difference between the geometrically correct corners and the geometrically incorrect corners was reliable, $t(19) = 4.45$, $p < .01$. The geometric error was significantly more frequent than the near error, $t(19) = 2.76$, $p < .01$, or

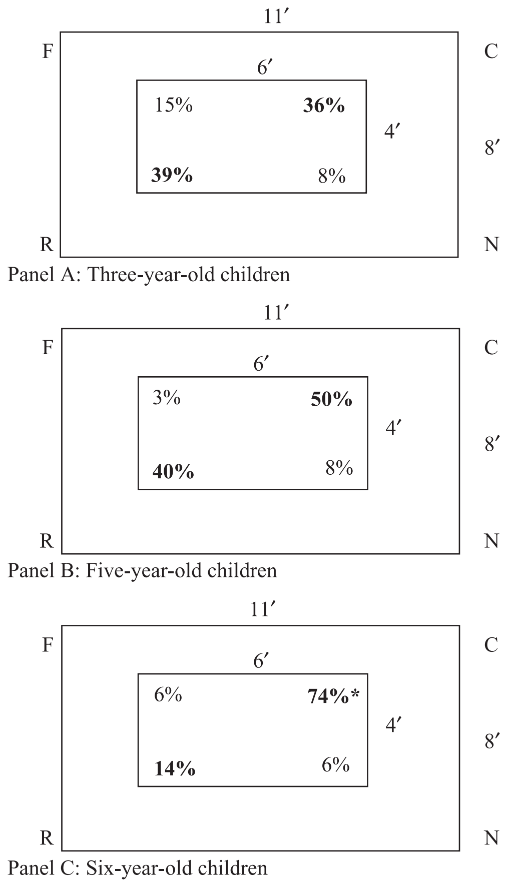

Figure 1 *Percentage of responses to each corner rotated such that correct corner is the same for all subjects. The correct corner is labeled C, the opposite (geometrically appropriate rotational equivalent) corner is labeled R, the corner on the other side of the short wall from the correct corner (the incorrect corner nearest the correct corner) is labeled N, and the incorrect corner on the other side of the long wall from the correct corner (the incorrect corner farther from the correct corner) is labeled F. Panel A shows 3-year-old responses, panel B shows 5-year-old responses and panel C shows 6-year-old responses. The asterisk indicates a significant difference in responding to the correct and rotationally equivalent corners.*

the far error, $t(19) = 2.48$, $p = .01$. The 5-year-olds also made relatively few responses to the corners that were geometrically irrelevant, and a geometrically correct box was reliably more likely to be chosen than a geometrically incorrect box, $t(19) = 10.51$, $p < .01$. There were again significant differences between the geometric error and the near corner error, $t(19) = 4.61$, $p < .01$, and the far corner error, $t(19) = 6.71$, $p < .01$. The 6-year-olds were also significantly more likely to choose a geometrically correct box over a geometrically incorrect box, $t(15) = 9.49$, $p < .01$.

Discussion

The 3- and 5-year-old children in this experiment went equally often to the correct corner and the congruent (rotationally equivalent) corner, indicating that they were unable to use the feature to determine which of the two corners contained the desired toy. (In fact, in many cases the conviction that the rotationally equivalent corner was correct on a given trial was so strong that children did not believe there was nothing in the box they had chosen until it was opened.) That is, in this experiment, as in previous research by Hermer and Spelke (1994, 1996), disoriented children were unable to distinguish between the correct corner and its rotational equivalent even at 5 years of age. The difference in responding to the correct corner between the 3- and 5-year-old children was likely a result of the 5-year-olds' better ability to concentrate their searches to the geometrically appropriate corners. The 6-year-old children were markedly more successful, finding the hidden toy on the majority of trials.

These data are similar to those obtained in previous research with a small room (Hermer & Spelke, 1994, 1996; Learmonth *et al*., 2002). This fact suggests the importance of movement restriction in limiting young children's ability to use features, and creating the late transition to successful use of features only at 6 years of age. But before endorsing this conclusion, we need to evaluate the role of a factor that has so far not received much attention. Because children were restricted to the central area of the larger room with a colored wall, with the toys hidden in unmarked corners of the small enclosure, the target toy in this situation was located at some distance from the feature that could disambiguate the perceptually identical corners in the small enclosure. No previous work has evaluated whether featural (or geometric) information can be used to orient with respect to locations removed from the features (or geometry). Such a situation seems to have the potential to cause difficulty. Note that the question is theoretically as well as methodologically interesting. If 'reorientation' does not extend to the entire spatial situation in which we find ourselves, it may not be very useful.

Experiment 2

Because Experiment 1 involved goal boxes that were adjacent to geometric information (the shape of the inner enclosure) but removed from the distal colored wall, so that featural information needed to be 'imported from afar', the purpose of Experiment 2 was to evaluate performance when this factor was removed from the task. Although there is no information available about reorientation under these conditions, there is a body of information from the animal conditioning literature that indicates a distance (spatial discontiguity) between the cue indicating that a response should be made and the location at which that response is to be made is important. Specifically, responding is better when the target is spatially contiguous with cue, or in this case landmark (Southerland & Mackintosh, 1971; Mackintosh, 1974). The target boxes were placed in the corners of the larger space instead of in the smaller enclosure, so the target boxes were proximal to the landmark as well as to the geometry, but outside of the space in which the children were allowed to move around. Thus, this task allows us a cleaner look at the effects of movement restriction when the landmark is larger and more distal than in the typical smaller room used in prior work.

Method

Participants

There were 20 3-year-old children, 20 5-year-old children and 21 6-year-old children in this experiment. Data from six additional 3-year-olds and one additional 6-year-old who refused to complete the task were discarded. Data from one additional 3-year-old were discarded because of maternal interference with the task. The average age of the 20 remaining 3-year-old participants was 39.68 months (range 36.23–46.82 months). The average age of the 20 5-year-old participants was 63.95 months (range 60.06–68.85 months). The average age of the 20 remaining 6-year-old participants was 77.77 months (range 72.06–84.46 months). Participants were obtained from a commercially available list.

Apparatus and procedure

The apparatus and procedure were the same as in Experiment 1, except that the boxes were placed in the outer corners of the larger (8′ × 11′) room, while the children stayed inside the (4′ × 6′) pen. The experimenter hid the toy duck in one of the boxes, and the children pointed to where they thought it was located.

Results

The 3-year-olds in this experiment went to the correct corner or the opposite (rotationally equivalent) corner the majority of the time, 34% and 38%, respectively. In Experiment 2, 5-year-olds were more successful than in Experiment 1, choosing the correct and rotationally equivalent corners 60% and 16% of the time, respectively. The 6-year-olds went to the correct corner the majority of the time, 73% of possible trials (see Figure 2).

A 3 (age) × 2 (correct or reverse) ANOVA was conducted to examine the relationship between the likelihood of making a correct or reversed choice and age. There was a significant age by correct or reverse interaction ($p < .01$). In addition there was a main effect of age ($p < .01$), and a main effect for reverse or correct response ($p < .01$). Post-hoc tests using Fishers LSD revealed that responding to the correct corner was not different from responding to the reverse corner in the 3-year-olds ($p = .71$); however, the 5-year-olds ($p < .01$), and 6-year-olds responding to the correct corner was significantly different from their responding to the

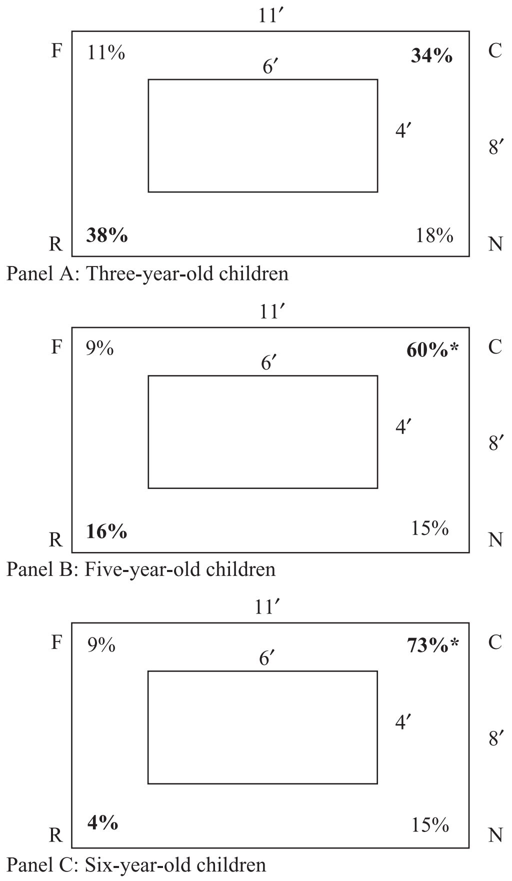

Figure 2 *Percentage of responses to each corner rotated such that correct corner is the same for all subjects. Panel A shows 3-year-old responses, panel B shows 5-year-old responses and panel C shows 6-year-old responses.*

reverse corner ($p < .01$). Responding to the correct corner was significantly different between the 5- and 3-year-olds ($p < .01$), and both groups and the 6-year-olds (all p-values < .05). Responding to the reverse corner was significantly different for the 3- and 5-year-olds ($p < .01$), but both groups were different from the 6-year-olds (all p-values < .05).

For the 3-year-olds the difference between the two geometrically correct and the two geometrically incorrect corners was reliable, $t(19) = 3.49$, $p < .01$. The geometric error was significantly more common than the near error, $t(19) = 2.22$, $p = .02$, or the far error, $t(19) = 3.12$, $p < .01$. In the 5-year-old group, the difference between the two geometrically correct and the two geometrically incorrect corners was also reliable, $t(19) = 5.29$, $p < .01$. There was no significant difference between the geometric error and the near corner error, $t(19) = .24$, $p = .41$, or the geometric error and the far corner error, $t(19) = 1.37$, $p = .09$. In the 6-year-olds, the difference between the two geometrically correct and the two geometrically incorrect corners was reliable, $t(19) = 4.27$, $p < .01$.

Discussion

In Experiment 2, the 3-year-old children still chose randomly between the correct and congruent corners, indicating they did not use the landmark for reorientation. However, with boxes adjacent to the featural as well as the geometric information, 5- as well as 6-year-old children did use the landmark and were successful in their attempts to find the target. The main contrast to Experiment 1 is the use of featural information by the 5-year-olds. This success at an earlier age indicates that adjacency of the target to the featural information influences use of the featural information. The continued difficulty of the task for 3-year-olds suggests the importance of restriction of movement.

Experiment 3

Experiment 3 addresses the question of whether the effect of the restriction of movement is dependent on the presence of a physical barrier. There is evidence that the presence of a physical barrier has an effect on the way children and adults categorize spaces (Newcombe & Liben, 1982; Nichols-Whitehead & Plumert, 2001). In Experiment 3 we restricted the movement of the children without the use of the physical barrier to see if the pattern of performance observed in Experiment 2 would replicate or change. Additionally, in Experiment 3, we did not examine the behavior of 6-year-olds because their performance in Experiment 2 was closely comparable to that of 5-year-olds. Instead, we chose to add a group of 4-year-olds in order to determine more exactly the age at transition to use of features in this situation.

Method

Participants

There were 20 3-year-old children, 20 4-year-old children and 20 5-year-old children in the experiment. Three additional 3-year-olds refused to complete the task. One additional 4-year-old child and two additional 5-year-olds refused to participate in the experiment. Data from one additional 5-year-old were discarded due to experimenter error. The average age of the 20 remaining 3-year-old participants was 41.27 months (range 36.33–47.66 months). The average age of the 20 remaining 4-year-old participants was 53.39 months (range 48.16–59.85 months). The average age of the 20 remaining 5-year-old participants was 65.53 months (range 60.0–71.56 months). Participants were obtained from a commercially available list.

Apparatus and procedure

The apparatus and procedure were the same as in Experiment 2, except that the wooden enclosure was replaced by an outline in masking tape on the floor of the room. The children were told that they must stay within the taped area. They were reminded of this rule repeatedly, and their data were not used if they moved outside the taped box more than twice. The experimenter hid the toy duck in one of the outer boxes, and the children pointed to where they thought it was located.

Results

The 3-year-olds in this experiment went to the correct corner or the opposite (rotationally equivalent) corner the majority of the time, 40% and 39%, respectively. By contrast, the 4-year-olds in this experiment were successful at using the feature. They went to the correct corner rather than the opposite (rotationally equivalent) corner the majority of the time, 63.8% and 15.0%, respectively. As in Experiment 2, the 5-year-olds were successful at using the feature, choosing the correct and rotationally equivalent corners 64% and 15% of the time, respectively (see Figure 3).

A 3 (age) × 2 (correct or reverse) ANOVA was conducted to examine the relationship between the likelihood of making a correct or reversed choice and age. There was a significant age by correct or reverse interaction, ($p < .01$). In addition there was a main effect of age, ($p < .01$), and a main effect for reverse or correct response ($p < .01$). Post-hoc tests using Fishers LSD revealed that responding to the correct corner was not different from responding to the reverse corner in the 3-year-olds ($p = .91$) but was significantly different for the 4-year-olds ($p < .01$), and the 5-year-olds ($p < .01$). Responding to the correct corner was significantly different between the 4- and 3-year-olds ($p < .05$) and the 3-year-olds and the 5-year-olds ($p < .01$), but not the 4- and 5-year-olds ($p = 1.0$). Responding to the reverse corner was significantly different for the 3- and 4-year-olds ($p < .01$), but not the 4- and 5-year-olds ($p = 1.0$).

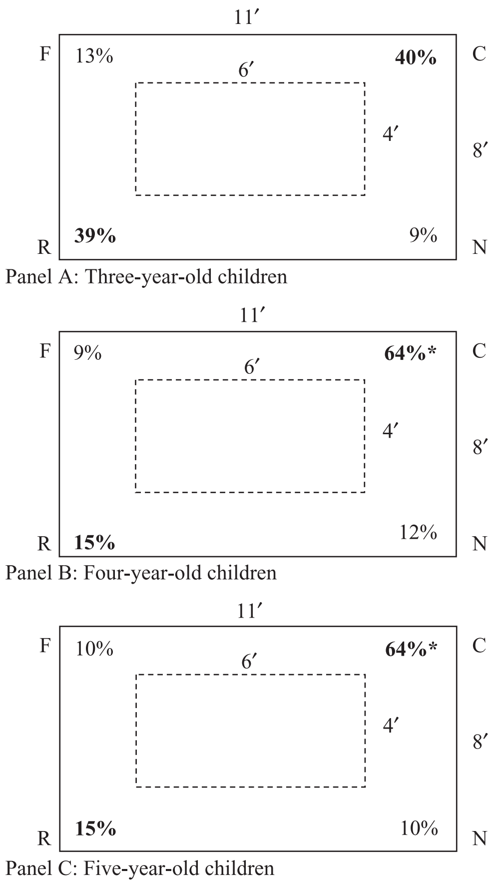

Figure 3 *Percentage of responses to each corner rotated such that correct corner is the same for all subjects. Panel A shows 3-year-old responses, panel B shows 4-year-old responses and panel C shows 5-year-old responses.*

In the 3-year-old group, the difference between the two geometrically correct and the two geometrically incorrect corners was significant, $t(19) = 05.21$, $p < .01$. The geometric error was significantly more common than the near error, $t(19) = 3.04$, $p < .01$, or the far error, $t(19) = 2.99$, $p < .01$. In the 4-year-olds, the difference between the two geometrically correct and the two geometrically incorrect corners was also reliable, $t(19) = 4.95$, $p < .01$. The geometric error was not significantly more common than the near error, $t(19) = 0.48$, $p = .34$, or the far error, $t(19) = 1.16$, $p = .13$. In the 5-year-olds, the difference between the two geometrically correct and the two geometrically incorrect corners was also significant, $t(19) = 5.62$, $p < .01$. There was no significant difference between the geometric error and the near corner, $t(19) = .94$, $p = .18$, or the geometric error and the far corner, $t(19) = 1.07$, $p = .20$.

Discussion

The results of Experiment 3 are very similar to those of Experiment 2. The 3-year-old children again failed to use features to reorient, and thus it appears that problems in using features by younger children are not due to the presence of the physical barrier itself, but rather to restriction of movement. The 5-year-old children again succeeded in using features. In addition, we saw that 4-year-olds were successful in using features, and in fact are indistinguishable from the 5-year-old children. This fact indicates a relatively sudden transition in use of features between the ages of 3 and 4 years. This abrupt transition is similar to the one seen between 5- and 6-year-olds in the 4 by 6 foot space (Hermer & Spelke, 1996; Learmonth *et al.*, 2002), although it occurs at an earlier age. Earlier age transitions in reorientation paradigms undermine the hypothesis that spatial language is vital to use of features, and this experiment is not the first to observe such earlier transitions. Hupbach and Nadel (2005) asked children to reorient within a rhombus, so that angular information instead of wall length provided the relevant geometric information. Successful reorientation using angular information was not seen until children were 4 years old, and the transition to using a landmark to concentrate searches to the correct corner also occurred between 3 and 4 years.

Experiment 4

The previous experiments indicate that restriction of movement is important to the inability of 3-year-old children to use the landmark to reorient in small spaces. We wondered whether prior physical activity in a space with a landmark would be sufficient to overcome this difficulty. In Experiment 4, children were given experience moving around the larger room before they were restricted to the small area as they were in the earlier experiments in order to determine whether initial experience in moving without restriction would allow them to treat the space differently once they were restricted to the smaller area.

Method

Participants

There were 20 3-year-old children in this experiment. Five additional children refused to complete the task. One additional participant was discarded because he left the taped enclosure. The average age of the 20 remaining 3-year-olds was 40.01 months (range 36.3–46.75 months). Participants were obtained from a commercially available list.

Apparatus and procedure

The experimental procedure was identical to that in Experiment 3, except that the disorientation procedure was preceded by a 3–4-minute game during which the experimenter asked the child to help pick up a variety of toys that had been previously scattered around the room. The experimenter engaged the child by asking, 'Do you see something that says "moo" on the floor? Can you put it in my basket?' This continued until all of the toys were placed in the basket or until the end of 4 minutes, at which point the experimenter picked up the remaining toys and explained the rules of the search task, emphasizing that now the child had to remain within the taped area.

Results

The children in this experiment went to the correct corner or the opposite corner (the rotationally equivalent one) the majority of the time, 39% and 36%, respectively (see Figure 4). Responses to the correct corner and to the rotationally equivalent corner were not significantly different, $t(19) = 1.0$. The difference between the two geometrically correct and the two geometrically incorrect corners was reliable, $t(19) = 6.84$, $p < .01$. The geometric error was significantly more common than the near error, $t(19) = 3.0$, $p < .01$, or the far error, $t(19) = 2.38$, $p = .03$.

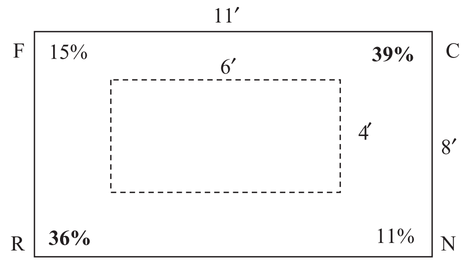

Figure 4 *Percentage of responses for 3-year-old children to each corner rotated such that correct corner is the same for all subjects.*

Discussion

The brief game that allowed the children to move freely around the room did not change the 3-year-olds' performance on the reorientation task. They still failed to use the feature to select the correct corner. However, the lack of change could be due to the fact that the task did not require attention to spatial location and the characteristics of the surrounding room. When gathering the toys, there was really no need to examine the surrounding room. Children only had to look at the toys, and the experimenter with her basket. It is possible that participation in a search task in which movement was not restricted would enhance young children's ability to use featural information once they were required to remain in a restricted area.

Experiment 5

In a second attempt to break the hold of restricted movement on the performance of the 3-year-old children, Experiment 5 introduced four trials in which the children's movement was not restricted preceding the trials in which their movement was restricted. Previous research indicated that, when their movement is not restricted, 3-year-old and even younger children are capable of combining landmark and geometric information in a room of this size (Learmonth *et al*., 2001). Giving them the experience of doing the task without restriction may help them see the importance of the landmark and allow them to continue to use it for the second four trials when they are again confined to the tape enclosure.

Method

Participants

There were 24 3-year-old children in the experiment. One additional child refused to complete the task. Three additional children failed to remain within the taped enclosure. The average age of the 24 remaining 3-year-olds was 39.57 months (range 36.16–46.36 months). Participants were obtained from a commercially available list.

Apparatus and procedure

This experiment used the same basic design as Experiments 3 and 4, with two variations: the number of trials was extended from four to eight, and the location of the toy duck was changed throughout the experiment. During the first four trials, the children were allowed to move freely around the room. During the second set of four trials, they were told they now had to remain within the taped area. Children were discarded if they left the tape more than twice. During each set of trials, the location of the duck was switched between two locations, following an ABBA order for the first four trials, and repeated (ABBA) for the second four trials. The order of the boxes was fully counterbalanced.

Results

During the first set of four trials, as found in previous work, the 3-year-old children in the larger room went to the correct corner or the opposite corner the majority of the time, 51% and 26%, respectively (see Figure 5). In the second set of four trials when the children remained in the taped enclosure, they chose the correct corner or the opposite corner the majority of the time, 67% and 20%, respectively.

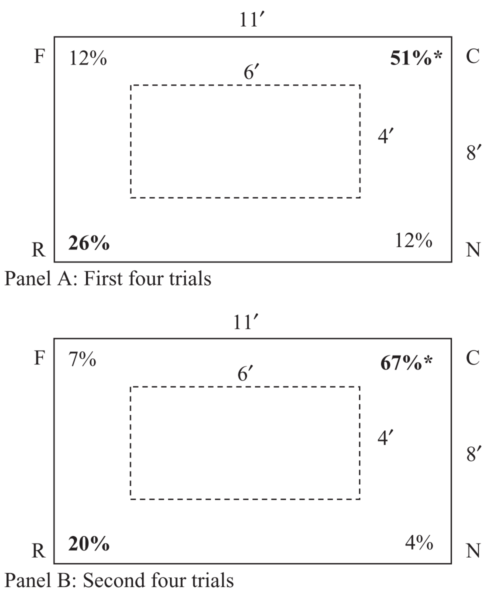

Figure 5 *Percentage of responses for 3-year-old children to each corner rotated such that correct corner is the same for all subjects. Panel A shows responses from the first four trials where the children were allowed to move around freely and panel B shows responses from the second four trials when the children were confined to the taped area.*

A 2 (trial set: first four and second four) × 2 (correct and reverse) ANOVA revealed no significant interaction ($p = .08$), but a significant main effect of trial set ($p < .05$) and corner ($p < .01$). Post-hoc tests using Fishers LSD revealed a significant difference in responding to the correct corner from the first four trials to the second four ($p < .05$) and no other significant differences.

The difference between the two geometrically correct and the two geometrically incorrect corners was reliable for both the first four trials, $t(23) = 6.84$, $p < .01$, and the second four trials, $t(23) = 12.84$, $p < .01$. The geometric error was significantly more common than the near error in the first, $t(23) = 2.9$, $p < .01$, and second set of trials $t(23) = 4.73$, $p < .01$, and the far error also in the first, $t(23)$ 2.17, $p = .04$, and second set of trials $t(23)$ 3.15, $p < .01$.

Discussion

In this final experiment, the experience of four trials without restricted movement in which they naturally used features allowed the 3-year-old children to use the landmark when their movement was restricted for the second set of four trials. Their use of features in the second four trials indicates that they are not incapable of noticing and utilizing features to reorient, but that they need to have this ability activated in order for it to appear in a more challenging situation. In Experiment 5, they used the experience gained on the first four trials to improve their searches even once their movement was restricted. This effect can be described as a 'practice effect', but such a description should not be used to minimize the importance of the result. If a brief period of practice is sufficient to create competent performance where we know that none would naturally be exhibited, we are invited to consider whether naturally occurring development might occur in similar ways, as transfer from more compelling situations. Of course, only further work will tell us exactly what components of the four trials of experience are vital, whether the practice effect is lasting, and whether transfer occurs in real-world situations in which experiences are far more widely distributed.

General discussion

The purpose of this series of five experiments was to determine why children are more likely to use features at younger ages in larger than in small rooms, and why at any age, features are more likely to be used in the larger rooms (Cheng & Newcombe, 2005). We originally aimed to contrast the effects of movement restriction with the effects of larger and more distal features. In Experiment 1, with the goal boxes inside the smaller enclosure and the colored wall in the larger room, we did not observe use of features until 6 years, suggesting the importance of movement restriction to the room size effect. However, because this arrangement introduced a third potential cause of difficulty in using features, namely positioning of the target at a distance away from the feature, in Experiment 2 the goal boxes were placed in the larger room, outside of the area where the children were allowed to move, and children were asked to point to the target. In this situation, successful use of features appeared in 5-year-olds although not in 3-year-olds. Experiment 3 replicated Experiment 2, except that we removed the physical barrier preventing the children's movement, and substituted a taped area in which the children were instructed to remain. Experiment 3 showed that 4- as well as 5-year-olds use features as well as geometry in this situation, but 3-year-olds continued to focus only on geometric information. In an effort to see if 3-year-olds' difficulty in using features could be overcome by prior physical activity, in Experiment 4 we introduced a game that required the children to move around the large space before being asked to stay within the tape-defined area of Experiment 3. However, this kind of experience did not affect their use of features. In Experiment 5, the 3-year-old children first experienced four reorientation trials in the larger space, with no restriction to their movement, in which they used features as expected from prior data. When four trials followed in which their movement was restricted by the enclosure, they did successfully augment geometric with featural information.

Overall, the experiments demonstrate that there are at least three factors that are important components of the ability to use features to reorient in space, and that may underlie the contrast in previous experiments using larger versus smaller enclosures in the ages at which children are successful and, at any age, how likely features are to be used. The data from these studies also indicate that a variety of developmental patterns can be observed that vary as a function of the task environment. Let us first examine the three relevant influences on performance that we have identified, and then consider what the developmental patterns imply for the viability of proposed conceptualizations of cognitive architecture for spatial processing and for developmental mechanisms.

Why are features easier to use in larger rooms?

Table 1 summarizes the findings regarding ages at which features are first used to reorient as a function of whether children could move freely in the space, whether the colored wall was distally located, and whether the target for which children searched after disorientation was adjacent to the feature (the colored wall). Comparing across studies in which two of these factors were constant allows us to draw inferences regarding whether the third factor affects the age at which successful use of features is first observed.

Movement restriction

The best comparison regarding the role of restriction of movement in creating the room size effect is between the

Table 1 *Age of success in rectangular spaces as a product of variations in the task demands*

	Colored wall distal?	Action possible?	Target proximal to colored wall?	
Hermer-Spelke	No	No	Yes	6 years
Learmonth *et al.*	Yes	Yes	Yes	18 months
Experiment 1	Yes	No	No	6 years
Experiments 2 & 3	Yes	No	Yes	4 years
Experiment 5	Yes	Yes then No	Yes	3 years

Learmonth *et al.* (2001) studies and Experiments 2 and 3 in this paper. In all these studies, there was a large colored wall reasonably distal from the child with a target located adjacent to that wall (or the white walls) in the larger enclosure. The only contrast between rows 2 and 4 in Table 1 involves restriction of movement. We see that this factor apparently increased the age at which features are used from 18 months (the youngest children tested) to 4 years. That is, confinement to a small space has a powerful effect on children's ability to use the landmark to reorient.

Distal features

The best comparison regarding the role of features being proximal versus distal in creating the room size effect is between the Hermer-Spelke (1994, 1996) studies and Experiments 2 and 3 in this paper. In all these studies, children's action was restricted and the target was located adjacent to that wall or one of the white walls in the larger enclosure. The only contrast between rows 1 and 4 in Table 1 was whether the colored wall was distal from the child. We see that this factor apparently increased the age at which features are first used from 4 years to 6 years. That is, the nature of the features (and their likely ecological usefulness as indicators of location) has an important effect on children's ability to use the landmark to reorient.

Relation of target to features

The best comparison regarding the role of target location is between Experiment 1 and Experiments 2 and 3 in this paper. In all these studies, children's action was restricted and a distal colored wall was available. The only contrast between rows 3 and 4 in Table 1 was whether the target was located adjacent to that wall or one of the white walls in the larger enclosure. We see that this factor apparently increases the age at which features are first used from 4 years to 6 years. This factor has never been considered before, and it seems important to evaluate it further in research on reorientation, with respect to geometric as well as featural information. All work on reorientation to date, including the present

Experiments 2–5, has used a paradigm in which targets are nested tightly within the surrounding geometry, located snugly in a corner of the enclosure. It is an open question as to whether geometric information would be used as easily and ubiquitously as it appears to be on the basis of existing data, in situations in which targets are located away from the enclosure. That is, adjacency may affect the use of geometry as well as the use of features.

Discounting an 'effort' hypothesis

The results of these experiments also allow us to reject a possible explanation of the room size effect as a matter of the effort required to make a choice in the large and small room. According to this explanation, in the small room there is relatively little cost to making a choice, leading the children under 6 years to go to the first corner that attracts them instead of taking the time to evaluate all four corners as they do in the larger room. However, Experiments 2, 3, 4 and the last four trials of Experiment 5 all required the children merely to point at the corner of their choice, which seems to take even less effort than making a choice in the small room. Nevertheless, younger children still failed to use features in Experiments 2, 3, and 4. This fact speaks against the room size effect being due to the cost of making a choice.

Developmental patterns and developmental mechanisms

These results show that the nature of developmental change in reorientation tasks depends strongly on the nature of the task. Many investigators have seen the abrupt transition observed by Hermer and Spelke between 5 and 6 years in the use of features as powerfully suggestive of a discrete factor, such as spatial language, that creates this change. However, in Experiment 3 in this paper, we saw that in a different task environment, there can be an abrupt transition at an earlier point in developmental time, between the ages of 3 and 4 years. Intriguingly, in a recent experiment that used a different sort of variation in the demands of a reorientation task, Hupbach and Nadel (2005) found a similar age transition. Thus, the present data speak against a strong modularity-plus-language view of reorientation, as presented by Hermer and Spelke (1996), according to which there is a cognitively impenetrable geometric module until the advent of certain kinds of spatial language around 6 years of age. Instead, many factors appear to be involved in the ability of young children to combine featural and geometric information to reorient. Spatial language may well be one of these factors but not the necessary and sufficient condition for developmental change.

An explanation often offered for findings such as these is a weaker modularity claim in which the modules still exist but without the strict impenetrability posited by Fodor (1983). This weak modularity lacks the explanatory power of the stronger view espoused by Hermer and Spelke. Could the available data be compatible with a weaker modular view? The answer to this question depends on what we mean when we use the term 'modularity' (Cheng & Newcombe, 2005; Newcombe & Ratliff, 2007). For example, there are clearly areas of the brain that show distinctive responses to distinctive kinds of spatial information. However, as long as data from these different sources of input are combined in determining behavior, there is no module that meets the impenetrability criterion originally proposed by Fodor (1983).

The alternative to the modularity-plus-language position is an adaptive combination view (Newcombe & Huttenlocher, 2006; Newcombe & Ratliff, 2007). In this way of thinking, the likelihood of using both geometry and features is affected by factors such as cue saliency, cue validity, and so forth. Let us consider each of the three factors identified in this paper from this point of view.

First, movement could be an example of a general factor that affects attention to the surrounding spatial framework. However, we then need to explain why movement affects the encoding and use of features but not geometry. One approach to this question is to point out that geometry has been assessed 'full strength' in this and other studies, but features have not. That is, geometry has generally been instantiated by fully enclosed spaces (without the gaps that may occur in the natural world), simple and regular shapes (unlike the more complex and irregular geometry of the real world), and, as already pointed out, with the targets adjacent to the geometry. Features, on the other hand, have often been instantiated as a single feature, rather than the more complex relational structure of two, three or more features that likely typifies the real world. Thus, lower spatial attention caused by restriction of movement might be expected to differentially affect the probability of use of the more weakly instantiated kind of spatial information. This phenomenon would influence both the 'passing age' and the likelihood of using features at any specific age.

Second, whether or not features are distal likely has an effect on the probability of using features because as we move about the wider spatial world, distal features change their orientation to the self more slowly than proximal features and hence provide better clues when we have become disoriented. Consider, for example, the fact that we may move a fair amount in a valley without greatly altering our relation to a distant mountain, and yet substantially altering and even reversing our relation to a particular tree stump. There are a number of possible explanations for this preference for distal landmarks. First, even preschool children are likely to have accumulated enough spatial experience to have (implicitly) absorbed the greater cue validity of distal features for reorientation. It may take longer for them to realize that, in particular situations, even proximal features can be useful. The likelihood of this realization could vary with age, perhaps because of strategic processing. In experiments with adults, we have noted that they sometimes examine the environment minutely to look for any possible cues to reorientation (e.g. extremely faint carpet stains). Another possibility, as suggested by Nadel and Hupbach (2006), is that the preference for distal landmarks could be built into the navigation system because it is so vital to survival. In this case even children with little experience in navigation would prefer the distal cue.

Third, the adjacency of targets to features (and to geometric information although that question was not studied in these experiments) deserves some thought. When we use the term 'reorientation', what seems to be implied is a complete adjustment of the spatial world, and yet the present findings suggest that, at least sometimes, we may reorient only partially – to locations that are directly associated with spatial cues, rather than in a thoroughgoing way in which all aspects of the spatial situation fall into place at once. Future work will be necessary to assess whether this kind of phenomenon is observed for reorientation using geometry as well as for features. Data on this question may have a profound impact on our conceptualization of the nature of these different kinds of spatial information, on the nature of development, and on when we can say that an organism is actually reoriented as opposed to merely locally reorganizing the environment.

Conclusion

The varying patterns of developmental change seen across the relatively short age span of these experiments are incompatible with the modularity-plus-language view, which allows for only one sharp age transition, between 5 and 6 years, and only one mechanism creating change, namely learning spatial language. By contrast, the adaptive combination model predicts that weighting of different spatial information sources will change over developmental time as well as vary by factors such as the certainty and salience of the information. Further work will be necessary to more thoroughly examine the predictions of this model, but the present studies show how it can explain the room size effect. Failure to use features in a small room seems to be due to characteristics specific to enclosures of that size, which are not typical in the wider world.

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