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Coding Location: The View From Toddler Studies

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The ability to locate objects in the environment is adaptively important for mobile organisms. Research on location coding reveals that even toddlers have considerable spatial skill. Important information has been obtained using a disorientation task in which children watch a target object being hidden and are then blindfolded and rotated so they cannot track their changing relation to the target. Even toddlers under two years of age search successfully for the hidden object, which shows that they can use geometric features of the spatial environment to determine object location. It has been claimed that these results show innate geometric abilities, but there is evidence that these early spatial skills are not simply geometric. The article presents an overview of experimental findings that provide the basis for a different interpretation of spatial development.

Keywords: spatial representation, spatial memory, egocentric versus allocentric representation

It is critical for humans and other mobile creatures to keep track of the locations of important objects and places after they change their positions in space. In this article I discuss mechanisms for maintaining location information and their development in childhood. I have worked on this issue for many years and have had several collaborators, whom I mention in connection with the articles we have done together.

Editor's Note

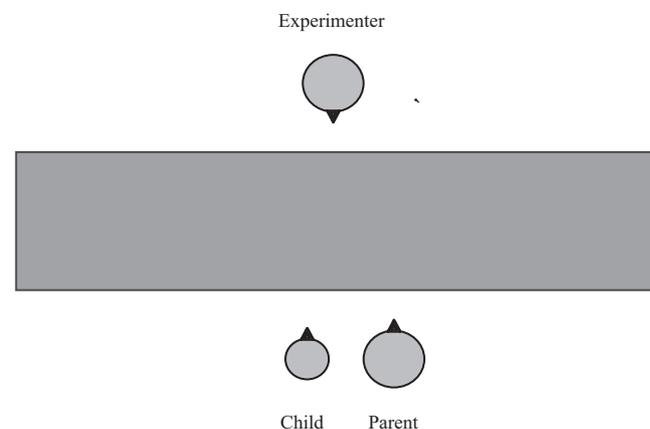
Janellen Huttenlocher received the Award for Distinguished Scientific Contributions. Award winners are invited to deliver an award address at the APA's annual convention. A version of this award address was delivered at the 116th annual meeting, held August 14–17, 2008, in Boston, Massachusetts. Articles based on award addresses are reviewed, but they differ from unsolicited articles in that they are expressions of the winners' reflections on their work and their views of the field.

Earlier Research on Spatial Coding

Piaget (Piaget & Inhelder, 1948/1967) believed that spatial coding is impoverished in young children. He thought that they initially conceptualize space egocentrically, coding distance and length in terms of reach from their own position. If this were true, there would have to be profound developmental changes, since adults clearly code length and distance and use a variety of cues to establish object location.

Research I did in the 1990s with Nora Newcombe and Elizabeth Sandberg (Huttenlocher, Newcombe, & Sandberg, 1994) showed that even very early in life, children *do* code distance and length independently of themselves. To examine the issue, we built a narrow sandbox 5 feet long (see Figure 1). We had a child between 1½ and 2 years old stand with a parent on one side of the box at the center, with the experimenter on the opposite side. The experimenter hid a toy in the sand and then moved away from the box. The parent turned the child around to break the child's gaze on the box and then had the child point to the hidden toy. Even the youngest children could point to the place where the object was hidden, which suggested that location was coded relative to the box. However, it was possible that location was coded in terms of reach from the child's own position. So we used a second procedure in which children watched the experimenter hide the toy and then were moved down toward one end to indicate its location. Clearly, they would not find the toy if they used a reach based on their original position. Children succeeded in finding the toy, which suggested that location was coded relative to the box, not to themselves. In a further test, children were moved to the other *side* of the box after watching the hiding and before retrieval. As they went to the other side, an object that had been on their right would appear on their left. Again, they could not solve the problem using a reach based on their original position. But they still could point to the toy.

Figure 1
Sandbox



Disorientation Studies

Later studies have provided additional evidence that toddlers code location in relation to the spatial environment rather than to their own bodily position. Several studies have used a disorientation procedure, in which very young children must use information about the shape of a space they are enclosed in to specify location. The task was introduced by Cheng (1986) to investigate spatial processes in rats and was adapted for use with human toddlers by Hermer and Spelke (1994, 1996).

In this task, a child is placed inside a rectangular enclosure with identical containers in the four corners (see Figure 2) and watches while a target object is hidden in one of the corners. The child then is rotated several times with eyes covered before retrieving the object. The procedure prevents the child from tracking his or her relation to the hidden object, but not from coding the relation of the object to the enclosure. Children rely on information about the relation of the object to the enclosure, because they cannot track their changing relation to the target. For two of the corners, the longer wall is to the left, and for the other two, the longer wall is to the right. If the target is hidden in a corner with the longer wall to the left, that would eliminate two corners as possible hiding places—namely, those where the shorter wall was on the left. If children are using the geometry of the enclosure, they should restrict their search to either the correct corner or to the corner diagonally opposite (C and R in Figure 2). Figure 3 shows Hermer and Spelke's (1994, 1996) results with adults and with toddlers. Adults pretty much restricted their searches to the two possible corners. Toddlers also searched most often at these "possible" corners, but they

Figure 2
Rectangular Enclosure Used in Hermer and Spelke (1994, 1996) Experiments

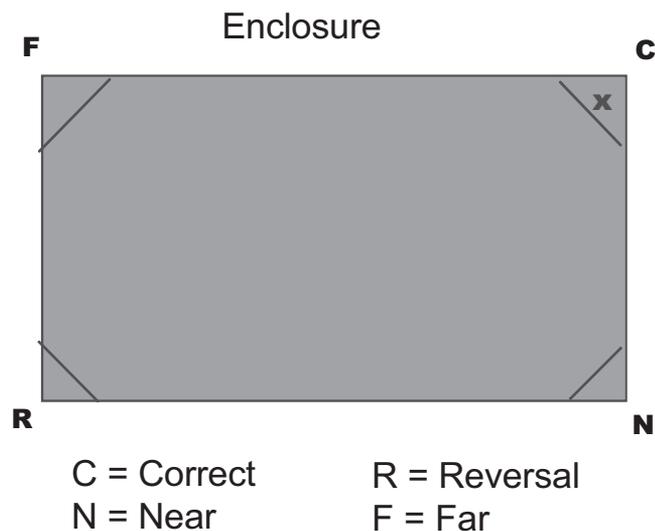
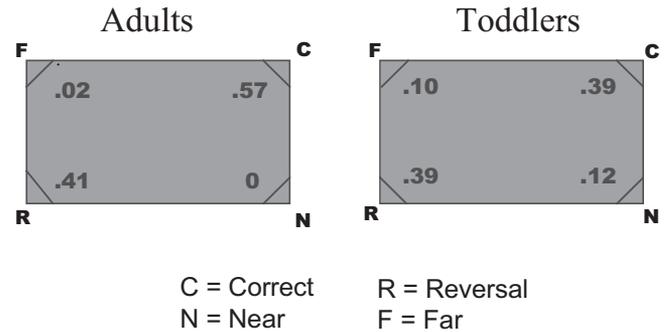


Figure 3
Search Rates for Adults and Toddlers in Hermer and Spelke (1994, 1996) Experiments

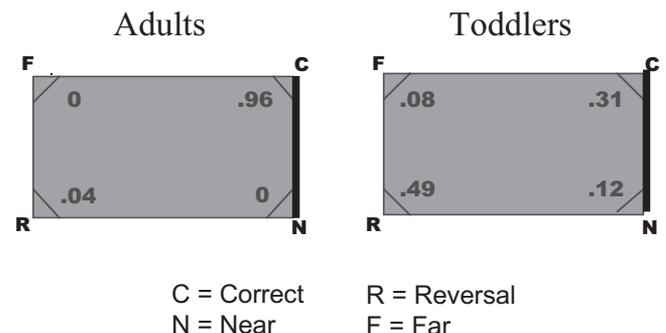


made errors. Further, there was evidence that the toddlers were actually disoriented, in that they chose each of the two geometrically equivalent corners equally often.

Another finding was that toddlers did not use nongeometric cues. In a later experiment, one of the short walls in the rectangular enclosure was painted blue. In addition to the fact that the shape of the enclosure made it possible to eliminate two of the possible hiding corners, the presence of the color cue permitted unique identification of the correct corner. Figure 4 shows that adults got almost all the problems right. However, toddlers ignored color and used only geometric cues, getting only half the problems right.

These findings led Hermer and Spelke (1994, 1996) to posit a geometric *module*—a specific innate ability that allowed toddlers to use information about the geometry of a space. The idea of innately available processes in spatial coding seems plausible, since the information is critical for locating objects and places. However, more work would be required to evaluate these claims. In my lab, we have used variations of the disorientation procedure to determine how young children represent the spatial environment and locate

Figure 4
Search Rates With Colored Wall in Hermer and Spelke (1994, 1996) Experiments



the target in it and what processes are involved in finding the object after disorientation.

Egocentric Versus Allocentric Encoding

Another claim by Spelke (Wang & Spelke, 2002) is that, in the disorientation task, viewer-dependent processes are involved in representation of the enclosure—that is, that the coding is “egocentric.” The claim is that toddlers code the portion of the enclosure they can see as the target is being hidden. After disorientation, they recover the look of the original hiding corner and then search the current situation until they find a corner that matches the original perspective. An alternative to this position is that the viewer is not represented in the initial coding at all—that is, that the coding is “allocentric.” What is represented is the shape of the enclosure with the target positioned in it. After disorientation, then, regardless of where they face, toddlers know the location of the target object in the enclosure and can simply get it. No search or matching processes are required. These alternatives have a long history in the study of spatial representation. In one, viewer perspective is an essential aspect of spatial coding. In the other, the space is represented in a perspective-free fashion and the viewer only becomes involved when the object must be found, after disorientation. Such differences in coding then give rise to different processes in object finding.

Coding in Disorientation Tasks Is Allocentric

To further explore location coding, I did a study with Marina Vasilyeva (Huttenlocher & Vasilyeva, 2003) examining the disorientation task further. Our findings support the notion that coding involves a representation of the entire enclosure and is not egocentric. We used an enclosure that was shaped like an isosceles triangle, with two equal walls and corners (Huttenlocher & Vasilyeva, 2003). For one of the equal corners, the long wall is on the right and the short wall is on the left, whereas for the other, the long wall is on the left and the short wall is on the right. The third corner is unique in angle with walls of equal length. In a triangle, contrary to a rectangle, geometric cues completely define the hiding location.

If coding is egocentric, that is, if the child codes the portion of the space with the hidden object, task difficulty might vary for different hiding corners. For the unique corner, both side length and angle provide cues, so accuracy might be greatest there. Instead, performance was equal for all three corners. Further, for the equal corners, where the only difference between the corners was in the left/right positions of wall lengths, toddlers might be more likely to confuse them with each other than with the unique corner. Instead, these different corners were equal in difficulty. The findings, showing equal difficulty for hidings at all three corners, are consistent with the notion that coding is allocentric, that is, that the entire enclosure is represented.

Huttenlocher and Vasilyeva (2003) introduced a variant of the disorientation task that provided even stronger evidence of allocentric coding. In this task, viewers were outside rather than inside the enclosure. The enclosure was shallow enough for the child to see the hiding from outside. In this situation, both the appearance of an angle and the left/right positions of the wall lengths depend on the viewer’s position along the perimeter of the figure. Consider an example: For a triangle, a particular corner viewed from one vantage point might have the long side to the left and the short side to the right, joined by an angle of 70 degrees (see Figure 5). From another vantage point, it has the short side to the left and the long side to the right, joined by an angle of 290 degrees. There are parallel differences for a rectangle: From outside, all corners have an angle of 270 degrees, and the only critical information is relative wall length; from another vantage point, corners all have an angle of 90 degrees, and relative wall length is reversed (see Figure 6). The look of a particular corner from outside the enclosure at the time of hiding may differ from its look after disorientation, because the child’s position is likely to be different. Thus, a particular corner may be the same one even if its appearance is very different. Our results indicated that toddlers could find the hiding corner from outside regardless of their position along the perimeter of the enclosure, but the task was more difficult than it was from inside. This finding suggests that the viewer does not use a perceptual matching strategy to solve the problem from outside the enclosure but rather codes the shape of the entire enclosure with the target positioned in it.

Finally, we explored the nature of the representation of the enclosure in still another way. In particular, we examined what path toddlers followed in searching for the target after disorientation, both from inside and from outside the enclosure. If toddlers coded only the corner with the hidden object, they would have to survey the different corners after disorien-

Figure 5
Alternative Perspectives for the Triangular Enclosure

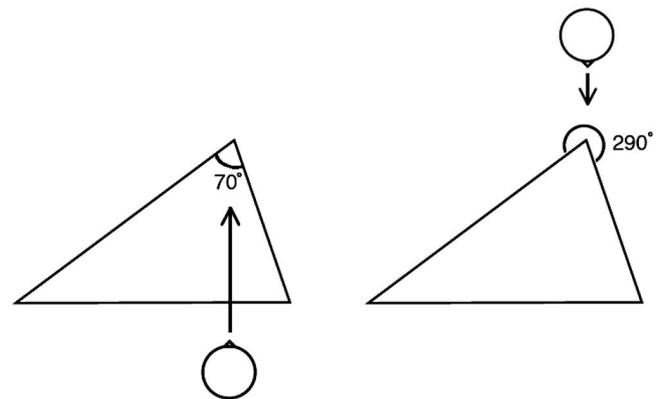
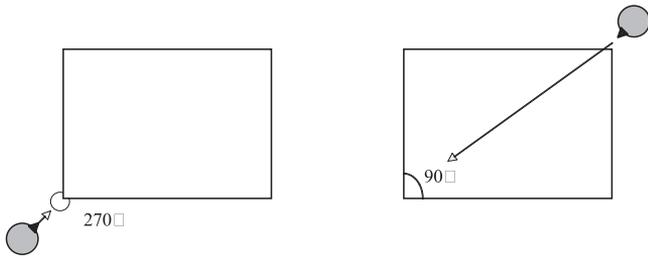


Figure 6
Alternative Perspectives for the Rectangular Enclosure



tation to identify the one that matched. On the other hand, if they coded the entire enclosure, they would know where they had coded the target in the enclosure without recovering the initial perspective, and they could go directly to that location no matter where they faced after disorientation.

To examine search behavior, we attached a video camera to the ceiling, so we could see if the toddlers surveyed the space after disorientation prior to going to a particular corner; in particular, we determined whether or not they surveyed the space by moving their heads, torsos, or whole bodies. Children only rarely surveyed the space; rather, they took a direct path to a particular corner. From outside, search behavior could be classified on all trials. Children went directly to one of the corners on 90% of trials, and they did no better on the 10% of trials where they surveyed the space than on other trials. From inside, we could classify the toddlers' behavior on only about 70% of trials. For these, children went directly to a particular corner without surveying the space on about 75% of the trials, and on 8% of the trials they looked around at the different corners. Again, children's success was equal whether or not they surveyed the space. Thus, toddlers did not search for their initial perspective after disorientation, which again suggests that they coded the entire enclosure. Although toddlers performed above chance from outside, the task was more difficult than the inside task. The possible reasons are discussed below.

In summary, Huttenlocher and Vasilyeva's (2003) findings suggest that toddlers represent the spatial environment allocentrically. If they had used an egocentric representation involving only the portion of the space with the hidden object, they would have had to search for a matching corner after disorientation to find the object. Rather, it seems that they coded the shape of the entire enclosure and that the representation of the corners was abstract enough to permit recognition of a corner as the "same" across the large variations in its appearance encountered in different positions outside the enclosure.

Distinctiveness of Cues in Disorientation Tasks

Work I did with Clark Presson in the 1970s (Huttenlocher & Presson, 1979) with somewhat older children suggested

that the greater difficulty of outside tasks could not be explained entirely by the presence of multiple perspectives. The tasks Clark and I used involved spaces with high walls, so that multiple perspectives were not involved, either from inside or from outside the enclosure (Huttenlocher & Presson, 1973, 1979). In the 1979 study, there were different figures on the four walls in both conditions. In the inside condition, we used a small room with the child seated on a swivel chair in the center. The children were asked to imagine rotating on a point by 90°, 180°, or 270° and to report what figure would be located in a particular position relative to themselves after such a rotational change. In the outside condition, we used a cube with different figures on each side. The children were asked to imagine walking around the circumference of the cube to a certain point (90°, 180°, or 270° from the start point) and to report what figure would have a particular location relative to themselves. Although the entire enclosure/cube could not be seen at once in either condition, the outside task (with the cube) was nevertheless more difficult than the inside task, as in the study by Huttenlocher and Vasilyeva (2003). Clearly, there must be another source of differences in difficulty between these conditions.

A possible explanation is that there are differences in the discriminative cues in the inside and outside conditions. From inside, the different figures are more highly differentiated relative to the viewer than they are from outside. As shown in Figure 7, the different positions from inside are in front, behind, to the left, and to the right; on the other hand, from outside, the different walls are all in front of the viewer. That is, the potential hiding corners are all in a frontal plane. Hence, the codings of different corners from outside are more similar and potentially more confusable.

Array Movement

If individuals code the entire enclosure, including the target, they will know the position of the hidden object after disorientation. An implication of this hypothesis is that

Figure 7
Representation of Enclosure From Different Perspectives

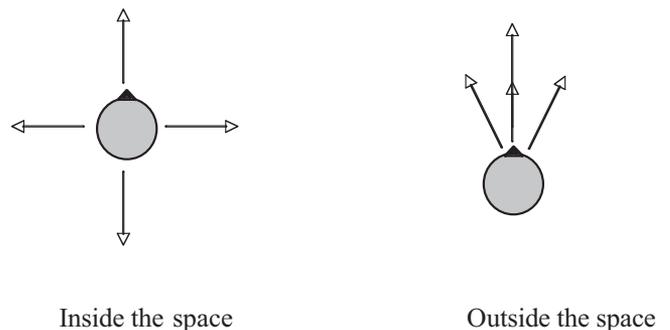
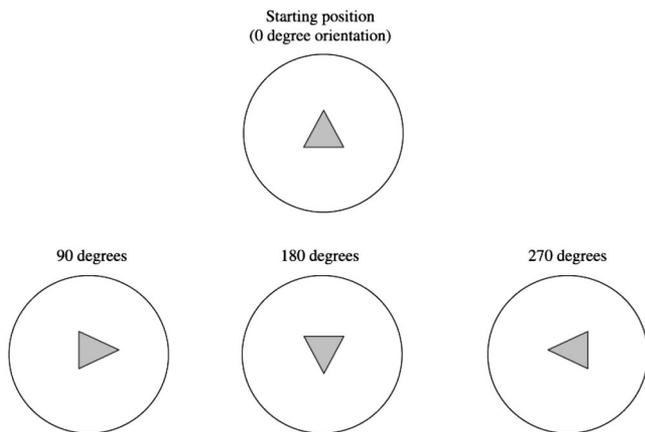


Figure 8
Array Movement



movements of the blindfolded viewer are not relevant to the location of the hidden object. That location is the one seen at the initial coding; in short, success on the task does not depend on what movements the viewer makes. We have found evidence for this hypothesis in the work described above.

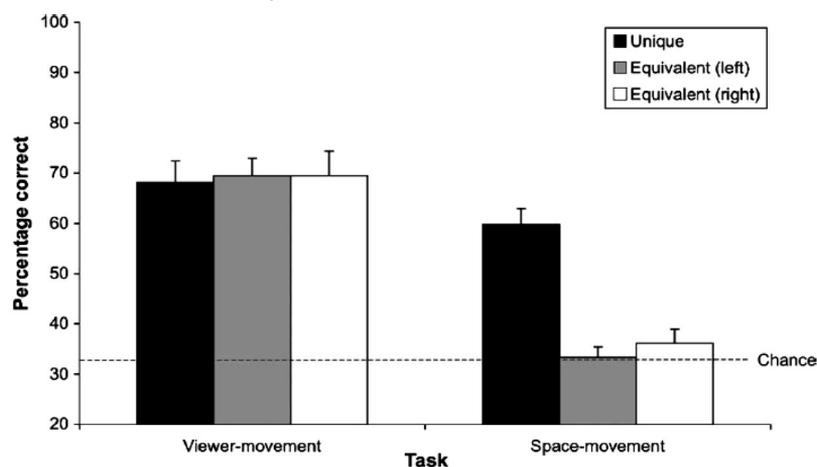
The changes we have considered in the relation between the viewer and the spatial environment have thus far involved viewer movement. However, there are many studies of array movement—of “mental rotation.” Array movement tasks, like viewer movement tasks, start with a particular relation between the viewer and the spatial environment, with the viewer watching an object being hidden in a particular portion in the space. The viewer might code the entire enclosure or only the portion with the hidden object. Then the array is rotated and the viewer must find the hidden object in the hiding corner

(see Figure 8). Lourenco and Huttenlocher (2007) examined the relative difficulty of these tasks using a disorientation procedure in a triangle space where either the viewer or the space underwent a rotational transformation. For viewer rotation, toddlers were above chance at all hiding corners, but for array rotation, they were only above chance when the hiding corner was the unique corner (see Figure 9). This result suggests a fundamental difference between coding in viewer and space rotation tasks. That is, for viewer movement, the entire space was coded, as in all the experiments we have discussed. However, for space movement, it seems that coding is not allocentric, but rather focused on only a portion of the space.

Geometric Cues Are Not Special

Work on disorientation thus far has explored the role of geometric cues in locating a hidden object in an enclosed space. In these disorientation studies, left/right bodily movement must be mapped onto different relative lengths of walls, for example, the longer wall to the right. Considerable evidence has been found that toddlers can use such geometric cues. The findings raise questions of whether toddlers might also be able to use other discriminative cues to reorient themselves. A variety of discriminative stimuli might potentially be used to specify location. To determine if the mapping abilities seen with geometric cues extend to nongeometric cues, one must use tasks for which only nongeometric cues are available. We used a square enclosure because there are no wall length (geometric) cues. Hence we can examine whether nongeometric cues are used. Such studies can be parallel in design to studies that vary wall length; for example, an object might be in a corner of a square enclosure with a red wall on the left and a blue wall on the right. We have examined the extent to which children use nongeometric cues about object location after be-

Figure 9
Contrast Between Viewer Movement and Array Movement



ing disoriented. That is, if an object is hidden in a corner with red to the left and blue to the right, can the object be found after disorientation? Or if an object is hidden in a corner with large circles on the left and small circles on the right, can the object be found after disorientation? If these cues are used, responses should be restricted to the two possible corners diagonally opposite one another, just as for geometric cues. The claim that there is a geometric module predicts that toddlers' object-finding skills in disorientation tasks should be restricted to geometric cues. However, that hypothesis had not been tested.

In determining what cues toddlers can use to locate a hidden object after disorientation, we began by using circles of two different sizes. These different size circles were presented on different walls (see Figure 10). The same size circles were shown on opposite walls, and contrasting size circles were shown on adjacent walls. The toy was hidden either in a corner with large circles on the right and small circles on the left or in a corner with small circles on the right and large circles on the left. Given a particular arrangement of circle size (e.g., right-large, left-small), two corners could be eliminated as possible hiding locations. We found that circle size is used much like wall length (Huttenlocher & Lourenco, 2007). Note that a difference in the sizes of figures on the walls is not a geometric cue because figure size does not provide information about enclosure shape.

Scalar Cues Are Special

Recent studies show that there are many discriminative cues that toddlers fail to use (Huttenlocher & Lourenco, 2007). Performance was at chance when the walls showed two simple but qualitatively different stimuli; for example, Xs to the left and Os to the right (see Figure 11), or when

Figure 10
Square Enclosure with Different Size Circles

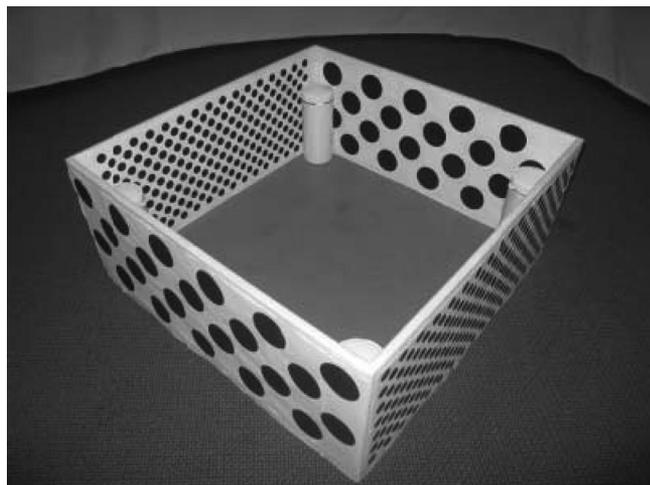
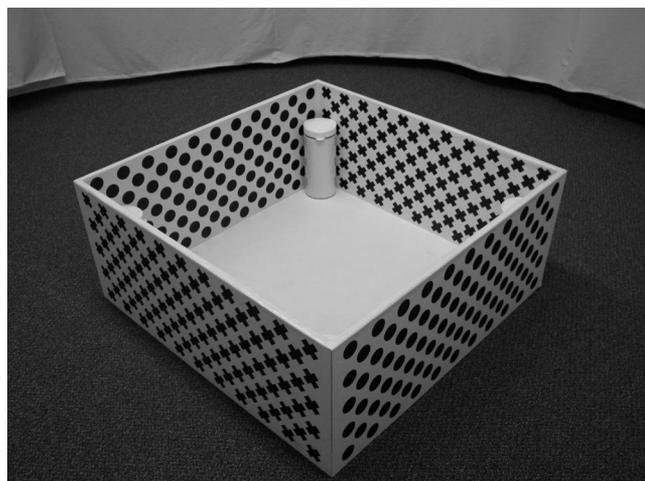


Figure 11
Square Enclosure with Differently Shaped Figures



walls were of different colors. The principle seems to be that toddlers cannot use discriminative cues to identify a hiding corner in a disorientation task if they are drawn from different categories or dimensions. Only if the discriminative stimuli form a single ordered set along a quantitative dimension can they be used to distinguish among different corners of an enclosure and make it possible to find a hidden object. Lourenco and I (Lourenco & Huttenlocher, 2008) have explored whether discriminative cues on a disorientation task must be scalar. We have found that, indeed, discriminative stimuli must fall along a single dimension in order for toddlers to use them to find an object hidden in a corner of an enclosure.

An object-finding task will be structurally more complex if a child treats discriminative stimuli as being in two categories than if the child conceptualizes them as falling along a single ordered dimension. If the stimuli are ordered along a dimension, the task will be simple enough to support success in object finding with a disorientation procedure. Conceptualizing discriminative stimuli as being from two categories introduces a layer of cognitive complexity beyond the case of two values on a single dimension. This difference seems to have a profound effect on whether toddlers can use the cues to serve the critical adaptive function of locating objects in space.

It should be noted that certain scalar differences in stimuli, such as differences in size or luminance, can engender an illusion of depth, so that, for example, different-size circles may be judged as differing in distance even though they are actually equally distant (e.g., smaller circles might be judged as farther away). However, this interpretation does not seem likely, because the enclosure was so small that toddlers could almost touch the walls. To test the hypothesis, it seemed important to find nongeometric cues that could not be interpreted in terms of geometric illu-

sions, like size or luminance can. Hue is an ordered dimension that does not produce depth cues. A master's study by Leslee Kellogg (2008) showed that variations in hue within the blue category could be used by toddlers to discriminate left/right bodily position in a disorientation task. That is, she found significant use of hue as a discriminative cue, indicating that scalar variants can be used in discrimination by toddlers, although they are not interpretable as illusions.

In conclusion, it seems that toddlers possess notions of continuous dimensional variation (length, size, etc.). When presented with stimuli that consist of different values along such dimensions, they can use them to discriminate different locations in space on a disorientation task. For toddlers to be able to line up stimuli relative to their bodily position requires that the stimuli have an inherent order, forming a cognitive structure that is simpler than one based on unrelated stimuli.

Speculations

Let me close by considering the possible significance of toddlers' ability to treat stimuli as variations along common underlying dimensions and to use such pairs to map on to other ordered information. The ability to order items across a dimension is involved in reasoning, as can be seen in ordering syllogisms. In these tasks, ordered pairs of items are described in successive sentences, as in my earlier example: If John is richer than Harry and John is poorer than Sam, who is richest? Solving the problem involves determining the overall order of stimuli along the dimension of wealth. The capacity to reason about order in this way in simple syllogism arises by 6 to 7 years of age. Existing models of syllogistic reasoning have posited general logical/linguistic principles as underlying this deductive ability. It should be noted that study participants of all ages are quite insistent in reporting that they mentally construct a vertical or horizontal spatial array consisting of the set of items, add in a new item from each sentence, and then read off answers to questions about order. There is strong supporting evidence for such claims. It consists of striking parallels between the difficulty of different forms of syllogisms and corresponding forms of verbal instructions about how to order actual objects. I was involved in such work in the 1960s and 1970s, and I know firsthand that models that posited reasoning processes in which people mentally construct spatial arrays and read off answers from them simply would not have been considered at that time. The issue, it was said, concerned logical/linguistic principles. A claim that representations might preserve order information in an embodied form was considered a throwback to introspectionism, or worse. However, findings from disorientation studies showing preservation of spatial order in prelinguistic children suggest that models of syllo-

gistic reasoning that posit construction of spatial images should be reconsidered.

Author's Note

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Hazel Rose Markus

Award for Distinguished Scientific Contributions

Citation

“For pioneering leadership in the study of the self in psychology. In her early work on self-schemas, Hazel Rose Markus helped found the conception of the self as a cognitive structure that can organize perception, reasoning, and memory. In later research on possible selves, she showed how such structures actually organize life goals and the life course. And in recent decades she has shown how powerfully the self and other psychological processes are rooted

in cultural and social contexts, an achievement that has urged all of psychology to broaden its focus beyond European American contexts. For three decades and continuing, she has been a zeitgeist leader, shaping the work of her own generation and of generations that have followed.”

Biography

Hazel Rose Markus (nee Hazel June Linda Rose) was born in London, England, in 1949 to a British Catholic mom and a Jewish American dad who had grown up in England. Her father's family had been milliners, and one of the many changes that no one counted on following World War II was that hats were no longer necessary. Seeking other opportunities, the family moved to sunny, orange-scented, 1950s-anything-was-possible Los Angeles, where her mother, father, and uncles all became public school teachers. Her father was sure his children were way above average. Her mother was less certain and instead modeled the value of a cup of tea and a determination to carry on.

In high school in San Diego, Markus followed the writings of sixties guru Alan Watts on Buddhism and a variety of then avant-garde poets. She was editor of the school newspaper and remembers most the claim of Mr. Toklas, the journalism teacher, who cautioned that no two sets of eyes see the same world. At San Diego State University, Markus worked for a large project led by a social psychologist and a political scientist. They coded *The New York Times* for instances of cross-national instability. What impressed Markus most about this project was the sheer fun of working together in a big multidisciplinary collaboration, and it was the first of many such projects that would organize her life.

A plan to pursue journalism as a career evaporated following a class demonstration in Psychology 101. The professor divided the class into two. He told one half of the class a story of traveling and the challenge of exotic locations. Out of earshot, he told the other half of the class a different story of shopping and the challenge of finding clothes and shoes that were just the right size. He then stood in the middle of the room, uttered three syllables, and asked the students to write what they heard. Markus tallied the results. One half of the class heard “Tripoli,” the other half, “Triple E.” Same sounds, different responses. Same world, different realities. Mr. Toklas was right. Later she would read Jerome Bruner and understand this effect as “going beyond the information given” and as “an act of meaning,” and come to believe that such meaning making is a basic and underanalyzed psychological process.

Markus went to graduate school at the University of Michigan, and while there was no surfing in Ann Arbor, it served up a heady mix of people, projects, theories, and visions for social change. The magic of the University of Michigan for a social scientist in the 1970s was that the social was real. Everyone knew this; no one had to be con-