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Location representation in enclosed spaces: What types of information afford young children an advantage?

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ABSTRACT

It has been suggested that young children can only reorient, locating a target object, when the geometry of an enclosed space provides distinctive shape information [e.g., Hermer, L., & Spelke, E. (1994). A geometric process for spatial reorientation in young children. *Nature*, 370, 57–59]. Recently, however, young children were shown to specify location in a square-shaped space, where geometry is uninformative, so long as scale-like information was available on the walls of the space [Huttenlocher, J., & Lourenco, S. F. (2007a). Coding location in enclosed spaces: Is geometry the principle? *Developmental Science*, 10, 741–746]. Here we build on this work by examining more closely what types of cues afford 18- to 24-month-olds an advantage in locating a target object following disorientation. Their performance was assessed when linear scale-like information was presented either in isolation or in composite form. It was found that, even in isolation, young children searched at the appropriate locations, with added benefit when presented as a composite. We suggest that linear scale-like dimensions, especially when available in composite form, play a critical role in supporting location representation in young children.

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Introduction

It was once believed that young children were incapable of using information in the surrounding environment to specify the location of objects or places (e.g., Piaget & Inhelder, 1948/1967). During recent years, however, there have been numerous demonstrations of even toddlers relying on

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geometric information about the shape of an enclosed space to locate a target object hidden at one of the corners of the space (e.g., Hermer & Spelke, 1994, 1996; for reviews, see Cheng & Newcombe, 2005; Lourenco & Huttenlocher, 2007). Despite the growing literature, questions concerned with how toddlers process location information such as geometry have been difficult to answer. Of particular importance is whether they can use only geometry to represent location or whether they are also capable of using other more general environmental cues. In the current study, we are concerned with characterizing more precisely how location is processed and remembered by young children. To this end, we examine whether particular types of environmental cues are advantageous when specifying the location of a target object.

Geometric information (shape of enclosed spaces)

In a seminal study, Hermer and Spelke (1994) showed that children as young as 18 to 24 months of age not only used geometric information about the shape of an enclosed space to specify location, but they also favored this information over nongeometric cues. In that study, young children were tested inside a rectangular room with and without a different-colored wall. There were four identical containers, one at each corner, and on every trial the child watched as a toy was hidden in one of the containers. Following the hiding event, and before being allowed to search for the toy, the child was disoriented by having the parent spin him or her around several times with the child's eyes covered. The disorientation procedure was critical because it prevented the child from relying exclusively on egocentric information (e.g., "to my left") to solve the location problem. In the condition without the different-colored wall, children searched for the hidden object at the two geometrically appropriate corners (e.g., the corners with the short wall to the left of the long wall), indicating that they could use the shape of the surrounding space to reorient and determine where to search for the hidden object. In the condition with the different-colored wall, children continued to rely on geometry; they did not use the additional nongeometric information to distinguish the corners (e.g., the corner with the short *blue* wall to the left of the long white wall vs. the corner with the short *white* wall to the left of the long white wall). Because young children appeared to favor geometry following disorientation, Spelke and colleagues have argued that the process of reorientation is modular, that is, based on geometry alone (e.g., Hermer & Spelke, 1994, 1996; Hermer-Vasquez, Spelke, & Katsnelson, 1999; Lee, Shusterman, & Spelke, 2006). In their view, other types of environmental cues are not used to represent location on disorientation tasks; only geometric information about the shape of an enclosed space is used for this purpose.

Other research, however, has not supported the modular view of geometric processing. For example, in larger rectangular spaces, young children have been shown to rely on nongeometric cues (e.g., a different-colored wall) to locate a hidden object (Learmonth, Nadel, & Newcombe, 2002; Learmonth, Newcombe, & Huttenlocher, 2001). Nevertheless, there is reason to believe that geometry may be highly salient and prepotent to young children. In particular, it has been shown that they use geometric information to represent the location of a target object under a variety of conditions, including spaces of different shapes (isosceles triangle: Huttenlocher & Vasilyeva, 2003; Lourenco & Huttenlocher, 2006; rhombus: Hupach & Nadel, 2005; octagon: Newcombe & Ratliff, 2006) and different sizes (larger rooms: Hupach & Nadel, 2005; Learmonth et al., 2001, 2002; smaller rooms: Lourenco & Huttenlocher, 2006; Lourenco, Huttenlocher, & Vasilyeva, 2005; models: Huttenlocher & Vasilyeva, 2003) as well as from different viewing perspectives (inside or outside: Lourenco et al., 2005) and following different types of disorientation procedures (viewer or space movement: Lourenco & Huttenlocher, 2006). There is even evidence that some sensitivity to geometric information may emerge during infancy, as early as 5½ months of age (Lourenco & Huttenlocher, 2008).

Scale-like properties

Why might the shape of an enclosed space be used so robustly by young children in representing location? And what are the specific properties that support location representation on disorientation tasks? To begin to address these questions, consider a rectangular-shaped space that has been used in several studies with young children (e.g., Hermer & Spelke, 1994; Learmonth et al., 2001; Lourenco

et al., 2005). For each corner in a rectangular space, there are two walls of unequal length: a shorter wall and a longer wall (joined together). Length information, like other dimensions of magnitude, is inherently ordered—a critical property of any scale. Anywhere along a magnitude scale, unequal values in a pair are ordered such that one member is always more or less than the other member. In addition to length information, the corners of a rectangular space are distinguishable because of their left and right positions. Together, relative length information (shorter/longer) and sense (left/right) allow the differentiation of pairs of corners (i.e., corners with the shorter wall to the left of the longer wall vs. corners with the shorter wall to the right of the longer wall).

Recently, Huttenlocher and Lourenco (2007a) examined location representation in a square-shaped space. The task was identical to that in previous experiments (e.g., Hermer & Spelke, 1996). An object was hidden at one of the corners, the child was disoriented following the hiding event, and finally the child was allowed to search for the hidden object. The only difference was that the shape of the surrounding space could not be used to distinguish the corners. What could be used, however, were the cues on the walls. In one condition, the cues were scale-like in nature, that is, ordered in terms of more/less relations along the magnitude scale of size (i.e., smaller vs. larger dots) (see Fig. 1). In two other conditions, the cues were nonscalar; that is, they could be considered discrete and unordered (i.e., blue vs. red and pattern vs. no pattern). Children's performance was shown to vary as a function of condition. In the scalar condition, they searched at the appropriate corners (e.g., the corners with smaller dots to the left of larger dots). In the other two conditions, however, children searched randomly, failing to restrict their choices to the appropriate corners. The difficulty with unordered cues was also reported in a subsequent experiment where the walls in the square-shaped space contained either Xs or Os (e.g., Xs on the left and Os on the right) (Huttenlocher & Lourenco, 2007b).

These results suggested that although young children can reorient using scalar information, they have difficulty in using information that is nonscalar (i.e., discrete and unordered). Based on these results, Huttenlocher and Lourenco (2007a) proposed that scale-like properties, which may be necessary for specifying the shape of an enclosed space but are not used exclusively for this purpose, afford young children an advantage in representing location. But why might such an advantage exist? As indicated above, this location task requires the mapping of two different cues (e.g., larger dots vs. smaller dots) onto left and right positions in space. This type of mapping may be especially difficult for young children; indeed, there are numerous reports of older children confusing left and right relations (e.g., Blades & Spencer, 1990; Lourenco, 2007; Vasilyeva & Bowers, 2006). Scalar information, such as dot size and wall length, may be more easily mapped onto directions in space because there is an inherent direction (order) along the scale. It is this directional analogy that may support the left/right mapping needed to locate a hidden object following disorientation (cf. Bryant & Squire, 2003).

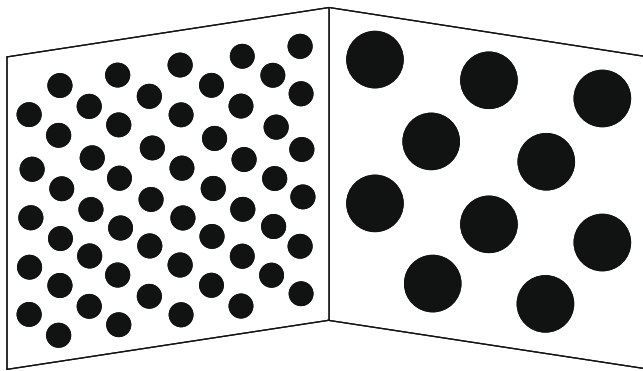


Fig. 1. Illustration of one of the corners in the condition with different-sized dots in the study by Huttenlocher and Lourenco (2007a).

The current study

Some scale-like properties are multidimensional. Consider the smaller and larger sized dots used by Huttenlocher and Lourenco (2007a). As can be seen in Fig. 1, the size dimension is not presented in isolation. There are other (identifiable) dimensions, namely, number and distance. More specifically, the smaller dots are greater in number than the larger dots, and the smaller dots are closer together than the larger dots. Huttenlocher and Lourenco did not isolate size information from number and distance; indeed, this is difficult to do experimentally because dimensions of magnitude are highly correlated. The same-sized walls, for example, place physical constraints on the allowable variation for the size, number, and distance of dots on those walls. Increases in dot size require that there be fewer dots (particularly if the distance between dots is held constant), and increases in the number of dots require that there be a decrease in the distance between dots (particularly if the size of dots is held constant). If scalar information enables reorientation, young children should search at the appropriate locations whether they relied on the size, number, or distance of dots. However, if young children relied on two or more dimensions in combination, this would leave open the possibility that the critical factor for specifying location is the composite of information. If composites enable reorientation, rather than scalar information per se, young children should be able to search at the appropriate locations only when there are multiple cues available, whether or not these cues are scalar in nature.

The focus of the current study is on how composite information affects location representation in young children. The term *composite* is used here to refer to information that is multidimensional and redundant such that each component could, in principle, be used to specify location. Although there is a long history of research showing that composite information is advantageous on a variety of object identification and discrimination tasks (e.g., Eriksen & Hake, 1955; Garner, 1974; Kellman, 1993; Smith, 1989), very little is known about its impact on young children's ability to determine location following disorientation.

Being able to represent location via cues in the external environment is among the most fundamental of cognitive capacities, and for many years it was believed that young children were only capable of relying on egocentric information related to their own bodies (e.g., Piaget & Inhelder, 1948/1967). More recent research, however, has shown that even 18- to 24-month-olds use the shape of an enclosed space to specify the location of a target object, with much attention paid to the possibility that geometric information holds privileged status. Here we expand on this literature by examining the potential impact of more general types of information on young children's ability to represent location. Of particular importance is the impact of composites, which we examined by comparing children's performance on a disorientation task when the available information was presented in multidimensional form with when it involved each of the component parts in isolation (Experiment 1). Of related importance is how performance is affected by isolated scalar information versus isolated nonscalar information (Experiment 1). We also compared children's performance with different types of composites, namely, one in which there was scalar information with one in which there was no scalar information (Experiments 1 and 2). Together, these experiments allow for testing directly whether and, if so, how composite information affords young children an advantage in specifying location.

In the following experiments, we tested 18- to 24-month-olds in a square-shaped enclosed space. As in previous disorientation experiments, children were disoriented after having seen an object hidden at one of the corners and before being permitted to search for it. As indicated above, the disorientation procedure prevents children from tracking their movements relative to the target corner directly. If they are to search for the hidden object at the appropriate corners, they need to use information in the surrounding environment (i.e., on the walls of the square space). The only factor that varied across experiments was the information placed on each of the walls.

Experiment 1: Isolated versus composite information

There were two questions motivating the current experiment. Do scale-like dimensions support location representation on a disorientation task even if presented in isolation? Does composite information afford young children added benefit on this task? To address the first question, we examined the

performance of young children when scalar information was presented in isolation, rather than as a composite, as in [Huttenlocher and Lourenco \(2007a\)](#). To quantify the extent to which scalar information might support location representation, we included two types of isolated dimensions, one of which was clearly scale-like in nature. The scale-like dimension was luminance (i.e., lighter and darker gray). Lighter and darker, like shorter and longer, are ordered such that one is more or less than the other. The other dimension was orientation (i.e., oblique lines facing one direction and oblique lines facing the opposite direction). Orientation of lines contrasts with luminance in that particular angles might be considered ordered in nature (e.g., 45° is less than 90° , at least with respect to distance from a vertical axis), but the more/less relations do not hold for all angles (e.g., 45 and 315° are equal in distance from a vertical axis). Thus, unlike luminance, orientation information is not linear; it cycles over 360° . To address the second question, we presented young children with composite information that we created by combining luminance and line orientation. By using the same dimensions in isolated and combined conditions, a direct measure of the influence of composite information would be possible.

Method

Participants

Across all groups, there were 72 children between 18 and 24 months of age ($M = 20.9$ months, $SD = 1.7$); each group consisted of an equal number of children (12 boys and 12 girls). An additional 5 children were excluded from subsequent analyses because they did not keep their eyes covered during the disorientation procedure ($n = 3$) or because of parental interference ($n = 2$). Although demographic information was not collected systematically, children appeared to come from a variety of ethnic and socioeconomic backgrounds. All children were given a small gift for their participation.

Design and apparatus

Children were assigned to one of three groups. The groups were identical except for the cues on the walls of the square-shaped space. Two of the groups involved isolated dimensions, namely, luminance or line orientation. For the luminance group, each corner involved an adjoining lighter and darker gray wall such that corners were distinguishable with respect to the left/right positions of lighter and darker gray walls (see [Fig. 2](#), top left). For the line orientation group, the corners were distinguishable with respect to the left/right positions of black oblique lines facing opposite directions (see [Fig. 2](#), top right). The third group involved composite information, namely, luminance and line orientation. For the composite group, the corners were distinguishable with respect to the left/right positions of the lighter gray lines in one orientation and the darker gray lines in the other orientation (see [Fig. 2](#), bottom). The grays and lines were identical to those in the isolated luminance and line orientation groups. The pairing of luminance and line orientation was counterbalanced across children.

The experiment took place inside a square-shaped space (wall length = 3.5 feet, height = 18 in.).¹ This space included four identical containers, one at each of the corners. Each container served as a possible hiding location. The square space was positioned at the center of a large (nontransparent) circular enclosure (diameter = 9.5 feet, height = 8 feet) that served to occlude objects in the surrounding room (e.g., toys, furniture). This environment was completely symmetrical, including the positions of circular lights on the ceiling.

Procedure

Each child was tested individually by an experimenter and his or her parent. Prior to the start of the experiment, children were told that they were going to play a “hide and seek game” and they

¹ Many of the initial experiments examining the use of geometric information by young children following disorientation used fully enclosed rooms (e.g., [Hermer & Spelke, 1994, 1996](#); [Learmonth et al., 2001](#)). More recent experiments, however, have included smaller spaces (e.g., [Huttenlocher & Vasilyeva, 2003](#); [Lourenco et al., 2005](#)) that do not fully enclose the participants. The smaller apparatus used in the current study is comparable in size to the spaces used more recently. Although space size has been shown to affect whether landmarks are used to specify location in rectangular-shaped spaces (e.g., [Learmonth, Newcombe, Sheridan, & Jones, 2008](#); [Learmonth et al., 2002](#)), several experiments have shown that young children use geometry following disorientation in spaces of different sizes even when not fully enclosing (e.g., [Huttenlocher & Vasilyeva, 2003](#); [Lourenco et al., 2005](#)).



Fig. 2. Photographs of the squared-shaped spaces used in Experiment 1. Top: The two groups involving isolated dimensions (left: luminance; right: line orientation). Bottom: The group involving composite information (luminance plus line orientation).

chose between one of two small toys (a dog or a duck) to hide. All children entered the circular enclosure through an opening in the curtain that, when shut, left no visible markings. On each trial, the child stood inside the square space and watched the experimenter hide the toy in one of the containers. (The experimenter always stood outside the space, reaching in to hide the toy.) Following the hiding event, the parent stepped inside the box, picked up the child, covered the child's eyes, and spun him or her around, completing approximately four revolutions. After the disorientation procedure, the child was placed in front of one of the walls (a different wall on each trial, randomly determined) and encouraged to find the hidden toy. (The parent always stood outside the box during search, moving around so as not to serve as a cue to the hidden toy's location.) Although the child was permitted to search for the toy until he or she found it, only the first selection was scored for accuracy. Across trials, the toy was hidden in the same corner (counterbalanced across children). If children searched at the hiding corner, the trial was terminated. If children searched at one of the other corners, they were encouraged to keep searching. There were a total of six test trials, with the majority of children (75% across condition) completing at least five trials. The entire experiment took approximately 20 min.

Results

Accuracy scores (i.e., percentage correct) were calculated for each child. The first response on each trial was scored as correct if search occurred at the corner where the target object was hidden or the

corner diagonally opposite it. These corners are identical because of the left/right relations of the cues on the walls (e.g., lighter gray on the left and darker gray on the right). Search included opening or attempting to open a container. Preliminary analyses revealed that accuracy did not vary as a function of the number of trials completed in any of the conditions (luminance group: $p > .50$; line orientation group: $p > .90$; composite group: $p > .50$).

Isolated dimensions

In the luminance group, the mean accuracy score was 59% ($SD = 19$), which was significantly greater than the chance level of 50%, $t(23) = 2.31$, $p < .05$, two-tailed. To ensure that children were disoriented and had not simply kept track of their changing relation to the hiding corner, search at the hiding corner was compared with search at the corner diagonally opposite it. If children are not fully disoriented, they should search more frequently at the hiding corner. This was not the case. Responses were evenly distributed across both corners (28.9% and 29.8%), $t(23) = -0.11$, $p > .90$. Analysis of individual performance revealed that approximately half of the children (11 of 24) performed above chance. To determine whether performance was affected by other factors, such as age (median split), sex, and the corner serving as the hiding location (four possibilities), an analysis of variance (ANOVA) was conducted. There were no significant effects involving any of these between-participants variables (all $ps > .30$).

In the line orientation group, the mean accuracy score was 54.6% ($SD = 14.4$). Unlike performance in the luminance group, the overall score did not differ from chance, $t(23) = 1.56$, $p > .10$, and an ANOVA with age (median split), sex, and hiding corner (four possibilities) as the between-participants variables revealed no significant effects (all $ps > .40$).

Composite information

The mean accuracy score for children in the composite group was 70.1% ($SD = 19.3$). This overall score was significantly greater than the chance level of 50%, $t(23) = 5.09$, $p < .001$, two-tailed, and an examination of individual performance revealed that the majority of children (20 of 24, binomial test, $p < .001$) performed above chance. To ensure that children were fully disoriented, performance at the hiding corner was compared with performance at the corner diagonally opposite it. There was no difference (each approximately 35%), $t(23) = 0.10$, $p > .90$, indicating that children had not simply tracked their changing relation to the hiding corner. As in the other conditions, an ANOVA was conducted to determine whether there were differences related to age (median split), sex, and hiding corner (four possibilities); the analysis revealed no significant effects (all $ps > .20$).

Comparisons across conditions

To determine whether the composite information had an added benefit on this task, planned comparisons across conditions were conducted. These comparisons revealed that performance in the composite condition was significantly better than that in the line orientation condition, $t(23) = 2.96$, $p < .01$, two-tailed, and, more important, was significantly better than performance in the luminance condition where performance was above chance, $t(23) = 2.18$, $p < .05$, two-tailed. It should be noted that there were no age differences across conditions (composite: $M = 20.6$ months, $SD = 1.6$; isolated, luminance: $M = 20.8$ months, $SD = 1.8$; isolated, line orientation: $M = 21.3$ months, $SD = 1.6$) (all $ps > .70$).

Discussion

There were two major findings in this experiment. The first is that when linear scale-like information was presented in isolation (luminance), young children searched at the appropriate corners. This was not the case when the isolated information involved a dimension that is not considered linearly ordered along a scale (line orientation). Without linear scale-like information, performance was at chance, consistent with previous work (Huttenlocher & Lourenco, 2007a, Huttenlocher & Lourenco, 2007b). As noted above, line orientation, although ordered to some extent, is not linear, as is luminance or other magnitude dimensions such as size and number. Thus, it would seem that linear scale-like information, even when presented in isolation, allows young children to determine location

following disorientation, perhaps by supporting the mapping of wall cues onto left and right positions in space.

The second finding is that composite information afforded young children added benefit on this task. Young children performed substantially better when luminance and line orientation were presented in combination than when either dimension was presented alone. Accuracy was highest in the composite condition, and the majority of young children performed above chance. It should also be noted that accuracy in the composite condition was comparable to that in a previous study with smaller and larger dots (i.e., 70% here vs. 71% in [Huttenlocher & Lourenco, 2007a](#)). In this previous experiment, dot size covaried with number and distance cues that generally are highly correlated in the physical world. Here the combination of luminance and line orientation was arbitrary, suggesting that the composite advantage may be quite robust.

Experiment 2: Another type of composite

Having shown that young children benefit from composite information on a disorientation task, it is important to explore the nature of this advantage. There are two issues to consider. The first concerns a possible explanation for the advantage. Perhaps performance is better with composites because there is a greater amount of available information, making it more likely that young children will be capable of using some of that information. Indeed, such redundancy has been shown to support performance on other spatial tasks (e.g., [Huttenlocher, Hedges, & Duncan, 1991](#); for reviews, see [Cheng, Shettleworth, Huttenlocher, & Rieser, 2007](#); [Huttenlocher & Lourenco, 2007c](#)). Relatedly, more dimensional information may make each of the walls more distinctive, increasing the likelihood that each wall will be distinguishable and not confused with another wall. If composite information affords young children an advantage in representing location for these reasons, other types of composites should enhance performance on a disorientation task.

The second issue to consider is whether the composite advantage depends on particular component dimensions. In the experiment by [Huttenlocher and Lourenco \(2007a\)](#), dot size was confounded with number and distance, both of which are scalar in nature (i.e., more or less numerosity and more or less distance between dots). Similarly, in Experiment 1, one of the dimensions comprising the composite was scalar (luminance). Thus, it is important to determine whether scalar information plays a critical role in the composite advantage.

To address both issues, we tested young children on our disorientation task with another type of composite. In the current experiment, we combined color (blue vs. red) and pattern (Xs vs. Os) dimensions, neither of which is experienced as linear scale-like information. As indicated above, red and blue and Xs and Os are discrete and unordered such that neither member in each pair is represented as more or less than the other member. If the composite advantage is due simply to the greater number of cues, young children should be able to search at the appropriate corners following disorientation. However, if the composite advantage is more specific and requires some scalar information, young children should have difficulty in this task.

Method

Participants

There were 24 children (12 boys and 12 girls) in this experiment. An additional 3 children were excluded from subsequent analyses because they did not keep their eyes covered during the disorientation procedure ($n = 1$) or because of experimenter error ($n = 2$). As in the previous experiment, the children were between 18 and 24 months of age ($M = 21.9$ months, $SD = 2.0$) and appeared to come from a variety of ethnic and socioeconomic backgrounds. All children were given a small gift for participating.

Apparatus and procedure

The apparatus and procedure in this experiment were identical to those in the previous experiment. The only difference was the cues on each of the walls. Here the composite was made up of

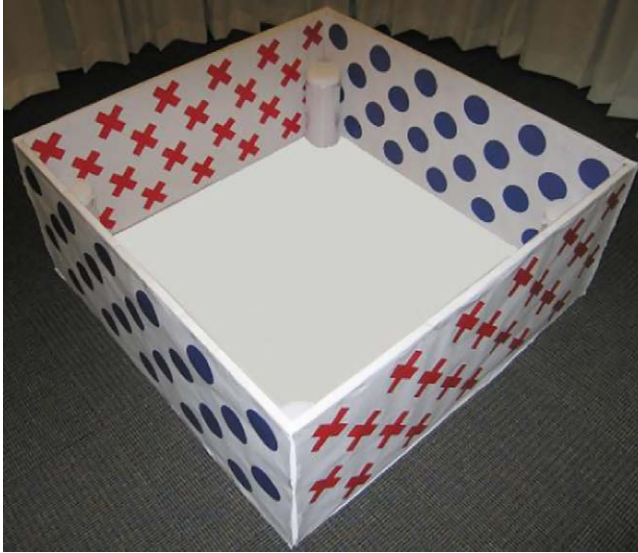


Fig. 3. Photograph of the square-shaped space used in Experiment 2. Unlike the previous experiment, the composite information here did not include a scalar dimension (color plus pattern). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

dimensions that are not considered scalar. As can be seen in Fig. 3, the dimensions were color (red vs. blue) and pattern (Xs vs. Os). The red and blue colors, which did not vary in luminance, and the sizes of Xs and Os were identical to those in Huttenlocher and Lourenco (2007a), Huttenlocher and Lourenco (2007b). The pairing of red and blue with Xs and Os was counterbalanced across children.

Results and discussion

All children completed at least five test trials, and as in the previous experiment, accuracy scores (i.e., percentage correct) were calculated for each child. On each trial, the first response was scored as correct if children searched at the hiding corner or the corner diagonally opposite it. Search included opening or attempting to open a container. The mean accuracy score for children in this experiment was 48.8% ($SD = 19.8$). Unlike the composite condition (or luminance condition) in Experiment 1, performance did not differ from chance, $t(23) = -0.31$, $p > .70$, two-tailed. And an ANOVA with age (median split), sex, and hiding corner (four possibilities) as between-participants variables revealed no significant effects (all $ps > .06$).

The results from this experiment suggest that the greater amount of information (i.e., two dimensions vs. one dimension), which may serve to make the walls more distinctive, is not sufficient for supporting location representation on this task. There was no advantage as in the previous experiment. Young children searched randomly at all of the corners. These results help to rule out the possibility that when a composite advantage exists, it is not due simply to the greater number of, and perhaps more distinctive, cues. These results instead point to the importance of scalar information on this task that, when paired with other information, may lead to an advantage in determining location following disorientation.

General discussion

In the current experiments, we examined the ability of young children to locate a target object after having themselves been disoriented. The target object was always located in one of the corners of a

square-shaped space, where geometry does not allow for distinguishing the corners. To distinguish the corners, then, young children would need to rely on the left and right positions of wall cues (e.g., lighter gray wall on the left and darker gray wall on the right). In previous work, it was shown that 18- to 24-month-olds were capable of representing location in a square space so long as the available information involved scalar dimensions. In the [Huttenlocher and Lourenco \(2007a\)](#) experiment, however, scalar information was not presented in isolation. Number and distance cues were also available, making it difficult to determine whether scalar information per se or the composite situation was the critical factor. Here we expanded on this work by examining the contributions of composite and scalar properties in location representation on a disorientation task.

There were two major findings in the current study. The first concerns the situation with isolated dimensions. In this situation, young children searched at the appropriate corners following disorientation only when the information on the walls involved a linear scale-like dimension (luminance); they searched randomly when the available information was not linearly ordered (line orientation). The second finding concerns the composite situation. It was found that young children searched with greatest accuracy when the composite involved a scalar dimension (luminance plus line orientation). There was no benefit if the composite did not include scalar information (color plus pattern).

The advantage of scale-like dimensions

The current findings reveal that particular types of information afford young children an advantage in representing location on a disorientation task. The first type involves scale-like dimensions. Distinguishing the corners in an enclosed space following disorientation requires the mapping of two wall cues onto left and right positions in space. It is not sufficient to be able to distinguish the two walls (i.e., lighter and darker gray); the relevant information must be related to spatial directions (i.e., left and right). Scalar information is inherently ordered. Anywhere along a linear magnitude scale, two unequal elements involve one that is more or less than the other. A size scale involves elements that are larger or smaller. A luminance scale involves elements that are darker or lighter. There is direction along these scales that may be critical for supporting the necessary mapping of wall cues onto left and right directions in space ([Bryant & Squire, 2003](#); [Huttenlocher & Lourenco, 2007a](#)).

In the current study, young children searched appropriately when the available information was luminance but not when it was line orientation. Above, we predicted that line orientation could be difficult to use on this task because of the nonlinear nature of the information. Although some angles might be considered as more or less than others (at least in reference to distance from a vertical axis), angular information cycles over 360° such that particular angles (e.g., 45 and 315°) are actually equivalent relative to a vertical axis. It should be noted that the oblique lines were oriented in opposite directions and could be conceptualized in terms of distinctive up versus down patterns. On the one hand, up/down patterns remove the need for left/right mappings in space that could have served to simplify the task. On the other hand, and as indicated above, the oblique lines form a mirror image that may be particularly difficult for young children to map onto left and right positions. Indeed, the difficulty with mirror images has been well documented on other spatial tasks with older children (e.g., [Casey, 1984](#); [Corballis & Zalik, 1977](#); but see [Bryant & Squire, 2003](#)).

It could be argued that luminance differs from other linear scale-like dimensions such as size and number. Unlike size and number, a luminance scale might not be clearly marked (at the minimum endpoint). Some individuals may regard lighter gray as less (with respect to black) than darker gray, whereas others may regard darker gray as less (with respect to white) than lighter gray. Although developmental differences in this ordering have been documented, there appears to be consistency within adults and within children (e.g., [Pinel, Piazza, Le Bihan, & Dehaene, 2004](#); [Smith & Sera, 1992](#)). Young children, for example, tend to regard lighter as less than darker. Even at a young age, then, there may be a clearly marked order for luminance that may function to support the mapping of lighter and darker gray onto directions in space. It will be important for future work to examine whether different types of scalar information affect performance in predictable ways as well as whether nonscalar information might, under certain conditions, be conceptualized along a continuum and considered ordered to some extent, so as to facilitate location representation in young children.

The advantage of particular composites

The second type of advantage involves particular types of composites. When additional information (line orientation) was combined with a scale-like dimension (luminance), there was clearly an added benefit on performance. Young children were more accurate in this composite situation than in the situation where the scale-like dimension was presented in isolation. The advantage is particularly striking because the composite involved the arbitrary combination of luminance and line orientation which, unlike dimensions such as size and number, do not appear to covary naturally in the world. It is also important to note that one of the component dimensions (line orientation), when presented in isolation, was not used by young children to determine location. Yet when line orientation was presented together with luminance, children's performance appeared to be comparable to that in the experiment by [Huttenlocher and Lourenco \(2007a\)](#) where size information (and perhaps number and distance) could be used to specify location.

So why might particular composites afford young children an advantage in representing location on a disorientation task? We would suggest that, together with scalar information, the composite situation serves to create a more stable representation of location by enhancing memory for the underlying representation. For the most part, it is taken for granted that the memory demands on disorientation tasks are not insignificant for young children ([Sluzenski, Newcombe, & Satlow, 2004](#)). The relevant location information must be maintained in memory, on every trial, following a disorientation procedure that is several seconds long and involves behaviors (spinning and covering eyes) that may interfere with maintenance and retrieval. In the memory literature, there is a well-established phenomenon suggesting that particular materials (e.g., stories and event sequences) are better remembered if there is some causal relation among the component elements (e.g., [Bauer, 1992](#); [Bauer & Travis, 1993](#)). There is also likely to be a greater advantage when causally related information is joined with some arbitrary dimension. Luminance, which involves ordered relations, may function similarly when combined with line orientation, increasing the likelihood that the relevant information will be maintained and retrieved from memory.

[Garner \(1974\)](#) once distinguished between separable and integral dimensions (see also [Smith, 1989](#)). When dimensions exist in combination, *separable* refers to dimensions that retain their perceptual independence, whereas *integral* refers to dimensions that form a single perceptual whole. Multi-dimensional information is not always advantageous, and on discrimination tasks adult participants are better and faster when dealing with integral dimensions than when dealing with separable dimensions. In addition to supporting the mapping of wall cues onto directions in space, scale-like dimensions (e.g., luminance) may support integration with other sources of information (e.g., line orientation) which, as indicated above, may enhance performance by ensuring that the relevant cues are accessible following a delay. Nonscalar dimensions (e.g., color and pattern), when presented in combination, may be treated independently and represented in separable form, doing little to support location representation on a disorientation task.

Some implications

The findings from the current study have important implications for existing research on location representation in young children. Consider the [Huttenlocher and Lourenco \(2007a\)](#) experiment where dot size covaried with number and distance information. When size, number, and distance cues all were available, children searched at the appropriate corners on approximately 70% of the trials, which is exactly the level of accuracy achieved by children in the current study with the composite of luminance and line orientation and, importantly, is higher than the situation where luminance information was available in isolation. Although it is not possible to directly compare performance across these experiments, it would be reasonable to suggest that young children in the previous study likely benefited from the *composite* of scalar information.

In another study, [Nardini, Atkinson, and Burgess \(2008\)](#) also tested 18- to 24-month-olds on a disorientation task in a square-shaped space. In all conditions, each corner consisted of adjoining blue and white walls. In their "plain" condition, there was no additional information; only the left/right positions of the blue and white walls could be used to specify location. In their "animals" and

“asymmetric” conditions, however, cues were added to these walls. In all three conditions, young children searched at the appropriate corners at levels significantly above chance. Huttenlocher and Lourenco (2007a) found that children in the same age range were unable to use colored walls (red and blue) to determine location. The blue and white walls in the study by Nardini and colleagues varied in luminance (M. Nardini, personal communication, March 31, 2007), whereas the red and blue walls in the study by Huttenlocher and Lourenco did not, providing a potential explanation for the discrepancy in results across these studies. Furthermore, the additional cues in the animals and asymmetric conditions might have served to support performance on the disorientation task by creating a composite situation that here was shown to afford young children an advantage in determining location.

Finally, it is worth considering how the account proposed in the current article might explain why young children are particularly good at representing geometric information such as the rectangular shape of a surrounding room. In rectangular rooms, accuracy levels during search are generally quite high, ranging from 70% to 80% (e.g., Hermer & Spelke, 1996; Learmonth et al., 2001; Lourenco et al., 2005). In rectangular rooms, the corners are distinguishable with respect to the left and right positions of shorter and longer walls. The length of walls in rooms might be considered composites of scale-like dimensions. There is information related to both area and perimeter, which even young infants have been shown to use for discrimination purposes (e.g., Clearfield & Mix, 1999; Feigenson, Carey, & Spelke, 2002). Although potentially quite different from the combination of luminance and line orientation, the multidimensional nature of wall length may function similarly, supporting the representation of location by young children on disorientation tasks.

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