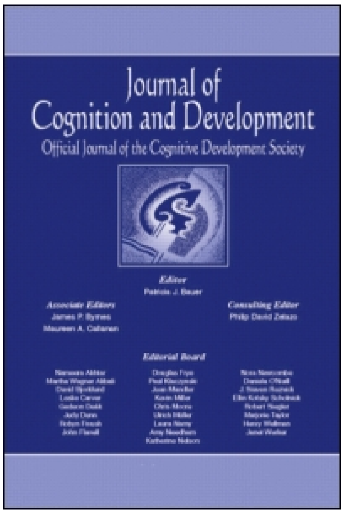


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# The Influence of Boundaries on Young Children's Searching and Gathering

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# The Influence of Boundaries on Young Children's Searching and Gathering

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Two experiments were conducted to examine how boundaries influence the organization of the gathering and searching of 3- and 4-year-olds. In Experiment 1, children retrieved miniature carrots that were in plain view from a dollhouse that was divided in half by a visual, a functional, or a visual–functional boundary. There was also a control condition in which no boundary was present. Children exhibited more organized gathering in the visual and visual–functional boundary conditions than in the functional boundary and no-boundary conditions. This suggests that visual rather than functional properties of boundaries influenced the organization of young children's gathering behavior. In Experiment 2, we increased task difficulty by requiring children to search for carrots that were out of sight. Unlike in Experiment 1, children produced more organized searching in the visual, visual–functional, and the functional boundary conditions than in the no-boundary condition. Our discussion focuses on the role of the physical environment in organizing behavior.

The ability to organize efficient searches is a fundamental aspect of human and animal behavior. How children organize their searches for objects has been of considerable interest to developmental psychologists because it can tell us something about how children organize information about location (e.g., Cornell & Heth, 1983, 1986; Plumert, Pick, Marks, Kintsch, & Wegesin, 1994). That is, the order in which children retrieve objects can provide useful information about their ability to group or cluster locations. Search behavior has also been widely used as an index of other cognitive abilities. For example, children's search behavior has been used to study forward planning (Fabricius, 1988), strategic remembering (DeLoache, Cassidy, & Brown, 1985; Wellman, Ritter, & Flavell, 1975), logical

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thinking (Haake, Somerville, & Wellman, 1980; Somerville & Capuani-Shumaker, 1984), and symbolic functioning (e.g., DeLoache, 1987). Despite the large body of work on children's search behavior, relatively little is known about the factors that influence the organization of young children's searches for objects. The purpose of this investigation was to explore how the structure of the physical environment influences efficient gathering and searching.

Two of the most obvious costs in any search endeavor are the expenditure of too much energy and failure to remember locations. In other words, one generally wants to avoid searching in a manner that results in going long distances to obtain very few goods or in forgetting to search some relevant locations. An effective way to minimize the distance traveled and maximize the number of locations remembered is to organize searches by proximity. That is, one can limit the number of times the search area is traversed and increase the likelihood of searching all locations by searching the locations that are in close proximity to oneself first and by searching locations that are in close proximity to each other in succession. Thus, one might start with the location nearest oneself and then move on to the next location closest to that one. Alternatively, one might concentrate searching in the most likely or most productive areas, even if they are not the locations nearest oneself.

To what extent do young organisms use the proximity principle to organize their searches? A classic study by Menzel (1973) demonstrated that juvenile chimpanzees used the proximity principle to produce a least distance strategy when searching for food. In Menzel's study, chimps watched while an experimenter randomly hid 18 pieces of food in their enclosure. After all the food was hidden, they were allowed to search for the food in any order they chose. The chimps typically started with the nearest location, then moved to the next nearest location, and so on. The chimps also demonstrated that they could embed this least-distance strategy within a preference strategy. That is, when the food was equally divided into preferred and nonpreferred foods (fruits vs. vegetables), the chimps used a least-distance strategy first to retrieve the fruits. Then, after consuming the fruits, they retrieved the vegetables using the same strategy. They also clustered their searches by proximity when the hiding locations were clustered at the far left and far right thirds of the enclosure and maximized their rate of acquisition by starting their searches in the most likely third of the enclosure when the food was divided unequally. In all of these search tasks, the number of redundant and inaccurate searches was very small, and the rate of recovery was very high.

Studies with children have shown that the ability to cluster locations by proximity develops over the preschool years and into early childhood (Cornell & Heth, 1983, 1986; Fabricius, 1988; Haake & Somerville, 1985; Plumert et al., 1994; Wellman, Somerville, Revelle, Haake, & Sophian, 1984). For example, Wellman et al. found that 4- and 5-year-olds used the proximity principle to organize their searches for a small set of objects. In this study, 3-, 4-, and 5-year-old children retrieved five Easter eggs they had previously seen hidden in a random order on their preschool playground. The Easter eggs were hidden in two clusters of locations, either in identical buckets or in natural locations. Although they did not minimize the overall distance traveled, 4- and 5-year-olds minimized the number of traverses across the playground when the hiding locations were identical containers. Three-year-olds, however, did not minimize the number of traverses across the playground. Cornell and Heth (1983) also found that 3-year-olds' searches were significantly less organized than 5-year-olds' searches. In Cornell and Heth's (1983) study, children retrieved 12 pieces of a puzzle that they watched the experimenter hide in various locations around the room. For some children the hiding locations were identical, whereas for others, they were unique. Also, some children were allowed to retrieve the items freely, whereas others were required to return to the center of the room after each search. As in the Wellman et al. study, children were most likely to use a proximity strategy when the containers were identical, indicating that they may have been more likely to consider the locations as a group when the locations were identical than when they were unique.

Although these findings suggest that structure in the physical environment may play a role in facilitating children's efficient searching, little is known about the type of structures that might have such an effect. One aspect of the physical environment that might be expected to influence the organization of children's searching is the presence of physical boundaries, which might serve to help children cluster their searches by proximity. To date, however, most studies of children's search organization have been carried out in spaces without boundaries. One exception was a study conducted by Plumert et al. (1994), which compared the organization of 6-year-olds' searches for objects with their directions for finding objects. In Plumert et al.'s study, children hid several objects on the three floors of their own home. Children then searched for the objects or gave directions to another person for finding the objects. When searching for the objects, the children clustered their searches by floor. However, when giving directions to another person, they did not produce directions organized by floor. Plumert et al. hypothesized that children's searches were more organized than their directions because the effort involved in traversing the stairs constrained their movement from floor to floor, thus promoting clustering by floor. If their hypothesis is correct, any functional boundary (i.e., a barrier that constrains physical movement) should have a similar organizing influence on searching. This hypothesis has not been directly tested, however.

Although little is known about how boundaries affect the organization of searches, numerous studies have shown that boundaries influence memory for location (e.g., Acredolo & Boulter, 1984; Allen, 1981; Cohen & Weatherford, 1980; Heth & Cornell, 1985; Hirtle & Jonides, 1985; Kosslyn, Pick, & Fariello, 1974; McNamara, 1986; Newcombe & Liben, 1982; Plumert & Hund, 2001). In general, people tend to think that locations separated by boundaries are further apart than they actually are. There is also some evidence to suggest that children and adults respond differently to different kinds of boundaries. In particular, Kosslyn et al. had children and adults learn the locations of objects in a room divided into four quadrants by opaque curtains (on the *x* axis) and a low picket fence (on the *y* axis). When asked to estimate the distance between pairs of objects that were separated by the opaque curtains, both adults and children overestimated the distances. However, when they were asked to estimate the distances between pairs of objects separated by the picket fences, only children overestimated the distances between objects. Thus, adults but not children were able to disregard the functional distance around the "transparent" boundary and estimate distances between objects accurately.

Kosslyn et al. (1974) suggested that the spatial representations of children may be more dependent on functional distance than those of adults (for an alternative view, see Newcombe & Liben, 1982). That is, children's estimations of distance may be more strongly tied to their own physical movements and, thus, may be more strongly influenced by the constraints placed on their movements by the functional aspects of boundaries. One problem with drawing this conclusion, however, is that the visual and functional properties of the two types of boundaries were not clearly separated. In other words, both the curtains and the fence visually subdivided the locations into regions and increased the functional distance between locations. However, the curtains were more visually salient than the fence because they fully occluded objects across the boundary. Conversely, the fence was more functionally salient than the curtains because it fully inhibited movement across the boundary (unlike the curtains, which could be pushed aside). Thus, it is not clear to what extent children were responding to the functional versus the visual properties of the two types of boundaries.

The goal of this investigation was to examine how the visual and functional properties of boundaries influence the efficiency of 3- and 4-year-olds' gathering and searching behavior in a small-scale space. We chose these ages because Wellman et al. (1984) found that 3- and 4-year-olds differed in their ability to organize efficient searches. In particular, 4-year-olds minimized the number of traverses across their school playground, whereas 3-year-olds did not. We chose to use a small-scale space rather than a large-scale space because younger children may be more likely to organize efficient searches when all the hiding locations are visible from a single vantage point. In other words, the 3-year-olds in the Wellman et al. study may have had difficulty organizing efficient searches because they had to both remember the arrangement of hiding locations and organize their retrieval of the objects. At present, it is not known whether younger children are more likely to organize efficient searches in small-scale spaces than in large-scale spaces. Moreover, it is not known whether boundaries operate differently in small-scale spaces than in large-scale spaces.

In two experiments, 3- and 4-year-old children retrieved a set of identical objects located in, on, or near various objects in a small dollhouse. The dollhouse was divided into two sides by boundaries that varied in terms of their visual and functional properties. The visual–functional boundary (a tall opaque barrier) subdivided the dollhouse both visually and functionally (i.e., it impeded movement from one side of the dollhouse to the other). The visual boundary (a short opaque barrier) subdivided the dollhouse visually but had no functional consequences (i.e., it did not impede movement from one side of the dollhouse to the other). The functional boundary condition (a tall transparent barrier) subdivided the dollhouse functionally but not visually. There was also a control condition in which no boundary subdivided the dollhouse. The no-boundary condition was included to provide a baseline measure of children's spontaneous tendency to organize their searches by side in the absence of any physical boundary demarcating the two sides. We reasoned that if functional considerations play a greater role in organizing young children's searching, any boundary (a tall transparent or opaque wall) that functionally subdivided the space should result in more organization (i.e., proximity clustering on each side of the boundary). Alternatively, if visual information plays a greater role, any visually salient boundary (a tall or short opaque wall) that subdivided the space should result in more organization.

## EXPERIMENT 1

### Method

#### *Participants*

The participants were 48 three-year-olds (*M* age = 3 years 6 months, range = 3 years 1 month–3 years 11 months) and 48 four-year-olds (*M* age = 4 years 5 months, range = 4 years 0 months–4 years 11 months) from primarily middle- to upper-middle-class families in the Iowa City area. Children were recruited through a child participant database maintained by the Department of Psychology at the University of Iowa. Parents received a letter describing the study, which was followed by a phone call inviting them to participate.

#### *Apparatus and Materials*

The experimental space was a model house, 76 cm wide × 43 cm deep × 33 cm high (see Figure 1). There were eight pieces of furniture in the model house. These included a TV, chair, piano, couch, bed, table, dresser, and a bookshelf. Sixteen miniature carrots served as the retrieval targets. One carrot was placed on and another carrot was placed next to each furniture item. Three different boundaries were used to divide the dollhouse in half. A tall opaque boundary, equivalent to a solid wall, was made of a 33 cm high × 43 cm long piece of plywood that was painted white. A short opaque boundary, equivalent to a low wall, was made of a 7.6 cm high × 43 cm long piece of plywood that was topped by a 1.2 cm wide × 43

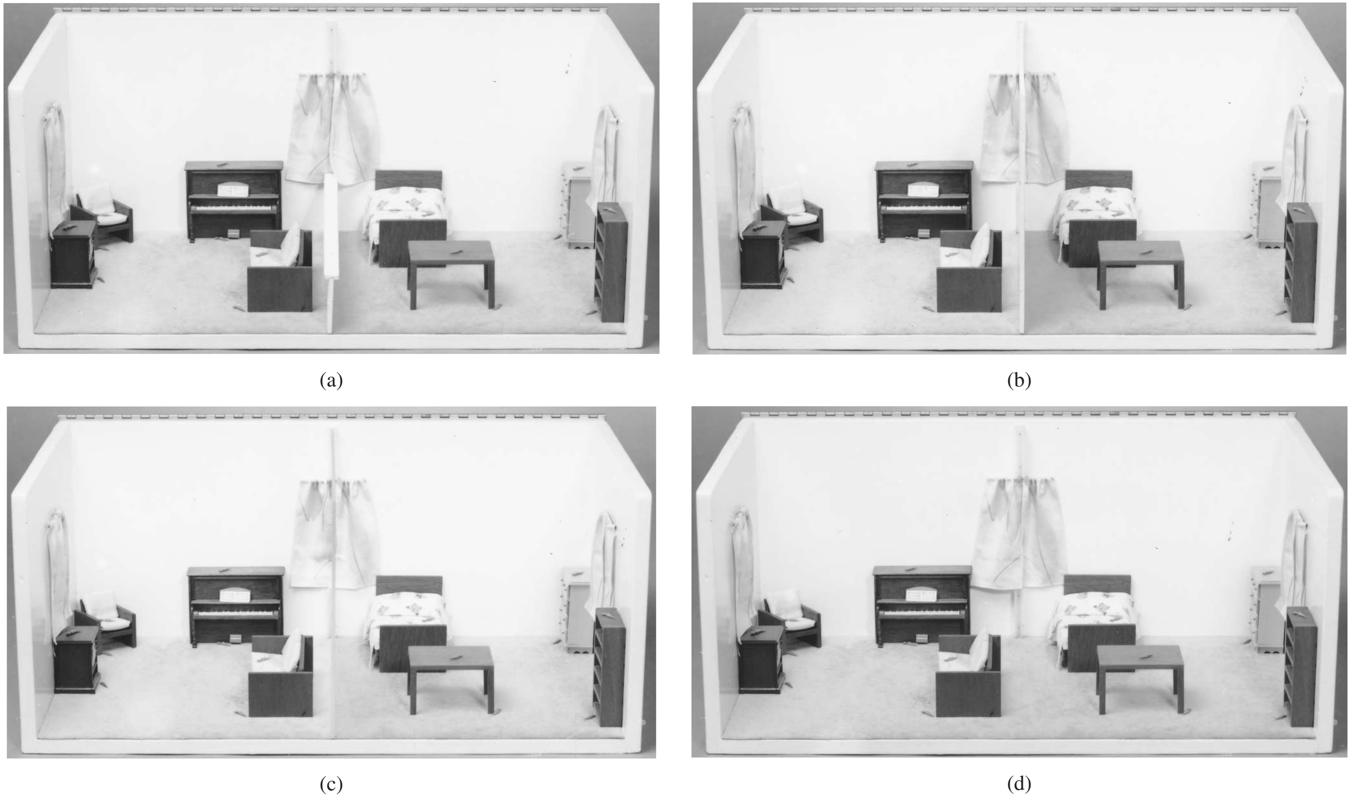


FIGURE 1 (a) Visual (short opaque) boundary condition, (b) visual–functional (tall opaque) boundary condition, (c) functional (tall transparent) boundary condition, and (d) no-boundary (control) condition.

cm long piece of plywood, which was also painted white. A tall transparent boundary, equivalent to a glass wall, was made of a 33 cm high × 43 cm long piece of Plexiglas™. The dollhouse was placed on a small table that was 76 cm high × 76 cm wide. A Panasonic camcorder was mounted directly above the dollhouse, providing a bird's-eye view of the dollhouse so that the session could be recorded on videotape.

### Design and Procedure

Children were randomly assigned to one of four boundary conditions. The boundaries varied in terms of their visual and functional properties. In the visual boundary condition (Figure 1a), the short opaque boundary subdivided the dollhouse visually but had no functional consequences (i.e., it did not impede movement from one side of the dollhouse to the other). In the visual–functional boundary condition (Figure 1b), the tall opaque boundary subdivided the dollhouse both visually and functionally (i.e., it impeded movement from one side of the dollhouse to the other). In the functional boundary condition (Figure 1c), the tall transparent boundary subdivided the dollhouse functionally (i.e., it impeded movement from one side of the dollhouse to the other) but not visually.[1] In the no-boundary condition (Figure 1d), there was no boundary subdividing the dollhouse.

Children were tested individually in a single session in the laboratory. They were familiarized with the dollhouse by participating in a direction-following study with the same apparatus (without boundaries) prior to this experiment. Immediately after the direction-following study, children were asked to sit with their back to the dollhouse while the experimenter placed the appropriate boundary and 16 miniature carrots in the dollhouse. One carrot was placed on each piece of furniture and one carrot was placed next to each piece of furniture on the floor of the dollhouse. All carrots were in plain view. The children were then called back and positioned directly in front of the dollhouse, at the midline, so that they had a clear view of both sides of the dollhouse. The experimenter gave children a small bucket and asked them to "Get all of the carrots out of the dollhouse and put them in the bucket." The bucket was used to minimize the use of both hands to retrieve carrots simultaneously. The experimenter recorded the order in which children retrieved the carrots. When children had retrieved all of the carrots or had paused for more than 15 sec, the experimenter asked the children, "Did you get all of them?" Once children answered in the affirmative, the experimenter praised their efforts. After choosing two prizes, the children were thanked for their participation.

[1]It should be noted that although the transparent barrier allowed visual access to both sides of the dollhouse simultaneously, it was not invisible to the children.

### Coding and Measures

*Organization of gathering.* We examined several issues that concerned the organization of children's gathering behavior. The first was where children began their gathering. That is, did children start at a location near themselves? To answer this question, we coded the initial starting point (location of the first carrot retrieved) in terms of the front versus the back of the dollhouse. The second issue was whether children clustered their retrieval efforts in accordance with the two sides of the dollhouse. To address this issue, we calculated adjusted ratio of clustering scores from the retrieval order data. Adjusted ratio of clustering scores represented the total number of observed category repetitions (i.e., repetitions in one side) divided by the total number of possible category repetitions and corrected for chance (Roenker, Thompson, & Brown, 1971). A score of 1.0 represents perfect clustering, and a score of 0 reflects chance clustering.

*Timing of the first midline crossing.* We also coded the number of carrots children retrieved from one side of the dollhouse before they moved to the other side of the dollhouse as a measure of the timing of the first crossing of the boundary. Although clustering scores indicated how much clustering by side children did, they did not give us any specific information about when the clustering began or ended. In other words, when the clustering scores were less than perfect, we did not know whether it was because children started out clustering and then their organization deteriorated for some reason or because they started out rather randomly and then got organized as they went along. In this task, where both sides of the dollhouse were visible from the child's initial perspective, early crossings would indicate that the initial gathering was driven by simple sighting, whereas later first crossings would suggest more strategic (forward planning) use of clustering by side.

*Effects of boundaries on physical movement.* To examine whether the boundaries had any effect on children's physical movements, we coded several hand and body movements.[2] First, we coded the number of times children in the no-boundary and visual boundary (short opaque) conditions reached laterally across the midline to retrieve a carrot from the other side without removing their hand from the dollhouse. This measure allowed us to determine whether children were in fact crossing the midline without removing their hands from the dollhouse

[2]These particular measures were developed in response to suggestions by reviewers about the determination of exactly what functional consequences the boundaries might have in such a small-scale space. Data for three children in Experiment 1 and four children in Experiment 2 were unavailable for all measures of physical movement because of video equipment failure. Three additional children in Experiment 1 and four additional children in Experiment 2 were omitted from the analysis of stepping movements because they were seated while retrieving the carrots.

when there was no functional boundary to prevent them from doing so. Children received a single score representing the number of times they reached laterally across the midline of the dollhouse. Second, the number of times children's hands collided with the barriers in the visual (short opaque), visual–functional (tall opaque), and functional (tall transparent) boundary conditions was recorded to determine whether children were inclined to move their hands laterally but were prevented from doing so by the presence of a boundary. This measure was of particular interest in determining whether children were aware of the transparent boundary to the same degree as the other two boundaries. Finally, we recorded the number of steps children took to the side as they moved their search efforts from one side of the dollhouse to the other on the first crossing of the midline. Only steps associated with the midline crossings were of interest because that was the point at which one would expect that the boundaries should have exerted their greatest influence. Only the first midline crossing was used because it was not influenced by previous experience. Hence, it provided the most conservative test of boundary effects. This score reflected the number of steps taken between the time children removed the last object before the midline crossing (when the hand holding the carrot crossed the threshold) and the time they removed the first object after the midline crossing. Intercoder reliabilities for all three measures (i.e., lateral reaches, barrier collisions, and steps) were calculated for 19 children (20% of the sample) with exact percentage agreement. Reliability was high for all measures, ranging from 95 to 100%

*Number retrieved and gathering times.* Finally, the total number of carrots retrieved and the total time required to retrieve the carrots was coded to provide some information about the amount of effort involved in the task. Gathering times were coded from the point at which the child's hand first crossed the threshold of the dollhouse to the time the child's hand crossed the threshold as they pulled out the last carrot they retrieved.

## Results

### Organization of Gathering

*Starting point.* Not surprisingly, the vast majority of children (98%) began their gathering at the front of the dollhouse, which indicates that they used the proximity principle to choose their starting point.

*Clustering by side.* The primary question of interest was how the various boundaries influenced children's tendency to organize their gathering behavior by dollhouse side. First, the clustering scores in all conditions were significantly above chance (i.e., 0), $ts > 10.0$, $ps < .0001$, which indicates that children had a tendency to organize their gathering behavior by side even when there was no visible line of demarcation between the two sides. To determine whether the level of clustering differed by boundary condition, clustering scores were entered into a 2 × 4 (Age × Boundary Condition) analysis of variance (ANOVA). This analysis yielded a significant main effect of boundary condition, $F(3, 88) = 4.30$, $p < .01$. Follow-up tests revealed that clustering scores were significantly higher when there was a salient visual boundary of any type present. That is, clustering scores were higher in the visual (short opaque $M = .84$, $SD = .14$) and visual–functional (tall opaque $M = .84$, $SD = .21$) boundary conditions than in the functional (tall transparent $M = .72$, $SD = .18$) and the no-boundary ($M = .71$, $SD = .18$) conditions.[3] No other differences were significant. In other words, children's tendency to cluster their retrieval efforts first in one side of the dollhouse and then in the other was significantly enhanced when a visually salient boundary divided the dollhouse.

*Timing of first midline crossing.* We also looked at when the first crossing of the midline from one side of the dollhouse to the other occurred. The number of carrots that were retrieved before the midline was crossed for the first time was entered into a 2 × 4 (Age × Boundary Condition) ANOVA. This analysis yielded a significant main effect of boundary condition, $F(3, 88) = 4.43$, $p < .01$. In contrast to the clustering scores, follow-up tests revealed that the boundary effect found for the timing of the first midline crossing extended to all types of boundaries. That is, children retrieved five carrots on average before moving from one side of the dollhouse to the other when there was a boundary of any type present (functional boundary $M = 5.13$, $SD = 2.36$; visual boundary $M = 4.96$, $SD = 2.46$; and visual–functional boundary $M = 5.54$, $SD = 2.59$). In contrast, children only retrieved three carrots on average before crossing the midline when there was no boundary present ($M = 3.2$, $SD = 2.29$). Thus, it would appear that children initially responded to all three types of boundaries by clustering their gathering by side but the organizing effect of the boundary diminished after the first crossing of the midline in the functional (tall transparent) boundary condition.

### *Effects of Boundaries on Physical Movement*

*Number of lateral midline crossings.* The first question we addressed was whether children were more likely to reach across the midline without removing their hand from the dollhouse in the no-boundary condition than in the visual (short opaque) condition. The number of times children crossed the midline laterally without removing their hand from the dollhouse was entered into a 2 × 2 (Age × Boundary Condition) ANOVA. This analysis yielded no significant effects of age or boundary condition. Children made an average of 0.17 ($SD = 0.49$) lateral

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[3]All follow-up tests were conducted using Fisher's protected least significant difference test.

crossings in the visual boundary condition and an average of 0.33 (*SD* = 0.56) lateral crossings in the no-boundary condition. Thus, although children were somewhat less likely to reach across the midline without removing their hand from the dollhouse in the visual than in the no-boundary condition, the presence of a boundary did not significantly inhibit their reaching across the midline in this experiment.

*Number of barrier collisions.* The second question we addressed was whether children were more likely to collide with the transparent barrier than the tall opaque or short barriers when reaching for an object on the other side of the dollhouse. Chi-square analyses revealed that the number of children whose hands collided with the barriers differed significantly across the three conditions, $\chi^2(2, N = 93) = 9.86, p < .01$. Further analyses revealed that more children collided with the tall transparent barrier than either the tall opaque barrier, $\chi^2(1, N = 46) = 6.90, p < .01$, or the short opaque barrier, $\chi^2(1, N = 46) = 4.21, p < .05$. The number of children colliding with the tall opaque and short opaque barriers did not differ significantly, $\chi^2(1, N = 46) = 1.02$, *ns*. The percentage of children colliding with the short opaque, tall opaque, and transparent barriers was 4, 0, and 26%, respectively. This suggests that the transparent barrier was less visually salient than the other barriers.

*Number of steps associated with the first midline crossing.* The third question we addressed was whether children were more likely to take a step or two to the side when they reached for an object on the other side of the dollhouse when a boundary was present. The number of steps children took as they crossed the midline for the first time was entered into a 2 × 4 (Age × Boundary Condition) ANOVA. This analysis revealed a significant effect of boundary condition, $F(3, 81) = 3.37, p < .05$. Follow-up tests indicated that children took significantly more steps in the visual (short opaque $M = 1.00$, $SD = .78$), visual–functional (tall opaque $M = .78$, $SD = .67$), and functional (tall transparent $M = .78$, $SD = .85$) boundary conditions than in the no-boundary condition ($M = .35$, $SD = .49$). Thus, children were more likely to take steps when crossing the midline if there was a boundary of any type present, which indicates that the barriers had functional consequences for the children's physical movements.

### Number Retrieved

Finally, we examined how many carrots children retrieved. The number of carrots retrieved was entered into a 2 × 4 (Age × Boundary Condition) ANOVA. This analysis yielded no significant effects of age or boundary condition. The mean number of carrots retrieved was 15.5 (*SD* = 0.71) out of 16, which indicates that this was a very easy task for children of these ages.

### Gathering Times

To gain some measure of the amount of physical effort involved in the gathering task, the total amount of time spent gathering was entered into a 2 × 4 (Age × Boundary Condition) ANOVA. No effect for age or boundary condition was found. The mean total time spent gathering was 53 sec ($SD = 16.2$), which further indicates that this was a relatively easy task for children.

## Discussion



The results of this experiment clearly indicate that 3- and 4-year-olds used the proximity principle to organize their gathering efforts. In all conditions, children organized their gathering behavior in accordance with the two sides of the dollhouse. More important, the tendency to organize by side was significantly enhanced when there was a salient visual boundary present. That is, despite the fact that children in the functional (tall transparent) boundary condition initially delayed crossing the midline just as long as did children in the visual (short opaque) and visual–functional (tall opaque) boundary conditions, children in the visual and visual–functional boundary conditions exhibited significantly more clustering by side than did children in the functional (tall transparent) and no-boundary conditions. More interesting, the analyses of children's physical movement clearly showed that both the tall transparent and tall opaque barriers had functional consequences for children's movement. That is, children were more likely to take a step to reach for a carrot on the other side of the dollhouse when a tall transparent or tall opaque barrier was present than when no boundary was present. However, the effect of the tall transparent boundary on children's physical movement did not generalize to children's search organization. Thus, it appears that the visual salience rather than the functional consequences of the boundaries led to more organized retrieval.

One might have expected that children would exhibit more organized gathering in response to functional aspects of the environment than to purely visual aspects of the environment, yet in this task it appears that just the opposite was true. Specifically, children exhibited more organized gathering in response to the highly visible short opaque barrier than to the functional but less visible tall transparent boundary. However, this was a very easy task with little or no cost to being inefficient in terms of physical effort or in terms of failing to find all of the carrots. Even though children took more steps when a tall transparent or tall opaque barrier was present than when no barrier was present, the physical consequences of circumnavigating the functional barriers were very minimal given the scale of the dollhouse and the ease of retrieval. Furthermore, with all of the retrieval targets in plain view, there was virtually no memory load. Consequently, children were unlikely to miss items that were in plain view, as evidenced by the nearly perfect retrieval scores of the children. Given that two of the major advantages of clustering by proximity are to minimize effort and avoid forgetting locations, it stands to reason that a task with so few demands is not as likely to motivate organization as a task with a heavier demands. Perhaps in a more demanding task, children would be more motivated to organize their efforts to minimize physical effort and to avoid forgetting or missing some of the carrots. As a result, they would be more sensitive to the functional but less visible tall transparent boundary.

Experiment 2 was designed to test the possibility that an increase in the task demands would also increase the salience of the tall transparent boundary for children. In addition, we wanted to replicate the results found for the two visually salient boundaries in Experiment 1. We again asked children to retrieve 16 miniature carrots from a dollhouse. As in Experiment 1, the dollhouse was divided into two rooms by either a visual (short opaque), visual–functional (tall opaque), or a functional (tall transparent) boundary. There was also a control condition in which no boundary was present. Unlike in Experiment 1, however, children saw the carrots hidden in or under small objects that were placed near furniture items. We expected that this increase in memory load would result in similar levels of clustering in the visual, visual–functional, and functional boundary conditions.



## EXPERIMENT 2

### Method

#### *Participants*

The participants were 48 three-year-olds (*M* age = 3 years 8 months, range = 3 years 6 months–3 years 10 months) and 48 four-year-olds (*M* age = 4 years 8 months, range = 4 years 5 months–4 years 11 months) from mainly middle- to upper-middle-class Caucasian families. Children were recruited in the same manner as in Experiment 1.

#### *Apparatus and Materials*

The same dollhouse and boundaries were used as in Experiment 1. There were four pieces of furniture in the dollhouse, a laundry basket, playpen, crib, and dresser. Eight pairs of identical smaller objects served as the hiding locations for the carrots. These included shoes, bears, boxes, bags, plants, trash cans, and towels. One member of each pair of identical objects was placed in or beside a piece of furniture, and the other member of the pair was placed a small distance away. As in Experiment 1, 16 miniature carrots served as the retrieval targets. The entire session was recorded via a Panasonic camcorder positioned directly above the dollhouse.

### Design and Procedure

As in Experiment 1, children were randomly assigned to one of four boundary conditions: visual, visual–functional, functional, and no boundary. Children again were familiarized with the dollhouse and all of its contents through their participation in a direction-following study with the same apparatus. Immediately after the direction-following study, the experimenter added the appropriate barrier while children sat with their back to the dollhouse. The children were then called back and watched as the experimenter hid the 16 miniature carrots in a random order in the dollhouse. A unique and unconstrained random order was used for each child. One carrot was hidden in or under each of the small objects that were used as hiding locations. Again, children were given a small bucket and asked to "Get all of the carrots out of the dollhouse and put them in the bucket." The experimenter recorded the order in which children retrieved the carrots. When children had retrieved all of the carrots or paused for more than 15 sec, the experimenter asked, "Did you get all of the carrots?" Once the children indicated that they were satisfied that they had, the experimenter praised their efforts. They were allowed to choose two small prizes and then thanked for their participation.

### Coding and Measures

The same measures and coding procedures were used as in Experiment 1. Intercoder reliabilities for the three measures of physical movement were calculated for 18 children (20% of the sample) with exact percentage agreement. Reliabilities for all three measures were again high, ranging from 94 to 100%.

## Results

### Organization of Gathering

*Starting point.* As in Experiment 1, most of the children (92%) started their search at the front of the dollhouse. In other words, children used the proximity principle to choose where to begin their search.

*Clustering by side.* The primary question of interest was whether a more difficult task involving a memory component would make children more sensitive to the functional but less visible tall transparent boundary. As in Experiment 1, clustering scores in all conditions were significantly above chance, $t$s > 10.0, $p$s < .0001. To determine whether clustering varied by age or boundary condition, clustering scores were entered into a 2 × 4 (Age × Boundary Condition) ANOVA. This analysis yielded a significant main effect of boundary condition, $F(3, 88) = 5.68$, $p < .01$. Unlike Experiment 1, follow-up tests revealed that children were significantly more likely to cluster their retrieval efforts by side when there was a boundary of any type present than when there was no boundary present (short opaque $M = .80$, $SD = .13$; tall opaque $M = .86$, $SD = .12$; and tall transparent $M = .83$, $SD = .11$ vs. control $M = .71$, $SD = .18$). That is, when children were required to remember where the carrots were hidden, their tendency to treat the space as two separate rooms was enhanced if it was divided by any type of boundary, functional or visual.

*Timing of first midline crossing.* A 2 × 4 (Age × Boundary Condition) ANOVA performed on timing scores revealed no significant effects. The mean number of carrots retrieved before the first crossing was 3.6 ($SD = 2.1$) in the no-boundary condition, compared to 4.3 ($SD = 2.5$), 4.3 ($SD = 2.2$), and 5.2 ($SD = 2.4$) for the visual, functional, and visual–functional boundary conditions, respectively.

### *Effects of Boundaries on Physical Movement*

*Number of lateral crossings of the midline.* The mean number of times children in the visual (short opaque) and no-boundary conditions reached across the midline without removing their hand from the dollhouse was entered into a 2 × 2 (Age × Boundary Condition) ANOVA. (Four additional children were omitted from this analysis because they were sitting while retrieving the carrots.) This analysis revealed significant effects of age, $F(1, 42) = 4.41$, $p < .05$, and boundary condition, $F(1, 42) = 9.34$, $p < .01$. Four-year-olds ($M = 1.1$, $SD = 1.1$) were more likely to reach across the midline without removing their hand from the dollhouse than were 3-year-olds ($M = 0.63$, $SD = 0.82$). Likewise, children in the no-boundary condition ($M = 1.3$, $SD = 1.0$) were more likely to move their hands laterally across the midline than were children in the visual (short opaque) boundary condition ($M = 0.50$, $SD = 0.78$). In other words, children appeared to inhibit their reaching across midline when there was a visible boundary present, even if that boundary did not physically prevent them from reaching across.

*Number of barrier collisions.* A chi-square analysis revealed that the number of children who collided with the barrier while reaching to the other side of the dollhouse did not differ significantly across the visual, visual–functional, and functional conditions, $\chi^2(2) = 2.66$, *ns.* Although a high percentage of the children collided with the transparent barrier (36%) in this experiment, a relatively high percentage of children also collided with the tall opaque (17%) and short opaque (21%) barriers.

*Number of steps associated with the first midline crossing.* The number of steps children took as they crossed the midline for the first time was entered into a 2 × 4 (Age × Boundary Condition) ANOVA. This revealed a significant effect of boundary condition, $F(3, 80) = 3.66$, $p < .05$. Follow-up tests indicated that children took significantly more steps in the visual–functional (tall opaque $M = 0.96$, $SD = 0.88$) and functional (tall transparent $M = 0.95$, $SD = 0.67$) boundary conditions than in the visual (short opaque $M = 0.50$, $SD = 0.59$) and no-boundary ($M = 0.43$, $SD = 0.51$) conditions. There was no significant difference between the visual–functional and functional boundary conditions and no significant difference between the visual and no-boundary conditions. Thus, children were more likely to take steps when crossing the midline if there was a functional boundary of any type present, which indicates that the tall opaque and tall transparent boundaries had real functional consequences for children's physical movements.

### *Number Retrieved*

As in Experiment 1, there was no effect of age or boundary condition on the number of carrots retrieved. On average, children retrieved 15.1 ($SD = 1.47$) carrots. As a manipulation check, the number of items retrieved in each experiment was entered into a 2 × 2 (Age × Experiment) ANOVA. This analysis revealed a significant main effect of experiment, $F(1, 176) = 6.14$, $p < .05$. Although the difference was very small, children nonetheless retrieved significantly more carrots in Experiment 1 ($M = 15.5$, $SD = 0.71$) than in Experiment 2 ($M = 15.1$, $SD = 1.47$).

### *Search Times*

To gain some measure of the amount of physical effort involved in the search task, the total amount of time spent gathering was entered into a 2 × 4 (Age × Boundary Condition) ANOVA. This analysis revealed no significant effects. To help determine whether we had succeeded in increasing the difficulty of the task, we compared search times in Experiment 2 to gathering times in Experiment 1. As expected, a 2 × 4 × 2 (Age × Boundary Condition × Experiment) ANOVA performed on the gathering and searching times revealed a significant main effect of experiment, $F(1, 176) = 330.6$, $p < .0001$. An examination of the means showed that search times for Experiment 2 ($M$ = 2 min 43 sec, $SD$ = 58 sec) were much longer than the gathering times for Experiment 1 ($M$ = 53 sec, $SD$ = 16 sec). The fact that it took children approximately three times longer to complete the search task than to complete the gathering task suggests that the search task was considerably more effortful for them.

## Discussion

The results of this experiment again show that children used the proximity principle to organize their search efforts. As in Experiment 1, virtually all children began their searches at a location near themselves (i.e., the front of the dollhouse). Likewise, children took more steps when retrieving an object from the other side of the dollhouse when a tall transparent or tall opaque boundary was present than when no boundary was present. Unlike in Experiment 1, however, children exhibited more clustering in response to all types of boundaries, visual as well as functional. That is, children exhibited more clustering when a short opaque, tall opaque, or tall transparent boundary was present than when no boundary was present. Thus, when task demands increased, children treated the functional but less visible tall transparent boundary like the highly visible tall opaque and short opaque boundaries.

The primary question these results raise is why increasing the task demands influenced how children responded to the functional boundary. At least two possibilities exist. One is that the difficulty of remembering all of the locations pushed children to be more organized in response to the functional but less visible tall transparent boundary. Although a direct statistical comparison of the number of carrots retrieved in the two experiments showed that children retrieved significantly more carrots in Experiment 1 than in Experiment 2, the difference was very slight. Thus, it seems unlikely that the memory demands of searching for objects that were out of sight resulted in increased sensitivity to the tall transparent boundary.

Another possibility is that the increase in the task demands simply slowed children down enough to allow them time to process the tall transparent boundary more completely. Clearly, it took children much longer to retrieve the carrots in Experiment 2 than in Experiment 1. In Experiment 1, children only had to pick up carrots that were on or next to pieces of furniture. In Experiment 2, children had to lift up objects such as pillows and teddy bears and open up objects such as boxes and bags to retrieve the carrots. Moreover, children often spent some time trying to put the objects that served as hiding places back into their correct locations. The increase in the time children took to retrieve the carrots may have helped them notice that the tall transparent boundary divided the dollhouse into two rooms and, hence, helped inhibit multiple midline crossings.

## GENERAL DISCUSSION

The results of these experiments clearly show that boundaries play an important role in structuring young children's gathering and searching behavior. When children retrieved carrots that were in plain sight (Experiment 1), they exhibited significantly more clustering when either the visual (short opaque) boundary or the visual–functional (tall opaque) boundary subdivided the dollhouse in half than when the functional (tall transparent) boundary or no boundary subdivided the dollhouse. Moreover, children treated the functional but less visible tall transparent boundary as if no boundary were present. When children searched for carrots that were out of sight (Experiment 2), they exhibited significantly more clustering when the visual (short opaque), visual–functional (tall opaque), or the functional (tall transparent) boundary was in place than when no boundary was in place.

Thus, when task demands increased, children treated the less visible tall transparent boundary like the highly visible short opaque and tall opaque boundaries. Together, these results show that young children rely on boundaries to help organize their gathering and searching behavior, even when the costs of being inefficient are quite low.

What do these results tell us about young children's ability to organize their searches for objects? Like other studies of young children's search organization (e.g., Cornell & Heth, 1983), children began their searches at the locations nearest to themselves. Thus, children used proximity to self as a means of organizing their initial search efforts. However, unlike other studies of 3- and 4-year-olds' search organization (e.g., Wellman et al., 1984), we found that children tended to cluster their searches by region. Even when no boundary was in place, children exhibited a strong tendency to retrieve the objects from one side of the dollhouse before retrieving the objects from the other side of the dollhouse. In contrast, Wellman et al. found no evidence that 3-year-olds retrieved Easter eggs from one side of the playground before retrieving those on the other side of the playground. What accounts for this discrepancy? Quite likely, the vastly different scales of the search spaces in the two investigations played a role in the organization of young children's searches. That is, young children may find it easier to organize their search efforts in small-scale spaces than in large-scale spaces. This hypothesis is in some sense counterintuitive because the costs of being inefficient are much greater in large-scale spaces than in small-scale spaces. However, this idea is consistent with other studies showing that children mentally subdivide smaller spaces before they subdivide larger spaces (Huttenlocher, Newcombe, & Sandberg, 1994). In particular, Huttenlocher et al. found that children subdivided a small rectangle drawn on a standard sheet of paper into two halves by about 4 years of age, but they did not subdivide a long, narrow sandbox into two halves until about 10 years of age. It is possible that the apprehension of a smaller scale space requires fewer information-processing resources, which leaves additional resources available for the organization of locations into groups. Further research is needed, however, to understand how the scale of the space influences children's ability to carry out organized searches.

A second issue these results raise is why the visual salience of the boundaries had a greater influence on children's search organization than did the functional consequences of the boundaries. In other words, why did children show more clustering in response to the highly visible but nonfunctional short opaque boundary than in response to the functional but not very visible tall transparent boundary? As we suggested earlier, one might have expected that children would exhibit more organized searching in response to the functional aspects of the environment than in response to purely visual aspects of the environment. One possible reason why children were less responsive to the tall transparent boundary than to the short opaque boundary is that the functional consequences of circumnavigating the tall transparent boundary were minimal. That is, even though children in both experiments produced more steps when a tall transparent or tall opaque boundary was present than when no boundary was present, the amount of effort required to circumnavigate the tall boundaries was minimal given the small scale of the dollhouse. As a result, children in Experiment 1 treated the tall transparent boundary as if no boundary were in place. Perhaps children would be more responsive to the functional consequences of circumnavigating transparent boundaries if more physical effort were involved.

One problem with the previous explanation is that it does not account for why children increased their clustering efforts in response to the highly visible but nonfunctional short opaque boundary. That is, if the functional consequences of boundaries (or lack thereof) played a major role in the organization of children's search behavior, children should have treated both the tall opaque and the short opaque boundaries like the tall transparent boundary. Instead, children in both experiments exhibited significantly more clustering when either the tall opaque or the short opaque boundary subdivided the dollhouse than when no boundary subdivided the dollhouse. This suggests that children placed more weight on the visual than on the functional properties of the boundaries, which leads to the conclusion that the children in Experiment 1 ignored the tall transparent boundary because it was not very visually salient. This conclusion is also supported by the finding that children were more likely to collide with the tall transparent boundary than with the short opaque or tall opaque boundaries when retrieving an object on the other side of the dollhouse.

Why might children place more emphasis on the visual than on the functional properties of boundaries? First, it is important to note that there is an asymmetry in the correlation between the visual salience and functional consequences of boundaries. That is, although visual boundaries do not always have functional consequences in the real world, functional boundaries are virtually always visually marked. For example, a transition from ceramic to wood flooring creates a visual but nonfunctional boundary between an entryway and a living room. In contrast, walls and fences create boundaries that are both functionally and visually salient. Even transparent windows, glass doors, and so on are usually marked by thresholds or transitions in flooring or other aspects of the environment (e.g., from indoors to outdoors) and are usually reflective to varying degrees. Truly unmarked and invisible barriers are very rare, especially in the limited experience of infants and young children. As infants begin to move around their environment, they quickly learn that functional boundaries are virtually always signaled by visual cues. Over time, infants and young children may begin to rely on the visual properties of boundaries to signal the functional properties of boundaries. As a result, even very young children may treat visual boundaries as if they were functional. If this is the case, one would expect that the more visually salient the boundary, the more likely children would be to respond to it as if it were functional. This may explain why children in Experiment 1 treated the visually salient but nonfunctional short opaque boundary as if it were functional and treated the functional but not very visible tall transparent boundary as if it were not functional.

Recent studies of infants' visual cliff behavior also support this experience-based explanation (Titzer, Thelen, & Smith, 2000). In the classic visual cliff experiment (Gibson & Walk, 1960), infants were confronted with at least two sources of information to guide their behavior. One was the visually salient but nonfunctional cliff, and the other was the functional but not very visible tabletop. When these two sources of information were put in conflict with each other, the majority of crawling infants placed more weight on the cliff than on the tabletop. Why might this be the case? According to Titzer et al., infants rely more on the information specifying the cliff than the tabletop because they have very little experience with transparency. In other words, infants have no idea that the transparent tabletop offers a surface of support. To test this hypothesis, Titzer et al. gave one group of infants extended experience with transparent objects and another group of infants extended experience with opaque objects. When the infants were later tested on the visual cliff, the infants who had played extensively with transparent objects were more likely to cross over the transparent tabletop. Thus, learning about the functional properties of transparent materials influenced the relative weights infants placed on the cliff and the tabletop.

Like transparent surfaces of support, instances of nontraversable but invisible boundaries are virtually nonexistent in the real world. As a result, young children may have little opportunity to learn directly about the consequences of transparent boundaries. Thus, one would not expect children to respond to such boundaries without additional prodding. The results of Experiment 2 suggest that increased task demands lead to increased sensitivity to the tall transparent boundary. By slowing down the rate at which children were able to retrieve the items, we gave them more time to both note the presence of the transparent functional boundary and to integrate that information into their behavioral strategies. The finding that young children are more likely to respond to transparent boundaries under more demanding task conditions may also explain why Kosslyn et al. (1974) found that 5-year-olds but not adults overestimated distances across functional but transparent boundaries, whereas Newcombe and Liben (1982) found that neither 5-year-olds nor adults overestimated distances across functional but transparent boundaries. As Newcombe and Liben pointed out, they used a less demanding distance-estimation task than did Kosslyn et al. Thus, it appears that both young children and adults are more likely to ignore transparent boundaries under less demanding task conditions (i.e., less likely to subdivide a space into regions or organize locations into clusters).

Traditionally, most research on the development of organized searching has focused on children's ability to impose order on the physical environment (e.g., Cornell & Heth, 1983; Plumert et al., 1994; Wellman et al., 1984). The results of this investigation, however, suggest that the reverse is also true. Namely, the physical environment functions to impose order on children's search behavior. The fact that young children exhibited more organized searching when boundaries subdivided the search space suggests that the structure of the physical environment can actually serve to scaffold children's search behavior. In other words, children can rely on physically present boundaries to help them organize their searches for objects. Over time, children may become increasingly adept at organizing their searches without the aid of physical boundaries. Together, the results of this investigation underscore the idea that thinking does not reside completely within the child but rather is a function of the interaction of the child and the specific context in which the thinking takes place.



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