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Visual Access and Attention in Two-Year-Olds' Event Reasoning and Object Search

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Several recent studies have revealed substantial limitations in 2-year-olds' ability to search accurately for objects that have undergone unseen movement, even along highly constrained paths. In many of these studies, children observed a ball as it rolled down a track and behind an occluding panel that contained 4 doors. The track had a barrier that was partly visible and could be placed in locations corresponding to the doors. When the ball came to a rest against the barrier and behind the occluder, the child's task was to find the ball by opening the correct door. The search accuracy of 2-year-olds has not differed from chance across several variations of this task. This research was conducted to identify the source of 2-year-olds' limitation in this domain. Children were granted a full view of the event before the ball was occluded with a door panel. Children's performance was better under this condition, but was still not systematically accurate unless their gaze remained locked onto the correct location. Two-year-olds' weak performance in these search tasks appears to be more a consequence of limitations in spatial integration than in their representation of unseen movement.

The analysis of children's performance in search tasks has proven very effective in advancing our understanding of developmental changes in several domains (e.g., DeLoache, 1986; Diamond, 1998; Piaget, 1954; Smith, Thelen, Titzer, & McLin, 1999; see Harris, 1987; Wellman, 1985 for overviews). A convergence of recent findings indicates that spatial accuracy in the search for outcomes of unseen dynamic physical events improves rapidly between 2.5 and 3 years of age (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000; Hood, Carey, & Prasada, 2000). This acquisition is an important achievement because events in everyday life are often not fully visible from start to finish. In their research, Berthier et al. (2000) asked

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young children to search for a ball that had rolled down a track and behind an occluding panel that contained four doors (see Figure 1). A barrier that was partly visible above the occluding panel rested on the track, and could be placed in four locations that corresponded to the locations of the doors. When the ball came to a rest against the barrier and behind the occluder, the child's task was to find the ball by opening the correct door.

While three-year-olds were successful in finding the ball after it rolled behind the panel, children aged 2.5 years and younger did not infer the ball's location from the visible top portion of the barrier; instead they opened doors that did not correspond to the ball's location. Subsequent research has indicated that young children's performance limitations observed in this task do not appear to be due merely to inadequate visual salience of the key components of the original apparatus (Poirier, Berthier, Clifton, Evans, & Cheries, 2000), and that young children's low success rate does not appear to merely reflect a lack of task engagement or motivation (Butler, Sylvia, Berthier, & Clifton, 2001). Thus, the available evidence seems to suggest that there is very limited ability to coordinate the physical relations specified by the layout of the apparatus in the service of accurately guiding search until some time after 2.5 years of age.

Hood et al. (2000) conducted a similar study in which 2.0- and 2.5-year-olds were asked to point to one of two possible locations of a round toy that had been rolled behind an occluder on a path that either did or did not contain a partially visible barrier. While the 2.5-year-olds were correct more often than expected by chance, the 2.0-year-olds were not. In another experiment, children were familiarized with a toy frog falling behind an occluder and onto a stage, after which one of two windows in the occluder was opened to reveal the location of the toy on the stage. During familiarization trials, children saw the toy land on either an upper or

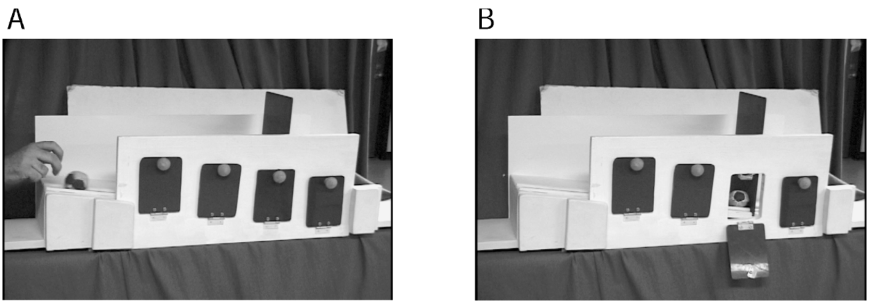

FIGURE 1 Panel A depicts the apparatus and event that were presented to children by Berthier et al. (2000). The ball was rolled from the left by an experimenter, and then disappeared behind the occluding door panel. The child's task was to retrieve the ball by opening the correct door. Panel B reveals the location outcome of the ball through the open door: the visible barrier is in Position 3, so the ball stopped behind Door 3.

lower shelf. After habituation, the upper shelf (partly visible beyond the screen) was either inserted or removed to change where the toy landed when dropped. Once again, 2.0-year-olds searched inaccurately, this time searching primarily at the location where they had seen the toy during the familiarization trials.

Though seeming quite simple, success in the tasks just described does require the detection, maintenance, and integration of several divergent factors. For one thing, children must understand the physical role of the barrier in stopping the object's movement and constraining its final resting position. They must also extrapolate the unseen movement of the object to the barrier to predict its final resting position. Additionally, the spatial location of the barrier, albeit visually supported, must be integrated into the solution, and the spatial location of the object's final resting position must be related to the configuration of outcome locations. Thus, limitations in meeting any one of these task demands would likely compromise the outcome of children's performance.

Previous research suggests that object solidity and its role in constraining movement trajectories may be recognized early in development, and used to form expectations about the structure and outcome of events (Baillargeon, 1986; Spelke, Breinlinger, Macomber, & Jacobson, 1992). Infants in the study conducted by Spelke et al., for example, observed a ball as it rolled over a horizontal surface that contained a barrier which was occluded from view. Compared to standard outcomes in which the ball appeared against the barrier when the occluder was raised, infants fixated longer on outcomes suggesting that the ball had traveled through the physical barrier. These findings suggest that the infants apprehended the barrier and its physical role in the event at least to the degree that it could influence their visual examination of the event's outcome. Because manual search tasks have different demands than preferential looking tasks (e.g., Hood, Cole-Davies, & Dias, 2003; Munakata, 2001), the available evidence suggests that detecting the physical constraints that are imposed by the barrier is an unlikely a source of limitation in young children's search performance.

Spatial analysis and memory, additional requirements of manual search, have also been examined in very young children, and these capacities also appear to emerge before age two. Huttenlocher, Newcombe, and Sandberg (1994) examined children's ability to locate a toy that they had seen hidden in a sandbox measuring five feet in length. First, the children's attention was guided away from the hiding location and the sand was smoothed over. Then they were asked to retrieve the toy. Even the youngest children were quite accurate in retrieving the toy from each of nine randomly sequenced hiding locations. Because the sand provided a continuous surface and other potential landmarks in the study room had been occluded, the children appear to have coded and retained the absolute locations of the hiding places. These findings suggest that by 16 months of age, children are able to code and represent the spatial locations of static hidden objects, and, furthermore, can utilize those representations to guide their search for hidden objects.

The relevant work on both the physical and spatial reasoning abilities of infants and young children seems to cast doubt that either domain is the primary basis of difficulty in event reasoning and search tasks. Note, however, that the object in the search task used by Huttenlocher et al. (1994) did not move after it was hidden. Thus, a likely source of limitation in the more recent search tasks may be an inability to predict the eventual resting location of a ball rolling toward an obstructive barrier when most of the ball's trajectory is occluded from view. In other words, young children may be unable to visualize a likely future trajectory of the ball, even when in the Berthier et al. (2000) study it was highly specified by the layout of the apparatus. Indeed, one of Piaget's central claims was that children's ability to reason beyond direct, immediate experience emerges over a protracted timeframe (e.g., Piaget, 1954).

Limitations observed in the recent studies of children's manual search may be manifest in at least two different ways. Children may have difficulty forming or accessing representations of hidden movement to guide search under any condition (i.e., forming and accessing dynamic representations), or they may be more specifically limited in the ability to accurately predict the termination of the hidden movement. Hespos and Rochat (1997) have provided preferential-looking evidence that is at least partly inconsistent with a general limitation, arguing that infants are indeed capable of formulating dynamic representations of partially visible movement trajectories. They presented 4- to 8-month-old infants with dynamic displays in which an object moved visibly across a stage before being occluded at the end of its trajectory. Two conditions of object movement were utilized: one in which the object simply moved in a consistent orientation down a vertical axis, and one in which the object rotated through its movement trajectory. Following familiarization with one of these two events, the occluding panel was lowered to reveal the static object in one of two orientations: one that would be probable in relation to the visible portion of the familiar trajectory, and one that was the reverse (improbable orientation). Infants preferentially fixated the improbable orientation, suggesting that they had represented the unseen portion of the object's movement trajectory and recognized an inconsistent outcome. The authors argue that the findings reflect infants' ability to represent unseen portions of dynamic events.

Although Hespos and Rochat's (1997) data are looking measures rather than search, such findings suggest that the ability to represent the unseen portion of the ball's trajectory in the search tasks used by Berthier, Hood, and their colleagues may not be the primary source of children's limitation in those tasks. Butler, Berthier, and Clifton (2002) examined this possibility directly by investigating the effects of an increase in two-year-olds' visual access to a dynamic event. They studied children's performance in a search task much like that used by Berthier et al. (2000), with the sole exception being that the occluding panel that contained the doors was transparent. Like the original study, the doors themselves were opaque, so the transparent panel allowed children to visually track the ball's movement across the portions of the track preceding the barrier wall that were visible between the doors, thus specifying the door beyond which it did not roll. Under these conditions, the performance of children at 2.0 and 2.5 years of age did improve relative to that observed by Berthier et al., but still did not approach consistent success at the 2.0 years test age.

One factor that differed substantially between the two age groups was their utilization of visual information. At both ages, children accurately tracked the ball through its trajectory and up to its termination on about half of the trials. However, only the older children were particularly likely to open the correct door following accurate tracking (83% correct on those trials). In contrast, younger children opened the correct door in only 46% of the trials in which they accurately tracked the ball. Thus, 2.0- and 2.5-year-old children do benefit from visual access to portions of the event, with 2.5-year-olds utilizing such information more systematically to aid their search. Though it was surprising that 2.0-year-olds still fell short of systematic success under these less demanding conditions, they nevertheless did have to infer the ball's final location since they did not actually see it come to rest behind the door.

Importantly, these findings indicate that representing the unseen portion of the ball's trajectory is not the sole source of young children's limitation in search tasks. If it were, the children would have searched accurately much more consistently in the transparent-panel condition. Because the visible portions of the ball's trajectory toward the barrier wall never included the wall itself, the termination of the event was never witnessed. Thus, an enduring question about development in this domain is whether young children's search is particularly limited by an inability to represent not just unseen movement, but the spatial location of the movement's termination.

This study was conducted to directly examine the role of visual access to the event's outcome in guiding children's search. In this study, children were allowed to view the ball rolling down the track until it stopped at the barrier—only then was the occluding door panel positioned in front of the track. Under these conditions, the children are required only to recall the spatial location of the ball and translate that onto the occluding panel's configuration of door positions, or else simply use the visible portion of the barrier as a cue to the ball's location and marker of the correct door to correctly perform the task. If children perform considerably better under these conditions, it suggests that their striking limitations in reasoning about occluded events may be due to difficulty with predicting outcomes for events in which a moving object continues to move after it is out of sight. If, on the other hand, performance does not improve dramatically with complete visual access to the ball's trajectory, the focal limitation would more likely be associated with some other factor, such as the spatial integration of the barrier and the ball's resting position with the doors to be opened.

METHOD

Participants

Eighteen children at each of two ages participated. The test ages were two years (*M* = 24.94 months, *SD* = 2.05), and two and a half years (*M* = 31.49, *SD* = 2.59). The data of four other children were excluded because of a lack of interest in completing the task or experimenter error. Children were identified through state birth records, and recruited through letters and follow-up telephone calls. Participants received a small gift of appreciation.

Apparatus

The task apparatus was the same as used in Berthier et al. (2000). It was comprised of an inclined wooden ramp (69.5 cm × 5 cm) situated behind a removable vertical panel (58.5 cm × 28 cm) that occluded the participants' view of all but 15 cm of the ramp. The occluding panel contained four doors that were hinged at the bottom (Berthier et al., 2000; see Figure 1). The doors were 14 cm × 9.5 cm, and had knobs attached on the front. Solid barriers could be inserted into the track at four locations along the length of the track. The barriers were 15 cm wide, 0.5 cm thick, and ranged in height between 27.5 and 33 cm to accommodate the track's slope. The top 8.5 cm of each barrier was visible above the top edge of the occluding panel. The locations of the four barrier positions corresponded to the locations of the four doors in the occluding panel. Thus, a ball rolled down the track when a barrier was in Position 2 would be accessible through Door 2, after having come to a rest against the barrier. A soft leather ball was used in the task instead of a standard rigid ball to minimize sound localization cues from contact with the apparatus. An additional small wooden figurine was used during the familiarization phase of the task. Two video cameras captured different views of the children's behavior. A Sony digital camera was situated directly behind the apparatus such that it recorded a close-up view of each participant's face while they were engaged in the task. A Panasonic VHS camera was attached to the ceiling directly above the apparatus to record the direction and location of participants' reaches.

Procedure

Children entered the lab and sat on their parent's lap in front of a table supporting the apparatus. A familiarization procedure consisting of several steps preceded the test trials. First, the experimenter demonstrated the doors by opening and closing each one. Next, a simple hiding task was used to ensure that children could retrieve a toy from behind a door with the occluder already in place. On each of two trials, one of the four doors was opened, and a small toy figurine was placed on the track through the opening. The door was then closed, and the child was asked to retrieve the man. In the second trial, a different door was opened, and the child's attention was momentarily diverted from the location of the door after it was closed. As before, the child was then asked to retrieve the man.

Following familiarization, a series of eight *stationary* test trials and a series of eight *moving* test trials were administered. The stationary trials consisted of the experimenter removing the occluding door panel, and inserting a barrier into one of the four positions in the track. The experimenter then rolled the ball down the track until it came to rest against the barrier (see Figure 2). The experimenter replaced the door panel in front of the track, occluding all but the left-most end of the track and the top of the barrier. The experimenter then slid the apparatus toward the child, and asked the child to retrieve the ball. If the child did not open the correct door on the first reach, the experimenter closed the incorrect door and encouraged a second attempt. In each trial, if the child did not retrieve the ball within two attempts, the experimenter closed the second incorrect door, opened the correct door, and verbally indicated that the ball had stopped at the wall.

The moving trials were conducted in a similar manner except that, at the beginning of each trial, the experimenter placed a barrier into one of the four positions on the track, drew the child's attention to it, then placed the occluding door panel in front of the track before the ball was rolled (cf. Berthier et al., 2000). Thus, the child was only able to view a small portion of the ball's trajectory down the track before it disappeared behind the left edge of the occluding door panel. After the ball came to a rest against the barrier, the experimenter slid the apparatus toward the child and asked the child to retrieve the ball.

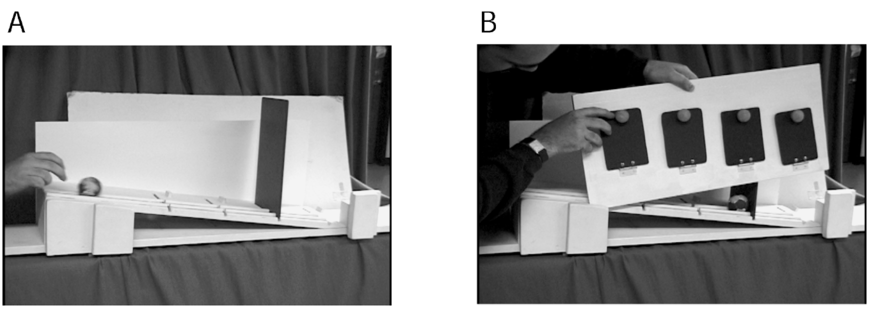

FIGURE 2 Panel A depicts the apparatus and event that were presented to children in the stationary trials; the ball was first rolled in clear view of the participating child. Panel B depicts the placement of the occluding door panel after the ball had come to a complete stop against the barrier. The child's task was to retrieve the ball by opening the correct door.

A test session consisted of two blocks of eight trials each that were distributed evenly across the four barrier positions, and over four distinct pseudo-randomized orders. An exception to complete random assignment of barrier-position order was that positions were never repeated in two consecutive trials. For each subject, the block of stationary trials was administered immediately after the familiarization phase, and the block of moving trials was administered last. This invariant order allowed the effects of seeing the complete trajectory, which was the main focus of this study, to be separated from any potential effects of accumulating experience with the apparatus. From previous work (Berthier et al., 2000), we know that children of these ages perform at chance when given the moving trials first. Our aim in including them here was to check the possibility that receiving eight stationary trials first might facilitate performance on subsequent moving trials.

Scoring

Videotapes were scored for the specific door or doors that each participant opened during each trial, and for the target of visual fixations during the stationary trials. Fixations were examined on each trial between the time that the ball came to rest against the barrier and the time that the child opened a door. Raters coded whether children were fixating the ball at the first instant that the occluding panel passed the child's face on its way to the apparatus base. For those children who were fixating the location of the ball at that particular instant, raters also coded whether children broke fixation before the panel was fully inserted, and before the child opened a door. One person coded the task performance of every participant, and a second rater coded approximately half of the participants at both ages. Inter-rater reliability was calculated as the percentage of trials on which performance was coded the same way by both raters. For door position of first attempt, the percent agreement was 99.26. For judgments of eye fixation as the occluding door panel was being lowered into position, percent agreement was 93.65, and for judgments of continuous fixation throughout the event, it was 95.24. In cases of discrepant coding, the values provided by the primary coder were retained.

RESULTS

Retrieval of Ball

The dependent variable of primary interest was the proportion of trials in which the participants correctly retrieved the ball after the panel was lowered. Thirty-four of thirty-six participants completed eight stationary trials, and two completed only seven. Twenty-one participants completed eight moving trials, seven completed seven such trials, four completed six trials, and four completed only five moving trials. The larger number of children participating in fewer than eight trials in the moving condition, relative to that in the stationary condition, was probably due to the moving trials coming second when children were perhaps beginning to tire.

Table 1 presents the mean proportion correct on the first reach and within two reaches by age and trial type. For comparison, data from Berthier et al. (2000) and from Butler et al. (2002) are also shown in the table. Consistent with previous observations, the youngest children's performance on the first reach was at chance in the moving trials, while the 2.5-year-olds performed somewhat better. The majority of children at both ages were able to find the ball within two reaches, with more success occurring again in the stationary trials.

Search accuracy was compared between ages and task conditions by conducting a mixed-model ANOVA of the proportion correct on the first reach, with condition as a within-subjects factor, and age group as a between-subjects factor. While the mean number of stationary trials completed was eight, the mean number of moving trials completed was only seven. A preliminary analysis was conducted to ensure that the variances associated with search accuracy means did not differ between conditions, $\chi^2(3) = 1.14$, $p = .77$. The main analysis revealed significant main effects of both age and condition. The older children were more accurate than the younger children, $F(1, 34) = 7.94$, $p = .008$, and across ages, children were more accurate on the stationary trials than on the moving trials, $F(1, 34) = 6.38$, $p = .016$.

Figure 3 presents the proportions correct for each participant on their first reach in the stationary and moving trials. Retrieval accuracy was examined individually by comparing each child's number of correct retrievals on their first reach to the number that would be expected by chance alone using the cumulative binomial distribution with a .05 rejection region (at least five correct out of either seven or eight completed trials). In the moving trials, only one 2.0-year-old out of 18 performed above chance level, while four 2.5-year-olds did. In the stationary trials, two 2.0-year-olds retrieved the ball with a greater-than-chance accuracy level, while seven 2.5-year-olds did (see Table 2).

TABLE 1
Mean Proportion Correct by Age

	On First Reach		*Within Two Reaches*	
Trial Condition	*2.0 Years*	*2.5 Years*	*2.0 Years*	*2.5 Years*
Stationary	.37	.52	.65	.79
Moving	.26	.41	.58	.68
Berthier et al. (2000)	.22	.34	—	—
Butler et al. (2002)	.39	.71	.68	.89

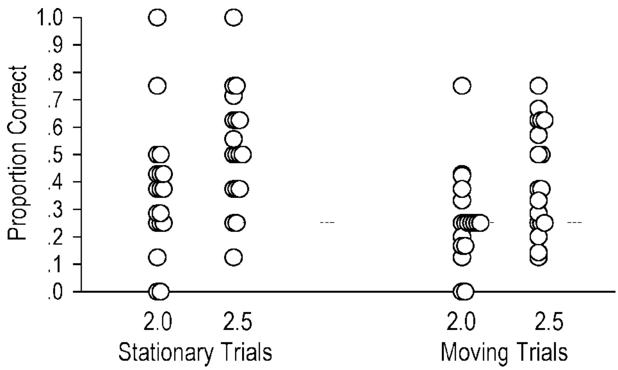

FIGURE 3 This plot represents children's search accuracy at each test age (2.0 and 2.5 years) under both stationary and moving conditions. The circles represent proportion correct on the first reach for each individual child. The dashed line indicates the mean level of performance per group that would be expected by chance alone.

TABLE 2
Number of Individual Children Exceeding Chance Level in Accuracy of Search on First Reach

	2.0 Years	*2.5 Years*
Stationary	2/18	7/18
Moving	1/18	4/18
Berthier et al. (2000)	0/16	3/16
Butler et al. (2002)	6/20	10/12

One potential source of error in young children's responses may have been their simply having had a "favorite" door. In fact, Berthier et al. (2000) observed that a majority of 2.0- and 2.5-year-old participants selected a single door on more than half of the trials. An analysis of the present data revealed that this pattern was clearly maintained in the moving trials, with 14 children at each age selecting a particular door on at least half of the trials. In the stationary trials, eight 2.0-year-olds and ten 2.5-year-olds selected a single door at least half of the time. At both ages, the most favored door was Door 2, having been selected on 39.6% of the stationary trials and on 49.4% of the moving trials.

To further investigate other potential sources of error in children's responses, perseverative reaching was examined by counting the number of times each child opened the door where the ball had been on the previous trial. This choice was always an error because the barrier wall was never in the same location on consecutive trials. Table 3 presents the mean proportion of incorrect trials in which participants opened the same door behind which the ball had been located on the

TABLE 3
Mean Proportions of Incorrect Responses by Type of Error

	Search at Previous Location		*Search at Adjacent Location*	
Trial Condition	*2.0 Years*	*2.5 Years*	*2.0 Years*	*2.5 Years*
Stationary	.39*	.30	.41	.39
Moving	.41*	.30	.40	.47

*t vs. .25, $p < .05$.

previous trial. Analyses revealed that 2.0-year-olds utilized this strategy greater than what would be expected by chance alone, $t(16) = 2.77$, $p = .014$, and $t(17) = 2.40$, $p = .028$ for the stationary and moving trials, respectively, while 2.5-year-olds did not. An ANOVA was conducted to examine potential differences in perseverative errors between age groups and conditions, but revealed no significant effects, $F(1, 32) = 2.65$, $p = .113$, and $F(1, 32) = 0.01$, $p = .929$ for the age and condition effect respectively.

Another possibility in accounting for children's errors is that they may have considered the location of the barrier, but chose a door that was adjacent to the correct one. Viewed from the front of the apparatus, the visible portion of the wall was always offset to the right of the correct door. Thus, for Positions 1, 2, and 3, the wall is situated between two doors, albeit nearer to the correct door on its left. If, in the stationary trials, children are simply using the spatial location of the wall to guide their selection without considering the side on which the ball came to rest, they are equally likely to choose a door to the right or the left of the wall. Likewise, if in the moving trials, children take into account the position of the wall without appreciating that the ball must stop to the left of the wall, the most likely error is again the adjacent door.

If children's performance was insensitive to the position of the wall, there was a 43.75 percent chance that they would open a door that was adjacent to the wall (with Position 4 having a door on only one side). Although this pattern characterizes a substantial proportion of incorrect responses across ages and conditions (see Table 3), analyses indicated that children did not select doors that were adjacent to the wall more frequently than would be expected by chance under either condition at either age, $t(17) = 0.12$, $p = 0.91$, $t(17) = 0.14$, $p = 0.89$, $t(17) = 0.14$, $p = 0.89$, $t(17) = 0.07$, $p = 0.95$, respectively, for stationary and moving trials at age 2.0, and stationary and moving trials at age 2.5.

Visual Attention

To better understand the role of visual access under the task demands of the stationary trial events, the target of participants' visual attention throughout each trial was also examined. Because each trial did not begin until the child was fixating the apparatus, most children tracked the ball's movement through the beginning of every trial. In most cases, participants of both age groups fixated the ball after it had come to rest against the barrier and while the door panel was being lowered during the eight stationary trials (M = 5.7 trials). However, they maintained their fixation of that same location throughout the entire trial infrequently (M = 1.2 trials). Thus, most children at both ages broke their fixation of the ball's general location in the apparatus at some point before they reached to open a door.

To determine whether visual fixation was related to task performance, the conditional proportion of response outcomes, given fixation of the ball and its occluded location, was calculated and compared to the overall proportion of response outcomes over every trial. Across both age groups, children reached correctly on their first attempt in 44% of all trials administered (124 out of 282 trials, in total, across all children). Each child had fixated the ball as the occluder was being lowered into position in at least some of the trials. Out of 205 trials in which the ball was fixated during its occlusion, 44% led to correct searches (see Table 4). Out of the 77 trials in which there was no fixation, the exact same proportion (44%) was followed by correct searches. This similarity suggests that children's search accuracy was not related to their visual attention to the event as the ball was being occluded from view.

About half of the children continuously fixated the ball—or its occluded position along the track—throughout the entire event in one or more trials (n = 19). To be included in this subsample, the child had to fixate on the ball during occlusion and not break the gaze until a door was opened. When these children fixated continuously throughout the entire event, 94% of their first reaches were correct (in total, 40 out of 43 trials), compared to only 56% correct reaches overall for this same group (85 out of 152 trials across children in the subsample; see Table 5). In this case, the corresponding mean proportions per child did differ significantly, $t(18) = 5.53$, $p < .0001$. This observation reveals a strong relation between children's search accuracy and their continuous fixation of the ball's location. When children fixated the ball after it came to rest against the barrier wall, and maintained fixation of that spatial location until they were cued to retrieve the ball, they tended to retrieve the ball successfully at both test ages.

TABLE 4
Trials by Ball Fixation and Search Outcome (row %)

Fixating Ball When Panel Lowered	*Search Outcome*		
	Correct	*Incorrect*	*Total*
Yes	90 (44)	115 (56)	205 (100)
No	34 (44)	43 (56)	77 (100)
Total	124 (44)	158 (56)	282 (100)

TABLE 5
Trials by Fixation Continuity and Search Outcome (row %)

Fixation of Ball's Location Throughout Event	*Search Outcome*		
	Correct	*Incorrect*	*Total*
Continuous	40 (94)	3 (6)	43 (100)
Broken	45 (41)	64 (59)	109 (100)
Total	85 (56)	67 (44)	152 (100)

DISCUSSION

The limited accuracy of young children's manual search performance in the moving trials was quite consistent with previous observations under similar conditions (Berthier et al., 2000; Hood et al., 2000). When required to search for a ball after it had rolled behind an occluder on an approach to a partially visible barrier, children either failed to consider the role of the barrier in the occluded event, or failed to integrate the spatial location of the barrier with the hidden ball's position. Children's performance on the stationary trials, however, was significantly better. Seeing the ball roll and come to a stop before being covered by the occluder appears to have facilitated young children's performance relative to that observed under conditions lacking such visual access. Because the stationary trials were always administered first, the effect cannot be simply due to cumulative experience with the task.

The magnitude of the favorable effect of visual access, however, was rather limited. Granting children complete visual access to the event improved the proportion of correct reaches by approximately 10 percentage points at each age. If the dynamic event's occlusion was the main source of limitation in children's performance, they should have searched substantially more accurately than they did in the stationary condition. The analysis of individuals' performance confirms this interpretation, with only four additional participants searching more accurately in the stationary condition than in the moving condition (one at age 2.0, and three at age 2.5). Thus, the hypothesis that the children's primary difficulty with this task was due to an inability to predict and represent the outcome of unseen dynamic events was not supported. The modest improvement of the children's performance when allowed to view the ball's movement and actual stopping point before occlusion suggests the presence of other, more potent factors.

Young children's utter dependence on continuous visual fixation of the ball's location for success in their search clarifies the severity of their performance limitation: they only searched correctly when their choice had been attentionally yoked to the correct location throughout the entire trial. While such continuous fixation was observed in only a relatively small proportion of the trials administered, it resulted in 94% correct choices on those trials. A similar degree of reliance on fixation vigilance was found by Butler et al. (2002) when the occluding panel was transparent but the doors were opaque. In this situation, the children visually tracked the ball's progress until it disappeared behind a door, but if they looked away before responding, performance was impaired. Breaking the gaze was particularly likely to result in errors for the 2.0-year-olds. This pattern of findings provides little evidence of effective reasoning during the search. Rather, these children need visual access to the point of the ball's disappearance, followed by continuous gaze on that location until they respond. Without such visual support, they appear to lose track of the ball's location (see also Diamond, 1983 [cited in Diamond, 1985]; and Smith et al., 1999, for related findings in the context of A-not-B search performance).

An analysis of the kinds of errors made by children revealed that large proportions of all errors made at both ages were of two distinct kinds. A substantial proportion of errors resulted from an inclination at both ages to disproportionately select one door more frequently than the others. As noted previously, Berthier et al. (2000) observed a similar pattern. In both studies, the favored door was the second one from the track's origin, despite the barrier wall being positioned equally often at the four positions. Other researchers have observed that children's object search may be more accurate when objects are hidden near the geographic center of a given space (Benson, deBlois, Bottani, & Hansen, 2000; Huttenlocher et al., 1994). This suggests the presence of a center-response bias that may account for the door preference observed presently as the second door was near the middle of the configuration. It is not clear whether children have, in advance, a door preference that prevents their selection of an alternative door, or if they simply gravitate toward the center of the configuration when they are uncertain of the ball's location.

The error analysis also revealed a large proportion of perseverative errors: errors resulting from searching for the ball at the location where it had come to a rest on the preceding trial. Because the barrier wall was never in the same position on consecutive trials, returning to the same location always resulted in error. Spatial perseveration in search is a very robust finding among infants and young children, often occurring even in the face of conflicting cues to physical relocation in the standard A-not-B paradigm (e.g., Harris, 1987; Smith et al., 1999). Such errors were not due to motor perseveration because they occurred when the experimenter revealed the ball's location after a child's incorrect response, as well as when the child had made a successful response on the previous trial.

A third potential source of error—selecting the door on the opposite side of the barrier from the correct one—was not observed more frequently than chance. This was somewhat surprising in relation to the contrasting findings from other similar studies in which children did search more systematically at adjacent locations (Berthier et al., 2000; Hood et al., 2003). It is possible that the attentional draw of the visible event dynamics in the stationary ball condition may have influenced the course of children's visual scene analysis and decision-making relative to that taking place in the previous studies. If so, this effect may have carried over to the moving trials in the present experiment because they were always administered second. Clearly, however, searches at adjacent locations in this research did not differ from chance.

Successful searches under both stationary and moving conditions could have relied partly on the maintenance of the ball's location in memory after the occluding panel was positioned during a given trial. Thus, the capacity to store and recall locations in space may seem a necessary target of exploration in accounting for children's performance. However, their difficulty with the task was probably not due solely to a spatial memory deficit. For one thing, previous work indicates that 2.0-year-olds are quite accurate in directing searches for hidden objects (e.g., Deloache, 1985), and even tend to focus on location memory over other available cues when searching for hidden objects (Horn & Myers, 1978). Furthermore, the familiarization procedure used in this study ensured that children could at least retrieve an object when they saw a door being opened and then closed after the object was placed inside. The activity around the correct door is similar to hiding a toy in a sandbox, as examined by Huttenlocher et al. (1994). In both cases, the object's location has been indicated on the surface covering it and the child need make no inference other than that the object has not moved. Children at 2.0 years of age and even younger have no trouble remembering an object's location under conditions that do not involve its independent movement. Finally, the location of the ball may have been more difficult because it moved through multiple locations before coming to rest, compared to the toy placed through the open door during familiarization.

Another direct route to success in this task is utilization of the visible portion of the barrier wall to infer the ball's location even after the panel had been positioned, and then selecting a door to search behind on that basis. Many studies have shown that children even younger than 2.0 years old can use visual cues to guide search under some conditions (Acredelo, 1978; Bremner & Bryant, 1977; Bushnell, McKenzie, Lawrence, & Connell, 1995; Schmuckler & Tsang-Tong, 2000). However, there was one aspect of this task that may have made the search more difficult: The visual cue to the target's location was merely adjacent to the hiding place, rather than actually being coincident with it (see also Hood et al., 2000). While the one-to-one correspondence of the four possible barrier locations to the four door positions yields a precise specification of a specific door, that specification still rests on an integration of the barrier location with its corresponding door. Previous research suggests that this kind of integration may actually be very difficult for 2.0-year-old children.

DeLoache (1986) examined developmental change in the ability to use location cues to guide search for an object that had been hidden in a container and then moved. She found that children aged 21 to 28 months had no problem finding an object hidden in one of four visually distinct containers, but failed when the same containers were mounted on top of four identical boxes and the object was hidden inside one of the boxes. DeLoache concluded that children in this age range had difficulty integrating the visual cues that were adjacent but not intrinsically connected to the hiding place. She considered whether the children were simply not noticing the visual cues, rather than having trouble integrating them. In a second experiment, she had the experimenter explicitly call the children's attention to the distinctive visual cues, as we did with the barrier wall in the current research. This did not appear to facilitate children's performance in either study.

Indeed, many studies have revealed a protracted developmental timecourse of children's ability to integrate visual elements over spatial separations (e.g., Chapman, 1981; Dukette & Stiles, 1996; Mash, 2001). From DeLoache's (1986) account, one would predict that 2.0-year-olds would have difficulty with our task, given the amount of spatial integration that is necessary. Specifically, the barrier wall is behind and partially occluded by the door panel. It nevertheless must be integrated spatially with the door's location, and used to arrive at a decision about the ball's location. Although similar spatial integration demands are also characteristic of the infant tasks in which successful performance is observed at earlier ages, important differences in the layout of the apparatus (Baillargeon, 1986) and in the size of the moving object (Spelke et al., 1992) likely render the integration demands less challenging in those tasks.

While the most salient difference between this and manual search tasks administered in the past is the visual access to the event that was available in this study, a more subtle difference exists between the manner in which the ball was occluded from view. In the Berthier et al. (2000) study, the ball moved behind a stationary occluder, while in this study, the ball came to a complete rest and then was occluded by a moving screen. Moore and Meltzoff (1999) directly compared these same manners of object occlusion in a study of 10-, 12-, and 14-month-olds' object search: in one case, a stationary object was hidden by pulling an occluder over it, and, in the other, a hand-held object was moved under a stationary occluder and left there. Interestingly, infants were successful with searching for objects that had been stationary when occluded by a moving screen earlier (12 months of age) than they were with searching for moving objects that had disappeared behind a stationary screen (14 months). This pattern of findings is consistent with the improvement observed presently in children's search accuracy when a stationary ball was occluded by a moving screen. Moore and Meltzoff suggest that the two tasks demand different levels of identity coding, and that infants' developing sense of object identity accounts for the performance difference. While it is not clear whether that view accounts equally well for this situation, differences observed seem to warrant further comparisons of manners of occlusion.

CONCLUSIONS

This study reveals that predicting and representing the outcome of an unseen movement trajectory is not the defining limitation in 2-year-olds' characteristically weak performance with event reasoning and object search. Their performance appears, instead, to depend more on maintaining attention to the target location throughout the trial. Errors due to spatial persereveration and limitations with visuospatial integration contributed additional variance to performance.

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REFERENCES

Acredelo, L. P. (1978). Development of spatial orientation in infancy. *Developmental Psychology, 14,* 224–234.

Baillargeon, R. (1986). Representing the existence and the location of hidden objects: Object permanence in 6- and 8-month-old infants. *Cognition, 23,* 21–41.

Benson, J. B., DeBlois, S., Bottani, M. A., & Hansen, S. T. (2000, July). Spatial location estimation from 18 to 36 months. Poster presented at the International Conference on Infant Studies, Brighton, England.

Berthier, N. E., DeBlois, S., Poirer, C. R., Novak, M. A., & Clifton, R. K. (2000). Where's the ball? Two- and three-year-olds reason about unseen events. *Developmental Psychology, 36,* 394–401.

Bremner, J. G., & Bryant, P. E. (1977). Place versus response as the basis of spatial errors made by young infants. *Journal of Experimental Child Psychology, 23,* 162–171.

Bushnell, E. W., McKenzie, B. E., Lawrence, D. A., & Connell, S. (1995). The spatial coding strategies of one-year-old infants in a locomotor search task. *Child Development, 66,* 937–958.

Butler, S. C., Berthier, N. E., & Clifton, R. K. (2002). Two-year-olds' search strategies and visual tracking in a hidden displacement task. *Developmental Psychology, 38,* 581–590.

Butler, S. C., Sylvia, M., Berthier, N. E., & Clifton, R. K. (2001, April). Motivation and children's reasoning about unseen events. Poster presented at the meeting of the Society for Research in Child Development, Minneapolis, MN.

Chapman, M. (1981). Dimensional separability or flexibility of attention? Age trends in perceiving configural stimuli. *Journal of Experimental Child Psychology, 31,* 332–349.

DeLoache, J. S. (1985). Memory-based searching by very young children. In H. M. Wellman (Ed.), *Children's searching: The development of search skill and spatial representation* (pp. 151–183). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

DeLoache, J. S. (1986). Memory in very young children: Exploitation of cues to the location of a hidden object. *Cognitive Development, 1,* 123–137.

Diamond, A. (1985). Development of the ability to use recall to guide action, as indicated by infants' performance on AB. *Child Development, 56,* 868–883.

Diamond, A. (1998). Understanding the A-not-B error: working memory vs. reinforced response, or active trace vs. latent trace. *Developmental Science, 1,* 185–196.

Dukette, D., & Stiles, J. (1996). Children's analysis of hierarchical patterns: Evidence from a similarity judgment task. *Journal of Experimental Child Psychology, 63,* 103–140.

Harris, P. L. (1987). The development of search. In P. Salapatek & L. Cohen (Eds.), *Handbook of infant perception, Vol. 2: From perception to cognition* (pp. 155–207). Orlando, FL: Academic Press.

Hespos, S. J., & Rochat, P. (1997). Dynamic mental representation in infancy. *Cognition, 64,* 153–188.

Hood, B., Carey, S., & Prasada, S. (2000). Predicting the outcomes of physical events: Two-year-olds fail to reveal knowledge of solidity and support. *Child Development, 71,* 1540–1554.

Hood, B., Cole-Davies, V., & Dias, M. (2003). Looking and search measures of object knowledge in pre-school children. *Developmental Psychology, 39,* 61–70.

Horn, H. A., & Myers, N. A. (1978). Memory for location and picture cues at ages two and three. *Child Development, 49,* 845–856.

Huttenlocher, J., Newcombe, N., & Sandberg, E. H. (1994). The coding of spatial location in young children. *Cognitive Psychology, 27,* 115–147.

Mash, C. (2001, April). Developmental change in the perception of similarity relations among object displays. Poster presented at the meeting of the Society for Research in Child Development, Minneapolis, MN.

Moore, M. K., & Meltzoff, A. N. (1999). New findings on object permanence: A developmental difference between two types of occlusion. *British Journal of Developmental Psychology, 17,* 1–24.

Munakata, Y. (2001). Graded representations in behavioral dissociations. *Trends in Cognitive Sciences, 5,* 309–315.

Piaget, J. (1954). *The construction of reality in the child.* New York: Basic Books.

Poirier, C., Berthier, N. E., Clifton, R. K., Evans, M. K., & Cheries, E. (2000, July). Where's the ball? Young children's reasoning about unseen events. Poster presented at the International Conference on Infant Studies, Brighton, England

Schmuckler, M. A., & Tsang-Tong, H. Y. (2000). The role of visual and body movement information in infant search. *Developmental Psychology, 36,* 499–510.

Smith, L. B., Thelen, E., Titzer, R., & McLin, D. (1999). Knowing in the context of acting: The task dynamics of the A-not-B error. *Psychological Review, 106,* 235–260.

Spelke, E. S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review, 99,* 605–632.

Wellman, H. M. (1985). *Children's searching: The development of search skill and spatial representation.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.