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RESEARCH ARTICLES

An Exploration of Toddlers' Problems in a Search Task

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Toddlers show a surprising lack of knowledge about solidity when they are asked to search for a ball that rolled behind a screen and stopped at a barrier whose top was visible above the screen. They search incorrectly, failing to take into account the position of the barrier. This study examined details of this failure by simplifying the task in 2 ways: by using a search task that did not require children to understand solidity, and by using a prediction task that did not require children to conduct a search. For the prediction task, children had to predict where a ball was going to stop when a barrier intersected its trajectory. Children 2.0 and 2.5 years old were able to conduct a simple search and could predict, to some extent, where the ball was going to stop when the barrier was fully visible. Children did not show this predictive knowledge when the barrier was partially occluded by the screen.

The principle of solidity refers to the physical truism that one solid object cannot pass through another. Infants are sensitive to this constraint. Even 2.5-month-olds appear to recognize when the solidity constraint is violated (Baillargeon, 1987a, 1987b; Spelke, Breinlinger, Macomber, & Jacobson, 1992). They looked longer at an event that was inconsistent with the solidity constraint (a rolling ball apparently moved through a barrier) than at an event that was consistent with that constraint (a ball stopped at the barrier). Measuring children's looking time to inconsistent events is referred to as the violation-of-expectation paradigm because it is assumed that infants expect a certain outcome and are surprised when

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something different happens. This paradigm yields similar results with 2.0- and 2.5-year-olds (Hood, Cole-Davies, & Dias, 2003; Mash, Clifton, & Berthier, 2002). Yet, when tested with a search task, toddlers do not show knowledge about solidity (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000; Hood, 1994; Hood, Carey, & Prasada, 2000).

In a search task that tests understanding of solidity, children were presented with a ramp that could be blocked by a barrier at one of four different locations (Berthier et al., 2000). A screen with four doors, one for each possible location of the barrier, was placed in front of the ramp. It occluded the ramp and the bottom part of the barrier. Only the upper part of the barrier was visible. A ball was rolled behind the screen and children were asked to open the door to find the ball. Despite intensive familiarization with the relation between ball and barrier, children younger than 3 years of age did not open the correct door at rates better than chance. They focused on a favorite door, they chose the door that was correct on the preceding trial, or they appeared to be simply guessing. These outcomes suggest that children did not take into account the location of the barrier. Even when the salience of the barrier was increased (Poirier, Berthier, Clifton, Evans, & Cheries, 2000) or more of the trajectory was revealed (Butler, Berthier, & Clifton, 2002), 2.0-year-olds did not base their choice on the barrier's location.

Although this search task appears relatively simple on the surface, careful analysis reveals many requirements that must be met (see Keen, 2003, for a review). We hypothesize that to perform correctly in this task, children have to (a) know the ball still exists when out of sight behind the screen, (b) plan and execute a search to retrieve the ball, (c) know that the barrier will block the ball, (d) use that knowledge to predict that the ball's location is at the barrier, and (e) link the visible portion of the barrier with the correct door. This study set out to test whether these components are present in children at 24 and 30 months of age. In particular, we were interested in two questions: Can children retrieve an object from behind a screen when no knowledge of solidity is required, and can children predict where a ball is going to stop when no search is required? Although it is clear that Berthier et al.'s (2000) original search task is not a simple sum of these components, simplifying and eliminating various components are first steps toward understanding children's difficulty in solving this problem.

The two most basic components (a and b) required for success in Berthier et al.'s (2000) search task are like those necessary in any Piagetian hidden object task. Will children search to find a hidden stationary object? To answer this question, we designed a task in which a handheld object was lowered behind a four-door screen and children were asked to find the object by opening the correct door. Children simply had to search at the point where the object disappeared; no knowledge of the solidity principle was involved. We expected 2.0- and 2.5-year-old children to perform well in this task, given that the procedure is close to the Piagetian object-permanence task passed by infants around 8 to 10 months of age. In addition, lowering a handheld object behind a screen and revealing it in place was the con-

trol condition in Spelke et al. (1992, Experiment 3), which showed that infants did not find this outcome to be a surprising event.

A second search task was devised to replicate more closely the visual display and procedure of Berthier et al.'s (2000) original search task. In that task it was necessary to link the barrier spatially to the correct door (component e), and children were told on every trial that the barrier would stop the ball. In our second search task we included the barrier but without requiring knowledge of the solidity principle. A handheld object was placed next to the barrier in full view, and then the screen was lowered over the front of the apparatus. With instructions modeled after those given in the original study, children were told that the object was right next to the barrier. Then they were asked to retrieve the object through the screen. This second search task was similar to one used by Mash, Keen, and Berthier (2003), and both were attempts to see if children could solve the problem when they did not have to reason about the barrier stopping a moving object. We expected children to perform well, given that they simply had to search where they saw the object disappear.

The two search tasks described so far, the one in which an object was lowered behind the screen, and the one in which the screen was placed in front of the object, require children to perform a simple search without reasoning about solidity. They are referred to as search-only tasks. They require similar motor acts to those in Berthier et al.'s (2000) task, but the cognitive processes directing the search are much less complex than those in the original study, given that prediction and knowledge of the solidity principle were removed. Both Berthier et al. and Hood et al. (2000) proposed that toddlers' lack of this predictive knowledge was a possible cause of failure in their tasks. Several authors have pointed out that the violation-of-expectation paradigm tests whether children detect a perceptual anomaly (e.g., Diamond, 1998; Williatts, 1997). Looking longer at the unexpected outcome of an event is a postdiction response and differs from search tasks in that no advance reasoning about solidity is needed.

To investigate the extent to which 2.0- and 2.5-year-olds can predict that a barrier is going to stop a rolling ball, we designed two prediction tasks that did not require children to perform a search, thus eliminating component b but adding other components. It is possible that children have predictive knowledge of solidity (component c) but still cannot perform a search that would use this knowledge. These tasks are referred to as prediction-only tasks. In both of these prediction-only tasks, children were asked to place an object at the location where they thought the ball would stop when rolled down the ramp. Note that placing an object may be more complex than asking the child to merely point to the location where the ball would stop. However, the use of the object was necessary to ensure that children could see the outcome of their prediction.

The simplest version of the prediction-only task allowed children to see all critical elements of the display. No screen was present, leaving the intersection between ramp and barrier visible to children. This prediction task required children

to imagine the trajectory of the ball, know about the principle of solidity, and use this to predict where the ball would stop. These cognitive processes involved component c, knowledge about the principle of solidity, and component d, ability to predict the ball's stopping location, while extending component a, knowledge of an object's existence, to imagining an object in a future location. Rochat and Hespos (1996; Hespos & Rochat, 1997) showed that infants between 4 and 8 months could extrapolate invisible trajectories, so we assumed toddlers would not have a problem with this aspect of the prediction-only task. The question was whether they understood that the barrier would stop the ball. Correct performance would suggest that the children had predictive knowledge of solidity when they could see where the barrier would stop the ball.

In a more complex version of a prediction-only task, the screen occluded parts of the display. We used the same prediction task described earlier, but a screen was placed in front of the apparatus. Children could not see the intersection between ramp and barrier; they could only see the onset portion of the ramp and the top part of the barrier. This prediction task required children to coordinate their physical knowledge about solidity with knowledge about hidden spatial relations. Children had to anticipate the event of a ball stopping at the barrier while imagining the intersection of the ramp with the barrier. It is possible that children have difficulty with coordinating these two pieces of knowledge (spatial knowledge about the intersection and physical knowledge about solidity), especially if their predictive knowledge about solidity is still fragile (cf. Munakata, McClelland, Johnson, & Siegler, 1997). Furthermore, because the child had to open a door to place the object on the track, component e, linking the barrier's position with the correct door, was now added. Correct performance in this task would suggest that children can integrate their predictive knowledge of solidity with their spatial understanding of the hidden parts of the display.

The original task used in Berthier et al. (2000) involved the additional step of search, thus covering all five components. Children had to coordinate their knowledge about solidity and their knowledge about hidden spatial relations with the motor act of searching. Bremner (1997) emphasized the difference between having physical knowledge and being able to use the knowledge to solve a problem. The original door task required that knowledge of solidity be used in reasoning about where to search for the ball. We included this task in this series for comparison within the same sample of children across all tasks. This task was presented at the end of the session to test whether children would benefit from extensive experience with the apparatus and perform better than in Berthier et al.'s original study.

A final consideration of this study refers to the impact of the screen on children's performance. The attractiveness of the doors used in Berthier et al. (2000) may have tempted children to pull the knob of a door before they took the time to reason about the location of the hidden object. Using a continuous surface such as a screen instead of the identical doors may help children in their attempt to reason about the location of the hidden object. Huttenlocher, Newcombe, and Sandberg

(1994) tested 16- and 24-month-olds' ability to search for an object hidden underneath a continuous surface and found that even the youngest participants were largely accurate, the mean performance never deviating more than 6% from the correct hiding location. As a means of testing whether discrete doors in the panel affect children's performance, a screen with a continuous surface was used with half of the children. This curtain screen allowed a reach to any location because the screen could be penetrated at any point. This screen was used for the search-only tasks as well as for the prediction-only tasks.

EXPERIMENT 1

The first experiment was conducted to test whether toddlers' poor performance in the original solidity search task was caused by difficulties with the search itself, by difficulties with using knowledge about solidity to make predictions, or by distracting aspects of the door apparatus. Children were presented with five tasks, each testing some aspect of components required to succeed in the original search task: two search-only tasks that excluded prediction based on solidity, two prediction-only tasks that excluded search, and the original solidity task used in Berthier et al. (2000), referred to as a prediction + search task. The same apparatus as in Berthier et al. was used: an inclined ramp with a barrier at one of four positions, and a screen that shielded the ramp from view. One of two screens was used throughout the tasks. In the door condition, the screen was a wooden door panel with four doors as in the original study. In the curtain conditions, the screen had uniform cloth strips that allowed children to reach through and retrieve the object at any location behind the screen. An effect of condition would suggest that children's weak performance in the original search task was due to doors and knobs that were attractive to play with and interfered with the main purpose of the task.

Each child received all five tasks, with the two search-only tasks preceding the two prediction-only tasks, followed by the combination prediction + search task. We regarded the prediction-only tasks as more difficult than the search-only tasks because the former required both prediction and knowledge of solidity. The prediction + search task was placed last because it was the most difficult. Correct performance in this task would suggest that children's experience with the apparatus in the previous tasks created some advantage over children in Berthier et al.'s (2000) study.

Method

Participants

Potential participants were selected from the state birth records. Parents were contacted via mail and subsequently by telephone. The final sample consisted of

16 2.0-year-olds (6 girls and 10 boys) and 18 2.5-year-olds (10 girls and 8 boys), placed randomly in one of the two conditions. The mean age for each age group in the door condition was 24 months, 0 weeks (range = 23 months, 3 weeks–24 months, 1 week) and 30 months, 1 week (range = 30 months, 0 weeks–30 months, 3 weeks). The mean age for each age group in the curtain condition was 24 months, 1 week (range = 24 months, 0 weeks–24 months, 2 weeks) and 30 months, 1 week (range = 29 months, 2 weeks–30 months, 2 weeks). Six additional children were tested and dropped from the sample because they did not complete a sufficient number of trials in all tasks.

Apparatus and Materials

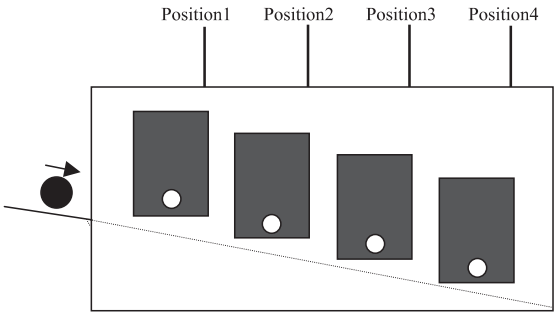
The basic apparatus was the same as the one used in Berthier et al. (2000). A wooden ramp, 75 cm long, 18.5 cm wide, and painted white, was mounted at an angle of 12°. Two dowels were glued onto the ramp (5 cm apart) to constrain the path of the ball rolling from left to right. A wooden barrier (36.5 cm high, 18.5 cm wide, and 0.5 cm thick), painted green, could be inserted at one of four different locations along the ramp (30.5 cm, 44.0 cm, 57.5 cm, or 71.0 cm from the top of the ramp). For ease of description, the positions of the barrier are numbered from 1 to 4, starting with the one closest to the top of the ramp.

Two types of screens were used that could be placed in front of the ramp. Both were 58 cm long (leaving the initial 17 cm of the ramp visible) and 28 cm high (leaving 8.5 cm of the barrier visible). In the door condition, the screen was a wooden panel, painted white, with four openings (Figure 1a). The openings (9.5 cm wide and 14 cm high) were 5 cm apart from each other and corresponded to the positions of the barrier. Each opening was covered by a gray door hinged on the top with a knob on the bottom. In the curtain condition, the screen was a curtain attached to a wooden frame (Figure 1b). The curtain was made of 2-cm-wide strips of opaque white fabric, attached to the top of the frame in two overlapping layers to ensure that the ramp behind the screen was not visible. Every third strip of the back layer was also attached to the bottom of the screen, preventing children from opening the entire curtain with one lateral sweeping movement. A small piece of lead covered with white fabric was glued onto the bottom of all other strips so that the weight kept the strips vertical.

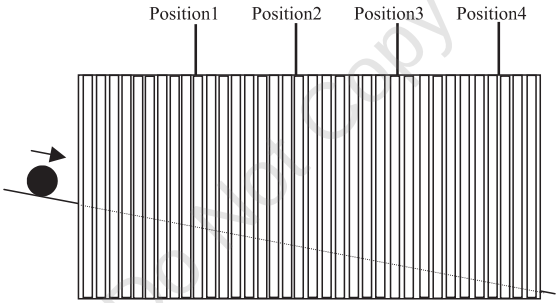
During the experimental session, a small Lego® doll (approximately 3 cm wide and 7 cm high), referred to as Lorie, could be placed on the ramp between the dowels. A soft Hacky Sack® ball (5 cm diameter) that produced a barely noticeable sound could be rolled down the ramp. A video camera was mounted to the wall directly behind and above the child to record the child's reaching behavior for later coding.

Procedure

Children were seated on a parent's lap or in a booster chair in front of the apparatus. The apparatus was positioned within reaching distance from the child. Dur-



(a)



(b)

FIGURE 1 Schematic drawings of the apparatus with screen and one barrier at each possible position: (a) screen used in the door condition, and (b) screen used in the curtain condition.

ing an initial warm-up phase, the screen was placed in front of the apparatus and children were encouraged to open the doors or reach through the curtain with one hand. Next, children participated in five tasks presented to them in a fixed order: two tasks in which children were asked to search for the doll (search-only tasks), two tasks that required children to predict where the ball would stop (prediction-only tasks), and a task in which children were required to search for the ball that stopped at the partially visible barrier (prediction + search task). The procedure for each task is described in detail next.

Search-only tasks. Children were told that the doll Lorie liked to hide behind one of the doors (or behind the curtain). Four familiarization trials followed. The experimenter held the doll above the screen and called to get the child's attention. Once the child looked at the doll in the experimenter's hand,

the doll was lowered vertically behind the screen onto the ramp. In the first two trials, the doll was placed at positions 2 and 3 (in random order), and the experimenter demonstrated how to retrieve it. In the next two trials, the doll was placed at positions 1 and 4 (in random order), and the child was encouraged to find it. Help was provided if necessary. These two trials ensured that the child noticed the extreme ends of the screen.

Eight testing trials followed in which children were encouraged to find the doll. During the first four trials (hiding without barrier), the doll was lowered from above the screen as was done during the familiarization. During the last four trials (hiding with barrier), a barrier was placed onto the ramp, the doll was placed next to the barrier (from the child's perspective on the left side of the barrier), and the screen was lowered in front of the doll. Each time, the experimenter prompted the child by saying, "Remember, Lorie is right next to the wall."

During each set of the four testing trials just described, the doll was hidden at all four positions (1, 2, 3, or 4) in one of two random orders or their reverse. The order of positions was counterbalanced across children. When incorrect at the first attempt to find the doll, children were encouraged to search at a different position until the doll was found.

Prediction-only tasks. During the warm-up phase, children were shown how the ball rolled down the ramp, first without the barrier then with a barrier at position 2. The experimenter explained that Lorie, the doll, wanted to catch the ball, and then placed Lorie correctly at position 2, just in front of the barrier and facing the ball. The ball was rolled down the ramp and the experimenter commented, "Lorie caught the ball. See, how she touches the ball with her tummy?" In two further demonstration trials with the barrier at position 2, the doll was placed first at position 3 and then at position 1. Each time, the ball was rolled and the experimenter said, "Oh no, she did not catch the ball; she was too far away" (position 3), or "The ball knocked her over" (position 1).[1] Finally, the correct position of the doll and its successful catch at position 2 was demonstrated again. Two trials followed (with the barrier at position 1 and then at position 4, or vice versa) in which the child was invited to place the doll on the ramp to catch the ball. After the child placed the doll onto the ramp, the experimenter rolled the ball and commented on the outcome ("Lorie caught the ball," "Lorie was too far away," or "Lorie got knocked over"). If the doll was placed incorrectly on one or both of these trials, the trials were repeated once to make sure the child understood the instructions.

[1]Note that in principle, the doll could "catch" the ball at position 1. However, because our question was whether children understand the importance of the barrier, care was taken to show children that position 1 was in fact incorrect, as the ball knocked the doll down.

Twelve testing trials followed in which two barriers were placed on the ramp at the same time. Having two barriers rather than one minimized the possibility that children would place the doll beside the barrier because it was the most salient object on the ramp. To address a similar concern in the original solidity task, Berthier et al. (2000) included trials with two barriers, rather than one barrier, for those children who performed correctly on the one-barrier trials (3-year-olds). To perform correctly under this condition, children had to understand that only the barrier closest to the ball was going to affect the movement of the ball. The second barrier, although equally salient, was irrelevant to the rolling ball.

On each testing trial, the child heard "Lorie wants to catch the ball. Where should she stand?" After the child placed the doll onto the ramp, the experimenter rolled the ball and commented on the outcome ("Lorie caught the ball," "Lorie was too far away," or "Lorie got knocked over"). During the first six trials, no screen was used so the child had a full view of both barriers and the ramp (prediction without screen). During the next six trials, the screen was placed in front of the apparatus leaving only the top part of the two barriers visible to the child (prediction with screen). Children had to place the doll through one of the doors or through the curtain onto the ramp. After each trial, the screen was lifted so that the child could observe the outcome. Again the experimenter commented on the outcome each time. In each set of six trials, the two barriers were placed in one of the six possible pairs of positions (1–2, 2–3, 3–4, 1–3, 2–4, and 1–4) in one of two random orders or their reverse. The four orders were counterbalanced across children.

Prediction + search task. The final task was a repeat of the original procedure in Berthier et al. (2000) in which the child was asked to find the ball behind the screen. The doll was removed and one barrier was placed on the ramp behind the screen. The ball was rolled down the ramp behind the screen, and children were asked to find it. When incorrect at the first attempt to find the ball, children were encouraged to search at a different position until the ball was found. Four trials were administered, with each position of the barrier occurring once. Positions were assigned by two random orders and their reverse, with the four orders counterbalanced across children.

Scoring

One person scored the videotapes of all children's performances. A second person scored the videotapes of half of the participants in each age group and each condition for reliability purposes. Two scoring schemes were developed: one for the search tasks (search-only and prediction + search), and one for the prediction-only tasks.

In the search tasks, the behavior of interest was children's first search location. Each trial was coded as correct or incorrect depending on whether the doll or ball

was revealed at the first search location. The relevant behavior in the door condition was the door that was opened first. In the curtain condition, it was the location in the curtain that was opened or reached through first. Here, children had to open or reach through the curtain within 4 cm of the doll's or ball's location to be correct. This value was chosen to approximate the width of the opening in the door panel used in the door condition. If children opened two doors or opened the curtain at two different locations at the same time, and neither of them revealed the doll or ball, the trial was coded as incorrect. If one of the two locations revealed the doll or ball, the trial was coded as not usable.

In the prediction-only tasks, the behavior of interest was the final position of the doll in relation to the barrier before the ball rolled down the ramp. The doll's position was coded as correct when it was placed within 4 cm of the left side of the first barrier (from the child's perspective). Placing the doll more than 4 cm to the left of the first barrier was coded as in front. The ball knocked the doll over at this location and any locations further to the left of the barrier. Other positions were between the two barriers or behind the second barrier. Trials of the prediction with screen task were coded as not usable when children placed the doll over the top or around the screen.

Interrater reliability was calculated as the percentage of trials that were scored the same by both scorers. For the search tasks, the percentage agreement was 98.9% in the door condition and 96.4% in the curtain condition. For the prediction-only tasks, the percentage agreement for placement of the doll was 100.0% for both conditions.

Results

For each child, the number of correct responses was divided by the total number of responses to yield the proportion correct score. These scores were used in all analyses. Table 1 shows the mean proportion correct scores across children in each age group and each condition separated for each task. For comparison, the means reported in Berthier et al. (2000) and Mash et al. (2003) are included below the relevant tasks. Tasks were analyzed separately, first the two search-only tasks, then the two prediction-only tasks, and finally the prediction + search task.

Search-Only Tasks

Across 272 trials, 3 were not usable because the child used two hands for the search. The mean number of completed trials was 3.97 for the hiding without barrier task and 3.94 for the hiding with barrier task. No child completed fewer than three trials.

A three-factor mixed design analysis of variance (ANOVA; Door or Curtain Condition × Age Group × Without Barrier or With Barrier Task) revealed no significant differences for type of screen, age, or type of search tasks (see Table 1 for

TABLE 1
Mean Proportions of Correct Scores for Experiment 1

	2.0-Year-Olds				*2.5-Year-Olds*			
	Door Condition		*Curtain Condition*		*Door Condition*		*Curtain Condition*	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Search-only tasks								
Hiding without barrier	.66	.08	.50	.10	.61	.13	.58	.11
Hiding with barrier	.53	.10	.64	.10	.83	.06	.63	.04
Mash et al. (2003)	.37[a]	—	—	—	.52[a]	—	—	—
Prediction-only tasks								
Without screen	.15	.10	.12	.08	.56	.14	.39	.12
With screen	.39	.07	.13	.03	.25	.14	.27	.08
Prediction + search task	.26	.07	.14	.05	.40	.07	.16	.06
Berthier et al. (2000)	.22[b]	—	—	—	.34[b]	—	—	—

Note. In the curtain condition of the prediction + search task, $n = 7$ for 2.0-year-olds, and $n = 8$ for 2.5-year-olds. For all other cells, $n = 8$ for 2.0-year-olds, and $n = 9$ for 2.5-year-olds.
[a]$n = 18$. [b]$n = 16$.

the mean proportion correct scores for all cells). To evaluate whether children performed better than would be expected by chance, only children's performance in the door condition was considered, given that a clear chance probability could be determined only for this condition ($p_{\text{chance}} = .25$). Two t tests, performed separately for each search-only task and collapsed across age groups, showed that children performed above chance: hiding without barrier, $M = .63$, $t(16) = 5.12$, $p < .01$; hiding with barrier, $M = .69$, $t(16) = 6.67$, $p < .01$. These findings suggest that 2.0- and 2.5-year-olds can find a stationary object hidden behind the screen. The addition of the barrier to mark the object's location neither helped nor hurt their performance.

Even though children performed above chance on search-only tasks, their accuracy was not at ceiling. It is possible that children had a somewhat vague knowledge of where the doll was hidden, reaching often to locations adjacent to the correct location. An error analysis collapsed across the two search tasks was conducted to explore this possibility. Only children in the door condition were considered, given that a clear chance probability could be determined ($p_{\text{chance}} = .5$).[2] The mean proportion of adjacent-door errors was .75 ($SD = .36$) for 2.0-year-olds and .77 ($SD = .29$) for 2.5-year-olds. No age difference was apparent. Adja-

[2]The chance probability of opening an adjacent door was .33 if the hiding location was at door 1 and 4, and .67 when the hiding location was at door 2 or 3, yielding a mean chance probability of .5 across all possible hiding locations.

cent-door errors were significantly above chance probability of .5, $t(16) = 2.37$, $p < .04$, suggesting that children had some knowledge about the location of the doll even when they did not search correctly.

Prediction-Only Tasks

A preliminary analysis assessed children's performance during the familiarization trials. Recall that children were presented with two trials, one with the barrier at position 1 and one with the barrier at position 4. If incorrect, a position was repeated once. The average number of familiarization trials was 2.9 for 2.0-year-olds and 2.7 for 2.5-year-olds (*SD* for both age groups = 0.8). The mean proportion correct on these trials was .61 for 2.0-year-olds (*SD* = .41), and .69 for 2.5-year-olds (*SD* = .33). No significant age difference was found, $t(32) = 0.60$, $p > .5$.

Across 408 testing trials, 18 were not usable because of experimenter error (5 trials) or because the child refused to place the doll on the ramp (13 trials). The mean number of completed trials was 5.82 for the prediction without screen task, and 5.65 for the prediction with screen task. No child completed fewer than 4 trials.

A three-factor mixed-design ANOVA (Door or Curtain Condition × Age Group × Without Screen or With Screen Task) revealed no effect of door versus curtain, a significant age effect, $F(1, 30) = 5.16$, $p < .03$, with older children ($M = .35$) performing better than younger children ($M = .20$), and a significant Age × Screen Task interaction, $F(1, 30) = 8.25$, $p < .01$. See Table 1 for a breakdown of means in each subgroup. Figure 2 shows children's mean performance for each age group and each prediction task collapsed across door or curtain condition. Bonferroni pairwise comparisons revealed that 2.5-year-olds performed better without the screen than with the screen (mean difference = .22, $p_{\text{adjusted}} < .02$), whereas 2.0-year-olds were not affected by this variation.[3]

The individual patterns of performance of 2.5-year-olds confirm the results of the pairwise comparison. Nine of the 18 children obtained a proportion score of .5 or higher when the prediction task was carried out without screen. All of these 9 children performed worse once the screen was in place to obstruct their view. Only 1 child who obtained a proportion score lower than .5 without the screen obtained a proportion score above .5 with the screen (see Figure 3 for a display of individual children's performance in the two prediction tasks).

[3]It is not possible to determine whether children performed above chance in the prediction without screen task, given that a sensible chance probability cannot be established. However, finding that 2.5-year-olds' performance was not different from chance in the prediction with screen task (calculated only for children in the door condition with $p_{\text{chance}} = .25$), $t(8) = 0.04$, $p = .97$, and finding that this performance differs from the corresponding performance in the prediction without screen task, $t(8) = 1.86$, $p = .05$, suggests, by inference, that 2.5-year-olds' performance in the prediction without screen task was better than would be expected by chance.

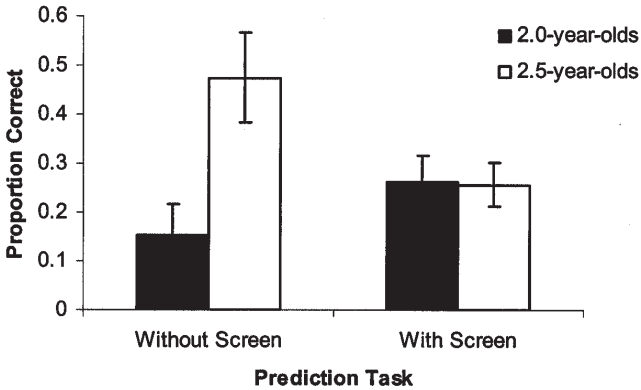


FIGURE 2 Children's mean proportion correct (with standard error) in the two prediction-only tasks of Experiment 1.

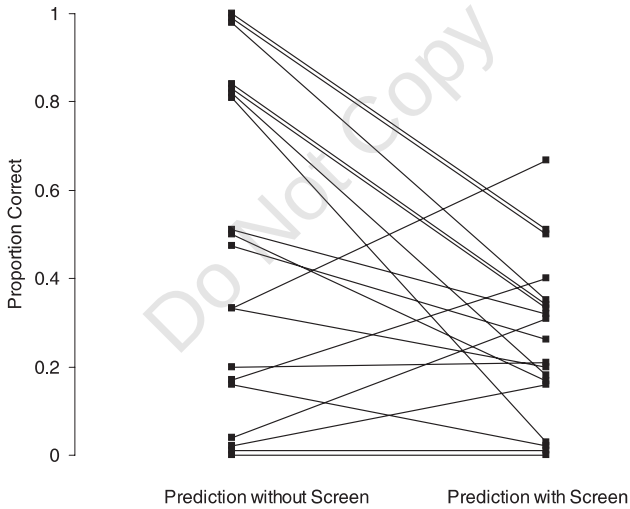


FIGURE 3 Proportion of correct performance of individual 2.5-year-olds in the two prediction-only tasks of Experiment 1.

The 2.0-year-olds performed incorrectly in both prediction tasks, independently of whether or not they could see the barrier intersecting the ramp (prediction without screen, $M = .14$; prediction with screen, $M = .26$). Erroneous positions of the doll were scored as too far in front of the first barrier, between the two barriers, or behind the second barrier. Figure 4 displays the distribution of error types made by 2.0-year-olds in comparison with choices of the correct position. The most common error across both tasks was to place the doll between the two barriers.

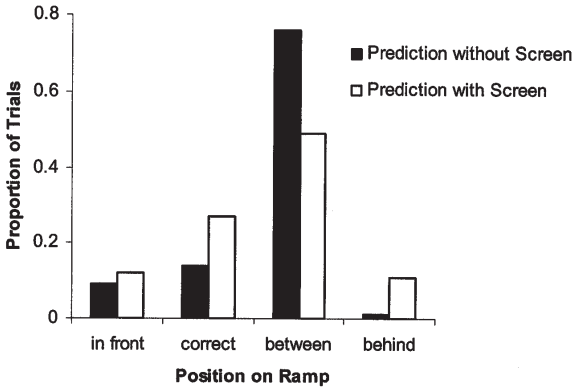


FIGURE 4 Spatial distribution of 2.0-year-olds' errors and correct responses in the prediction-only tasks of Experiment 1.

Note, however, that the probability of placing the doll between the two barriers is more likely by chance than any other position because three placements of the barriers excluded the choice of "in front of the first barrier" (1–2, 1–3, 1–4), and three placements excluded the choice of "behind the second barrier" (1–4, 2–4, 3–4). No placement excluded the choice of "between the barriers." It is reasonable to assume that children's errors in the prediction with screen task reflect these restrictions. In the prediction without screen task, however, children appeared to show a systematic error beyond chance probability: They placed the doll between the two barriers on 76% of trials when they could see the barrier on the track, compared to 49% of trials with the screen in place. A proportion between score was calculated for children who performed incorrectly in at least two trials of each prediction-only task ($n = 15$) to follow up on this finding. A repeated measure t test comparing these proportion scores for the two prediction-only tasks showed that children were more likely to place the doll between the barriers in the prediction without screen task than in the prediction with screen task, $t(14) = 3.34$, $p < .01$. The high rate of placing the doll between the barriers when they were in view suggests that 2.0-year-olds may not have understood the task instructions.

Prediction + Search Task

Across 136 trials, 8 were not usable because the child refused to find the object (7 trials), or used two hands for the search (1 trial). Two children completed only 2 trials and are not included in the analysis. All other children completed 3 or more trials ($M = 3.82$).

The main purpose for including this task was to see if elaborate experience with the apparatus would produce improved performance. Two t tests (one for each age

group) comparing children's performance in the door condition to a chance probability of p_{chance} = .25 revealed no significant difference, a finding similar to the findings of Berthier et al. (2000; see Table 1). Apparently, children did not profit from having completed several tasks on the same apparatus, including the prediction-only tasks for which children obtained feedback after every trial.

A two-factor between-subject ANOVA (Door or Curtain Condition × Age Group) revealed a significant effect of condition, $F(1, 28) = 7.34$, $p < .02$, with children in the curtain condition ($M = .15$) performing worse than children in the door condition ($M = .33$). Better performance with doors on these tasks was likely due to the constraining effect of four discrete search locations. If a child had no idea where the toy was behind the curtain or where to place the doll, performance could easily go below being correct one out of four times. Having chance restricted to .25 by four doors raised performance, but did not lift it above chance.

Discussion

Can Children Retrieve an Object From Behind a Screen?

When a doll was lowered behind the screen, children performed well independently of whether they had to open one of the four doors or reach through the curtain to retrieve it. Finding no differences between screen type suggests that 2.0-year-olds' difficulty in the original Berthier et al. (2000) solidity search task did not come from their interaction with an apparatus featuring intriguing doors to be opened. In a second search task, the doll was placed on a ramp beside a barrier, the screen was lowered in front of it, and a verbal hint about the barrier was given to mimic the procedure in Berthier et al.'s original search task. These variations did not affect children's search. Finally, there was no difference in performance due to age.

The main point of giving these search-only tasks to children was to determine whether the difficulty in the tasks of Berthier et al. (2000) or Hood et al. (2000) stemmed from the search activity per se. In our simplified search tasks we sought to remove the knowledge requirements of solidity and reasoning about how a solid barrier would block a moving object's trajectory at a particular point. Using the same apparatus as in Berthier et al., but hiding objects that remained stationary after being hidden, we found that toddlers opened the correct door significantly above chance, with a mean performance of .59 for 2.0-year-olds and .72 for 2.5-year-olds, better than children in the original study (*M*s = .22 and .34, respectively for 2.0- and 2.5-year-olds). Even children who did not search correctly in our simplified search tasks seemed to have a vague idea about the hiding location of the toy. Considering the error trials in the door condition, children were likely to open a door adjacent to the correct door. It is striking that when the same children in Experiment 1 were subsequently given Berthier et al.'s original search task,

termed prediction + search, their performance resembled closely that of children in the Berthier et al. experiment, despite the considerable and diverse experience with the apparatus.

Considering the simplicity of the search-only tasks, near perfect performance might have been expected for children in the third year of life. A mean of .66 indicates that children made numerous errors. It is possible that children's search performance, although fairly accurate, is dependent on keeping uninterrupted attention. Mash et al. (2003) showed that maintaining gaze on the hidden ball's location is critical in directing search for the hidden ball, such that performance was above 90% on trials when children kept their gaze locked on the disappearing ball. In Experiment 2 we repeated a simple search task and recorded gaze behavior to determine if it was related to correct choice.

Can Children Predict Where the Ball Is Going to Stop?

The two prediction tasks were attempts to see if children could use their knowledge of object solidity to reason about a barrier. The primary manipulation was to expose critical elements to view (prediction without screen task) or to conceal them (prediction with screen task) as was true for the original Berthier et al. (2000) task. Children had to place the doll on the ramp where the ball would stop when two barriers were present. When children could see the full length of the barriers and the full length of the ramp, 2.5-year-olds, but not 2.0-year-olds, had some success at predicting where the ball would stop. With the screen blocking their view of the apparatus, both age groups' performance was at chance. Individual performance confirmed the group trends. In the older age group half of the children (9 of 18) performed correctly on a majority of the trials without the screen, but all 9 performed worse when the screen hid their view. In the younger age group, only 2 children (of 16; 12%) performed correctly on trials without the screen, and 3 children (19%) performed correctly on trials with the screen. These findings suggest that 2.5-year-olds have some predictive understanding of solidity when they can see the intersection between ramp and barrier. Once the screen obstructs their view and forces them to imagine the hidden trajectory and the position of the barrier, their performance drops. Again, there was no difference in performance for type of screen, curtain versus panel with doors.

The pattern of errors in the 2.0-year-olds suggests that children in this age group did not perform according to the task instructions. Their errors were not random as they placed the doll consistently between the two barriers. Instead of reasoning about solidity, children in this age group may have played their own game, for example, by understanding the barriers as a sort of house for the doll. To investigate whether 2.0-year-olds are able to predict the stopping location of a ball, we carried out a new set of prediction-only tasks in Experiment 2 using only one barrier. In addition, we repeated a simple search task while recording children's gaze behavior.

EXPERIMENT 2

What caused 2.0-year-olds to show an incorrect bias in the prediction task with no screen? The correct position for placing the doll on the track was to the left of the first barrier, but 2.0-year-olds consistently placed it between the two barriers. Did they fail to understand the instructions, did they lack an understanding of solidity, or did they find the two barriers confusing? To investigate these questions, we administered three prediction-only tasks, all of which involved only one barrier. The first task was identical to the familiarization phase of Experiment 1: After the experimenter demonstrated the correct and incorrect placements of the doll, children were asked to place the doll on the ramp at the position where the ball would stop. In Experiment 1, children were given fewer than three familiarization trials on average, making it difficult to establish whether children clearly understood the instructions given during demonstrations. In Experiment 2, the number of familiarization trials was increased to six for all children.

The ensuing two prediction tasks corresponded to the prediction-only tasks of Experiment 1. First, no screen was present, giving children visual access to the ramp and the barrier (prediction without screen task). Then the screen was placed in front of the apparatus, occluding the ramp and the lower portion of the barrier (prediction with screen task). Only the door panel was used as the screen, given that the curtain screen did not aid children's performance in Experiment 1. To rule out the possibility that children could base their predictions on a simple, nonphysical rule extrapolated during familiarization (e.g., "Put the doll to the left of the barrier"), the slope of the ramp was reversed after the familiarization trials. To perform correctly, children had to understand that the direction of the ball's movement matters. If the ball rolls from the right, the correct position of the doll is to the right of the barrier, and if the ball rolls from the left, the correct position of the doll is to the left of the barrier. This method of switching the ramp was used in a search task that tested 3-year-olds' understanding of solidity (Sylvia, Butler, Berthier, & Keen, 2005). Three-year-olds searched accurately when the ramp switched direction. Finding that 2.0-year-olds could take into account the direction of the ramp would suggest that children have predictive knowledge of solidity.

A second goal of Experiment 2 was to record children's gaze behavior during a simple search. Mash et al. (2003) noted that 2.0-year-olds' search performance was predicted by their gaze behavior. In that study, children were shown a ball rolling down a ramp and stopping at a barrier. A door panel was then lowered to conceal the ramp, and children were encouraged to find the ball by opening the correct door. We wanted to confirm this connection between search success and gaze behavior with the hiding with barrier, a search task that closely resembles the search task of Mash et al. Eye movements were recorded during the period between the disappearance of the object and the child's search for it. Because this task was not the main focus of Experiment 2, it was given after the prediction-only tasks.

Method

Participants

Potential participants were selected from state birth records. Parents were contacted via mail and subsequently by telephone. The final sample consisted of 17 2.0-year-olds (9 girls and 8 boys), with a mean age of 24 months, 0 weeks (range = 23 months, 2 weeks–24 months, 1 week). An additional 4 children were tested and dropped from the sample because they did not complete at least four trials in each prediction-only task.

Apparatus and Materials

The same apparatus as described in Experiment 1 was used, except that the direction of the ramp was switched during some trials, so that the ball rolled from left to right (as was done in Experiment 1) or from right to left. The spatial relations between the barriers and the top of the ramp were the same for both directions of the ramp. Position 1 was at the top of the ramp, and position 4 was at the bottom of the ramp. For each direction of the ramp, a door panel was used for which the locations of the doors corresponded to the locations of the barriers.

As in Experiment 1, a doll referred to as Lorie and a Hacky Sack ball were used throughout the experiment. Two video cameras recorded children's behavior. One camera was mounted directly behind and above the child. The other camera was placed on the table behind the apparatus to record children's looking behavior.

Procedure

Children were seated on a parent's lap or in a booster chair in front of the apparatus. During an initial warm-up phase, the experimenter placed the screen in front of the apparatus and encouraged children to open the doors with one hand. Four warm-up trials followed, identical to the hiding without barrier task in Experiment 1, in which the doll was lowered by hand from the top of the screen behind the screen onto the ramp and children were asked to find it. The doll was hidden once at each of the four positions (1, 2, 3, or 4) in one of two random orders or their reverse. The order of positions was counterbalanced across children.

After this warm-up, children participated in three prediction-only tasks and in the search-only task, presented in a fixed order. Within each of these tasks, children completed maximally six trials, and only one barrier was placed onto the ramp in each trial. Across each set of the six trials the barrier was placed at position 1, 2, 3, 4, and two further positions in one of two random orders, or their reverse. The two additional barrier positions and the four possible orders were counterbalanced across tasks and across children. The three prediction-only tasks and the search-only task are described in detail next.

Prediction-only tasks. To orient children to the task of predicting where to place the doll, they saw the same demonstrations that were used in Experiment 1: The experimenter placed the barrier at position 2 and demonstrated to children the correct and incorrect positions of the doll (correct: position 2; incorrect: positions 1 and 3). Three prediction tasks followed in a fixed order: the familiarization task, the prediction without screen task, and the prediction with screen task.

During the familiarization task, children were asked on six trials to place the doll on the ramp in such a way that it would catch the rolling ball. Once the child placed the doll onto the ramp, the experimenter rolled the ball and commented on the outcome ("Lorie caught the ball," "Lorie was too far away," or "Lorie got knocked over"). The ramp was inclined from left to right for half of the children, and from right to left for the other children.

For the prediction without screen task, the experimenter switched the direction of the ramp and rolled the ball down the ramp just once, with no barrier present, to familiarize the child with the new setting. At the beginning of each trial the experimenter placed the barrier on the ramp and reminded the child, "I am going to roll the ball from here. Where should Lorie stand to catch the ball?" At the end of each trial, the experimenter commented on the outcome as in Experiment 1.

The prediction with screen task was conducted immediately after the prediction without screen task, without changing the direction of the ramp. The screen corresponding to the direction of the ramp was placed in front of the apparatus. Children were asked to place the doll through one of the doors onto the ramp so it would catch the rolling ball. After each trial, the experimenter rolled the ball behind the screen and lifted the screen briefly to show the outcome.

Search-only task. As was done in the hiding with barrier task of Experiment 1 (door condition), the experimenter placed a barrier onto the ramp, placed the doll next to the barrier (either to the right or to the left of the barrier depending on the direction of the ramp), and placed the screen in front of it. Each time, the experimenter prompted the child by saying, "Remember, Lorie is right next to the wall. Can you find her?"

Scoring

One person scored videotapes of all children's performances. A second person scored the videotapes of half of the children for reliability purposes. Interrater reliability was calculated as the percentage of trials that were scored the same by both scorers.

The relevant behavior in the prediction-only tasks was the placement of the doll in relation to the barrier before the ball was rolled down the ramp. The placement was coded as correct when children placed the doll close to the barrier (within 4 cm) at the appropriate side of the barrier (to the left when the ramp was inclined

from left to right, and to the right when the ramp was inclined from right to left). Incorrect placements were to place the doll in front of or behind the barrier. Trials in which children placed the doll over the top or around the screen were not usable. The percentage agreement across the three prediction-only tasks was 98.5%.

The relevant behaviors in the search-only task was the door that children opened first and their eye gaze before they opened the door. A trial was coded as correct or incorrect depending on whether the doll was behind the door opened first. Trials in which children opened the correct and an incorrect door at the same time were not usable. For the gaze behavior, each trial was described in terms of (a) whether the child looked at the door where the doll disappeared while the screen was lowered, and (b) whether the child broke their gaze for more than 1 sec after the screen was lowered and before they opened a door. The percentage agreement was 97.4% for children's search performance and 96.1% for their gaze behavior.

Results and Discussion

Prediction-Only Tasks

Across the three tasks (familiarization, prediction without screen, and prediction with screen), 13 trials (out of 306) were not usable because children lost interest (5 trials) or refused to place the doll onto the ramp (8 trials). No child completed fewer that 4 trials in each of these tasks. The average number of completed trials was 5.76 in the familiarization task, 5.71 in the prediction without screen task, and 5.76 in the prediction with screen task.

A proportion correct score was calculated for each child to reflect his or her performance when asked to place the doll on the ramp. Table 2 shows the means of

TABLE 2
Mean Proportion of Correct Scores for Experiment 2

	Experiment 2		*Experiment 1 (Door Condition)*			
	2.0-Year-Olds		*2.0-Year-Olds*		*2.5-Year-Olds*	
	M	*SE*	*M*	*SE*	*M*	*SE*
Prediction-only tasks						
Familiarization	.87	.06	—	—	—	—
Without screen	.49	.10	.15	.10	.56	.14
With screen	.32	.04	.39	.07	.25	.14
Search-only task						
Hiding with barrier	.42	.07	.53	.10	.83	.06

Note. For Experiment 2, $n = 17$ for the prediction-only task, and $n = 10$ for the hiding with barrier task.

these scores for each task and, for comparison, the means obtained in the prediction-only tasks of Experiment 1 for each age group.

During the familiarization task, when the ramp was not switched, children performed very well ($M = .87$). Twelve children (of 17) performed correctly on every trial, and only 1 child performed correctly in less than half of the trials. This high performance indicates that 2.0-year-olds could follow the instructions of placing the doll where it could catch the ball. It does not indicate a predictive understanding of solidity. Children simply needed to repeat the action seen during the demonstrations without having to understand that the barrier stops the movement of the ball. Children's knowledge of solidity could be assessed only after the slope of the ramp was changed.

Children's mean performance was .49 in the prediction without screen task and .32 in the prediction with screen task. A paired-samples t test revealed that children performed better without the screen than with the screen, $t(16) = 2.30$, $p < .04$. Their performance in the prediction with screen task was not better than would be predicted by chance, $t(16) = 1.69$, $p > .11$. The group findings were confirmed by the individual patterns of performance. Eight children (of 17) performed correctly on at least half of the trials without the screen, all of whom performed worse when ramp and barrier were screened from view (Figure 5). When children made an error in the prediction without screen tasks, they were 3 times more likely to place the doll behind the correct position than in front of it (Figure 6). Finding that children persisted in placing the doll on the previously correct side of the barrier sug-

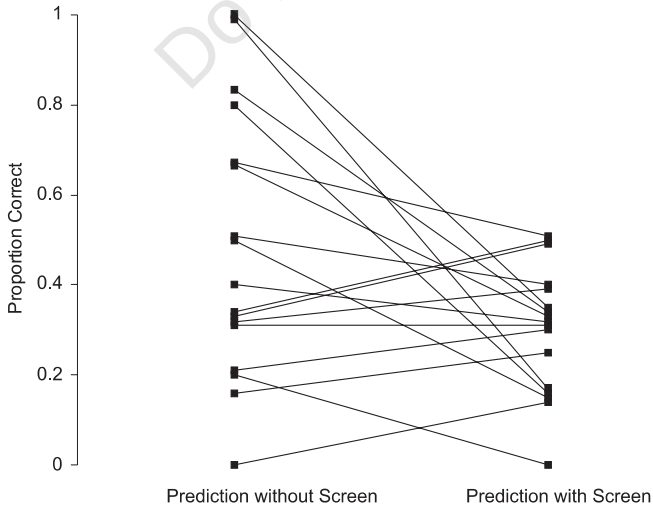


FIGURE 5 Proportion of correct performance of individual 2.0-year-olds in the prediction-only tasks of Experiment 2.

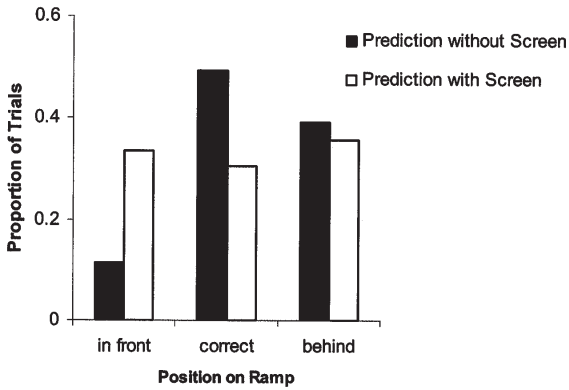


FIGURE 6 Spatial distribution of 2.0-year-olds' errors and correct responses in the prediction-only tasks of Experiment 2.

gests that their good performance during the familiarization task was due to a simple association between the ball and the barrier during the demonstrations.

These results suggest that some 2.0-year-olds have an understanding of solidity when they are not required to infer the spatial relations behind a screen. Once children had to use their knowledge about solidity while remembering spatial knowledge about ramp and barrier, their performance dropped. Note that 2.0-year-olds' performance found in this experiment is comparable to that of 2.5-year-olds in the prediction-only tasks of Experiment 1: Both age groups showed some understanding of solidity when they could see the full display but not when a screen covered the display.

Search-Only Task

Ten children completed at least 4 trials in the hiding with barrier task, with an average of 5.9 trials. (Three children did not complete this task due to equipment failure, and 4 children completed 3 or fewer trials due to loss of interest.) The mean of children's proportion correct score is given in Table 2 together with the means obtained in Experiment 1. A t test comparing children's performance to the chance probability ($p_{\text{chance}} = .25$) revealed that children performed better than would be expected by chance, $t(9) = 2.33$, $p < .05$. No significant difference was found between the performance of 2.0-year-olds in Experiment 1 and in Experiment 2, $t(17) = 0.92$, $p > .37$.

The main purpose in repeating this task was to assess looking behavior prior to search. Table 3 shows the number of correct and incorrect trials as a function of children's looking behavior. Children performed correctly on all 15 trials when they fixated the doll throughout its disappearance and maintained their gaze until

TABLE 3
Number of Correct and Incorrect Trials in the Hiding With Barrier Search Task as a Function of Children's Looking Behavior

	Correct Trials	*Incorrect Trials*	*Sum*
Was the child looking at the door when the doll disappeared?			
No	7	28	35
Yes	18	6	24
If yes, did the child break his or her gaze before opening the door?			
Yes	3	6	9
No	15	0	15

Note. A total of 59 trials were completed.

they opened a door. When children's eyes did not fixate the doll as it disappeared behind the screen (59% of the trials), they performed correctly on 20% of these trials. Clearly, breaking the gaze led to frequent errors. These findings are consistent with the findings reported in Mash et al. (2003) and suggest that children's search performance depends critically on maintaining gaze where the toy disappeared.

GENERAL DISCUSSION

The goal of this study was to investigate possible reasons for children's failure in apparently simple search tasks in which an object moved behind a screen and stopped at a barrier that was partially visible above the screen. To find the object children had to coordinate knowledge of solidity (i.e., that the barrier would stop the object) with the activity of search. Children between 2 and 3 years of age perform at chance on such a search task (Berthier et al., 2000; Hood et al., 2000). Several variations that simplified the original task were used to investigate why toddlers fail to solve this problem. In addition, we used two types of screens to address whether children's poor performance in the original study was due to the attractiveness of pulling or playing with a knob to open a door. If true, this could lead to impulsive decisions about action, with little consideration about which door was correct. One screen was the original panel with four doors, and the other was a continuous curtain with no distinguishing features.

In brief, toddlers performed fairly well in search tasks that did not require using knowledge of solidity, and they were unaffected by manipulations concerning the barrier and type of screen. In the tasks requiring prediction, some children showed convincing evidence of their knowledge of the solidity principle, but all children's performance fell to chance when the screen hid critical elements of the display.

Executing a Simple Search

Because infants 8 to 10 months of age search under covers for hidden objects, 2.0-year-olds were expected to do that as well. In the original study (Berthier et al., 2000) children were given a pretest in which the experimenter opened a door, placed a toy inside, and closed the door. Almost all children readily opened the door and retrieved the toy. In the experiments reported here, 2.0- and 2.5-year-olds received two variations in the manner in which the toy was hidden. A handheld object was lowered behind the screen, or the object was placed on the track and the screen was drawn over it. The latter task closely replicated previous procedures and visual displays (Berthier et al., 2000; Mash et al., 2003): The object was placed next to a barrier on the track and the experimenter verbally noted its presence. In both of these simple search tasks, children did not have to reason about the solidity principle or use the barrier as a marker of the hidden object's position.

As predicted, children in both age groups performed well in the simple search task, unaffected by the hiding variation or by the type of screen. Across age group, type of task, and type of screen, children found the hidden toy, on average, on 62% of the trials in Experiment 1 and on 42% of the trials in Experiment 2. For children in the door condition, where performance could be compared with chance, children performed above chance. Clearly, low performance in the original search task was not due to a tendency to open the doors just for the sake of impulsively opening attractive doors or to a general inability to isolate the correct door from identical but incorrect alternatives.

Note, however, that children's search success was not at ceiling, indicating that although knowledge of a hidden object's existence behind a screen may be firm, knowledge of its exact whereabouts is less secure. Further support for this possibility comes from the search findings of Experiment 2: When gaze was included in the analysis of children's performance, the correct door was nearly always chosen if gaze at the point of the toy's disappearance was held until a response was made. At least the younger toddlers seem to need the visual support of keeping their eyes on the hidden object's point of disappearance in order not to lose track of its location (but see Huttenlocher et al., 1994).

In Berthier et al.'s (2000) original search task, children could not lock their gaze on the correct hiding location because the ball continued to move out of sight behind the screen. Instead, children had to use the visible portion of the barrier above the screen as a cue to infer the correct search location. Finding that children need to maintain their gaze on the object's hidden location indicates that they would not perform well in a search task in which they have to use an indirect cue like the barrier. DeLoache (1986) reported findings consistent with this prediction: Children at 21 months of age could not find an object hidden in one of four identical containers even though the containers could be distinguished by the color of the box placed on top of each container. Taken together, these findings suggest that tod-

dlers' failure in Berthier et al.'s original search task may be due to the difficulty of the search, even though children perform well in the simple search tasks of this experiment.

Predicting the Effect of Solidity

Both Berthier et al. (2000) and Hood et al. (2000) proposed that toddlers' lack of predictive knowledge was a possible cause of failure in their search tasks. We tested this possibility by using a task that does not involve search: Children were asked to predict where the doll should be placed to catch the ball. The correct response was to place the doll just in front of the barrier that intersected the ball's trajectory. The experimenter demonstrated that if the doll were out in front of the barrier, the ball would knock her over, and if placed further down the ramp beyond the barrier, the ball would stop at the barrier, leaving the doll empty-handed.

In Experiment 1 there were two barriers on the ramp to prevent simple imitation of the experimenter's demonstrations. When no screen was present, children at 2.5 years of age were fairly successful. They placed the doll correctly on 47% of the trials, and 9 of the 18 children performed correctly on at least half of the trials, showing that many of the older toddlers have an understanding of the effect of solidity. This understanding may even be underestimated by the specific prediction task, given that children had to relate the ball's trajectory to the doll as well as to the correct barrier, while ignoring the irrelevant barrier.

The 2.0-year-olds seemed confused about the task requirements. They showed a strong error bias once two barriers were placed on the ramp. They placed the doll between the barriers, ignoring the outcome (demonstrated after each trial) that the doll could not catch the ball in that position. Children 2.0 years of age showed knowledge of solidity only in Experiment 2 when more familiarization trials were given than in Experiment 1 and only one barrier was used. Children had to take into account the change in direction of the ball's motion, but they did not have to ignore an irrelevant barrier. Under these more simplified circumstances, 2.0-year-olds placed the doll correctly, on average, on 49% of the trials, with 8 of the 17 children performing correctly on at least half of the trials. This level of performance was comparable to that of 2.5-year-olds in Experiment 1.

Older toddlers were not tested with the more simplified prediction task. Finding that 2.5-year-olds performed better than 2.0-year-olds in the prediction task with two barriers (Experiment 1) suggests that predictive knowledge of solidity of older toddlers is more stable than that of younger toddlers. The older children could ignore the irrelevant barrier and performed rather well, although not perfect, in the prediction task without a screen. The younger children performed at the level of the older children only when the distracting aspect of a second barrier was removed. It is possible that older children would have performed better in the one-barrier prediction task than the younger age group did.

Although both 2.0- and 2.5-year-olds showed some predictive knowledge of solidity when they could see the ramp and barriers, children performed worse when the screen obstructed their view. With the screen in front of the apparatus, children performed at chance, regardless of whether the screen was a panel with doors or a curtain with no distinguishing features. Seeing the spatial layout of ramp and barrier appears to be critical for toddlers' prediction of a future event.

The devastating effect of concealing the elements involved in prediction of a future event may explain why children perform better in a looking-time version of this search task. Hood et al. (2003) converted the search task into a violation-of-expectation procedure comparable to that used with infants (Spelke et al., 1992). Hood wanted to see whether toddlers who could not solve the search task would look longer at "impossible" events as infants do. The same apparatus and events were used: The experimenter placed a barrier on the ramp, lowered the screen with four doors, and rolled the ball. Instead of asking children to open a door and find the ball, the experimenter lifted two doors next to the barrier simultaneously. Children looked longer when the ball had apparently rolled through the barrier and was on the wrong side, compared to trials when the ball rested on the expected side of the barrier.

The looking-time version of the search task does not require children to imagine a hidden spatial layout, nor did they have to predict in advance where the ball was hidden. They simply had to recognize that something odd had happened (Diamond, 1998), a post hoc analysis of events. (For an extended discussion of differences in task requirements between preferential looking and search tasks, see Keen, in press.) Hood et al. (2003) hypothesized that prediction might be the stumbling block, rather than a lack of knowledge about the effects of solidity. The data from our prediction tasks suggest an alternative: It is having to imagine critical elements that makes prediction difficult. In the prediction without screen task children can see the ball, the barrier, and the intersection of ramp and barrier as they plan where to place to doll within the array. In the prediction with screen task these elements are concealed, no constraints are provided about the trajectory of the ball, and children have to infer the intersection of ramp and barrier. The prediction without screen task and the violation-of-expectation paradigm are similar in their full disclosure of elements. In the former task, when children have to actively make a prediction about future events, they are able to do so. We hypothesize that when elements are concealed, the need to represent the entire situation places an additional cognitive burden on the predictive process. The problem is not prediction per se, but rather the need to imagine the spatial layout and objects within it.

Success in the search tasks developed by Berthier et al. (2000) and Hood et al. (2000) depends on numerous requirements being met. When some of these requirements were eliminated, we found that children can search for hidden objects when no reasoning about solidity is necessary, and they can use their knowledge to predict in advance how a barrier is going to affect a moving object. Their reasoning

about solidity becomes deeply impaired when they must represent critical aspects of the spatial relations of objects involved in the prediction.

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