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Toddlers' Use of Cues in a Search Task

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Search for a ball that has undergone hidden motion rapidly improves during the second year of life (*Dev. Psychol.*, 2000; 36:394–401). In three experiments we investigated whether the poor performance of younger toddlers was due to attentional failure by highlighting the major cue for the hidden object. We observed only slight improvement in search behaviour. We performed two other experiments that tested the depth of understanding of 3-year-olds in this task and found that their performance was robust to changes in the apparatus and experimental procedures. Overall, the results point to a rapidly developing ability in the second year of life to either reason about space or select the correct motor response in search tasks. Copyright © 2008 John Wiley & Sons, Ltd.

Key words: infant; object search; physical reasoning

Piaget (1954) concluded that object permanence and the understanding of unobserved physical events develop over the first two years of life. While a number of studies using looking time have shown much earlier understanding of physical events (e.g. Baillargeon, 1987; Spelke, Breinlinger, Macomber, & Jacobson, 1992), research continues to show that toddlers have surprising difficulty in manual search tasks that involve the same physical laws (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000; Hood, 1995; Hood, Carey, & Prasada, 2000). Such research also shows that a rapid transition to successful search occurs between 2.5 and 3 years-of-age (Berthier *et al.*, 2000; Hood, Cole-Davies, & Dias, 2003).

Berthier *et al.*'s (2000) and Hood *et al.*'s (2000) manual search tasks were designed to resemble Spelke *et al.*'s looking time task. The studies involved either vertical or horizontal hidden motion with two or four possible goal locations. In Berthier *et al.*, a solid wall was placed on a horizontal track in full sight of the toddler. Subsequently, an occluding panel with four doors was placed in front of

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the track. The function of the occluding panel was to block the toddler's view of the motion of the ball while allowing the child sight of the top half of the solid wall. The ball was then rolled down the track behind the occluder and the toddler was asked to select a door in order to obtain the ball. The data showed that 2-year-olds were correct on 22% of the trials and that 3-year-olds were correct on 74% of the trials (Berthier *et al.*, 2000). Other studies with this design showed very similar success rates, with performance slightly better in the two-choice version of the task (Hood *et al.*, 2000, 2003; Mash, Keen, & Berthier, 2003; Mash, Novak, Berthier, & Keen, 2006; Shutts, Keen, & Spelke, 2006).

There are two puzzling aspects of these data from manual search by toddlers. The first is why 2-year-olds are at chance on a task whose solution seems quite simple and straightforward—the wall stops the ball; hence, open the door by the wall. The second aspect is how 3-year-olds are solving the problem. In fact, it is not sufficient to 'open the door by the wall' because the motion of the ball determines which side of the wall the ball is resting against. Three-year-olds might be solving the problem by simply associating a door with the wall, without understanding the physics of motion and solidity. In three experiments, we explored the first puzzle by enhancing certain aspects of the apparatus and procedure for younger toddlers, and in two experiments we explored the basis of the success in 3-year-olds.

REASONING ABOUT HIDDEN MOTION

Why are these tasks so difficult for young children? While the task outlined above appears simple at first glance, it uses a complicated apparatus along with a procedure that tests children's attentional abilities, understanding of hidden motion, visuospatial reasoning, and response selection and inhibition (see Keen, 2005, for an analysis of this task's requirements).

Perhaps the most obvious explanation for the failure is that the child does not fully understand the unobserved motion of the ball. Several studies have been performed in order to determine whether this is the case. The strategy in these studies was to provide direct information about the motion of the ball and to test whether performance improved. For instance, Butler, Berthier, and Clifton (2002) tested toddlers with a modified apparatus in which most of the motion of the ball was made visible by using a transparent occluder with opaque doors. Butler *et al.* observed poor performance by 2-year-olds with this apparatus even when the children's gaze tracked the ball in motion, but they did find substantial improvement in 2.5-year-olds. In a similar attempt to provide information about the ball's motion, Mash *et al.* (2003) allowed children to view the entire motion of the ball as it came to rest next to the barrier wall *before* the occluder was lowered to cover the track. Two-year-olds still showed chance performance when asked to open a door to obtain the ball.

Finally, Shutts *et al.* (2006) tested toddlers in this apparatus with an aim towards providing direct information about movement of the hidden object by attaching a visible flag to the object. Shutts *et al.* found that toddlers were no more successful than in the original experiments if the distance from the visible flag to the hidden moving object was 28 cm, approximately the height of the wall. On the other hand, if that distance was shortened to 7.5 cm, dramatic improvement in performance was observed. Thus, providing direct information about the moving object did not improve performance, but providing a local marker did. Only when the need for reasoning about the spatial layout of track and barrier

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was eliminated and close direct marking of the correct door was provided did the 2-year-olds succeed.

In sum, studies to date that have provided partial or complete information about the motion of the ball have not led to improvement in performance in 2-year-olds. If the failure of manual search in Berthier *et al.*'s (2000) study was solely due to failure to understand hidden motion, these manipulations should have resulted in high levels of performance as the tasks no longer involved hidden motion. The continued poor performance of young toddlers suggests that the difficulty may lie instead in reasoning about the unseen resting ball, the wall, and their position with respect to the access doors.

THE ROLE OF THE BARRIER WALL

The complex nature of the manual search task suggests that young toddlers might fail because they are not attending to the relevant aspects of the problem. According to this line of reasoning, a toddler's poor performance might reflect an attentional failure instead of a failure of visuospatial reasoning and search. Although there are many important components of the task, attention to the barrier wall is the most critical. If children recognized the significance of the barrier and used its location to guide their search, performance could be perfect. In each of the studies cited above, however, there was little indication that toddlers attended to and used the location of the barrier wall as a cue to guide their search. This failure is striking because the cue is visible and entirely reliable in leading to a successful search. The studies suggest that either toddlers do not notice the barrier wall, notice it but do not see it as important in solving the problem at hand, or are unable to incorporate the knowledge of its location into their spatial reasoning about the task.

Because understanding the significance of the wall and attending to it are important components of solving the task, young toddlers whose attention is drawn to the wall might find the solution of the task much easier. The goal of the first three experiments in the current study was to determine whether increasing the salience of the wall would lead toddlers to attend to its position and to incorporate that knowledge into their search plans. The wall that served as the barrier was only approximately 1 cm thick, and was very thin compared with the rest of the apparatus. It may not have been salient to the child because it took up such a small portion of the field of view. In addition, the wall was probably less attractive to the children than a moving object like the ball rolling down the ramp. We used several manipulations involving different modalities to increase the salience of the barrier wall. In Experiment 1 we added the sound of the ball hitting the barrier wall, in Experiment 2 we altered the wall so that it overhung the front of the occluding panel next to the correct door, and in Experiment 3 we substituted a human hand in place of the barrier wall.

EXPERIMENT 1

In previous studies using the ramp apparatus, the soft ball was barely audible as it rolled down the track and contacted the wall. The distance between the ball, the child, and the occluding panel further reduced the sound of the ball. Therefore, children would not have heard any sound associated with the motion and stopping of the ball.

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In the current experiment, 2- and 2.5-year-old children were tested using the original apparatus (Berthier *et al.*, 2000). The apparatus was modified so that the ball made a clearly audible sound as it rolled down the ramp and a final clunk when it contacted the wall. We hypothesized that hearing the ball roll and stop might help children to locate the ball for several reasons. First, in everyday environments, sound frequently accompanies physical events. For example, when a door closes, it is both visible and audible. Thus, by making the ball's motion audible in our experiment, we hoped to make the rolling and stopping of the ball more realistic. Second, research with infants shows that their attention is grabbed by corresponding information presented in more than one sensory modality (intersensory redundancy) and that infants selectively attend to this information (for reviews see Bahrick, Lickliter, & Flom, 2004; Lewkowicz, 2000; Lickliter & Bahrick, 2000). In addition, young infants are more sensitive to amodal information presented simultaneously in auditory and visual modalities for example, both seeing and hearing the tempo and rhythm of a toy hammer tapping, compared with information presented unimodally. Older infants can pick up amodal properties from both unimodal and bimodal information (see Bahrick *et al.*, 2004 for a review).

Given this previous research with infants, we predicted that in our study, simultaneously seeing and hearing the ball roll and stop during the familiarization phase would draw children's attention to the motion of the ball and to the role of the wall in stopping the ball. In the test phase, children could not see the ball roll and stop behind the panel, but they could hear the ball roll and stop. The length of the sound trajectory depended on the position of the wall on the ramp and the final clunk against the wall marked the end. Research with infants has shown that there is rapid improvement in auditory localization in the first year of life, with precision in localization approaching adult performance by 18 months of age (Clifton, 1993). Although sound localization was not assessed in this study, it is likely that sound provided a direct cue as to which door the ball stopped behind, but in any event sound should draw attention to the ball's motion and stopping against the wall.

Method

Participants

The participants in this study were 20 2-year-old children (mean age = 24 months 14 days; range = 24 months 1 day–24 months 27 days; 10 boys and 10 girls) and 12 2.5-year-old children (mean age = 30 months 14 days; range = 30 months 3 days–31 months 0 days; eight boys and four girls. The data from two other 2.5-year-old children were excluded due to their unwillingness to participate. The children were recruited from Massachusetts state birth records with an explanatory letter sent to their families followed by a telephone call. The same recruitment technique was used in subsequent experiments.

Apparatus and procedure

Figure 1(A) shows a photograph of the apparatus. The apparatus is described in Berthier *et al.* (2000). Briefly, it consisted of a ramp that was 75 cm long and 18.5 cm wide. The left side of the ramp was 14 cm above the bottom of the apparatus. A pair of dowels were glued to the top of the ramp to form a track down which the ball could be rolled. A removable occluding panel was constructed with four opaque doors that allowed the child access to the track.

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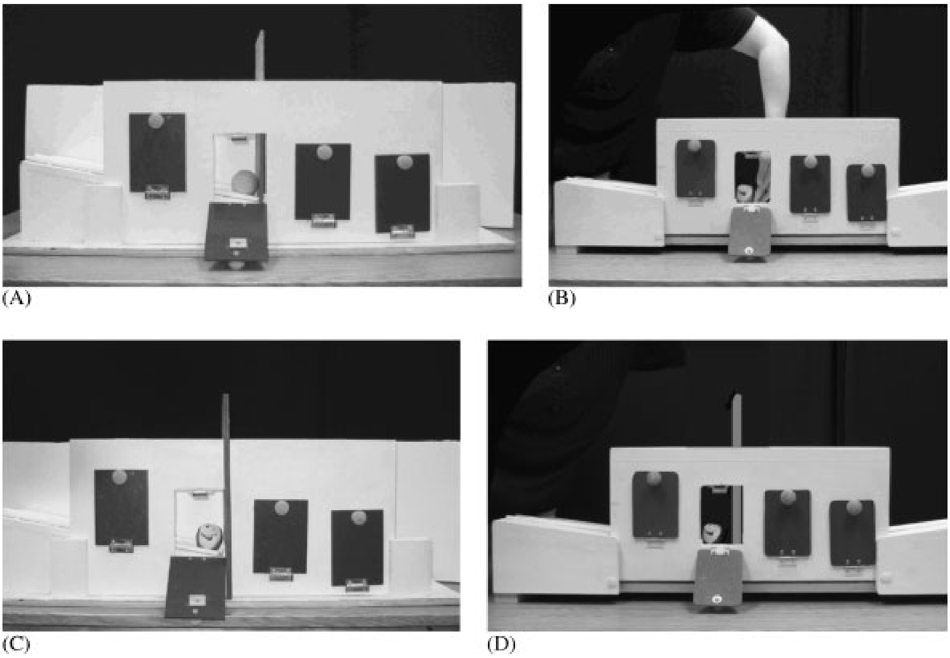

Figure 1. (A–D) Photographs of variations of the apparatus used in Experiments 1–4, with the correct door opened. For each experiment, the apparatus consisted of a ramp with an occluding panel with four doors. A ball was rolled down the ramp and the child was asked to locate the ball by opening one of the doors.

The doors were hinged at the bottom and had wooden knobs at their tops, making them easy to open with a downward pull. Four green walls were constructed to correspond to the four doors to stop the motion of the ball. The tops of the walls were visible to the child with the occluding panel in place.

In this experiment, wooden craft sticks (3.1 cm long, 0.95 cm wide, and 0.21 cm deep) were attached to the ramp between the two dowels forming the track for the passage of the ball. The craft sticks were perpendicular to the dowels and were approximately 3.5 cm apart. Thus, the dowels and craft sticks created a track down which the ball rolled. The soft ball from the original study was replaced with a wooden ball. The ball made a 'ratta-tatta' noise as it rolled down the ramp and a clunk as it hit the wooden wall.

Familiarization in this experiment was identical to that used by Berthier *et al*. (2000). First, children opened all four doors one at a time. The experimenter then opened one door, put a small toy inside, closed the door, and asked the child to find the toy. The experimenter hid a toy either behind doors 1 and 3, or behind doors 2 and 4, balanced across children. On the next trial, the experimenter removed the panel, placed the wall in position 4, and rolled the ball down the track. This familiarized the child with the sound and trajectory of the moving ball. On the next two trials, the experimenter inserted the panel, opened all four doors, and rolled the ball down the track. On the next four trials, only the door immediately in front of the wall was open when the experimenter rolled the ball down the track. The wall was moved to a different position on each of these trials.

Following the familiarization trials, each child was presented with 12 test trials. During test trials, the experimenter placed a wall in one of four locations in full

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view of the child, and drew the child's attention to the wall by tapping on it. Then the experimenter lowered the occluding panel, with all doors closed in front of the ramp. After pointing out the wall once again, the experimenter drew the child's attention to the beginning portion of the ramp and, once the child looked at the ball, the ball was released. After it had rolled down the ramp and stopped at the wall, the experimenter slid the apparatus to within reach of the child and asked him or her to find the ball.

During each test trial, children were allowed to open two doors. If they were successful on either attempt, the experimenter verbally praised the child, pulled the apparatus out of reach, and ended the trial. If, on the other hand, the child was unable to locate the ball after two attempts, the experimenter pulled the apparatus out of reach and opened the appropriate door. After pointing out that the ball had stopped at the wall, the experimenter removed the occluding panel of doors so that the child again could see the ball resting beside the wall. Both the ball and the wall were removed and the experimenter proceeded to the next trial.

Scoring: All testing sessions were videotaped from an angle that provided a clear view of the child's reaching behaviour. Two observers independently scored each trial for the first door the child opened. For the following studies, the inter-rater reliability for the first door opened was 97% in Experiment 1 (sound 2-year-olds), 99% (sound 2.5-year-olds), 100% in Experiment 2 (overhanging wall), and 95% in Experiment 3 (hand as a barrier). For the few disagreements between coders, a third scorer was used in Experiments 1 and 3, and the primary coder was used in Experiment 2.

Results and discussion

All of the 2-year-old participants completed at least eight trials, with 13 of the children completing all 12 trials. The mean proportion correct on this task was 0.24 and the median was 0.25. A *t*-test revealed that the group mean did not differ significantly from chance (0.25), $t(19) = 0.48$, $p < 0.64$, effect size $g = 0.10$. We examined each individual's performance on the task to determine if it exceeded what would be expected by chance, using the binomial distribution with a one-tailed rejection region of 0.05. In this experiment, none of the 20 participants performed significantly better than would be expected by chance.

All of the 2.5-year-old participants completed at least eight trials, with eight of the children completing all 12 trials. The mean proportion correct on this task was 0.33 and the median was 0.31. A *t*-test revealed that the group mean did not differ significantly from chance (0.25), $t(11) = 1.22$, $p < 0.25$, effect size $g = 0.33$. In this experiment, one of the 12 participants performed significantly better than would be expected by chance using the binomial distribution. Individual performance for 2.5-year-old children is displayed in the column labelled 'sound' in Figure 2. Adding auditory information about the ball's movement and collision with the wall did not help either 2- or 2.5-year-old children to solve the task.

EXPERIMENT 2

In the preceding experiment and in the original study (Berthier *et al.*, 2000), the lower half of the barrier wall was not visible when the occluding panel was in place. In Experiment 2, we sought to remind the children of the wall's location and extent by testing with a modified barrier wall whose entire front edge was

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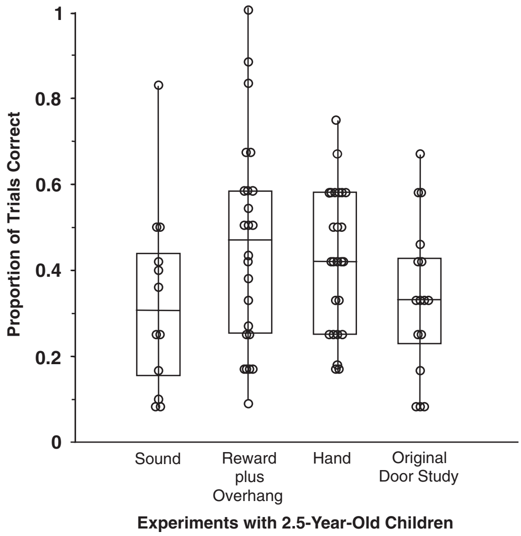

Figure 2. Box plots of 2.5-year-old children's performance on the sound, reward plus overhang, hand as a barrier, and original (Berthier *et al.*, 2000) door studies. The box contains the central 50% of the data, while the middle line represents the median for each distribution.

visible (see Figure 1(B)). Additionally, we rewarded the children on correct trials with stickers to increase their motivation. We hoped that the additional reward would encourage more children to complete all 12 trials. Because the previous study as well as some unreported pilot studies showed no gain in performance for 2-year-olds, age of participants in the next two studies was limited to 2.5 years.

Method

Participants

The participants in this study were 24 2.5-year-old children. The mean age was 30 months 24 days with a range of 30 months 6 days–31 months 12 days. There were 12 boys and 12 girls. The data from six additional children were excluded due to unwillingness to participate.

Apparatus and procedure

Figure 1(B) shows a photograph of the apparatus. The apparatus was the same as in Experiment 1 except that the wall now hung over the occluding panel, there were no wooden sticks on the ramp to produce sound, and a soft Hacky Sack® ball was used. The wall, measuring 20 cm deep, had a small opened split that extended $\frac{3}{4}$ of the way up the wall. This split was slightly wider than the occluding panel and allowed the wall to be placed over the occluding panel. When in position, the wall stood 8.5 cm higher than the occluding panel and extended over the front of the occluding panel. The procedure was the same as that used in Experiment 1.

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Results and discussion

All of the participants completed at least eight trials, with 19 children completing all 12 trials. The mean proportion correct on this task was 0.46 and the median was 0.47. A *t*-test revealed that the group mean differed significantly from chance, $t(23) = 4.12$, $p < 0.001$, effect size $g = 0.81$. We examined each individual's performance on the task to determine if it exceeded what would be expected by chance, using the binomial distribution with a one-tailed rejection region of 0.05. In this study, eight of the 24 participants performed significantly better than would be expected by chance. Individual performance for children in this experiment is displayed in the column labelled 'reward plus overhang' in Figure 2. The increased visibility of the wall and reward for correct responses helped some 2.5-year-olds, but the majority still performed at chance, as did the same age group in the original Berthier *et al*. (2000) study (see Figure 2 to compare these distributions).

EXPERIMENT 3

In this experiment rather than modifying the wall itself as in previous studies, another experimenter placed his or her hand onto the ramp and caught the ball. This procedure was used because infants have been shown to be very sensitive to the intentions of others' manual acts (Falck-Ytter, Gredeback, & von Hofsten, 2006; Woodward, 1999) and we presumed that a human arm would be a powerful visual cue. The occluding panel covered the person's hand and wrist, whereas the rest of the arm extended above the ramp apparatus, making it relatively easy to follow the arm down and deduce where the hand and ball were located behind the occluding panel.

Method

Participants

The participants in this study were 25 2.5-year-old children. The mean age was 30 months 9 days and the range was 29 months 17 days–30 months 27 days. There were 12 boys and 13 girls. The data from five additional children were excluded due to experimental error (1) or unwillingness to participate (4).

Apparatus and procedure

Figure 1(C) shows a photograph of the apparatus. The complete apparatus measured 108 cm long by 23.5 cm wide and consisted of a white wooden ramp that was divided into three sections. The two stationary end sections measured 25.5 cm each in length and sloped inward towards the centre of the apparatus, with their highest and lowest points rising 15.2 and 9.5 cm, respectively, above the base of the apparatus. The centre section of the ramp was attached to the base of the apparatus at its centre only so that it could be tilted to the left or right. When tilted, the highest portion of the centre section aligned with the lowest point of one of the end sections in order to form a continuous ramp. With this configuration, a Hacky Sack® ball measuring 5 cm in diameter could be rolled down two consecutive sections of the ramp in either direction (left to right or right to left) by simply rotating the centre section. However, in this experiment as in Experiments 1 and 2, the ramp was always tilted so the ball rolled left to right, as shown in Figure 1(C). Two removable occluding panels with four opaque

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doors completed the apparatus. On one panel the doors were positioned 4 in apart and at descending heights from left to right; the doors on the remaining panel sloped in the opposite direction. When either panel was placed in front of the centre of the apparatus, the ball was visible as it rolled down the first 25 cm of the ramp. No walls were used in this experiment.

The procedure was the same as in Experiments 1 and 2, except that another experimenter stood behind the ramp apparatus, placed his or her hand on the ramp, and looked away from the child to avoid eye contact during the ball-rolling event. This change was made for all familiarization and test trials. No additional reinforcement was used.

Results and discussion

Figure 2 shows the proportion of trials in which each child retrieved the ball on the first search (the column labelled 'Hand'). All but one of the participants completed all 12 trials, with one child completing the minimum of eight trials. The mean proportion correct on this task was 0.43 and the median was 0.42. A *t*-test revealed that the group mean for the proportion correct differed significantly from chance (0.25), $t(24) = 5.37$, $p < 0.0001$, effect size $g = 1.04$. In this study eight of the 25 participants performed significantly better than would be expected by chance using the binomial distribution. As in Experiment 2, the performance of 2.5-year-olds in the present study is slightly better than the performance of 2.5-year-olds in Berthier *et al*. (2000).

In Experiment 1, 2-year-olds' performance did not differ statistically from 25%, and while 2.5-year-olds in Experiments 2 and 3 did perform significantly above chance, 2.5-year-olds in Experiment 1 did not. In all of these studies children were given 8–12 test trials because they maintained interest in the task. However, it may be that the relatively large number of test trials ultimately resulted in worse overall performance because children may have become fatigued or become confused about the protocol. It is also possible that they chose the correct door on trial 1 and perseverated on that door, which would result in poor performance because our protocol called for moving the wall to a different location on every trial. Suddendorf (2003) found that 2-year-olds searched correctly on the first trial of a photo version of the DeLoache task and subsequently persisted in selecting that same location.

In order to test whether performance decreased with repetition of test trials, we compared performance on the first test trial with the average performance over all test trials. One complication in attempting this comparison is that the first-trial measure is the proportion of children who succeeded on the first trial, and the overall-performance measure is the average across children of each child's overall proportion correct. In order to make an appropriate comparison, we computed the 95% confidence intervals for the first trials in the three experiments and compared them with the average proportion correct for the entire session. We used the modified Wald interval suggested by Agresti and Coull (1998) to provide a robust confidence interval for the binomial proportions.

Table 1 shows the overall averages for the three experiments and the first-trial confidence intervals. Also shown in the bottom row are the across experiment confidence intervals along with the overall mean proportion correct. In comparing the four confidence intervals for the three experiments with the overall performance, we find that the first-trial intervals contain the overall mean in three cases and that the overall mean is below the lower bound in one case (Experiment 3). Averaging across all three experiments, the 2.5-year-olds mean is

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Table 1. Children's performance on trial 1 within experiments compared with overall performance across Experiments 1–3

	Age	Overall mean performance (%)	Trial 1 95% CI, lower bound (%)	Trial 1 95% CI, upper bound (%)
Experiment 1	2.0	24	23	62
	2.5	33	4	46
Experiment 2	2.5	46	25	61
Experiment 3	2.5	43	50	86
Across experiment 2.5-year-olds		42	38	64

within the first-trial confidence interval. These comparisons suggest that performance was marginally better on the first trial than overall in Experiment 3, but even so, the estimates suggest that performance was as mediocre on the children's first trial as it was throughout the session.

The current three studies attempted to increase the salience of the key feature of the visual layout, the barrier wall, in order to improve children's spatial reasoning about the task. None of these manipulations resulted in more than a marginal improvement in the toddlers' success. A few children in Experiments 2 and 3 benefited from enhancement of the barrier, beyond the number who were above chance in the original Berthier *et al*. study (three out of 16 2.5-year-olds). Nonetheless, it is surprising that the switch to a human arm and hand in Experiment 3 did not make the connection for more children. This suggests that even when children are encouraged to attend to the barrier with very salient cueing before, during, and after the hidden object comes to rest, this cueing does not seem to enter into the planning of a search for the majority of children. The failure of toddler search in the task appears to lie not in a failure of attention to the barrier, but in reasoning about the three-dimensional layout of the ball, barrier, and access door or possibly in the planning and organization of the search behaviour itself.

EXPERIMENT 4

The data showing that younger toddlers have a substantial inability to solve this task even with extensive cueing and prodding are in stark contrast to the high success rate of 3-year-olds. In the standard task with chance performance expected to be around 25%, 2-year-olds are successful on about 20–30% of trials, and 2.5-year-olds on about 35–45% of trials, while 3-year-olds succeed 70–80% of the time (Berthier *et al*., 2000). While this dramatic change in performance is suggestive of a substantive improvement in spatial reasoning and manual search at around 3-years-of-age, it is possible that the improvement reflects a small change in sensitivity to cueing. For example, toddlers need to perform no reasoning about the physics of rolling balls and barrier, but rather simply learn to open the door to the immediate left of the clearly visible wall in order to be successful. This possibility was discounted but not definitively ruled out in the original Berthier *et al*. (2000) study by a testing condition using two barrier walls. If the 3-year-olds were using a simple associative strategy to find the ball, having two-wall test trials should have resulted in at least temporary disruption of performance, but it did not. Nevertheless, even in the two-wall test conditions, an

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associative strategy of opening the door to the left of the left-most wall would be successful on all the test trials.

In order to determine whether 3-year-olds' success was based on simple strategies such as that just outlined or whether their success represents a deeper cognitive achievement, we tested 3-year-olds in two additional experiments. In the first experiment we tested toddlers in the standard task with the ball rolling from left to right but then switched to the reverse direction (right to left) after eight trials. If they understood the problem they should immediately adjust on the first post-shift trial and show very little disruption after the reversal.

In a final experiment we removed the visible cue of the barrier wall by using a barrier wall that was shorter than the top of the occluder. Toddlers were shown the wall's position on each trial and the occluder was lowered immediately thus obscuring the wall and track. The ball was then rolled behind the occluder and the toddler was asked to search for it. This manipulation required the toddler to maintain a memory of the wall and its location with respect to the correct door for a period of time in order to plan a successful reach.

Method

Participants

A total of 29 3-year-olds were recruited. The data from five of these participants were eliminated due to either their inability to complete a minimum of four pre-shift test trials and four post-shift test trials ($n = 3$) or their failure to retrieve an occluded stationary toy at least twice during familiarization ($n = 2$). The remaining 24 participants ranged in age from 36 months–37 months ($M = 36.5$ months). There were an equal number of males and females contributing to the data.

Apparatus

The same apparatus was used as in Experiment 3 except that the walls were again used to stop the ball (see the photograph in Figure 1(D)). This apparatus was designed with a hinge in the centre section of the ramp that allowed the slant to be reversed so that the ball could be rolled from right or left, a critical aspect for this experiment.

Procedure

Familiarization was the same as in Experiments 1 and 2. Following the familiarization trials, each child was presented with a series of eight pre-shift and eight post-shift test trials interrupted by two additional familiarization trials. The eight pre-shift trials were standard test trials as in the previous experiments, with the ramp tilted in the left to right position. After the eighth trial, the experimenter removed the occluding panel and tilted the ramp in the opposite direction. Two additional familiarization trials then were presented in order to demonstrate that the ball continued to stop at the wall even though it now rolled in the opposite direction. The experimenter placed a wall in the far left position and then in the second position, rolling the ball each time from the right. The ball's movement was fully visible until it came to rest to the right of the wall. Each time the experimenter verbally noted that the ball stopped at the wall. Following these two trials, the experimenter continued with the standard test-trial procedure for an additional eight test trials (i.e. post-shift trials) with the ramp tilted in the right

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to left position. The reliability between observers, computed as the number of agreements divided by the total number of selections scored, was 98.7%, with the primary coder used for disagreements.

Results and discussion

All of the children included in the analyses completed a minimum of four pre-shift and four post-shift trials, with 23 children completing all eight pre-shift trials and 14 completing eight post-shift trials. Because every child did not complete an equal number of trials, the proportion of trials on which each child selected the appropriate door on his/her first attempt was computed for the entire session overall and for the pre- and post-shift trials separately.

Over the entire session, the mean proportion of trials correct with the first attempt was 0.63 (S.D. = 0.23). In addition to group performance, individual performance also was examined. Each child was classified as being above or below chance by comparing the actual number of trials on which s/he was successful on the first attempt with the number needed to be above chance using a one-tailed binomial criterion. Of the 24 children tested, 16 were above chance in selecting the correct door on their first attempt using the binomial criterion. (see Figure 3 for distributions of proportion correct responses on pre- and post-shift trials).

More interesting than the children's overall performance was the difference in their performances once the ramp was rotated and the direction of the ball was changed. If 3-year-olds in the current study did not understand the physical relationship of the wall to the ball's motion, it is possible that they developed a simple associative rule; that is, 'open the door to the left of the wall' in order to locate the ball during pre-shift trials. If this were the case, then performance should have declined during post-shift trials, when the ball rolled from right to left and always came to rest to the right of the wall. This possibility was

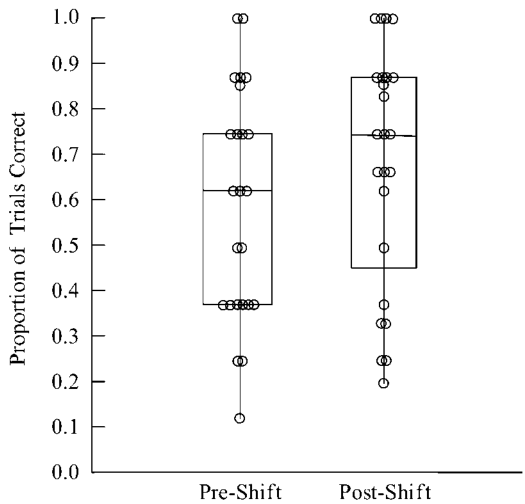

Figure 3. Proportion of pre-shift (left) and post-shift trials (right) in which each child retrieved the ball in Experiment 4.

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Table 2. Number of children who were above (pass) or below (fail) chance during the two phases of testing in experiment 4

Post-shift phase	Pre-shift phase	
	Pass	Fail
Pass	9	2
Fail	0	3

examined in several different ways. First, the proportion of trials in which each child selected the correct door was computed separately for pre- and post-shift trials. The proportion of trials on which participants selected the correct door on the first attempt actually increased slightly from pre-shift to post-shift trials (mean proportions = 0.59 and 0.68, respectively). This was not a statistically significant difference, but does indicate that there was no decline when the ball's motion changed direction.

In addition to comparing group performance on pre- and post-shift trials, individual performance on these different trial types also was examined. To determine whether children who did well on the pre-shift trials continued to perform well on post-shift trials, we classified children as 'passing' or 'failing' each block of trials. The decision to include only children who had all eight trials in each block was the result of power calculations that minimized the probability of misclassifying a child as failing (with reasonable assumptions, the probability of each misclassification with the stated criteria was approximately 0.10–0.20). Data for the 14 children who completed all 16 trials are shown in Table 2. A Fisher Exact Probability test indicated a significant dependence of performance in the two phases ($p < 0.0274$) with a correlation between the performances in the two phases of 0.70 (phi-coefficient). Inclusion of data from all children in a similar analysis led to a similar conclusion with the Fisher Exact Test's p-value of 0.0078. This close correspondence in performance for individuals, as well as the group finding of no difference between pre-shift and post-shift trials, supports the conclusion that children who searched correctly understood the causal relationships in these physical events.

Finally, the first post-shift trial was of particular interest with regard to the associative rule hypothesis. It is possible that children who performed above chance on both types of trials were using the rule, 'open the door to the left qof the wall', on pre-shift trials and then altered the rule to 'open the door to the right of the wall' on post-shift trials. This change may have occurred once they observed that the 'left of the wall' rule was not working during the first trial or two of the post-shift trials. If this were the case, performance on the first post-shift trial should be informative. Of the 13 children who performed above chance on pre-shift trials, nine were successful on their first attempt during the first post-shift trial. Taken together with the pattern of group and individual results, this result suggests that 3-year-olds in this experiment were not using an associative rule to solve this invisible displacement problem, but rather they seemed to immediately infer that the ball would be in a new position with respect to the wall.

The results of Experiment 4 indicate that 3-year-olds who successfully solved the invisible displacement problem did not rely on a simple associative rule, but rather appeared to reason about the position of the wall with respect to the direction of the ball's movement. No drop in performance occurred after motion

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of the ball switched directions. Children appeared to use the wall as an important cue to guide their search.

EXPERIMENT 5

The purpose of Experiment 5 was to investigate children's necessity to use the wall as a visual cue when searching for an object undergoing invisible displacement as in Experiment 4. While the results of that experiment suggested that children who were above chance in solving the problem used the visible portion of the wall to guide their selections, the question remains as to whether children need a constant visual reminder of the location of the wall. Could they locate the ball by relying on their memory for the wall's location? To answer this question the height of the walls was trimmed so that it was no longer visible above the occluding panel. The procedure of Experiment 4 was followed and children's selections, along with their looking behaviour, were observed.

Method

Participants

A total of 20 3-year-olds were recruited. The data from four of these participants were eliminated due to their inability to complete a minimum of four pre-shift trials and four post-shift trials. The range in age of the remaining 16 participants was 36 months–37 months (mean = 36.7 months) with an equal number of males and females contributing data.

Apparatus

The apparatus, occluding panels, and ball from Experiment 4 were used. The only change was that the four, green walls were cut to stand 19.5 cm above the base of the apparatus at each of their locations. At this reduced height, the walls were no longer visible above the occluding panels and could not serve as a visual cue to the ball's location. Two cameras were used, one to record reaching behaviour and a second with a frontal view of the face to record looking behaviour.

Procedure

The procedure was almost identical to that used in Experiment 4. Because the walls were no longer visible above the occluding panels, one procedural alteration was made. On test trials, the experimenter pointed to the wall only before lowering the occluding panel in front of the apparatus; children's attention was not drawn to its location after the occluding panel had been lowered, as it was in Experiment 4.

Scoring: In scoring looking behaviour, observers recorded whether or not a child looked towards the wall at any point in time when the occluding panel was being lowered for each trial. For this behaviour, reliability was computed as the number of agreements divided by the number of trials scored and was 93%. For door selections, reliability was 98.5%, with the primary coder used for disagreements.

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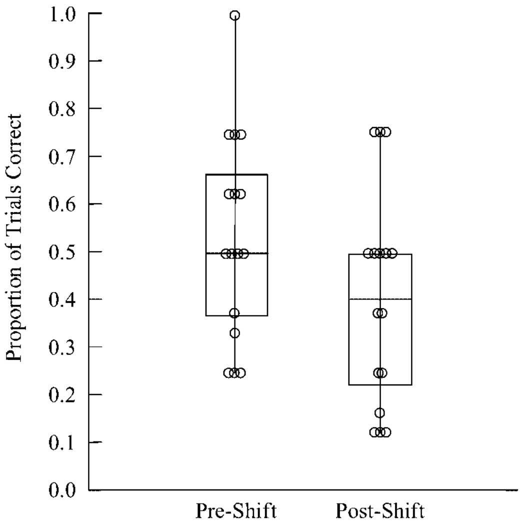

Figure 4. Proportion of pre-shift (left) and post-shift trials (right) in which each child retrieved the ball in Experiment 5.

Results and discussion

All of the children included in the analyses completed a minimum of four pre-shift and four post-shift trials, with 15 children completing all eight pre-shift trials and 14 completing eight post-shift trials. Because every child did not complete an equal number of pre- and post-shift trials, the proportion of trials on which each child selected the appropriate door on his/her first attempt was computed for the entire session overall and for the pre- and post-shift trials separately.

Overall, the mean proportion of trials correct was 0.47 (S.D. = 0.20). In addition to group performance, individual performance also was examined. Of the 16 children tested, eight children were above chance in selecting the correct door. See Figure 4 for distributions of proportion correct responses on pre- and post-shift trials.

In contrast to the 67% of participants who performed above chance in Experiment 4, only 50% performed above chance in the current experiment. The overall proportion correct was significantly lower in Experiment 5 compared with Experiment 4 ($M = 0.49$ and $M = 0.63$, respectively, $t(35) = 2.43$, $p < 0.03$), effect size $g = 0.75$.

In comparison with data from Experiment 4 in which the wall was visible throughout the trial, performance of children in Experiment 5 was adversely affected by loss of sight of the wall. On the other hand, half of the participants were able to find the ball without a visible cue. How might they have accomplished this? If a child looked at the wall and watched as the occluding panel was lowered in front of it, this should have increased the likelihood that s/he could determine with which door on the occluding panel the short wall would align. To examine the possibility that the children who performed above chance were successful because they watched this event significantly more often than those who performed below chance, the looking behaviour of all participants during the lowering of the occluding panel was examined. The proportions of trials during which participants looked towards the wall while the occluding

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panel was being lowered were 0.73 and 0.54 for the above and below chance groups, respectively. Children who performed above chance looked towards the wall as the occluding panel was lowered during significantly more trials than those who did not perform above chance ($t(14) = 2.45$, $p = 0.03$), effect size $g = 1.11$.

In addition to examining children's overall performances, the difference in performance once the ramp was rotated and the direction of the ball was changed was also investigated. The proportion of trials in which the correct door was selected on the first attempt of the pre-shift trials differed significantly from the proportion of correct reaches on the post-shift trials ($M = 0.54$ and 0.41, respectively, $t(15) = 2.59$, $p < 0.03$), effect size $g = 0.62$.

Perhaps more telling than the overall performance on the pre-shift versus the post-shift trials were the individual performances of participants. As in Experiment 4, individual performance on pre- versus post-shift trials was examined. According to this criterion, seven of the 16 children performed above chance on the pre-shift trials while only three performed above chance on the post-shift trials (see Figure 4). Continuity in performance was shown in that the three children above chance during the post-shift trials also performed above chance during the pre-shift trials. Taking away the visible cue to the ball's location significantly impaired 3-year-olds' search. The change in direction of the ball's movement placed an additional memory burden that proved too difficult for most of the children. These two demands appeared to increase cognitive load sufficiently so that performance was seriously disrupted.

GENERAL DISCUSSION

The first, three experiments of the current paper found that manipulations designed to highlight the role of the barrier wall failed to improve the performance of young children in the hidden-motion task of Berthier *et al.* (2000) and Hood *et al.* (2000). The lack of success of 2-year-olds in this task contrasts with the consistently strong performance of 3-year-olds who were able to solve the task even when a second wall was added (Berthier *et al.*, 2000) or when the direction of motion of the ball was reversed halfway through testing (Experiment 4). Three-year-olds' performance does weaken when the barrier wall is removed from view, but performance is still quite high given the demands on memory in the hidden-barrier task (Experiment 5).

The complex nature of the task suggests that young toddlers may fail because they are not attending to the relevant aspects of the problem. While there are many important components of the task, attention to the barrier wall is the most critical. If children recognize the significance of the barrier and use its location to guide their search, performance could be perfect. When the wall is not highlighted, 2-year-olds seldom look back at the wall after the ball is introduced and when they do look at it, performance is not improved (Kloos, Haddad, & Keen, 2006). Our experiments sought to improve performance by increasing the salience of the barrier wall by sight and sound, by increasing motivation with sticker rewards, and changing the wooden barrier to a human hand. As in previous studies (Berthier *et al.*, 2000; Butler *et al.*, 2002), we also noted its presence verbally. The sound manipulation had no detectable effect on the 2- and 2.5-year-old children's performance; the other manipulations slightly improved the performance of 2.5-year-olds. The present results are also consistent with Shutts *et al.* (2006), who increased the visibility of the barrier through the use of

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windows in the top half of the doors and observed no improvement in performance. In sum, drawing more attention to the wall did not lead these toddlers to use this visual information to solve the problem. While a few children were helped (see Figure 2 for comparisons of individual data across experiments), most were not.

On the basis of the results of our experiments, the most likely reasons for failure in this task are a deficiency in visuospatial reasoning about the partly obscured layout and a failure of response selection or inhibition. The task is one of a family of spatial search tasks on which young toddlers show surprising deficits. Two-year-olds in another hidden-motion task (Hood, 1995) show a remarkable ignorance of the laws of object movement, and 2-year-olds in the spatial search experiments of DeLoache (1987, 2000) likewise show a lack of spatial reasoning and representation. All of these tasks involve reasoning about relationships among unseen objects in a spatial context.

Using an apparatus similar to that of the current experiments, Kloos and Keen (2005) found that toddlers could predict with some success the trajectory of the ball if they could see the barrier and the ramp, but not when these elements were occluded by the panel. They concluded that the problem was not in predicting the ball's future location but rather the dual task of imagining the spatial layout while engaged in planning where to search. This difficulty was also shown by 3-year-olds in Experiments 4 and 5, who grasped the physics of the ball's movement, including dealing with a change in directional movement, but still needed a visible marker of the barrier.

Besides requiring reasoning about the movement of unseen objects, the current task requires children to inhibit inappropriate responding and to selectively attend to the relevant aspects of the situation as it unfolds in time. These psychological abilities have been attributed to prefrontal cortical circuits that have been shown to be late developing (Diamond, Prevor, Callender, & Druin, 1997; Miller & Cohen, 2001). While speculative on our part, perhaps the reason that our manifold manipulations have generally failed to significantly improve performance is that 2-year-olds lack the capacity to reason about space in the context of a complex evolving situation that places a significant demand on the child's improving executive functioning.

The hypothesis that solution of the current task relies on prefrontal development suggests that modifications of the door task in ways that require only abilities mediated by sensorimotor networks of the posterior cortex will lead to success by younger children. Butler *et al*. (2002) found substantial improvements, particularly by 2.5-year-olds who tracked the ball's motion as it moved behind a transparent screen with opaque doors. Shutts *et al*. (2006) found near-perfect performance by 2-year-olds in a two-door version of the task when a small flag was placed on the moving object so that it was visible during the entire trial. These two latter manipulations show that when the task is primarily a sensorimotor tracking experiment, young children show excellent performance. Hood *et al*. (2003) and Mash *et al*. (2006) found that children looked longer on trials where the ball was not in a location where it should have been under the physical laws of motion. Again, children may be sensitive to the moving object because looking was controlled by the posterior cortical perceptual circuits. Thus, successful looking in such tasks is more plausible for younger children and even infants than tasks involving planning and searching.

In sum, the current study demonstrates that simple attentional and motivational mechanisms do not explain the poor performance on the door task observed by young toddlers at 2 and 2.5 years of age. At 3 years of age, children

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do quite well on the task, although far from perfect. The improvement in performance on the task may depend on development of prefrontal areas involved in visuospatial reasoning and in response selection.

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