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CHAPTER 12

Object and event representation in toddlers

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Abstract: Mental representation of absent objects and events is a major cognitive achievement. Research is presented that explores how toddlers (2- to 3-year-old children) search for hidden objects and understand out-of-sight events. Younger children fail to use visually obvious cues, such as a barrier that blocks a moving object's path. Spatiotemporal information provided by movement cues directly connected to the hidden object is more helpful. A key problem for toddlers appears to be difficulty in representing a spatial array involving events with multiple elements.

Keywords: object search; reasoning; cognitive development; toddlers

Representation of absent objects is a hallmark of cognition because it frees the organism from reliance on simply what is in sight at the moment. Tasks requiring search for hidden objects have been used to explore cognitive development since Piaget made it a critical feature of testing infants' representation of out-of-sight objects (Piaget, 1954). While it is easy to replicate Piaget's finding that infants will not search for a desired toy that has disappeared under a cloth, it has been hard to interpret this puzzling behavior. In his chapter in the Handbook of Child Psychology (1983), Paul Harris proposed that the reason for infants' failure in the Piagetian search task is not that they lack object permanence, but rather they do not know where to search for the hidden object. Eventually the infant overcomes this problem and knows to lift the cloth to find the toy.

Knowing where to search for a hidden object depends on one's ability to use the cues that indicate where the hidden object is. For the 10-month-old in Piaget's search task, the cue is the place of disappearance. The infant sees the toy disappear under a cover, so under the cover is the obvious place to look. For the toddler, more complex cues can be used. In our lab we have tested toddlers' understanding of motion cues of disappearance and reappearance from behind multiple hiding sites, and the contact mechanical cue of a barrier. The movement cues are appreciated at a younger age, but the barrier cue is not used until around 3 years of age. What are the constraints that prevent a child from using readily available cues? Why does a child have difficulty in applying relevant knowledge to solve a problem? We will review research from our lab and seek some resolution to these problems in this chapter.

First, let us describe the task. The child is seated in front of an apparatus that features a ramp and an opaque screen that can be placed to hide a large section of the ramp. Four doors cut into the screen can be opened to reveal a hiding place, and a barrier can be placed perpendicular to the ramp behind any of these doors. The barrier protrudes above the screen by several centimeters and stands

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out because it is painted a different color from the screen and the ramp. The final element of the apparatus is a ball, which the experimenter holds at the top of the ramp in plain view of the child, and then releases to roll behind the screen and stop at the barrier. The ball can then be retrieved by opening the door by the barrier (see Fig. 1 for a view of a child successfully locating the ball). The actual motor action to retrieve the ball is trivial for a 2-year-old, and experience is given to children before trials start to make sure they know how to open all the doors and find a toy.

Multiple studies in multiple labs have established that 2-year-olds do not know where to search for the ball, apparently ignoring the visible portion of the barrier that should serve to remind them that "the ball stops here". Berthier et al. (2000) presented children with the horizontal version of this task described above and illustrated in Fig. 1, and Hood et al. (2000) presented children with a 2-choice vertical version of the task. The direction of the ball's movement does not appear to make a difference, but the simpler 2-choice task was solved by 2.5-year-olds and the 4-choice task was not solved until 3 years of age.

To understand the toddler's difficulty with this task, we need to examine the underlying components leading to the solution. Previous analyses of the task have yielded many possibilities including (1) understanding the task as a search for a hidden object; (2) understanding the role of the barrier; (3) keeping track of an object's hidden movement; (4) attending to the visible portion of the barrier as a cue; (5) predicting the ball's location; (6) using knowledge of the ball's location to orchestrate the appropriate motor response; and (7) representing the spatial integration of the critical but hidden features of ball, barrier, and door (Keen, 2003, 2005; Keen and Berthier, 2004). While these analyses outlined possible problems that toddlers may have with the task, which is rich with cognitive pitfalls, no clear answers have been reached. Through a series of recent studies we have manipulated the available visual information and the response the child makes, in order to arrive at a more comprehensive understanding of toddlers' problem solving.

Fig. 1. View of the apparatus used in Berthier et al. (2000). The child has opened door 3 and found the ball resting against the barrier. Copyright 2000 by the American Psychological Association. Adapted with permission.

Beginning with the simplest possibility for failure, did the toddlers exhibit object permanence and understand they were to find the ball? Certainly they did. They always searched eagerly and they stopped opening doors if they found the ball. This was a game they appeared to understand and enjoy. They were willing to play for a dozen or so trials with no more reward than occasionally finding the ball and handing it back to the experimenter for the next round. Children in all studies reported here were thoroughly familiarized with the apparatus and the game before test trials began. They were shown how the ball rolled down the ramp and stopped at the barrier without the screen present. When the screen was then placed in front of the ramp, all four doors were opened so the child could see the ball rolling down the ramp, passing behind the doors and stopping at the barrier, fully visible through one of the doors. Finally, children were pretested on their ability to open the doors by having the experimenter pull down one door, place a toy on the ramp, close the door, and ask the child to find the toy. They were able to find the toy in this simpler situation, presumably because it did not move after it was hidden.

A second possible problem, also easy to rule out, is that toddlers did not understand the physical law of solidity, namely that the solid barrier would stop the solid ball. Mash et al. (2003) gave 2-year-olds full visual access to the ball's movement by first rolling the ball so that it came to rest against the wall before lowering the screen. When the screen was lowered to conceal ramp and ball, the top of the wall showed above the screen, serving as a continual reminder of the ball's location as in the original study (Berthier et al., 2000). Seeing where the ball stopped actually benefited the children very little. In the original study no 2-year-old performed above chance; in Mash et al. (2003) only 2 out of 18 children were above chance. The 2.5-year-old children fared a bit better; 7 out of 18 were above chance compared to 3 out of 16 in the original study. In this study children did not have to remember the bottom of the barrier as a physical obstacle on the ramp and reason how that would stop the ball. Although this would seem to be a major challenge in selecting the correct door, removing this aspect of the problem did not help 2-year-olds, although it may have been a major block for a few 2.5-year-olds. These data are compelling in that they rule out two possible reasons for toddlers' failure to search correctly: the necessity to reason about the solid barrier stopping the ball, and losing track of the ball because of hidden movement.

An important distinction to remember is that simply knowing that the barrier stopped the ball's progress is not sufficient to infer the ball's location. In Mash et al. (2003) after children saw the screen lowered, the problem of where to search came down to either using the top of the barrier as a cue or remembering which of the four doors covered the ball. We now know that it is easy for a 2-year-old to lose track of where they last saw the ball disappear. In Mash et al. (2003) and in Butler et al. (2002) we scored children's eye movements as they tracked the ball's movement down the ramp. In the former study children saw the ball's complete trajectory whereas in the latter study they saw an interrupted trajectory. Butler et al. (2002) used a transparent screen so the ball was visible as it rolled between doors (see Fig. 2). The door of last disappearance marked the ball's hidden location. In both studies merely tracking the ball until it stopped (Mash et al., 2003) or disappeared behind a door and failed to reappear (Butler et al., 2002) did not ensure a correct response. Two-year-olds needed to both track the ball and hold their gaze on the point of last disappearance until they opened a door. If they shifted their gaze elsewhere

Fig. 2. View of the apparatus used in Butler et al. (2002). The transparent screen allows the ball to be seen rolling between doors 2 and 3. Copyright 2002 by the American Psychological Association. Adapted with permission.

before responding, they usually lost track of the correct door and opened another one. Thus, a child might track the ball down to door 4, look somewhere else, and come back to open door 2, despite having seen it roll past this door. Because children tended to frequently break their gaze, they had a high error rate overall. Children at 2.5 years of age seemed able to keep track of the location better. When they tracked the ball to the point of last disappearance, they opened the correct door ~85% of the time (Butler et al., 2002).

In both Mash et al. (2003) and Butler et al. (2002) children could direct their search based solely on spatiotemporal information provided by the ball's movement. Were they using the barrier cue at all? To answer this question an eye-tracking system was employed that measured where children's point of gaze was directed during the entire dynamic event (Kloos et al., 2006). On the assumption that looking at the barrier at some point during the hiding event would signify recognition of its role, we scored whether children fixated the barrier at least once between onset of the ball's movement and opening a door. Even with this generous interpretation of the meaning of eye fixation on the barrier, we failed to find evidence to support the view that 2-year-olds used the barrier as a cue to the ball's location. They fixated the barrier on only 20% of trials and when they did, performance was not improved. Correct search was present on only 25% of trials when children had looked at the barrier. Clearly, a look toward the barrier before opening a door was not guiding their response (Kloos et al., 2006). The clear screen with four opaque doors from Butler et al. (2002) was used in this study, and overall performance of 36% correct was comparable to Butler et al.'s (2002) 39% correct. Thus, the eye data supported the view that although 2-year-olds were using the spatiotemporal information available through the clear screen somewhat, they were not attending to the barrier at all. On the other hand, we know that 3-year-olds, who solve this search task readily, look frequently at the barrier. They also make use of spatiotemporal information, and weigh these two cues appropriately when they are in conflict (Haddad et al., submitted).

Younger children's failure to use the barrier cue may be because it is more abstract than the spatiotemporal cue. Santos (2004) found that rhesus could use spatiotemporal information but not contact mechanical information of the barrier when searching for a hidden food item. She hypothesized that the spatiotemporal cue was more basic and would be used earlier in development than the more complex cue of the barrier. Data from all of our studies presented here and from Hood et al. (2000, 2003) bear this out. Neither search behavior nor eye gaze indicated that 2-year-olds were using the barrier to mark the ball's hiding place. When reasoning about the world, both macaques and young children attended to the direct information about an object's movement, but failed to use more indirect signals.

One obvious reason that toddlers ignore the barrier in favor of motion cues is that movement is extraordinarily captivating. A wealth of research attests to infants' attention to and understanding of objects' motion when undergoing occlusion (e.g., Wynn, 1996; Spelke, 1988; Gredebäck and von Hofsten, 2004; Johnson et al., 2004). The attractiveness of motion may have overshadowed the stationary wall. In a series of studies we sought to enhance the presence of the wall by a number of means. We used a hard wooden ball that clattered down a bumpy track to hit the wall with an audible clunk; we wrapped the wall in flashing red lights; we extended the wall over the screen so that its edge was visible all the way down to the ramp; and finally we substituted a human arm and hand to catch the ball (Keen et al., submitted). None of these manipulations increased correct responding by more than a few percentage points. One could conclude that our imagination was limited, or we were unlucky and did not hit on just the right means to draw attention to the barrier. We think a more conservative conclusion is that getting the child to notice the barrier is not the problem. Remember, even when they happened to look at the wall during the hiding event, performance did not improve (Kloos et al., 2006).

The search task used in all the studies presented here was modeled after studies testing very young infants' knowledge of solidity and continuity (Spelke et al., 1992). Initially both Bruce Hood and we saw the toddlers' failure to search correctly as disagreeing with the infant data (see discussions in Berthier et al., 2000; Hood et al., 2000). At the same time both sets of authors independently suggested that task differences might explain the success of infants and the failure of toddlers to recognize the importance of physical solidity. One key distinction was that the infancy research used preferential looking whereas the toddler research used manual search. A critical difference between these two paradigms is that the latter response requires prediction of the ball's location whereas the former does not. Preferential looking studies rely on the child's ability to recognize an anomalous visual display: the object is not in the right place. Several authors have pointed out that this after-the-fact recognition of something odd does not require the child to predict the object's exact location in advance (Diamond, 1998; Haith, 1998; Meltzoff and Moore, 1998). One would assume that 2-year-old children would respond the same as infants if the "door" task were converted into a looking-time task, but this had to be tested.

Using the 4-door, horizontal version of this task, Hood et al. (2003) tested the same children first with looking-time as the response, then with manual search. For the looking-time procedure Hood et al. (2003) had an experimenter roll the ball that disappeared behind an opaque screen with the barrier showing above one of the doors. The experimenter then simultaneously opened two doors on either side of the barrier. The object was revealed on the correct side of the barrier for half of the test trials and on the incorrect side (as though it had rolled through the solid barrier) for half the trials. Children in this study were 2.5 and 3.0 years of age. As in previous research with infants, toddlers looked longer when the object was on the wrong side of the barrier than when it was in the expected location. Nevertheless, when given the opportunity to search for the object in the usual procedure, 2.5-year-olds failed.

The findings of Hood et al. (2003) pointed to a clear dissociation between looking and searching in children's understanding of a hidden object's location. In a follow-up study Mash et al. (2006) corrected a design problem and changed the procedure to test whether children could predict the ball's location as well as react to an anomalous visual display. The design problem concerned the fact that Hood et al. (2003) always rolled the object from the same direction. This resulted in the toy resting on the same side of the barrier numerous times throughout familiarization of the apparatus and on half of the test trials. When the toy was on the wrong side of the barrier, it was not only anomalous but also novel. Confounding perceptual novelty with the cognitive anomaly can be serious because of the well-known preference for novelty (for review, see Haith and Benson, 1998). Mash et al. (2006) redesigned the ramp so that it could be rotated in either direction. During familiarization and test trials children saw the ball equally often on the right and left of the barrier (see Fig. 3 for a photograph of the apparatus in both positions). A final difference between our study and Hood et al.'s (2003) was age of children. We tested 2-year-olds rather than 2.5- and 3.0-year-olds because the younger group had shown virtually no success on the opaque screen version of this task (Berthier et al., 2000; Mash et al., 2003; Keen et al., in press).

The beginning of our procedure was the same as in the manual search version of the task. The experimenter placed the barrier on the ramp, lowered the screen, and released the ball, which rolled out of sight behind the screen (see Fig. 3). At this point the experimenter manipulated a hand puppet that traversed up and down the screen before opening a door. On 10 standard trials the puppet pulled down the correct door (i.e., on the side nearest to the barrier from the direction the ball had rolled)

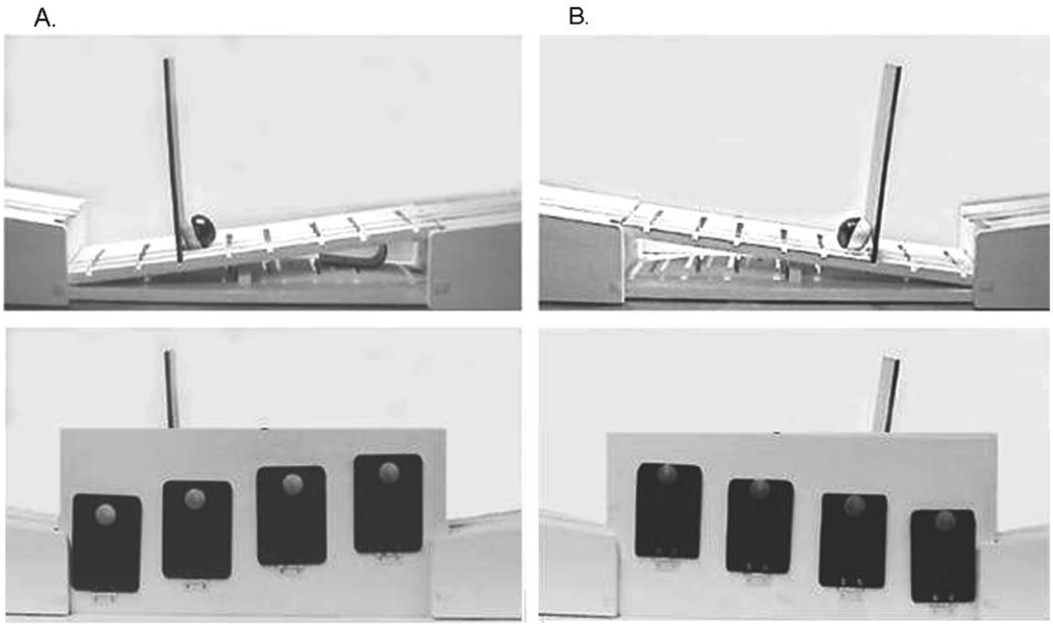

Fig. 3. View of the rotating ramp apparatus used in Mash et al. (2006). The ramp, barrier, and ball are depicted in the top pictures and the apparatus with the door panel in place is depicted in the bottom pictures. (A) Ramp inclined to the right. (B) Ramp inclined to the left. Copyright 2006 by the American Psychological Association. Adapted with permission.

and found the ball. These standard trials were important to maintain the notion that the barrier would stop the ball; we did not want children to regard this as a magic show put on by the puppet in which balls could be found randomly behind doors. There were 4 critical test trials interspersed throughout the standard trials, for a total of 14 trials. On all test trials the puppet opened a door and found no ball on the ramp. On consistent trials, the puppet opened an incorrect door, which should be no surprise if the child realized in advance that it was incorrect. When the screen was lifted the child saw the ball beside the barrier in the correct spot. On inconsistent trials, the puppet opened the correct door to reveal no ball; this would surprise the child if he/she had predicted the ball's location. When the screen was lifted, the ball was seen at a location beyond the barrier.

Given this two-step revelation about the ball's whereabouts, it was possible to devise two measures: (1) looking time when the puppet opened a door and found no ball; and (2) looking time when the screen was lifted to reveal the ball in either the correct or incorrect location. The former measure has the potential to tap whether the child predicted the ball would be in a specific location beside the barrier. The second measure is like that of infant looking-time procedures and also Hood et al.'s (2003) task in which looking time was compared when the object was in an anomalous location to when it was not. Analysis of the first measure found that toddlers looked longer when the puppet opened the correct door to find no ball than when it opened the incorrect door. Looking time did not differ between the two trial types for the second measure when the screen was raised to reveal the ball's location. These results agree with Hood et al. (2003) that when placed in the role of a passive observer, toddlers appear to have some knowledge about the ball's location. Even more compelling, our data indicate that children also appear to predict the ball's specific location by looking longer when it was not in the exact spot where it was expected to be. Why did they also not look longer when the screen was raised to reveal the ball beyond the barrier? We speculated that it was because the view of the ball beyond the barrier simply confirmed what they already knew — that the ball was not in the expected location. The second event was not unexpected, given that they understood and had already responded to the first event (Mash et al., 2006).

Must the child be a passive observer in order to display knowledge of the ball's hidden location? We attempted to devise a task that allowed the child to actively predict where the ball would stop, but without searching manually for it. Using the same rotating ramp and barrier as in Mash et al. (2006), we invited children to place a toy doll, Lorie, on the ramp where she could "catch" the ball (Kloos and Keen, 2005, Experiment 2). The game was explained in terms of Lorie wanting to stand on the ramp and catch the ball. To demonstrate the task, the experimenter placed the barrier on the ramp at an intermediate position. Lorie was then placed on the ramp at three positions in succession: in front of the barrier so the rolling ball knocked her over, right against the barrier where she "caught" the ball, and behind the barrier so the ball stopped at the barrier, leaving Lorie empty-handed. The experimenter commented on what happened each time after the ball was rolled. The children then had six familiarization trials with the ramp tilted in the same direction as the demonstration and the barrier placed in all possible positions over trials. For each trial the experimenter said, "I'm going to roll the ball. Where should Lorie stand to catch the ball?" After the child placed Lorie on the ramp, the experimenter rolled the ball and described the outcome ("Lorie caught the ball", "Lorie was too far away", or "Lorie got knocked over"). For test trials the ramp was tilted in the opposite direction and the ball was rolled just once, with no barrier present. The experimenter proceeded immediately to six trials of placing the barrier on the ramp, and invited children to place Lorie where she could catch the ball.

Children performed at a high level (87% correct) during the familiarization phase, indicating they understood the task; however, their placement of the doll against the correct side of the barrier may have been in imitation of the experimenter's demonstration rather than prediction of where the ball would stop. After the ramp was rotated, children placed Lorie correctly on 49% of trials. An examination of individual children's performance showed the widest possible spread of ability in these 2-year-olds' capacity to predict the ball's future position from a new direction. Two children out of 17 tested had perfect performance, and another 2 maintained high performance at 80% correct, with another 2 near 70%. The rest were at 50% or below and one child had none correct (see Fig. 5 in Kloos and Keen, 2005). Their most frequent error was to put her next to the barrier on the wrong side, clearly a holdover from their placement on familiarization trials.

In a second procedure we tested these same children on placing Lorie behind a screen to catch the ball. Without changing the direction of the ramp the barrier was first placed on the open ramp and the screen was lowered with the barrier showing above it. The children were asked to pull down a door and place Lorie on the ramp so she could catch the ball. After Lorie was placed and the ball was rolled, the experimenter lifted the screen to show the outcome. The purpose of this follow-up procedure was to see the effect of removing the child's view of a critical element in determining placement, the point where the bottom of the barrier met the ramp. Removal of this view resulted in plummeting performance, 32% correct, which was not better than chance.

In some ways, the percentage correct cannot be compared across these two procedures because chance is .25 when the child chooses among four doors, but chance cannot be calculated when Lorie is simply placed on the open ramp because she could be placed at a large number of incorrect locations and only one specific space was correct. We scored the doll's placement as correct if it was within 4 cm of the appropriate side of the barrier. One must appreciate that 49% correct is a high number because Lorie was a small doll (3 cm wide and 7 cm high) and she could be placed anywhere on the 75 cm long ramp. Kloos and Keen (2005) concluded that 2-year-olds could use their knowledge about the barrier to predict where the ball would stop with fair success, but only if they could see all critical elements. In the condition with no screen, children could see the ball, the barrier, and the intersection of ramp and barrier while they were planning where to place the doll within the array. This same task but with a screen occluding the ramp and bottom portion of the barrier appears to wipe out their capacity to imagine the ball's future location, in both the Lorie study and in all the studies reported here when they were simply opening a door to find the ball.

We hypothesized that the key to prediction for the 2-year-old is having the elements visually available within the spatial array. Having to imagine the arrangement of critical elements in the spatial array makes prediction difficult or impossible for children of this age. This analysis of the 2-year-old's problem fits with the looking-time data. In both the Lorie study and the looking-time procedure children do not have to imagine a hidden spatial layout. In Hood et al. (2003) children recognized that the ball was on the wrong side of the barrier. In Mash et al. (2006) they responded to the empty ramp next to the barrier after the puppet opened the door. In this case they responded to the absence of an expected object in an exact location, but note that they could see that exact location rather than having to imagine it.

The results discussed thus far seem to suggest that toddlers' capacity for object representation differs radically from that of adults and older children. Surely no adult (and very few 3-year-olds!) would fail to use the barrier wall to successfully locate the ball in the door task. Previous research suggests however, that even adults can at times be "blind" to the positions of objects that occlude ones they are attempting to track (Scholl and Pylyshyn, 1999). Inspired by literature on constraints on adults' attentive tracking of objects, we conducted a series of experiments to test the hypothesis that young children approach the door apparatus as an object-tracking task (Shutts et al., 2006). Research with adults has shown that attention is directed to whole objects and spreads continuously within an object from points nearer to points farther (e.g., Egly et al., 1994; see Scholl, 2001). We reasoned that if 2-year-olds approached the door apparatus as an object-tracking task, this signature profile should be revealed in their search performance.

We hypothesized that children might perform better on the door task if they could see part of the object they needed to track, because their attention might spread from the visible part of the object to its hidden body. To this end, we attached an antenna with a pompom to a toy car, rolled it down the ramp, and asked children to search for it. In one experiment the antenna was tall and therefore visible above the occluding screen, about equal in height to the barrier wall. In another condition the antenna was short and visible through clear windows we created in the doors. Children in the first experiment performed slightly above chance, but children in the second experiment were near ceiling. A control experiment eliminated the possibility that children in the second experiment were simply reaching for the door with something visible in the window, rather than searching for the specific object to be tracked. This pattern of results is consistent with the idea that children's attention was directed toward the visible part of the object (i.e., the pompom and antenna), and spread in a gradient-like fashion within the object (Egly et al., 1994).

As noted above, if children's attentive tracking resembles adults', then objects further away from the focus of attention may be overlooked. Was the problem with the wall all along due to the screen being too high? Was the top of the wall too far away from its hidden base on the ramp and the ball to serve as a cue? A final experiment tested whether the wall could serve as a cue to the object's location if it showed prominently through the window. Children saw the wall placed on the ramp, and it was positioned to show through the middle of the window, just as the pompom had. Then the car without a pompom was rolled and stopped by the wall out of sight in the same procedure as before. Two-year-olds' performance dropped to chance, just as when the wall was more distant above the screen. The failure to use a nearby cue underscored the need for spatiotemporal information directly connected to the object.

Every experiment that moved 2-year-olds' performance above chance featured spatiotemporal information directly connected to the hidden object. When children saw the ball moving between doors behind a transparent screen, careful tracking and maintenance of gaze helped them choose the correct door (Butler et al., 2002; Kloos et al., 2006). The Shutts et al. (2006) series of experiments similarly showed the power of spatiotemporal information that directly connected the cue with the object's location. During all familiarization procedures children were shown that the barrier stopped the object. Yet knowing that the stationary barrier stops the moving object is not sufficient to support reasoning that connects this information with where to find the ball.

It may be that the spatial layout is too complex for 2-year-olds to imagine the juxtaposition of ramp, barrier, object, and door (Keen, 2005). In this regard, the "door task" joins other search tasks in which toddlers show a remarkable inability to reason about a hidden object's location. DeLoache (1986) found that 2-year-olds could locate a hidden object only when the visual cue was part of the hiding place. When the distinctive cue was indirect, i.e., adjacent but not part of the hiding place, performance dropped. In a unique test of understanding hidden movement, Hood (1995) dropped balls down twisted opaque tubes connected to cups at the bottom. He found that 2-year-olds could not use the path of the tube to predict which cup a ball would land in. Rather they made a "gravity error", choosing the cup directly underneath the position where the ball was dropped, ignoring the path of the tube.

In summary, 2-year-olds have great difficulty following an object's hidden movements when no direct spatiotemporal information is available. Reasoning about contact mechanical effects such as one object blocking another's progress, and combining this information with a hidden spatial layout containing the ball's location requires a level of cognitive development not reached by most 2-year-olds. In tasks of passive observation or active participation toddlers appear to represent complex events, but only if they see the whole spatial array where a hidden past event took place (Hood et al., 2003; Mash et al., 2006), or where a future event will take place (Kloos and Keen, 2005). Children under 3 years of age need the support of viewing the critical elements involved in a contact mechanical event in order to engage in reasoning about an object's specific location. Three-year-olds show a major cognitive advance when they can predict the effect of a barrier in a moving object's path (Berthier et al., 2000; Hood et al., 2000) or evaluate conflicting spatiotemporal and contact mechanical information (Haddad et al., submitted). In a thorough review of the literature Newcombe and Huttenlocher (2000) covered location coding, landmark use, place learning, and motor learning as important processes in understanding space and objects. Our research adds to this body of knowledge by laying out a developmental course for using spatiotemporal and contact mechanical information in young children.

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