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FAST-TRACK REPORT

Representational momentum and children's sensori-motor representations of objects

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Abstract

Recent research has shown that 2-year-olds fail at a task that ostensibly only requires the ability to understand that solid objects cannot pass through other solid objects. Two experiments were conducted in which 2- and 3-year-olds judged the stopping point of an object as it moved at varying speeds along a path and behind an occluder, stopping at a barrier visible above the occluder. Three-year-olds were able to take into account the barrier when searching for the object, while 2-year-olds were not. However, both groups judged faster moving objects to travel farther as indicated by their incorrect reaches. Thus, the results show that young children's sensori-motor representations exhibit a form of representational momentum. This unifies the perceptually based representations of early childhood with adults' dynamic representations that incorporate physical regularities but that are also available to conscious reasoning.

Introduction

Roger Shepard suggested that some forms of internal representation have a second-order isomorphism to the physical structure of the world. Thus, rotating an internal image of an object follows similar temporal and spatial constraints as rotating a physical object (see Shephard, 2001). Internal representations of objects moving along a path also seem to follow some physical laws of motion, exhibiting, for example, what has been called representational momentum (Freyd & Finke, 1984). That is, mental representations of moving objects, like their real world complements, take time to reach a stopping point. Using either static or dynamic displays of objects in motion, studies with adults consistently show that when the stimulus of a moving object is no longer in view, the internal representation persists in time, 'moving' along the same path at an internal velocity (and thus distance) related to its prior perceived velocity (Freyd & Finke, 1984; Hubbard, Matzenbacher & Davis, 1999). Thus, the internal representation adheres to some of the dynamics of real physical movement.

Dynamic representations that incorporate physical laws of movement might be viewed as akin to the sensori-motor representations suggested by Piaget to characterize infant thought (1952). This raises the question as to whether the sensori-motor representations proposed to be used by young children in some tasks, like the dynamic representations of adults, show a second-order isomorphism to physical movement in the world, and in particular, representational momentum. An affirmative answer would unify proposals about sensori-motor representations in infants with advances in the study of dynamic representations more generally.

The present two experiments use a task designed by Berthier, DeBlois, Poirier, Novak and Clifton (2000) that is surprisingly difficult for $2\frac{1}{2}$-year-olds. Children watch an object roll down a ramp on a path that takes it behind an occluder. The object is stopped by a barrier, which children watch being placed before each trial and whose top is clearly visible above the occluder. The child's task is to indicate where the object stopped by opening a door in the occluder. Although 3-year-olds show some ability to use the barrier to infer the stopping point, $2\frac{1}{2}$-year-olds fail completely, often perseveratively choosing the same door over and over again. This errant failure has been interpreted as indicating a sensori-motor kind of thought that is incapable of making inferences about the location of the barrier, an unobserved obstruction on the path, and an unseen stopping point (Kloos, Haddad & Keen, 2006; Shutts, Keen & Spelke, 2006; Mash, Novak, Berthier & Keen, 2006).

Young children's dismal performance in this task suggests that they do not reason about barriers and stopping points. It does not, however, show that their performance is based on sensori-motor representations. This is the purpose of this paper: to provide direct support for this idea by demonstrating that young children's performance in this task shows a signature characteristic of dynamic sensori-motor representations – representational momentum. If young children attempt to solve

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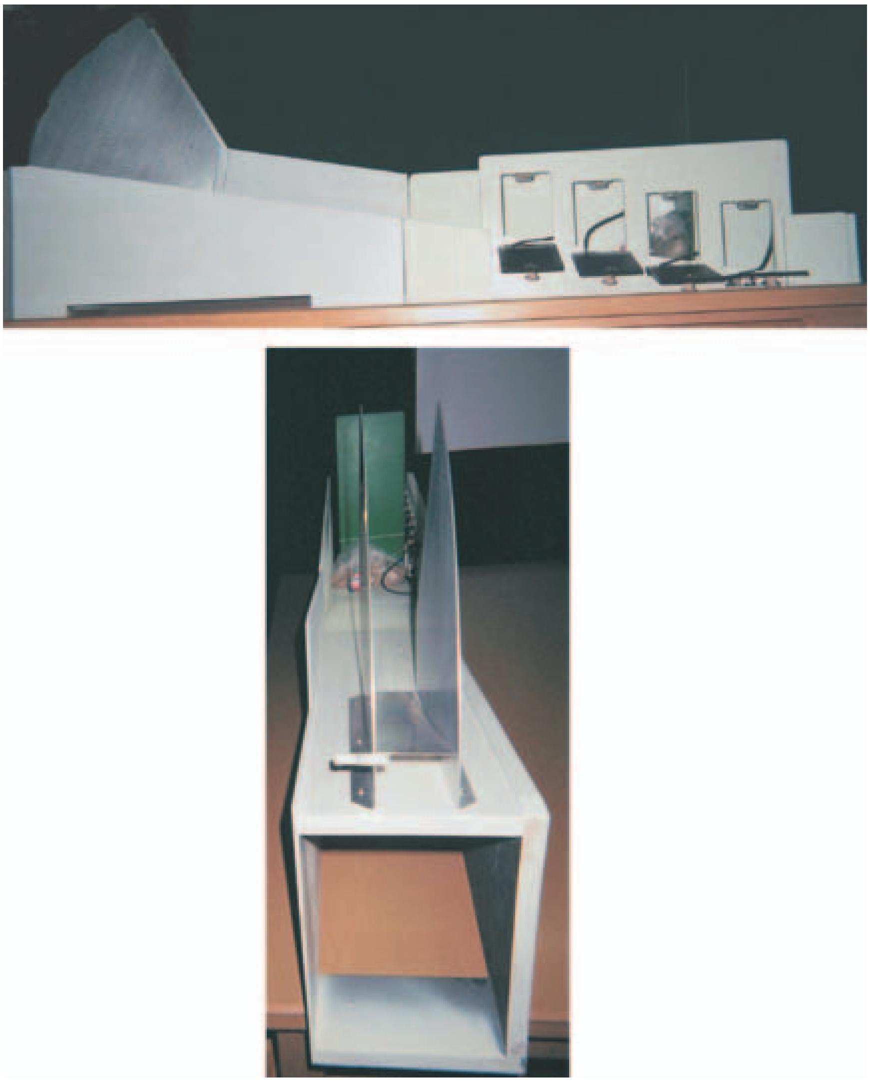

Figure 1 *Top panel shows the participant's view of apparatus. The bottom panel shows how ramp 1 can be lifted .5 to 24 cm higher than ramp 2 to manipulate starting speed.*

this task through processes that include the dynamics of the perceptual events, then they should predict that faster moving objects–regardless of the location of the path-blocking barrier – would come to a stop further along the occluded path than slower moving objects. We test this in the following two experiments.

Experiment 1

The experiment is similar to the Berthier *et al.* (2000) study, but with three conditions that vary the velocity of the object before it goes behind the occluder.

Method

Participants

Thirty-two children (14 male, 18 female) ages 24 to 32 months old, mean age 28.6 months, and 30 children (13 male, 17 female) ages 39 to 48 months old, mean age 43.7 months, were randomly assigned to one of three between-subjects conditions. Two of the children in the 2-year-old group became fussy and did not complete the study. Children were drawn from a working- to middle-class population in a midwestern college town.

Apparatus

The apparatus was like that used by Berthier *et al.* (2000), but was designed to yield three speed conditions, Slow, Medium, and Fast. As can be seen in Figure 1, this was accomplished by using a series of three connected ramp segments to (1) manipulate – out of sight of the observer – the starting height of the object, (2) include a common-to-all-conditions *in-view* path of the object before it moved behind the occluder, and (3) include a final segment in which the object moved behind an occluder and was stopped by a variable-position barrier. The object (a small toy car, 6.35 cm by 5 cm) was placed on the metal piece of ramp 1 at the specified height for the condition so that it rolled down the series of ramps and behind the occluder.

The first ramp segment was 38 cm long, 7.5 cm deep, and 24 cm tall. It was enclosed in a metal box attached to ramp segment 2 and thus was not in view of the participant (Figure 1). From the participant's point of view, then, the car emerged from an opening in this metal 'box' onto ramp segment 2. Importantly, the first ramp section was adjustable; the thin, pliable metal ramp could be raised to three heights (relative to the ramp in section 2): .5 cm, 5.75 cm, and 24 cm. These corresponded to the Slow, Medium and Fast experimental conditions, respectively. Thus, the velocity of the car on coming into view on ramp segment 2 was (on average) .82, 1.47, and 2.14 m/s in the three conditions, respectively. The second ramp segment – the section supporting segment 1 and the metal box and showing the majority of unoccluded motion – was, in all conditions, 76.25 cm long, 20.25 cm deep, and descended from a starting point of 30.5 cm above the table top (meaning that the car started on ramp 1 from a height of 31, 36.35, and 54.5 cm above the table in the three conditions, respectively) to 28 cm, at which point the moving car entered ramp segment 3 and then went behind the occluder. Ramp 3, as also shown in Figure 1, consisted of a wooden ramp (28 cm tall, 57.75 cm long) and an occluder with four doors (each 10.75 cm wide, 14 cm tall). Each door had a unique picture on it (randomized across subjects) to help memory. The car rolling down the three consecutive ramp segments was visible to the participant for 53.25 cm (the length of ramp 2 minus the 38 cm length of ramp 1 plus 15.24 cm of ramp 3). A removable piece of wood (15.25 cm wide, 43.25 cm tall) painted green was used as a barrier. It could be placed to the right of each door so as to stop the rolling object at that position. The barrier stood 17 cm higher than the top of the occluder so that it was clearly visible to the child. The bottom surface of the barrier was lined with a thin sandbag such that the rolling object came to rest silently upon hitting the barrier.

Procedure

The apparatus sat on a table. The child sat facing the apparatus, approximately 1.4 m away so that the full apparatus could be seen. A series of four practice trials were used to familiarize the child with the experiment. The experimenter rolled the car down the ramp while all doors were open and with the barrier in place at one of the four locations. The child was then allowed to retrieve the car from inside the ramp and hand it back to the experimenter. Across the four practice trials the barrier was located at each door once so that the child witnessed the car stopping at each of the four locations.

During the test phase, all of the doors were closed so that the child had to use the position of the barrier to correctly locate the car. On each trial the barrier was placed at one of the four positions. The car was then placed on ramp 1 and released. The child was asked to retrieve the car by opening the door she believed it to be behind. Only the child's first choice was recorded, but she was allowed to search until she found the car.

Each test phase was made up of 12 trials; the barrier was placed in each location three times in one of four randomly varying orders. Speed was varied between participants so that each participant witnessed the car moving at one constant speed throughout training and testing trials. The subjects were divided evenly between speed conditions so that there were 10 children of each age group in each speed group.

Results and discussion

As in the earlier studies, 2-year-olds generally performed poorly, choosing the correct door on average on .27 of trials which does not differ from chance (.25), $t(1) = .74$ *ns*. In contrast, 3-year-olds were significantly more accurate (.67) than chance, $t(1) = 9.2$, $p < .001$, using the barrier, at least as a partial guide, to locate the stopped car. Figure 2 shows the relationship between the position of the barrier and the children's reaches. Complete accuracy in this task would be indicated by a 1 to 1 relationship between barrier position and reach (in other words a line with a slope of 1). As Figure 2 indicates, the door children chose to open first better corresponds to the position of the barrier for 3-year-olds (top panel) than for 2-year-olds (bottom panel). This replicates previous findings that 3-year-olds perform this task with more accuracy than 2-year-olds.

The main question, however, is whether children's errorful searches show a systematicity suggestive of a dynamic representation of the physical event. Specifically, do children in the Fast condition choose a door farther down the ramp than children in the Medium or Slow conditions? To examine this, each child's first choice of a door on each incorrect trial was scored as 1, 2, 3 or 4 to indicate whether they chose the first, second, third, or fourth door. In the 3-year-old group, four children (one in each of the Slow and Fast conditions, and two in the Medium condition) were 100% accurate in their reaches and so could not be included in our analysis of errorful reaches. The average scores for older and younger children in the three speed conditions are shown in Figure 3. A two-way ANOVA showed that these scores increase with velocity, $F(2, 56) = 5.93$, $p < .006$. Although, as shown in Figure 3, both groups appear to be showing this pattern of reaches suggestive of the influence of velocity, further analysis reveals that most of the effect was driven by the 2-year-olds. Tests of simple effects showed that 2-year-olds' average score was significantly affected by condition, $F(2, 30) = 7.38$, $p < .003$, but the 3-year-olds' average score, while showing a trend of an effect, was not significant, $F(2, 26) = 1.36$, $p < .28$. Thus, these results suggest that, even though 2-year-olds' accuracy is at chance, their searches are far from random. These children are more likely to choose a door further

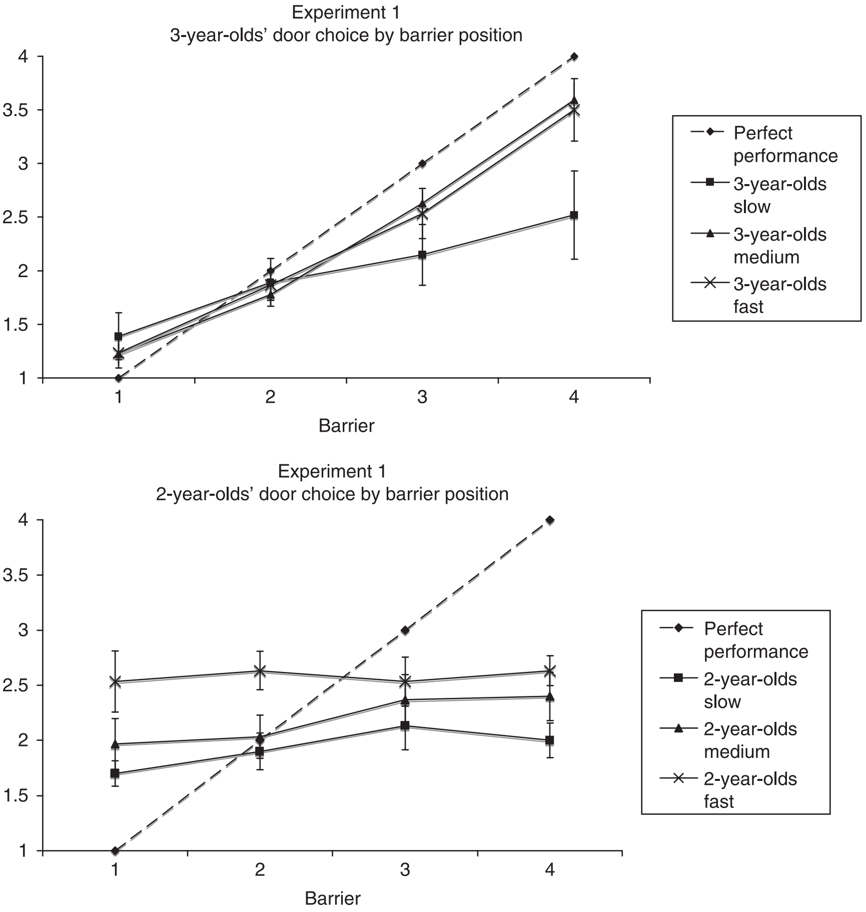

Figure 2 *This figure shows that the door choices of 3-year-olds in Experiment 1 (top panel) in all conditions better corresponded to the position of the barrier than did those of 2-year-olds in Experiment 1 (bottom panel). This reflects the higher accuracy level of 3-year-olds.*

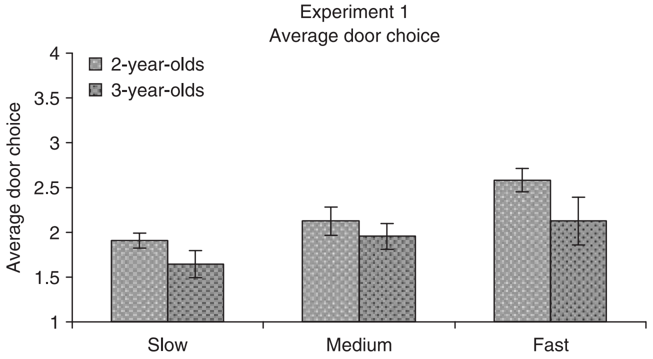

Figure 3 *Average incorrect door choice for each speed condition for each age group. First door from the left was assigned 1 point, second door 2 points, and so on. Children in the faster conditions are more likely to choose a door further in the direction of motion.*

in the direction of motion in the Fast condition and less likely to do so in the Slow or Medium conditions. Similarly, as can be seen in Figure 3, 3-year-olds show a tendency to choose a door further in the direction of motion in the Fast condition. However, they are generally performing with such accuracy that the few mistakes they do make are not enough to reveal a significant effect. The data from 2-year-olds, then, suggest a representation that includes the physics of the event itself and, as such, suggest that these young children's representations of the events in this task share a fundamental similarity with a form of dynamic representation that is also available to adults.

Experiment 2

Studies of representational momentum in the adult literature suggest that these effects are, at least in part, the product of learning – either during the experiment or from the physics of everyday experiences (Kerzel, 2002; Freyd & Finke, 1984). Experiment 2 provides further evidence for the nature of these dynamic representations in 2-year-olds by examining how experiences of movements at one speed may subsequently influence the representation of movements at other speeds.

Method

Participants

Forty-five children between the ages of 24 and 32 months, mean age 28 months, participated in this study.

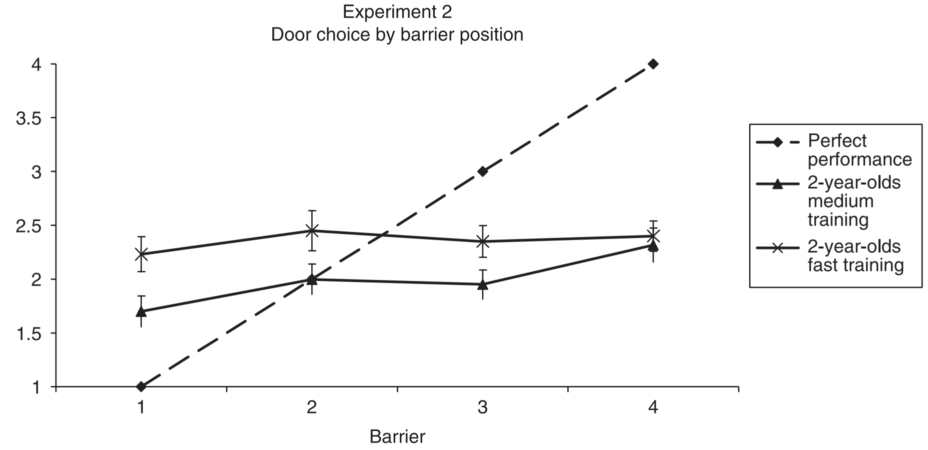

Figure 4 *This figure shows that the average door choice did not correspond with the position of the barrier for either familiarization condition.*

Five children failed to complete the study due to fussiness. There were 23 boys and 17 girls in the final group. Participants were randomly assigned to the following four between-subjects conditions (familiarization speed/test speed): Medium/Medium, Fast/Medium, Medium/Fast, and Fast/Fast; there were 10 subjects in each condition.

Apparatus and conditions

The same apparatus was used as in the first experiment. The height of ramp 1 used and thus the speeds of the object correspond to those in the Medium and Fast conditions of Experiment 1.

Procedure

The general procedure was identical to Experiment 1 with the exception that two familiarization trials were added before the practice and test trials and there were twice as many (eight) practice trials. During the Familiarization trials the *doors on the occluder were all open* and the experimenter showed the participant how the car rolled down the ramp with all the doors open without allowing the child to reach. On the eight practice trials, the child was allowed to reach for the car through the open door on each trial. Across these trials, the barrier was located at each door position twice, presented in one of two randomly determined orders. For half of the participants, the car moved at a medium speed on these trials (Medium/Medium and Medium/Fast conditions). For the other half of the participants, the car moved at the fast speed on these trials (Fast/Medium and Fast/Fast conditions). Thus, the effect of the familiarization trials was to give children differential experience with the speed of the car, but not differential experience finding the car or reaching to a particular location (because children reached equally to each of the four positions through an open door).

The Test trials were identical to those in Experiment 1. Half the participants received test trials with the car moving at the same speed as in the Familiarization (the Medium/Medium and Fast/Fast conditions) and half received test trials at the other speed (the Medium/Fast and Fast/Medium conditions).

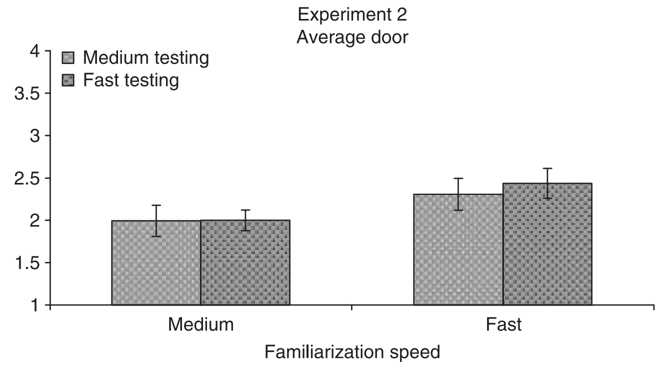

Figure 5 *Average incorrect door choice in each training condition during Experiment 2. Choices during testing are driven by familiarization speed rather than testing speed.*

Results and discussion

Again, performance on the test trials was very poor – children were not able to use the position of the barrier to choose the right door. The 2-year-olds chose the correct door on .28 of the test trials, and thus did not differ from chance (.25), $t(1) = 1.6$, *ns*. Figure 4 shows, again, that for this age group the position of the barrier does not influence children's choices. To measure representational momentum effects on children's errorful searches during test trials, the average door choice made by each child on incorrect trials was determined. A two-way ANOVA showed a significant effect of *familiarization* speed, $F(1, 36) = 4.84$, $p < .04$ but no effect of *test-trial* speed, $F(1, 36) = .16$, $p > .6$, and no interaction, $F(1, 36) = .13$, $p > .7$. As shown in Figure 5, these results indicate that children familiarized with a faster moving car chose doors further down the ramp, on average, than those familiarized with a slower moving car, regardless of test-trial speed. The fact that memories for familiarization speeds – and not the immediate perceptual experience on a trial – influenced children's choices strongly suggests that their choices reflect dynamic representations that are built from prior experience. It seems that learning to predict what something will do is part of learning to represent it.

General discussion

To the best of our knowledge, these are the first empirical demonstrations of representational momentum in 3-D physical space: these representations are not a byproduct of viewing simple 2-D presentations of movement but rather are indicative of the way in which we perceive movement in general. These are also among the first empirical demonstrations of representational momentum in very young children. While there are indices of this phenomenon in studies of infants' predictive reaching and object tracking (e.g. Spelke & von Hofsten, 2001; von Hoftsen, Feng & Spelke, 2000; von Hofsten, Kochukhova & Rosander, 2007), our data are the first to demonstrate this phenomenon in a task where children were predicting the stopping point rather than the reappearance of an object. Clearly, the dynamic representations that often govern adult judgments of spatio-temporal events also govern those of young children. Thus, these results also tell us that despite their chance-level performance in this task, 2-year-olds are at least attending to the events and do represent the hidden objects behind the occluder. More importantly, the fact that children's responses were influenced by the dynamics of the event indicates that they represent the dynamics of the perceptual event but not the relational structure of the unseen car and barrier.

If 2-year-olds' sensori-motor representations incorporate velocity, why don't they incorporate the barrier that blocks the path? What is the fundamental difference between the dynamic representations that enable a child to predict that a faster moving object will move farther but not to predict that a barrier will stop the object's continued movement? There is a large literature on both children and adults that suggests that the sensori-motor system is capable of capturing deep regularities about physics that are not available to more explicit forms of reasoning (e.g. Krist, Fieberg & Wilkening, 1993; Schwarz & Black, 1999; McCloskey, 1983). For example, adults as well as children as young as 5 years cannot predict whether a tall narrow glass or wide one will spill water first when tipped, but when given empty glasses to hold and tip, they can tip them with great accuracy to the precise point at which water would first spill (Schwartz & Black, 1999). Similarly, children and adults cannot symbolically or conceptually predict with any success the path of a ball that leaves a circular tube, but can put their hands to just the right place to catch the ball (see McCloskey, 1983). These facts suggest the power of sensori-motor representations in generating expectations relevant to perception and action and also the availability of these representations throughout development. These representations, however, may also be limited by being more graded, continuous, integrative, and noncompositional. Apparently, predicting where the car will stop – given only the position of a barrier showing above the occluder – requires a different kind of knowledge, involving explicit components and their relations to each other, compared to knowledge that is deeply embedded in the processes of perceiving and preparing for action. Without the use of such knowledge of the task stucture, children cannot attend to the barrier of the wall and will fail. Furthermore, nonhuman primates as well as human 2-year-olds fail at this task (Santos & Hauser, 2002), raising the further interesting possibility that developmental differences in children's ability to represent the relational components of the task may be connected to language acquisition. This possibility is consistent with Piaget's characterization of infant thought.

In particular, Piaget (1952) suggested that young children fail conceptual tasks like the ramp task because their thinking is based in the sensori-motor processes that underlie perceiving and acting. This idea has been brought into question in the past by research suggesting that this may not be true for all forms of infant thought – data suggest that infants can solve problems similar to those presented in the ramp task under some conditions (e.g. Spelke, Breinlinger, Macomber & Jacobson, 1992). More recently, however, research has shown that adults as well as toddlers may often rely on mental processes close to the sensori-motor surface in certain tasks (Schwartz & Black, 1999). Like these more recent findings, the current data are thus consistent with Piaget's original idea that cognitive behaviors are grounded in sensori-motor information in that they suggest that 2-year-old children's failures in this task show positive indicators of dynamic sensori-motor representations – representational momentum.

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