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Cotton-Top Tamarins' (*Saguinus oedipus*) Expectations About Occluded Objects: A Dissociation Between Looking and Reaching Tasks

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Recent work with human infants and toddlers suggests a dissociation between performance on looking and reaching tasks. Specifically, infants appear to generate accurate representations of occluded objects and their actions when tested in expectancy violation looking tasks but often fail to use this information when reaching for occluded objects. We explore a similar dissociation in cotton-top tamarin monkeys (*Saguinus oedipus*). We presented adult tamarins with an event in which a piece of food rolled behind an occluder and into a solid barrier. In Experiment 1, subjects were required to retrieve the hidden food using the location of the solid barrier. Like human toddlers, adult tamarins failed to take into account solidity information when reaching for an invisibly displaced object. In Experiments 2 and 3, we presented subjects with expectancy violation looking versions of the same solidity problem using an identical apparatus and setup. We presented subjects with an event in which a piece of food appeared to roll unexpectedly through a solid barrier or stopped at the appropriate spot. Although tamarins failed to locate the food in

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Experiment 1, the same subjects successfully detected violations of solidity in these 2 looking studies. This performance dissociation is discussed in light of similar dissociations in human toddlers and other primate species.

The question of how infants reason about hidden objects is one of the most studied (and undoubtedly one of the most controversial) topics in the field of developmental psychology today. Much of this controversy stems from a growing body of work indicating that infants seem to demonstrate drastically different competencies when tested in different kinds of methodological paradigms. When infants are asked to reason about hidden objects in manual search paradigms, in which they must use their knowledge of objects to guide where they reach, infants perform quite poorly (e.g., Ahmed & Ruffman, 1998; Piaget, 1954). On some tasks—particularly those involving solidity and containment—poor reaching performance continues even as late as 2 to 3 years of age (e.g., Berthier, DeBlois, Poirier, Novak, & Clifton, 2000; Hood, Carey, & Prasada, 2000).[1] In contrast, infants seem to possess much richer knowledge of occluded objects when tested in expectancy violation looking paradigms. By at least 6 months of age, infants expect hidden objects to continue to exist when occluded (e.g., Aguiar & Baillargeon, 2002; Baillargeon, Spelke, & Wasserman, 1985; Simon, Hespos, & Rochat, 1995; Wynn, 1992), to act as cohesive wholes across motion (e.g., Chiang & Wynn, 2000; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Wynn, Bloom, & Chiang, 2002), to maintain their own unique spatial locations (e.g., Spelke, 1988; Spelke et al., 1992; Xu & Carey, 1996, 2000), to trace continuous paths in time and space (e.g., Spelke, Kestenbaum, Simons, & Wein, 1995), and to move when contacted by other inanimate physical objects (Kotovsky & Baillargeon, 1998; Leslie & Keeble, 1987).

Such successes on expectancy violation tasks have led to the idea originally articulated by Spelke and her colleagues (1992) that infants come into the world endowed with an innate understanding of objects and how they interact, a type of understanding often referred to as infants' *core knowledge.* In particular, Spelke et al. argued that infants reason about objects in accord with a set of three basic principles: cohesion, continuity, and contact. The *cohesion* principle asserts that objects move through time and space as bounded entities; according

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[1] Note that infants and toddlers do not always fail in search tasks. Young infants, for example, search successfully when required to search for objects "occluded" in the dark (Goubet & Clifton, 1998; Hood & Willatts, 1986; Shinskey & Munakata, 2003). Young infants also perform well in search experiments in which they are required to search visually for hidden objects (Hofstader & Reznick, 1996). Similarly, older infants do perform well on studies in which they must search for hidden objects; by 12 months of age, infants are able to successfully enumerate and search for objects hidden inside a box (see Feigenson et al., 2000). For these reasons, the dissociation between looking and reaching performance is somewhat complex, and often very specific. We return to this idea of specificity in our General Discussion.

to this principle, infants understand that objects maintain their boundaries and thus do not tend to break apart and come together again. The *continuity* principle states that objects move in continuous paths through time and space. This principle gives rise to a number of corollary ideas: (a) an object will continue to exist even when hidden behind barriers (i.e., it cannot disappear from its current spatiotemporal location), (b) an object cannot jump from one place in space to another, and (c) an object cannot exist in the same spatial position as another object and as such, must obey the constraints of solidity. Finally, the *contact* principle states that physical objects move if and only if contacted by another physical object.

If infants have access to this knowledge of objects, as the core knowledge hypothesis suggests, why do they show such poor performance in reaching tasks involving occluded objects? A number of explanations have been put forth to explain the dissociation between infants' performance on looking and reaching tasks, and these explanations tend to fall into two general classes. The first class of explanations, which we refer to here as *discontinuity explanations,* contends that infants' poor performance in reaching studies reflects true limitations in their early competencies (e.g., Bogartz, Shinskey, & Speaker, 1997; Haith & Benson, 1997). Under this view, infants do not reach for objects because they do not know anything about objects. Many discontinuity theorists tend to characterize performance on looking tasks as insignificant, based largely on low-level sensory biases. Others take infants' performance on looking tasks to reflect some kind of knowledge or ability, but argue that whatever this competence is, it is distinct from a later emerging understanding of objects. As such, discontinuity theorists argue that infants undergo a major developmental shift in their conceptual ability to reason about objects; this shift coincides with later successful performance on reaching tasks.

The second class of views—what we refer to here as *continuity explanations*—tends to focus more on infants' successes in looking tasks rather than their failures in reaching measures. Most continuity theorists reason that infants' poor performance on reaching tasks reflects problems with performance rather than problems of competence. To this end, many continuity theorists argue that infants perform poorly on reaching measures for extraneous reasons: Infants fail reaching tasks because they are limited in their motor capacities (e.g., Diamond & Gilbert, 1989), because they lack the capacity to plan means–end action sequences (e.g., Baillargeon, Graber, DeVos, & Black, 1990; but see Munakata, Bauer, Stackhouse, Landgraf, & Huddleston, 2002, for infants' successes in means–end tasks), or even because they have problems inhibiting prepotent responses (e.g., Diamond, 1993). Most important, under this view, infants can represent objects, and do so in many of the same ways as adults; what they lack is the capacity to act on their representations in various ways, using them in the service of reaching for or acting on an object.

Continuity theorists differ greatly in the extent to which they think infant object representations are similar and different from those of adults. Most researchers argue in favor of some developmental change in the way infants represent objects (e.g., Baillargeon, 2004; Munakata, McClelland, Johnson, & Siegler, 1997; Spelke & Hespos, 2001). What develops under this view is the precision with which infants reason about objects. Under some accounts, infants begin with a few basic object concepts that allow them to succeed in representing hidden objects generally (e.g., occluded objects continue to exist), but develop richer representations with more adultlike precision later in the first year of life (e.g., Baillargeon, 2004). In other versions, all of infants' object representations begin in a weaker, graded form and gain strength slowly across the first few years of life (e.g., Munakata et al., 1997). Importantly, infants and adults share some ability to represent objects, but differ in the precision and flexibility with which they can employ these representations (Spelke & Hespos, 2001). A slightly different continuity thesis is the cognitive load theory (see Berger, 2004; Berthier et al., 2001; Boudreau & Bushnell, 2000; Keen, Carrico, Sylvia, & Berthier, 2003). Under this idea, young infants can represent objects, but slowly develop both better performance in physical reasoning tasks and better competence in object reasoning. This account argues that infants fail to reveal their knowledge of objects in any task (looking or reaching) in which the total processing demands overwhelm their limited resources. Such processing demands can depend both on the complexity of the actions involved in the task and the complexity of the object representations needed for success.

At present, the debate between continuity and discontinuity theorists continues. Here, we attempt to provide a different angle on this controversy. Specifically, we present findings from nonhuman primates demonstrating a similar dissociation between looking and reaching. These results not only allow us to rule out certain explanations for this dissociation, but also provide new insights into the evolution of our own capacity to represent objects.

NONHUMAN PRIMATES AND CORE KNOWLEDGE

The core knowledge hypothesis argues that infants' knowledge of objects is innately endowed, the result of phylogenetically ancient selection pressures that shaped the primate mind. In support of this view, studies using looking measures suggest that our closest evolutionary relatives, nonhuman primates (hereafter, primates), share infants' capacities for reasoning about objects. Like human infants, adult primates tested in looking time paradigms expect physical objects to continue to exist when occluded (Hauser, MacNeilage, & Ware, 1996; Uller, Hauser, & Carey, 2001), to act as cohesive wholes even across motion (Munakata, Santos, O'Reilly, Hauser, & Spelke, 2001), to maintain their own unique spatial locations (e.g., Uller, Xu, Carey, & Hauser, 1997), to trace continuous paths in time and space (Santos & Hauser, 2002), and to move only when acted on by other physical objects (Hauser, 1998; Santos, Schecter, & Hauser, in preparation). In short, both human and nonhuman primates tested with expectancy violation procedures seem to expect the same things about objects: that objects will obey the principles of cohesion, continuity, and contact.

Despite their successes in reasoning about physical objects in expectancy violation tasks, recent studies suggest that, like human infants and young toddlers, some primates perform poorly on tasks in which they are required to reach for objects that undergo interactions with other objects (Hauser, 2001; Hauser, Williams, Kralik, & Moskovitz, 2001; Hood, Hauser, Anderson, & Santos, 1999; Santos, 2004). We have shown, for example, that rhesus monkeys search incorrectly for objects that have rolled into or dropped onto solid barriers (Hauser, 2001; Santos, 2004), despite their successful performance on similar looking tasks that tap into putatively similar abilities (Santos & Hauser, 2002). Rhesus macaques' failures are peculiar in part because many of the explanations put forth to explain human infants' failures on similar tasks do not apply in the case of adult macaques. Adult macaques have sophisticated motor capacities, have the capacity to solve tasks involving inhibitory control and working memory (e.g., Diamond 1990, 1993; Diamond & Goldman-Rakic, 1989), and perform well on tasks involving means–end action sequences (e.g., tool tasks: Hihara, Obayashi, Tanaka, & Iriki, 2003). In short, adult macaques are not affected by the task demands thought to impair human toddlers, yet they nevertheless demonstrate robust failures on tasks in which they must search for hidden objects. As such, the rhesus monkey reaching failures pose a challenge to the view that task demands alone can account for toddlers' problems in reaching tasks.

One problem with the rhesus macaque data, however, is that subjects were tested with methods that differ slightly from those used in developmental work (see, e.g., Hauser, 2001, vs. Berthier et al., 2000). In particular, developmental studies often include a brief training or orientation stage, in which participants are allowed to familiarize themselves with the apparatus before testing begins. Rhesus monkey subjects, in contrast, each received only a single trial with little familiarization. It is possible, then, that rhesus monkeys' poor performance on previous studies stems from the fact that they were not adequately familiarized with the apparatus before testing began. As such, it is difficult to determine whether their failures are the result of a true inability to perform the task or whether they instead result from problems related to the exact methods used during the macaque search experiments.

NEW EXPERIMENTS ON AN OLD PROBLEM

The series of experiments reported here had three goals. The first was to extend the dissociation seen in rhesus macaques to another primate species—the cotton-top tamarin (*Saguinus oedipus*). Tamarins have been tested successfully both in looking measures (Hauser, 1998; Santos & Hauser, 1999; Santos, Miller, & Hauser, 2004;

Uller et al., 2001) and in tasks involving reaching for objects (e.g., Hauser, 1997; Hauser et al., 2001), and therefore provide excellent potential for examining looking–reaching dissociations. In particular, we chose to explore whether tamarins would demonstrate a dissociation between looking and reaching dissociation in the context of reasoning about object solidity, a problem that has previously demonstrated such dissociations in human infants (Berthier et al., 2000; Spelke et al., 1992) and rhesus monkeys (e.g., Santos, 2004; Santos & Hauser, 2002).

The second goal was to determine whether this dissociation could be observed within a single individual. Although our previous studies of looking and reaching in rhesus macaques were carried out on the same population, these studies were unable to test the same individual on both looking and reaching measures due to the large number of free-ranging subjects involved. Similarly, relatively few infant studies have presented both looking and reaching measures to the same subjects (see Ahmed & Ruffman, 1998; Hofstader & Reznick, 1996; Ruffman, Slade, & Redman, 2005; and Hood, Cole-Davies, & Dias, 2003, for exceptions). With the captive tamarin subjects tested here, we were able to explore looking and reaching measures within a single individual.

The third goal was to develop a slightly different methodology for testing primate subjects. As mentioned earlier, our previous rhesus monkey search task utilized a procedure slightly different than the ones typically used with human toddlers (e.g., Berthier et al., 2000). Specifically, toddler-aged subjects often begin their manual search testing with a few familiarization trials that serve to orient the subjects to the apparatus and objects. It is possible that our rhesus subjects would have performed better on these search tests if they were given similar familiarization trials. As such, these experiments not only extend a manual search task to a new species, but also test subjects using methods more similar to those used with human toddlers.

EXPERIMENT 1: SOLIDITY SEARCH EXPERIMENT

Method

Subjects. We tested adult cotton-top tamarins (*Saguinus oedipus*), a small New World monkey native to the rainforests of Colombia. Our subjects were born in captivity, either at the New England Primate Research Center (Southborough, MA), or at the Primate Cognitive Neuroscience Laboratory, Harvard University (Cambridge, MA). Their daily diet includes monkey chow, nuts, and fruit, with an ad libitum supply of water. All subjects have had experience using objects and watching objects move during experiments (see Table 1 for details). Nine individuals participated in Experiment 1. We counterbalanced the order in which subjects participated in Experiments 1 (the search experiment) and 2 (the looking experiment).

TABLE 1
Individual Participants and Their Past Experimental Experience

Monkey	*Sex*	*Experiment*	*Past Studies With Objects*
EM	F	1, 2, 3	A, D, H, J
EN	F	1, 2, 3	B, H
ID	M	1, 2, 3	B, D, H, J
JK	F	2, 3	C
KW	F	1, 2	B
PB	M	2, 3	B, H
PJ	M	2, 3	C
RB	F	1, 2, 3	B, D, H
RJ	M	2	—
RW	M	1, 2, 3	B, D, H
SH	F	1, 2, 3	B, H
SP	M	1, 2, 3	A, D, E, F, G, H, I, J
TF	F	2	C
UB	F	1, 2, 3	A, D, E, F, G, H, I, J

Note. A = Hauser (1997); B = Hauser, Santos, Spaepen, & Pearson (2002); C = Hauser, Pearson, & Seelig (2002); D = Hauser, Kralik, Williams, & Moskovitz (2001); E = Hood, Hauser, Anderson, & Santos (1999); F = Hauser, Kralik, & Botto-Mahan (1999); G = Hauser (1998); H = Santos, Miller, & Hauser (2004); I = Uller, Hauser, & Carey (2001); J = Santos, Ericson, & Hauser (1999).

Apparatus. We presented subjects with a blue wooden stage (see Figure 1). The stage was built with a back (24 in. long × 7 in. high) and a floor (2.5 in. deep × 24 in. long × 0.25 in. thick). The left side of the blue stage contained a curved ramp that could be used to launch a minimarshmallow along a track on the floor of the stage. Using this track, the marshmallow could roll continuously from the left side of the stage to the right side. A removable red barrier (2.5 in. deep × 14 in. high × 0.25 in. thick) could be inserted perpendicular to the floor of the stage such that it blocked the movement of the marshmallow along the track. We also included a fixed red barrier (2.5 in. deep × 14 in. high × 0.25 in. thick) at the far end of the stage. A white occluding screen (9 in. × 7 in.) equipped with two rectangular doors (2.5 in. × 2.0 in.) could be placed in front of the stage to block subjects' access to the marshmallow and the stage. Subjects could reach onto the stage by opening one of these two doors.

We moved subjects from their homeroom and tested them inside a stainless steel mesh transport box equipped with a Plexiglas door that the experimenter could raise and lower. We placed the transport box in front of a clear Plexiglas shield with two 2-in. circular holes in the lower left and right quadrants. Subjects could reach through the shield to gain access to the doors of the occluding screen and the marshmallow. During testing, subjects were placed in their transport box

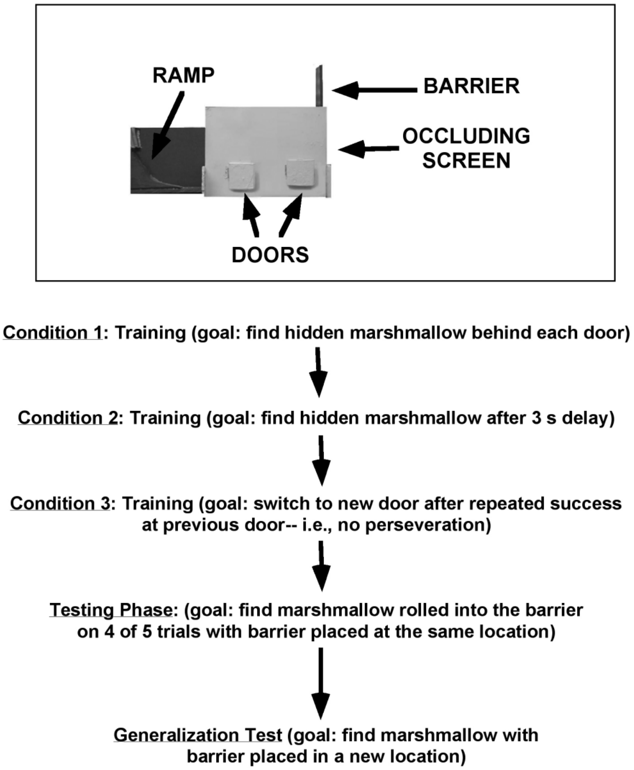

FIGURE 1 An illustration of the apparatus and procedure used in Experiment 1.

facing the shield and stage. A digital video camera filmed both the subject and apparatus.

Tamarins searched for a marshmallow food reward. Each marshmallow was rolled in powdered sugar to reduce its adhesiveness, thereby allowing it to roll smoothly along the track. In all of the experiments, we played white noise through a speaker placed beside the testing apparatus. We used the white noise to eliminate any possible sound cues that subjects might use to locate the marshmallow.

Procedure. As in previous studies (e.g., Hood et al., 1999), subjects were run on several training conditions (see Figure 1) to ensure that they were familiar with the apparatus, did not develop a bias for one particular occluding box, and got used to the presence and potential positions of the barrier and the occluder.

The first training condition, Condition 1, consisted of the following procedure. The experimenter showed the subject the apparatus without the occluding screen, demonstrating that the track was empty. The experimenter then lowered the occluding screen, displayed a marshmallow, lowered the marshmallow behind one of the two doors, and then removed his hand, showing it was empty. The experimenter then raised the door of the transport box and allowed the subject to pick one door. We coded the first door touched as the subject's choice. Each session consisted of 20 trials with the position of the marshmallow (left or right from the subject's point of view) randomized throughout. Subjects moved onto the next training phase when they chose the correct door on 18 of 20 trials (i.e., 90% accuracy) for two consecutive sessions. Condition 2 proceeded just as Condition 1, except that the experimenter introduced a 3-sec delay before allowing subjects to search for the marshmallow. This delay ensured that subjects could remember the location of the marshmallow for the length of time it would take to roll the marshmallow during the test trial. Again, subjects moved into the next condition once they had achieved 18 of 20 correct trials per session for two consecutive sessions. Condition 3 was designed to ascertain that tamarins could switch to a newly reinforced location after being reinforced repeatedly in a previous location. This condition was identical to Condition 2 except that at some point during the session, subjects received five consecutive trials in the same location (e.g., the left door). After this run of trials, subjects were then presented with a "switch" trial in which the location of the marshmallow switched to the new location (e.g., one trial at the right door). To move on from this condition subjects had to both perform accurately on this switch trial and perform at 90% accuracy for two consecutive sessions.

After training, subjects moved onto the test condition, which consisted of two phases: a testing phase and a generalization phase (see Hood et al., 1998, for a similar design). Each testing phase session began and ended with five training trails (Condition 2). These trials allowed us to be sure that subjects were attending to the task and motivated to perform. After succeeding on these initial training trials, subjects moved onto the test trials. Each test trial began with the experimenter inserting the barrier onto the stage. Half of the subjects were assigned to a near barrier placement, in which the barrier was placed in the middle of the stage just to the side of where the left door would be placed, stopping the marshmallow behind the left door. The other half of subjects were assigned to a far barrier placement, in which the barrier was inserted at the end of the stage just to the side of where the right door would be placed and adjacent to the fixed red barrier at the far end of the stage. After inserting the barrier, the experimenter placed the occluding screen down, tapped on the top of the barrier to be sure subjects remembered its location, displayed the marshmallow, and then rolled it along the track, behind the screen, and into the barrier. The marshmallow naturally stopped at the position of the barrier (specifically, behind the right door for subjects in the far barrier placement or behind the left door for subjects in the near barrier placement). Subjects were then allowed to search for the displaced marshmallow by opening one of the two doors. We reasoned that if subjects understood that the solid barrier blocked the marshmallow's trajectory, they should use the position of the barrier to ascertain the marshmallow location behind one of the two doors. If subjects achieved four out of five consecutive trials correct, they moved onto the generalization trial. Subjects were given 10 trials to achieve this criterion in a single session; if subjects did not achieve this criterion in 10 trials the session was terminated.

Subjects reaching criterion in the testing phase moved onto a generalization trial. We used this phase to determine whether subjects understood how the barrier worked. The generalization trial consisted of a single trial in which we switched the location of the barrier (i.e., subjects previously tested with the near barrier placement were tested on a far barrier placement and vice versa). We reasoned that if subjects solved the testing phase trials by attending to the placement of the barrier, then they should successfully generalize to a condition in which we switched the barrier's location. In contrast, if subjects solved the testing phase trials merely by learning to search behind a particular door, irrespective of where we positioned the barrier, then they would perform poorly on the generalization trial, failing to search in the new location. As such, the generalization trial allowed us to explore what our subjects learned during the testing phase.

Subjects who performed successfully on the generalization trial were given one more session. This session consisted of 10 test trials, a random mix of near barrier and far barrier placement test trials. This session was used to more fully determine subjects' comprehension of the barrier problem. This session began and ended with five training trails (Condition 2) to confirm subjects' motivation throughout.

Results

Training phase. Most subjects, with the exception of subject EM, completed the training phase. Subjects moved successfully through each training phase (mean number of sessions to criterion: Condition 1 = 4.6, Condition 2 = 7.4, Condition 3 = 3.6).

Testing phase. Subjects completing the training moved onto the testing phase. Subjects performed differently in the testing phase depending on whether they were tested in the near or far barrier condition (see Table 2). All subjects who began in the near barrier condition ($n = 4$) chose correctly on their first trial, whereas only 1 of the 4 subjects who began in the far barrier condition chose correctly on the first trial. Taken together, then, 87.5% of subjects (binomial probability $p < .04$) chose the near barrier door on their first trial. Subjects in the near barrier group then moved quickly through the training ($M = 4.50$ trials), whereas subjects in the far barrier group took longer ($M = 20.25$ trials; Mann–Whitney $Z = 2.02$, $p < .04$). Once reaching criterion, all subjects moved onto the generalization trial.

TABLE 2
Results of Testing and Generalization Phase of Experiment 1 Showing the Initial Condition (Near/Far), First Trial Performance, Number of Trials to Criterion, and Performance on the Final Generalization Trial

Monkey	*Near/Far*	*First Trial*	*No. Trials*	*Generalization?*
EN	N	Yes	4	No
KW	N	Yes	4	No
RW	N	Yes	5	Yes
SH	N	Yes	5	No
ID	F	Yes	5	No
RB	F	No	25	No
SP	F	No	6	No
UB	F	No	45	No

Only 1 of the 8 subjects (RW) passed this trial. Seven out of 8 subjects ($p < .04$) failed to generalize to a new placement of the solid barrier; instead, these subjects neglected the location of the solid barrier and continued reaching in the location in which they were previously reinforced.

Subject RW (the only subject who passed the generalization test) was presented with a final test session, a random mix of near barrier and far barrier placement test trials. RW performed at chance on these trials, achieving a score of 6 of 10 trials correct. RW searched the near barrier door 70% of the time, regardless of where the barrier was placed.

Discussion

Like adult rhesus monkeys and human toddlers, our adult tamarin subjects failed to reason about the location of a hidden barrier when reaching for an invisibly displaced object. Subjects performed poorly on the first trial. Instead of reasoning about the position of the barrier, subjects instead selected the door adjacent to the near barrier, regardless of where the marshmallow had actually rolled. This choice may have resulted from the use of a simple strategy to search where the marshmallow was last seen (i.e., the marshmallow first disappeared close to the door adjacent to the near barrier). Interestingly, rhesus macaques seem to follow a similar strategy when searching for a plum that rolled into a barrier (Hauser, 2001; Santos, 2004; see also de Blois & Novak, 2000). Moreover, subjects seemed to continue using this search-the-near-door strategy throughout testing; subjects in the far barrier condition (in which the marshmallow rolled to the far door) took longer to reach criterion than those in the near barrier condition (in which the marshmallow landed behind the near door). After reaching criterion in Experiment 1, all but 1 subject failed to generalize to a new barrier position. Instead, subjects seemed to continue choosing the door in which they were previously reinforced. Interestingly, even the subject who succeeded on the generalization trial performed at chance in a final testing session.

Taken together, the results of Experiment 1 indicate that adult tamarins perform poorly on a task in which they must search for an object that rolls behind an occluder and into a partially occluded solid barrier. These results suggest that tamarins may not employ core knowledge principles when reaching for objects. The next experiment explores the same conceptual problem—tracking the spatial location of an object moving behind an occluder—using a different measure of performance: looking. Although tamarins fail to search for the invisibly displaced object, do they nonetheless generate appropriate expectations concerning the object's location as evidenced by looking longer when it appears in a physically impossible location?

EXPERIMENT 2: SOLIDITY EXPECTANCY VIOLATION STUDY

Method

Subjects. We tested 14 tamarins (see Table 1). Nine of these subjects had also participated in Experiment 1. Again, the order in which subjects received the two experiments was counterbalanced across subjects.

Apparatus. We presented subjects with an event in which an occluded marshmallow moved along the stage and into a barrier (see Figure 2). We used the same stage, barrier, and occluding screen as in Experiment 1. In this experiment, however, the occluding screen was equipped with a secret panel in the back. This panel was used to catch the marshmallow and allowed the experimenter to covertly manipulate the final location of the rolled marshmallow. As in the first experiment, subjects were tested inside their transport boxes. Subjects were placed inside their transport box on a table approximately 36 in. from the apparatus. To make the food object equally salient from this distance, we used a larger regular-sized marshmallow as the rolling object. A video camera positioned above and to the side of the stage recorded the subject's looking behavior throughout the session. The camera did not, however, record the actions of the marshmallow on the stage; consequently, these videotapes could be scored blind to the experimental condition.

Procedure. We mimicked the design of Santos and Hauser's (2002) rhesus experiment. Subjects were presented with two familiarization trials followed by two test trials. The familiarization trials were intended to present the subjects with the two different outcomes they would see in the test trials. In the near barrier familiarization, the experimenter showed subjects the empty stage with the barrier

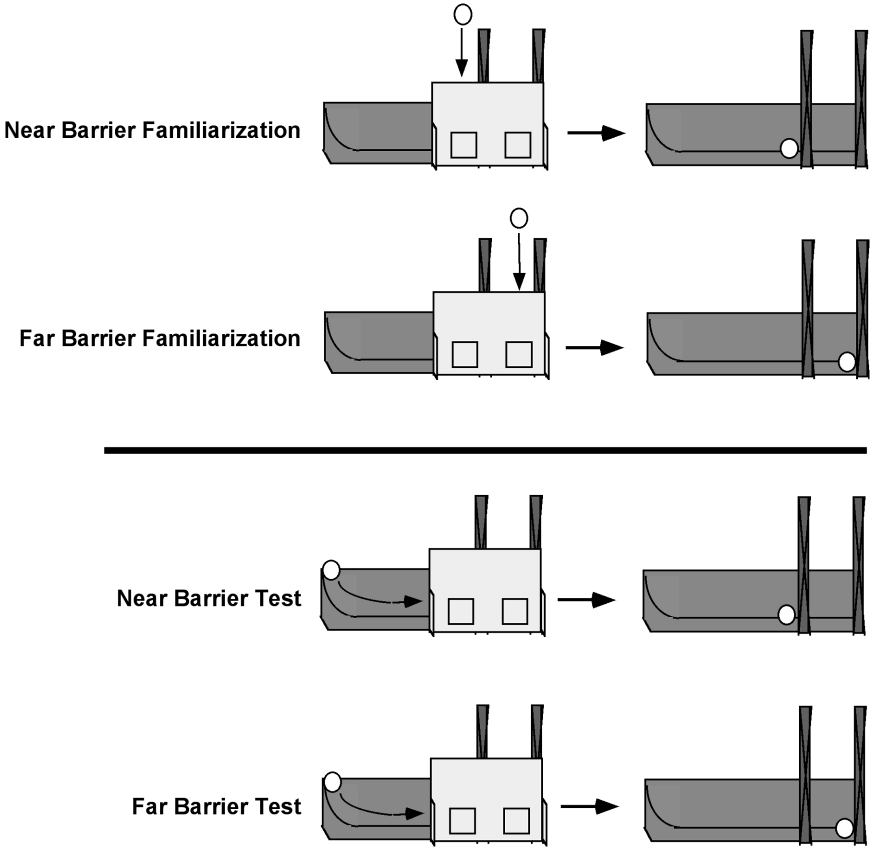

FIGURE 2 A depiction of the familiarization and test conditions used in Experiment 2. On familiarization trials, subjects were first shown the empty stage with the barrier in place. They then watched as the occluder was added, and then as the marshmallow was dropped onto the stage. Then the occluder was lifted to reveal the marshmallow in either the near or far position. On test trials, subjects were first shown the empty stage with the barrier in place. They then watched as the occluder was added, and then as the marshmallow rolled behind the occluder and into the barriers. Then the occluder was lifted to reveal the marshmallow in either the near or far position.

in place, making clear that the barrier extended all the way to the back of the stage by touching the solid barrier with her hand. The experimenter then placed the occluding screen on the stage. After the screen was in place, she lowered the marshmallow on the stage behind the screen and to the left of the red barrier. She then lifted the screen to reveal the marshmallow resting on the floor of the stage just to the left of the red barrier. She then called “Start” and allowed the subject’s looking to be recorded for the next 10 sec. The second familiarization trial, the far barrier familiarization, occurred in the same way as the near barrier familiarization except that the experimenter placed the marshmallow down on the right side of the apparatus, between the barrier and the end of the stage. After placing the marshmallow down, the experimenter again called “Start” and recorded the subject’s looking time for the next 10 sec. The order of the two familiarization trials was counterbalanced across subjects.

After completing both familiarization trials, each subject received two test trials in a counterbalanced order. In the near barrier test, the experimenter showed subjects the empty stage with the barrier in place. The experimenter then placed the occluding screen down, concealing the stage; at the same time, and out of the subject’s view, the experimenter placed a marshmallow behind the screen to the left of the red barrier. Once the screen was in place, the experimenter showed the subject a marshmallow, placed it on the far left end of the ramp, and rolled it along the stage and behind the occluding screen; thus, the marshmallow appeared to roll behind the occluding screen. In reality, however, the marshmallow rolled onto the secret panel behind the occluding screen. The experimenter then lifted the screen, called “Start”, and recorded the subject’s looking for the next 10 sec toward the stage as a marshmallow was revealed on the floor just to the left of the red barrier. Because the barrier physically blocked the trajectory of the rolling marshmallow, this was the correct final location.

The far barrier test was similar to the near barrier test except for a few differences. Specifically, after putting the occluder in place, the experimenter then placed, out of the subject’s view, a marshmallow behind the screen to the right of the red barrier; consequently, when the experimenter raised the occluder, the subject saw a marshmallow resting on the floor of the stage just to the right of the red barrier. This is a physically impossible outcome given the trajectory of the marshmallow and the location of the barrier. The experimenter called “Start” as soon as the occluder was raised, and then recorded looking time for the next 10 sec.

Videotape scoring. Videotapes were acquired onto a Macintosh G3 as digital video files using iMovie software. The files were then analyzed using Adobe Premiere. A single experimenter, blind to experimental condition, coded subject looking during the 10-sec period after the experimenter called “Start.” A look referred to a period when the subject’s head was facing the apparatus. Interobserver reliability for 10 trials was high ($r = .92$).

Results

We first explored subjects’ duration of looking on the familiarization trials. There was no significant difference between subjects’ looking on the near barrier and far barrier familiarizations, $t(13) = 0.96$, $p = .36$ (two-tailed). We then examined looking times across the test conditions. Here, we found a significant main effect of test condition, $t(13) = 2.24$, $p = .04$ (two-tailed). Subjects looked longer at the unexpected far barrier test trial (3.56 sec) than the expected near barrier test trial (2.81 sec). Nonparametric Wilcoxon signed rank tests confirmed this pattern ($Z = 2.01$, $p < .05$).

We next explored the role of prior experience, comparing subjects previously tested in Experiment 1 with naive subjects. Both previously tested and naive subjects showed the predicted pattern of performance.[2] Seven of the 9 subjects tested in Experiment 1 showed the predicted pattern of performance (Wilcoxon signed rank, $Z = 1.84$, $p = .066$). We then entered the complete sample of looking time data into a repeated measures analysis of variance (ANOVA) with group (subjects tested in Experiment 1 vs. subjects not tested in Experiment 1) as a between-subjects factor. We observed no interaction between group and looking performance, $F(1, 12) = 1.15$, $p = .30$; all subjects tended to show this looking pattern equally independently of prior test experience.

Discussion

Experiment 2 aimed to explore whether cotton-top tamarins are sensitive to the constraints of solidity when tested in an expectancy violation paradigm. In contrast to what one might have expected based on the results of Experiment 1, tamarins tested in Experiment 2 apparently set up appropriate expectations about the movement of occluded objects, thereby detecting solidity violations. Subjects demonstrated longer looking at the far barrier test trial, in which the marshmallow appeared to roll through the solid barrier, than at the near barrier test trial, in which the marshmallow appeared to stop rolling when it hit a solid barrier. These results suggest that tamarins may in fact reason about objects in accord with Spelke et al.'s (1992) core knowledge principle of solidity. Specifically, tamarins appear to understand, at some level, that one solid object cannot move through another solid object. These results add to a growing body of looking time studies (e.g., Hauser, 1998; Uller et al., 2001) suggesting that this species is able to represent and reason about the motions of hidden objects in accord with the principles of the core knowledge thesis.

There is, however, at least one potential alternative explanation for these findings. Subjects may have looked longer on the far barrier test trial not because they reasoned about the solidity of the barrier but, instead, because they always expected to see the object end up as close as possible to the first solid barrier, regardless of whether this barrier had a causal role in actually stopping the object's motion. If this account is correct, tamarins succeed not because of a rich

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[2] Note that we could not statistically analyze the role of experience due to small and unmatched sample sizes between experienced and naive tamarin groups.

understanding of solidity, but instead, because of a naive assumption about where the marshmallow will stop after it is occluded; more specifically, they expect it to stop at the near position, regardless of whether the barrier was there to impede the object's trajectory at the time it was moving.

To test this alternative account, we designed an additional looking time experiment (Experiment 3) in which we placed the barrier in the near barrier position only after the marshmallow had stopped rolling. Note that with this new configuration, there is no violation if the marshmallow rolls behind the occluder and ends up at the far barrier position. At the time the marshmallow was rolled, there is no barrier in the middle of the track to block the movement of the marshmallow, and thus it is conceivable, perhaps even expected, to find the marshmallow at the far end of the stage rather than the near end. As such, we predicted that subjects should show a different pattern of looking in Experiment 3 than in Experiment 2. Specifically, subjects should look equally at near and far barrier test events.

EXPERIMENT 3: EXPECTANCY VIOLATION STUDY CONTROL

Method

Subjects. We tested 11 tamarins (see Table 1), all of whom had previously participated in Experiment 2. An additional subject (RJ) began but did not complete experimental testing due to agitation during his testing session. Eight of the 11 subjects that had completed testing had participated in Experiment 1 as well. A full year had elapsed between the first two experiments and Experiment 3.

Procedure. We once again presented subjects with two familiarization and test trials (see Figure 3). The familiarization trials were identical to those used in Experiment 2. The test trials presented were also identical to those used in Experiment 2, with the exception of the placement of the solid barrier. In the near barrier test, the experimenter showed subjects the empty stage without the barrier in place. The experimenter then placed the occluding screen down, concealing the stage; at the same time, and out of the subject's view, the experimenter placed a marshmallow in the middle of the track (what we still referred to as the near position). Once the screen was in place, the experimenter showed the subject a marshmallow, placed it on the far left end of the ramp, and rolled it along the stage and behind the occluding screen; thus, the marshmallow appeared to roll behind the occluding screen. In reality, however, the marshmallow rolled onto the secret panel behind the occluding screen. After the marshmallow was rolled, the experimenter then placed the barrier behind the occluder and onto the stage. The experimenter then lifted the screen, called "Start", and filmed the subject's looks toward the stage revealing a marshmallow resting on the floor just to the left of the newly

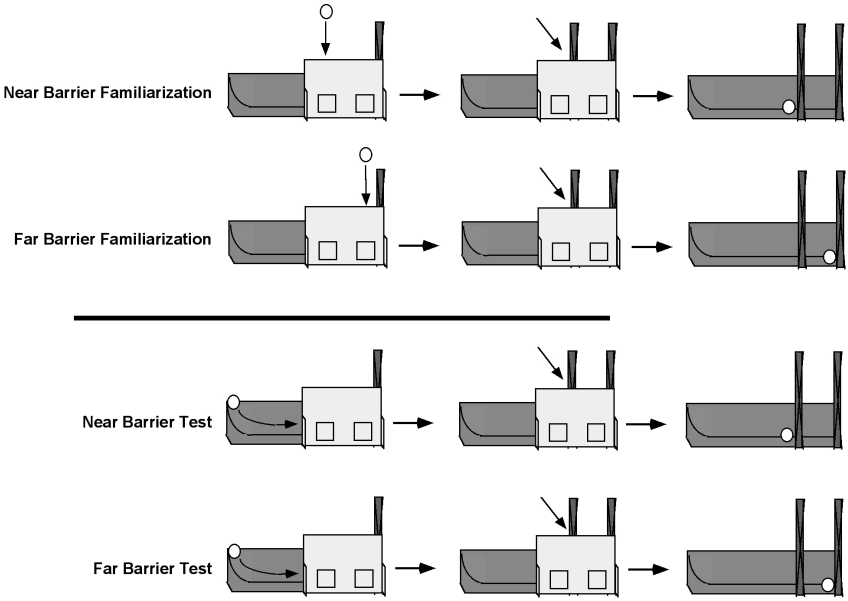

FIGURE 3 A depiction of the familiarization and test conditions used in Experiment 3.

placed barrier. Because the barrier was put in place after the marshmallow had already rolled, it could therefore not have affected its final positioning (i.e., it would not have been able to stop its trajectory when it was originally rolled). As such, this near position test trial could be considered unexpected if subjects assume that the marshmallow will continue rolling until it hits a barrier.

The far barrier test was similar to the near barrier test except for a few differences. After putting the occluder in place, the experimenter then placed, out of the subject's view, a marshmallow behind the screen to the right of the stage; consequently, when the experimenter raised the occluder, the subject saw a marshmallow resting on the floor of the stage just to the right of the red barrier. Note that because the barrier was inserted after the marshmallow was rolled, this position is an expected, physically possible outcome given the trajectory of the marshmallow and the absence of the barrier. The experimenter called "Start" as soon as the occluder was raised, and then recorded looking time for the next 10 sec.

Results

We first explored subjects' duration of looking on the familiarization trials (see Figure 4). There was no significant difference between subjects' looking on the

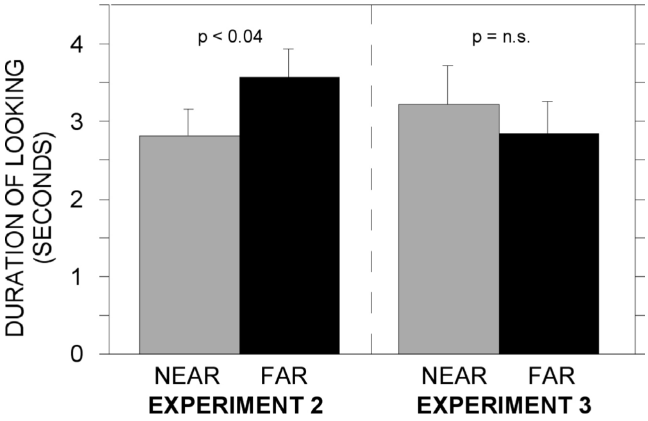

FIGURE 4 Duration of looking (measured in seconds) across different test conditions in Experiments 2 and 3.

near barrier and far barrier familiarizations, $t(10) = 0.41$, $p = .69$ (two-tailed). We then examined looking times across the test conditions. In contrast to Experiment 2, we found no main effect of test condition, $t(10) = 0.96$, $p = .36$ (two-tailed). Subjects looked equally during the near barrier test trial (3.23 sec) and the far barrier test trial (2.85 sec). We also failed to observe this effect using nonparametric tests ($Z = 0.53$, $p = .59$ (two-tailed).

We then compared subjects' performance on Experiments 2 and 3 directly using an ANOVA with experiment (1 or 2) and test event (near or far barrier) as factors. We found no effect of either experiment, $F(1, 23) = 0.09$, $p = .77$, or test trial, $F(1, 23) = 0.48$, $p = .49$ (two-tailed). We did, however, observe an interaction between experiment and test event, $F(1, 23) = 4.77$, $p = .04$ (two-tailed). This interaction demonstrates that subjects showed a different pattern of looking on near and far barrier test trials across the two experiments.

Discussion

Experiment 3 was designed to explore in greater detail the nature of our significant effects in Experiment 2. Did subjects succeed in Experiment 2 because they detected a violation of solidity, or did subjects instead succeed because they had a bias to expect the object in the near, but not the far, position. Experiment 3 distinguished between these alternatives by presenting tamarins with an event in which the marshmallow could physically wind up in the far position because no barrier impeded the marshmallow's trajectory as it moved across the stage. Here, subjects demonstrated a different pattern than they had in Experiment 2; subjects failed to demonstrate longer looking at either of the two test events, suggesting that they found both events to be equally likely. The results of Experiment 3 therefore suggest that subjects do not have a general bias to expect objects in the near position; instead, they seem to look longer at the far barrier test trial in Experiment 2 because this event is physically unexpected given the trajectory of the marshmallow.

GENERAL DISCUSSION

The studies presented here were designed to explore what cotton-top tamarins understand about solidity. In particular, our goal was to explore the nature of their understanding of solidity by using two different measures of performance: looking and reaching. The two different measures used in these experiments paint somewhat divergent pictures of what tamarins actually know about solid objects. On the one hand, the looking time results of Experiment 2 suggest that tamarins spontaneously detect violations of solidity, and thus use this principle when representing hidden objects. On the other hand, the search results of Experiment 1 suggest that most tamarins fail to use the location of a solid barrier to determine the location of an invisibly displaced marshmallow. Like rhesus monkeys tested with similar measures (Santos, 2004; Santos & Hauser, 2002), adult tamarins exhibit a dissociation between what they seem to know when tested in looking studies and what they seem to know when tested in reaching studies.

The dissociation between tamarins' performance on looking and reaching measures mirrors that observed in human infancy. Interestingly, however, the explanations that continuity theorists typically use to explain human infants' poor search performance do not apply as well to adult cotton-top tamarins. Arboreally living adult cotton-top tamarins certainly do not suffer from the motor problems that plague human infants' reaching (e.g., Diamond & Gilbert, 1989). In addition, adult (and even infant) tamarins are unlike human infants in that they are adept at means–end planning when confronted with a variety of tool-related tasks (Hauser, 1997; Hauser, Pearson, & Seelig, 2002). Lastly, there is evidence that tamarins are able to overcome problems with rule shifting that sometimes plague human infants' and children's search performance. Santos, Ericson, and Hauser (1999), for example, presented tamarins with a task in which they were required to retrieve a piece of food from inside a transparent Plexiglas box. Subjects initially perseverated with an inappropriate reaching pattern, banging into a solid Plexiglas front. But with minimal training, individuals learned to override this prepotent strategy and shift to a new, more successful reaching pattern. This result and others (see Hauser, Kralik & Botto-Mahan, 1999) suggest that tamarins can easily overcome the prepotent inhibitory biases that plague human infants (Diamond, 1990). In short, tamarins do not seem to suffer from many of the problems thought to impede infants' reaching performance; minimally, if such deficits exist they are unlikely to explain the current pattern of results.

Our observation that adult cotton-top tamarins exhibit a dissociation between looking and reaching may pose a challenge to some continuity theorists' typical interpretations of these dissociations. Comparative and developmental researchers typically employ analogous looking and reaching methods with different subject populations under the (often unstated) assumption that analogous tasks will tap into analogous cognitive abilities, even in very different subject populations. It remains an open question, however, whether the task demands that affect performance in these tasks are also analogous across populations. If task demands differ, then the cause of success or failure may also differ between species. In contrast, if task demands are comparable, then the tamarins' failures present a problem for continuity theorists. We have argued that the usual explanations for infants' poor reaching performance—motor problems, prepotent response biases, poor means–end planning, and rule-shifting difficulties—cannot completely explain tamarins' search failures and that another explanation for tamarins' poor reaching performance is required.

There is, however, at least one slightly different account of our pattern of results, one that would fit with the cognitive load theory advocated by Keen, Berthier, and their colleagues (see Berger, 2004; Berthier et al., 2001; Boudreau & Bushnell, 2000; Keen et al., 2003). Under this account, subjects succeed in our looking study but fail in our search task because these methodologies pose different demands on subjects in terms of physical reasoning. The search task used in Experiment 1 required tamarins to predict exactly how far the marshmallow would move behind the occluder, and then to use this information to plan a correct search. Our looking task, in contrast, required subjects to simply judge post hoc whether the marshmallow could have landed in one of two particular points relative to the barrier. Subjects therefore may have succeeded in the looking task not because this type of task is inherently easier than a search task, but instead because our particular looking measure did not require subjects to reason about exactly how far the marshmallow rolled behind the occluder. The results of Experiment 3 give some support for this interpretation; when there was no barrier blocking the marshmallow's trajectory, subjects' looking times were consistent with the interpretation that both outcomes are possible or expected. It is possible that an adult human tested on this task may have performed differently, perhaps generating the expectation that the marshmallow would wind up in the far position precisely because no impediment blocked its path. It would therefore be of interest to test tamarins using looking and reaching versions of a solidity task that required subjects to make more exact predictions about the final position of a rolling object, perhaps one that involved more than two final positions (see Berthier et al., 2001, for this type of task). Future work could therefore profit from the specific physical demands of looking and reaching tasks to better explore which physical reasoning components tend to generate these particular dissociations.

Another factor complicating the pattern of dissociation observed here is the question of its specificity. The looking–reaching dissociation we have observed in primates seems limited to only some domains of physical reasoning. In particular, we have observed looking–reaching dissociations when primate subjects reason about mechanical interactions—problems like solidity (this article; Hauser, 2001; Santos, 2004; Santos & Hauser, 2002), containment (Hauser, in preparation; Hauser et al., 2001), and contact (Santos et al., in preparation)—but not when they reason about occluded objects that do not undergo mechanical interactions. For example, when adult rhesus macaques are tested on their knowledge of numerosity, the pattern of results is largely the same across looking and reaching methods (Hauser & Carey, 2003; Hauser, Carey, & Hauser, 2000; Hauser et al., 1996; Santos, Spaepen, & Hauser, 2002; Sulkowski & Hauser, 2000); the same pattern emerges for tests involving the identification of particular individuals across motion and occlusion (Santos & Hauser, 2002; Uller et al., 1997). The domain specificity of these effects in primates also holds for human infants. For example, 12-month-old infants tended not to show classic toddler-age search failures (e.g., Hood et al., 2000) when tested in search tasks involving problems of enumeration and individuation (Feigenson & Carey, 2003; Feigenson, Carey, & Hauser, 2002; Van de Walle, Carey, & Prevor, 2000). Together, these findings raise the possibility that the looking–reaching dissociation observed here may not reflect a domain-general pattern in tamarin search performance; instead, the task demands that impede tamarins' search performance in this study might be specific to particular domains of knowledge—in this case, the domain of object mechanics.

The question now facing developmental and comparative researchers is why we seem to observe looking–reaching dissociations only in select domains of knowledge and what this specificity implies about the nature of the representations underlying performance in different tasks. There are at least two accounts of this pattern of findings. The first is that mechanical and nonmechanical tasks place different demands on subjects' physical reasoning capacities, with mechanical interactions simply requiring more processing than nonmechanical tasks (see Keen et al., 2003). We, in contrast, have advocated a different account, speculating that domain-specific differences in looking–reaching performance can be used to reveal underlying differences in the structure of the representations subserving different domains of knowledge (cf. Hauser, 2003; Santos, 2004). If our speculation is correct, future research may be able to use looking–reaching performance dissociations as a tool to explore the structure of core knowledge. In particular, domain-specific patterns in looking–reaching performance could potentially be used to reveal domain-specific differences in the structure of different knowledge domains. To give one example, Santos (2004) argued that differences in looking–reaching performance across mechanical and nonmechanical problems might reflect interesting differences in the representations required to solve these different tasks (see Leslie, 1994; Leslie, Xu, Tremoulet, & Scholl, 1998; Scholl & Leslie, 1999, for the original version of this hypothesis). More specifically, she reviewed data that infants and primates perform better on object search tasks involving nonmechanical problems (e.g., number, individuation) than those involving mechanical problems (e.g., solidity, collision) and used this pattern to argue for a dissociation among spatiotemporal knowledge, the representations that subserve number tasks; and mechanical knowledge, the representations that subserve tasks involving collision, support, and solidity. Using a similar logic, researchers may be able to use similarities and differences in patterns of performance to tease apart subtle differences in both the structure and development of different types of knowledge (e.g., mechanical vs. spatiotemporal, etc.).

It is unlikely that the data on nonhuman primates will solve the enigma of the infants' looking–reaching dissociations. One of our goals in these studies, however, was to reveal how work with nonhuman primates can provide a new test bed for exploring hypotheses about the nature of infants' early object representations. In particular, we believe that the findings presented here and elsewhere will constrain developmental hypotheses about the nature of looking–reaching dissociations, and may also provide insight into the organization and structure of core knowledge more generally.

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