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A Non-Human Primate's Understanding of Solidity: Dissociations Between Seeing and Acting

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Abstract

Studies often reveal a dissociation between what infants know as revealed by action and what they know as revealed by perception. We explored whether non-human primates exhibit a similar dissociation, focusing on what rhesus macaques know about solidity. In a series of search experiments, Hauser (2001) found that rhesus do not possess a complete understanding of solidity, searching below a solid shelf for an invisibly displaced object. In the present experiments, we explored how rhesus would perform in expectancy violation versions of the same tasks. Subjects looked longer when an apple appeared to fall through a solid shelf and when it appeared to roll through a solid barrier. These results suggest that macaques have some understanding of solidity when tested using looking paradigms even though they do not appear to use this knowledge when searching for food. We speculate that this dissociation is similar to that demonstrated in human development.

As psychologists, we commonly assume that organisms use their knowledge of the visual world to guide their actions. Recent work using perceptual tasks such as the expectancy violation procedure suggests, however, that infants have some knowledge of the objects in their environment even before they possess the capacity to act on them (see Spelke, 1994). The logic of the expectancy violation paradigm is that individuals will look longer at an event that is inconsistent with their expectations about the world than at a more consistent control event. Using looking as an indicator of knowledge, researchers have found that infants know that hidden objects continue to exist behind occluders, that objects move in continuous spatiotemporal paths, and that two objects cannot pass through one another (Baillargeon, 1995; Leslie, 1994; Spelke, 1994).

Given that infants possess some understanding of the permanency of objects when tested with expectancy violation procedures, why do they perform so poorly when searching for hidden objects (Piaget, 1954; Diamond, 1991; Munakata, McClelland, Johnson & Siegler, 1997)? Developmental psychologists have suggested that infants' reaching problems arise because they lack the capacity to inhibit prepotent response biases (Diamond, 1991), to plan means–end motor sequences (Baillargeon, Graber, DeVos & Black, 1990; Hood & Willatts, 1986) or to form representations detailed enough to support action (Munakata *et al.*, 1997).

Although these researchers provide compelling explanations for infants' failures on reaching tasks, some recent experiments with toddlers suggest that there may be more to the dissociation between infants' looking and searching than previously thought. Hood, Carey and Prasada (2000) examined whether or not 2-year-old children used the principle of solidity when reasoning about the location of a falling object. Previously, Spelke, Breinlinger, Macomber and Jacobson (1992) found that 4-month-old infants look longer at an event in which a falling ball appears to land on the lower of the two solid surfaces in its path. They argued that by 4 months of age, infants understand that falling objects behave in accord with the principle of solidity, namely that falling objects can only move in an unobstructed path. Hood and his colleagues set out to test whether toddlers are able to use this same principle when searching for a falling toy. They used a stage with a solid shelf that could be occluded with a small screen. They allowed toddlers to watch as an experimenter dropped a toy behind the screen and on to the shelf. The toddlers were then asked to search for the hidden toy. Hood and colleagues reasoned that if 2-year-olds understand solidity as 4-month-old infants seem to, then they should use this principle when searching for the toy and should choose to look for the toy on top of the shelf. Surprisingly, 2-year-old children searched below the shelf for the toy, suggesting that they don't consider the solidity of the shelf when

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searching for the toy. Similarly, although 4-month-old infants looked longer at an object that appeared to roll through a solid barrier (Spelke *et al.*, 1992), 2-year-olds failed to search in the correct location for an object rolled in the direction of one or more barriers (Berthier, Deblois, Poirier, Novak & Clifton, 2000; Hood *et al.*, 2000). These two sets of studies imply that when toddlers search for objects, they do not take into account the principle of solidity, a principle that is thought to be understood by 4 months of age.

What is most puzzling about the failure of toddlers on these tasks is that the problems typically thought to disrupt reaching performance in infants have been resolved by 2 years of age. For example, although infants are thought to lack means–end problem solving capacities, 2-year-old children demonstrate success on many means–end tasks (Brown, 1990). Similarly, by 2 years of age, children readily succeed on many classic tests of inhibition (e.g. Diamond, 1991). Furthermore, infants' representations of hidden objects should be strong enough to facilitate mature searching by 2 years of age (Munakata *et al.*, 1997). If these obstacles are no longer troublesome for 2-year-olds, why aren't toddlers able to solve searching tasks?

Although developmental psychologists have yet to answer these questions, recent work on adult non-human primates suggests that such search errors may not be unique to the developing human infant (Hood, Hauser, Anderson & Santos, 1999; Hauser, 2001; Hauser, Williams, Kralik & Moskovitz, 2001). For example, Hauser (2001) tested free-ranging rhesus macaques (*Macaca mulatta*) on a search experiment similar to the one Hood and colleagues (2000) used to test human toddlers. In these single trial experiments, an experimenter presented subjects with a table-like apparatus with one opaque box on top of the table and one on the ground directly below it. After occluding the table with an opaque screen, the experimenter dropped an apple slice directly above the two hidden boxes. The screen was removed and the subject was allowed to search one of the two boxes. Like toddlers, rhesus macaques failed to predict the location of the fallen apple slice. They consistently searched in the incorrect box under the table despite the fact that the table clearly impeded the trajectory of the apple slice. Unlike toddlers, however, rhesus macaques were successful on a rolling version of this task. In this condition, an experimenter presented two linearly arranged boxes each of which was open on one side. He then occluded both boxes with an opaque screen, rolled a plum behind the screen and into one of the boxes, removed the screen, and allowed the subject to approach and search one of the two boxes. Rhesus correctly searched for the plum in the near box.

These results suggest that adult rhesus lack a complete understanding of the principle of solidity, at least when tested using a searching paradigm. The results nevertheless leave open the question of how rhesus would perform on a looking version of the same task. It is possible that adult rhesus truly lack an understanding of solidity and will show similar errors when tested with a looking version of these tasks. Alternatively, adult rhesus may demonstrate the same dissociation as human infants, forming correct expectations about where a solid object will land in a looking time experiment even though they are unable to accurately search for a fallen object in a search task.

We decided to directly examine the possibility of a dissociation between looking and searching in non-human primates by testing rhesus monkeys on an expectancy violation version of Hauser's (2001) searching tasks. In recent years, Hauser and colleagues have successfully adapted the expectancy violation paradigm for work with captive and wild non-human primates (Hauser & Carey, 1998). The design of our expectancy violation experiments mimicked those of Spelke *et al.*'s (1992) infant experiments.

Experiment 1

Methods

Subjects

We tested 23 adult rhesus macaques living on the island of Cayo Santiago, Puerto Rico (Rawlins & Kessler, 1987). The population consists of eleven social groups totaling approximately 1100 individuals. Subjects are well habituated to human observers and can be identified using ear notches and chest tattoos. The experiments discussed here were conducted approximately one year after Hauser's (2001) search studies were completed. We tested 21 additional subjects whose data could not be used due to subject inattention and/or experimental error.

Apparatus

We presented subjects with a display in which half an apple was dropped on to a foamcore stage (Figure 1). The stage consisted of two yellow sides (20 × 30 cm), a yellow back (30 × 20 cm), a green floor (60 × 20 cm), and a green shelf identical in size to the floor positioned 10 cm above the bottom. A red screen (30 × 18 cm) could be inserted in front of the apparatus such that the middle portion of the apparatus was covered. This screen was equipped with a secret pouch that could be used to catch the falling apple. The back of the apparatus was equipped with two doors through which another apple could be surreptitiously inserted and removed.

Procedure

Subjects were chosen opportunistically by finding individuals who were alone and in a seated, resting position. Two experimenters ran each session. The first, kneeling approximately 1.5 m in front of the subject, performed all the actions on the apparatus and timed the session. The second experimenter, who stood directly behind the first, videotaped the session. The second experimenter positioned the camera such that the apparatus was not in view; therefore, we were able to score videotapes blind to the experimental condition being carried out.

Each subject was presented with two familiarization trials followed by two test trials (Figure 1). We designed the familiarization trials to introduce the subjects to the outcomes that they would witness in the test trials. In the *top shelf familiarization*, the experimenter presented the apparatus to the subject with the screen in place. Once the subject was looking, the experimenter removed the screen to reveal the apple resting on the top shelf. After the screen was removed, the experimenter called 'now' and the subject's looking was recorded for the next ten seconds. The *bottom shelf familiarization* began when the experimenter presented the apparatus to the subject with the screen in place. Once the subject was looking, the experimenter removed the screen to reveal the apple resting on the floor of the apparatus. The order of these two familiarization trials was counterbalanced across subjects.

Each test trial began when the experimenter removed the screen and drew the subject's attention to the shelf. To do this, the experimenter banged on the shelf three times. After making sure that the subject had seen the shelf, the experimenter replaced the screen. Once the screen was in place, the experimenter took the apple from her waist pouch, held it 20 cm over the stage, and dropped it behind the screen and into the secret pouch. The experimenter then surreptitiously added an identical apple through the secret doors on the back of the stage. The experimenter then removed the screen to reveal one of two test events. In the *top shelf test condition*, subjects see the apple resting on the top shelf, an expected outcome given that the apple could not penetrate the shelf. In the *bottom shelf test condition*, subjects see the apple resting on the floor of the stage, an unexpected outcome given the trajectory of the apple and the location of the solid shelf. The order of these two test trials was counterbalanced across subjects.

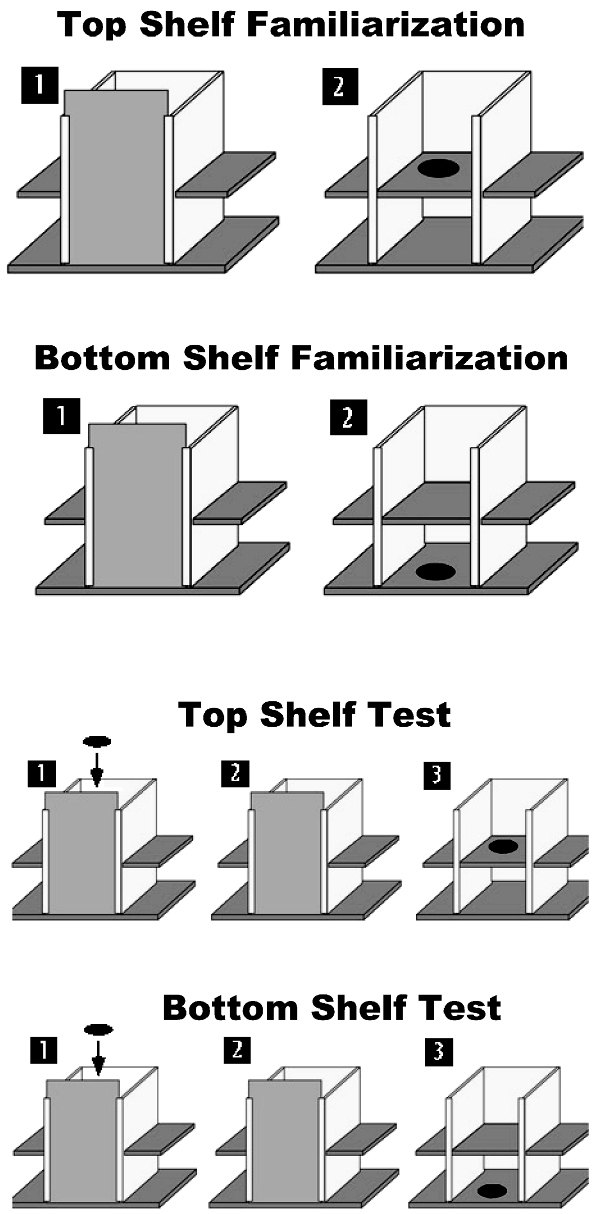

Figure 1 *A depiction of the familiarization and test conditions used in Experiment 1.*

Videotape scoring

Videotapes were recorded on to a Macintosh G3 and were analyzed with Adobe Premiere 5.1 software. A single experimenter coded subject looking during each frame (30 frames = 1 second) of the 10-second looking period that followed each trial. A look for the purposes of the experiment referred to a period of 3 frames or longer during which the subject's head was oriented towards the display. One-quarter of all trials were scored by an additional coder (interobserver reliability: $r = 0.91$).

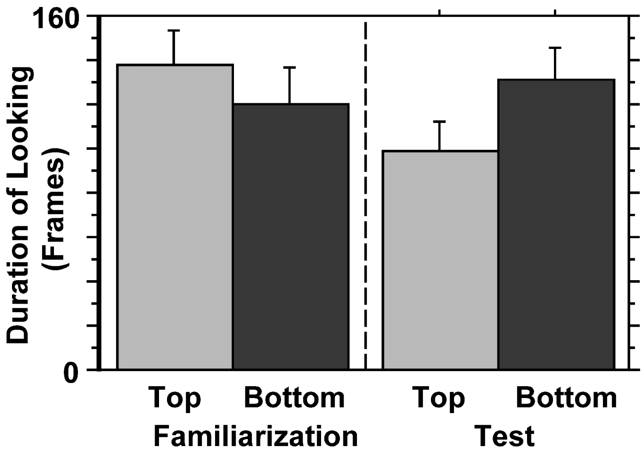

Figure 2 *Mean (+/– SE) duration of looking across familiarization and test conditions in Experiment 1.*

Results

There was no difference in duration of looking on the two familiarization conditions ($t(22) = 0.90$, $p = 0.38$; Figure 2). However, subjects looked significantly longer at the bottom shelf test condition than the top shelf test condition ($t(22) = 2.27$, $p = 0.03$). We confirmed this result using non-parametric tests as well. Fourteen out of the 23 subjects looked longer at the bottom shelf test trial than at the top shelf test trial (Wilcoxon signed rank: $Z = 1.98$, $p = 0.048$).

Discussion

Like 4-month-old infants, rhesus macaques look longer at an event in which an apple appears to fall through a solid shelf than a control event in which it appears to land on top of the shelf. This result suggests that rhesus macaques detect that a violation of solidity has occurred and thus, use the principle of solidity when observing falling objects. This result stands in contrast to what one might expect given Hauser's (2001) search results, in which subjects failed to predict the location of a falling object behind an occluder. Although subjects seem to detect violations associated with visually occluded falling objects, they seem unable to use their knowledge of these physical principles in order to find food.

To further explore the distinction between looking and searching, we tested subjects' understanding of rolling events with an expectancy violation paradigm. As in Experiment 1, we used an expectancy violation version of Hauser's (2001) search task. Given that rhesus correctly search for an invisibly displaced object along the horizontal plane, we expected the results from our looking time measures to corroborate such knowledge. Specifically, we predicted that rhesus would look longer when the ball appeared to roll past a solid wall than when it appeared to roll into a solid wall.

Experiment 2

Methods

Subjects

Subjects were 18 rhesus macaques from the Cayo Santiago population who had not been previously tested in Experiment 1. Twenty-four additional subjects were tested, but their data could not be used due to subject inattention and/or experimenter error.

Apparatus

We presented subjects with an event in which an experimenter rolled an orange on to a foamcore stage (Figure 3). The stage consisted of a white floor and back (each 63 × 10 cm), a white left side panel (15 × 10 cm), a longer, black right side panel (15 × 15 cm), and a black barrier equal in size to the black side panel which was placed 10 cm from the edge of the stage. The floor of the stage was slightly inclined such that an orange placed on the left side of the stage would roll towards the right hand side of the stage. A red screen (18 × 8 cm) could be inserted in front of the apparatus such that the right portion of the apparatus was covered. The back of the apparatus was equipped with two doors through which oranges could be surreptitiously inserted and removed.

Procedure

As in Experiment 1, we presented each subject with two familiarization trials followed by two test trials (Figure 3). In the *near wall familiarization*, the experimenter presented the apparatus to the subject with the screen in place. Once the subject was looking, the experimenter placed an orange on the stage behind the screen. She then lifted the screen to reveal the orange resting on the floor of the stage just to the left of the barrier. The *far wall familiarization* began when the experimenter showed the apparatus to the subject with the screen in place. The experimenter then placed the orange on the stage behind the screen. She then lifted the screen to reveal the orange resting on the floor of the stage just to the left of the right side wall. Each test trial began when the experimenter removed the screen and drew the subject's attention to the barrier. The experimenter then replaced the screen, took the orange from her waist pouch, placed

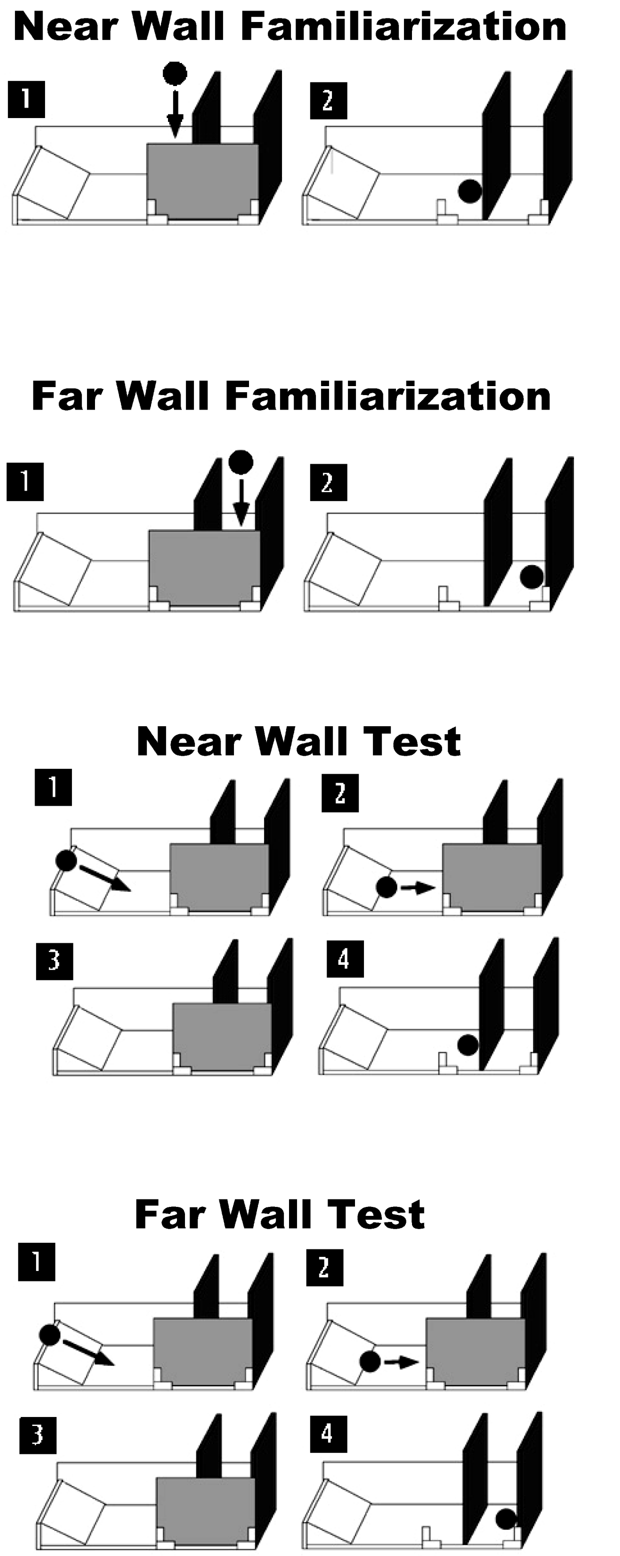

Figure 3 *A depiction of the familiarization and test conditions used in Experiment 2.*

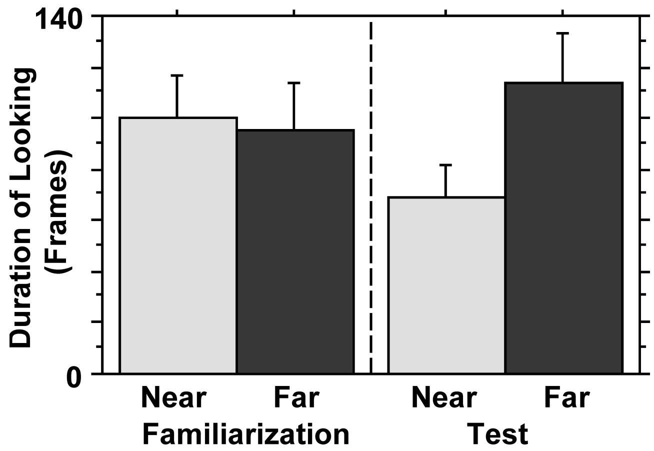

Figure 4 *Mean (+/– SE) duration of looking across familiarization and test conditions in Experiment 2.*

it at the leftmost part of the stage, and released it. The orange then rolled down the incline and behind the screen. The experimenter then surreptitiously removed this orange and replaced it with an identical orange through one of the two secret doors on the back of the stage. The experimenter then removed the screen to reveal one of two test events. In the *near wall test condition*, the orange was stationary and just to the left of the barrier; this is an expected outcome since the barrier should have blocked the trajectory of the orange. In the *far wall test condition*, the screen was removed to reveal the orange stationary and just to the left of the right side wall. This outcome represents a violation of where one might expect the orange to roll since the solid barrier should have blocked the orange from moving all the way to the end of the stage.

Results

There was no difference between the two familiarization conditions ($t(17) = 0.25$, $p = 0.80$, Figure 4). Subjects looked equally at the near and far wall familiarization trials. However, subjects looked significantly longer at the far wall test condition than the near wall test condition ($t(17) = 2.84$, $p = 0.01$). We observed this result using non-parametric tests as well. Fourteen out of the 18 subjects looked longer at the far wall test trial than the near wall test trial ($Z = 2.66$, $p = 0.008$).

Discussion

Adult rhesus macaques, like 4-month-old human infants, look longer at an event in which an object appears to move through a solid barrier than at an event in which the object stops at a solid barrier. As in Experiment 1, they seem to expect that objects cannot travel through solid barriers. Taken together, these results suggest that adult macaques understand that a solid object cannot pass through another solid object. These findings stand in contrast to what one might expect based on the results of Hauser's (2001) searching experiments conducted with the same population. In these studies, rhesus apparently failed to use the principle of solidity when searching for an apple that had been dropped behind an occluder and on to a solid shelf. The results reported here therefore suggest a dissociation between rhesus macaques' performance in looking and searching versions of the same task, a dissociation that is similar to the one seen in human development.

These results with rhesus macaques complement a growing body of work suggesting that in certain situations non-human primates, like human infants, exhibit dissociations between performance on looking and action tasks. Cotton-top tamarin monkeys, for example, incorrectly search for an object dropped inside an opaque tube (Hood *et al.*, 1999) or on to an occluded ramp (Hauser *et al.*, 2001); nonetheless, the same individuals look longer at an impossible event in which an object dropped into a tube or on to a ramp emerges in an incorrect location (Hauser, in preparation). Tamarins also look longer at violations of the contact principle (Leslie, 1994), but do not use information about contact when searching for moving objects (Santos and Hauser, in preparation).

Despite the above examples of a looking/action dissociation in non-human primates, there are some situations where looking and action measures actually *converge*. Unlike toddlers, rhesus macaques successfully locate an object that has rolled into one of two solid boxes (Hauser, 2001); this searching result converges with the looking results we report here in Experiment 2. In a slightly different domain, both rhesus macaques and cotton-top tamarins correctly distinguish between small numbers of objects in a looking task (Hauser, MacNeilage & Ware, 1996; Uller, Hauser & Carey, 2001) and a variety of searching tasks (Hauser, Carey & Hauser, 2000; Santos, Sulkowski, Spaepen & Hauser, in press). Similarly, rhesus macaques successfully individuate objects when tested in looking (Munakata, Santos, Spelke, Hauser & O'Reilly, 2001) and searching tasks (Santos *et al.*, in press). Developmental psychologists have also observed this convergence of looking and action measures on number and individuation tasks. Infants successfully discriminate small numbers of objects in a range of different looking tasks (Wynn, 1998) as well as a recent search experiment (Feigenson, Carey & Hauser, in press). Similarly, infants show similar performance on looking and reaching versions of individuation tasks (Van de Walle, Carey & Prevor, 2000; Xu & Carey, 1996).

The pattern of dissociations observed in non-human primates complicates the interpretation of similar dissociations seen in human development. First, the dissociation between performance on looking and searching measures can no longer be considered an exclusively human phenomenon; as reviewed above, two different non-human primate species – rhesus macaques and cotton-top tamarins – have now demonstrated this dissociation in a number of different tasks. In addition, this dissociation can no longer be considered simply a developmental occurrence. The experiments demonstrating looking/action dissociations in non-human primates have all been performed on *adult* animals, all of whom have had a wealth of experience acting on objects. Third, our data suggest that looking/searching dissociations are not ubiquitous; they may in fact rely heavily on the specific knowledge system being investigated (e.g. gravity problems versus number problems).

Evidence of this dissociation in non-human primates also challenges many of the explanations currently put forth to explain dissociations between looking and action in human infants. One explanation, which is often put forth to account for infants' failures on similar types of search tasks (e.g. Baillargeon *et al.*, 1990), is that subjects have general problems with means–end task performance. This possibility seems unlikely given the wealth of data demonstrating that macaques and tamarins can succeed at means–end tasks (e.g. Hauser, 1997). Another suggestion is that looking/action dissociations result from difficulties with inhibition andprepotent response biases. Numerous studies, however, beginning with Diamond's (1991) classic object retrieval task, suggest that adult rhesus are readily able to inhibit their actions. In short, many of the explanations put forth to explain infants' reaching failures simply do not apply to adult non-human primates. As such, our results demand that comparative and developmental researchers take a more critical look at the differences between performance in looking and searching experiments in order to determine the root of this striking dissociation.

Although the experiments presented here clearly do not quiet the controversy surrounding the discrepancies between infant looking and reaching, we hope that our results will contribute to a more comprehensive investigation of physical knowledge across primates. This approach, which would compare across species, across tasks and across development, should provide a more thorough understanding of the principles governing looking and action across development and may provide clues to resolving these unsettled issues in the field of cognitive development.

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