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REPORT

A nonhuman primate's expectations about object motion and destination: The importance of self-propelled movement and animacy

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Abstract

Human infants have considerable understanding of why objects move and what causes them to take one trajectory over another. Here, we explore the possibility that this capacity is shared with other nonhumans and present results from preferential looking time tests with a New World monkey, the cotton-top tamarin. Experiments examined whether individuals form different expectations about an object's potential capacity to change locations. Test objects were: 1) self-propelled, moving, animate; 2) self-propelled, moving, inanimate; 3) non-self-propelled, moving due to an external agent, inanimate; 4) non-self-propelled, motionless, inanimate. When category 1 objects, either a live mouse or frog, emerged from behind an occluder in a novel location, this did not affect looking time; subjects appeared to expect such changes. In contrast, when the other objects emerged in a novel location following occlusion from view, subjects looked longer than when the object emerged in the location seen prior to occlusion; such locational changes were apparently not expected. Some feature other than self-propelled motion accounts for the tamarins' looking time responses and at least one candidate feature is whether the object is animate or inanimate.

When an object moves, we pick up, quite automatically, considerable information about its constituent properties as well as the cause of its motion. Developmental studies have demonstrated that at a young age (2–10 mos), human infants know a considerable amount about objects, including: (i) objects that move out of sight continue to exist (i.e., an early form of object permanence), (ii) two solid objects cannot occupy the same space at the same time, (iii) moving objects follow a spatiotemporally continuous path unless obstructed, (iv) to avoid falling, an object must be supported by another object, (v) large objects can cause small objects to move further than the reverse, and (vi) stationary objects move if and only if they are contacted by another moving object or have an internal mechanism that permits self-propelled motion (Baillargeon, 1994; Baillargeon and DeVos, 1991; Gelman, 1990; Leslie, 1982, 1994; Leslie and Keeble, 1987; Premack, 1990; Premack and Dasser, 1991; Spelke 1994; Spelke *et al.*, 1995a,b). Although these data cannot exclude the possibility that experience within the first two months of life shapes the infant's object concept, they do suggest that human infants are born with some innate principles for understanding objects.

In this paper, I explore the following general problem: Is the domain-specific knowledge that humans exhibit with respect to objects unique to our species or is it shared with other species? The specific problem is: What expectations do nonhuman animals form with respect to moving objects and their potential destinations?

To address these questions, a preferential looking time procedure was used with a small New World monkey, the cotton-top tamarin (*Saguinus oedipus oedipus*). The preferential looking time procedure (see Spelke, 1985) has been used extensively by developmental psychologists to assess cognitive abilities in prelinguistic human infants, and recently, has been employed with nonhuman primates to explore comparable skills (Hauser *et al.*, 1996; Hauser and Carey, in

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press; Santos, 1997; Uller, 1997). The logic underlying this procedure is that if an observed event violates knowledge from a given domain, then the observer should show greater interest in the event as evidenced by his or her heightened attention to it, relative to an event that does not violate expectancy. The power of the technique is that it provides a tool to investigate cognitive abilities across species in the absence of training by reinforcement or punishment.

General methods

Participants were captive cotton-top tamarins living in social groups. Tamarins, a New World monkey species, diverged from the human lineage between 40–60 million years ago. In the wild, they are natives to Colombia's rainforests, inhabiting the upper canopy. They tend to live in small family groups, typically a breeding pair and their offspring.

The colony at Harvard's Primate Cognitive Neuroscience Lab consists of 13 individuals, all adults; individuals were born in captivity at the New England Regional Primate Center, Southborough, MA. Each group's enclosure consists of branches, a nest box, a few ropes, ladders, perching platforms, and a water bottle. Sample sizes for each experimental condition are listed in Table 1. All subjects have been tested in other experiments, using both similar and different procedures (Hauser *et al.*, 1995; Hauser, 1997; Hauser and Carey, in press; Santos, 1997; Uller, 1997). The tamarins have daily contact with humans during experimentation, but are never handled; they move freely from their home cage to test cages located in different rooms. All tamarins have seen and/or handled inanimate objects (e.g., tools constructed out of cloth and hard clay; Hauser, 1997), and have seen, but not handled a few animate objects including humans, mice and pigeons.

The test apparatus consisted of two identical chambers separated by an opaque partition; the front panel of each chamber (facing the subject) was clear plexiglass and all other sides were opaque (Figure 1, top). The partition had a rectangular opening, allowing objects to move between each chamber; the tamarins never observed test objects moving from one chamber to the other. Subjects were presented with all objects and were allowed to look, but not touch them. They were then familiarized with the test apparatus by entering it and exploring each chamber; we also showed them a hand moving from one chamber to the other by way of the opening in the partition.

Seven different objects were used as test stimuli (see Table 1). Each object could be characterized on the basis of three critical dimensions: (I) self-propelled vs. non-self-propelled (i.e., required an external agent to move); (ii) moving vs. motionless; (iii) animate vs. inanimate. Each subject received four familiarization trials and two test trials; trials within sessions were counterbalanced for order across subjects. Familiarizations were designed to provide subjects with experience of all objects and events to be used in the test trials. In test trials, subjects watched an object placed in one chamber. Both chambers were then momentarily occluded from the subject's view, and then the occluder was removed, revealing the test object in either the same (Test-1) or opposite (Test-2) chamber. In Test-2, therefore, the tamarins should infer that the object has moved based on its own given the difference in its original and then terminal position.

Looking time was scored from digitized video records. Raw video footage was acquired onto a computer using the Adobe Premiere software and Radius' VideoVision board; this system provides an acquisition rate of 30 frames/second. Once a trial was acquired, it was stored as a file. All trials were then scored for the total amount of time subjects spent looking at the display out of a 10 sec period. Because the video image showed little else than the subject's face, and the assigned filename provided no information on trial number or condition within a session, all trials were scored blind. For Familiarization 1 and 2, looking time was scored as soon as the object touched the floor of

Table 1 *Objects used in experiments with cotton-top tamarins.*

Object	Motion features	Animate?	Condition	No. Subjects
live mouse	self-propelled, moving	animate	A	10
live frog	self-propelled, moving	animate	F	8
froot loops	non-self-propelled, motionless	inanimate	B	10
raisin ball	non-self-propelled, moving	inanimate	C	9
clay face	self-propelled, moving	inanimate	D	9
toy mouse	self-propelled, moving	inanimate	E	5
furry monkey	self-propelled, move in place	inanimate	G	9

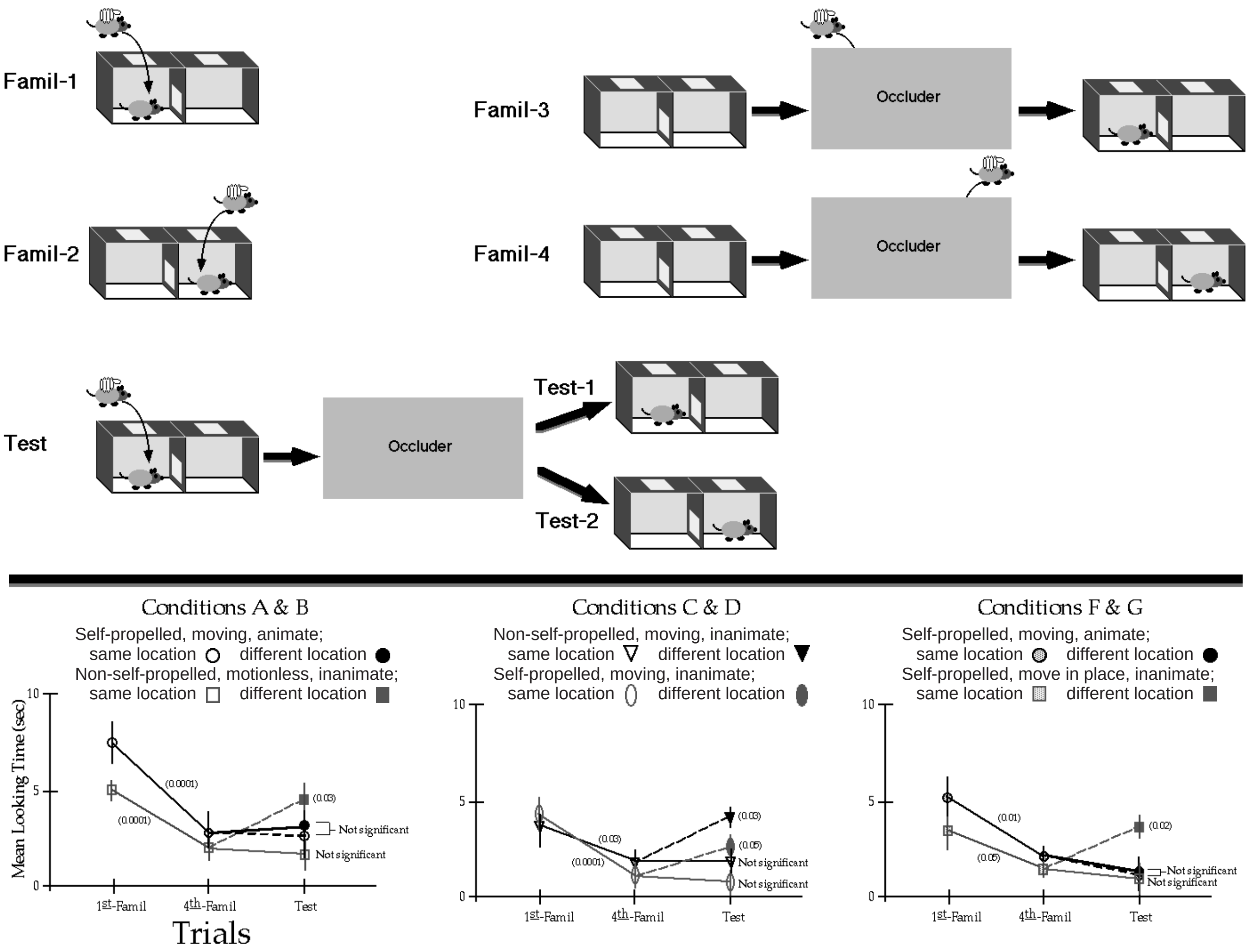

Figure 1 Top: *Apparatus and conditions for testing the tamarins' knowledge of object motion and destination; only the mouse is shown, but the procedure was identical for all other objects.*

Bottom: *Changes in mean looking time (seconds) from the first to the fourth familiarization trial, and from the fourth familiarization to the two test trials. Symbols are as follows: black rings = live mouse (animate, self-propelled); grey squares = froot loops (inanimate, non-self-propelled); black triangle = raisin ball (inanimate, non-self-propelled with motion); vertical grey ellipse = clay face (inanimate, self-propelled); black circle with stippling = tree frog (self-propelled, moving, animate); grey square with stippling = furry toy monkey (self-propelled, move in place, inanimate). Trials where the object remained in the same chamber throughout the session are indicated by solid lines and open symbols; trials where the object appeared in the opposite chamber from where it was originally placed, are indicated with dashed lines and solid symbols. Two-tailed p-levels are indicated in parentheses or labeled as 'Not significant' if values exceeded 0.05.*

the chamber. For Familiarization 3 and 4, as well as Test 1 and 2, looking time was scored as soon as the occluder was removed and the subject could see the object.

A total of 30 trials were also scored by an independent observer; a random number generator was used to sample both different conditions and subjects. Using a regression analysis, the inter-observer reliability for the duration of time spent looking was 0.96. The average difference in looking time scores between the two observers was 0.53 frames (SD = 21.8; max = 72).

Conditions A and B: methods and results

Condition A examined the tamarins' response to a live mouse (self-propelled, moving, animate) whereas condition B examined their response to a cluster of froot loop cereal (non-self-propelled, motionless, inanimate); the tamarins have seen mice and often receive froot loops as a food reward. For the froot loops to move, an external agent is required; this is not the case for the mouse. Thus, if tamarins have a concept of self-propelled objects, they should generate different expectations about the potential motion and spatial location of the mouse and froot loops – the mouse can potentially move to any location in space, whereas the froot-loop requires an agent to change locations. One subject group received tests with the mouse first and the froot loops second; a second group received the reverse testing order.

Subjects looked longer at the mouse then at the froot loops in the first familiarization, but there were no differences in looking time by the final familiarization (Figure 1, bottom). For both objects, subjects showed a highly significant decrease in looking time from the first to the fourth familiarization (**mouse:** $t = 7.26$, $df = 19$, $p < 0.0001$; **froot loops:** $t = 7.30$, $df = 19$, $p < 0.0001$). On test trials, subjects failed to show a statistically significant change in looking time to the mouse, regardless of whether they saw it on the same or different side from where it was originally placed. Note that this pattern emerged even though the mouse sometimes moved throughout the chamber during the 10 sec period and at other times moved to a side wall and remained still. Subjects failed to show a change in looking time when the froot loops appeared in the same chamber. Looking time increased significantly, however, when the froot loops appeared in a different chamber ($t = 5.19$, $df = 19$, $p < 0.03$); 8 out of 10 subjects showed this pattern.

The looking time differences obtained may have been due to motion in general, rather than self-propelled motion, or to a difference between an animate and inanimate object. In an attempt to eliminate some of the possible factors underlying the difference in looking time, five additional conditions were run, using the same experimental design.

Conditions C and D: methods and results

Condition C involved presentation of an inanimate non-self-propelled object, moved by an external force (Table 1): an experimenter rolled a yellow ball covered with raisins into one of the test chambers. In Familiarization 3 and 4, the ball was dropped from above the occluder and allowed to come to a resting position before the occluder was removed and looking time scored. In Test 1 and 2, the ball was rolled into the chamber and once it stopped moving, the occluder was put in place. Thus, when the occluder was removed, looking time was scored with the ball in a resting position. Condition D involved the presentation of a small clay face, capable of self-propelled motion due to a concealed magnet. When the clay face was placed into the chamber, it remained in a resting position for one second, then moved fluidly and with variable trajectories across trials. That is, sometimes the clay face moved throughout the chamber for the entire 10 sec period, and at other times it moved to a corner and remained still; the motion was thus comparable to that of our test mouse in Condition A. Half of the subjects received the yellow ball first and half received the clay face first.

In condition C, subjects showed (Figure 1, bottom) a significant decrease in looking time from the first to the fourth familiarization ($t = 5.88$, $df = 17$, $p < 0.03$). Mean looking time for the fourth familiarization was virtually identical to the mean response to froot loops, and not statistically different from the mean response to the mouse. Paralleling results obtained for the froot loops, subjects failed to show a statistically significant change in looking time when the raisin ball remained in the same chamber, but showed a significant increase in looking time when it appeared in the opposite chamber ($t = 5.73$, $df = 17$, $p < 0.03$); 7 out of 9 subjects showed this pattern. These results suggest that motion per se cannot account for the tamarins' expectations about object location.

Looking times in condition D (Figure 1, bottom) decreased significantly from the first to the fourth familiarization trials ($t = 7.83$, $df = 17$, $p < 0.0001$), and remained low in Test 1 when the clay face remained in the same chamber. However, in Test 2, when the clay face apparently moved from the original chamber, subjects showed a significant increase in looking time ($t = 3.46$, $df = 17$, $p < 0.05$); 7 out of 9 subjects showed this response pattern. These results suggest that self-propelled motion, of the kind exhibited, is not responsible for the looking time pattern obtained, and thus, not directly related to the tamarins' expectations in this test.

Condition E: methods and results

The mouse and clay face elicited different responses even though both moved on their own and showed variable motion from trial to trial. To zero in on which factors most significantly effect the tamarins' expectations, conditions E through G were run. The object for Condition E was a self-propelled *furry* toy mouse, moved in the same way as the clay face. Only 5 subjects completed all trials within a session; the 4 other subjects failed to look at the display on two or more of the familiarization trials and thus, the session was aborted.

Looking times decreased, as in previous conditions, from the first (mean = 4.47, SD = 1.38) to the fourth familiarization (mean = 1.27, SD = 0.89). When the toy mouse remained on the same side for Test-1, a non-significant decrease in looking time (mean = 0.93, SD = 0.67) was observed. When the toy mouse appeared to change locations in Test 2, there was a non-significant increase in looking time (mean = 2.27, SD = 1.21). However, 4 out of the 5 subjects showed a slight increase in looking time over the final familiarization trial for Test 2, whereas only one of the subjects did so for Test 1. These results suggest that the self-propelled toy mouse may be physically more similar to the live mouse than the other objects, at least with respect to the tamarins' expectations.

Results from condition E are weakened, however, by the fact that several subjects appeared to have habituated to the test display. Due to this problem, and given our incomplete understanding of the factors guiding expectations about object motion, we decided to stop our experiments for a period of four months. We assumed that a break from the test display might allow us to run additional conditions at a later date.

Conditions F and G: methods and results

When we started these conditions, three of our original subjects were ill and thus, could not be tested; a fourth subject failed to attend to the displays in the familiarization trials. We therefore ran five of the original subjects and four new subjects.

In condition F, we presented a live Indonesian tree frog and in condition G, a furry toy monkey that jiggled in place when set on a flat surface. We selected the tree frog because it was animate and self-propelled, but its pattern of movement was quite different from the mouse; rather than moving on the floor alone, the frog would often climb the walls of the chamber. The toy monkey was selected because it moved on its own, but only in place. Consequently, we predicted (see also, Premack and Premack 1994b) that the tamarins would generate similar expectations about spatial location for the frog as for the mouse. Further, although the toy monkey moved on its own, it failed to move beyond the location in which it was originally placed. Thus, we expected the tamarins to look longer when it appeared in a novel location.

Figure 1 (bottom) reveals that subjects readily habituated over the course of the four familiarization trials ($p <$ 0.05 to 0.01) in both conditions F and G. By the fourth familiarization trial, there was no statistically significant difference in looking time in response to the frog as compared with the toy monkey. For Test 1, subjects showed a non-significant decrease in looking time to both frog and toy monkey. For Test 2, subjects showed a non-significant decrease in looking time to the frog; there was no difference in looking time between Test 1 and Test 2 for the frog. In contrast, subjects showed a significant increase ($t = 4.43$, d$f = 17$, $p < 0.02$) in looking time when the toy monkey appeared to shift locations, and 7 out of 9 subjects showed this pattern. Performance by the four new subjects was comparable to the subjects tested on the earlier conditions; of the subjects failing to show an increase in looking time in Test 2 of the toy monkey condition, one was a new subject and one was an old subject.

Discussion

Under natural conditions, animals confront a wide variety of moving objects. Some objects can move on their own whereas others require an external agent to move. Though animals may respond appropriately to such objects (e.g., run away from a predator, approach a piece of fruit that has dropped from a tree and rolled next to a rock), they may not understand why such objects move or whether they have the capacity to move to a new location. Understanding such distinctions is critical, however, because domain-specific knowledge about object motion appears to provide the foundational input for the developmentally emerging theory of mind (Gergerly *et al.*, 1995; Leslie, 1994; Premack, 1990; Premack and Woodruff, 1978; Premack and Premack, 1994a,b). Although nonhuman animals may not develop a full blown theory of mind (e.g., Cheney and Seyfarth, 1990; Povinelli, 1993; Whiten, 1994), they may acquire some of the relevant building blocks (Povinelli and Eddy, 1996; Hauser and Carey, in press).

In contrast to work on nonhuman animals focusing on putatively higher level cognitive phenomena such as perspective taking, ignorance, seeing-as-knowing and self-awareness (reviews in Cheney and Seyfarth, 1990; Hauser, 1996; Povinelli and Eddy, 1996; Russon, Bard, and Parker, 1996), this study represents an attempt to explore some lower level processes. Our results suggest that cotton-top tamarins form different expectations about an object's potential capacity to move to a new location. Although we are not, at present, able to precisely specify which features are most salient in generating such expectations, some factors can be ruled out and consequently, new experiments generated.

When the object appeared in a novel location (a form of invisible displacement), the tamarins were apparently surprised (as indicated by the change in looking time) for all objects except the live mouse and tree frog, and perhaps the furry toy mouse. This pattern allows us to rule out at least one, somewhat surprising factor, as being causally related to the tamarins' expectations: self-propelled motion. One might have expected the tamarins to generate similar predictions about any self-propelled object with the potential to move to a new location. Given the fact that they did not, there are at least two candidate dimensions that may account for the pattern observed, and that can be addressed experimentally. First, though the clay face and toy mouse were self-propelled, neither had limbs. In order to move from one chamber to the other, the object must climb over the base of the partition and through the opening. If the tamarins were attending to the capacity to climb over the partition, then in the absence of limbs, such objects would have difficulty. This can be tested by using self-propelled objects with moveable limbs and other animals without limbs (e.g., snakes); although the toy monkey had limbs, it stayed in place, and thus would not be expected to change locations in the absence of some external force (Premack and Premack, 1994b). Second, the live mouse and tree frog were the only animate objects tested. Animate objects may not only move differently from inanimate objects (e.g., biological motion, breathing, eyes open), but they may be perceived to have goals. In tests of human infants, studies have demonstrated that biological motion is readily discriminated from non-biological motion, animate objects are discriminated from inanimate objects (both with and without motion cues) and even self-propelled inanimate objects can be perceived as having goals (Carey, 1985; Gelman *et al.*, 1994; Gergerly *et al.*, 1995; Premack and Premack, in press; Spelke *et al.*, 1995a). Given our tamarin results, several new tests are now possible, and some are currently under way in our lab. For example, how would the tamarins respond to seeing an anesthetized mouse or frog lying still in one chamber and then reappearing in the opposite chamber after the occluder was removed? Or, how would the tamarins respond if another tamarin sat in one chamber without food and, following removal of the occluder, failed to appear in the adjacent chamber with food? Presumably, different expectations would be formed if the adjacent chamber housed a poisonous snake? Such experiments will help us understand why tamarins form certain expectations about object motion and destination, and on a more general level, will contribute to our understanding of how domain-specific systems of knowledge evolved in our own species (Cosmides and Tooby, 1994; Hauser and Carey, in press).

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