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REPORT

Gravity biases in a non-human primate?

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Abstract

*Pre-school children expect falling objects to travel in a straight line even when there are clear physical mechanisms that deviate the object's path (Hood, 1995). The current study set out to determine whether this expectancy is limited to humans. Cotton-top tamarins (*Saguinus oedipus oedipus*), a New World monkey species, were tested on Hood's (1995) experimental task where objects are dropped down a chimney connected by an opaque tube to one of three containers. Like human children, there was a significant tendency to search in the container underneath the chimney where the food was dropped on the first trial, even though aligned chimneys and containers were never connected. These search errors suggest that there may be a gravity bias that operates when both primate species fail to understand the constraints operating on object trajectories. Unlike human children however, tamarins were generally more likely to perseverate in making errors even though repeated testing and cost incentives were used.*

Comparative studies of cognition can shed light on those mechanisms that are shared in common across species and those which are species-specific. For example, several studies have used Piaget's search paradigms to explore object permanence in non-human animals (see review by Doré & Dumas, 1987). While there is evidence that some species such as dogs can understand Stage VI object permanence (Gagnon & Doré, 1992), the research on primates is still equivocal. There appears to be a consensus that the great apes achieve Stage VI object permanence (chimpanzees: Mathieu, Bouchard, Granger & Herscovitch, 1978; Woods, Moriarty, Gardner & Gardner, 1980: gorillas: Natalie, Antinucci, Spinozzi & Poti, 1986; Redshaw, 1978), while the upper limit for monkeys may be Stage V as indicated by their failure to pass the invisible displacement task (de Blois & Novak, 1994). Although invisible displacement studies indicate impoverished Stage VI object representation in monkeys, there have been too few experimental treatments of this problem, thereby limiting current understanding of the non-human primate's object concept (Hauser, in press; Hauser & Carey, in press; Tomasello & Call, 1997). The current study therefore set out to determine whether non-human primates understand invisible displacement, and in particular, those displacements which involve gravity. One reason for our interest in gravity comes from findings which indicate that falling objects represent a special category of object displacement for humans (Hood, 1995, 1998; Kaiser, McCloskey & Profitt, 1986; Kaiser, Profitt & McCloskey, 1985). Specifically, both adults and children exhibit naive reasoning about the path of falling objects relative to reasoning about other types of displacement (McCloskey & Kargon, 1988).

Hood (1995) investigated a new type of invisible displacement where children searched for occluded falling objects. Unlike traditional search tasks, the movement of the object was conveyed by a physical force rather than an animate agent such as an experimenter who moved the object manually. This was achieved by dropping a ball into the top of an opaque chimney that fed into one of three potential containers. When the tube followed a non-vertical trajectory, children made the error of searching in the container directly below the last seen position of the ball rather than following the tube to the container connected at the end. The most striking finding was the inability of 2 to $2\frac{1}{2}$ year-olds to correct their performance and the extent of repetitive search at the container underneath. This perseveration was maintained in spite of evidence from

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repeated trials where the object was dropped down the same chimney and landed in the same container. Hood (1995) also demonstrated that children allowed to watch the object fall through transparent tubes could pass the task, but this experience did not transfer to opaque trials. Older children would also make errors if multiple chimney-box pairs were connected suggesting that the bias re-emerges under more difficult testing situations. This pattern is consistent with studies showing that when preschool children are asked to predict the trajectory of a ball rolling off a cliff, they choose a straight-down movement as opposed to the correct parabolic trajectory (Kaiser *et al*., 1985, 1986).

To account for the consistent error when predicting where the ball will be after it is dropped, Hood (1995) suggested that the perseverative search at the container directly below reflects a naive theory of gravity; namely that objects always fall in a straight line. The behavior was theory-like because the children did not modify their search patterns in spite of numerous attempts and feedback indicating where the ball really was. This bias may have emerged as a result of common experience with falling events and the resistance to counterevidence was consistent with theory-like reasoning (Karmiloff-Smith & Inhelder, 1975; Karmiloff-Smith, 1992). The learned theory explanation was also supported by subsequent studies where children would search correctly on the tubes apparatus if the direction of motion was reversed so that the ball traveled upwards (Hood, 1998). As children had comparatively less experience with anti-gravity events, there was less bias to choose the box directly above.

The current study set out to determine if the pattern of gravity biases evidenced by young children is unique to humans. Although comparative cognition has received renewed interest (Cheney & Seyfarth, 1990; Povinelli, 1993; Roitblat & Meyer, 1995), there has been relatively little experimental work to compare human and non-human primates on the same cognitive tasks (for exceptions see Diamond, 1988; Povinelli & Eddy, 1996; review by Hauser & Carey, in press). One of the main problems is that there are a number of methodological difficulties in testing different species, especially when language and motor skills form a major component of the task. However, Hood's (1995) tubes task was specifically developed to study children with impaired language and motoric limitations which makes it particularly suited for comparative studies.

The species chosen to test this form of invisible displacement was the cotton-top tamarin, a small New World monkey. In addition to answering the main question of whether gravity biases are specific to human cognition, the tamarin is also an appropriate test subject because of a growing body of work that suggests that the core principles underlying their understanding of objects overlaps considerably with those guiding the human infant's knowledge (e.g., Hauser, in press; Hauser & Carey, in press).

Method

Participants

Subjects were nine adult cotton-top tamarins (*Saguinus oedipus oedipus*), a species that is native to the rain forests of Colombia (Savage, Giraldo, Soto & Snowdon, 1996). All individuals were born in captivity. There were five males and four females coded as 'B, C, F, H, L, N, P, Q & Y.'

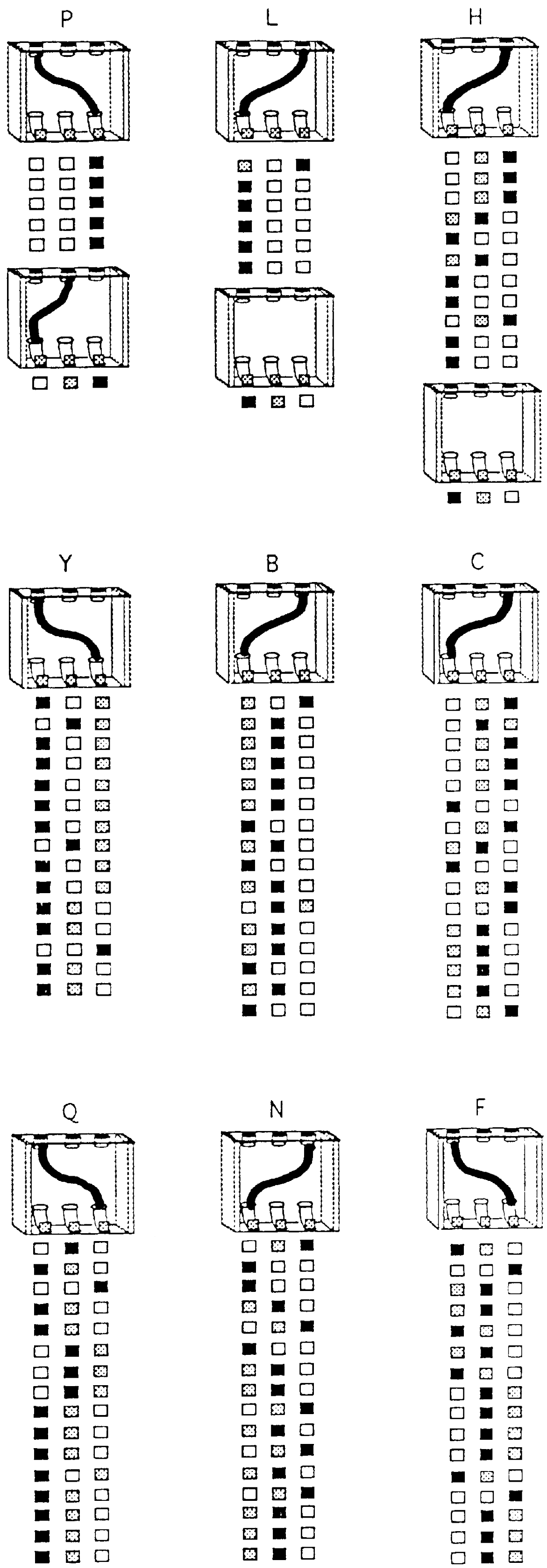
Apparatus

The apparatus was a scaled down version of that used by Hood (1995). On the upper level there were three chimneys of 5 cm diameter and separated by 5 cm. On the bottom 23 cm below, were three hiding containers with a hole on the top and a door to the front (containers A, B and C). The upper and lower levels of the apparatus could be connected together by plastic opaque tubes. Subjects were placed in a transparent holding box whose front panel was solid except for a tiny rectangular opening at the bottom. This opening was covered by a Plexiglas screen which could be raised or lowered by the experimenter and provided control over the subject's exposure to the apparatus.

Procedure

Training phase

Subjects were run on three training conditions to ensure that they were free from any potential door biases, could switch search patterns following a period of repeated responding to one door, and were not selectively influenced by the addition of a tube to the apparatus. Each training condition had 20 trials. If subjects did not pass each condition, they were re-trained on the following day with the same condition until they were trained. Each condition began with the following procedure. First, the experimenter opened each of the three doors to show that each of the containers was empty and then closed them again. The experimenter then lifted the transparent Plexiglas screen of the holding box allowing the subject to open the doors ('spontaneous searches') and check for themselves that the containers were



empty. After the subjects stopped these spontaneous searches, the experimenter lowered the Plexiglas screen. The subject then watched as a raisin was moved back and forth above the lower level of containers. After the subject tracked this motion for a few seconds, the raisin was placed in one of the containers.

In the first training condition, subjects were given 20 trials in which a raisin was placed in each container in a randomized order. Subjects had to achieve at least 90% accuracy (18/20) before moving onto the next training condition. In the second training condition, subjects were presented with 10 trials where the raisin was placed in each of the three containers, using a randomized order as in the first training condition. However, the raisin was then placed in the same container for the next 5 consecutive trials. Following this, the location was switched to a new container. Subjects had to correctly search on this switch trial in order to proceed to the third condition. In this condition, subjects were presented with 10 trials in which the raisin was placed in the three containers in a randomized order as in the first training condition. There then followed 10 catch trials in which a tube was attached to the apparatus but no raisin was hidden. The experimenter attached an opaque tube from the upper level chimney on the extreme left or right to a diagonally corresponding container on the bottom level (see Figure 1). After the tube was in place, the experimenter then lifted the transparent Plexiglas screen of the holding box allowing the monkeys to open the doors of the apparatus and check for themselves that the containers were empty. The screen was lowered once the monkey stopped these spontaneous searches. Criteria to move on from the third training condition included an accuracy of 90% on non-tube trials, attentive tracking, and no spontaneous searching when the tube was attached during the catch trials.

Testing phase

Following training, each subject was presented with the task on two sessions over two days. The reason for testing the subjects twice on the task was simply to increase the opportunity for the subjects to pass the task.

Figure 1 *Schematic representation of the search patterns for individual tamarins on the Test and Generalisation condition in Session 1. Each row of squares represents a single trial. The order of search is determined by the darkness of each square. (■) indicates the location of the first search and (⊡) indicates the second search location. If the correct box was not opened on the second search then (□) indicates a third search. If there is only one (■) on each row, then only one search was made.*

The same locations were used on both sessions. Each session had a test condition. If the subject passed the test condition, they were given one trial in a generalisation condition to determine if they understood the mechanism underlying the displacement of the raisin from the upper chimney to the lower box.

Test condition (Sessions 1 and 2)

In the test condition, the experimenter attached an opaque tube as in the third training phase. This time a raisin was dropped down the tube. Five subjects were given the upper left to bottom right configuration while the remaining four subjects were given the opposite arrangement. Subjects were never shown a straight up and down configuration where the tube is connected between an upper chimney and box directly below. The experimenter then opened and closed each door to allow the monkey to investigate the boxes. Subsequently, a raisin was moved back and forth above the top of the chimneys. After the subject tracked this motion for a few seconds, the raisin was dropped into one of the chimneys and allowed to fall down the designated tube. The screen was then lifted so that the monkey could open a door and retrieve the raisin from the container. The subject was allowed to search until they found the raisin and the order of door opening was recorded. If the subject found the raisin correctly on the first search attempt in at least four out of five consecutive trials, they proceeded on to the generalisation condition. This was the 3-choice binomial significance criterion used by Hood (1995). If a monkey did not reach this criterion within 16 trials, the session was terminated.

Generalisation condition (Sessions 1 and 2)

In order to determine whether the subjects understood how the invisible displacement worked, subjects who passed the test condition were given a single, subsequent generalisation trial. Here the tube was now connected from the middle chimney on the top of the apparatus to the box on the bottom that was previously considered the gravity-error box in the test condition. The hiding procedure from the test condition was repeated.

One-choice condition

A final condition was devised for those subjects who were unable to pass the test condition during the two sessions of the testing phase. As subjects were allowed multiple responses until they found the food, there was no cost in making an error on first attempts. In order to introduce a cost and increase the incentive to search accurately, only one response was permitted on the one-choice session. Once a door had been opened, the Plexiglas screen was dropped to prevent further responses and the animal received no reward unless the correct hiding container had been selected as the first response. If the subject found the raisin correctly in at least four out of five consecutive trials, they proceeded on to the same generalisation condition as described above.

Results

Training phase

All subjects eventually passed the criterion for each of the three training phases. If a subject failed on any phase, training was halted and they were re-trained on the following day. The mean number of days required to pass the criterion for each phase was 4.9 (S.D. = 1.52) for the first, 3.4 (S.D. = 2.99) for the second and 5.87 (S.D. = 3.4) for the third phase.

Testing phase

Test condition (Session 1)

There was a significant first trial effect with 7 out of 9 subjects initially searching in the gravity container ($p < 0.01$, 3-choice binomial distribution; Howell, 1992). Three subjects (P, L & H) passed the test condition within 16 trials (see Figure 1 for an illustration of these search patterns). The remaining six subjects failed to pass the test condition. Their searches were equally distributed between the gravity defined location (44%) and middle location (43%) with only 14% of responses to the correct box.

Generalisation condition (Session 1)

None of the three subjects (P, L & H) who passed the test condition, passed the single generalisation trial with the new arrangement as they all searched initially in the previously correct location prior to the switch, followed by the middle box.

Test condition (Session 2)

All subjects were tested again at Session 2. There was some improvement in performance from the first session but in general, the findings were replicated. Again, there was a significant first trial effect with 5 out of 9 ($p < 0.05$, 3-choice binomial distribution) initially searching in the gravity container during the test condition. Subjects P, L and H again passed the test, as did subjects B and Y. The remaining four subjects (F, N, Q & C) did not pass the test condition. Their searches were predominantly directed to the gravity box (70%) compared with the middle box (30%) while none responded to the correct box first on any trial.

Generalisation condition (Session 2)

Unlike the first session, two subjects (L & Y) now passed the generalisation condition when the tube was switched to the new arrangement while P, H and B, searched at the previously correct location.

Search patterns analysis (Sessions 1 and 2)

An analysis of the search patterns on all trials during the test condition was conducted. There were nine possible search patterns if no selection was repeated or search terminated after a (C) response. The most common search strategy over sessions 1 and 2 was to search in the gravity defined container, move to the middle container then open the correct container (A, B, C: 36% of trials). There was suggestive evidence that subjects tended to know where the food was on the second search attempt following an error as subjects who initially searched incorrectly at the middle door (B) were much more likely to search next at the correct container (B, C: 27% of trials) rather than search at the gravity container (B, A, C: 4%). Also, on 8% of trials, subjects who initially made a gravity error (A), skipped the middle door and searched in the correct container (A, C).

One-choice condition

Subjects C, Q, N and F were tested in a condition where only one response per trial was permitted. No subject passed the test condition and therefore no generalisation trials were administered. Two subjects had marked gravity errors (C = 63% response errors, N = 87% response errors), whereas subject Q chose both the gravity and middle container equally often and subject F's errors were mostly directed towards the middle box (79% response errors). Again, there was a significant first trial effect with 3 out of 4 initially searching in the gravity container ($p < 0.05$, 3-choice binomial distribution).

Discussion

The current study reveals that most tamarins fail to solve this type of invisible displacement despite extensive testing and cost incentives to choose the correct container. Even in the face of repeated trials with no reinforcement, subjects returned to boxes without food. In subsequent studies, we conducted further training with transparent tubes and found no evidence of transfer from transparent to opaque testing (Anderson, Santos, Hauser & Hood, 1996). This seems quite remarkable considering that the outline of the tube is a salient visual cue to tell the animal where to look and that these particular subjects have in the past demonstrated considerable competence in other paradigms where responses are contingent on visual cues (Hauser, in press). Further, even if they never followed the trajectory of the falling object, they should eventually learn that the food is always located in the box connected to the tube. Search was not, however, random. Even if the subjects had responded by chance alone, performance would have been better than that observed in the current study. It was almost as if subjects were avoiding the correct door on their first search. The biases observed on the first trial and as a percentage of overall trials indicate that the monkeys, as a group, were predisposed to search at the box directly beneath the drop point which could be interpreted as a bias towards the box that would be expected on the basis of gravity. Hood (1998) recently demonstrated that a gravity account was the most likely explanation for similar errors in children.

In terms of comparative issues, there are a number of similarities and differences between the performance of cotton-top tamarins and pre-school children. The main difference is that performance on the test condition is much better in children, with 90% passing the search criterion within 16 trials on their first encounter with the tubes apparatus as opposed to 22% of tamarins on Session 1 and 56% of the same group on Session 2. Also some tamarins developed a preference to search at the middle box. This strategy was not observed in the children and indicates that both the middle and gravity box were chosen in preference to the correct box. One possibility is that tamarins did not differentiate between the gravity and middle boxes because both are more likely to be correct landing locations for a falling object in comparison to a location that is further away; namely the correct box. Note that if no middle box had been available, then it is likely that search would have been almost exclusively at the box below the drop point.

However, despite the children's superior performance, there are a number of striking similarities between the two species. To begin, there is a predominant gravity response when presented with the problem for the first time. Most children initially searched in the gravity box on the first trial and this was also the tamarin's most significant response. Unlike later trials where various response strategies learned in the context of the testing may have been employed, the first trial reflects the knowledge that the subject brings to the task on the first encounter. Secondly, even though children were better at passing the test condition, only 10% of children passed the generalisation condition. This performance is comparable to the 22% of tamarins (subjects L and Y) who passed the generalisation condition on Session 2. The remaining children were equally likely to search at the previous location or in the middle container (which is now the gravity response). It should be noted that this second behavior is not seen in the tamarins as their errors where always directed towards the previously correct location. Therefore, both children and tamarins have a bias towards the gravity box but tamarins also have much more marked perseveration.

The origins of such a bias may be linked to the experience of dropping objects and noticing their landing location. Piaget (1954) suggested that prior to 7–8 months, infants do not anticipate the landing location of dropped objects. As motor skills increase, however, the infant encounters many such situations. It is not known what the developmental sequence would be for tamarins but it is clear that adult subjects do not readily solve an invisible displacement for falling events. It may be that this species has a problem with invisible displacements in general and so further studies should examine this capacity. Nevertheless, the perseveration for search at the gravity and middle box does suggest naive reasoning in that search was non-random. The strength of the argument for naive theories in tamarins would be strengthened by demonstrating that subjects can understand the mechanism of the tube in other circumstances not involving falling events. This appears to be the case for children when the object travels upwards (Hood, 1998).

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