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4 Modulation of Physical Understanding by Common Marmosets

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Introduction

Understanding physical causation is one of the most important cognitive requirements for animals to survive effectively in the wild. Without such knowledge, they have to learn by trial and error, which produces a high mortality rate and a low effectiveness of foraging.

Among non-human primates, chimpanzees are known to use various tools, and sometimes they can combine different materials to make the tool more effective (e.g., a "meta-tool" as described by Matsuzawa, 1994). These observations have led us to conclude that, although chimpanzees fully understand physical causation related to tool use, this might not always be the case. Povinelli (2001) observed that chimpanzees sometimes attend to irrelevant physical features, yet fail to attend to relevant features in tasks, such as the "support problem" (Experiments 21-23). The support problem is used to determine whether the subjects understand the concept of "support" (Mathieu, Daudelin, Dagenais, & Decarie, 1980). For example, pulling a cloth with a toy on its surface makes the toy come closer. In this case, the cloth *and* the toy must be contacted and supported. If the toy is not on the cloth, or the cloth is separated into two parts and the toy is on the more distant part, then the animal cannot obtain the toy by pulling on the cloth part closest to it. In addition, if the cloth is touching the toy, but not underneath the toy, pulling the cloth would have no effect

because the toy is not supported by the cloth. By systematically manipulating variables, Povinelli (2001) concluded that chimpanzees' understanding of "support" has its limitations, and they were mainly relying on perceptual judgement about contact.

On the other hand, Hauser, Kraik and Botto-Mahan (1999) reported that the cotton-top tamarin, a new world monkey, has a good understanding of relevant physical features in the means–end task, which corresponds to the support problem in Povinelli (2001). Furthermore, their animals showed transfer from one task ("Connected problem") to the other task ("On problem"), which should require a highly sophisticated type of "learning set" (Harlow, 1949). The results are counterintuitive considering that chimpanzees are tool users while cotton-top tamarins do not use tools in their natural habitat.

Difference in the results obtained Povinalli (2001) and Hauser et al. (1999) would be attributable to, not only the species difference, but also the procedure used in their : The concept of support was examined without any training in the former, and with training in the latter. Thus, it is not clear in Hauser et al. (1999) whether their animals had sophisticated transfer ability of understanding of physical causality, or they could learn specific aspects of the tasks which was not necessarily related to the concept of support itself (Povinelli, 2001). Or, is there any reasonable tendency for new world monkeys to show a good understanding of the physical world, compared to chimpanzees? In this study, we examined the behaviour of common marmosets to answer these questions, using support problems.

The common marmoset (*Callithrix jacchus jacchus*) is a small (300–400 g) new world monkey, originally from Brazilian tropical forests. They are diurnal, live in trees and have stable pair bonds. In general, they are not tool users, although they can be trained to do so (Echigo, Yamazaki, Iriki, & Watanabe, in preparation). Using this animal, we examined their understanding of physical causation by using the support problems, as used in Hauser et al. (1999). Thus, the specific question is the extent to which the common marmoset understands the physical relationship of "support" as a general rule in the physical world.

Experiment 1

Experiment 1 was conducted how far the marmosets understand the concept of support using support problems used in Hauser et al. (1999). In addition, we tested whether they could inhibit responses when the food could not be retrieved on viewing the relationship of sheets and foods.

Method

Subjects

Two adult common marmosets, one female (about 310 g) and one male (315 g), were used in the experiments. They were obtained from the Clea company in Japan. They were housed individually in a breeding room where the light/dark cycle was 8:00/20:00. The animals were not food deprived, and water was freely available in their cages.

All the experimental procedures and handling methods were performed in accordance with the Guidelines of Animal Experiment at Keio University, and the experiments were approved by the ethics committee of Keio University.

Apparatus

The experimental chamber was 42 (h) x 34 (w) x 35 (d) cm, made of stainless steel. At the bottom of the front panel, there was an aperture (26 (w) x 2 (h) cm) through which the subjects could insert their arms and hands to retrieve either the string (described below) or food. The aperture was shaped like a comb, with 2cm x 5cm teeth, so that the animals could reach the food or string without leaving the experimental box. The experimental materials such as black sheets and food, described below, were placed on a white acrylic table (9.5 (h) x 35 (w) x 24 (d) cm), which was located next to the experimental chamber and connected to the aperture. A transparent, acrylic board (0.5 (h) x 27 (w) x 14 (d) cm) was used to present the choice items simultaneously.

Honey cake, used as a reinforcer for the marmoset, was cut into tiny portions, each of which was shaped into a small ball (5mm in diameter). In

the high-incentive condition, the size of the ball was much increased (10mm in diameter).

Black sheets, made from thin vinyl, were used in the support test. Each sheet was 4 cm wide, with varying length (2–12 cm).

Because the marmosets were nervous when they were alone in the experimental chamber, we placed another marmoset in a cage (27.5 (h) x 23 (w) x 42 (d) cm) near the experimental chamber. Although this companion animal could see the behaviour of the experimental marmoset, we knew from our experience that the companion animal's performance would not be affected or enhanced.

During the experimental sessions, the subjects' behaviour was captured on a video camera (HDR-HC9, Sony), which was placed to the left in front of the marmoset. When the experimenter placed the sheets and food on the transparent board, a black acrylic thin board (35 (w) x 25 (d) cm) was placed around the experimenter's hands to prevent such behaviour from being viewed by the marmosets.

Procedure

Habituation

To habituate the marmosets to the experimental situation and set-ups, at first we simply transferred them into the experimental chamber and tried to feed them with the sweets (i.e., the honey cake, used as the reinforcer, and also marshmallow). After they had consistently come to the experimenter's hand to retrieve the food, the black sheet was introduced. In this phase, the sheets were not presented in pairs, as was the case in the experimental conditions described below, but they were presented one at a time, always with the reinforcer. The subjects were trained to grab the sheet in order to retrieve the food. Thus, there was no need for them to understand any kind of physical causation in this situation.

Support test I

The conditions of support test I are depicted in the upper panels of Figure 1. There were 14 different pairs of sheets and reinforcers, and successful

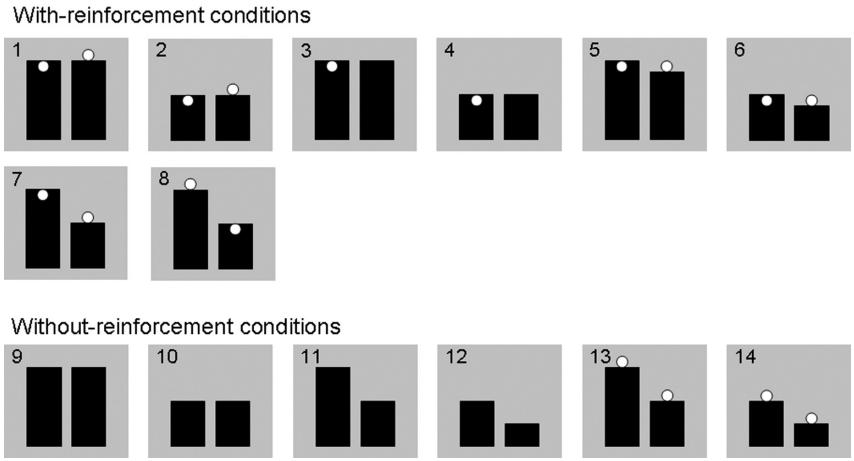

Figure 1. Experimental conditions of the sheets in Experiment 1. Sheets 1–8 are experimental conditions in which the marmosets could obtain food if they chose one of the sheets having food on its surface. Sheets 9–14 are control conditions for evaluating the animals' choice preference and any unexpected cueing by the experimenter.

choice (pulling a sheet with food on its surface) was reinforced in "with-reinforcement conditions" 1 to 8. In these reinforced conditions, there were three levels of difference that might have affected choice: presence or absence of food, distance of the food from the subjects, and the distance between the foods on the correct and incorrect sides. The "without-reinforcement conditions", 9–14, were prepared to see whether there would be a specific or unknown preference for the experimental materials, perhaps guided by unintended cueing by the experimenter. Each condition was conducted twice per session, and the left and right positions were counterbalanced. Conditions with food reinforcement (i.e., Conditions 1-8) were conducted in six sessions, resulting in 12 trials in total per condition. Conditions without food reinforcement (conditions 9-14) were conducted in the first 3 sessions, 6 trials in total per condition. In each session the conditions were randomly interspersed, with the limitation that the reinforced sheets were not placed in the same right-left position in more than three trials consecutively. The first touch to either of the sheets was defined as a choice response. If the animals touched the correct (reinforced) sheet but could not retrieve the food successfully, they were fed by the experimenter. If they chose the non-reinforced sheet, the trial

was concluded at that point and the next trial followed. When the sheets and the food were presented to the marmoset, they were separated from each other by at least 5 cm. To provide the marmosets with enough observation time before making a choice, the stimuli were slowly presented to the marmoset, with three seconds allocated to move the stimuli from the start position to the choice position, where the marmoset could reach and pull one of the sheets (5 cm from the edge of the chamber). During this procedure, the experimenter could not see the subjects directly, but looked at the centre between the sheets. If the subjects did not choose either of the sheets during the 30 seconds following their presentation, the sheets were removed, or the next trial was started after an intertrial interval. If the marmoset did not attend to the materials, the experimenter sometimes touched its body to encourage its interest in the front panel and the materials. The intertrial interval was set equal to at least 10 seconds, during which the experimenter prepared the materials for the next trial.

Results and discussion

The percentage of correct choices is depicted in Figure 2. In general, this percentage tended to be higher for the female marmoset. Except for condition 7, both animals showed a relatively high percentage of correct choices. In condition 7, the percentage accuracy was 41.7% and 33.3% for the male and female subject, respectively. The reason for the lower performance in this condition than in the seven other conditions could be due to the distance to the food placed near the non-reinforced sheet. Thus, this condition required the subjects to inhibit their choice based on their view of the food, but to understand the physical relations of contact between the sheet and the food. The result suggested that their understanding of physical relations were well affected by availability of the food.

The number of response in 6 test trials in the conditions where there was no chance to obtain the food reward (conditions 9–14) is depicted in Table 1. In case of female, she made few responses to the sheets when there was no food on the table at all (conditions 9-12), whereas she made random responses when there were food placed near, not on, the sheets

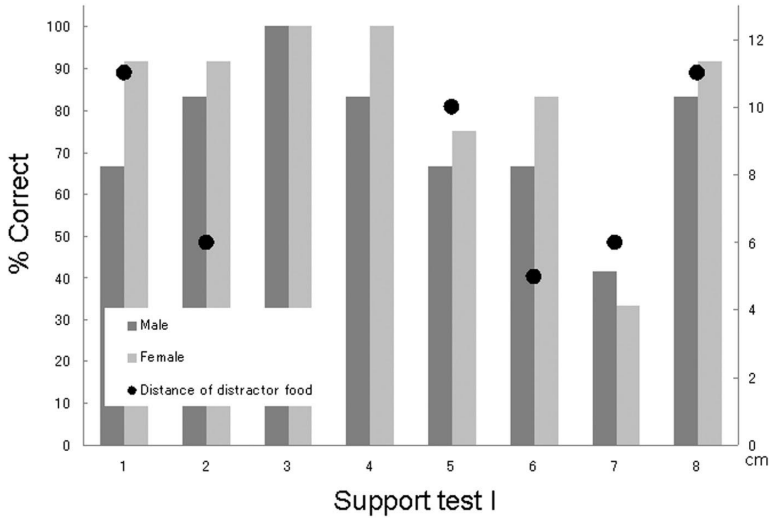

Figure 2. The percentage of correct choice (i.e., pulling the sheet with a piece of food on its surface) in Experiment 1. Dark bar: male animal's choice, light grey bar: female animal's choice. In the graph, the distance (cm) between the animal and the distracter food is also plotted in black circles against the y-axis on the right-hand side.

Table 1. The number of response in the "without-reinforcement conditions" where there was no chance to obtain the food reward (conditions 9–14). R: response to the sheet on the right, L: response to the sheet on the left.

Conditions	Female		Male	
	R	L	R	L
9	0	0	2	3
10	1	0	4	2
11	0	1	3	3
12	0	0	5	0
13	3	3	4	2
14	2	4	4	2

(conditions 13 and 14). In case of male subject, he made random responses in the conditions 9-11, 13, and 14, and also showed side preference in the condition 12. If showing no response on these conditions is an indication of response inhibition or self-control, then female had a tendency to inhibit the response better than male, but both animals failed to shows such tendency when there was view of the food on the table.

Experiment 2

Experiment 2 was conducted to determine whether a greater distance between the animals and the food near the distracter sheet would enhance their correct performance based on the physical causation of contact.

Method

Subject and apparatus

The same subjects and apparatus as those used in Experiment 1 were used in Experiment 2.

Procedure

Support test II

The conditions for support test II are depicted in Figure 3. Support test II was identical to support test I except that the difference in the distance between the animals and the distracter food (i.e., food located near the incorrect sheets) was increased in support test II. Each condition in Experiment 2 was identified with the suffix “D”. Since this experiment was designed to determine the effect of distance from the animal and the distracter food, conditions 3 and 4 in support test I were excluded from the experiment because there was only one food item in these conditions. In conditions 1D, 2D, 7D, and 8D, the food was placed 1 cm further away than in the conditions in Experiment 1, resulting in 2 cm separation between food and the sheets. Thus, the total distance between the animal and the distracter food was also increased by 1 cm. However, in conditions 5D and 6D, the distance was the same as in conditions 5 and 6 in Experiment 1, but the distance between the distracter food and the sheet was increased by 1 cm (i.e., 2 cm separation), and the distances between the animal and the correct and distracter food were unchanged. Each condition was tested 12 times, six times in each of the left and right counterbalanced positions.

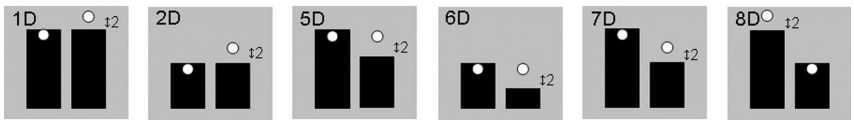

Figure 3. Experimental conditions of the sheets in Experiment 2. The numbers in each panel show distance of the food and the sheet (cm).

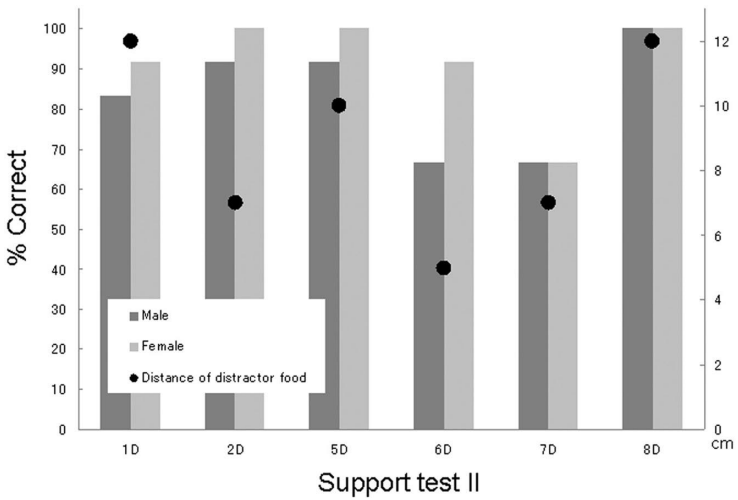

Figure 4. The percentage of correct choice (i.e., pulling the sheet with a piece of food on its surface) in Experiment 2. Dark bar: male animal's choice, light grey bar: female animal's choice. In the graph, the distance (cm) between the animal and the distracter food is also plotted in black circles against the y-axis on the right-hand side.

Results and discussion

Figure 4 shows the results for support test II, together with the distance between the animal and the distracter (black dots). Similar performance to that obtained with support test I was observed, except for condition 7D. Both animals showed higher scores (66.7%) in this condition than in the previous, shorter distance condition 7, but this performance was not significantly different from the chance level of 50%. Thus, the lengthening of the distance between the distracter and the food location was not sufficiently effective for these animals to rely mainly on physical contact with an object as the basis for their understanding of physical causation.

The female subject's performance exceeded 80% in all the conditions except 7D. The male subject also showed an improvement in performance in conditions such as 1D and 5D. Thus, it is possible that an effect of training in Experiment 1 might have occurred in support test II. However, the male subject did not show any progress on conditions 6D and 7D. The reason for the male subject's low performance in condition 6D might result from the position of the distracter food, which was closest in 6D than in any of the other conditions, as indicated by the black dots in the graph. Thus, the findings from this condition also suggested that the distance of the distracter food was the most critical factor in support test II, a situation that could not be overcome by increasing learning experience.

General discussion

The present preliminary experiments showed that the marmosets were sensitive to the physical relation of contact. However, their understanding of the physical rule of support was easily modulated by the distance of the distracter food. They made more errors when the distracter food outside the sheet was nearer than was the food on the sheet. Moreover, their behaviour was not easily modified by increasing the distance between the food and the sheet to increase the saliency of "no-contact".

However, these findings are comparable to those obtained using cotton-top tamarins (Hauser et al., 1999) as subjects. In Hauser's study, cotton-top tamarins were trained to pull correct (reinforced) sheets in similar conditions to those of conditions 1–8 in Figure 1, using 20 trials per session. Although they reached the criterion of 92–100% accuracy after about 20 sessions, accuracy on the first day was around 60% for subjects starting with the "On problem". In this study, the correct percentage for each sheet condition was not shown, so it is not clear whether the tamarins made errors on the task that were similar to those made by subjects in condition 7 using our procedure.

The performance of the female animal in conditions 9–14 in Experiment 1 would indicate "inhibition", which is considered to be important in problem-solving tasks (e.g., Diamond, 1988; Deacon, 1997; Hauser et al., 1999; Evans & Westergaard, 2006). On the other hand, the

male animal did not inhibit his pulling, but made random choices in these conditions. However, it is not clear whether inhibition is a good indicator of intelligent cognitive manipulation: There was no need to inhibit the pulling response even when the animals noticed that there was no food at all. Because common marmosets are fairly curious animals, testing every object around them could be interpreted as another type of intelligent behaviour that is used to learn about their own environment. Whether inhibition is an effective intelligent strategy or not would depend on the condition of the environment, such as a severe lack of food, or threats to safety.

In summary, the common marmosets' performance in the two types of support test indicated that their understanding of physical relationship was generally high, but there were some aspects of their performance that were easily modulated by irrelevant physical aspects of the comparison stimuli. By manipulating different levels of physical features, such as size of reinforcer and the gap in the sheet, it might be possible to clarify the types of factors (perceptual, ethological, or computational) that would be most affected by these manipulations.

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