

Observational learning of tool-use in human infants and macaques

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Abstract— We compared learning new manual skills by observation in sixteen 15- and 18-month-old human infants and in three young macaques, in tool-use and no-tool tasks. We chose tasks of comparable difficulty for the two age groups of infants. In the spontaneous condition, the tool-use tasks were less successfully achieved than the no-tool tasks at both ages. After observation, there was only a moderate increase in the frequency of success at 15 months of age, whereas all 18-month-olds could successfully perform both tool-use and no-tool tasks. The macaques did not differ significantly from the human infants in the spontaneous condition. None of them learned by observation to use a tool, and all of them failed on the no-tool 18-month-old task after demonstration, even after two additional sessions. In contrast, when the task was made easier by some modifications of the objects, the macaques could spontaneously perform them successfully. These results show that learning to use a tool is extremely difficult for macaques, and that they do not benefit from a demonstration by a human, as opposed to 18-month-old human infants.

I. INTRODUCTION

The goal of the study presented here was to compare observational learning of the same complex object-retrieval tasks, with or without a tool, in human infants and macaques. When interacting with an object, one must i) perceive the object's properties (size, shape, number of parts, etc.), ii) perceive the affordance of this object (graspable, extractable, for instance), and iii) generate and control the action to meet this affordance. Because of the infant's limited processing capacity, the perception of the affordance depends on the level of the difficulty of the action [1]. It is usually recognised that a few parameters

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describe the difficulty of an action for infants: for instance one-step actions are easier than two- or three-step actions [2]. And actions requiring the use of a tool are more difficult than simple means-end actions [3] [4].

Tool use has often been observed in primates, particularly in apes [5] [6], [see 7 for a review], but also in a few species of monkeys such as Cebus monkeys [8], or capuchin [9]. Although tool use in monkeys is not frequently observed in the wild, several studies have shown that some monkeys can be trained to use tools, for instance macaques [10] [11] or capucins [12] [13] [14]. How do primates learn to use a tool?

There are two main strategies to acquire a new manual skill, with or without a tool: practice alone, through trials and errors, and observational learning (imitation of a model). We prefer to speak about observational learning rather than imitation i) when the observed action applies to an act that is absent from the participant's motor repertoire (in other words, a novel act and not only a novel object to be acquired), and ii) when the observer is not allowed to perform the modeled action before a delay. Some studies were aimed at evaluating the benefit of modeling in learning a new motor action in humans, but most concerned older children or adults (see [15] for a review). In infants, there has been many studies on imitation, but most of them either concern early neonate imitation, following Meltzoff and Moore's study [16], or imitation in a social cognition perspective, such as Gergely's studies [17]. A few studies, however, showed that infants can understand specific relations between observed actions and effects by the second year of age, when they start to benefit from observation of others' actions to organize their own or to relate means and end in complex actions [18] [Fagard et al, 2008 submitted](#), [19; 20]; [see 21 and 22 for reviews].

The role of social interactions in learning new manual skills in non human primates has been often emphasized. Many studies concerned apes [6] [23]. The transmission of tool use is considered rare in monkeys [24], but has been sometimes observed [25] [see 26 for a review on compared tool use among primates]. Few studies compared infants with non human primates for the capacity to learn a new manual skill by observation. Some concerns apes, mostly chimpanzees [27; 28]. There are, to our knowledge, no studies directly comparing human infants and macaques learning by observation the same manual tasks. Since

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macaques are used to establish the neural bases of imitation or observational learning, it would be useful to know to what extent they represent a good model for that.

Reaching and grasping an object are controlled by different muscles (proximal and distal forelimb muscles, respectively), and these in turn by different circuits that involve many parietal and frontal areas [29; 30]. When we observe another individual performing the same action, a large number of these areas involved in execution of grasping are activated. Studies on this subject have started more than a decade ago in the monkey, when Rizzolatti's group found in the ventral premotor cortex the existence of "mirror neurons" [31] [32]. The mirror neurons discharge both when the monkey executes an action and when the same monkey observes another subject executing the same action and thus provide the neural substrate for understanding the actions of others. Cells with these characteristics have been found also in other parts of the brain, as the parietal cortex, outside the classical motor cortex [33]. Thus observing another individual performing an action influences the neuro-motor system of the observer.

Here, we report of a direct comparison of human infants and macaques on observational learning of new manual skills. We compared the learning of two kinds of skill, one involving tool use and the other not. The manual skills were the same in the two groups of primates.

II. METHODS

The task consisted in retrieving an object presented in such a way that its grasping required solving an additional problem. The tasks were different for both age groups, so as to be just slightly too difficult for the infant of the targeted age to be spontaneously successful.

The objects were identical or almost identical for macaques and infants: however, for infants what was to be retrieved was always a toy whereas for the macaques it was always a piece of food (piece of apple, banana, or candy). They were the following:

1/ Bottle with a peg inside (raisin for macaques) (15-month-olds): the neck of the bottle was too narrow for a finger to be inserted in it to retrieve what was inside, so that to retrieve the peg (or the raisin, in the case of monkeys) it was necessary to turn the bottle upside down.

2/ Rake (Tool-use, 15-month-olds): the rake was placed in the middle of the table, within reach, in front of a plastic block (piece of food for macaques) which was placed out of reach, behind the rake. In order to grasp the block (or food), the rake had to be used as a tool to bring it within reach.

3/ Finger-in-the-lid (18-month-olds): the object was a high transparent plastic box, with a lid which had a hole in the middle, and a plastic block (infants) or a piece of food (macaques) at the bottom of the box. The participant had to open the lid using one finger of one hand, and grasp the toy (food) with the other hand.

4/ Stick (infants) or fork (macaques) (tool used vertically,

18-month-olds): the object was a high transparent plastic box, half covered with a piece of tape, and a plastic block (infants) or a piece of food (macaques) inside the box. A wooden stick (infants) or a plastic fork (macaques) was placed to the side of the box. In order to get the plastic block, the infants must grab the stick which terminated with a piece of "Velcro", touch the block with the tool: the plastic block, on which the other half of the "Velcro" had been glued, could then be retrieved. In order to retrieve the food, the macaque had to grasp the plastic fork, hit the banana with the fork, and get it out of the box. A tape covering part of the top prevented from grasping the block or the food with the hand.

The tasks we chose required understanding different spatial relationships between the object to be grasped and its environment, or within the different parts of the object, and figuring out the action to retrieve the object, which involved two to three steps with the cooperation of the two hands.

For the first session, the protocol was similar for infants and macaques. The object was presented to the participant for 30 sec, during which he could explore it. After this spontaneous trial, the experimenter showed the participant how to perform the task, three times in a row (left – right – left hand) out of reach from the participant. For that, she was particularly cautious to check that the participant was looking at her throughout each demonstration.

The demonstration was followed by a two-minute delay. During the delay the infants were shown other interesting objects, such as mechanical toys or finger puppets, for example; the macaques were given raisins. After the two-minute delay, the object was presented again (test trial). Each infant only received the objects corresponding to his age group. The macaques received all four objects, starting with the 15-month-olds' objects and ending with those of the 18-month-olds.

For the macaques, we did additional testing to check whether they would be able to learn by observation after repeated sessions. There was a second and a third session exactly similar to the first one. During the fourth session we tested a few changes in some of the objects to check whether it would simplify the task for the macaques.

For both infants and monkeys, digital video recordings allowed off-line frame by frame analysis of recorded data.

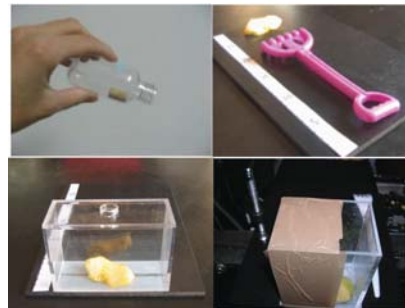


Fig. 1 Objects used in the tasks.

III. RESULTS

A. Observational learning of manual skills in infants

Sixteen infants participated in this study. There were nine 15-month-olds, and seven 18-month-olds.

The infants showed a spontaneous rate of success that ranged from 0% to 45%, as shown in Figure 2. There was no difference in the rate of spontaneous success between the two age groups. To evaluate the influence of observation on learning manual skills, we analyzed the change in success between the trial before observation and the test trial. A MANOVA on the percentage of success (0, 1), with age (x 2) as independent measures, and task (x 2, tool-use and no-tool) and condition (x 2, before and after demonstration) as dependent repeated measures, indicated no main effect for age, a significant effect for task ($F(1,14) = 15.2, p < 0.01$), a significant effect for condition ($F(1,14) = 63.3, p < 0.00001$), and a significant age x condition interaction ($F(1,14) = 14.4, p < 0.01$).

The percentage of success was higher after observation (75%) than before (25%). For both age groups the tool-use tasks were less spontaneously successfully achieved (6.2% success) than the no-tool tasks (43.75% success). For the 18-month-olds, the effect of learning through observation (100% success after observation versus 21% before) was larger than for the 15-month-olds (56% success after observation versus 25% before).

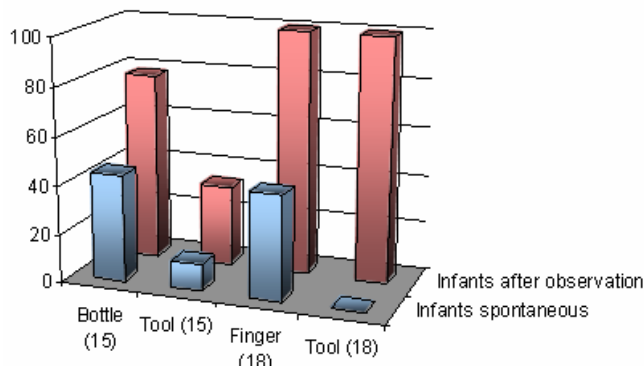


Fig. 2. Frequency of success in infants as a function of task and condition.

B. Observational learning of manual skills in macaques

The subjects of this study were three macaques monkeys born in captivity and used to collaborate with the experimenter in the laboratory and to sit in a primate chair to perform manual tasks and interaction with the laboratory set-up. One of the monkeys has been the subject of a several months electrophysiological recording session preceded by a long period of training and thus of interaction with the laboratory.

Comparing the spontaneous rate of success between infants and monkeys (Fig. 2 and 3) it can be seen that the macaques tended to be less successful than human infants. There was only one spontaneous success by one of the three macaques at the Bottle task. None of the 18-month-old tasks

were successfully completed and the tool-use task of the 15-month-olds was also failed by the three macaques. However, the macaques were not significantly different from the human infants, as shown by a chi-square test applied separately for each task.

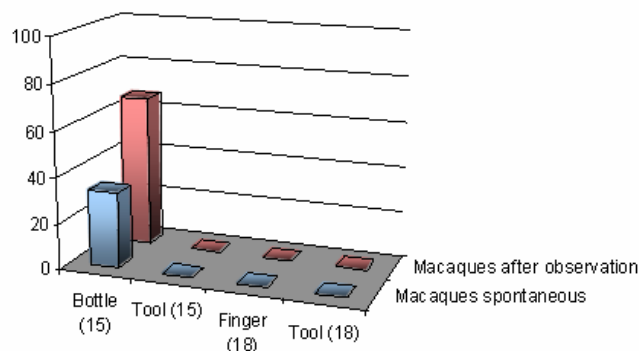


Fig. 3. Frequency of success in macaques as a function of task and condition.

Considering the success rate of monkeys after observation of the experimenter performing the tasks, it is evident that macaques learned almost nothing by observation (see Fig. 3). We observed only one additional success at the Bottle task after observation. None of the three macaques succeeded after observation at the tool-use tasks, or at the 18-month-old no-tool task. This clearly differs with respect to infants who showed learning by observation, particularly at 18 months of age.

C. Additional training in macaques on the four tasks

Since it was possible to test the macaques several times over a few days, we decided to check whether they would learn by observation after two additional sessions. The second and the third sessions were conducted exactly like the first one. At a fourth session we did a few supplementary testing on some of the tasks in different conditions.

For the bottle task, since two out of three macaques performed the task successfully after demonstration, the only possibility to observe a change after repeated sessions concerned one macaque. This macaque did not perform better during the second and the third sessions.

For the three other tasks, the three macaques had failed at the first session, even after demonstration. All of them failed again to perform successfully the tasks, even after two more sessions of practice followed by modeling of the human adult. In summary, for none of the tasks did the macaques benefit from observation even after two more sessions.

We finally tried a few changes in three of the tasks, to see whether the macaques would succeed in easier conditions. For instance, we attached the piece of apple to one tooth of the rake. The macaques immediately grabbed the rake, and pulled the piece of food to eat it (see Fig. 4). We did the same with the fork, and success was also immediate without demonstration.



Fig. 4 Food attached to one tooth of the rake: immediate success.

For the Finger task, we changed the box so that it became clear that the only way to open the lid was by using the finger. With the former version of the box (see Fig. 5A), the lid was placed on the box in such a way that, even though it was easier to grasp the lid using a finger, it could have been possible to raise it with a slight pressure upward of the two thumbs. With the new version (see Fig. 5B), the lid was placed one centimeter below the top of the box, on four plexiglas pillars glued inside the box at each of the four corners, so that the only way to open the box was clearly by using the finger through the hole. With this modification, two out of the three macaques immediately and spontaneously used their finger to open the lid with success. The third macaque was not willing to try the task, neither before nor after observation.

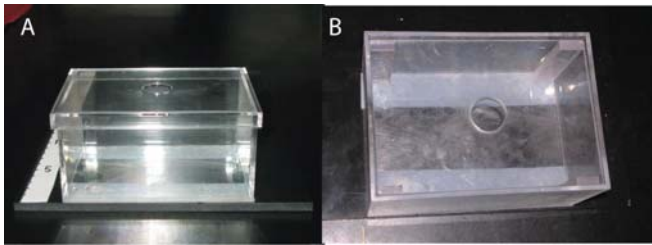


Fig. 5 A) Finger-in-the-lid. B) Finger-in-the-lid modified.

IV. DISCUSSION

We compared the performance of 15-month- and 18-month-old human infants and macaques on two tool-use and two no-tool tasks in two conditions: a spontaneous condition and a post-observation condition. The tasks were of comparable difficulty for the 15- and the 18-month-olds, as shown by the spontaneous successes which never exceeded 45%. For both age groups and for the macaques the tool-use tasks were less often spontaneously successfully completed than the no-tool tasks. The macaques did not differ significantly from infants in the spontaneous behavior before demonstration, with only one macaque performing successfully the 15-month-olds' no-tool task, and complete failure on all three other tasks. We thus considered that we could compare the effect of observational learning across ages and between human infants and non human primates on these tasks.

The results after observation of a human modeler showing how to perform the tasks indicate some benefit from observational learning already at 15 months of age, but this benefit increases in human infants between 15 and 18 months of age. In contrast, the macaques showed almost no

benefit from observation of a human modeler, even though they were well used to her presence in the laboratory and in their working space. In particular, we observed no benefit at all concerning the two tool-use tasks.

The fact that observation becomes more effective as the infant grows up agrees with previous studies [20] [19]. Our results show that such change apply particularly to tool-use tasks, which are more difficult than no-tool tasks.

What could be responsible for this change in the effect of observational learning on object retrieval in the second year of life? Critical factors in the efficiency of observational modeling are the observer's cognitive-developmental level (based on processes such as attentional span, coding capabilities, etc.) and motivational orientation [34]. In our study, one possibility could be that only at 18 months of age do infants better understand the contingency between observed action and their effects, as they do for their own actions and their effects on the environment. Or, that only then can they transfer this contingency to their own behavior. Another possibility, not exclusive of the first ones, could be that older infants are more likely to pay attention to the relevant parts of the modeled action.

For the macaques, discovering how to put a bottle upside down in order to get a raisin out of it, was something possible without training at least for one macaque. But discovering how to use a rake to bring a piece of apple closer, to use a fork to pick a piece of food from a box, or to use a finger to raise a lid so as to retrieve the food from inside was not possible within 30 seconds practice. These results were not unexpected. Tool-use has been observed in macaques, but after many trials and errors when in captivity [35], or in free or semi-free habitat where practice is not limited [24] [36] [37]. However, here the macaques still failed to complete the task even after two additional sessions.

Our results indicate that captive macaques do not learn from observing a human adult modeling a tool-use task, or even a no-tool task successfully performed at 18 months after observation. Thus, the capacity for observational learning of the macaques was lesser than that of a 18-month-old infant. Observation of a human using a tool did not help them as it did for 18-month-old infants or as it does for chimpanzees [38].

To explain those differences in observational learning between human infants and macaques, one could also hypothesize that the tool-use tasks are too far from the manual repertoire of the macaques to be learned by observation. The motor-simulation theory proposes that perceiving actions triggers internal simulation of the movement to be produced, with more or less approaching dynamics as a function of the novelty of the action for the observer. This internal simulation involves not only action programming but also the generation of a copy of the movement to be reproduced [39], a signal reaching widespread regions of the monkey brain [40]. The theory is

supported by increasing knowledge about the common neural pathways underlying observation of an action and its actual execution [41]. The mental simulation theory assigns the role of perceiving others' actions to the neural substrate that is also responsible for action execution and assigns this role to considerable portions of the central nervous system. Recent works found that, far from being restricted to ventral premotor cortex and inferior parietal lobule, the so-called "action observation/execution matching system" also involves primary motor cortex, primary somatosensory cortex, and extensive parts of the frontal lobe, as well as the cingulate cortex and the parietal and temporal cortex [42] and [43].

Alternately, it could be hypothesized that critical differences involve causal reasoning mechanisms rather than those implementing sensorimotor transformations [44]. It could be that macaques failed to recognize the functionality of the tools. For example, it was observed in capuchin monkeys that after they discovered, through practice, new means to get a piece of food, using sticks in a complex condition, they kept making the same errors throughout the trials [45], unlike chimpanzees [46].

In conclusion, observational learning of new manual skills does not reach, in macaques, the level of 18-month-old human infants, and concerning a tool-use task, tends to be less effective than for a 15-month-old infant. It is likely that cognitive, perceptual and motor processes involved in complex tool use are responsible for the difficulties of the macaques to learn new skills, whether it is by observation or by practice alone [47]. The fact that by attaching the piece of food to the rake or to the fork, or by lowering the lid of the box of a few millimeters, we induced a spontaneous success in the macaques shows that success can be spontaneous just by lowering the level of cognitive difficulty of the task. It might indicate that, as long as the task is cognitively too difficult and emulation impossible, a macaque does not learn easily by observation of a human.

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