Research report

Do robots have goals? How agent cues influence action understanding in non-human primates☆

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HIGHLIGHTS

► Marmoset monkeys attribute intentions to a human actor and unfamiliar monkey-like artificial agents.
► Monkeys' system for goal attribution cannot be extended to inanimate abstract agents.
► The capacity to attribute goals may have developed early during primate evolution.

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ABSTRACT

The capacity to understand goals and intentions emerges early and universally in humans and is a basic precondition for the interpretation and prediction of others' actions, be it other humans, animals, or even robots. It is unclear, however, how this goal attribution system is acquired, in particular with regard to the role of prior experience with the actor and visual characteristics that are necessary. In four preferential looking time experiments we examined how familiarity, appearance, and movement of different agents influence the capability of marmosets to perceive the behavior of these agents as goal directed. To this end we compared the monkeys' reactions to the same goal-directed actions performed by four different agents: a human actor, a conspecific, a monkey-like small robot, and a black box. The results showed that monkeys attributed goals to the human actor, the conspecific, and the robot, but not the box. Thus, the monkeys extended their capacity for goal attribution not only to familiar agents, but also to agents not previously encountered, provided that they had some conspecific-like features. Our results suggest that in non-human primates, the system for goal attribution does not require previous experience with a specific agent or agent-category, as long as it exhibits certain visual characteristics like face, body or legs. Furthermore, the results suggest that the capacity to attribute goals emerged very early during evolution and, at least in marmoset monkeys, does not necessarily require pre-learned associations in order to fulfill its function when dealing with unfamiliar agents.

1. Introduction

Many every day social activities rely on our ability to accurately detect and understand the intentions of others, to anticipate their upcoming actions, and to appropriately adjust our own behavior. The perception of actions in terms of their goals rather than in terms of physical properties might be a necessary precondition for understanding intentional actions and attributing mental states to agents [1]. Previous studies indicate that understanding of others' goals emerges early in childhood and develops gradually during human ontogeny. Infants younger than 9 month attribute goals only to humans [2] and agents with a certain degree of human-likeness such as humanoid robots [3], but not to boxes [3], claws/rods [2,4], mechanical devices [5], or geometrical shapes [6]. After 9 months of age, they are able to perceive actions of both morphologically familiar and unfamiliar inanimate agents [6–12] as goal-directed. Finally, at 12 months of age, infants have been shown to attribute goals even to geometrical shapes [8].

Among nonhuman primates, chimpanzees [13,14], rhesus monkeys [15], capuchin monkeys [16], cotton-top tamarins [17] and common marmosets [18] are sensitive to intentional action of humans, similar to human infants [4,5]. However, capuchin monkeys show no sensitivity to intentions when inanimate objects

(and not humans) are involved in the observed action [16]. This finding is not only consistent with the ontogeny of goal-attribution in humans, but also with results from adult humans suggesting that animacy and biological motion are fundamental in this context. The capacity to detect animacy and biological motion has both behavioral [19] and neurological correlates [20] and is crucial for more complex understandings such as causal interpretations of action [21] and attributions of mental states [22].

Nevertheless, in humans, the role of agent cues (e.g. presence of a body with a head, biological motion, shape and size, ability to manipulate objects) for the identification of intentional behavior is controversial. Some researchers argue that early forms of intentional understanding are hardwired brain functions, triggered by specific morphological and behavioral cues such as faces and eyes [9,22,23], biological motion [22], self-propulsion [11,24,25], or contingent and reciprocal interactions with other agents [9,26]. Thus, no prior experience with the agent should be required if these cues are present [6,8,11,22,24,25]. Alternatively, goal attribution may result solely from statistical learning of the association between the observed actions and their target, through everyday experience with human agents and later extension of these associations gradually to less human-like agents [4,5,27,28] such as dolls.

In our study we investigate which cues an inanimate agent has to exhibit to be accepted by a marmoset monkey as an intentional agent, and whether pre-experience with such an agent behaving in a goal-directed way is necessary. The common marmoset (*Callithrix jacchus*) is a small New World monkey renowned for its well developed social skills (reviewed in [29]). These monkeys diverged from the human lineage between 40 and 60 million years ago [30]. In our four preferential looking-time experiments modeled on the paradigm used in previous work with infants [4], we presented the marmoset monkeys with actions of different agents exhibiting certain morphological features and lacking other cues mentioned above. To avoid the possibility that the monkeys could have relied on experience with other conspecifics and humans for goal attribution to new agents by, in two out of 4 experiments in we used previously never encountered artificial agent as models.

In the first experiment we tested whether marmosets can extend their ability to understand simple grasping actions to morphologically highly dissimilar non-conspecifics, i.e. humans [31]. However, because captive marmosets are exposed to humans behaving in goal-directed ways on a daily basis, it is not possible to distinguish whether this flexibility is simply based on associative learning processes or whether there is a more general goal-attribution mechanism which responds to a broader array of potential intentional agents. To pinpoint the role of familiarity, biological motion kinematics and monkey-like features for intention understanding, in the following experiments, we presented the monkeys with actions performed by different models: a conspecific (Experiment 2), a monkey-sized quadruped robot with head and tail (Experiment 3) and finally the same robot disguised as a box (Experiment 4).

The robot used in the experiment had a dog-like appearance with a tail, a head and 4 limbs. Since the limbs had no joints, the robot's movements looked very artificial. Covering the robot with a black box allowed us to test for the role of body appearance for goal attribution. Importantly, in contrast to human agents and conspecifics, the marmoset monkeys had never observed dogs, the robot or the box being engaged in goal directed actions so that goal attribution to these agents might indicate a hardwired capacity to attribute goals based on certain features of appearance and movement.

As in human child experiments conducted by [4], monkeys were familiarized with an agent grasping one of two target objects located on the left and right side of them (Experiment 1 and 2) or approaching it (Experiment 3 and 4). After switching the location of the target objects, goal attribution was inferred if the monkey's attention recovered when the target of the grasp changed (incongruent event) but not if the trajectory of the grasp changed (congruent event). The underlying assumption is that in case of intention attribution to the agent, monkeys will look longer at unexpected test events (goal shift) than at expected test events (path trajectory change).

2. Methods

2.1. Subjects

The participants in the following three experiments were 43 captive-born adult common marmosets (*Callithrix jacchus*) (see Fig. 1a). They were housed in social groups either at the Primate Station belonging to the Konrad Lorenz-Institute located in the proximity of Vienna, Austria (in the first experiment) or at the Primate Station of the Anthropological Institute of the University of Zurich, Switzerland (in the second, third and forth experiments).

The participants in Experiment 1 were three males and seven females ranging between 4.1 and 7.5 years. They were kept in two groups (4 and 6 individuals) in different cages separated by a wire grid. In Experiment 2, nine adult marmosets (five males and four females) were tested. The monkeys were kept in two family groups (two breeding pairs and their offspring) and their age ranged from 1 to 11 years (mean age 3.5 years). In the third experiment, 10 adult marmosets living in two groups (age range 2 to 8 years, mean age 4.2 years) were tested. The first group consisted of two parents and five offspring and the second group of three siblings (hand-reared, two adult females and one adult male). In the fourth experiment, we first tested 10 subjects and decided to add 4 additional ones in order to also be able to detect potentially weaker effects. However, adding these four subjects did not alter the results. Altogether, in the forth experiment we tested 14 adult individuals (5 females, 9 males, age range from 1 to 7 years, mean age 4.5 years) from three family groups. Two of the monkeys were hand-reared.

2.2. Housing and experimental setup

The subjects participating in the first experiment were housed in indoor home cages (size: 2.5 m × 1.5 m × 3 m) connected via wire tubes (40 cm × 60 cm × 110 cm) with each other and the testing cage. The marmosets participating in experiment 2–4 were also housed in indoor home cages which consisted of one or multiple units (1.0 m × 0.75 m and 1.7 m height) depending on the group size. These cages contained ropes, branches and a heated sleeping place. During the summer, the animals had free access to outdoor cages, either every day (in case of bigger groups) or every second day (in case of smaller groups). The floor of the cage was covered with a substrate of biological soil. The marmosets were fed three times a day: early in the morning (with gum, mealworms, and pap supplemented with vitamins and minerals), at 11 o'clock (with fresh fruits, vegetables and mushrooms), and in the afternoon (with cheese, boiled egg, fish or nuts). Water was always available.

The testing of the participants in the experiments took place either in the morning after the first feeding or in the afternoon before the last feeding. Therefore, during the testing, the animals were neither food nor water deprived. The experiments were approved by the Veterinary Office of the Canton of Zurich (license number 105/2004). During the testing, the monkeys were free to join or leave at any time: their participation was voluntary, and their feeding habits were not modified to encourage participation. Most subjects have previously been tested in other experiments und thus often had contact with humans during experimentation, but were never handled directly except for veterinary reasons.

For the first experiment, the marmoset monkeys were placed in a testing cage consisting of a single compartment. The testing cage was connected to the housing cages by means of tubes. The frontal wall of the testing cage was replaced by a transparent door. Between the testing cage and the experimenter a table was located on which the objects were put (see Fig. 2). The testing cage used in the last three experiments consisted of three compartments: a screen compartment, an experimental compartment and a preparatory compartment (see [18]). The first compartment containing an LCD-monitor was separated from the experimental compartment by a Plexiglas divider. The monitor was connected to a laptop located outside the cage. While watching the videos, the marmosets stayed in the experimental compartment and between the trials they entered the preparatory compartment through a guillotine door. During the testing of each animal, the rest of the group stayed in the preparatory compartment which was visually isolated from the testing cage. The ceiling and the lower part of the grid of the experimental compartment were lined with Plexiglas, so that the marmosets would stay on the floor during testing.

In all four experiments, the marmosets were filmed with a digital video camera from a distance of ca. 50 cm during the entire duration of the experiment. In the last three experiments, the video image depicted the whole testing cage including the image on the LCD screen.