



Domestic goats, *Capra hircus*, follow gaze direction and use social cues in an object choice task

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Gaze following is a basic social cognitive skill with many potential benefits for animals that live in social groups. At least five primate species are known to follow the gaze of conspecifics, but there have been no studies on gaze following in other mammals. We investigated whether domestic goats can use the gaze direction of a conspecific as a cue to find food. They were able to do this, at a level comparable to that of primates. In a second experiment, we tested goats' ability to use gaze and other communicative cues given by a human in a so-called object choice situation. An experimenter hid food out of sight of the subject under one of two cups. After baiting the cup the experimenter indicated the location of the food to the subject by using different cues. The goats used communicative cues (touching and pointing) but not gaze by itself. Since domestic dogs are very skilled in this task, whereas wolves are not, one hypothesis is that the use of communicative cues in the object choice task is a side-effect of domestication.

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Perhaps the most basic skill of social cognition is gaze following. Individuals note where a conspecific is looking and they look there also, often gaining valuable information about such things as the location of food, the presence of predators, and the occurrence of important social interactions in the group.

Some nonhuman primates can follow the gaze direction of both conspecifics and humans to outside locations that they cannot directly see. Tomasello et al. (1998) studied five primate species: chimpanzees, *Pan troglodytes*, sooty mangabeys, *Cercocebus atys torquatus*, rhesus macaques, *Macaca mulatta*, stumptailed macaques, *M. arctoides*, and pigtailed macaques, *M. nemestrina*. They waited until pairs of individuals were appropriately aligned, one facing an experimenter in a tower and one with its back turned to the experimenter, facing the first one. They then attracted the attention of the first individual, who often made a distinct head movement in order to look, and they then noted whether the second individual followed the looking direction of the first within 10 s. In a control condition, experimenters simply engaged in the attention-attracting behaviour (holding up food) with an isolated individual whose back was turned (also for 10 s). Individuals turned around and looked to experimenters much more often in experimental than in control trials.

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Other studies have also found positive results for orang-utans, *Pongo pygmaeus* (Kaplan & Rogers 2002) and macaques (Emery et al. 1997; Anderson & Mitchell 1999) but not lemurs, *Eulemur macaco* (Anderson & Mitchell 1999). Chimpanzees also follow human gaze direction, sometimes even around barriers and past distractors (Povinelli & Eddy 1996a; Tomasello et al. 1999) and check back to the human when nothing is there to be seen (Call et al. 1998). However, there is no experimental evidence that any nonprimate species follows the gaze direction of conspecifics. Some bird species can detect when conspecifics are looking at them, and, for example, refrain from caching food when they are being watched (Emery & Clayton 2001), but this is not the same thing as following gaze direction to outside objects and events. There is evidence that domestic dogs, *Canis familiaris*, are also sensitive to others looking at them (Call et al. 2003), but there is no evidence that they follow the gaze direction of others to outside locations that they cannot directly see.

There is a second context in which the use of gaze following has been investigated. In this task, food is hidden in one of several locations and a human indicates that location for a subject using a communicative cue such as looking or pointing at the baited cup. Nonhuman primates do not perform well in this so-called object choice task. Although they can learn to use these cues over dozens or even hundreds of trials (Itakura & Anderson 1996; Neiworth et al. 2002), primate individuals almost always respond at chance levels for many trials

before learning (with some exceptions, Vick & Anderson 2003). Those individuals that succeed are mostly those with extensive human experience (Itakura & Tanaka 1998). Thus nonhuman primates show variable results in gaze following to outside locations and gaze following in an object choice situation. For a review, see Call & Tomasello (2003).

In contrast, the one nonprimate species that has been extensively tested in the object choice paradigm is very skilful. Domestic dogs use a variety of human communicative cues (looking, pointing, etc.) to locate hidden food, and they do this from the first trial (Hare et al. 1998; Miklosi et al. 1998; Hare & Tomasello 1999; Soproni et al. 2002). These skills are apparently a result of domestication, as dogs' closest undomesticated relatives, wolves, *Canis lupus*, do poorly in this task, but even domestic dog puppies with almost no human experience still do well (Hare et al. 2002; Miklosi et al. 2003). Dolphins, *Tursiops truncatus* (Herman et al. 1999; Tschudin et al. 2001), fur seals, *Arctocephalus pusillus* (Scheumann & Call, in press) and a grey seal, *Halichoerus grypus* (Shapiro et al. 2003) were also skilful at using some human communicative cues in the task (for example pointing and head orientation), but these were individuals reared and extensively trained for other tasks by humans (e.g. for public shows in an aquarium). Of four horses, *Equus caballus*, tested, only one was skilful (McKinley & Sambrook 2000).

These studies indicate that there are at least two routes by which animals can become proficient at reading human communicative signals. On the one hand, studies with marine mammals and apes suggest that extensive interaction with humans (in the absence of domestication) enables subjects to use human-given cues. On the other hand, studies on dogs suggest that domestication alone, even in the absence of interactions with humans during ontogeny, is also sufficient to produce a similar outcome. However, it is unclear what traits have been selected to follow human cues. Alternatively, dogs' ability to follow human cues may derive from a more general effect of domestication. Therefore it is of interest to study another domesticated animal, not trained like the dolphins or seals, to investigate whether domestication alone would help an individual to perform well in an object choice task.

We investigated the social cognitive skills of domestic goats. Goats were domesticated at least 10000 years ago and therefore are thought to be the first ungulate domesticated by humans (Zeuner 1967; Luikart et al. 2001). Goats can cope with many different living conditions and therefore were an important food resource for humans at the time of domestication (MacHugh & Bradley 2001). Feral goats live in large, complex social groups with a strong linear hierarchy (Barroso et al. 2000), so some social cognitive skills could therefore be expected. We investigated the social cognitive skills of domestic goats in tasks of (1) gaze following to outside locations that they cannot directly see and (2) object choice. Evaluation of goats' skills in gaze following is important because there is no experimental evidence of gaze following in any non-primate species, and so it is unknown whether this is a specifically primate skill. Evaluation of goats' skills in the

object choice task is important because goats' were not domesticated to communicate with humans in the ways that dogs were (e.g. for herding and hunting), and the individuals we tested, unlike the seals and dolphins, had no special amount or type of training.

EXPERIMENT 1: GAZE FOLLOWING

In this experiment we replicated the procedure of Tomasello et al. (1998) using domestic goats as subjects to investigate whether mammals other than primates follow the gaze direction of conspecifics.

Methods

Subjects

Subjects were 10 domestic goats housed in a social group in a relatively small outdoor (10 × 15 m) and indoor (2 × 5 m) enclosure in the zoological garden of Leipzig, Germany, tested with the permission of the Zoo's veterinarians. The group consisted of 10 adults (one male and nine females) and a variable number of juveniles. All animals were reared by their mothers except Knickohr who was reared by humans (Table 1). The group was fed three times per day in the morning, at noon and in the evening throughout the study. The diet consisted of vegetables, hay and grass. The daily caretaker routine consisted of feeding the animals and cleaning the cages once a day. During these activities direct contact between

Table 1. Name, age, gender and group of the subjects that participated in experiments 1 and 2

Name	Age	Gender	Group	Experiment
Haesslich	10 years	Female	Leipzig	1
1links	11 years	Female	Leipzig	1
Halbohr	11 years	Female	Leipzig	1
Nichts	11 years	Female	Leipzig	1, 2
2limi	8 years	Female	Leipzig	1, 2
2links 1 oben	2 years	Female	Leipzig	1
1 rechts	2 years	Female	Leipzig	1
Bock	Unknown	Male	Leipzig	1
Knickohr	6 years	Female	Leipzig	1, 2
Kleine	Unknown	Female	Leipzig	1, 2
Maedchen	Unknown	Female	Leipzig	2
Kluge	9 years	Female	Leipzig	2
Trudi	Unknown	Female	Hirschfeld	2
Weissohr	Unknown	Female	Hirschfeld	2
Lisa	Unknown	Female	Hirschfeld	2
Puenktchen	Unknown	Female	Hirschfeld	2
Marie	Unknown	Female	Weissenfels	2
Schwarze	Unknown	Female	Weissenfels	2
Weissshuf	Unknown	Female	Weissenfels	2
Parallelhorn	6 months	Female	Hirschfeld	2
Spitzhorn	6 months	Female	Hirschfeld	2
Stumpfhorn	6 months	Female	Hirschfeld	2
Haarig	4 months	Female	Leipzig	2
Lotte	4 months	Female	Leipzig	2
Hanna	4 months	Female	Leipzig	2
Lili	4 months	Female	Leipzig	2
Max	4 months	Male	Leipzig	2
Franz	4 months	Male	Leipzig	2
Blacky	5 months	Male	Weissenfels	2

the caretakers and the animals was rarely observed; therefore we assumed that the subjects had little exposure to communicative cues. To move the animals, the caretakers reported that they usually use the broom with which they clean the cage and not pointing or any other communicative gestures. The zoo visitors are not allowed to feed the animals at any time. The animals were observed in their outdoor enclosure with free access to the indoor area at any time. The experiment was conducted from November 1999 to April 2000 and testing took place in the mornings before the first feeding time to ensure that the animals were highly food motivated. Water was available ad libitum and subjects were not food deprived at any time.

Procedure

The experiment was conducted by a single human standing outside and above the enclosure. For an experimental trial the experimenter (E) waited for spatial situations in which one goat (the subject) was facing away from E and the other (the looker) was in a position where it was in front of the subject facing E (Fig. 1). The setting for control trials was the same as for the experi-

mental trials except that there was no looker; the subject was standing by itself, back turned, with no conspecific nearby. The distance between looker and subject in experimental trials varied between ca. 1 and 3 m, as every potential trial setting was used. The same was true for the distance between the experimenter and the looker or subject, which, depending on the position of the animals in the enclosure, varied between ca. 1 and 5 m.

After identifying a potential trial setting, E held up a piece of apple in the air for 10 s (so that in experimental trials the looker could see it). After 10 s the food was thrown into the enclosure independent of the behaviour of the animals. E could reliably identify individuals and so took care that all adult individuals participated in a minimum number of trials of both types. All trials were videotaped from E's position.

Scoring

All scoring was done by J.K. from the videotapes. We conducted 97 experimental trials and 48 control trials. An experimental trial was considered successful when (1) the looker gave a visible cue such as raising/turning its head in the direction of E and (2) the subject was in a potential position to see this cue. Attempted experimental trials in which the looker gave no discernable cue were counted as No Cue trials. Attempted experimental trials in which the subject changed position before or while the cue was being given, and therefore was not in a position to see it, were counted as Cue Not Perceived trials. We used these latter two types of trials as secondary control trials, since the subject did not perceive a cue even though a looker was in the immediate area (either because the looker did not give one or the subject did not see it).

For both experimental and control trials, if the subject looked to E during the 10 s the food was in the air the trial was assessed as positive; otherwise it was assessed as negative. The definition of looking to E was that both eyes of the subject had to be visible in the video frame after the animal had turned its head in E's direction. Because all subjects received a different number of experimental and control trials we calculated percentages for any further analyses. A second observer independently scored 20% of the videotapes coding the type of trial and whether it was positive or negative. Interobserver reliability was excellent: Cohen's kappa = 0.96.

Results

Subjects looked at the food significantly more often in the successful experimental trials than in the control trials (Wilcoxon test: $T = 0$, $N = 9$, $P < 0.02$ Bonferroni corrected; Fig. 2). Because we could not be certain whether the subject perceived the cue given by the looker, we also compared all trials in which the looker gave a cue (i.e. all successful experimental trials plus all Cue Not Perceived trials) to control trials. Again subjects looked to E more in experimental ($56 \pm 7.6\%$) than in control trials (23%; Wilcoxon test: $T = 0$, $N = 8$, $P < 0.04$ Bonferroni corrected; Fig. 2).



Figure 1. (a) Two goats (top) look towards food with another goat (bottom) watching. (b) The subject follows the gaze of the conspecific and looks at the food.

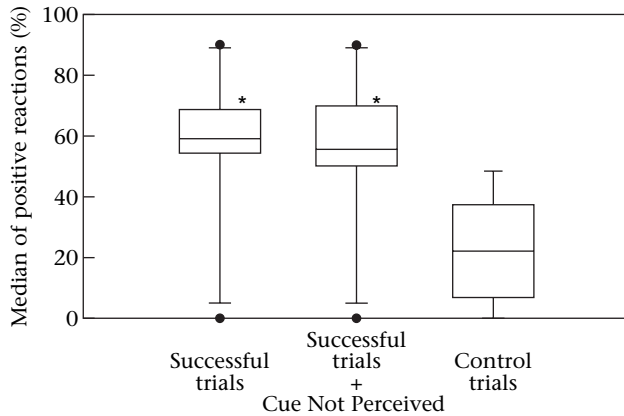


Figure 2. Box plot chart of percentage of positive reactions of the subjects as a function of experimental condition in experiment 1. *Indicates significant differences at $\alpha = 5\%$ level of experimental compared to control trials (Wilcoxon). The top, middle and lower horizontal lines show the 75th, 50th and 25th percentiles, respectively.

Discussion

The results of this experiment show that goats followed the gaze direction of conspecifics to an object above and behind them. They did this in almost 60% of the trials in which the looker gave a visible cue and the subject was in a potential position to perceive this cue. This is much more often than in control trials in which subjects were standing alone, and also much more often than in secondary control trials in which a cue was not given by the looker or not perceived by the subject. Furthermore, this result held even if the trials in which the subject apparently did not perceive the gaze cue (i.e. all those trials in which a cue was given) are included in the experimental trials. The results of this experiment are therefore comparable to the results of the primate study on which it was based (Tomasello et al. 1998).

One worry at the outset was that goats might be able to see behind themselves to some extent, since ungulate eyes are on the sides of the head. However, the relatively low rates of looking to E in the control condition, and also in the No Cue and Cue Not Perceived trials, provide clear evidence that this is not the case. In fact the looking rate in the control condition was even lower than for the pigtailed macaques in the Tomasello et al. (1998) study. It is also not the case that subjects were simply reacting to the body orientation of the looker in general, since this orientation was the same in the No Cue and Cue Not Perceived trials as in the successful trials (which produced more gaze following). Goats were thus reacting to the gaze cue.

Nevertheless, the current results do not allow us to determine which part of the gaze cue was effective for subjects, for example, head direction or eye direction. Kobayashi & Kohshima (2001) argued that detecting eye direction independently of head direction is a uniquely human skill, because among primates only human eyes have a large white sclera. As goats have no white sclera, their eye direction independent of head direction is hard

to detect, and so the most plausible hypothesis is that goats use head direction as the major cue.

Goats are domesticated animals, and some theorists have proposed that domestication reduces sensitivity to predators, because life with humans means most of all protection against predators (Hemmer 1990). If the function of goat gaze following is not scanning for predators, the most plausible hypothesis is that gaining information about food resources, or possibly the social interaction of groupmates (including mating opportunities), provided the adaptive context within which these skills developed. However, until other mammals (both wild and domesticated) are tested in this same paradigm, possible evolutionary scenarios must remain highly speculative.

From a cognitive point of view, gaze following can be explained in a number of ways. Individual goats could have learned that turning around when a conspecific lifts its head can have the advantage of finding something interesting; this is the so-called 'low-level' model (Povinelli & Eddy 1996b). Alternatively, individuals might have some understanding that other individuals see something different from what they see; this is the so-called 'high-level' (perspective-taking) model. Again, until there is more research, perhaps using more complex gaze following situations (e.g. looking behind barriers), this will have to remain an open question.

EXPERIMENT 2: OBJECT CHOICE

In experiment 2 we investigated whether goats can use not only cues of conspecifics in a gaze-following situation but also human-given cues to locate hidden food in the so-called object choice task.

Methods

Subjects

Subjects were 23 domestic goats from three groups. Thirteen were adult females (greater than 12 months of age) and 10 were juveniles, six males and four females (4–6 months of age). Four of the adult subjects had previously participated in experiment 1 (Table 1). Subjects were housed in relatively large social groups, with outdoor and indoor areas. All subjects were reared by their mothers, except Knickohr who was reared by humans. In two of the groups (Leipzig and Hirschfeld) the zoo visitors are not allowed to touch or feed the animals at any time and the animals had no substantial human contact beyond that involved in the normal caretaking procedures of the zoo (see Methods of experiment 1 for further details). In the third group (Weissenfels) the zoo visitors are allowed to enter the cage and touch and feed the animals. The experiment was conducted from August 2001 to September 2002. Subjects were fed according to their normal routine two to three times per day. Water was available ad libitum and subjects were not food deprived at any time during the study.

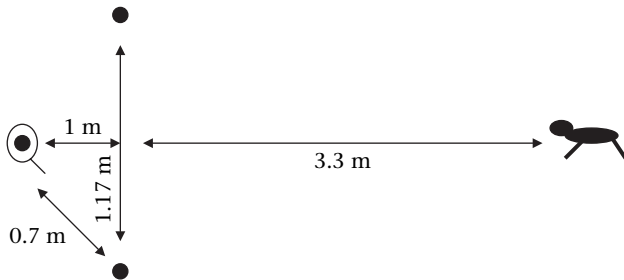


Figure 3. Experimental set-up for experiment 2. The two dots in the middle represent the two buckets. On the left is the experimenter, on the right the subject.

Procedure

Each individual was tested for its ability to find food after receiving different communicative cues. Testing was conducted individually in the indoor area, with subjects separated for ca. 15–20 min from the rest of the group. To separate one of the animals from the group the two experimenters entered the indoor area and attracted the focus animal to food (crispbread), while forcing the other animals to leave the indoor area through the sliding door. As soon as only the subject was in the indoor area one of the experimenters shut the sliding door. For each trial a human E stood on a predetermined point, with two identical inverted buckets (diameter 12 cm, 117 cm apart) at two predetermined locations in front of her. The experimenter was 70 cm from the two buckets (Fig. 3). Food (pieces of apple) was hidden under one of the buckets. Across trials, food location was counterbalanced and randomly varied, with the stipulation that it was never placed in the same bucket/location for more than two consecutive trials.

Each trial was conducted as follows. During the baiting process the subject stayed in a waiting area separated from the rest of the group. The waiting area was connected to the test room by a sliding door, which was opened by a second human when the baiting by E was completed. As soon as the sliding door was opened the subject entered the test area, facing E who stood equidistant between the two buckets; E then gave the communicative cue towards the hidden food until the subject made a choice. There were four experimental conditions.

(1) Touch. E squatted in front of the buckets, looking at the subject and moved her equilateral arm repeatedly towards the correct bucket without looking at the bucket. Each time her hand touched the bucket without producing any noise.

(2) Point and Gaze. E stood in front of the buckets and continuously pointed to the correct bucket with the equilateral hand while alternating her gaze between the subject and the bucket. The distance between her index finger and the bucket was approximately 120 cm during the pointing, which would be classified as distal pointing (Miklosi & Soproni, *in press*).

(3) Head and Gaze. E stood in front of the buckets and alternated her gaze between the subject and the correct bucket. The distance between the head and the bucket was approximately 160 cm during the gazing.

(4) Control. E stood in front of the buckets without moving and stared at a predetermined point on the opposite wall.

Each subject received 18 trials per condition, for a total of 72 trials altogether. Conditions were counterbalanced and presented to the subject in sessions of eight mixed trials each, nine sessions per subject. Sessions were at least 24 h apart.

In almost all trials subjects went straight to one of the buckets, indicating their choice by touching the bucket with the snout. If the subject was correct, E turned with the bucket and the subject was allowed to have the food. If incorrect, the subject was shown the empty bucket and then the food under the correct bucket without being allowed to eat it. All trials were videotaped.

Scoring

The first bucket that the subject touched was counted as its choice on that trial. Subjects' responses were unambiguous, and they touched one bucket in every trial. All scoring was done by J.R. from the videotapes. A second observer independently scored 20% of all trials. Interobserver reliability was excellent: Cohen's kappa = 0.99.

Results

Binominal tests (two tailed) showed that 14 subjects were significantly above chance in the Touch condition whereas five subjects were above chance in the Point condition and only one in the Gaze condition (Table 2). No subject was above chance in the control condition.

A repeated measures ANOVA with the within-factors condition and the between-factors group (Leipzig versus Hirschfeld versus Weissenfels) and age (adult versus juvenile) showed a significant main effect only for condition ($F_{3,54} = 21.25$, $P < 0.0001$) and no significant interaction between the factors. The factors group and age were therefore not considered in further analyses.

Post hoc pairwise comparisons (Bonferroni corrected) between each experimental condition and the control condition revealed significant differences for the condition Touch ($P < 0.0001$) and for the condition Point ($P = 0.025$). In both conditions the subjects chose the correct bucket significantly more often in the experimental than in the control condition. In contrast there was no difference between the Gaze and the control condition ($P = 1.000$).

To test for a learning effect, we compared the first and second halves of trials. A repeated measures ANOVA with the factors condition and block (first 9 trials versus second 9 trials) showed a significant effect of block ($F_{1,22} = 16.207$, $P = 0.001$) and condition ($F_{3,66} = 25.87$, $P < 0.0001$). There was no interaction effect ($F_{3,66} = 1.45$, $P = 0.236$). Goats chose the correct bucket significantly more often in the first block of trials than in the second block of trials (block 1: $\bar{X} \pm SE = 5.85 \pm 0.146$, $N = 23$; block 2: 5.17 ± 0.157 , $N = 23$). This could be due to subjects developing a bias for one particular side. Subjects thus did not learn to use the cues during the experiment.

Table 2. Number of correct choices across conditions for each individual in experiment 2 (total number of trials = 18)

Subject	Condition			
	Touch	Point	Gaze	Control
Adults				
Nichts	10	8	8	11
2limi	18*	14*	8	9
Knickohr	17*	12	12	6
Kleine	14*	10	9	9
Kluge	18*	11	6	8
Maedchen	12	9	10	8
Trudi	14*	9	7	10
Weissohr	13†	10	14*	10
Lisa	11	13†	9	9
Puenktchen	18*	17*	10	9
Marie	11	12	8	11
Schwarze	11	7	8	11
Weisshuf	16*	10	8	10
Adult $\bar{X} \pm SE$	14.1 ± 0.83	10.91 ± 0.75	9 ± 0.58	9.3 ± 0.39
Juveniles				
Parallelhorn	15*	11	9	8
Spitzhorn	18*	17*	11	8
Stumpfhorn	17*	11	10	7
Haarig	18*	14*	10	10
Lotte	17*	13†	11	4
Hanna	14*	11	11	7
Lili	10	11	9	9
Max	11	10	10	12
Franz	12	14*	13†	8
Blacky	14*	9	9	8
Juvenile $\bar{X} \pm SE$	14.6 ± 0.92	12.1 ± 0.75	10.3 ± 0.39	8.1 ± 0.65
All $\bar{X} \pm SE$	14.3 ± 0.61	11.4 ± 0.54	9.6 ± 0.39	8.8 ± 0.37

*Data points that are significantly above chance (two-tailed binomial test).

† $P = 0.096$.

Discussion

Domestic goats were able to use the touching/tapping cue and the pointing cue given by the human experimenter. In contrast there was no evidence that they used the gaze cue. With the touching/tapping cue, more than two-thirds of the subjects performed at above the chance level as individuals (and every individual was numerically above 50% correct). Compared with the other cues, however, touching/tapping has a clear component of local enhancement or stimulus enhancement, as the subjects' attention may be drawn to the movement produced directly on the correct bucket.

The goats also used the pointing cue effectively, although in this case the results were not quite as strong (about one-third of the subjects performed at above the chance level as individuals). To some degree, a kind of local enhancement or stimulus enhancement may also be at work here, as a normal pointing cue naturally draws the subject's attention in the direction of the correct bucket, although not all the way to it.

On the one hand these results are generally comparable to those with dolphins (Tschudin et al. 2001) and fur seals (Scheumann & Call, in press) and even better than those for horses (McKinley & Sambrook 2000), since only one of

the four horses tested used a pointing cue effectively in this task. On the other hand they are not as strong as the results for domestic dogs, since almost three-quarters of individuals of this species perform at above the chance level with a pointing cue (see especially Hare et al. 1998; McKinley & Sambrook 2000; Soproni et al. 2001). Furthermore, dogs have also performed successfully with various forms of pointing in which the extended finger is not physically closer to the correct than to the incorrect bucket (so-called cross-pointing and belly pointing; Soproni et al. 2002); none of the other species has been tested with these variations.

The goats in this experiment as a group did not use the gaze direction cue effectively. Only two of the 23 subjects used the Head and Gaze cue to find the hidden food. On the surface, this is a puzzling finding since in the first experiment they did follow gaze effectively to outside targets. Of course in the current experiment the looking was done by a human, but probably more importantly, the gaze cue produces very little in the way of local enhancement or stimulus enhancement in the direction of the correct bucket. Thus, with the tapping and to some degree even with the distal pointing cues, the subject could see the cue and the target without changing its head direction very much, since the cue was near the target, whereas the gaze direction cue required subjects to look to the human face away from the buckets. However, the three other nonprimate species tested with both pointing and looking, dogs, dolphins and fur seals, all used both of these cues at similar levels, whereas in another study none of four horses used looking as a cue (McKinley & Sambrook 2000). So out of three domesticated species (dog, horse and goat) only one species, the dog, seems to use looking as a communicative cue in an object choice situation. The successful performance of dolphins in this task (Tschudin et al. 2001) and that of the fur seals (Scheumann & Call, in press) and the grey seal (Shapiro et al. 2003), of course, cannot be explained by domestication, but might be at least partially explained by the extensive experience of the individual subjects, which were trained by humans to respond to various human cues, for example for performances in public shows (Tschudin et al. 2001; Scheumann & Call, in press).

Of these three domesticated species, the dog is the only one where facial expressions and the face itself are important for communication (Zimen 1990). So one reason why dogs are especially good at using gaze cues may be that for dogs facial expressions are important and they therefore naturally watch the face of humans (Miklosi et al. 2003).

With regard to learning, three facts are important. First, the young goats in the current study, age 4–6 months, were as skilful at using the cues of tapping and pointing as were the adults. Second, only four of our 23 subjects had had contact with humans, except the regular contact associated with zoo caretaking, and as there were no group differences in the results this contact did not seem to play any role. Third, the subjects in the current experiment did not improve their performance over trials; in fact their performance decreased. For all of these reasons, it is unlikely that our subjects' performance was

due to learning from humans, either before or during the experiment. This accords also with the recent findings of Hare et al. (2002), who showed that dog puppies at 2–6 months of age, even those who had experienced virtually no human contact, effectively used two different cues in the object choice task.

GENERAL DISCUSSION

Our experiments had two basic results. First, domestic goats followed the gaze direction of conspecifics to outside objects/events, and they did this at the same general level as primates. Second, they were able to use some cues in the object choice task to locate hidden food. We discuss the cognitive and evolutionary implications of each finding.

From a cognitive point of view, following the gaze direction of others can reflect a number of different cognitive processes. As noted above, simply following gaze direction may reflect processes of local or stimulus enhancement, or cue learning, or it may reflect processes involving an understanding of the other's visual experience or perspective. To discriminate between these possibilities in the case of goats further studies are needed. For example, they could be tested for their ability to follow gaze direction behind barriers or past distractors (Tomasello et al. 1999), or they could be tested with conspecifics in their ability to discern whether a competitor is or is not able to see food behind a barrier (Hare et al. 2000, 2001).

From an evolutionary point of view, it may be that, even though they both involve sensitivity to gaze, different functions are served by following gaze direction to outside objects and by detecting the gaze of others directed at oneself. Thus, food-caching birds and other animals must be able to detect eyes directed at them at certain points in the caching process if they are to forage and cache effectively (Emery & Clayton 2001), and knowing when predators are watching is important for survival. Following gaze direction to outside objects, in contrast, is less about protecting oneself or one's food and more about gathering useful information about important objects or events in the surrounding environment.

Our second finding was that domestic goats used cues in the object choice task to locate hidden food. From a cognitive point of view, their use of the touching/tapping cue is not surprising, as it obviously involves local or stimulus enhancement. Their use of the pointing cue is more surprising, although it may be subject to different interpretations. Thus, the pointing also drew the subjects' attention in the direction of the correct bucket (although presumably less so than tapping/touching), and so again a kind of local or stimulus enhancement may be playing some role. Support for this interpretation comes from studies with chimpanzees in which subjects were able to use effectively a pointing cue in the object choice task only when it was provided close to the target, although in our study the pointing was still some distance from the target. Further support for this interpretation comes from the fact that our subjects did not use gaze direction as a cue in the object choice task, even though they were able to follow gaze direction in the first

experiment, a more naturalistic situation. Gaze direction supplies very little in the way of local or stimulus enhancement, and indeed subjects in this study had to look away from the buckets to detect the gaze cue. Resolution of the question of how goats understand the pointing cue in this task awaits further experiments in which pointing cues are given at different proximities to the target and with unequal topographies (Soproni et al. 2002).

From an evolutionary point of view, the function of being able to read human communicative cues to locate hidden food is not clear. In their natural environments nonhuman animals do not normally experience conspecifics pointing, for example, and other individuals (conspecifics or otherwise) do not normally stare at food right in front of them, refraining from taking it, in order to indicate its location for others. We have thus hypothesized that perhaps experience with humans, who in some cases encourage animals to follow their communicative cues, is an important factor. Thus, the experts at this task are domestic dogs, who have been domesticated to live in human society and to follow human directions in such activities as herding and hunting (Coppinger & Coppinger 1998). On the basis of what little data there are, goats and, to a much lesser extent, horses show some skills as well. However, horses and goats were not domesticated for the same purposes as dogs; they do not live in as close proximity to humans as do dogs nor do they work as closely with them (MacHugh & Bradley 2001). Nevertheless, reacting to human cues may be a side-effect of domestication for goats as well as for dogs. To avoid getting bitten by herding dogs, goats may learn to react to the cues of the shepherd, and humans may have selected the ones that have been the easiest to herd. There is some anecdotal evidence that sheep sometimes react to the cues of the shepherd without herding dogs being needed at all (Byrne 1995).

The wild ancestors of dogs, wolves, do not do well in the object choice task (Hare et al. 2002; Miklosi et al. 2003). Goats have been domesticated for at least 10 000 years (Luikart et al. 2001), almost as long as dogs. The necessary comparison in this case (analogous to the wolf–dog comparison) would be to the wild ancestor of the domestic goat, the wild goat, *Capra aegagrus*. Unfortunately, our attempts to test wild goats were unsuccessful, as they were very fearful and refused to come close to the human experimenter even after a habituation period of several days.

Since dolphins and seals are not domesticated animals, their skills in this task must come from somewhere different, perhaps from their extensive individual experience with humans, although this possibility has never been tested. Wolves and chimpanzees, some with much experience with humans and many opportunities to learn in experiments, are less skilful in this task than either young goats or dog puppies. This leads to the hypothesis that domestication by humans in some way contributes to animals' ability to read human communicative cues. Horses have been domesticated for about 5000 years (Jansen et al. 2002), and, although the data are sparse, their performance does not seem quite as solid as that of goats (McKinley & Sambrook 2000). Our study represents an attempt to begin to investigate the social cognitive skills of animal species other than primates. Such investigations are necessary if we wish to reconstruct the

evolution of cognitive skills and to understand their ecological foundations.

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