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ORIGINAL PAPER

Sensing sociality in dogs: what may make an interactive robot social?

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Abstract This study investigated whether dogs would engage in social interactions with an unfamiliar robot, utilize the communicative signals it provides and to examine whether the level of sociality shown by the robot affects the dogs' performance. We hypothesized that dogs would react to the communicative signals of a robot more successfully if the robot showed interactive social behaviour in general (towards both humans and dogs) than if it behaved in a machinelike, asocial way. The experiment consisted of an interactive phase followed by a pointing session, both with a human and a robotic experimenter. In the *interaction phase*, dogs witnessed a 6-min interaction episode between the owner and a human experimenter and another 6-min interaction episode between the owner and the robot. Each interaction episode was followed by the *pointing phase* in which the human/robot experimenter indicated the location of hidden food by using pointing gestures (two-way choice test). The results showed that in the *interaction phase*, the dogs' behaviour towards the robot was affected by the differential exposure. Dogs spent more time staying near the robot experimenter as compared to the human experimenter, with this difference being even more pronounced when the robot behaved socially. Similarly, dogs spent more time gazing at the head of the robot experimenter when the situation was social. Dogs achieved a significantly lower level of performance (finding the hidden food) with the pointing robot than with the pointing human; however, separate analysis of the robot sessions suggested that gestures of the socially behaving robot were easier for the dogs to comprehend than gestures of the asocially behaving robot. Thus, the level of sociality shown by the robot was not enough to elicit the same set of social behaviours from the dogs as was possible with humans, although sociality had a positive effect on dog–robot interactions.

Keywords Dogs · Robots · Third-party interactions · Pointing

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Introduction

Dogs often live in close relationships with humans, and many individuals excel in engaging in cooperative interactions with people (Naderi et al. 2001). It has been assumed that such skills emerged out of dogs' preference for complex social interactions with humans (e.g. Topál et al. 2009).

Numerous studies have shown that dogs are sensitive to human behaviour in a wide range of dyadic interactive situations. A recent study showed that dogs are able to adapt their human directed behaviour to the actions of their human partner (Horn et al. 2011), that is, the experience of previous interactions with a human partner affected subsequent dog-initiated interactions with that person in a problem situation. Gácsi et al. (2004) demonstrated that dogs are able to detect the attentional state of humans based on body and head orientation and on the visibility of the eyes, in a begging situation. Dogs' sensitivity to human ostensive-communicative signals (e.g. gaze alterations) also has a strong effect on their performance in an object choice task (e.g. the "A not B" object search task; Topál et al. 2009). Human social influence may even elicit counterproductive behaviour in a food-choice situation in dogs. Dogs prefer to choose the location of food that is indicated by humans, even if this amount is significantly smaller than the food at the alternative location (Prato-Previde et al. 2008).

As a special case of dog–human dyadic interactions, dogs' utilization of human gestural cues has also been widely investigated and examined from different aspects (Hare et al. 2002; Miklósi and Soproni 2006; Gácsi et al. 2009a, b; Lakatos et al. 2007). Previous studies investigating the importance of human-likeness of the signaller showed that a socially interactive projected image of a human signaller can be a viable alternative in experimental work with dogs (Pongrácz et al. 2003).

Additionally, social animals are often sensitive to triadic interactions, usually referred to as "eavesdropping" (e.g. McGregor 1993). In these cases, the observer gains some knowledge by watching (or listening to) social interactions between two other individuals and then utilizes it in subsequent actions or interactions.

Eavesdropping has received relatively little attention in the context of dog–dog or human–dog interactions. In the case of triadic human–dog interactions, dogs seem to rely on gaze direction to detect whether a command was directed at themselves or at another individual (human) (Virányi et al. 2004). Rooney and Bradshaw (2006) studied dogs' understanding of third-party interactions in a play context. Having observed playing human–dog dyads, observer dogs preferred to interact with the human who showed more play signals. More recently, Marshall-Pescini et al. (2011) investigated whether dogs are able to deduce humans' "generous" or "selfish" character based on food-sharing interaction between them. In a subsequent choice test, dogs preferred to interact with the human who behaved generously.

In summary, there is some evidence that by observing social interaction between dogs or between humans and dogs, dogs are able to extract information which they can advantageously utilize in future decisions.

The use of robots in ethological research has many advantages. From an ethological perspective, by using a robot, we can investigate the importance of life-likeness of a communicative partner for the dogs. In addition, by working with a social robot, we can investigate the attribution of sociality per se, without the confounding factor of morphological similarity to humans. A further advantage is that experimenting with robots enables ethologists to carry out experiments that are free from the threat of the Clever Hans effect (Pfungst 1911).

Outside of the field of ethology, studies such as this can also provide important contributions to social robotics (Fong et al. 2003) since they can provide information on how to construct an efficient and believable social robot partner. It has been assumed that socially interactive robots—often inspired by biological systems—may integrate into human society in the future (Jones et al. 2008) as they can fulfil a variety of purposes, e.g. as household assistants, educational tools or as therapeutic aids. In this regard, the methodology of testing dogs' behaviour with robots (or testing robots' efficiency with dogs) offers two important innovations. First, using simple socio-cognitive models, the robots' behaviour can be tested to determine how the biological partner reacts to them in a given situation. Second, utilization of dogs has the advantage of using unbiased subjects that may react to the robot per se and are not influenced by other cultural factors including individual presumptions towards interaction with robots, movie portrayal of robots, etc. Thus, behavioural research involving dogs might help designers and engineers discriminate between socially acceptable and unacceptable robots.

In the present study, we aimed to examine whether dogs are able to interact with an unfamiliar robot and whether they are able to attribute sociality to this non-living agent. The robot used in this study (see the "Apparatus" section below) is human sized and has two "arms", but it does not resemble humans in any other way. In two experimental groups, we manipulated the quality of the interaction with the robot so that the robot showed either a socially enriched humanlike behaviour or a rather machinelike asocial behaviour towards a human (the owner of the dog) in the presence of the dog and towards the dog itself. As a first step, dogs could observe an interaction (either social or asocial depending on the group) between the robot and their owner (triadic interaction), and then, the dogs were given the opportunity to become engaged in a communicative interaction with the robot themselves (dyadic interaction). In order to test the communicative interaction performance, we utilized a two-way choice test in which the hidden food was signalled (pointed at) by either a human or a robotic experimenter (see Miklósi and Soproni 2006 for a review of dogs' performance to pointing).

We hypothesized that a robot, which is able to use verbal communication and call a dog by its name, conveys a higher level of sociality than a robot which is not able to speak. In the case of humanoid robots, it has been previously claimed with human partners that it is a necessity to use natural language for open communication and that the communication must be speech-based (Steels 2001). The importance of verbal communication in attention getting has also been demonstrated earlier in dogs (e.g. calling the dog by its name: Kaminski et al. 2012; Pongrácz et al. 2004). Therefore, we can assume that verbal communication would enhance believability and social acceptance also in the context of humanoid robots and non-human receivers.

We predicted that dogs would be more interested and show more social behaviour with the robot, as well as perform better in a communicative interaction test (two-way choice test based on pointing gesture, e.g. Hare et al. 2002; Miklósi and Soproni 2006; Gácsi et al. 2009a, b; Lakatos et al. 2009), when the dogs had observed the robot behaving in a humanlike way (e.g. capable of verbal communication) compared to when it shows machinelike behaviour.

Materials and methods

Subjects

Forty-one dogs participated in this study, twenty-one males and twenty females; the dogs were $4.52 + 2.45$ (mean + SD) years old (the range was 1.5–13 years). Thirty-one individuals were naïve, and ten individuals had participated previously in other experiments using gestural communication between dogs and humans (Lakatos et al. 2009). The participation of these experienced individuals was balanced between the social and the asocial group (see below).

Some of the video recordings were lost due to video recording failure and could not be analysed later. Thus, the behaviour of twenty-nine dogs was analysed in the *social interaction phase*, and the behaviour and performance of thirty-seven dogs were analysed in the *pointing phase*. The behaviour of twenty-five dogs was analysed in both phases, although all the dogs who participated in the pointing phase had previously participated in the interaction phase.

General method

Each dog witnessed two 6-min interactions between the owner and the human experimenter, and between the owner and a robot. Both interactions were followed by a two-way choice test using pointing actions as cues with the corresponding partner, either the human experimenter or the robot ("Pointing test", see below).

The dogs were divided into two groups depending on the nature of human–robot interaction (see also Table 1). In the case of the *Asocial Group* (interaction phase: $N = 14$; pointing phase: $N = 17$), one set of the subjects (interaction phase: $N = 8$; pointing phase: $N = 10$) first observed an interaction between two humans (the owner and the human experimenter) followed by observing an "asocial" interaction (see below) between the owner and the robot. The remaining dogs (interaction phase: $N = 6$; pointing phase: $N = 7$) participated in these interactions in the reverse order.

In the case of the *Social group* (interaction phase: $N = 15$; pointing phase: $N = 20$), one set of dogs (interaction phase: $N = 7$; pointing phase: $N = 10$) watched an interaction between the owner and the human experimenter followed by observing a "social" interaction (see below) between the owner and the robot. The remaining dogs (interaction phase: $N = 8$; pointing phase: $N = 10$) participated in these interactions in the reverse order.

Apparatus

Experiments were carried out using a customized PeopleBot mobile platform (Fig. 1) equipped with a 5 degree range of freedom robotic arm that had a four-fingered hand. The PeopleBot robot is a differential-drive mobile robot used for service and human–robot interaction (HRI). The PeopleBot is built on the robust P3-DX base and has a chest-level extension with a touchscreen mounted on its top to facilitate interaction with people. The robot is manufactured by the MobileRobots company. The arm used in experiments has been designed for simple gesticulation tasks, but is also capable of grasping objects. The robotic arm, which was designed at the Wroclaw University of Technology, consists of 2 links connected via a single 1 degree of freedom joint (1DOF). The arm is mounted to the robot body via a 3DOF joint and is endowed with another 1DOF joint, to which a hand is mounted. The hand is composed of four 1DOF fingers. The thumb and the index fingers are driven by two separate micro servos. The other two fingers are driven by one shared micro servo. In the construction, digital servos DYNAMIXEL (RX-64, RX-28) and standard, 8-gram micro servos are used. An arm mock-up endowed with a dedicated dog food feeder was mounted on the robot. The robot was controlled by an industrial PC computer running under the Ubuntu Linux with real-time Xenomai (http://www.xenomai.org) extension. It was responsible for two main tasks. First, it executed motion commands sent from the remote operator interface. Second, it controlled robot movements including the mobile base, the arm and the feeder. During the experiments, the robot base was remotely controlled by an operator in accordance with the experiment scenario. Gestures performed by the robot were pre-programmed, and their execution was controlled by the operator. Communication with the robot was carried out by Player/Stage framework (http://playerstage.sourceforge.net/) infrastructure. In the case of verbal communication, words/sentences were pre-recorded with a human voice (female) and played back by the robot.

Table 1 Short overview of the experimental procedure

	Interaction I	Pointing test I	Interaction II	Pointing test II
Asocial group	Owner–human experimenter ($N = 8$)	Human experimenter ($N = 10$)	Owner–robot experimenter ($N = 8$)	Robot experimenter ($N = 10$)
Asocial group	Owner–robot experimenter ($N = 6$)	Robot experimenter ($N = 7$)	Owner–human experimenter ($N = 6$)	Human experimenter ($N = 7$)
Social group	Owner–human experimenter ($N = 7$)	Human experimenter ($N = 10$)	Owner–robot experimenter ($N = 7$)	Robot experimenter ($N = 10$)
Social group	Owner–robot experimenter ($N = 8$)	Robot experimenter ($N = 10$)	Owner–human experimenter ($N = 8$)	Human experimenter ($N = 7$)

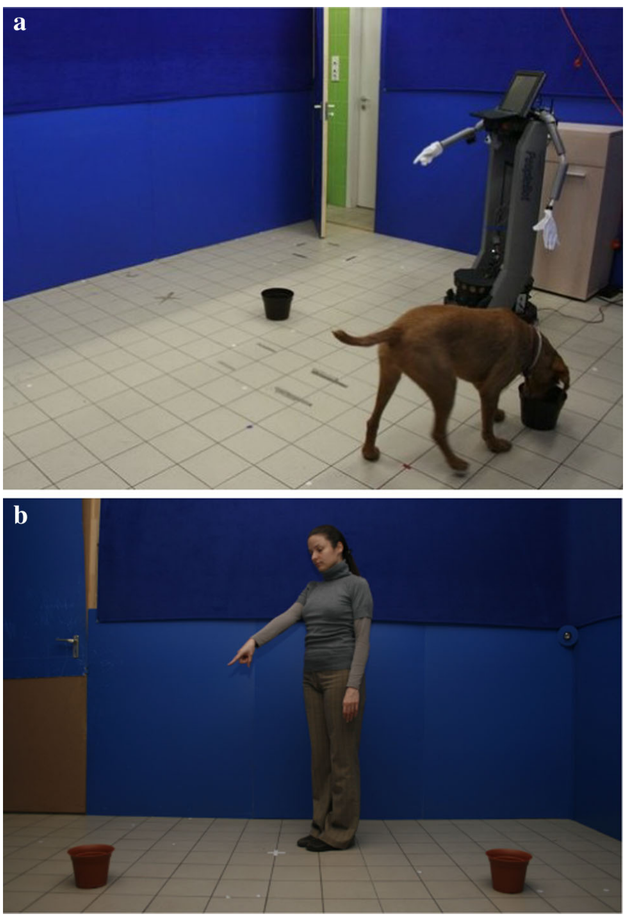

Fig. 1 **a** The customized PeopleBot mobile platform, which was equipped with a 5 degree of freedom robotic arm endowed with a four-fingered hand. **b** The human experimenter adjusted her movements to the physical abilities and constraints of the robot. The robot had only one moveable pointing arm, and thus, the human experimenter always used the same arm for pointing

The behaviour of the human experimenter was adjusted to the physical abilities and constraints of the robot. The robot had only one moveable pointing arm (the right one), and thus, the human experimenter used always the same (right) arm for pointing.

Procedure

Human experimenter session

Social interaction phase

This interaction phase lasted 6 min and consisted of five sub-phases, which occurred consecutively.

(1) The dog and the owner entered the room where the human experimenter was located. The owner stood next to the door for half a minute, while the dog had the opportunity to explore the room (30 s). (2) The owner approached the experimenter and shook hands with her, and they started a conversation (30 s). (3) The owner and the experimenter touched each others' arms and continued talking to each other (60 s). (4) The owner and the experimenter walked around in the room together and finally arrived back at the starting position where they continued talking until the end of this sub-phase (180 s). (5) At the end of the fifth minute, the experimenter called the dog's name and dropped a piece of food on the floor in front of the dog, and the dog was allowed to eat it. This was repeated three times (60 s).

Pointing phase

Pre-training: familiarization with the situation

We used the same method as described in earlier studies (e.g. Lakatos et al. 2009). The pointing experimenter (G.L.) placed two bowls (brown plastic flower pots: 13 cm in diameter, 13 cm in height) in front of her, 1.3–1.6 metres apart, on the floor. In the presence of the subject, the experimenter put a piece of food (a small piece of frankfurter) into one of the bowls. The subjects could witness this hiding process from a distance of 2–2.5 m while their owner stood behind them. After the experimenter put the food in the bowl, the owner allowed the dog to take the food from the bowl. One trial lasted about 30 s, and the procedure was repeated twice for each bowl to ensure that the subject knew that either bowl might contain some food.

Testing

The 4 pre-training trials were followed by 24 pointing trials (test trials). The position of the participants was the same as described above, but during the testing, the subject was prevented from observing the hiding location of the baited bowl with the help of an assistant. The pointing experimenter (pointer) picked up the bowls, and after that the assistant carried a barrier into the room and placed it in front of the pointer. The pointer then put a piece of food into one of the bowls and placed both bowls back onto the floor behind this barrier so that the dog could not witness the hiding and where the baited bowl was placed. After the hiding was completed, the assistant carried the barrier out of the room. During the actual pointing gesture, the pointer was standing 0.5 m back from the middle line between the two bowls, facing the subject at a distance of 2–2.5 m.

In the pointing test, the human pointer acted in accordance with the technical limitations of the robot. The signalling experimenter displayed the pointing signal using only her right arm for both hiding directions. In order to gain the attention of the dog, the pointer pulled up her arm in front of her body by bending her elbow, she then moved her fingers and called the dog by its name. The experimenter then turned her whole body towards the baited pot while displaying the pointing gesture.

Two types of gestures were used in an equal number of trials (see also Lakatos et al. 2009):

Momentary pointing gesture: The arm of the experimenter signalled the baited pot for 1 s, and then, she lowered her arm, turned back to face the dog and the dog could choose a pot only when the experimenter's arm was already in resting position next to her body.

Dynamic (sustained) *pointing gesture:* The experimenter kept her arm in a signalling position while the dog was making its choice.

The different kinds of trials were presented in a predetermined semi-random order (e.g. Lakatos et al. 2009) so that neither the same side nor the same kind of gesture (momentary or dynamic) was presented more than two times in a row. If the subject did not set out at the first cue, the experimenter repeated the pointing gesture again, for a maximum of three times. The subject was allowed to choose only one bowl. If the dog made an incorrect choice, selected the location without food, the owner showed the dog the correct bowl but prevented the dog from eating the bait.

Robot experimenter session

Social interaction phase

The two different groups of dogs (*asocial group* and *social group*) were exposed to different types of 6-min interactions between their owner and the robot. Each interaction consisted of five sub-phases. Owners wore headphones, through which they were instructed by an assistant located in another room.

Socially deprived interaction (for dogs in the asocial group): (1) The dog and the owner entered the room where the robot was located, and the owner then stood next to the door for half a minute while the dog had the opportunity to explore the room. (2) The owner approached the robot, but instead of shaking hands and talking to the robot, the owner typed on the keyboard of the robot for 10 s with 30 s pauses (60 s). (3) The owner held out an arm as if they were asking for the arm of the robot, but the robot ignored the request. The robot performed the same action a few seconds later in order to make the dog aware that it was capable of performing these movements (60 s). (4) The owner and the robot walked around the room in opposite directions. When they arrived back at the starting point from opposite directions, the owner continued typing the keyboard of the robot for 10 s with 30 s pauses (180 s). (5) At the end of the fifth minute of the interaction, the robot called the dog's attention by emitting a "beep–beep" sound and dropped a piece of food on the floor in front of the dog, which the dog was allowed to eat. This was repeated three times. If the dog did not find the food, the owner could help the dog to find it.

Socially enriched interaction (for dogs in the social group): (1) The dog and the owner entered the room where the robot experimenter was located, and the owner stood next to the door for half a minute while the dog had the chance to explore the room (30 s). (2) The owner approached the robot and shook its hand, and they conversed with each other (30 s). (3) The owner and the robot touched each other's arms and continued speaking with one another (60 s). (4) The owner and the robot walked around the room together in the same direction, while talking continuously, and finally arrived back at the starting position (180 s). (5) The robot called the dog's name and dropped a piece of food on the floor in front of the dog, which the dog was allowed to eat. This was repeated three times, and if the dog did not find the food, the owner could help.

Pointing phase (two-way choice test)

The pointing phase with the robot was the same as it was with the human pointer in the test trials, with a few exceptions. In the robot session, two additional human assistants participated. The role of the second assistant was to give instructions from another room to the owner through previously placed headphones, while the role of the third assistant was to execute the hiding process instead of the robot in the test trials. The hiding procedure was hidden from the dogs' view by the barrier carried in by the first assistant, as it was done in the human pointing trials, so this modification in the procedure did not create any difference for the subjects. However, during the pre-training, the hiding of the food was done by the robot just as it was done by the human pointer in the human session.

The robot's attention-getting signal differed according to the group (asocial/social). In the asocial group, the robot got the dog's attention by pulling up its arm in front of its body by bending its elbow, and then, it moved its fingers and emitted a "beep–beep" sound. In the social group, the robot got the dog's attention by making the same movements, but in this group, the robot called the dog by its name.

Observed behavioural variables

Interaction phase

From the six-minute interaction phase, we analysed dogs' behaviour only in the second sub-phase, in which the owner and the robot became involved in interaction for the first time, as the following sub-phases' only purpose was to make the dogs see what kind of movements the robot was able to carry out, and these later sub-phases consisted of similar behaviour elements from the part of the robot in both groups. We predicted that if dogs interacted differently with the human and the robot experimenter (either in the social or in the asocial condition), there would be a difference in dogs' gazing behaviour and in the time spent in the vicinity of the experimenters. On the basis of this prediction, the following behavioural variables were observed:

Staying near human/robot experimenter: Time (s) spent sitting or standing next to the human experimenter/robot within a distance of one body length of the dog.

Approaching human/robot experimenter: Time (s) spent moving towards the human experimenter/robot from any distance and arriving within a distance of one body length of the dog.

Gazing at the "head" of human/robot experimenter: Time (s) spent gazing at the head of the human experimenter/the monitor of the Robot.

Gazing at owner: Time (s) spent gazing at the owner.

Apart from the principal coder (V.F.), a naïve observer (unaware of the test hypothesis) coded the behaviour of four dogs from both groups (eight dogs in total) using the list of behavioural units described above by looking at the videotapes. The calculation of the index of concordance yielded the following values: staying near human experimenter/robot: 0.88; approaching human experimenter/robot: 0.94; gazing at the "head" of human experimenter/robot: 0.93; gazing at owner: 0.93.

Pointing phase

The observed variables were the following:

Gazing at human/robot experimenter: Time (%) spent gazing at the human/robot experimenter.

Gazing at owner: Time (%) spent gazing at the owner.

Gazing at the baited bowl: Time (%) spent gazing at the baited bowl.

Gazing at the unbaited bowl: Time (%) spent gazing at the unbaited bowl.

All the variables were measured in percentage since the length of the trials could be different. Furthermore, in the case of "gazing at the baited bowl" and "gazing at the unbaited bowl" variables, we also measured the latencies in each trial.

Apart from the principal coder (V.F.), a naïve observer coded the behaviour of four dogs from both groups (eight dogs in total), also in the pointing session, on the basis of the list of behavioural units described above by looking at the videotapes. The index of concordance for the gazing directions was 0.82.

Statistical analysis

Behavioural variables observed in the interaction phase showed no significant departures from a normal distribution (Kolmogorov–Smirnov test), hence parametric procedures were used [repeated measures general linear model (GLiM)].

Analysis of the pointing phase was based on the number of correct choices. A response was considered correct if a dog chose the container that the experimenter pointed at. Effects of gestures type (dynamic versus momentary), type of experimenter (human versus robot), condition (social versus asocial situation) and the potential interaction of these factors were analysed by linear mixed model for performance data (%) after transformation of the data (SPSS, version 17). To analyse the dogs' performance at the individual level compared to the 50 % chance level, nonparametric procedures were used (binomial test).

Analysis of behavioural data in the pointing phase was based on parametric procedures (repeated measures GLiM and Paired t test).

Results

Behavioural analysis of the interaction phase

We performed repeated measures GLiM (within-subject factor: human versus robot experimenter; between-subject factor: social versus asocial situation) to analyse dogs' behaviour in the interaction phase.

Results revealed that dogs spent more time staying near the robot experimenter as compared to the human experimenter ($F = 5.236$, $df = 1$, $p = 0.03$), and this difference was even more pronounced in the social situation (interaction between the two factors: $F = 4.773$, $df = 1$, $p = 0.038$) (Fig. 2). Similarly, dogs spent more time approaching the experimenter when it was a robot ($F = 10.759$, $df = 1$, $p = 0.003$), and they spent more time gazing at their owner when encountering the robot experimenter ($F = 8.289$, $df = 1$, $p = 0.008$). In addition, the interaction between the two factors (type of the experimenter and condition type) in the case of the "gazing at the head of experimenter" variable, showed that dogs spent more time gazing at the head of the robot experimenter when the situation was social ($F = 4{,}316$, $df = 1$, $p = 0.04$) (Fig. 2).

Pointing phase (two-way choice test)

Analysis of the performance

Linear mixed model was used to assess the effect of gesture types (dynamic vs. momentary), type of experimenter (human vs. robot), condition (social vs. asocial situation) and the potential interaction of these factors on dogs' performance. In the model, performance data (in percentage) was taken as the dependent variable after arcsin transformation, gesture types, type of experimenter and condition were taken as fixed factors, and name of the dogs was set as random effect. According to the model that explains the data best (AIC = −17.88), both gesture type and the type of experimenter affected the success of finding the indicated object, and additionally, there was an interaction between these two factors. Condition had no significant effect according to the model. Dynamic gestures had a positive effect on the performance relative to the momentary ones (parameter estimate = 0.18, SE = 0.048, $df = 108$, $t = 3.90$, $p < 0.001$). Gestures displayed by the robot experimenter resulted in a lower performance than gestures given by the human experimenter (parameter estimate = −0.42, SE = 0.048, $df = 108$, $t = -8.77$, $p < 0.001$). In addition, the interaction between the two factors suggests that momentary gestures given by the robot experimenter resulted in an even lower performance (parameter estimate = −0.17, SE = 0.068, $df = 108$, $t = -2.46$, $p = 0.016$).

However, it is possible that the strong effect of the experimenter type (human vs. robot experimenter) on dogs' performance could mask smaller effects between the two robot sessions. Also, and even more importantly, we have to take into account that in the human sessions, the human experimenter behaved in the very same way in the social and in the asocial condition. Since the conditions differed only in the robot sessions (and not in the humans), we can get more accurate results on the effect of condition by further analysing dogs' performance only in the robot sessions. In further statistical analysis, linear mixed model was used again to assess the effect of gesture types (dynamic vs. momentary), condition (social vs. asocial situation) and the potential interaction of these factors. Similar to the model described above, performance data (in percentage) was taken as the dependent variable after arcsin transformation, gesture types and condition were taken as fixed factors, and name of the dogs was set as random effect. According to the model that explains the data best (AIC = −45.41), the condition affected the dogs' performance in the robot sessions, while the gesture type had no effect and there was no interaction between the two factors. Dogs showed lower performance in the asocial condition compared to the social condition (parameter estimate = −0.11, SE = 0.049, $df = 35$, $t = -2.26$, $p = 0.03$) (Fig. 3).

We also analysed dogs' performance at the individual level compared to the chance level (50 %). Signal utilization at the individual level was tested with binomial tests. Results showed that in the human sessions, a large number of dogs chose significantly above chance (10 out of 12 trials) at the individual level in both types of pointing gesture, while with the robotic experimenter, only a few dogs performed individually above chance in the social condition and none of them in the asocial condition (see Fig. 3).

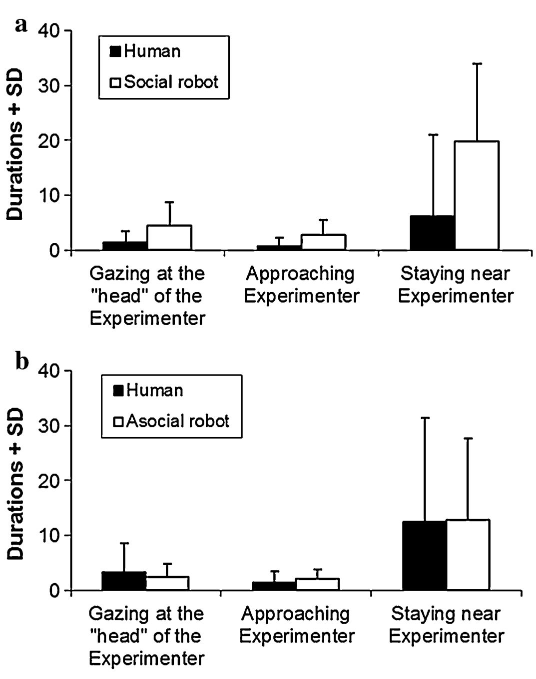

Fig. 2 **a** Dogs' behaviour in the interaction phase in the human and the robot sessions—social group; **b** dogs' behaviour in the interaction phase in the human and the robot sessions—asocial group

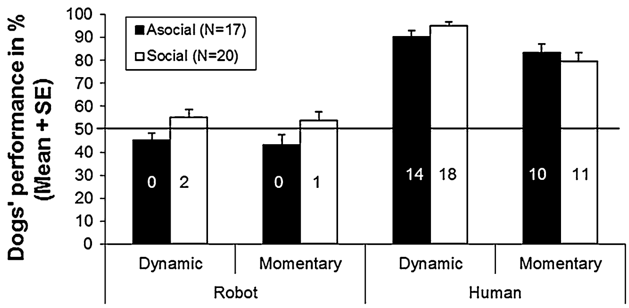

Fig. 3 Dogs' performance in the pointing sessions with the human experimenter and the robot. Numbers in the *bars* indicate the number of dogs performing higher than chance based on binomial test (10 out of 12 trials). Definition of "momentary pointing gesture": The arm of the experimenter signalled the baited pot for 1 s then she lowered her arm back to her side and turned to face the dog, once her arm was back at her side the dog could choose a pot. Definition of "dynamic pointing gesture": The experimenter kept her arm in a signalling position while the dog was making its choice

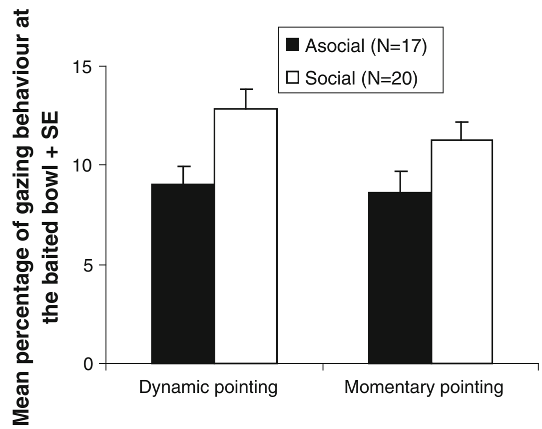

Fig. 4 Comparison of dogs' gazing behaviour towards the baited bowl in the social and in the asocial group with the robot experimenter

Behaviour analysis

In the behaviour analysis, we focused on dogs' gazing behaviour at the time of the pointing gesture, using repeated measures GLiM (within-subject factors: dynamic versus momentary gesture, human versus robot experimenter; between-subject factor: social versus asocial situation). Results showed that dogs gazed at the experimenter longer in the case of the momentary pointing gestures than in the case of the dynamic ones ($F = 23.70$, $df = 1$, $p < 0.0001$; means: momentary gestures: human experimenter: 54.89, robot experimenter: 48.52; dynamic gestures: human experimenter: 49.23, robot experimenter: 47.26). We also found that dogs looked at their owner longer when the gesture was displayed by the robot ($F = 5.81$, $df = 1$, $p < 0.05$; means: human experimenter: momentary gestures: 0.48, dynamic gestures: 0.27; robot experimenter: momentary gestures: 2.10, dynamic gestures: 1.87). In addition, dogs gazed at the baited bowl longer when the pointing signal was shown by the human experimenter ($F = 221.12$, $df = 1$, $p < 0.0001$) and they also gazed longer in the case of the dynamic pointing than with the momentary pointing ($F = 69.24$, $df = 1$, $p < 0.0001$) (means: human experimenter: momentary gestures: 29.73, dynamic gestures: 36.72; robot experimenter: momentary gestures: 10.06, dynamic gestures: 11.08). In addition, these results are strengthened by significant interactions between the within-subject factors (human vs. robot experimenter × dynamic versus momentary gesture) in the cases of the "gazing at experimenter" ($F = 8.13$, $df = 1$, $p < 0.01$), "gazing at the baited bowl" ($F = 24.84$, $df = 1$, $p < 0.0001$) and "gazing at the unbaited bowl" ($F = 35.0$, $df = 1$, $p < 0.001$) variables.

However, as in the performance analysis, we have to take into account the asymmetry of the experimental design (one condition in the human sessions and two conditions in the robot sessions) and the strong effect of the experimenter type (human versus robot experimenter) on dogs' gazing behaviour. For these reasons, we decided to analyse dogs' behaviour in the robot session separately. This repeated measures GLiM (within-subject factors: dynamic versus momentary pointing; between-subject factors: social versus asocial group) showed that dogs gazed at the baited bowl longer in the social group than in the asocial group independently of the type of gesture (between-subject effect of social versus asocial situation: $F = 6.69$, $df = 1$, $p = 0.014$; within-subject effect of dynamic versus momentary gestures: $F = 2.19$, $df = 1$, $p = 0.15$) (Fig. 4).

One can assume that if dogs can utilize a pointing gesture easily they will gaze to the baited bowl sooner than to the unbaited bowl, so we analysed dogs' latencies of looking at the two bowls. We found that in the human sessions, dogs gazed significantly earlier at the baited bowl than at the unbaited one. However, no such difference was found in the robot sessions (human session—asocial group: $t = 13.40$, $p < 0.0001$; human session—social group: $t = 14.45$, $p < 0.0001$; robot session—asocial group: $t = 1.37$, $p = 0.19$; robot session—social group: $t = 1.70$, $p = 0.10$). It is worth noting that while 12 out of 20 dogs (60 %) gazed earlier towards the baited bowl in the social group with the robot experimenter, only 8 dogs out of 17 (47 %) followed the pointing gesture of the robot with their gaze in the asocial group, although this difference was not significant.

In summary, both the behaviour analysis and the choice performance indicate that dogs processed the gestures made by the human signaller more easily. Furthermore, the dogs' performance analysis and gazing behaviour suggest that they could utilize dynamic pointing gestures more readily than the momentary gestures. In addition, separate analysis of the robot sessions suggests that dogs reacted more skilfully to the gestures displayed by the socially behaving robot, than to gestures of the asocially behaving robotic agent.

Discussion

Results of the present study provide some support for our prediction that dogs would be more attentive and behave more socially towards a robot behaving in a social manner and that the level of sociality shown by the robot would have a positive effect on dogs' comprehension of the communicative gestures of this non-living agent.

Results from the interaction phase showed that dogs' behaviour towards the robot was affected by the different types of exposure. It was especially revealing that dogs in the social group spent more time near the robot experimenter compared to the human experimenter and they looked more at the "head" of the robot in comparison with the human experimenter. This reaction could be explained by a novelty effect and could have resulted from the dogs' curiosity towards the socially behaving agent. However, if dogs' reaction was only a result of novelty effect, we could expect dogs to show similar behaviour towards the differently behaving agents. On the other hand, dogs' behaviour might have been a reaction to the unexpected social behaviour of a strange, machinelike being (shaking hands and talking, etc.) towards a human. There is a wealth of literature on humans (Aguiar and Baillargeon 1999, 2003; Wang et al. 2004) and non-human species including dogs (West and Young 2002) that such expectancy violation leads to extended looking. This experience may have changed the dogs' attitude towards the robot also when they confronted it in the pointing phase (two-way choice test). Also, dogs gazed more at their owner when the interacting partner was the robot than when the interacting partner was the human experimenter. This might have been a social referencing reaction on the part of dogs (Merola et al. 2012), looking at the owner to gain information about the robot.

Although dogs' performance was worse in the two-way choice task with the gesturing robot than with the gesturing human, we found that dogs in the social group were more successful than dogs in the asocial group. In respect of the dogs' performance with the human experimenter, this study not surprisingly provided further evidence that dogs readily respond to human cueing and can recover hidden food items. At the same time, dogs certainly have more experience with humans, and their gestures, than with robots.

Findings on dogs' gazing behaviour during the two-choice task were in line with the earlier choice results. Dogs gazed at the baited bowl longer when the pointing signal was shown by the human experimenter. This provides further support for previous findings that dogs can choose more easily on the basis of human given pointing gestures. In addition, in the robot sessions, dogs gazed at the baited bowl longer in the social group than in the asocial group, further suggesting that gestures displayed in the social situation were easier for the dogs to comprehend than gestures made in the asocial situation.

This latter difference could directly stem from the different way of attention getting, more specifically, from dogs' sensitivity to the usage of their name. While the social robot called the dog's name when addressing it, the asocial robot provided a machinelike sound. The positive effect of using a dog's name in attention getting has also been demonstrated in previous studies (e.g. Kaminski et al. 2012). The same effects have been found in social learning situations (Pongrácz et al. 2004), revealing that verbal attention getting makes social learning more effective.

At present, there are two non-exclusive cognitive accounts that might apply to dogs' behaviour in the pointing phase. Based on Tomasello (2008), one may assume that dogs' high performance in the pointing task indicates an ability to recognize both the communicative intent and the referential intent of the signaller in this situation. Although the second part of this assumption may be questioned by recent findings (see Lakatos et al. 2012), it may still be the case that dogs attribute a communicative and cooperative attitude to the pointing human. In the case of the robotic experimenter, dogs in the social group may have generalized previous experience from observing the human–robot interaction and attributed such humanlike skills to the robot during the pointing interaction as well, where the robot also behaved socially directly towards the dogs (e.g. addressing them by their name). The model of natural pedagogy introduced by Csibra and Gergely (2009) leads to similar predictions in the case of dogs (see also Topál et al. 2009), assuming that this species has been selected specifically for being sensitive to human behaviour cues associated with a teaching interaction. This theory places additional emphasis on the importance of ostension, that is, addressing the learner (in this case, the dog). Accordingly, the behaviour sequence utilized by the human experimenter and mimicked by the social robot is enough to evoke attention and expected action from the dog ("communicative imperatives"). However, it is important to note that the dogs' performance was quite poor also in the social robot session compared to their performance with the human gestural cues. This weak performance in the present study might have been the result of the less perfect behavioural coordination of the robot and of the lack of previous experience with robotic agents.

The second possible account of the dogs' behaviour in the pointing phase is in terms of experience with the human hand (Wynne et al. 2008). Such an effect of learning may have also played a role here because the robot "fed" the dogs before the pointing trials. However, as dogs had the same feeding experience with the social and the asocial robot, this does not explain the observed differences between the social and the asocial condition during the choice test. Additionally, if the experience with the human hand were enough to provide a basis for generalization, then one would have expected a better performance when dogs faced the robot experimenter. We should add that in this regard, our findings are not strong, which means that further testing to consider details of such influences will be necessary.

In pointing tests, researchers often apply a control procedure in which dogs choose in the absence of the pointing gesture. This is used to ensure that the successful performance is indeed controlled by the intended human cuing (pointing) only. It has been observed (e.g. Lakatos 2010) that dogs often do not choose readily in control situations when the experimenter is not pointing. In the case of the robot, we did not experience any resistance from the dogs to setting out and choosing (correctly or incorrectly). Irrespective of their success, dogs set out to look for the hidden food readily after the pointing gestures displayed by the robot during all trials, both in the social and in the asocial situation. This suggests that the pointing action provided by the robot was considered as a communicative signal by the dogs.

The present study may also provide insight for the design of social robots (Fong et al. 2003). Despite their lack of experience with robots, dogs appeared to attribute sociality to a robotic agent—which does not resemble a human—after having observed a social interaction between the robot and a human. Although the level of sociality shown by the robot was not enough to release the same set of social behaviours on the part of the dogs as that they show towards humans, it had a positive effect on dog–robot interactions. These findings suggest that enhancing sociality in robotic agents may be a good direction for roboticists to consider when designing interactive robots, independently from the embodiment of the agent.

In summary, utilization of robots as partners in experimentally staged social interactions may provide important insight into both the mental processes of living creatures and the design of social robots.

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