Anim Cogn (2017) 20:397–405
DOI 10.1007/s10071-016-1056-4

ORIGINAL PAPER

Domestic horses send signals to humans when they face with an unsolvable task

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Received: 24 April 2016 / Revised: 31 October 2016 / Accepted: 10 November 2016 / Published online: 24 November 2016

Abstract Some domestic animals are thought to be skilled at social communication with humans due to the process of domestication. Horses, being in close relationship with humans, similar to dogs, might be skilled at communication with humans. Previous studies have indicated that they are sensitive to bodily signals and the attentional state of humans; however, there are few studies that investigate communication with humans and responses to the knowledge state of humans. Our first question was whether and how horses send signals to their potentially helpful but ignorant caretakers in a problem-solving situation where a food item was hidden in a bucket that was accessible only to the caretakers. We then examined whether horses alter their behaviours on the basis of the caretakers' knowledge of where the food was hidden. We found that horses communicated to their caretakers using visual and tactile signals. The signalling behaviour of the horses significantly increased in conditions where the caretakers had not seen the hiding of the food. These results suggest that horses alter their communicative behaviour towards humans in accordance with humans' knowledge state.

Keywords Horses · Social cognition · Communication · Knowledge state

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Introduction

Understanding the mental state of others provides benefits to individuals in a social environment. Knowing what others see and know helps individuals to use conspecific information (where to get food from or when to run away from a predator). Non-human primates, close evolutionary relatives of humans, are thought to share some abilities of taking the visual perspective of conspecific others (Byrne and Whiten 1989), and among these great apes may be the most sophisticated in such cognitive abilities (Hare et al. 2000, 2001; Yamamoto et al. 2012).

Unlike great apes who are evolutionarily closely related to humans, domestic animals are in close relationship with humans. They may have developed social interaction and communication skills with humans due to the interaction with humans. There have been various investigations concerning interactions between humans and domestic animals, and recent studies have shown that dogs demonstrate high social communication skills with humans (Hare and Tomasello 2005). Dogs have the ability to flexibly use signals from humans in object choice paradigms (Hare et al. 1998; Mckinley and Sambrook 2000; Miklósi et al. 1998) and are sensitive to the attentional state of humans (Call et al. 2003; Schwab and Huber 2006; Virányi et al. 2004). While it has been suggested that dogs can distinguish between knowledge and ignorance in humans (Virányi et al. 2006), their ability to understand humans' knowledge state seems to be limited (Kaminski et al. 2009). Dogs' social communication skills with humans have been suggested to be influenced by domestication process of dogs. Previous studies comparing dogs with other domesticated animals or hand-reared wolves suggested that the domestication process has influence on dogs' ability to follow and comprehend human gestures (Hare and Tomasello 2005; Maros et al. 2008; Virányi et al. 2008) and the dogs' predisposition to look at humans' faces (Miklósi et al. 2003). There are also some studies showing the ability of dogs to understand humans' pointing and attentional state and their looking at humans are influenced by their environment and life experiences (Gácsi et al. 2009; Passalacqua et al. 2011; Udell et al. 2011; Wobber et al. 2009). These studies indicate that dogs' social skills with humans are shaped both by genetic factors and life experiences.

Like dogs, horses have had a close relationship with humans since being domesticated approximately 6000 years ago (Leblanc 2013; Levine 2005; Outram et al. 2009). However, they have seldom been investigated for their social cognitive skills. Their social cognitions and communication with humans may differ from those of dogs due to differences in their original ecological niches (horses being prey and dogs being predators) and their interaction with humans during the domestication process. Although previous studies have suggested that, like dogs, horses understand humans' attentional states and some bodily signals (Pfungst 1911; Krueger et al. 2011; Maros et al. 2008; Proops and McComb 2010; Sankey et al. 2011), there have been few studies investigating how they communicate with humans. No study has investigated how horses respond to humans' knowledge state. Furthermore, all previous studies considered the signals initiated from humans to horses.

The present study aimed to investigate horses' signals directed towards humans. Furthermore, it also aimed to investigate how horses respond to humans' knowledge states. We first set up an Experiment 1 to observe whether and how horses send signals to helpful but ignorant humans in a problem-solving situation where a food item was hidden in a bucket accessible only to the humans. Then in Experiment 2, we examined whether horses alter their signals according to humans' knowledge states using the same problem-solving situation as in Experiment 1. In this experiment, we investigated whether horses modified their behaviour in accordance with the humans' knowledge and ignorance of the hidden food.

Experiment 1

In Experiment 1, we investigated whether and how a horse can send signals to a human. In this task, food was accessible only to the person, but he/she did not know about the presence of the food. The process of hiding the food was witnessed only by the horse.

Methods

Participants

The domestic horses (*Equus caballus*), eight thoroughbreds (Table 1), all horses of the equestrian club at Kobe University, participated in this experiment. They were housed in their own stalls at the equestrian club, and the club's students took care of the horses, feeding them four times a day. They were not food deprived for this study. Each student was a 'caretaker' of, and thus responsible for, one or two horses, participating in the daily training and health care of the horses. Each horse interacted with his/her caretaker more than any other student in the club.

Apparatus

This experiment was conducted in an outdoor paddock familiar to the horses (Fig. 1). The paddock was triangular (with sides 9, 12 and 15 m long) and covered with sand. On one side of the paddock, we placed two food buckets that were familiar to the horses in which we hid the food item during the experiment. Next to the paddock, there was a hut

Table 1 Characteristics of the horses and the order of conditions in the experiments for each horse

Name	Sex	Age	The order of the conditions in Experiment 1	The order of the conditions in Experiment 2
Cymbal	Gelding	6	Caretaker + Food, Food only, Caretaker only	Not witness, Witness
Chess	Mare	9	Caretaker only, Caretaker + Food, Food only	Not witness, Witness
Tanakarabotamochi	Gelding	9	Food only, Caretaker + Food, Caretaker only	Witness, Not witness
Siberian heat	Gelding	12	Caretaker only, Food only, Caretaker + Food	Not witness, Witness
Mont-branc	Gelding	16	Caretaker only, Caretaker + Food, Food only	Witness, Not witness
Takao	Gelding	16	Caretaker + Food, Caretaker only, Food only	Witness, Not witness
Rondo	Gelding	18	Caretaker + Food, Food only, Caretaker only	Witness, Not witness
Hime	Mare	19	Food only, Caretaker only, Caretaker + Food	Not witness, Witness

The Experiment 1 conditions are the Caretaker + Food, the Caretaker only (without food with caretaker), the Food only (with food without caretaker). The Experiment 2 conditions are the Not witness, that is, caretaker is unaware about where the food was hidden and the Witness, that is, caretaker is aware about where the food was hidden

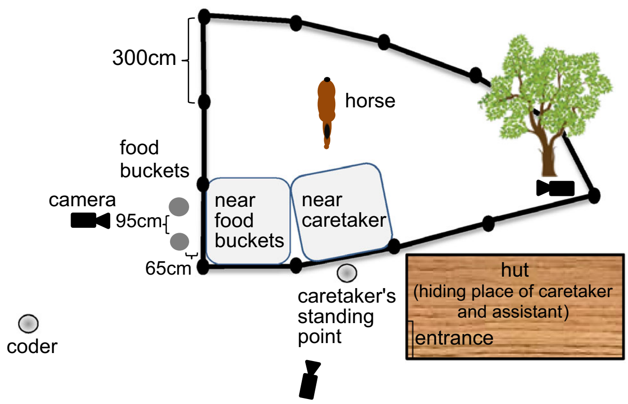

Fig. 1 Overhead view of the paddock used in the experiments

for the caretakers and assistant experimenters to go in and out during the experiments. Three cameras (one SONY HDR-PJ590V with wide conversion lens and two SONY HDR-CX535s) recorded everything that occurred from three different angles. Each horse was separately taken to the paddock to participate in the experiment alone.

Procedure

The experiment comprised three conditions (one test and two control conditions). Each horse participated in all three conditions (one trial for each) on a single day, and the order of the three conditions was randomized between individual horses (Table 1). To avoid any learning during trials, we conducted one trial/condition for each horse. Each trial began when the horse was calm in the paddock and was not engaged in any specific activity, such as eating or dust bathing. The trial was divided into three phases.

Phase 1 (1 min) A caretaker came out from a hiding place adjacent to the paddock (the hut) to a predetermined point (6.3 m away from the food buckets) just outside the paddock and stood still reading. The caretaker was asked to ignore the horse and inhibit any interaction to prevent any influence of his/her reaction on the horse's behaviour. After 1 min, he/she left.

Phase 2 (30 s) An assistant experimenter came to the paddock with a piece of food (carrot) and let the horse see and smell it. Then, the assistant put the carrot in one of the food buckets placed on one side of the paddock, covered it and left.

Phase 3 (1 min) The caretaker returned to the paddock and stood still, reading a book, while ignoring the horse. After 1 min, he/she went to the place where the food buckets were and gave the carrot to the horse.

Along with the test condition, the Caretaker + Food condition, we developed two control conditions to evaluate the effects of the presence of the caretaker alone (with caretaker but without food: Caretaker only condition) and that of the hidden food alone (with food but without caretaker: Food only condition).

Caretaker only This control condition was identical to the Caretaker + Food condition, except for Phase 2. The three phases were as follows:

Phase 1 (1 min) The caretaker came out from a hiding place (the hut) to a predetermined point just outside the paddock and stood still reading a book. After 1 min, he/she returned to the hiding place.

Phase 2 (30 s) The assistant experimenter came and gently stroked the horse for 30 s instead of hiding the food.

Phase 3 (1 min) The caretaker returned to the paddock and stood still, reading a book, while ignoring the horse. After 1 min, he/she went to the place where the food buckets were and gave the carrot to the horse.

Food only This control condition was identical to the Caretaker + Food condition, except for Phase 3. The three phases were as follows:

Phase 1 (1 min) The caretaker came out from a hiding place adjacent to the paddock (the hut) to a predetermined point just outside the paddock and stood still reading a book. After 1 min, he/she returned to the hiding place.

Phase 2 (30 s) The assistant experimenter came to the paddock with a piece of food (carrot), let the horse see and smell it. Then, the assistant put the food item into one of the food buckets, covered it and left.

Phase 3 (1 min) The horse was left alone in the paddock and no one came. After 1 min, the caretaker and the assistant experimenter went to the place where the food buckets were and gave the carrot to the horse.

Coding and analysis

Three video cameras recorded all the scenes. We compared the horses' behaviours between Phases 1 and 3 (each 1 min) in each condition.

Coding of behaviours

The target behaviours were determined by referring to previous studies on horses and dogs (Feh 2005; Kusunose et al. 1995; Lampe and Andre 2012; Miklósi et al. 2000; Proops et al. 2009):

Investigate stand and explore the ground or the bars of the paddock.

Paw scratch the ground with the front leg. This can often be seen when a horse is frustrated (Nicol 2005).

Touch the caretaker: physical contact with the caretaker's body, such as touching, pushing or pulling. Vocalizing to the caretaker: vocalizations directed towards the caretaker. Mostly nicker, a low and rumbling sound used for familiar individuals, was included here (Feh 2005).

Looking look towards the caretaker and the food buckets. The direction of looking was defined when a horse faced its nostrils directed (within 45°) to a specific target (e.g. caretaker or food buckets) more than 1 s with its ears focused forward.

Coding of standing position

The place where the horse stands still, not walking. Target places were 'near the caretaker' (<3 m from the caretaker) and 'near the food buckets' (<3 m from the food buckets). Horses sometimes engaged in other behaviours, such as investigate, look and touch the caretaker, while they were standing in these places.

Coding reliability

Behavioural analyses were performed by the first author. As look direction was the most confusing behaviour, comparing to the other behaviours which could be clearly identified, we dual-coded it. A second coder, who was naïve to this study's aim, coded 20% of the video recordings to assess the reliability of the horse's look direction. Inter-observer reliability was good (Cohen's $\kappa = 0.65$).

Statistical analysis

We compared the changes in the duration of horses' behaviours in Phases 1 and 3 (before and after the assistants interacted with the horses) in each condition and also the differences in these behaviours in the same phase between the conditions. The duration of behaviours was analysed with analysis of variance (ANOVA) using a generalized linear mixed model (GLMM) with binomial distribution and logit link function, including all the phases and conditions as fixed effects and the horse's identity as a random effect. As the interaction of phases and the conditions in the conducted models were significant for all the behaviours, the differences between phases and conditions were analysed by Tukey's all pair comparison method, using the glht function in the multicomp package of R (R Development Core Team 2005).

Results and discussion

Figure 2 shows the duration of the horses' individual behaviours in Phases 1 and 3 of the three conditions. The horses' looking at and touching the caretaker increased significantly in Phase 3, after the assistants hid the food such that it was unreachable for the horses, as compared with those in Phase 1 within the Caretaker + Food condition (looking at the caretaker: $z = 9.275$, $P < 0.001$, touching the caretaker: $z = 5.151$, $P < 0.001$). However, this was not observed in the Caretaker only condition, a condition with no hidden food (looking at the caretaker: $z = 1.557$, $P = 0.577$, touching the caretaker: $z = 0$, $P = 1.000$). Moreover, the duration of these two behaviours in Phase 3 was significantly longer in the Caretaker + Food condition than in the Caretaker only condition (looking at the caretaker: $z = -4.529$, $P < 0.001$, touching the caretaker: $z = -4.979$, $P < 0.001$), whereas they were shorter ($z = 3.814$, $P = 0.001$) or insignificant ($z = -0.720$, $P = 0.972$) in Phase 1. Thus, horses looked at and touched the caretaker the longest in Phase 3 of the Caretaker + Food condition, when the food was hidden and an ignorant caretaker arrived. The horses stayed near the caretakers significantly longer in Phase 3 than in Phase 1 within the Caretaker + Food condition ($z = 11.989$, $P < 0.001$) and within the Caretaker only condition ($z = 8.089$, $P = 0.026$). The duration of this behaviour in Phase 3 was significantly longer in the Caretaker + Food condition than in the Caretaker only condition ($z = -4.375$, $P < 0.001$) while it was shorter in Phase 1 ($z = 5.185$, $P < 0.001$). Thus, horses stayed near the caretakers whenever the caretaker arrived (regardless of the presence of food), but that the duration was longer when there was hidden food.

The duration of horses' looking towards the food buckets increased significantly in Phase 3 as compared with Phase 1 in the Food only condition ($z = 6.090$, $P < 0.001$), but not in the Caretaker + Food condition ($z = 1.288$, $P = 0.7810$) or in the Caretaker only condition ($z = -0.391$, $P = 0.998$). Furthermore, the duration of this behaviour in Phase 3 was significantly longer in the Food only condition than in the Caretaker + Food condition ($z = 4.539$, $P < 0.001$) and in the Caretaker only condition ($z = 5.834$, $P < 0.001$), whereas this was not so in Phase 1 (the Caretaker + Food condition: $z = -2.265$, $P = 0.1976$, the Caretaker only condition: $z = -1.955$, $P = 0.354$). The horses stayed near the food buckets significantly longer in Phase 3 as compared with Phase 1 in the Food only condition ($z = 8.100$, $P < 0.001$), but for shorter durations in the Caretaker + Food condition ($z = -3.813$, $P = 0.002$) and insignificant in the Caretaker only condition ($z = 0.975$, $P = 0.926$). The duration of this behaviour in Phase 3 was significantly longer in the Food only condition than in the

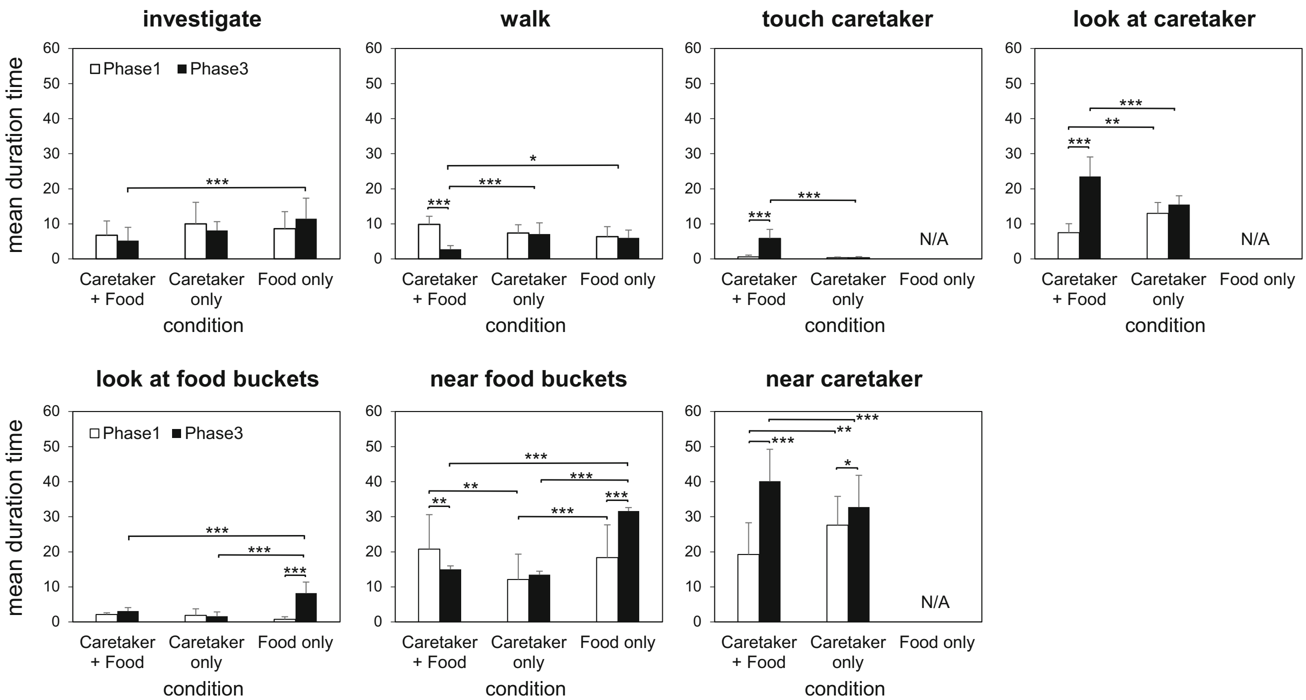

Fig. 2 Mean duration + SE of horses' behaviours observed in Phases 1 and 3 in the Caretaker + Food condition, the Caretaker only condition, and the Food only condition of Experiment 1. The differences among phases and conditions were analysed using the generalized mixed linear model (GLMM; family = binomial, link = logit) followed by Tukey's all pair comparison method. As the horses did not demonstrate pawing and only one individual demonstrated vocalization for one min during the experiment, we excluded these behaviours from the analyses. Significant difference between phases is indicated as $^{***}P < 0.001$, $^{**}P < 0.01$, $^{*}P < 0.05$. N/A indicates the condition we did not have the data to compare with other conditions in analysing the targeted behaviour

Caretaker + Food condition ($z = 10.076, P < 0.001$) and in the Caretaker only condition ($z = 10.940$, $P < 0.001$), whereas it was insignificant in Phase 1 in the Caretaker + Food condition ($z = -1.603$, $P = 0.596$) and less in the Caretaker only condition ($z = 4.200$, $P < 0.001$). These results suggest that the horses stayed near the food buckets and looked at them when food was hidden and the caretaker did not arrive. Horses investigated in Phase 3 of the Food only condition significantly longer than in that of the Caretaker + Food condition ($z = 4.943$, $P < 0.001$) while this was not observed in Phase 1 ($z = 1.558, P = 0.625$). No differences were found compared with other phases and conditions (Phase 1 in the Caretaker only condition and in the Caretaker + Food condition: $z = 2.613$, $P = 0.093$, Phase 1 in the Caretaker only condition and the Food only condition: $z = -1.072, P = 0.892$, Phase 3 in the Caretaker only condition and the Food only condition: $z = 2.578$, $P = 0.102$). Thus, the horses may have attempted to obtain the food by themselves when the food was hidden in an unreachable bucket and the caretakers did not arrive. Moreover, the duration of walking was significantly longer in Phase 3 than in Phase 1 within the Caretaker + Food condition ($z = -5.714, P < 0.001$), but this did not change in Phases 1 and 3 in other conditions (the Caretaker only condition: $z = -0.201, P = 0.999$, the Food only condition: $z = -0.323$, $P = 1.000$). The horses walked significantly shorter in Phase 3 of the Caretaker + Food condition than in other conditions (the Caretaker + Food condition and the Caretaker only condition: $z = 4.018$, $P < 0.001$, the Caretaker + Food condition and the Food only condition: $z = 3.188$, $P = 0.017$), whereas this was not observed in Phase 1 (the Caretaker + Food condition and the Caretaker only condition: $z = -1.865$, $P = 0.419$, the Caretaker + Food condition and the Food only condition: $z = -2.666$, $P = 0.081$). This may be because the horses stayed still near the caretakers for a longer time if there was hidden food and the caretaker was present, but if there was no hidden food and no caretaker, the horse did not stay still and walked or investigated longer. We did not include pawing and vocalization in our analysis because the horses did not demonstrate any pawing throughout the experiment, and only one individual (Mont-branc) demonstrated a 1 s vocalization in Phase 1 of the Caretaker + Food condition.

Horses' looking at and touching the caretaker increased significantly, and it was also significantly longer than all the other behaviours in the other conditions only when the food item was hidden and the caretaker arrived later (the Caretaker + Food condition). It seems that the horses used visual (look) and tactile (touch) signals for ignorant caretakers when in a problem-solving situation where food was hidden in a bucket accessible only to the caretakers. Thus, we used looking at and touching the caretaker as horses' signals to humans for further investigation in Experiment 2.

Experiment 2

In Experiment 2, we investigated whether horses change their behaviour according to the caretaker's knowledge state.

Methods

Participants

The same horses as in Experiment 1, eight thoroughbreds (Table 1), of the equestrian club at Kobe University, participated in this experiment.

Apparatus

This experiment was conducted in the same outdoor paddock as in Experiment 1 (Fig. 1).

Procedure

We manipulated whether the caretaker witnessed the process of hiding food by the assistant experimenters: 'Witness' and 'Not Witness'. These were same as the Caretaker + Food conditions in Experiment 1, except for the Phase 2 procedure. The order of the two conditions was counterbalanced between the participants (Table 1).

Not witness In Phase 2 of this condition, the caretaker did not see the food being hidden, that is, the caretaker was unaware of the food's location; thus, this condition was identical to that in Experiment 1. In Phase 2, the assistant experimenter came to the paddock with a piece of food (carrot) and allowed the horse to see and smell it. Then, the assistant put the carrot in one of the food buckets, covered it and left.

Witness In Phase 2 of this condition, the caretaker witnessed the assistant's food hiding procedure, that is, the caretaker knew the food's location.

Phase 1 (1 min) The caretaker of the horse came out from a hiding place (the hut) to a predetermined point just outside the paddock and stood still reading a book. After 1 min, he/she left.

Phase 2 (30 s) The assistant with the food item (carrot) and the caretaker came to the paddock, and the assistant let the horse see and smell the carrot. The assistant then put the carrot in one of the food buckets and covered it while the caretaker was standing beside her/him. Then, the assistant and caretaker left.

Phase 3 (1 min) The caretaker returned to the paddock and stood reading a book while ignoring the horse. After 1 min, he/she went to the place where the food buckets were and gave the carrot to the horse.

Coding and analysis

The three video cameras recorded all the scenes. We compared the horses' behaviours between Phases 1 and 3 (each 1 min) in each condition.

Coding of behaviours

From the Experiment 1 results, the target behaviours in Experiment 2 were touching the caretaker (tactile signal) and looking at the caretaker (visual signal).

Coding reliability

The behavioural analysis was performed by the first author. As look direction was the most confusing behaviour, comparing to the other behaviours which could be clearly identified, we dual-coded it. A second coder, who was naïve to the study's aim, coded 20% of the video recordings to assess the reliability of the horses' look direction. The inter-observer reliability was good (Cohen's $\kappa = 0.70$).

Statistical analysis

We compare the duration of horses' behaviours in Phases 1 and 3 in each condition and that of the same phases between the Witness condition and the Not witness condition. Each behaviour duration was analysed with analysis of variance (ANOVA) using a generalized linear mixed model (GLMM) with a binomial distribution and logit link function, including all the phases and conditions as fixed effects and the horse's identity as a random effect. As the interaction of phases and the conditions in conducted models were significant in all the behaviours, the differences between phases and conditions were analysed by Tukey's all pair comparison method using the glht function in the multicomp package of R (R Development Core Team 2005).

Results and discussion

Figure 3 shows the duration of the horses' individual behaviours in Phases 1 and 3 of the two conditions. The duration of touching the caretaker increased significantly in

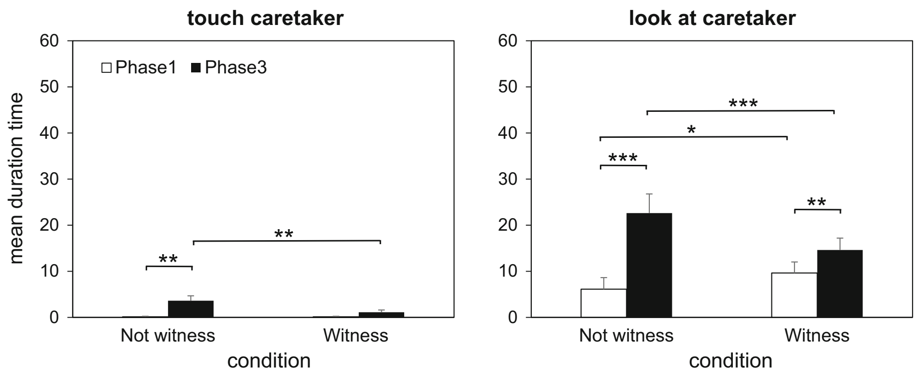

Fig. 3 Mean duration + SE of horses' behaviours in Phases 1 and 3 observed in the two conditions of Experiment 2. Not witness: the caretaker did not see the food being hidden. Witness: the caretaker saw the food being hidden. The differences among phases and conditions were analysed using the generalized linear mixed model (GLMM; family = binomial, link = logit) followed by Tukey's all pair comparison method. Significant differences between phases are indicated as ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$. N/A indicates the condition we did not have the data to compare with other conditions in analysing the targeted behaviour

Phase 3 as compared with Phase 1 in the Not witness condition ($z = 3.421$, $P = 0.003$), but not in the Witness condition ($z = 2.127$, $P = 0.127$). Furthermore, in Phase 3, the horses touched the caretaker significantly longer in the Not witness condition than in the Witness condition ($z = 3.190$, $P = 0.006$), whereas this was not observed in Phase 1 ($z = 0$, $P = 1.000$). This result suggests that the horses significantly increased the use of the tactile signal when the caretaker was not a part of the food hiding process. The duration of looking at the caretaker significantly increased in Phase 3 as compared with Phase 1 in the Not witness condition ($z = 9.722$, $P < 0.001$) and in the Witness condition ($z = 3.300$, $P = 0.005$). In Phase 3, the duration of looking at the caretaker was significantly longer in the Not witness condition than in the Witness condition ($z = 4.620$, $P < 0.001$), whereas it was shorter in Phase 1 ($z = -2.720$, $P = 0.03$). This suggests that the horses used the visual signal more whenever there was hidden food and a caretaker was present (regardless of the caretaker's witnessing the food hiding process), but they used this signal less when the caretaker had previously seen the food being hid. As we could not separate the effect of horses' life experience on their behaviours towards humans observed in this study, it might be argued that the difference in duration of these behaviours (visual and tactile signals) between two conditions was influenced by the difference in duration of the caretakers' presence between the two conditions. For example, the caretakers were present in Phases 2 and 3 of the Witness condition and in Phase 3 of the Not witness condition. However, the horses always looked at the assistants who brought and hid the food, and also they could not interact with the caretakers during Phase 2. Thus, we consider that duration of the caretakers' presence did not affect the visual and tactile signals of horses towards the caretakers observed in Phase 3 of the conditions. Thus, the horses seem to alter their visual and tactile signals towards humans according to the humans' witnessing of the food hiding process. It suggests the possibility that horses may possess the ability to relate humans' past attentional state to their current knowledge state.

General discussion

This study shows that horses communicate with ignorant humans using visual and tactile signals when faced with an unsolvable problem (food hidden at unreachable location). Their visual and tactile signals may be interpreted as requests or attention-getting behaviour to convey their intention to obtain the food and inform the caretaker of the food's presence. Significant changes in signalling behaviour only appeared in the presence of both unreachable food and an ignorant caretaker, and not in the control condition of Experiment 1 (the Caretaker only condition) and the Witness condition of Experiment 2. Thus, the presence of the caretaker or the food alone seemed to have no influence on these behavioural changes, nor did the presence of a caretaker knowing the food's location.

The results of Experiment 2 suggest the possibility that horses knew what humans did and did not see; moreover, they could flexibly use this information in their signalling behaviour towards humans. Previous studies indicated that horses are sensitive to humans' attentional states (e.g. open or closed eyes, Maros et al. 2008; Proops and McComb 2010). This study suggests that horses may possess a more advanced cognitive ability. We show that it is possible that horses are sensitive to humans' past attentional state and they can alter the signalling behaviour accordingly. Some non-human primates are considered to possess the abilities to understand what others know and can flexibly alter their subsequent behaviour according to this knowledge (Call

2001; Hare et al. 2000, 2001; Yamamoto et al. 2012). Although we need further investigation to confirm whether and to what extent horses possess this ability, this study is the first to show that horses possess some cognitive basis for this ability of understanding others' knowledge state in social communication with humans. Unlike primates, who are close evolutionary relatives of humans, horses are a phylogenetically distant species; nevertheless, horses have had long-term close relationship with humans through domestication. This domestication process, along with ontogeny, may have caused their social cognitive abilities to become sophisticated, as observed here. However, how and whether these factors influence horses' communicative ability with humans is as yet unclear. The human-related cognitive ability of domestic horses needs to be further investigated, and a comparison with wild equids also needs to be conducted.

Comparing the means of horses' communication methods observed here and that of dogs observed in a previous similar study (Miklósi et al. 2000), we note some differences. The horses touched and continuously looked at their caretaker, which could be interpreted as a request, while dogs demonstrated gaze alternation between a human and the food's location, which was interpreted as a directional signal (or 'showing' behaviour) in the previous study. Although both species live in close relationships with humans, it is possible that differences in their original ecological traits and interspecific interaction with humans have caused the difference in their communications to humans. Originally, dogs are scavengers that hunt occasionally, whereas horses are herbivores, and their roles in human society are different. Compared to horses, many dogs have been selected and trained for herding, hunting, service and rescue. As several studies suggested that there are differences in dogs' gaze towards humans across breeds and developmental stages (Jakovcevic et al. 2010; Passalacqua et al. 2011; Wobber et al. 2009), dogs' roles in human society may have caused the ability for directional signals such as gaze alternation to direct humans' attention to a particular thing to have become sophisticated. In contrast, horses have never undertaken such roles. These differences between dog–human and horse–human interactions might have caused the different communicational signals towards humans between dogs and horses. In addition, there is a possibility that the experimental situation where the caretakers stood sideways, inattentive and ignoring the horses, might have affected the horses' behaviour. As horses are sensitive to humans' attentional state (Proops and McComb 2010; Sankey et al. 2011), this situation might have led the horses to understand that the caretakers were not noticing them or the presence of the food. Then, the horses first approached and touched the caretaker to get attention and to convey their intention of obtaining the hidden food. However, more comparative studies on these two species are required to clarify this hypothesis. At this moment, we still know little about the social cognition of horses (Murphy and Arkins 2007), and few comparative studies exist that involve other species (McKinley and Sambrook 2000; Tomonaga et al. 2015). Further investigation of the social cognitive abilities of horses and other domestic animals and comparison with other non-domestic animals, such as primates, will improve our understanding of how domestication has influenced animals and provide insight into the evolutionary and developmental process of advanced social cognition that domestic animals possess.

Acknowledgements Special thanks to the students of the equestrian club in Kobe University. We are grateful to Fuki Maehara for her support in our study's video analysis. We also thank Dr. Shigeto Dobata for his support in the study's statistical analysis. The study was supported by grants from the Japan Society for the Promotion of Science (KAKENHI Nos. 26118509, 15H01619 and 15H05309 to Shinya Yamamoto).

Compliance with ethical standards

Ethics The experimental procedure for the horses was approved by the Institutional Animal Care and Use Committee (Permission number: 27-12-02) and carried out according to the Kobe University Animal Experimentation Regulation. All procedures adhered to the Japanese Act on the Welfare and Management of Animals.

Conflict of interest We have no competing interests.

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