Knowledge attribution in a competitive set-up

A thesis on pet dogs' (Canis familiaris) ability to attribute knowledge to humans

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Abstract

Theory of mind (ToM) refers to the ability to attribute mental states to others and the ToM abilities that pet dogs possess are crucial to understanding their behaviour, ecology and evolution. Pet dogs (Canis familiaris) live closely to humans, they possess abilities to attribute intentions and perspectives to humans, however, their ability to attribute knowledge to humans has not been proven. This study aimed to assess pet dogs' ability to attribute knowledge to humans, using a competitive three-choice two-reward set-up. Twenty-six dogs participated and completed the full procedure, of which one was excluded due to misconduct, leaving twenty-five dogs for further analysis. The dogs were first trained to understand the assignment: 2 out of 3 bowls were baited in front of the dog and a human competitor. The competitor would empty one of the bowls, after which the dogs could make a choice. Nine dogs chose the second baited bowl above chance, while sixteen did not. Nonetheless they all continued to the test phase to measure the effect of the training. In the test phase, again 2 out of 3 bowls were baited, although the knowledge of the competitor now varied, as did the first choice. In test conditions, one of the three identical bowls was not baited (the Empty bowl) and two bowls were baited: one was known only to the dog (the Dog only bowl), while the other was known to both the dog and the competitor (the Both bowl). When the dog chose first (DF), they were expected to choose from two baited bowls with no discrimination. When the competitor chose first (CF; this choice was hidden from the dog), dogs were expected to shift their choices towards the Dog only bowl rather than the Both bowl if they would take the knowledge of the competitor into account. In control conditions, nothing was known to the competitor, so dogs should choose from the two baited bowls with no discrimination, regardless of whether the condition was DF or CF. In the DF test condition, dogs indeed made no distinction between the two baited bowls and avoided the Empty bowl, as expected. However, in the CF test condition, dogs did not shift their preference towards the Dog only bowl, but rather chose randomly from the three bowls, including the Empty bowl. A comparison between DF and CF even suggested that they chose the Dog only bowl less often in CF than in DF, which is contrary to our expectation. This suggests that something in the CF condition distracted them. This is supported by the control conditions, where dogs also chose the Empty bowl more in CF condition than DF condition. When we only took the subset of trained dogs into account there was no difference in the results, suggesting that dogs also struggled with the CF condition if they passed the training. Likely, the method for obscuring the dogs' view during the CF condition distracted the dogs from the task at hand. No evidence for knowledge attribution in dogs was found from this study, although the existence of this ability is also not disproven. Improvement of methodology, especially regarding CF treatment might lead to clearer results.

Keywords: Dog cognition; Knowledge attribution; Theory of mind

Introduction

Social cognitive skills help social animals to utilize the benefits of belonging to a social unit (Frith, 2008), including the ability to understand that others may have a mental state that differs from their own, such as different perspectives, intentions, knowledge and beliefs. This Theory of Mind or ToM (Premack & Woodruff, 1978) allows individuals to comprehend others' actions and foresee their upcoming behaviour, making it essential for competition and cooperation (de Weerd et al., 2022; Krupenye & Call, 2019). ToM supports individuals to cope with their social surroundings, especially in unstable situations, as it helps to predict actions of others using rather limited information (de Weerd et al., 2022). ToM has different aspects, including the recognition of emotions, understanding of beliefs (attribution of intentions and beliefs), comprehension of language, actions in social contexts, empathy and moral judgement (Tirapu-Ustárroz et al., 2007).

Non-human animals may have an ability to attribute mental states to others, but possibly to a different degree than humans. A first-order ToM is about understanding that others may have their own belief about an event. The inability of doing so is called zero-order ToM, where individuals only respond to the real event without considering others' mental states (Goodie et al., 2012; Perner & Wimmer, 1985). Second-order ToM involves the comprehension of others' perception of others' mental states, for instance, when A knows that B knows C has certain beliefs about an event. Third-order ToM and higher levels involve several parties in the reasoning process and increase the layers of nested understanding (De Weerd et al., 2013; Goodie et al., 2012; Perner & Wimmer, 1985), which so far has only been proven to exist in humans. ToM research in non-human species remains focused on a more basic and narrower interpretation of the concept and aims to distinguish between zero-order ToM and first-order ToM, as animals' cognition is believed to be more rudimentary (Krupenye & Call, 2019; van der Vaart & Hemelrijk, 2014). First-order ToM in animals can be broken down into the attribution of intentions, perceptions, knowledge and beliefs (van der Vaart & Hemelrijk, 2014). ToM is thus not an ability to be fully possessed or not, but it rather consists of multiple layers. The objective of studies on ToM in non-human animals is to find out the extent to which ToM is possessed by a species (Allen, 1998; Horowitz, 2011). Understanding the degree of ToM abilities in animal species helps to make sense of their behaviour, ecology, and evolution.

Chimpanzees showed the ability to understand human's intentions and to discriminate between when a human was unwilling or unable to give the food in a test where the human experimenter stalled food delivery (Call et al., 2004). Understanding of intentions is, however, only a first step to predict others' action, as knowing others' perception and knowledge is also necessary (Call & Tomasello, 2008). Experiments on more advanced ToM abilities, such as perspective-taking and knowledge attribution in animals, should be in line with the nature of the study species, and model natural situations to which the species is adapted. For chimpanzees this generally means to test them in a competitive situation rather than a cooperative one (Call & Tomasello, 2008). Chimpanzees hide food from a human competitor, suggesting that they understand others' perception (what they can or cannot perceive) and manipulate it for food competition (Hare et al., 2006; Melis et al., 2006). Chimpanzees have also been shown to take the knowledge of conspecifics into account in competitive contexts. In a food competition task involving a dominant and a subordinate chimpanzee, the subordinate chose to collect the food more often when the food hiding was not seen by the dominant, thus showing that they understand the knowledge others hold via their perception (Hare et al., 2001). In another set-up, the subject chimpanzees were shown the baiting of two cups while the competitor chimpanzees were shown only one and were then allowed to choose first. The subject, who had second choice, typically chose the cup only it saw being baited, rather than the one both saw. When the subject could choose first, it showed no preference between baited cups. This indicates an understanding of knowledge processed by the conspecific competitor, based on the perception of the competitor (Kaminski et al., 2008). However, in the same set-up, when the competitors were provided with incorrect information about the location of food, chimpanzees failed to exploit the false belief of competitors. Thus, they seem to struggle with distinguishing between true and false beliefs (Kaminski et al., 2008). Understanding false beliefs seems to require a higher level of cognitive ability than understanding knowledge, since the former involves situations where one holds false beliefs (has wrong knowledge), whereas the latter only requires only a distinction between ignorance and knowledge.

Domestic dogs are frequently used for social cognition research, since dogs' ancestors were social animals (wolves), and they have formed a close bond with humans during the domestication process (Cooper et al., 2003). The special connection with humans does make dogs different from other animals, in the sense that dogs are especially attentive to humans and their behaviours (Horowitz, 2011). Dogs readily respond to various human communicative signals such as gestures and vocalizations (Horowitz, 2009; Udell et al., 2011) and attentional states: e.g. dogs obeyed longer when their owners were actively watching them, compared to when their owners were doing something else or not looking at them (reading a book, watching TV, turning back or leaving the room) (Schwab & Huber, 2006); dogs that were told not to eat a food reward, stole food more often when the person forbidding it was not paying attention to them (leaving the room, closing eyes, turning away or being distracted), compared to when the person was continually looking at them (Call et al., 2003). These results indicate that dogs understand different attentional states of humans via social cues, such as eye contact and body orientation, and change their behaviour accordingly. This seems to include understanding a human’s visual perspective. In a study, dogs had to choose between two toys and bring one toy to the experimenter, with the two toys being placed on the dog’s side of two barriers (Kaminski et al., 2009). One of the barriers was transparent and the other opaque, so the dog could see both toys, but the researcher could only see the toy behind the transparent barrier. When the person asked for ‘the toy’ without specifying which in any way, the dogs tended to bring the toy at the transparent barrier, rather than the toy at the opaque one. They didn’t show the same tendency when the person could see both toys and neither toy (Kaminski et al., 2009). In a follow-up study, this set-up was used to test for dogs’ understanding of human knowledge. When the two barriers were both opaque and the human saw one toy being placed, but not the other one, the dog would randomly choose from the two toys instead of reaching for the one the human had just seen being hidden (Kaminski et al., 2009). Apparently, dogs failed to comprehend what humans know from the immediate past when visual access was discontinued. However, a single set-up doesn't disprove that dogs have the cognitive ability to comprehend human knowledge as there could be other explanations for the dogs' failure. For instance, the link between humans having seen the toy and the fetch order was not clear, or dogs simply preferred a self-centred choice strategy instead of considering the mental state of the human (Kaminski et al., 2009).

It remains unclear whether dogs can attribute knowledge to humans as no firm proof has been found yet. However, since dogs live in a very human-dominated world (Schilder et al., 2014) , we do expect them to benefit from this ability. It seems likely that they do not only understand a human's perspective, but also the knowledge that comes with that. Possibly, the cooperative paradigm of Kaminski et al. (2009) did not fit with the nature of this study species. Contexts should be of evolutionary and ecological importance for the species to show their cognition abilities (Woo et al., 2021). Although pet dogs are often used to cooperate with humans, it may not be inherently natural for the species, as the training experience and plays essential role in dogs' reactivity to cooperate with humans (Csepregi & Gácsi, 2023). With enough familiarization, wolves can cooperate with humans as well (Range & Virányi, 2014), in contrast, when lacking co-living experience with humans, feral dogs showed tendency to avoid humans, free-ranging dogs stopped following human pointing in the later stage of life (Bhattacharjee et al., 2017; Boitani & Ciucci, 1995). Cooperative paradigms with pet dogs could measure simple obedience rather than invoke situations in which dogs have to attribute knowledge to others. The toy-fetching task (Kaminski et al., 2009) was under cooperative circumstances and could not demonstrate knowledge attribution. Studies with chimpanzees have found that chimpanzees made more correct choices with a human competitor pointing at the right food location, than with a human cooperator, indicating better performance in competitive conditions. One explanation is that competitive contexts require more cognitive effort and attention (Garcia et al., 2006; Hare & Tomasello, 2004). Chimpanzees are often tested in food-competition tasks for cognitive abilities, as food competition is natural for them (Call & Tomasello, 2008). The studies that found that dogs are especially sensitive to humans' attentional states were also conducted under semi-competitive situations, in which dogs had to take the attention of a human into account to gain access to food. Free-ranging and pack dogs show extreme food competition, and lower ranking individuals will leave food if it is claimed by a more dominant individual (Cafazzo et al., 2010; Dale et al., 2017). Pet dogs likely see humans as more dominant individuals (Range & Virányi, 2014), and might as such take their attention – and possibly knowledge – into account in competitive situations. Therefore, this study aims to find out whether dogs are able to attribute knowledge to a human, using a competitive set-up.

In this study set-up, a competitive situation is created, in which a dog subject competes with a human competitor for food, which is hidden in two out of three bowls. Once the food is hidden, it is invisible to both, but the dogs see the hiding of both food rewards. In contrast, the human competitor sees only one food reward being hidden. Then, either the human or the dog gets first choice, which remains hidden for the other. We expect dogs to be capable of attributing knowledge to the human in this competitive situation, although individual variation due to different backgrounds of dogs is also anticipated. An understanding of knowledge of the human competitor in this study would be expressed as an avoidance of choosing the bowl with food that the human competitor sees being baited when the competitor chooses first, but no specific preference for baited bowls when the dog chooses first. If the competitor has no knowledge of the food, the dogs should show no preference for one of the bowls, regardless of who chooses first.

Methods

In this study, we used a food competition paradigm in which dogs had to base their decisions on what they saw a human competitor observe during the hiding of two food rewards. Dogs' choices were noted to determine whether the dogs took the knowledge of the competitor into account and were thus able to attribute knowledge to humans.

Time and place

The study was conducted at Carus research facilities, Wageningen University, the Netherlands, in the observational room for dog tests of the university. Try-outs of the competitive set-up had been carried out in winter 2023 and spring 2024, with the actual test running from September 2024 to January 2025.

Subjects

Fifty-six dogs participated in this test or the try-out of this test, of which twenty-six completed the whole process. The dogs that served as subjects in the study were pet dogs recruited from Dutch society via online questionnaires. We preferably selected food-motived dogs, but did not restrict the breed, sex or age of the dog. Dog owners were informed about details in the test, the video recording and data being used for research and asked to officially sign a consent form before the test. Dogs were checked for allergies before receiving any treats. In case the dog's owner brought multiple dogs to the lab, we made sure no dogs were left unattended.

The test was deemed to not be an animal experiment by the animal welfare body of Wageningen University (NAE_2024.W-050), as it did not cause harm or serious stress to the dog and was fully under the consent and supervision of the dog owner.

Setup of competitive test

Dogs' choices in a food competition test were used to infer their ability to attribute knowledge to humans. Two identical chairs were placed on both sides of the room, one was placed against the wall and the other faced the wall. The dog owner and the dog took place on one side of the room, with the dog owner sitting on the chair against the wall, holding the dog in front of him or her with a long leash attached to the wall and a V shaped fence next to them. The competitor took place on the other chair and tried to remain unfamiliar to the dog throughout the test. The experimenter stood in the middle of the room, carrying a bag of treats (acted friendly to the dog, had greeted the dog and the owner prior to the test). Three low opaque barriers were placed at predetermined places in the middle of the room (all with equal distance from the dog and each other). A bowl was placed behind each of them on the dog's side, all three bowls were identical and were rubbed with dog treats to make sure they smelled the same and that dog could not rely on odor to differentiate the bowls (Figure 1).

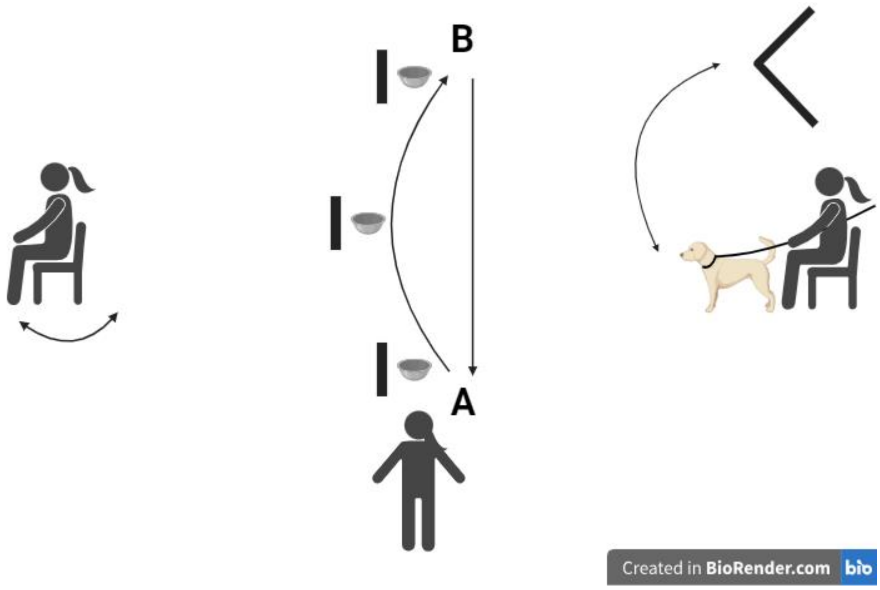

Figure 1. Schematic illustration of the test set-up. The competitor (left) moved from chair to the front of the chair. The experimenter (middle) moved alongside the bowls between location A and B as shown by the arrows. The screen next to the dog (right) could be moved in front of the dog and back.

Procedure of competitive test

Training phase

To make sure that dogs understand the general principle of the test, with the experimenter hiding two pieces of treats and the competitor competing over treats with dogs by taking one away (the competitor acted dominantly every time she took the treat from the bowl), the test started with a training phase consisting of 2 parts.

Part 1: This part aimed to teach dogs the gestures the experimenter made during baiting, that were related to an empty or baited bowl.
The experimenter started the baiting by making eye contact with the dog and walking towards the first bowl (in the direction from location A to B; Figure 1). Here, she kneeled down, made eye contact with the dog, and either showed her empty hands or a dog treat to the dog. In the case of the dog treat, she dropped it in the bowl, making sure it made a sound. After this, she stood up and continued to the next bowl, where this was repeated. Only one treat was hidden during this part of the training phase. After visiting all the bowls and arriving at the opposite side (location B), she signalled the dog's owner to release the dog, which could only select one bowl. The dog could eat the treat if it's the correct bowl. After eating the food, or selecting an incorrect bowl, the dog was called back by its owner, and the experimenter removed the treat. After this, the experimenter walked back to location A in a straight line (Figure 1) and another trial started. This was repeated until the dog selected the correct bowl three times in a row, after which training phase part 2 took place. The competitor sat quietly on the chair with her back to the dog throughout this phase.

Part 2: This part aimed to teach dogs the concept of competition and the rules of choosing. The competitor stood in front of the chair and watched the experimenter baiting the bowls.

In part 2, the experimenter baited the bowls in the same way as in part 1, only now there would be a treat hidden in two of the three bowls and the treat was shown to both the dog and the competitor. Once the experimenter reached location B, she told the competitor to choose first, using the word ‘choose’. The same word was always used, to signal to the dog that it was the competitor’s turn to choose. The competitor then walked forward to one of the baited bowls and clearly took the treat out of it while making eye contact with the dog. Once the competitor was back to standing in front of the chair and watching, the experimenter signalled the dog owner to release the dog, using the word ‘okay’. The dog was then released and could go and select one bowl*. Both continued until all treats were found. When all treats were found, the experimenter walked back in a straight line to location A and started another trial.

To make it obvious that the competitor took the treat away, Part 2 started with 5 trials where the bowls were removed to make everything visible to the dog. The next five trials were performed in the normal set-up, with the bowls, followed by a break. After the break, the dog completed another two bouts of five trials with bowls in place. If the dog had seven correct choices out of the last ten, it was considered to understand the set-up and the test would follow immediately after a longer break. Otherwise, the dog was asked to come again and continue with the training for 20 more trials, after which the test happened irrespective of whether the dog had 7 out of 10 correct. The dogs who did not have enough correct choices proceeded to the testing phase instead of repeating the training trials, to maintain their interest in this set-up.

The location of each treat throughout part 1 and part 2 was randomized into six sets (sheet 1-6), with each dog randomly assigned to a sheet.

*: a change was made later in which dogs were given one extra choice in the first ten trials of part 2. This meant that if the dog chose an incorrect bowl first, it had a second chance to choose another bowl. This extra choice was given to the dogs in order to reduce the frustration of not receiving a treat and to facilitate their understanding of this set-up. These first 10 trials did not count towards the 7 out of 10 correct benchmark.

Testing phase

In the testing phase, dogs were tested for whether they took the knowledge of a competing human into account. The testing phase included four different treatments, in which the competitor’s knowledge of treat locations and the order of selection varied. Again, the competitor acted dominantly each time she took the treat from the bowl.

Just as in the training phase, the experimenter would hide two food rewards. In all the conditions, the dog observed both baiting. The competitor sat on her chair and only stood up to watch the baiting of one predetermined bowl, then returned to the seat. The experimenter would only look at the competitor and show her the treat if she stood up. In the control situation, the competitor remained seated throughout the baiting and the experimenter only showed the treats to the dog. In the testing phase, extra padding was added to the bowls so the treats no longer made a sound when dropping in the bowl, so the competitor should have had no knowledge of the location of treats she did not see the hiding of.

Within both test and control conditions, there are two separate treatments regarding who chose first: dog first (DF) or competitor first (CF).

In the DF condition, the experimenter reached location B and asked the owner to release the dog to select a bowl first. After the first choice of the dog, correct or not, the dog went back to its owner. Then the experimenter asked the competitor to choose, again using the word 'choose'. In the test situation (T-DF), the competitor then stood up, turned around and walked to the bowl she saw baited, taking out the treat in the same way as in the training phase. In the control situation (C-DF), the competitor stood up, turned around and walked to a bowl randomly. If the bowl did hold a treat, the competitor took out the treat in the same way as in the training phase. If the bowl was empty (either was not baited or emptied by the dog), the competitor acted disappointed. Both continued until all treats were found.

In the CF condition, the experimenter reached location B and used the screen to block the dog's view or asked the dog's owner to block the dog's view*. Then she returned to location A and asked the competitor to choose, using the word 'choose'. In the test situation (T-CF), the competitor then stood up, turned around and walked one step forward and started pointing to the bowl she saw baited. In the control situation (C-CF), the competitor then stood up, turned around and walked one step forward and stated pointing to a random bowl. The experimenter then again walked from location A to B, stopping and kneeling at each bowl and taking the treat from the chosen bowl. Once the experimenter reached location B, she handed the treat to the competitor if the chosen bowl was baited, or pretended to hand something to the competitor if the chosen bowl was not baited. After this, the experimenter removed the screen or told the owner to release the dog to choose. Both continued until all treats are found. After the first 'invisible choice', the competitor could again choose by walking to the bowl and taking the treat themselves.

The testing phase consisted of six trials in total: four test trials (two times T-DF two times T-CF) and two control trials (one time C-DF, one time C-CF; Table 1). The testing phase was conducted without breaks. The order of treatments and the location of each treat was randomized into six sets (sheet 1-6), with each dog randomly assigned to a sheet. Dogs' first choice in each trial was recorded.

Treatment	**Dog First**	**Competitor First**	**Total trials**
Test	2 (T-DF)	2 (T-CF)	4
Control	1 (C-DF)	1 (C-CF)	2
Total trials	3	3	6

Table 1. Overview of trials in the test phase. Pet dogs (N = 25) were tested for knowledge attribution ability under a three-choice two-reward set-up with a human competitor in one testing phase consisting of 6 trials. The 6 trails were divided into 4 different treatments, in test conditions the competitor had the knowledge of one treat location, while in control conditions the competitor had no knowledge of treat

location at all. In test conditions, dogs did 2 trials where they select first and 2 trials where the competitor select first. In control conditions, dogs did 1 trial where they select first and 1 trial where the competitor select first.

*: The usage of screens depended on the discussion with the dog's owner. If the owner believed that the metal screen could frighten the dog, other methods of blocking the dog's view were used, i.e., blocking the dog’s view with a blanket held by the owner, or the owner covering the dog's eyes with hands.

Precaution and safety

Dogs were kept on leash during the tests to minimize risks of incidents. The whole test process was under the supervision of the owner as the owner had been informed of everything that would happen during the test and was present throughout the test. The owner could pause or terminate the test at any time if he or she believed the dog needed it. Constant access to clean water and adequate rest periods were provided for the dog.

Data processing and statistics

For data analysis, a clear distinction between the three bowls in the testing phase was made. In the test trials, the bowl that’s not baited was dubbed the Empty bowl and a choice for this bowl was scored as 0. The bowl that's baited in view of only the dog was dubbed the Dog only bowl and a choice for this bowl was scored as 1. The bowl that’s baited in view of both the dog and the competitor was dubbed the Both bowl, and a choice for this bowl was scored as 2. In the control trials, the bowl that’s not baited was still dubbed the Empty bowl and a choice for this bowl was scored as 0. However, in this condition, both baited bowls were baited in view of only the dog, a choice for either bowl was scored as 1. Only if the dog chose the baited bowl that happened to be emptied by the competitor (only possible under C-CF), the choice was scored as 2. The experimenter would immediately note the dog's choice per trial. Additional information or rechecks were obtained from video recordings.

During data processing, it was noted for each dog how often each bowl was chosen for each condition, and whether or not the dogs had chosen the correct bowl above chance during training phase (Trained or Untrained). With the data of counts, the percentage of each dog selecting each bowl under test conditions was calculated (by taking average of choice counts the two trails per test condition) with Excel.

Data analysis was done with R studio. With the data of counts, binomial tests were used to test for each bowl in each condition whether it was chosen above or below chance. Fisher’s exact test was used to analyse the choice counts in the control condition, for which the choices of dogs were marked as baited bowl (in C-CF, the choice previously noted as 1 and 2 were combined) or Empty bowl. With the data of percentages, which was not normally distributed, Wilcoxon rank-sign tests were used to compare the percentage of dogs selecting each bowl between the two test conditions (T-DF and T-CF) as it could handle paired data, and Wilcoxon sign-sum tests were used to compare the percentage between the Trained group and Untrained group as it was proper for independent data.

Additionally, binomial test, Chi-square test (for all dogs) and Fisher-Freeman-Halton exact test (for Trained and Untrained group) with Monte Carlo simulation (B = 10,000) were used to compare the counts of dogs' choices for the same bowl across treatments. See appendix for detailed methods and results.

Moreover, binary logistic regression models were used to analyse the effect of the extra choice provided during the training phase on the training outcome, and the usage of screen (to block dogs' view) on the performance of dogs (see appendix).

Results

Overview

Fifty-six dogs participated in a three-choice two-reward set-up with a human competitor, to measure potential knowledge attribution in a competitive context, of which twenty-six completed the training and testing phase, while the other thirty dogs dropped out during the training phase due to stress signs or decisions of the owners. From the twenty-six dogs, one was removed from the dataset due to misconduct during the testing phase. Of the remaining twenty-five dogs, nine dogs (36%) chose a baited bowl above chance (33%) in training and were considered 'Trained' to fully understand the competition between the human competitor and itself. The 'Untrained' dogs (N = 16) still participated in the test to measure the influence of training on the dogs' choice. This resulted in a dataset of 100 test trials (the competitor had knowledge of one food reward location) and 50 control trials (the competitor had no knowledge of food reward locations), where the dogs' first choice was recorded. In half of the trials the dog chose first (DF) and in half the competitor (CF).

Without making a distinction between Trained and Untrained group, dogs selected the Empty bowl 16 times (out of 100; binomial, $p < 0.01$), the Dog only bowl 41 times (out of 100; binomial, $p = 0.065$), and the Both bowl 43 times (out of 100; binomial, $p = 0.027$; Figure 2). Dogs selecting the Empty bowl below chance indicates that they understood the Empty bowl wasn't baited. Dogs chose the baited bowls (Both bowl significantly and Dog only bowl with a trend) above chance, suggesting that they understood the baiting process. Between the two baited bowls, dogs didn't show a preference (43 out of 84 times, binomial, $p = 0.913$).

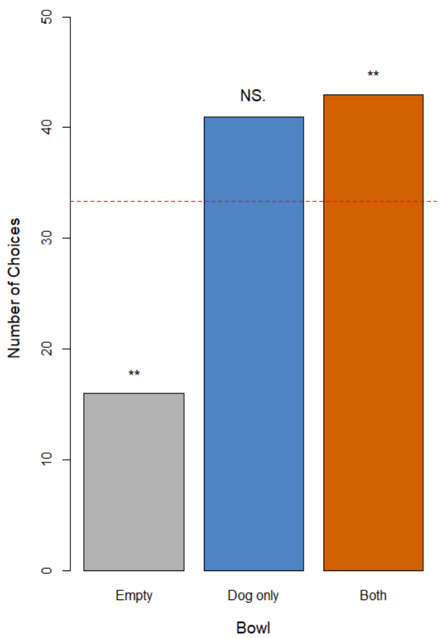

Figure 2. Choices' frequency in test trials of all dogs. Pet dogs (N = 25) were tested for knowledge attribution ability under a three-choice two-reward set-up with a human competitor. One bowl was not baited (the Empty bowl), two bowls were baited, of which one bowl was only known to the dog (the Dog only bowl) and the other bowl was known to both the dog and the competitor (the Both bowl). The first choice of the dog was noted regardless of selection order in this figure. The choices for each bowl were tested against chance level with binomial test separately, the significance was marked in the figure with

'**' for significant and 'NS.' for not significant. The dashed line indicates the chance level (1/3).

Dogs' choices in all four treatments were summarized to give an overview of their performance. In the test-dog first (T-DF) treatment, there was a difference between the knowledge of the dog and the competitor regarding the baiting process, and the dog was able to choose first. Dogs only chose the Empty bowl 3 out of 50 times, which was significantly below chance (binomial, $p < 0.01$; Figure 3). In contrast, dogs chose the Dog only bowl above chance (25 out of 50 times, binomial, $p = 0.011$; Figure 3) and showed a trend towards choosing the Both bowl above chance (22 out of 50 times, binomial, $p = 0.075$; Figure 3). Dogs did not choose the Dog only bowl more than the Both bowl (25 out of 47 times, binomial, $p = 0.385$). In the test-competitor first (T-CF) condition, there was a difference between the knowledge of the dog and the competitor regarding the baiting process, and the competitor was able to choose first. This choice was hidden from the dog. In the T-CF condition, dogs did not select the Empty bowl below chance (13 out of 50 times, binomial, $p = 0.173$; Figure 3). Moreover, they chose the Dog only bowl (16 out of 50 times, binomial, $p = 0.629$; Figure 3) and Both bowl (21 out of 50 times, binomial, $p = 0.125$; Figure 3) at chance level as well, dogs were selecting one bowl from the three bowls randomly.

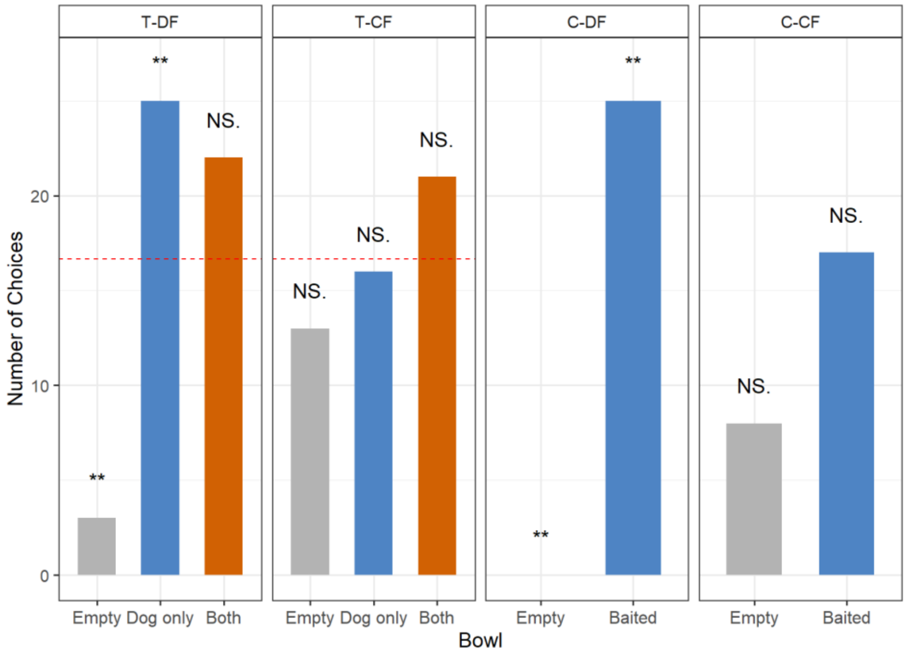

Figure 3. Overview of dogs' choices against chance level under all treatments. Pet dogs (N = 25) were tested for knowledge attribution ability under a three-choice two-reward set-up with a human competitor. There were four treatments in total. Under test condition, one bowl was not baited (the Empty bowl), two bowls were baited, of which one bowl was only known to the dog (the Dog only bowl) and the other bowl was known to both the dog and the competitor (the Both bowl). Under control condition, one bowl remained not baited (the Empty bowl), two bowls were baited (the Baited bowls), and both were only known to the dog, whereas the competitor had no knowledge of the reward locations. There were two treatments with different selection order under both test and control condition, one with dog choosing first (DF) and the other one with competitor choosing first (CF). The first choice of the dog was noted under each treatment in this figure (under C-CF, dogs' choice for Baited bowls was noted regardless of if the

bowl was already emptied by the competitor). The choices for each bowl were tested against chance level with binomial test separately, the significance was marked in the figure with ‘**’ for significant and ‘NS.’ for not significant. The dashed line indicates the chance level (1/3) for T-DF and T-CF.

In the control condition, the baiting phase was still open to the dog, but the competitor did not observe the baiting process and thus had no knowledge of the food location. The control condition was also split up in Dog First (C-DF) and Competitor First (C-CF). Under C-DF, dogs chose the Empty bowl below chance with 0 time out of 25 times (binomial, $p < 0.01$), and the baited bowl above chance with 25 times out of 25 times (binomial, $p < 0.01$), which indicates that they understood the distinction between Empty and baited bowls. Furthermore, dogs chose between the Empty bowl (8 out of 25 times, binomial, $p = 1$) and the baited bowls (17 out of 25 times, binomial, $p = 1$) at chance under C-CF, regardless of if the baited bowl was emptied by the competitor.

Effect of selection order

Dogs’ choices for each bowl were compared across treatments (T-DF and T-CF) with Wilcoxon sign-rank test for the percentage of time they chose each bowl. There seemed to be a difference in the percentage of time the dogs selected the Dog only bowl in T-DF (M±SE = 0.50±0.03) and T-CF (M±SE = 0.32±0.06), with a trend of selecting the Dog only bowl less in T-CF (Wilcoxon, $p = 0.095$; Figure 4). There was no difference in the selection percentage of the Both bowl between T-DF (M±SE = 0.44±0.06) and T-CF (M±SE = 0.42±0.06) (Wilcoxon, $p = 0.854$; Figure 4). Dogs were significantly more likely to choose the Empty bowl under T-CF (M±SE = 0.26±0.06) than T-DF (M±SE = 0.06±0.03) (Wilcoxon, $p = 0.009$; Figure 4).

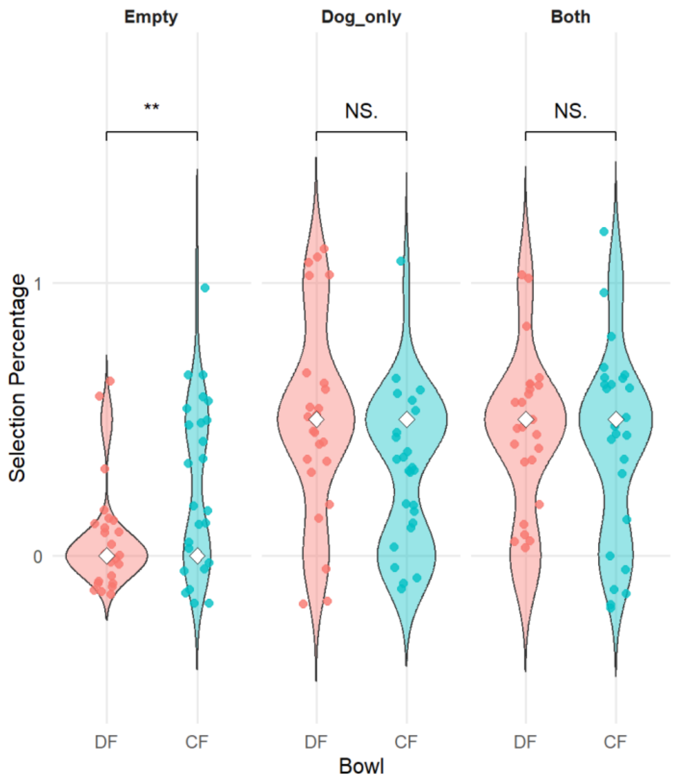

Figure 4. Selection percentage across two treatments of all dogs. Pet dogs (N = 25) were tested for knowledge attribution ability under a three-choice two-reward set-up with a human competitor. One bowl was not baited (the Empty bowl), two bowls were baited, of which one bowl was only known to the dog (the Dog only bowl) and the other bowl was known to both the dog and the competitor (the Both bowl). There were two treatments with different selection order, one with dog choosing first (DF) and the other one with competitor choosing first (CF). The selection percentage of dogs was compared across treatments in this figure with Wilcoxon sign-rank test. The red colour represents DF and the blue colour represents CF. The white diamond represents median for each group. The significance was marked in the figure with '**' for significant and 'NS.' for not significant.

Subgroup analysis in test conditions

Nine dogs passed the training section prior to the testing phase (the Trained group), while sixteen dogs did not choose a baited bowl above chance (the Untrained group). Under T-DF, the Trained group chose the Empty bowl below chance (0 out of 18 times, binomial, p = 0.0007) and the Both bowl above chance (10 out of 18 times, binomial, p = 0.043), the Dog only bowl was selected at chance level (8 out of 18 times, binomial, p = 0.222). However, they did not choose the Both bowl more than the Dog only bowl (10 out of 18 times, binomial, p = 0.407). In T-CF, the dogs did not choose Empty bowl below chance (4 out of 18 times, binomial, p = 0.232), nor did they choose the Both bowl and Dog only bowl above chance (7 out of 18 times, binomial, p = 0.390), all bowls were chosen at chance (Figure 5).

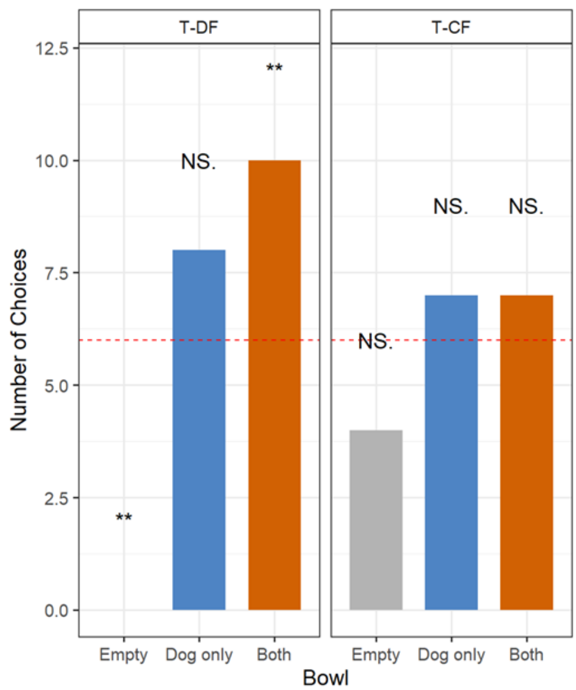

Figure 5. Trained group's choices for each bowl against chance level. Pet dogs who passed the training (N = 9) were tested for knowledge attribution ability under a three-choice two-reward set-up with a human competitor. One bowl was not baited (the Empty bowl), two bowls were baited, of which one bowl was only known to the dog (the Dog only bowl) and the other bowl was known to both the dog and the competitor (the Both bowl). There were two treatments with different selection order, one with dog choosing first (DF) and the other one with competitor choosing first (CF). The first choice of the dog was

noted under each treatment in this figure. The choices for each bowl were tested against chance level with binomial test separately, the significance was marked in the figure with '**' for significant and 'NS.' for not significant. The dashed line indicates the chance level (1/3).

Under T-DF, dogs from the Untrained group chose the Empty bowl below chance (3 out of 32 times, binomial, $p = 0.002$) and the Dog only bowl above chance (17 out of 32 times, binomial, $p = 0.016$). The Both bowl was chosen at chance (12 out of 32 times, binomial, $p = 0.369$). Furthermore, they did not select the Dog only bowl more than Both bowl (17 out of 29 times, binomial, $p = 0.229$). In T-CF, untrained dogs chose the Both bowl (14 out of 32 times, binomial, $p = 0.143$) more than Dog only and Empty bowl (9 out of 32 times, binomial, $p = 0.580$), but not showing any preference from chance (Figure 6).

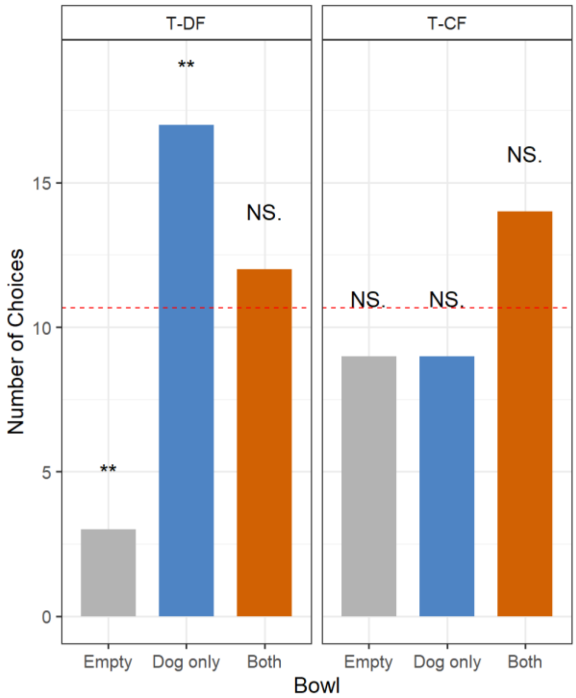

Figure 6. Untrained group's choices for each bowl against chance level. Pet dogs who did not pass the training (N = 16) were tested for knowledge attribution ability under a three-choice two-reward set-up with a human competitor. One bowl was not baited (the Empty bowl), two bowls were baited, of which one bowl was only known to the dog (the Dog only bowl) and the other bowl was known to both the dog and the competitor (the Both bowl). There were two treatments with different selection order, one with dog choosing first (DF) and the other one with competitor choosing first (CF). The first choice of the dog was noted under each treatment in this figure. The choices for each bowl were tested against chance level with binomial test separately, the significance was marked in the figure with '**' for significant and 'NS.' for not significant. The dashed line indicates the chance level (1/3).

Wilcoxon sign-rank test performed on the selection percentage of dogs from the Trained group only showed that there was no difference between groups for choosing for the baited bowls (Dog only: Wilcoxon, $p = 0.850$; Both bowl: Wilcoxon, $p = 0.374$; Figure 7) However, trained dogs showed a trend of choosing the Empty bowl more often in T-CF ($M \pm SE = 0.00 \pm 0.00$) than T-DF ($M \pm SE = 0.22 \pm 0.09$) (Wilcoxon, $p = 0.072$; Figure 7).

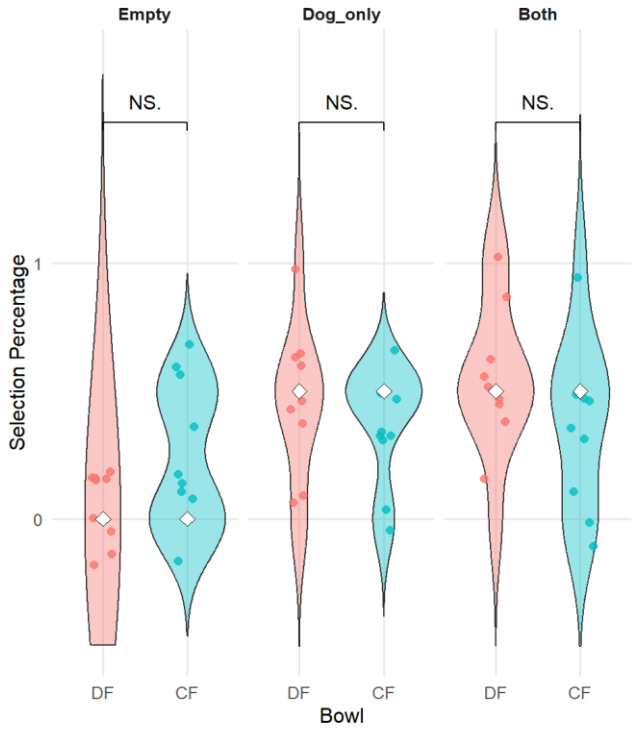

Figure 7. Selection percentage across two treatments of Trained group. Pet dogs who passed the training (N = 9) were tested for knowledge attribution ability under a three-choice two-reward set-up with a human competitor. One bowl was not baited (the Empty bowl), two bowls were baited, of which one bowl was only known to the dog (the Dog only bowl) and the other bowl was known to both the dog and the competitor (the Both bowl). There were two treatments with different selection order, one with dog choosing first (DF) and the other one with competitor choosing first (CF). The selection percentage of dogs was compared across treatments in this figure with Wilcoxon sign-rank test. The red colour represents DF and the blue colour represents CF. The white diamond represents median for each group. The significance was marked in the figure with '**' for significant and 'NS.' for not significant.

For dogs of the Untrained groups, there were only trends showing less choices towards Dog only bowl in T-CF (M±SE = 0.28±0.08) than T-DF (M±SE = 0.53±0.09, Wilcoxon, p = 0.094) and more choices towards the Empty bowl under T-CF (M±SE = 0.28±0.08) than T-DF (M±SE = 0.09±0.05) can be seen (Wilcoxon, p = 0.071; Figure 8). The selection percentage of Both bowl did not change significantly between T-CF (M±SE = 0.44±0.08) and T-DF (M±SE = 0.38±0.07) (Wilcoxon, p = 0.608; Figure 8).

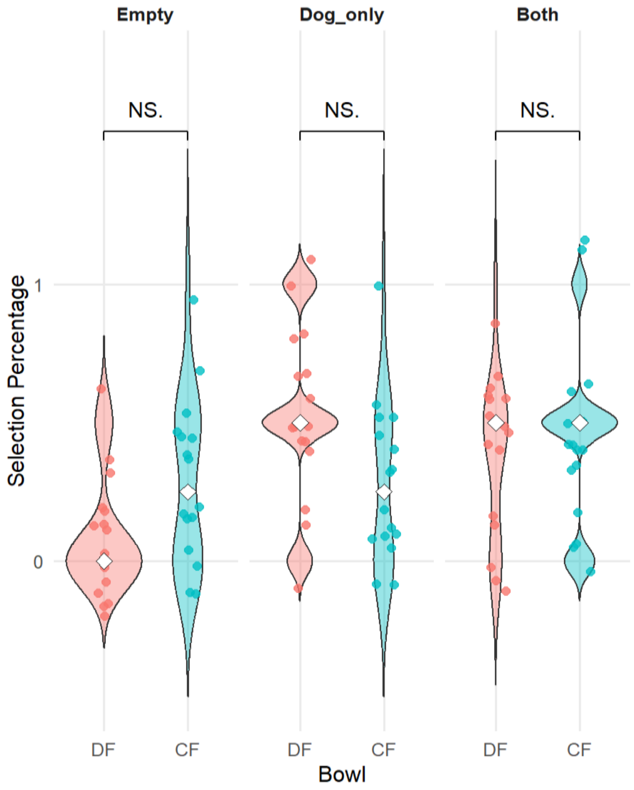

Figure 8. Selection percentage across two treatments of Untrained group. Pet dogs who did not pass the training (N = 16) were tested for knowledge attribution ability under a three-choice two-reward set-up with a human competitor. One bowl was not baited (the Empty bowl), two bowls were baited, of which one bowl was only known to the dog (the Dog only bowl) and the other bowl was known to both the dog and the competitor (the Both bowl). There were two treatments with different selection order, one with dog choosing first (DF) and the other one with competitor choosing first (CF). The selection percentage of dogs was compared across treatments in this figure with Wilcoxon sign-rank test. The red colour represents DF and the blue colour represents CF. The white diamond represents median for each group. The significance was marked in the figure with '**' for significant and 'NS.' for not significant.

Furthermore, we compared the choices between Trained group and Untrained group with Wilcoxon rank-sum test. Under both T-DF (Dog only bowl: Wilcoxon, p = 0.540; Both bowl: Wilcoxon, p = 0.162; Empty bowl: Wilcoxon, p = 0.191) and T-CF (Dog only bowl: Wilcoxon, p = 0.299; Both bowl: Wilcoxon, p = 0.721; Empty bowl: Wilcoxon, p = 0.723) conditions, but no significant difference between the choices of the two groups was found (Figure 9).

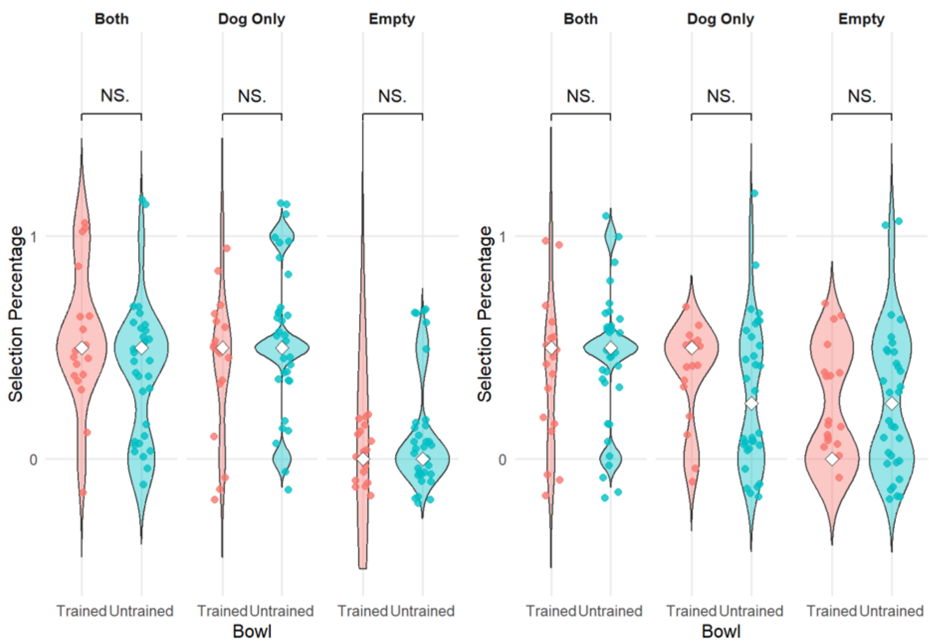

Figure 9. Selection percentage across Trained group and Untrained group under DF (left) and CF (right) conditions. Pet dogs were tested for knowledge attribution ability under a three-choice two-reward set-up with a human competitor. One bowl was not baited (the Empty bowl), two bowls were baited, of which one bowl was only known to the dog (the Dog only bowl) and the other bowl was known to both the dog and the competitor (the Both bowl). There were two treatments with different selection order, one with dog choosing first (DF) and the other one with competitor choosing first (CF). The dogs could be divided into two subgroups by training status, Trained group (N = 9) and Untrained group (N =16). The selection percentage of each bowl was compared across two groups in this figure with Wilcoxon rank-sum test. The red colour represents Trained group and the blue colour represents Untrained group. The white diamond represents median for each group. The significance was marked in the figure with '**' for significant and 'NS.' for not significant

Control conditions

The control treatment was used to check if dogs' choice changed across selection order. Fisher's exact test showed that dogs' choice distribution changed significantly between C-DF and C-CF ($p = 0.004$), and dogs chose Empty bowl more in C-CF (8 out of 25 times) than C-DF (0 out of 25 times), this suggests that dogs' understanding of the baiting process under C-DF was disrupted under C-CF (see appendix for subgroup analysis in control conditions).

Moreover, C-CF treatment was used to check if dogs used other cues (visual or acoustic) to find out which bowl the competitor chose under CF condition, instead of attributing knowledge to the competitor. To test for influence of competitor's choice, two analyses were run for C-CF: one in which the trials where the dog or competitor chose the Empty bowl were excluded from the analysis, resulting in 11 trials, and the other one where all the trials were taken into account except for one (in which the choice of the competitor could not be checked due to missing video recordings), resulting in 24 trials. If dogs would take the knowledge of the competitor into account rather than using additional cues, they should choose between the two baited cups without preference and not be influenced by the choice of the competitor. For the first analysis, dogs chose the bowl emptied by the competitor 3 times (out of 11, binomial, $p = 0.226$), and the bowl that was baited but not chosen by the competitor 8 times. They chose between the two baited bowls randomly, regardless of if one bowl was emptied by the competitor. If dogs were affected by other signals, they might follow or avoid the competitor's choice (irrespective of whether the competitor chose an empty or baited bowl). For the second analysis, dogs selected the bowl chosen by the competitor 5 times (out of 24, binomial, $p=0.278$), and a different bowl 19 times. Therefore, no evidence of dogs resorting to other cues was found.

Effect of extra choice

Additionally, a binary logistic regression model was used to explore the effect of providing an extra choice on the training success(yes/no). As in the training phase, a part of the dogs was provided with an extra choice when selecting a bowl, which was expected to increase the dog's chance to pass the training. With the extra choice, dogs seemed to have a higher possibility of passing training (OR = 1.556), but the effect of extra choice was not significant (β = 0.442, SE = 0.501, z = 0.881, $p = 0.378$).

At last, the main results described above were summarized in the table below.

	Choice against Chance						**Choice across Treatments**		
	T-DF			T-CF			T-DF vs. T-CF		
	Empty	Dog only	Both	Empty	Dog only	Both	Empty	Dog only	Both
All dog	↓	↑	↑	NS.	NS.	NS.	↑	↓	NS.
Trained	↓	NS.	↑	NS.	NS.	NS.	↑	NS.	NS.
Untrained	↓	↑	NS.	NS.	NS.	NS.	↑	↓	NS.

Table 2. Overview of main results. Pet dogs (N = 25) were tested for knowledge attribution ability under a three-choice two-reward set-up with a human competitor. Dogs could be divided into Trained group (N = 9) and Untrained group (N = 16). First, dogs' choices were tested against chance level (1/3) under T-DF and T-CF, downwards arrows indicate this bowl was selected below chance, upwards arrows indicate this bowl was selected above chance, 'NS.' indicates this bowl was selected at chance. Second, dogs' choice percentage for each bowl was compared across selection order, downwards arrows indicate this bowl was selected less in T-CF than T-DF, upwards arrows indicate this bowl was selected more in T-CF than T-DF, 'NS.' indicates no significant difference between T-DF and T-CF. For both tests, green colour indicates significant difference (p-value was less than 0.05), red colour indicates probable difference (p-value was between 0.05 and 0.1).

Discussion

Domestic dogs can understand human social cues and visual perspective (Bräuer et al., 2004; Horowitz, 2009; Kaminski et al., 2009; Udell et al., 2011), providing the basis to explore the more advanced ToM ability of knowledge attribution. We chose to explore this using a competitive set-up, as this is possibly more ecologically relevant for dogs as a species, and competitive tests have shown to require more cognitive effort and attention (Garcia et al., 2006; Hare & Tomasello, 2004), which might pressure animals into using more advanced cognitive abilities. In this competitive set-up, we studied pet dogs' ability to attribute knowledge to a human competitor with a three-choice two-reward set-up, adapted from a chimpanzee study of Kaminski, Call and Tomasello (2008). Dogs' choices were expected to change, according to the specific knowledge of the competitor and the selection order in which dog and human competitor could choose. Two rewards were hidden in three bowls, which was observed by the dog. A human competitor could see the hiding of one reward and thus only had knowledge on the location of that treat. We expected dogs to be able to take the knowledge of the competitor into account and to show no preference between the two baited bowls in the condition when the dog chose first (DF), but to show a preference for the bowl only they saw being baited (Dog only bowl) when the competitor chose first (CF), as this would show an understanding that the competitor would take the food they saw being hidden. In the control trials, in which the competitor had no knowledge at all, the dogs should show a preference for the baited bowls over the bowl that was not baited (Empty bowl), but not for one specific baited cup, as this would show an understanding that the competitor would be choosing randomly. Moreover, they should not be influenced by the choice of the competitor in the control trials, as this would show that they could use additional cues.

When the dogs (N = 25) chose first (DF), they selected the Empty bowl below chance, the Dog only bowl and the bowl both they and the competitor saw being baited (Both bowl, with a probable difference) above chance, with no preference for a specific baited bowl. This is in line with our prediction, as this could show an understanding that both bowls still held a food reward because the competitor had not yet chosen. If our dogs did attribute knowledge to the competitor, we expected a shifting in their choices towards Dog only bowl under CF. However, when the competitor chose first, dogs chose at random between the three bowls and there was even a trend towards choosing the Dog only bowl less in CF than in DF, which is against our prediction. Moreover, dogs chose the Empty bowl more in CF than in DF. This indicates that dogs did not take the knowledge of the human competitor into account to gain access to the food rewards, but it also shows that dogs might have been more distracted during the CF condition, causing them to choose a bowl they knew to be empty more often. Control trials showed that dogs also preferred to choose a baited bowl over the Empty bowl in DF condition but chose between baited and non-baited bowls randomly in CF condition. The fact that they also chose Empty bowl more in CF further reinforces the suspicion that dogs may be distracted in CF treatment. Control trails were also used to analyse whether dogs followed competitor's choice and showed that they were not influenced by the competitor's choice during the CF condition.

Dogs' inability to take the knowledge of the competitor into account when this person chose first might be due to several reasons, only one of which being them not having the ability to attribute knowledge to humans. Other reasons include that dogs might have failed to understand one of the cognitive steps that were required to comprehend this task, or that the specific method during the CF condition left dogs confused.

The first cognitive step needed for dogs to understand this set-up is to understand object permanence, which refers to the ability to understand object's nature to continuously exist out of sight (Miller et al., 2009). Dogs have been proven to understand object permanence via visual information as they succeeded in finding an object after witnessing it being placed or moved out of sight (Gagnon & Doré, 1992; Miller et al., 2009). In our study, dogs did also seem to understand object permanence, as they chose the Empty bowl less often during the DF trials and they all passed the first part of training, which required them to find an out-of-sight treat as well based on what they saw. Another challenge for dogs was to understand the competition between themselves and the human competitor. We saw that many dogs already struggled with this during the training phase, resulting in only nine dogs passing a benchmark of choosing a still baited bowl above chance, after they saw the competitor take the treat out of the other baited bowl. The dogs who did not pass the training chose the bowl picked by the competitor most of the time. Likely, dogs struggled with understanding that the competitor was taking the treat out of the bowl she chose and would leave the chosen bowl empty. It's highly possible that the dogs failed to pass the training were following the simple mechanism of local enhancement, meaning they focused more on a location because they observed others directing their attention toward it, which also plays a role in food-finding behaviours of animals (Galef & Giraldeau, 2001; Range & Virányi, 2013). In this case, the fact of competitor approaching a certain bowl instead of the specific action of taking treat out, seems to capture more attention of the dog. It is difficult to eliminate the effect of local enhancement, but effort can be made to counteract it by emphasizing the causal effect that competitor would always empty the bowl she chose. As dogs needed the reasoning ability to link the causation of competitor choosing a bowl and the consequences of no reward could be gained from this bowl, thus, to pass the training. Dogs could demonstrate ability to reason by exclusion, as they were able to find the object from one of two locations when the other location has been shown to be empty (Erdohegyi et al., 2007). The extra choice given to dogs during training of this test might help them reason the situation using exclusion, that the baited bowl that was not chosen by the competitor might be the correct choice. Furthermore, dogs generally prefer to follow human communicative cues rather than resort to reasoning abilities, they show more reasoning abilities when it's not possible to rely on easy social cues (Bräuer et al., 2006; Erdohegyi et al., 2007), making it crucial to minimize social cues towards a certain bowl. It might also be questioned whether the training phase actually trains the dogs for an understanding of the working principle of the test, as the Trained group and the Untrained group selected randomly between the three bowls in the CF condition, suggesting that something other than training affected dogs' performance during CF conditions.

The fact that dogs did not show a preference for any of the bowls in the CF condition and they actually chose the Empty bowl more in CF than in DF, suggests that there must be interfering factors causing stress or confusion during the CF treatment. When the competitor chose first, her choice had to remain hidden from the dog. To accomplish that, the dog's view was blocked during the first choice of the competitor in CF conditions. The view-blocking step was new to the dogs, as they had not been exposed to or familiarized with this process during the training phase. The sudden move of the screen or blanket may have distracted the dogs and/or caused them additional stress, as sudden move that could not be foreseen by the dog (such as a falling bag) often causes stress and increases in saliva cortisol level (Beerda et al., 1998). Although no additional stress was reported by the owners. Moreover, the dogs had to wait longer before they could make their choice in the CF condition than in the DF condition. A longer waiting time within 240 seconds can affect dogs' working memory but does not completely impair it, as dogs are shown to be able to find a hidden object at above-chance levels within 240 seconds, though their performance decreases as the waiting time extends (Fiset et al., 2003). This means that although the longer waiting time might have decreased their success levels, the view-blocking step is likely the main factor causing distraction during the CF treatment.

Another unexpected finding was that dogs from the Trained group showed a trend towards choosing the Empty bowl more often in the CF condition, although this might again be explained by the added distraction during this condition. The dogs of the Untrained group showed a trend of choosing the Empty bowl more often in the CF condition as well, suggesting that this is not affected by whether or not the dogs understood the training. However, untrained dogs also chose the Dog only bowl less often during the CF condition, which is against our original prediction. In contrast, the trained dogs chose the Dog only bowl at chance level during both CF and DF conditions with no difference between the two. This indicates that the trend that was found for a decrease in choosing the Dog only bowl in the CF condition for all the dogs was likely due to the untrained dogs, suggesting that the dogs that did pass the training benchmark might have shown a greater understanding of the working principles of this test after all. Untrained dogs were unable to understand the role of competitor, therefore, instead of avoiding the Both bowl during the CF condition, they might have paid more attention to this bowl due to local enhancement. As more human attention was directed to it during the baiting process of both T-CF and T-DF treatment (the experimenter stopped at it for a longer time and the competitor paid extra attention to it). This might explain why the extra distraction in CF treatment influenced their choices towards the Dog only bowl more than choices towards the Both bowl, so the choices for Both bowl remained stable.

We expected the competitive set-up to be more natural and ecologically relevant for pet dogs, however, this study might actually hold a risk of being unnatural for them, which could impair the effectiveness in assessing knowledge attribution abilities. The unnaturalness arises from the specific food competition scenario in this test, where dogs compete over food reward placed in dog bowls with a human competitor, rather than competition in general. Multiple studies using competitive set-up yielded positive results, especially those mirroring situations like 'human forbidding a dog from eating certain food' or 'human ordering a dog to lay down', which resemble everyday experiences for pet dogs (Bräuer et al., 2004; Call et al., 2003; Schwab & Huber, 2006). As a logical extension, this set-up could be improved by create a life-similar context instead of the direct food competition, for instance, create a scenario where the owner forbids the dog to eat treats, but has knowledge of one treat and not the other treat. Although the direct food competition with human seems not natural for pet dogs, it might be rather natural for free-ranging or pack dogs, as they have more food competition situation in daily life and they have less tendency to cooperate with unfamiliar humans (Bhattacharjee et al., 2017; Cafazzo et al., 2010; Dale et al., 2017; Vanak & Gompper, 2009), they thus might easily see a human as competitor. We expected the pet dog-human competition to mirror the competition within conspecifics for free-ranging dogs, pack dogs or wolves on the basis that pet dogs could see humans as dominant individuals (Cafazzo et al., 2010; Dale et al., 2017; Range & Virányi, 2014). The fact our dogs struggled with this competitive setting, despite that the human competitor tried to act dominantly throughout the test, not just suggests unnaturalness as mentioned above but also makes us doubt if dogs could actually see humans as dominant individuals. To further explore the possible differences between the way dogs perceive humans and the way they perceive conspecifics, future research could test free-ranging dogs, pack dogs and even wolves' knowledge attribution abilities to conspecifics and to humans. This would allow comparisons and a deeper dive into the mechanisms behind canine cognitive abilities. For pet dogs, we could either create a more competitive situation between them and humans (i.e. let the human competitor steal food from the dog as a pre-expose might promote dog's understanding of competitor's role), or it might be more natural for them to compete with conspecifics rather than humans, which also mirrors the study from which this study adapted, where the chimpanzees were competing with conspecifics (Kaminski et al., 2008). Following this thought, we attempted to conduct a two-dog try-out with a dog competitor instead of a human competitor (protocol in the appendix). Due to time limitations, this try-out has not been performed with enough repetitions, future research is needed.

For future continuation of this study, a few improvements should be made. For the training phase, providing the extra choice to the dog (allow the dog to choose again even it makes the wrong choice at first) is advised. Although its effect was not significant, this may be due to the limited number of dogs that participated in the study with the extra choice. When it comes to food competition, affiliative relationship and bonding largely determines the tolerance of sharing food for pack dogs (Dale et al., 2017). The familiarity between dogs and humans also affect their responses to the humans, especially in negative contexts (Kerepesi et al., 2015). Therefore, to promote dogs' understanding of the human competitor, the competitor should stay unfamiliar with the dog and should not interact in any way with the dog even during the breaks. To tackle the interfering factors in the CF condition, dogs should be exposed with the view-blocking process prior to the testing phase. Owners could repeat this process a few times during the break before the testing phase in a playful way. Furthermore, the view-blocking step can be done with other equipment, such as curtains on a rack. A previous study using similar paradigm to this set-up but with curtains blocking dogs' view found that dogs chose the Empty cup below chance, also in CF conditions (Noordenbos et al., under review).

This study could not find support for the existence of the knowledge attribution ability of dogs, as dogs did not take the knowledge of their human competitor into account when competing for food rewards. However, this study also does not disprove the existence of knowledge attribution in dogs, as the paradigm used in this study has been shown to need improvement, especially regarding CF treatment. It is likely that there is large individual variation between dogs, which also becomes apparent when looking at whether dogs passed the training or not. The variation in the personality of dogs might account for their ability to pass the training, for example, dogs with anxious personality might have poor performance (Naderi et al., 2002). Independent dogs might be less likely to rely on human cues, thus were less affected by local enhancement and more actively engaged in reasoning process. Also, highly food-motivated dogs might show more motivation and put more cognition effort in this task, in order to get more food rewards. However, further research is needed to explain the individual variation and its effect on cognition abilities. Improvement and refinement of the methodology can make this competitive paradigm still useful when testing dogs for their ability to attribute knowledge to humans. Thus, we can explore the more advanced ToM abilities in dogs and shed light on the relevance of competitive contexts and cognitive tasks in domestic dogs and other animal species.

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Appendix

1. Binomial test and Chi-square test or Fisher-Freeman-Halton exact test with Monte Carlo simulation (B = 10,000) on choices counts of dogs

Methods

To conduct comparison with binomial test, dogs' choice counts for each bowl were noted separately, in a way of yes or no (binary). The data from one treatment was used to calculate the probability of selecting each bowl. This probability was then set as the chance level for the counts of the other treatment. By testing the counts of one treatment against the chance level of another, the counts for each bowl within the two treatments can be compared. For example, under T-DF, dogs chose the Dog only bowl 25 out of 50 times, the chance level of dogs selecting Dog only bowl under T-DF is thus 0.5. Under T-CF dogs chose the Dog only bowl 16 out of 50 times, then we could test if dogs chose the Dog only bowl below chance level (0.5) via the method of binomial test (i.e. if dogs chose the Dog only bowl under T-CF less than under T-DF). Chi-square test (for all dogs) and Fisher-Freeman-Halton exact test with Monte Carlo simulation (B = 10,000)* (for Trained and Untrained group) were also used to compare the counts of dog's choices across treatments, serving for purpose to focus on the change in global choice distribution across conditions, while binomial test served the purpose to focus on the selection change of one specific bowl.

Fisher-Freeman-Halton exact test with Monte Carlo simulation (B = 10,000) was used to handle the small three dimensional dataset (2×3 table) and to get a more reliable p-value.

Results

Dogs (N = 25) did not choose the Dog only bowl more in T-CF than T-DF (16 out of 50 times, binomial, $p = 0.997$, chance level = 0.5). In contrast, they selected the Dog only bowl significantly less often (16 out of 50 times, binomial, $p = 0.008$). Unexpectedly, dogs' choices shifted towards the Empty bowl under T-CF than T-DF (13 out of 50 times, binomial, $p < 0.01$, chance level = 0.06). For the Both bowl, no significant difference was found in the dogs' choices between T-CF and T-DF conditions (21 out of 50 times, binomial, $p = 0.887$, chance level = 0.44). Chi-square test also shows that the distribution of dogs' choices changed between T-CF and T-DF (X2 = 8.249, Chi-square, $p = 0.016$).

Compared to T-DF, trained dogs (N = 9) showed no difference in choosing the Dog-only bowl (7 out of 18 times, binomial, $p = 0.813$, chance level = 0.44) or the Both bowl (7 out of 18 times, binomial, $p = 0.160$, chance level = 0.56) under T-CF. They did choose the Empty bowl more under CF treatment (4 out of 18 times, binomial, $p < 0.01$, chance level = 0). However, Fisher-Freeman-Halton exact test with Monte Carlo simulation (B = 10,000) didn't show significant shift in their choice distribution across T-CF and T-DF ($p = 0.160$).

Untrained dogs (N = 16) selected the Empty bowl more (9 out of 32 times, binomial, $p = 0.002$, chance level = 0.094) and the Dog only bowl less (9 out of 32 times, binomial, $p = 0.004$, chance level = 0.531) in T-CF than T-DF, but their choices for the Both bowl did not differ (14 out of 32 times, binomial, $p = 0.289$, chance level = 0.375). Fisher-Freeman-

Halton exact test with Monte Carlo simulation (B = 10,000) didn't find a significant difference in dogs' choice distribution between T-CF and T-DF ($p = 0.069$), but a probable difference.

2. Subgroup analysis in control conditions

Trained group chose the Empty bowl below chance with 0 time out of 9 times (binomial, $p = 0.034$), and the baited bowl above chance with 9 times out of 9 times (binomial, $p = 0.034$) in C-DF; they chose between the Empty bowl (2 out of 9 times, binomial, $p = 0.727$) and the baited bowls (7 out of 9 times, binomial, $p = 0.727$) at chance under C-CF, regardless of if the baited bowl was emptied by the competitor.

Fisher's exact test did not show that their choice distribution changed significantly between C-DF and C-CF ($p = 0.471$), but this was likely due to small dataset.

Untrained group chose the Empty bowl below chance with 0 time out of 16 times (binomial, $p = 0.002$), and the baited bowl above chance with 16 times out of 16 times (binomial, $p = 0.002$) in C-DF; they chose between the Empty bowl (6 out of 16 times, binomial, $p = 0.792$) and the baited bowls (10 out of 16 times, binomial, $p = 0.792$) at chance under C-CF, regardless of if the baited bowl was emptied by the competitor.

Fisher's exact test showed that their choice distribution changed significantly between C-DF and C-CF ($p = 0.018$).

3. The effect of screen usage (to block dogs' view under CF treatment) on the performance of dogs

Under CF treatments, the vision of some dogs was blocked with a screen and that of others with a blanket. Since we found an increase in choices for the Empty cup in CF treatments, this might be explained by this method. A test of whether dogs would choose empty bowls more often with screen or with blanket in the CF condition was therefore conducted, where choices of Dog only bowl and Both bowl were combined into 'baited bowls'. A binary logistic regression model was thus used (baited/Empty) and it was found that, there was no effect of vision blocking method on dogs' selection between the Empty bowl and the baited bowls ($\beta = 0.065$, $SE = 0.519$, $z = 0.124$, $p = 0.901$).

4. Protocol of two-dog try-out

We propose try-out with two dogs (competitor dog and subject dog) from the same household.

A second (competitor) dog sits on the left side with a student or a friend of the owner (a familiar person). The owner sits with the subject dog on the right side. The second dog can either be the direct competitor that the subject needs to take into account (try-out 1) or the second dog is led by the competitor (human) and simply gets the treats, so the subject still needs to take the knowledge of the person into account (try-out 2).

The training and test go the same as in the previous set-up with only the human competitor, with these changes:

Training:
As with the human competitor, the competitor still chooses first, but now the competitor dog gets to eat the food— immediately note how many trials the subject dog was right (without taking bowls aways), to see if having a dog as a competitor really helps the subject dog to make the right choice. You can still give the subject dog a second choice in case of a wrong choice for the first 10 trials.

Try-out 1:
The competitor dog is also on a long leash, able to reach the bowls. The person holding the competitor dog (handler), sits on a chair with the dog in front of them, just as the subject dog, and lets the leash go when told to, to let the competitor dog go to a bowl and eat the food in it. the handler does not interfere with its decision. After one choice, the competitor dog needs to be called/pulled back and then the subject dog can choose as usual. The 2 dogs keep choosing in turn till both treats are taken. As in the previous set-up, the experimenter uses different words to let the handlers know to release the dogs (for instance 'choose' and 'okay').

Try-out 2:
The competitor dog is on a short leash held by the competitor, who stands in front of the chair as in the original set-up. The competitor clearly observes the baiting and when it gets the okay to choose, walks (with the dog) to a bowl he/she decided upon. The competitor dog then gets to eat the food from this bowl. The human competitor should not point at a bowl or crouch next to it, to avoid local enhancement for the subject dog, but should simply take the competitor dog to the bowl to let it eat. After the dog ate the treat, the competitor walks back with the dog and stands in front of the chair again. The subject dog then gets to choose as usual. For the first 10 rounds, if it chooses wrongly it gets to have a second choice. After that, the competitor and the competitor dog walk to the bowl with the other food reward and the competitor dog gets to eat it when told to. As in the previous set-up, the experimenter uses different words to let the handlers know to release the dogs (for instance 'choose' and 'okay').

Testing:
The same set-up was kept the same as during the training (depending on try-out 1 or 2). The conditions are the same as with only a human competitor. In the condition where the competitor chooses first, in both try out conditions the person sitting or standing with competitor dog (handler/competitor) points at the bowl to choose, after which the experimenter will get the treat the same way as the original set-up and give it to the competitor dog. This way, the choice remains hidden from the subject dog (also sound wise).

During the baiting the handler sits on the turned around chair with the dog in front of them, trying to keep the attention of the dog with treats (try to avoid peeking; try-out 1) or only the human competitor sits turned around on their chair with the dog on a short leash next to them (try-out 2).