Published in final edited form as:
J Comp Psychol. 2014 February ; 128(1): 31–39. doi:10.1037/a0033202.

Dogs can learn to attend to connectivity in string pulling tasks

Stefanie Riemer, **Corsin Müller**, **Friederike Range**, and **Ludwig Huber**
Messerli Research Institute, University of Veterinary Medicine Vienna, Medical University of Vienna and University of Vienna; Department of Cognitive Biology, University of Vienna; Clever Dog Lab, Vienna, Austria

Abstract

String pulling tasks are commonly used to investigate recognition of means-end connections. Previous studies suggested that dogs base their choice on proximity rather than connectivity (Osthaus, Lea, & Slater, 2005), nonetheless, dogs performed successfully in the related support problem (Range, Hentrup, & Virányi, 2011). To re-investigate dogs' means-end understanding, we tested 34 Border collies in string pulling tasks in which the proximity of the reward to the connected string's end was varied. First, subjects were presented with a four-string task (four parallel perpendicular strings, one baited, with the reward in line with the correct string's end). Dogs that performed above chance in this task were tested with a curved string task, involving one straight and one curved string. When the reward was attached to the curved string, it was equidistant from both strings' ends so that choosing by proximity was not possible. While group level performance was significantly above chance, only three of 20 dogs met criterion individually, of which one dog subsequently solved a broken string task upon its first presentation. However, the dogs seemed to be unable to overcome their proximity bias in a parallel diagonal string task where proximity of the unconnected string's end to the reward was misleading. We conclude that although dogs may not demonstrate means-end understanding spontaneously, some can learn to pay attention to connectivity when proximity is not a confounding factor. This study supports the notion that animals may apply several alternative strategies to solve physical problems, which are influenced by the test-setup.

Keywords

string-pulling; means-end connections; proximity; strategy selection; dogs; *Canis familiaris*

Introduction

The ability to gain access to an out of reach object by means of pulling a string attached to it has long been regarded as a valid example of non-human animals' apprehension of means-end relationships. However, mere acquisition of the reward by pulling at the string does not necessarily reflect means-end understanding; alternatively, it could be due to associative learning (e.g. Schmidt & Cook 2006) and/or manipulating the vicinity of the food (Heinrich

---

Correspondence concerning this article should be addressed to Ludwig Huber, Division of Comparative Cognition, Messerli Research Institute, University of Veterinary Medicine, Veterinärplatz 1, 1210 Vienna. ludwig.huber@vetmeduni.ac.at.

& Bugnyar 2005; Osthaus, Lea, & Slater, 2005). To distinguish between these possibilities, several strings, which may be laid out at various angle orientations or crossed, are often provided (Heinrich & Bugnyar 2005). Animals as diverse as pigeons (*Columba livia*, Schmidt & Cook, 2006), corvids (Heinrich, 1995), psittacids (Werdenich & Huber, 2006; Schuck-Paim, Borsari, & Ottoni, 2009), several monkey species (Harlow & Settlage, 1934; Cha & King, 1969; Halsey, Bezerra, & Souto, 2006; Gagné, Levesque, Nutile, & Locurto, 2012), and great apes (Herrmann, Wobber, & Call, 2008; Povinelli, 2000) have performed successfully in tasks requiring them to select a baited over an unbaited string or paying attention to a gap between the string and the reward. Based on the performance in these tasks, various cognitive processes have been proposed for different animals, including associative learning (e.g. squirrel monkeys, *Saimiri sciureus*, Cha & King, 1969; pigeons, *Columba livia*, Schmidt & Cook 2006), operant conditioning (New Caledonian crows, *Corvus moneduloides*, Taylor, Medina, Holzhaider, Hearne, Hunt, & Gray, 2010), attending to perceptual contact but not necessarily connectivity (great apes, Herrmann, Wobber, & Call, 2008; Povinelli, 2000) and spontaneous apparently “insightful” solutions (individual ravens, *Corvus corax*, Heinrich 1995; grey parrots, *Psittacus erithacus*, Pepperberg, 2004; and keas, *Nestor notabilis*, Werdenich & Huber, 2006).

In fact, a combination of ontogenetic development and experience may have led to such apparently insightful behavior. For instance, Bruce, a 7-month-old kea fledgling, failed to retrieve food attached to a string initially, but a month later, he showed the same competence as those individuals that were several years old when tested for the first time (Huber & Gajdon, 2006; Werdenich & Huber, 2006). A combination of sensorimotor development (beak-foot coordination) and experience might have facilitated means-end understanding (Werdenich & Huber, 2006). Indeed, experience is of paramount importance in the development of physical cognition: It is through exploration that human children detect and relate affordances between objects, coordinate spatial frames of reference, and incorporate early-appearing action patterns into instrumental behaviors (Lockman, 2000). Given appropriate experience, young children quickly learn, transfer and extend their current knowledge about physical causality (Brown, 1990). Also in animals, cognitive development comes about through an interaction between the subject and its environment (Doré & Dumas, 1987). Moreover, specific experiences may be necessary for a functional understanding of physical tasks. For instance, in a tool using task, great apes initially failed to select the correct cane tool when it was not in contact with the reward (Herrmann, Wobber, & Call, 2008). However, after only a small amount of experience with the plastic material of the canes (in the context of different experiments), they improved relative to the first experiment (Herrmann, Wobber, & Call, 2008). Besides enhancing physical understanding, certain experiences may furthermore aid animals in overcoming impulsive responses or in examining the task more carefully, leading to improved performance (Seed, Call, Emery, & Clayton, 2009).

Domestic dogs (*Canis familiaris*) have generally shown an inferior performance in physical cognition tasks when compared to primates and some birds (e.g. Osthaus, Lea, & Slater, 2005; Bräuer, Kaminski, Riedel, Call, & Tomasello, 2006). In the string pulling paradigm, they were able to select a baited over an un-baited string when parallel perpendicular strings were presented (Osthaus, Lea, & Slater, 2005). However, they failed in more complex two-choice tasks when the proximity of the unconnected string's end was misleading (Osthaus, Lea, & Slater, 2005; Range, Möslinger, & Virányi, 2012), as well as in a task requiring them to select an entire string connected to a reward over a shorter one that was not connected, but close to a second reward (Range, Möslinger, & Virányi, 2012), with no sign of learning within 20 trials in either task (Osthaus, Lea, & Slater, 2005; Range, Möslinger, & Virányi, 2012). Dogs have a strong tendency to paw near the reward and accordingly perform successfully in tasks where the correct string's end lies closest to the reward, but not when the unconnected string's end is closer to the reward than the connected string's end (Osthaus, Lea, & Slater, 2005; Range, Möslinger, & Virányi, 2012). Based on these results, it is assumed that dogs do not possess means-end understanding but follow a proximity rule instead, pawing near where they perceive the reward (Osthaus, Lea, & Slater, 2005).

In contrast, Range, Hentrup, & Virányi (2011) demonstrated that dogs have the ability to solve a means-end task in the related support problem. In this task, two identical rewards were presented behind a fence, one on top of a board, another one next to a second, parallel board. The dogs spontaneously chose to pull out the correct board more often than would be expected by chance, even when the food reward on the board was further away than the inaccessible reward. Possible explanations for the better performance in this task are that during their daily experiences dogs have more opportunities to learn something about objects placed on other objects than about objects connected to strings, that the contact is easier to perceive in the support problem than in string pulling tasks, or that only very simple conditions were tested in Range et al.'s (2011) study. In any case, the study does indicate that dogs may possess the capacity to attend to means-end connections.

This led us to predict that, given the right conditions, dogs are capable of tracing means-end connections in the string pulling problem and that they can solve a connectivity task if proximity is not a confounding factor. We also predicted improvement in performance with increasing experience (number of string pulling trials performed), which would reflect learning. To test these predictions, we tested 34 dogs in a series of string pulling tasks, varying the proximity of the reward to the correct and the incorrect strings' accessible ends.

Methods

Subjects

All subjects were Border collies (10 males, 24 females), which participated in a larger research project on physical cognition, of which the string pulling task was the first one tested. In this project, the subjects were restricted to a single breed to rule out breed differences. Border collies were chosen because most individuals of this breed are highly motivated to engage in such tasks and they are quite common. Border collies are neither extremely brachycephalic ("short-nosed") nor dolichocephalic ("long-nosed"), characteristics that may provide advantages or disadvantages in visual discrimination tasks, respectively (McGreevy, Grassi, & Harman, 2004; Gácsi, McGreevy, Kara, & Miklósi, 2009), and we have no reason to assume that Border collies would be selected for performance in means-end tasks. All the dogs were tested at the same age (12-15 months) and had extensive experience with string pulling from a previous experiment conducted when they were 6-8 months old (up to 50 trials with single and two strings, in which they showed no evidence of means-end understanding, unpublished data).

Experimental Setup and Procedure

The tests were performed in a room (6m × 5m) at the Clever Dog Lab, Vienna (Figure 1). One corner of the room was fenced off. Experimenter 1 entered this area through a door from the outside and laid out the strings, which were 1.5 cm in diameter and 60 cm long, with knots at their distal ends (where the rewards could be attached). Rewards were strips of sausage approximately 8 cm long and 0.5 cm wide. A wire-mesh fence prevented the dogs from accessing the baited ends while allowing visual access. The proximal 10 cm of the strings were accessible to the dogs, which could pull out the strings through a 5 cm gap between the floor and the fence. As dogs have dichromatic color vision and can discriminate best between stimuli whose predominant spectral energies lie around 480nm (Miller & Murphy 1995), blue strings were used to ensure that the dogs could distinguish well between the strings and the dark brown floor. The baited location and the configuration of the strings were pseudo-randomised so that no location was baited more often than twice in a sequence and all locations were baited equally often.

During the baiting, the dog waited with experimenter 2 behind a wooden partition preventing it from observing the baiting (Figure 1). After experimenter 1 had laid out the strings and exited the room, experimenter 2 walked the dog to the starting point one meter away from the fence. As soon as the dog had looked at the setup for five seconds (i.e., facing towards the strings and not looking sideways or upwards, regardless of whether it was apparently focusing on the correct or the incorrect string), she released the dog by letting go of a 30 cm long leash attached to its harness.

When a dog had pulled out an unbaited string, experimenter 2 pushed the baited string behind the fence or led the dog away by its harness to prevent a second choice. Only in the last trial of each session were the dogs allowed to try until they obtained the reward to keep up motivation. During testing, switching to a different string was allowed as long as the first string had not been pulled out more than halfway. However, aiming to draw inferences about means-end understanding and not alterations of responses due to visual feedback, we considered a choice as correct only when the dog touched the correct string first (and subsequently pulled it out completely). Thus, our criterion was more stringent than that used by Osthaus and colleagues (2005), who considered a choice as correct when the first string to be completely pulled out was the one with the food attached.

The dogs were usually given a session of 10 trials followed by a break of at least 5 minutes, with a maximum of 3 sessions per test day. For five dogs, breaks were taken after a smaller number of trials due to decreased focus on the task (not looking at the setup). Their performance was not significantly different from that of the dogs that completed all sessions without additional breaks (Mann Whitney U tests, p-values of 0.24 or higher).

If possible, testing was performed without the owners present in the room; however, during the first condition, three dogs would not work without their owners. Their owners remained in the test room but stayed behind the wooden partition (Figure 1) so that they could not influence their dogs' choices. Mann Whitney U tests yielded no significant differences in performance between dogs working with or without their owners present in the test room (p-values of 0.14 or higher).

Tasks and Conditions

Initially the dogs were given two "warm-up" trials in which they had to pull out single perpendicular strings to obtain an otherwise inaccessible reward behind a fence. These trials were performed to make sure that the dogs still remembered the action of string pulling from the previous experiments several months earlier. All dogs succeeded and were subsequently tested in tasks requiring them to select a baited string out of a choice of two or four strings. The proximity of the reward to the correct and the incorrect strings' ends was systematically varied: in the four-string task (task 1, Table 1), the reward was directly in line with the correct string's end so that choosing by proximity would lead to success. Dogs that performed above chance in this task were subsequently tested in the curved string task (task 2, Table 1). Here, the reward was equidistant from both strings' ends on half of the trials, so that the task could only be solved by tracing the connection between the reward and the string. Finally, dogs that mastered the curved string task were tested in further tasks in which the proximity of the unconnected string's end to the reward was inconclusive (gap task, task 3, Table 1) or misleading (parallel diagonal string task, task 4, Table 1).

Four-string task (Task 1)—The four-string task (task 1, Table 1) involved four parallel perpendicular strings, one of which was baited. It has previously been found that dogs are capable of selecting a baited string out of two options when choosing by proximity is possible (Osthaus, Lea, & Slater, 2005); however, learning may be less likely to occur when success rate is high at 50% (see Tebbich, Seed, Emery, & Clayton, 2007). Therefore, we provided a choice of four, not two strings, one of which was baited, to lower chance probability of success to 25% and thus increase the pressure on the dogs to pay attention and choose correctly. The criterion to proceed to task 2 was at least 11 of 20 correct choices in two consecutive test sessions with 5 or more correct choices in each session (binomial probability: $p<0.01$). For dogs (N=13) that did not meet criterion within 60 trials, testing was terminated.

Curved string task (Task 2)—The majority of subjects (N=21) succeeded in the four-string task, and 20 subjects were presented with a novel task, the curved string task (task 2, Table 1; one dog did not return for testing). While in previous string pulling studies, dogs' correct or incorrect choices were facilitated by the linear proximity of the reward to the connected or the unconnected string's end, respectively, the curved string task is the first string pulling task tested in dogs in which proximity is not a confounding factor (but see e.g. Range, Möslinger, & Virányi, 2012 for a task with two rewards). The curved string task involved one straight and one curved string (Table 1). When the reward was attached to the curved string, it was an equal distance away from both strings' ends so that choosing by proximity was not possible. Dogs that initially committed the proximity error (defined as pawing at the fence near the reward and not at the strings; scored as present/absent in each trial) had the chance to rectify their decision and pull out the correct string. Proximity errors, likely reflecting an inhibitory problem, were not considered as incorrect choices - only touching one of the strings was considered as a choice.

Each dog received 20 trials of the curved string task. In half of the trials, the straight string was baited and in the other half the curved string was baited. The trials of the two conditions were presented in a random order to exclude associative learning and to disentangle use of the proximity strategy (successful only when the straight string was baited) from attending to connectivity (successful in both conditions). The analysis was performed separately for each condition (10 trials each). This was done to take account of the fact that above chance performance (15/20 correct choices, binomial probability, $p<0.05$) would theoretically have been possible for dogs that performed at chance level in the curved string baited condition (5/10 correct) if they achieved 10/10 correct choices in the straight string baited condition. Thus, our criterion was at least 8 of 10 correct choices in both the straight string baited and the curved string baited condition (binomial probability, $p<0.01$).

Gap task (Task 3) and Parallel diagonal string task (Task 4)—Most tested dogs (N=17) showed no evidence of means-understanding in the curved string task, and therefore testing was terminated for these individuals. The three dogs that met criterion in the curved string task were tested in further task variations, the gap task and/or the parallel diagonal string task to distinguish the possible use of a task-specific strategy from the ability to trace means-end connections.

The gap task (task 3, Table 1) involved two rewards attached to two parallel perpendicular strings; one string was entire while the other one was broken, leaving a 10 cm gap between the reward and the inaccessible end. The parallel diagonal string task (task 4, Table 1) involved two strings (one baited), laid in parallel at an acute angle to the fence (see Osthaus, Lea, & Slater, 2005). It was varied randomly whether the tilt of the strings was to the left or to the right and which side was baited. When the exterior string was baited (non-overlapping condition), the reward did not lie directly in line with any string's end; however, the string closest to the reward was the connected one. Thus this task was solvable by selecting according to proximity. In contrast, when the interior string was baited (overlapping condition), the unconnected string's end was directly in line with the reward and was thus potentially misleading for animals adhering to a proximity strategy (Table 1).

Originally, we intended to counterbalance the order of these additional tests across successful individuals to take order effects into account. However, it turned out that only three individuals mastered the curved string task, leading to an unbalanced distribution: Two dogs were tested in the gap task first, of which one mastered the task and proceeded to the parallel diagonal string task. One dog was tested in the parallel diagonal string task first and was not tested further upon failure.

Coding and Analysis

The trials were video-recorded and experimenter 1 furthermore noted the dogs' choices by pen and paper during testing (based on observations from the video screen outside the testing room). For analysis, the videos were subsequently coded by the first author using Solomon coder (© András Péter). No video was made for five test sessions (of different dogs) due to experimenter error. In these cases, the data noted by experimenter 1 were used for analysis. Correspondence between notes and coded data was excellent (Cohen's weighted kappa, as determined based on 10 randomly selected test sessions, was 0.96). Statistical analysis was carried out using R 2.12.0 (R Core Development Team 2010). One-sample Wilcoxon tests (two-tailed) were performed to test whether group level performance in the first 20 trials and in the last 20 trials was significantly different from chance. To test for differences between the first and the last session of 20 trials, Wilcoxon two-sample tests (two-tailed) were applied. To determine whether the number of proximity errors (defined as pawing at the fence between the strings, near the reward) in the curved string task was related to performance in this task, Spearman rank correlation tests were calculated.

A Wilcoxon signed ranks test was performed (separately for the first and the last 20 trials) to test whether the dogs performed better in the four-string task when the inner two strings (which were in closer proximity to them) were baited compared to when the outer strings were baited. We used binomial tests ($p<0.05$) to determine whether individual dogs were more likely to pull the inner or the outer strings, whether they chose the right half or the left half of the setup more often than expected by chance, or whether they had specific location preferences.

Results

Four-string task (Task 1)

At the group level, the dogs selected the correct string significantly more often than would be expected by chance (25%) within the first 20 trials (one-sample Wilcoxon test, $V = 534$, $p<0.0001$), with 30 of 34 dogs being above the chance level of 5 correct choices. These results confirm previous findings that dogs are able to select the baited string when parallel perpendicular strings are presented (Osthaus, Lea, & Slater, 2005). Learning was also involved: The dogs' performance improved significantly from the first 20 trials to the last 20 trials (two-sample Wilcoxon test, $W = 321.5$, $p <0.01$) (Figure 2). At the individual level, four dogs met the criterion of at least 11 of 20 correct choices within the first 20 trials ($p<0.01$). Another seventeen dogs met this criterion within 30-60 trials. Thirteen dogs did not meet criterion within 60 trials.

Overall, success rate was significantly higher when the inner string was baited than when the outer string was baited, both in the first 20 trials (Wilcoxon signed ranks test, $Z=2.34$, $p=0.019$) and in the last 20 trials ($Z=2.22$, $p=0.026$), indicating that the dogs were more prone to pulling those strings in closer proximity to them. Individually, 10 dogs significantly preferred to pull on the inner strings in the first 20 trials, while one dog preferred to pull on the outer strings (location preference for the outer left string, binomial test, $p<0.05$). In the last 20 trials, nine dogs significantly preferred to pull on the inner strings, and a different dog from the one in the first 20 trials preferred to pull on the outer strings (binomial test, $p<0.05$). In the first 20 trials, eight dogs developed a significant bias for the left two strings, and four dogs for the right two strings (binomial tests, $p<0.05$). In the last 20 trials, one dog significantly preferred the left two strings and five dogs significantly preferred the right two strings. Biases towards particular locations were shown by six dogs in the first 20 trials and also by six dogs in the last 20 trials (three of these showed location biases both in the first and the last 20 trials, of which one dogs changed its preferences to a different position). In total, six of the 13 unsuccessful dogs but none of the 21 successful dogs showed a significant location bias in the last 20 trials of the four-string task (binomial tests, $p<0.05$).

While switching from an incorrect to a correct string was shown by all but two dogs at least once in the course of testing (up to four occasions per session of 10 trials of the four-string task), only seven dogs switched from a correct to an incorrect string on one occasion each. Of these, six dogs made this mistake during the first 20 trials of the four-string task and one dog during the last 20 trials. Note that choices in which dogs switched from a correct to an incorrect string or vice versa were considered as incorrect for analysis.

Curved string task (Task 2)

Group level performance (N= 20) was significantly above chance both when the straight string was baited (one-sample Wilcoxon test, $V = 171$, $p<0.001$) and when the curved string was baited ($V = 108$, $p = 0.04$) (Figure 3), indicating that at least some dogs were paying attention to the connection between the reward and the string. However, an analysis of the number of dogs meeting the individual criterion confirms that the proximity rule was favored: 13 of 20 subjects achieved at least 8 of 10 correct choices in the straight string baited condition, whereas only 3 of 20 dogs reached this level also in the curved string baited condition (when choosing by proximity was not possible). One individual had 9 of 10 correct choices in the curved string baited condition but missed criterion with 7 of 10 correct choices in the straight string baited condition. Three dogs did not meet criterion in any condition; of these, one dog consistently corrected its errors very early and switched to the correct string, apparently following a rule of adjusting the behavior according to the visual feedback received (the sausage moving or not). The difference in number of correct choices between the straight string baited condition and the curved string baited condition was highly significant (two-sample Wilcoxon test, Z=3.4, $p<0.001$).

Proximity errors were shown in at least one trial by 10 of 20 dogs in the curved string baited condition (median 0.5; range 0-4). Success in this condition was independent of the number of proximity errors a dog committed in this task (Spearman rank correlation, $Rho = 0.24$, $p = 0.30$). Six of the dogs that failed to meet criterion exhibited a significant side bias (binomial test, $p<0.05$); four of them preferring the right string and two preferring the left string.

Gap task (Task 3) and Parallel diagonal string task (Task 4)

In the gap task, one of the two dogs tested met criterion with 8 of 10 correct choices in two consecutive sessions. The second dog chose at chance level in the first session (5 of 10 correct), but achieved 8 of 10 correct choices in the second session. No dog met criterion in the parallel diagonal string task. One dog (tested only in this and not in the gap task) committed the classical proximity error: He achieved 2 of 10 correct choices in the overlapping condition whereas the success rate was 10 of 10 in the non-overlapping condition. The one dog that proceeded to the parallel diagonal string task after successful performance in the gap task achieved 5 of 10 correct choices in the overlapping condition and 9 of 10 in the non-overlapping condition.

Discussion

We predicted that dogs can solve a connectivity task when proximity is not a confounding factor. Our prediction was confirmed for a subset of our sample of Border collies, those that had already succeeded in the four-string task (note that Osthaus, Lea, & Slater (2005) reported that they found no evidence that breed had an impact on the results). In the curved string task, group level performance was significantly above chance even in the curved string baited condition when choosing by proximity was not possible. Nonetheless, individual performance was relatively poor in this condition, compared to the good performance in the straight string baited condition and in the four-string task. This indicates that the majority of dogs selected the strings according to the proximity rule, confirming previous findings (Osthaus, Lea, & Slater, 2005). (Note, however, that the dogs only had a single chance to master the curved string task and that our criterion was more stringent than in Osthaus, Lea, & Slater (2005) – choices were only considered correct if the dog touched the connected string first and subsequently pulled it out completely).

A few dogs were apparently able to use information on connectivity, at least when there was no useful information on proximity in the curved string task. To further explore their abilities, we tested the successful dogs in the gap task and/or the parallel diagonal string task. The performance of two individuals in the gap task may suggest that they may have gained at least a vague understanding of connectivity; in contrast, the dogs seemed to be unable to choose correctly when the information on connectivity conflicted with information about reward proximity (parallel diagonal string task, see below). Although a sample of two dogs is not representative, the relatively good performance of our subjects in the gap task is notable in the light of previous evidence that dogs are unable to solve this task (Range, Möslinger, & Virányi, 2012). Our subjects' performance was superior to that of all 10 dogs in Range et al.'s (2012) study, where most subjects developed a preference for the shorter string and none met criterion. This difference could be explained either by the fact that we tested only the most proficient subjects in this difficult task (i.e., only a few animals out of a large sample, which had already proven to be able to solve the curved string task), by the greater amount of experience with string pulling tasks of the successful subjects or by breed and/or keeping conditions (in the study by Range and colleagues only Huskies kept in kennels were tested).

Despite performing comparatively well in the gap task, the dogs seemed to be unable to choose correctly when the information on connectivity conflicted with information about reward proximity in the parallel diagonal string task. Here, the performance of our two subjects was similar to that by the dogs tested by Osthaus, Lea, & Slater (2005) and Range, Möslinger, & Virányi (2012): They tended to choose correctly when the non-overlapping string was baited (where choosing by proximity led to success), but performance was poor in the overlapping condition (where the incorrect string was closest to the reward). Thus, although some individual dogs apparently attended to connectivity when choosing by proximity was precluded, they were unable to solve a task where proximity and connectivity information conflicted, suggesting that they may favor proximity rules over connectivity rules. Along similar lines, Herrmann, Wobber, & Call (2008, p. 229) suggest that great apes might possess some causal knowledge with respect to tool use, but that certain task features make it hard to express it consistently, suggesting that “motor or attentional biases present in the two-choice situation may have introduced some noise into the data”.

Note that Range, Hentrup, & Virányi (2011) reported that dogs could solve a different means-end task, the on-off problem, even when proximity was misleading. The dogs succeeded in selecting a baited board over an unbaited one, even when the reward placed next to the unbaited board was closer to the dog than the reward placed on the baited board. Two factors may explain why the dogs were able to overcome their proximity bias in the on-off task unlike in the string pulling task. Firstly, the misleading effect of proximity was less pronounced in the on-off task than in the diagonal baited string task, as the inaccessible reward was not directly in line with the incorrect board (even though it was closer to the incorrect board’s end than to the correct board’s end). Secondly, the contact between the board and the reward was most likely easier to perceive for the dogs than the contact between the thin string and the reward.

While our findings suggest that at least in Border collies, some individuals are capable of attending to connectivity, they also indicate that this strategy can easily be overruled by other, simpler strategies. In a different context (logical reasoning), Erdőhegyi, Topál, Virányi, & Miklósi (2007) suggested that dogs base their decisions on a set of rules, preferentially choosing the simplest one and switching to more cognitively demanding ones only under certain circumstances. This may also apply to their decision-making in string-pulling tasks. According to Osthaus, Lea, & Slater (2005), dogs’ two main strategies when encountering food are first pawing close to the food, even when there is no string attached (thereby committing the proximity error), and – when unsuccessful – switching to pawing at the string where the proximal end is closest to the food. Our data suggest that a third strategy – attending to the connection between the string and the reward – may be activated in some dogs when the proximity strategy failed, as in our curved string task, or when the dogs have experienced that the costs of failing are high. A fourth possible strategy appears to be based on visual feedback (movement of the reward) received by pulling on a string. Still, despite the evidence that paying attention and choosing accordingly is within the cognitive repertoire of the species, there were large individual differences, and many subjects seemed to follow even simpler decision rules, preferentially pulling on the strings that were closest to them (the inner strings in the four-string task), or developing a significant preference for one particular location (c.f. occurrence of side biases in dogs, e.g. Hare & Tomasello, 1999; Gácsi, M., Kara, Belényi, Topál, & Miklósi, 2009).

Despite the occurrence of such alternative problem solving strategies, our results give the first evidence – to our knowledge – that (some) dogs can attend to means-end connections in the string-pulling paradigm. There are a number of possible explanations why some of our subjects were able to solve means-end tasks independent of proximity unlike dogs in previous studies (Osthaus, Lea, & Slater, 2005, Range, Möslinger, & Virányi, 2012).

First, our subjects had considerably more experience with strings and string pulling than dogs in either Osthaus, Lea, & Slater (2005) or Range, Möslinger, & Virányi (2012). Therefore it is likely that the greater amount of experience with string pulling in general (potentially leading to learning about means-end connections) or the specific experience gained from the four-string task contributed to our subjects' better performance. There is much evidence that young humans as well as non-human animals acquire knowledge about objects' affordances, learn perceptual rules, and build up motor representations through exploration (Lockman, 2000; Matsuzawa, Tomonaga, & Tanaka, 2005; Takeshita, Fragaszy, Mizuno, Matsuzawa, Tomonaga, & Tanaka, 2005; Sommerville, Hildebrand, & Crane, 2008). Both tool-using species (e.g. chimpanzees, *Pan troglodytes*, Seed, Call, Emery, & Clayton, 2009) and non-tool-using species, including monkeys and rodents (Spaulding & Hauser, 2005; Santos, Pearson, Spaepen, Tsao, & Hauser,, 2006; Okanoya, Tokimoto, Kumazawa, Hihara, & Iriki, 2008), seem to develop some understanding of the functional aspects of objects/tools through (extensive) experience with them. Also in goldfinches (*Carduelis carduelis*) and siskins (*C. spinus*), an individual's string-pulling competence seemed to be influenced by prior experience of handling branchlets, but also by trial-and-error learning and social learning (Seibt & Winckler, 2006). Even though the four-string task was solvable by choosing according to proximity, latent learning about the properties of the strings and connectivity may have occurred. Furthermore, the higher cost-benefit tradeoffs in the four-string task may have increased the dogs' awareness that a choice had to be made and that choosing incorrectly meant obtaining no reward, potentially leading to greater attentional focus and better inhibitory control.

Second, a relatively small task modification – precluding choosing by proximity in the curved string task – may have enabled the dogs to utilize an alternative strategy to the proximity rule. Studies on other species have shown how small alterations in the procedure can lead to dramatic improvements in animals' performances in cognitive tasks. Similarly to this study, a recent study on string pulling in marmosets (*Callithrix jacchus*) showed that the animals were initially prone to choosing by proximity, but alterations of the setup enabled the subjects to develop a new strategy, to bypass the spatial proximity rule and to master novel nonlinear tasks (Gagné, Levesque, Nutile, & Locurto, 2012). Also, chimpanzees (Mulcahy & Call, 2006, Seed, Call, Emery, & Clayton, 2009, Girndt, Meier, & Call, 2008) and orangutans (*Pongo pygmaeus and* and *Pongo abelii*, Mulcahy, Schubiger, & Suddendorf, 2013) performed successfully in some physical cognition tasks only after some task alterations were introduced (modes of tool use were altered or tool use was no longer required).

Third, while a previous study found no effect of breed on dogs' performance in string pulling tasks (Osthaus, Lea, & Slater, 2005), it is nonetheless a possibility that some differences might be accounted for by the different breeds used (Border collies in our study, various breeds in Osthaus, Lea, & Slater, 2005, and Huskies in Range, Möslinger, & Virányi, 2012). There were furthermore environmental differences – dogs in this and Osthaus et al.'s (2005) study were pet dogs while the huskies in Range et al.'s study were kept in kennels.

Fourth, regarding the direct comparison of performance of our dogs and Range et al.'s (2012) dogs in the gap task, the superior performance of our subjects could be explained by the fact that we had only tested the most proficient subjects in this difficult task (i.e., only a few animals out of a large sample, which had already proven to be able to solve the curved string task).

Our study differed from Osthaus, Lea, & Slater (2005) and Range, Möslinger, & Virányi (2012) in that we found a clear learning effect in the four-string task in the course of 30-60 trials, whereas there was no effect of trial number on dogs' performance in Osthaus, Lea, & Slater's (2005) parallel diagonal string task or Range et al.'s (2012) gap task. Task differences and differences in statistical methodology might account for the diverging results of our study and those by Osthaus, Lea, & Slater (2005) and Range, Möslinger, & Virányi (2012). Conceivably, experience with tasks which appear to be too difficult for dogs to solve at all, such as the parallel diagonal strings task, resulted in no learning.

Future research could investigate how much experience is necessary for dogs to develop an (apparent) understanding of connectivity and to be able to trace means-end connections in the curved string task. This could be determined by testing experimentally naïve dogs with the curved string task and assessing learning in the course of e.g. 60 trials. Further control studies, systematically altering the costs of choosing incorrectly, could be performed to disentangle the effect of general experience with string pulling – potentially enabling learning about connectivity – from the benefits of the four-string task, which made random choice more costly.

Like dogs and marmosets, several species have previously failed in tasks involving crossed or parallel diagonal strings, including wolves (*Canis lupus*, Range, Möslinger, & Virányi, 2012), macaws (Schuck-Paim, Borsari, & Ottoni, 2009), hooded crows (*Corvus corone*, Bagotskaya, Smirnova, & Zorina, 2012), and even New Caledonian crows (*Corvus moneduloides*), which are famous for their tool-use competence (Taylor, Medina, Holzhaider, Hearne, Hunt, & Gray, 2010). Re-testing individuals of these species with the curved string task introduced in this study or with some of the non-linear tasks used by Gagné, Levesque, Nutile, & Locurto (2012) would yield further insights into animals' strategy selection when faced with physical problems.

To conclude, our study shows that even though dogs may not demonstrate spontaneous means-end understanding, some can learn to pay attention to connectivity. Our results support the notion that animals may apply several alternative rules or strategies to solve problems in their environment (Erdőhegyi, Topál, Virányi, & Miklósi, 2007). Strategies used by tool-using species such as the great apes and New Caledonian crows, by non-tool using, but dexterous marmosets, and by carnivores, which are less ecologically prepared for object manipulation tasks, may not be so different after all. Members of different taxonomic groups appear to devise certain rules to deal with physical problems, with species-specific as well as considerable individual differences in associative and perceptual abilities and behavioral flexibility. Some individuals may be better at the formation of concepts or representations, based on observable features of problems (Seed, Tebbich, Emery, & Clayton, 2006), than others, or they may be better at inhibiting prepotent responses (e.g. going for the string nearest the reward; Lea et al., 2006), leading to the large inter-individual variability observed in performance in physical problems. In light of our findings, as well as those of Gagné, Levesque, Nutile, & Locurto (2012), follow-up studies on other species with modified string pulling problems might yield novel insights into animals' selections of strategies to deal with physical problems.

Acknowledgments

This research was discussed and approved by the institutional ethics committee in accordance with Good Scientific Practice guidelines and national legislation. Funding was provided by the Austrian Science Fund (FWF) grant P21418 to L.H and F.R, the FWF grant P21244-B17 to F.R., and the DK CogCom Programme (FWF Doctoral Programs W1234; S.R.). The Clever Dog Lab receives financial support from Royal Canin and a private sponsor. We thank our student helpers Alina Gaugg, Amelie Göschl, Elisabeth Pikhart, Serena Tommasi and Magdalena Weiler for help with the experiments, the dog owners for bringing in their dogs regularly and our subjects for their enthusiastic participation. Furthermore, we thank the editor and the anonymous reviewers for constructive comments on the manuscript.

References

Bagotskaya MS, Smirnova AA, Zorina ZA. Corvidae can understand logical structure in baited string-pulling tasks. Neuroscience and Behavioral Physiology. 2012; 42:36–42.

Bräuer J, Kaminski J, Riedel J, Call J, Tomasello M. Making inferences about the location of hidden food: Social dog, causal ape. Journal of Comparative Psychology. 2006; 120:38–47. [PubMed: 16551163]

Brown A. Domain-specific principles affect learning and transfer in children. Cognitive Sciences. 1990; 14:107–133.

Cha JH, King JE. Learning of patterned strings problems by squirrel monkeys. Animal Behaviour. 1969; 17:64–67.

Doré FY, Dumas C. Psychology of animal cognition: piagetian studies. Psychological Bulletin. 1987; 102:219–233.

Erdőhegyi Á, Topál J, Virányi Zs, Miklósi Á. Dog-logic: inferential reasoning in a two-way choice task and its restricted use. Animal Behaviour. 2007; 74:725–737.

Gácsi M, McGreevy P, Kara E, Miklósi Á. Effects of selection for cooperation and attention in dogs. Behavioral and Brain Functions. 2009a; 5:31. [PubMed: 19630939]

Gácsi M, Kara E, Belényi B, Topál J, Miklósi Á. The effect of development and individual differences in pointing comprehension of dogs. Animal Cognition. 2009b; 12:471–479. [PubMed: 19130102]

Gagné M, Levesque K, Nutile L, Locurto C. Performance on patterned string problems by common marmosets (*Callithrix jacchus*). Animal Cognition. 2012; 15:1021–1030. [PubMed: 22576582]

Girndt A, Meier T, Call J. Task constraints mask great apes' ability to solve the trap-table task. Journal of Experimental Psychology: Animal Behavior Processes. 2008; 34:54–62. [PubMed: 18248114]

Halsey LG, Bezerra BM, Souto AS. Can wild common marmosets (*Callithrix jacchus*) solve the parallel strings task? Animal Cognition. 2006; 9:229–233. [PubMed: 16541239]

Hare B, Tomasello M. Domestic dogs (*Canis familiaris*) use human and conspecific social cues to locate hidden food. Journal of Comparative Psychology. 1999; 113:1–5.

Harlow HF, Settlage PH. Comparative behavior of primates VII. Capacity of monkeys to solve patterned string tests. Journal of Comparative Psychology. 1934; 18:423–435.

Heinrich B. An experimental investigation of insight in common ravens (*Corvus corax*). Auk. 1995; 112:994–1003.

Heinrich B, Bugnyar T. Testing problem solving in ravens: String-pulling to reach food. Ethology. 2005; 111:962–976.

Herrmann E, Wobber V, Call J. Great apes' (Pan troglodytes, Pan paniscus, Gorilla gorilla, Pongo pygmaeus) understanding of tool functional properties after limited experience. Journal of Comparative Psychology. 2008; 122:220–230. [PubMed: 18489238]

Huber L, Gajdon GK. Technical intelligence in animals: the kea model. Animal Cognition. 2006; 9:295–305. [PubMed: 16909237]

Lea SEG, Goto K, Osthaus B, Ryan CME. The logic of the stimulus. Animal Cognition. 2006; 9:247–256. [PubMed: 16909234]

Lockman JJ. A perception-action perspective on tool use development. Child Development. 2000; 71:137–144. [PubMed: 10836567]

Matsuzawa T, Tomonaga M, Tanaka M. Exploring by doing: How young chimpanzees discover surfaces through actions with objects. Infant Behavior and Development. 2005; 28:316–328.

McGreevy P, Grassi TD, Harman AM. A strong correlation exists between the distribution of retinal ganglion cells and nose length in the dog. Brain, Behavior and Evolution. 2004; 63:13–22.

Miller PE, Murphy CJ. Vision in dogs. Journal of the American Veterinary Medical Association. 1995; 207:1623–34. [PubMed: 7493905]

Mulcahy NJ, Call J. How great apes perform on a modified trap-tube task. Animal Cognition. 2006; 9:193–199. [PubMed: 16612632]

Mulcahy NJ, Schubiger MN, Suddendorf T. Orangutans (*Pongo pygmaeus* and *Pongo abelii*) understand connectivity in the skewered grape tool task. Journal of Comparative Psychology. 2013; 127:109–113. [PubMed: 22686164]

Okanoya K, Tokimoto N, Kumazawa N, Hihara S, Iriki A. Tool-use training in a species of rodent: the emergence of an optimal motor strategy and functional understanding. PLoS ONE. 2008; 3:e1860. [PubMed: 18365015]

Osthaus B, Lea SEG, Slater AM. Dogs (*Canis lupus familiaris*) fail to show understanding of means-end connections in a string-pulling task. Animal Cognition. 2005; 8:37–47. [PubMed: 15338446]

Pepperberg IM. “Insightful” string-pulling in grey parrots (*Psittacus erithacus*) is affected by vocal competence. Animal Cognition. 2004; 7:263–266. [PubMed: 15045620]

Povinelli, D. Folk physics for apes: The chimpanzee’s theory of how the world works. Oxford University Press; Oxford: 2000.

Range F, Hentrup M, Virányi Z. Dogs are able to solve a means-end task. Animal Cognition. 2011; 14:575–583. [PubMed: 21445577]

Range F, Möslinger H, Virányi Z. Domestication has not affected the understanding of means-end connections in dogs. Animal Cognition. 2012; 15:597–607. [PubMed: 22460629]

Santos LR, Pearson HM, Spaepen GM, Tsao F, Hauser MD. Probing the limits of tool competence: experiments with two non-tool-using species (*Cercopithecus aethiops* and *Saguinus oedipus*). Animal Cognition. 2006; 9:94–109. [PubMed: 16341524]

Schmidt GF, Cook RG. Mind the gap: means-end discrimination by pigeons. Animal Behaviour. 2006; 71:599–608.

Schuck-Paim C, Borsari A, Ottoni EB. Means to an end: Neotropical parrots manage to pull strings to meet their goals. Animal Cognition. 2009; 12:287–301. [PubMed: 18766389]

Seed AM, Tebbich S, Emery NJ, Clayton NS. Investigating physical cognition in rooks, *Corvus frugilegus*. Current Biology. 2006; 16:697–701. [PubMed: 16581516]

Seed AM, Call J, Emery NJ, Clayton NS. Chimpanzees solve the trap problem when the confound of tool use is removed. Journal of Experimental Psychology: Animal Behavior Processes. 2009; 35:23–34. [PubMed: 19159160]

Seibt U, Wickler W. Individuality in problem solving: String pulling in two *Carduelis* species (Aves: Passeriformes). Ethology. 2006; 112:493–502.

Sommerville JA, Hildebrand EA, Crane CC. Experience matters: The impact of doing versus watching on infants’ subsequent perception of tool use events. Developmental Psychology. 2008; 44:1249–1256. [PubMed: 18793059]

Spaulding B, Hauser M. What experience is required for acquiring tool competence? Experiments with two Callitrichids. Animal Behaviour. 2005; 70:517–526.

Takeshita H, Fragaszy D, Mizuno Y, Matsuzawa T, Tomonaga M, Tanaka M. Exploring by doing: How young chimpanzees discover surfaces through actions with objects. Infant Behavior & Development. 2005; 28:316–328.

Taylor AH, Medina FS, Holzhaider JC, Hearne LJ, Hunt GR, Gray RD. An investigation into the cognition behind spontaneous string pulling in New Caledonian crows. Plos One. 2010; 5:2.

Tebbich S, Seed A, Emery N, Clayton N. Non-tool-using rooks (*Corvus frugilegus*) solve the trap-tube task. Animal Cognition. 2007; 10:225–231. [PubMed: 17171360]

Werdenich D, Huber L. A case of quick problem solving in birds: String pulling in keas. Nestor notabilis. Animal Behaviour. 2006; 71:855–863.

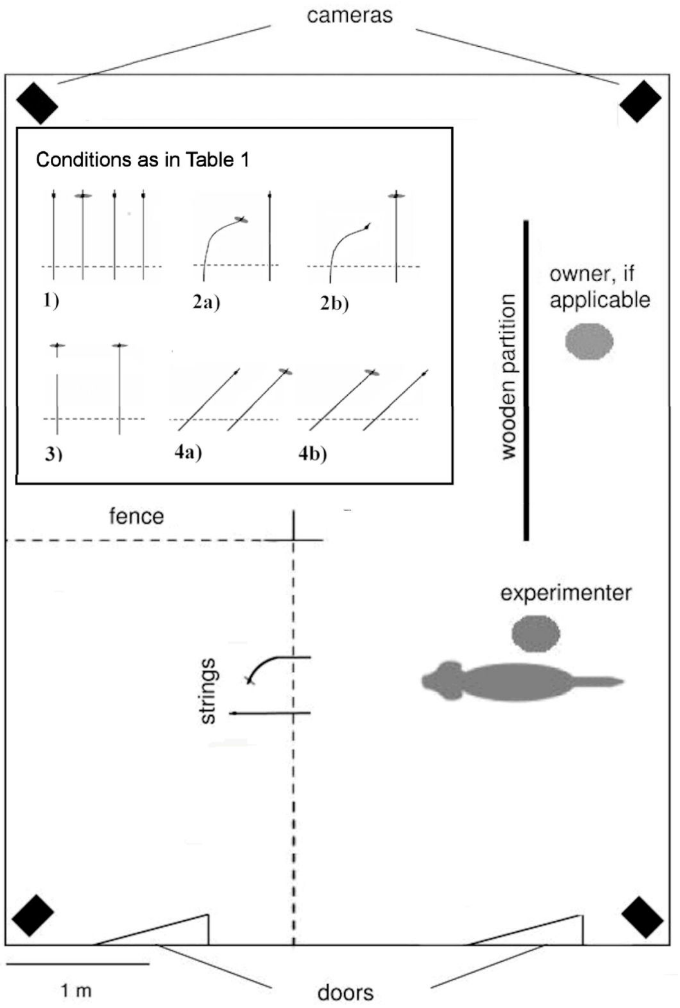

Figure 1. Setup of the test room and depiction of conditions.

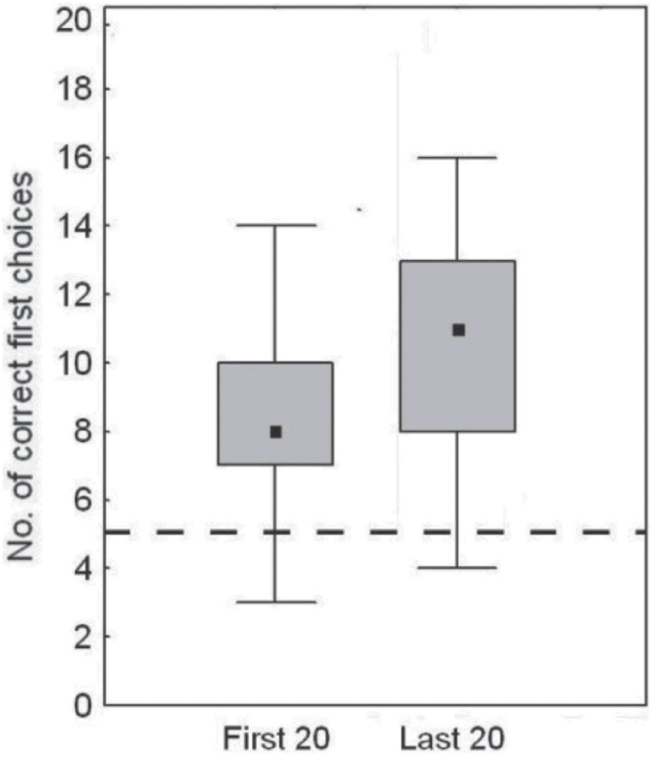

Figure 2. Number of correct choices in the first 20 trials and the last 20 trials in the four-string task (task 1).

Median, interquartile range and range are given. The dashed line indicates chance level.

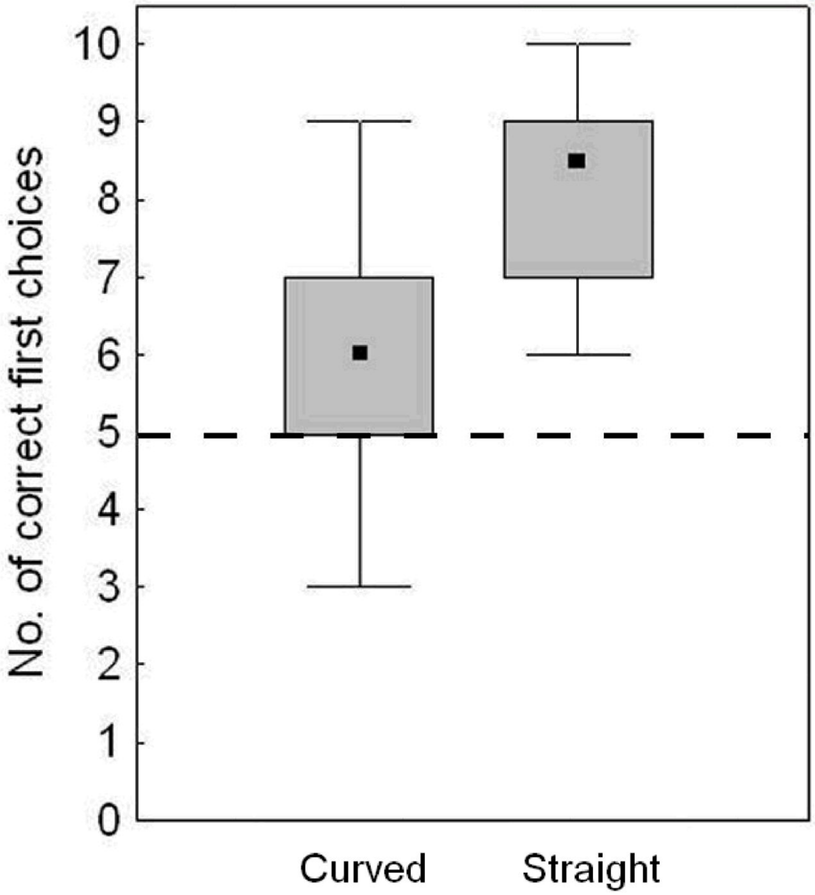

Figure 3. Number of correct choices in the curved string task (task 2) when the curved string was baited and when the straight string was baited, respectively.

Median, interquartile range and range are given. The dashed line indicates chance level.

Table 1

Setup of tasks

Task	Criterion	No. of subjects
1. Four-string task: Four parallel, perpendicular strings, 20 cm apart, one baited.	11 of 20 correct choices	34
2. Curved string task: Two strings (one curved) 40 cm apart. The distal end of the curved string at the centre is equidistant from both strings' proximal ends. **a.** Curved string baited **b.** Straight string baited	8 of 10 correct choices in both the straight string baited and the curved string baited condition	20
3. Gap task: Two parallel perpendicular strings, 40 cm apart, with two food rewards; one entire string connected to the reward, one short string (45 cm) leaving a 10 cm gap to a 5 cm long string connected to the reward.	8 of 10 correct choices in both sessions	2
4. Parallel diagonal string task: Two parallel diagonal strings, 30 cm from each other, laid out at an angle of approximately 45° with the fence, one baited. **a.** Overlap **b.** No overlap	8 of 10 correct choices in both sessions	2