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String Pulling



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Definition

Retrieving an out-of-reach object by pulling a string attached to it.

Introduction

During a cold Swedish winter, a raven watches a fisherman cut a small hole in a frozen lake. He drops in a baited fishing line attached to a stick to secure it over the hole. After he leaves, the raven flies down and examines the situation. Although she cannot see deep down the dark waters, she takes the line in her beak, pulls it, and steps on the loop. Repeating this sequence several times, she eventually reaches the end and eats the bait. Other ravens observe how she got her easy catch and make their own attempts with the numerous ice-fishing holes in the country's largest lake. By the end of the winter, local fishermen have stopped ice fishing because they nearly always return home empty-handed due to the ravens' efficient pilfering (Larsson 1958).

These ravens exhibited spontaneous string pulling: they retrieved out-of-reach food (bait

and fish) by pulling a string (fishing line) attached to it. String pulling is one of the oldest and most common tests of animal cognition. The Roman naturalist Pliny the Elder (23–79 AD) first documented how goldfinches pull up strings with food and containers of water. Since the beginning of the twentieth century, researchers have investigated the cognitive abilities of a wide array of species by using various string-pulling tests. Around 170 species have been tested in over 210 studies, with these numbers rising rapidly (Jacobs 2017; Jacobs and Osvath 2015).

Cognition and String Patterns

String pulling provides countless testing conditions when the number and patterns of strings are varied. The simplest configuration is a single straight string that can be pulled to retrieve the attached out-of-reach reward. Its orientation strongly influences performance; horizontal strings are typically easier to pull than vertical ones. Vertical string pulling requires better coordination and motor planning, involving multiple steps of grasping, pulling, and securing the string, with gravity pulling the string back to its original position if a mistake is made. In contrast, horizontal strings require fewer and easier steps and stay in position when pulling has stopped. Most animals therefore perform better on horizontal than vertical setups. For example, human and gorilla infants can pull horizontal strings at an earlier age

than vertical ones (Redshaw 1978). Different test orientations hinder species comparisons, with mammals typically tested on horizontal tasks and birds on vertical ones.

Although a single string is the most common condition, it is unclear what cognitive abilities underpin a successful response. String pulling is often seen as a test for means-end understanding, which involves the deliberate execution of a sequence of steps and the removal of an obstacle to achieve a goal (Huber and Gajdon 2006). However, other mechanisms, such as play behavior, and associative learning can also explain successful string pulling. For example, some animals play with strings and may accidentally pull in baited strings as part of their play behavior rather than due to a deliberate attempt to retrieve the food. This alternative interpretation can be avoided by allowing the animal to interact with unbaited strings before testing begins, so they habituate to the string prior to testing. It is also possible to succeed on string-pulling tasks through associative learning. Touching the string may cause the reward to move, which can lead to an association between both events and eventually successful pulling through trial and error. The reward immediately moves closer with every pull, which can form a positive association leading the animal to repeat whatever behavior caused it. Consequentially, experienced animals may pull strings indiscriminately. For example, after pulling up a string and removing the food, some rats pull up the same string again only to find there is nothing attached to it (Ewer 1971).

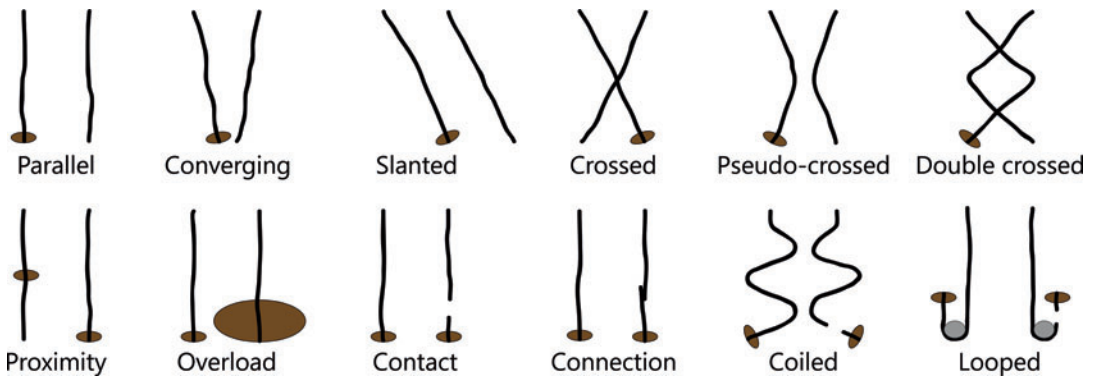
Animals should be tested on multiple conditions to reveal the cognitive mechanisms they employ during string pulling. In the *parallel* condition, an unbaited string is placed parallel to the baited one (see Fig. 1). Goal directness is shown when animals repeatedly pull the baited instead of the unbaited string. If they only pull strings accidentally, through play, or without attention to the reward, they would pull both equally. For example, a common myna did not perform above chance on the parallel condition in over a thousand trials, and neither did a young jackdaw in over 500 trials, possibly because they were too inattentive and playful (Dücker and Rensch

1977). The *converging* condition requires animals to attend more to the orientation of both strings (see Fig. 1). Nonetheless, a successful strategy in both conditions is to use reward proximity as a cue for which string to pull. The *slanted* condition can show the presence of this heuristic (see Fig. 1). When the baited string slants toward the outside of the pattern, pulling the end of a string closest to the reward will still be successful. In contrast, when the baited string slants toward the inside, reliance on the proximity of the reward will result in failure. This proximity error is common in many species, with dogs being an especially susceptible example (Osthaus et al. 2005). When the strings are *crossed* (see Fig. 1), reliance on proximity always leads to failure. This may explain why animals typically perform worst on the crossed condition.

Myriad variations of string patterns of various complexities are possible. The *pseudo-crossed* and *double crossed* patterns (see Fig. 1) are meant to increase complexity by introducing non-linear strings, but success on these conditions does not necessarily imply visually tracing the strings; here, too, animals may simply reply on the proximity of the reward (Jacobs and Osvath 2015). Two rewards are present in the *contact* condition (see Fig. 1), but only the correct one is attached to a continuous string, while the other reward is attached to a string with a gap. The proximity error is then revealed when animals pull both strings indiscriminately.

Means-end understanding excludes heuristic strategies such as using the proximity of reward as a cue for which string to pull. Nonetheless, attending to proximity can sometimes be beneficial. In the *proximity* condition, two functional baited strings are present, so either can be pulled to retrieve a reward, but pulling the string with the closest reward is the optimal response (see Fig. 1). This kind of efficiency is exhibited by some ravens that attend to object identity (food or not) and proximity simultaneously (Pfuhl 2012).

In the *overload* condition (see Fig. 1), both parallel strings are baited, but one reward is too heavy for the animal to pull in. Under typical circumstances, the subject first approaches the large reward due to its saliency. If he is capable



String Pulling, Fig. 1 Twelve common string-pulling conditions (patterns). These examples are horizontal, and most also work vertically. The correct string is always shown on the left, but the position of the baited string is typically counterbalanced across sides. This can make a large difference in the *slanted* condition, because it is asymmetrical and can show the proximity error when the baited string slants to the inside, as shown here. In the

proximity condition, both strings can be pulled to retrieve the reward, but the string with the closest reward is the optimal choice. The top row shows the six most common traditional patterns, always having only one reward present. The bottom row shows more recent adaptations with two rewards, which ensures subjects cannot use the position of the reward alone as a cue to which string to pull

of knowing he cannot pull in a large reward, he should only pull the string attached to the smaller reward. Most ravens ignore overloaded strings without trying to pull them even once (Heinrich 1995; Pfuhl 2012). Such behavioral flexibility is another component of means-end understanding.

Animals go beyond superficial perceptual cues through functional generalization and affordance learning. Recognizing the functional aspects of string pulling allows for successful transfer between conditions. Moreover, changes to the strings' color, texture, or material will then not affect performance. This is indeed not a significant challenge for most species tested after such changes (Jacobs and Osvath 2015). Functional generalization is also evident when individuals use different pulling techniques, which shows they do not have stereotyped responses to similar situations. This can best be investigated with vertical strings, which some animals, particularly birds, may pull in diverse manners. Up to eight different techniques have been reported in kea (Werdenich and Huber 2006).

Most patterns involve straight strings that will immediately bring the reward closer when pulled. Approaching food is rewarding and can therefore create a positive association that leads to repeated pulling without means-end understanding. Unbaited

strings are then not repeatedly pulled because they are not reinforced with food moving closer. The effects of visual feedback, or absence thereof, is tested with nonlinear strings. The *coiled* condition involves two coiled strings such that pulling one does not immediately cause its distal end to move (see Fig. 1). As in the *contact* condition, a reward is present next to the broken strings to control for strategies based on reward location. Some Neotropical parrots chose the connected coiled string above chance, but their previous experience with other patterns may have influenced their choices (Schuck-Paim et al. 2009). In the *looped* condition, the strings loop around a solid object, which when pulled causes its distal end to move away at first (see Fig. 1). An olive baboon appeared to prefer the correct looped string (Bolwig 1962), but this condition has not been tested recently or reliably (Jacobs and Osvath 2015).

Animals relying solely on the reward moving closer would therefore not succeed in these conditions. Visual feedback is also minimized when a straight string is attached to a reward that cannot be seen at first. Ice-fishing ravens exemplify this; it is initially impossible to see the bait or fish when the fishing lines are long and the water is dark. Similar setups are possible for other modes of

feedback, such as the weight of closed containers at the string's end (Klüver 1961).

Some authors consider successful string pulling to show means-end understanding, but this is not necessary in all cases. Animals show means-end understanding if (1) they are goal-directed, as tested with the *parallel* condition; (2) they do not rely on reward proximity, as tested with the *slanted*, *crossed*, and *contact* conditions; (3) they can functionally generalize, as shown by overall behavioral flexibility or tested with the *overload* condition and changes to nonfunctional elements of other conditions; and (4) they do not rely strongly on perceptual feedback, as tested with the *coiled* and *looped* conditions (Jacobs and Osvath 2015).

Understanding strings as means to retrieve out-of-reach goals does not guarantee success on all conditions. For instance, it does not necessarily involve an understanding of connectedness. In addition to revealing proximity errors, the *contact* condition tests for the ability to recognize the necessity of contact between string and reward. This is more challenging than the *parallel* condition for many species, such as galahs and cockatiels (Krashennikova 2013). However, it is also possible that animals prefer continuous surfaces or generalize from previous conditions in which the baited string always looked similar: continuous and contacting the reward. They may simply disregard the incorrect option or only consider it as an unbaited piece of string.

In the *connection* condition (see Fig. 1), the distal end of the “broken” string lies against its proximal end, so no gap is visible. Recognizing contact as a relevant property does not suffice here; it requires knowledge of the necessity of a structural connection between string and reward. Chimpanzees appeared unable to distinguish between these possibilities (Povinelli 2000). When animals perform better on the *contact* than *connection* condition, it is likely because they consider contact to be a sufficient and necessary mechanism. They may also try to move away with the reward still attached to the string connected to the substrate. For example, some ravens and

American crows tried to fly off with food attached to a string tied to a perch, resulting in them being yanked back unless they dropped the food first (Heinrich 1995).

A controversial cognitive mechanism often associated with string pulling is insight. Definitions vary but often revolve around suddenly arriving at a solution by recombining previous experiences. How different amounts and types of experience influence problem-solving abilities is a contentious issue central to the string-pulling paradigm (Jacobs and Osvath 2015). Performance often improves within conditions and may depend on previous experience on different conditions. For instance, juvenile rhesus macaques perform worse on the *pseudo-crossed* condition when having previous experience on the *crossed* condition compared to the *parallel* condition (Mason and Harlow 1961). This suggests they transferred their previous experience based on proximity.

Heinrich (1995, p. 1001) tested ravens on vertical string pulling and proposed four explanations for spontaneous success: “(1) random chance; (2) programming already present at birth; (3) learning both the sequence and its effects; (4) insight associated with or without some or all of the above.” He considered chance an unlikely explanation for immediate execution of the different action sequences. Neither did he regard genetic programming likely because little or no behavior in the wild corresponds to it. He acknowledged that the ravens might have learned some aspects of the tasks but that this does not explain their spontaneous solution of several conditions. He therefore concluded that insight is the most plausible explanation.

However, there are plausible alternatives to these explanations, as already discussed above. Possibly the most convincing case of insightful string pulling would be an immediate solution to the *crossed* condition after an initial impasse without any previous string-pulling experience and not resulting from chance, trial and error, visual feedback, or innate processes (Jacobs and Osvath 2015). This has so far not been shown in any species because some factors, such as chance

and rapid trial and error, cannot be excluded in the first trial. Insight remains a vague concept that is more informative when deconstructed into its fundamental cognitive abilities that can be investigated independently (Shettleworth 2012).

Ecology and Evolution

The cognitive abilities required for successful string pulling may benefit animals in their natural environments. Numerous reports have documented how several species pull stringlike objects to retrieve attached food. For instance, olive baboons pull up the nests of weaverbirds to take their eggs (Laidre 2008), Eurasian jays pull up oak seedlings to retrieve buried acorns (Bossema 1979), tufted titmice pull up caterpillars hanging from branches by their threads (Dickinson 1969), and orangutans obtain 61% of their plant intake by pulling branches to reach leaves and fruits (Chevalier-Skolnikoff 1983). Therefore, this behavior may be facilitated, in some cases, by a species' natural ecology.

Some authors argue that such ecological parallels reduce the cognitive abilities required for string pulling (e.g., Altevogt 1954). Genetic programming could result in functional means-end behavior without complex cognition. Some adaptations are beneficial for string pulling, whether originally selected for these behaviors or not. There is suggestive evidence that playfulness, attentiveness, visual acuity, and manipulation skills increase the string-pulling performance of primates (Harris and Meyer 1971; Jolly 1964). In birds, one of the most important species-specific factors is the use of feet in feeding. Birds that do not use their feet for holding food generally fail to anchor pulled-up vertical strings under their feet and therefore cannot retrieve the reward. They perform markedly better on horizontal string pulling since it does not require stepping on the string (Jacobs and Osvath 2015).

Ice-fishing ravens illustrate these issues. While it shows string-pulling behavior in the wild, countering Heinrich's (1995) argument that little to no such behavior exists under natural circumstances, it is unlikely ravens specifically adapted to ice

fishing since it is a regional tradition that humans have been practicing for a time period that is very brief in evolutionary terms. Moreover, ravens improve with experience, differ individually in pulling technique, and are initially neophobic toward food suspended on strings (Heinrich 1995). Genetic programming for string pulling is therefore unlikely. Conversely, ravens frequently use their feet in feeding, which is more likely to have been directly selected genetically. Individuals innovate how to perform multi-step string-pulling sequences, which benefits from sensorimotor skills adapted for other reasons, such as holding food (Jacobs 2017). Future studies should investigate how wild ravens learn to pull up unattended fishing lines and how this behavior spreads through the population.

Since string-pulling tests are easy to administer, they are often used as indicators of general cognitive abilities in studies on ecology and evolution. For instance, 25% of wild great tits tested on vertical string pulling obtained the food within an hour. Their performance was stable over years, independent of various factors such as sex, neophobia, and body condition, and correlated with performance on another operant task (Cole et al. 2011). Females that performed better laid larger clutches but were also more likely to abandon their nests, showing a trade-off in fitness value for the cognitive abilities associated with string pulling (Cole et al. 2012). Large-scale studies on problem-solving abilities in wild species with controls on many variables are unfortunately rare. The string-pulling paradigm offers a relatively easy tool that is suitable for such purposes.

Until recently, only mammals and birds have done string-pulling tests. Alem et al. (2016) investigated string pulling in bumblebees and found that 2 out of 135 subjects spontaneously pulled a single horizontal string within 10 min, possibly through their persistence, exploration, trial-and-error learning, or sheer luck. Others learned to do so through social learning, resulting in the behavior slowly spreading throughout the colony. Three out of eight successful bumblebees also passed the *coiled* condition, but none of the 27 observing bees pulled in a coiled string completely. The authors concluded that observing

bumblebees are attracted to the demonstrator's location and the position of the string and that carrying out the pulling sequence relies on trial and error mediated by perceptual feedback of the reward moving closer. Thus, associative mechanisms and trial and error appear to explain string-pulling behavior in bumblebees, not means-end understanding or insight. This study illustrates the requirement of multiple testing conditions to distinguish between alternative explanations and yield conclusive results.

Species comparisons are difficult because many factors may influence string-pulling abilities, and these can obscure intra- and interspecific cognitive differences. With increased awareness of these issues and better study designs to accommodate or control for them, some meaningful comparisons are possible. Most tested animals have successfully pulled in single baited strings. As already discussed, the cognitive abilities required for this behavior are often unclear and less sophisticated than typically assumed, but it shows which species have the required sensorimotor capacities and are therefore suitable for further testing. Although around 170 species have been tested on the string-pulling paradigm, most of them are primates, carnivores, passerines, and parrots, which limits the scope of phylogenetic analyses (for the most recent phylogeny of string-pulling species, see Jacobs 2017).

Even in primates, not enough studies have been done with comparable methods or multiple species to allow for larger comparisons. However, one meta-analysis ranked species performances across several studies and showed that apes generally outperform monkeys on string-pulling tasks (Deaner et al. 2006). This parallels findings on numerous other tasks, which likely reflects differences in brain anatomy and socio-ecology between apes and monkeys. String pulling is highly suitable for phylogenetic comparative psychology because it involves minimal training, relatively few trials per subject, and the ability to easily adapt materials and testing protocols for different species (MacLean et al. 2012). However, a large-scale comparative phylogenetic study of string pulling does not exist yet. While the total number of studies is very large for this field, they

have a limited phylogenetic scope. To better reconstruct the evolution of the cognitive skills underlying this ability, some uncommon taxa should be tested, such as monotremes, marsupials, and paleognaths. This will increase the phylogenetic breadth significantly more than additional studies on common taxa such as primates and passerines. With the discovery of string pulling in bumblebees, researchers should be encouraged to investigate species outside the mammal and bird clades.

Conclusion

String pulling has a rich history and promising future. The variety in experiments conducted, species tested, and explanations offered attests to its broad utility in animal cognition and behavior. However, strong conclusions should not be made without exploring possible confounding factors and administering several conditions due to the many different cognitive mechanisms that may underlie string pulling. Nearly endless patterns are possible to this end. When investigating different cognitive abilities, the patterns in Fig. 1 may be most useful, especially the *parallel*, *slanted*, *crossed*, *overload*, *contact*, *connection*, and *coiled* conditions. Considerate use of the string-pulling paradigm will likely prove to be invaluable in the study of various cognitive abilities, including their relationships to ecology and evolution, throughout the animal kingdom.

Cross-References

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- [Folk Physics](#)
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- [Means-End Reasoning](#)
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- [Problem Solving](#)

- Technical Intelligence Hypothesis
- Tool Use

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