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Corvidae Can Understand Logical Structure in Baited String-Pulling Tasks

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The ability of the *Corvidae* to understand the logical structure of a task consisting of pulling a string attached to a bait was studied in a series of experiments with different relative positions of multiple strings. Some hooded crows (*Corvus cornix* L.) and common raven (*Corvus corax* L.) could successfully solve tasks in which the strings did not cross each other but were arranged in such a way that the bait was opposite the end of an "empty" string. Hooded crows also solved a task in which the bait was attached to each of two strings, but one string was broken, preventing it from pulling the bait. A task in which two crossing strings, in which the bait was again opposite the end of the empty string was not solved by hooded crows. These data lead to the conclusion that some members of both species are able to pick out the logical structure of tasks of this type.

Keywords: ravens, crows, baited string-pulling tasks, animal thinking.

One model used for studying thinking in animals consists of so-called tool tasks, in which a bait is placed within the animal's field of vision outside the zone that the animal can reach. The animal can obtain the bait only if it uses a tool, i.e., objects extending its physical capacity, particularly "compensating" for insufficient limb length [8].

In classical experiments on anthropoids, objects capable of being used as tools are placed in the animal's field of vision but without any physical connection with the bait [2, 4]. However, this method is unsuitable for wide-ranging studies, as the manipulatory capacities of most species are limited. A simplified analog of "tool" tasks may be provided by a test based on procuring a distant bait attached to a string. The complexity of this task can be altered by varying the number and mutual positions of the strings and bait. Use of different arrangements of multiple strings allows the animal's ability to understand the logical structure of these tasks to be evaluated and provides more precise assessments of the level of development of cognitive activity in different species [24].

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Comparative studies performed to date have shown that some carnivorous mammals (dogs and cats) appear to be unable to identify the connection between the bait and a particular string [9, 21, 26]. They pull the string whose end is opposite the bait.

Unlike carnivorous mammals, most of the primate species studied successfully solve even quite complex versions of this test for procuring a distant bait attached to a string (for example, with crossing strings). Anthropoids (chimpanzees, gorillas, and orang utans) cope with these tasks from the first trials [6, 7, 15, 16, 24]. Among the lower monkeys, these tests are successfully performed by capuchins [5] and mandrills [11]. Squirrel monkeys fail to solve the task with multiple strings in the first trial, but quickly learn the correct actions for strings in different positions [13].

Tasks with multiple strings have also been presented to a number of highly organized birds: corvids and psittacines. Individual members of both families successfully coped with a whole set of such tests (including those in which the bait was placed opposite the end of an empty string), evidencing their ability to analyze the logical structure of these tasks [20, 25]. The greatest difficulties were seen with tasks with two crossing strings in which the bait was positioned

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opposite the end of an "empty" string. Only some ravens [20] and keas [25] coped with this task. Budgerigars successfully procured the bait when it was placed opposite the end of an empty string as long as the strings did not cross (see Table 1, task 5) but were unable to solve the task with crossing strings [14]. Hyacinth macaws, Lear's macaws, and blue-fronted amazons successfully solved the task when the strings were hung vertically. If the strings crossed, these birds either pulled the end positioned opposite the bait or chose randomly [22]. Overall, the behavior of individual members of the corvids and psittacines in these tests is comparable to that of lower monkeys.

In our previous experiments [1], we presented hooded crows and common ravens with a task with a single string hanging a bait from the perch. The results showed that both common ravens and hooded crows (used in our laboratory for many years as a model species for studies of cognitive activity in birds) were able to procure the suspended bait, some ravens successfully solving this task in the first trial. This provides grounds for suggesting that the behavior of these birds can be regarded as a manifestation of cognitive activity, though a final conclusion requires studies of the mechanism by which these tasks are solved using a set of different tests of this same type.

The aim of the present work was to evaluate the ability of hooded crows and common ravens to solve tests with multiple strings to determine whether these birds understand the logical structure of these tasks. Our experiments differed from Heinrich's studies [20] on crows in that the strings were positioned in the horizontal plane. This made it easy to create different combinations of the mutual positions of different strings and bait without using the additional accessories required when the bait is suspended.

METHODS

Studies were performed using ten hooded crows (*Corvus cornix* L.) and four common ravens (*Corvus corax* L.) of different ages (all older than one year). All the ravens and some of the crows had been in captivity since they were fledglings and had no experience of life in the wild. All birds except 9M, 10M, and 11M (the letter M designates crows and the letter B designates ravens) had previously taken part in experiments assessing the ability of corvids to procure suspended bait [1].

The birds were kept in groups in aviaries in the open air. Their daily diet consisted of the corpses of small rodents and oat and buckwheat gruel supplemented with plant oil and vitamins. During the experiments, the birds were subjected to complete food deprivation, which continued until the birds started to try to pull the bait. The maximum acceptable durations of deprivation were selected individually.

During the experiments, each bird was placed in an individual cage of size 70 × 35 × 35 cm in which it had free access to a bowl containing water. The strings and bait were presented on an Orgalit platform (50 × 30 cm) and were marked in such a way that they could repeatedly be placed at the same distances from each other and from the edge of the platform. Tasks 1–3 used nylon ropes of diameter 5 mm and length 20 cm; tasks 4–6 used colored cords of diameter 2 mm (all will henceforth be termed strings). A knot was tied 2 cm from the end of each string. The bait consisted of a flour beetle larva (henceforth a worm) attached to the knot. The platform was brought into tight contact with the front wall of the cage such that the bird could grasp the end of the string with the beak.

During the experiments, the experimenter was positioned at one side of the cage containing the bird, behind an opaque screen (70 × 40 cm), such that they could not see each other (Fig. 1). Thus, the possibility that the experimenter had unconscious influences on the bird was minimized. The experimenter could see the ends of the strings further away from the bird and assess the birds' selection from the movements of the strings.

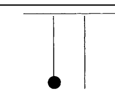
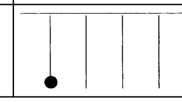
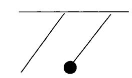
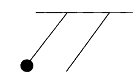
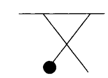
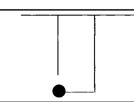
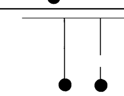
The experimenter could be located either on the right or the left side of the cage. Throughout each test, the mutual positions of the experimenter and the cage remained constant for each individual bird. This allowed subsequent assessment of the possibility that any preference for the string on a particular side of the experimental platform influenced selection.

Preparation of the platform for presentation was performed outside the animal's field of vision. The strings were placed on the platform in accordance with a previously specified scheme. The position of the string attached to the bait relative to the other strings was changed in pseudorandom order. In order to allow the bird to see the contents of the platform, it was placed for 3–5 sec in a position that allowed it to be seen but without the bird being able to reach the strings, and only then was the platform moved up against the cage. If the bird selected the string to which the bait was attached, the experimenter waited until the bird had pulled the bait into the cage. If the bird selected an "empty" string, the platform was removed and the experiment proceeded to the next task trial (i.e., any attempt to manipulate the string was taken as a selection). If the bird did not select any of the strings within 1 min, the platform was removed.

The bird was initially familiarized with the experimental apparatus by placing worms attached to strings in the cage. Once the bird had eaten the worms, several further strings with worms were placed close to the cage. Only then was the platform with worms attached to strings moved against the cage. If the bird pulled a string and ate a worm, it was regarded as ready to take part in the experiments.

Tasks 1–3 were presented to all ravens and four crows (1M, 2M, 3M, and 9M). Tasks 4–6 were presented only to crows (eight birds, 1M, 3M, 4M, 5M, 6M, 7M, 10M, and 11M). Tasks 1, 2, 3a, and 3b were presented 32 times to each bird, while tasks 4, 5, and 6 were presented 30 times. A bird was presented with only one task on any given day.

TABLE. 1. Positions of Strings in Tasks 1–6

Task No.	Number and positions of strings	
1	Two parallel strings perpendicular to the front wall of the cage	
2	Four parallel strings perpendicular to the front wall of the cage	
3	Two parallel strings at an angle of 45° to the front wall of the cage	
	a) bait positioned opposite the end of the “empty” string	
	b) bait positioned to one side of the ends of both strings	
4	Two strings crossing at an angle of 90° such that the bait is located opposite the end of the “empty” string	
5	Two strings: one straight, the other angled such that the bait is close to the far end of the “empty” string	
6	Two stings, both with baits, one string being complete and the other having a break preventing the bait from being pulled	

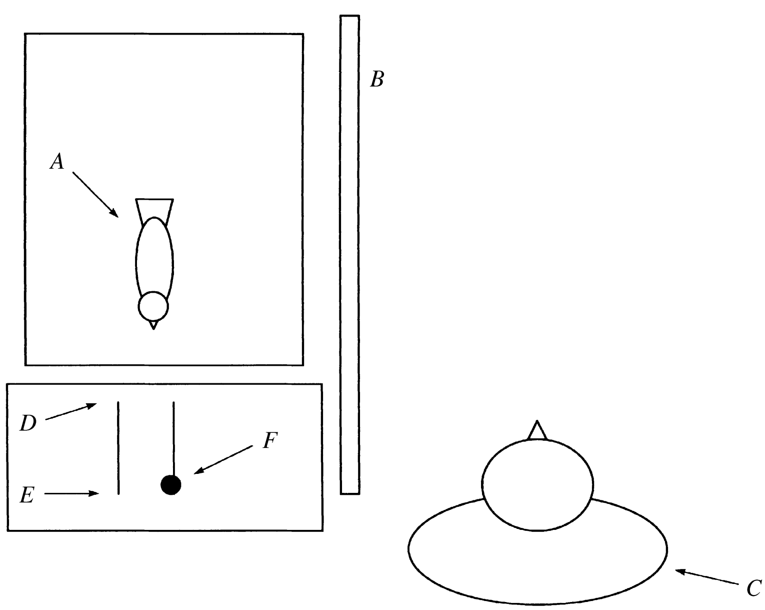
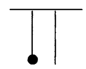
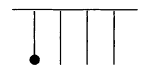
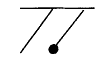
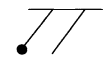


Fig. 1. Experimental arrangement. *A*) Bird; *B*) opaque screen; *C*) experimenter; *D*) close end of string; *E*) far end of string; *F*) bait.

Task 1 was presented on the first day and task 2 on the second; tasks 3a and 3b were presented in pseudorandom order on subsequent days. Tasks 4–6 were presented to birds one year after tasks 1–3, also on three sequential days.

Task 1. Two parallel strings 20 cm in length were placed perpendicular to the front wall of the cage, 15 cm from each other. The bait was attached to one of the two strings (Table 1).

TABLE 2. Numbers of Correct Solutions in Tasks 1, 2, and 3 by Hooded Crows

Crow No.	Task 1 (32 trials) 	Task 2 (32 trials) 	Task 3	
			a (32 trials) 	b (32 trials) 
1M	27*** (13)	17***	26*** (22*)	27*** (19)
2M	16 (20)	12*	15 (13)	14 (8**)
3M	32*** (16)	30***	18 (14)	31*** (17)
9M	29*** (12)	15**	29*** (17)	29*** (9*)

Note. Numbers in parentheses are the numbers of correct string selections. Significant differences from the random level (binomial test): *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Task 2. Four parallel strings 20 cm in length were placed perpendicular to the front wall of the cage at a distance of 10 cm from each other. The bait could be attached to any of the four strings (Table 1).

Task 3. Two parallel strings 20 cm in length were placed at an angle of 45° to the front wall of the cage and 15 cm from each other. The bait was attached to only one of the strings (Table 1). In half of the presentations, the bait was positioned opposite the end of the "empty" string (task 3a), and in the other half it was shifted sideways relative to the ends of both strings (task 3b). The latter string positioning version was used to assess the ability to compare the results of solving "complex" (bait located closer to the end of the "empty" string) and "simple" tasks (the "empty" string was to the side of the string carrying the bait).

Task 4. Two strings of different colors, 20 cm in length, were positioned such that they crossed at the center at an angle of 90° to each other (both were positioned at an angle of 45° to the front wall of the cage). The bait was attached to only one of the strings (Table 1). In this task, as in task 3a, the bait was closer to the end of the "empty" string.

Task 5. Two strings of different lengths were used: a shorter "empty" string (15 cm) and a longer string (25 cm) with the bait attached. The strings were placed on the platform such that their ends were parallel to each other (separated by 5 cm). At a distance of 18 cm from its end, the bait-carrying string was bent at a right angle, such that the bait was positioned close to the far end of the "empty" string (Table 1).

Task 6. Two parallel strings of length 20 cm were positioned perpendicular to the front wall of the cage separated from each other by 10 cm. One of the strings consisted of two fragments: an initial fragment (13 cm long) and a final fragment (5 cm long). The fragments were separated by a gap 2 cm long. Worms were attached to the ends of the target string and the 5-cm fragment of the interrupted string (Table 1).

Data were analyzed statistically in Statistica 7. Significance levels for correct solutions and preferences for strings located on particular sides of the experimental platform were assessed using a binomial test. Levels of correct solutions were compared by determining the error of the difference between proportions using Student's t test (two-tailed test).

Experiments were performed in accordance with the "Regulations for Studies using Experimental Animals" (USSR Ministry of Health Decree No. 755 of 08.12.1977).

RESULTS

Crows. Results on crows' solutions of the first three tasks are shown in Table 2. In task 1, three birds out of four 1M, 3M, and 9M) successfully pulled the string with the bait ($p < 0.001$). Task 2 was successfully performed by all four birds ($p < 0.05$).

Task 3a, in which the bait was positioned opposite the end of the "empty" string, was solved by two birds (1M, 9M, $p < 0.001$), with no significant difference between the levels of correct responses in tasks 3a and 3b ($p > 0.75$, Student's t test). The "simpler" task 3b, in which the "empty" string was on the side of the bait-bearing string, was solved by those birds which solved task 3a, and also by an additional crow (3M).

Preference for the string located on a particular side of the platform was seen only in task 3 in three of the four birds: crow No. 1 used this strategy in solving task 3a, while birds 2M and 9M used it in solving task 3b (see Table 2).

The results for solution of tasks 4–6 are shown in Table 3. None of the eight crows coped with task 4. Two birds (6M and 7M) predominantly selected the string whose end was located opposite the bait, while birds 3M, 4M, and 10M preferred the string whose end was located on a particular side of the experimental platform (the preferred side).

Task 5 was solved by four of the eight crows tested: 1M, 3M, 7M, and 10M. Bird 1M also showed a tendency to select the string located on a particular side (Table 3). Crow 6M predominantly selected the string whose end was positioned opposite the bait.

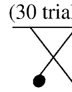
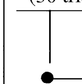
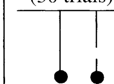
Six of the eight crows (1M, 3M, 4M, 5M, 7M, and 10M) coped with task 6. Some of them (1M, 3M, 5M, and 10M), as well as bird 6M, were unable to cope with this task, showing preference for the string located on a particular side (Table 3). Comparison of the levels of correct responses in the first and second halves of the presentations of each task (16 presentations in tasks 1–3 and 15 in tasks 4–6) revealed no significant differences ($p > 0.05$). A statistically insignificant tendency to a decrease in the number of correct solutions was seen in the second half of the presentations.

Ravens. Results from experiments with ravens are shown in Table 4. Task 1 was successfully solved by three birds (1B, 2B, and 4B, $p < 0.001$) of the four. Task 2 (with four strings) was solved by all four ravens ($p < 0.05$).

Task 3a, in which the bait was positioned opposite the end of the "empty" strong, was solved by only raven 3B ($p < 0.05$), though this bird could not cope with the simplest task 1 ($p > 0.05$) and produced more erroneous responses in task 2 ($p < 0.05$) than the other birds ($p < 0.001$). In task 3a, the level of correct responses by this bird was significantly lower than that in task 3b ($p < 0.01$, Student's t test). The three remaining ravens, which did not solve task 3a, nonetheless showed no preference for the string located opposite the bait. Two of these birds (1B and 2B) predominantly selected the strong located on a particular side in task 3a. All four ravens coped with the "simpler" task 3a, none preferring strings located on a particular side.

Comparison of the levels of correct responses in the first and second halves of the presentations of each task revealed no significant differences ($p > 0.05$).

TABLE 3. Numbers of Correct Solutions in Tasks 4, 5, and 6 by Hooded Crows

Crow No.	Task 4 (30 trials) 	Task 5 (30 trials) 	Task 6 (30 trials) 
1M	16 (17)	25*** (20*)	23** (22**)
3M	15 (30***)	28*** (17)	25*** (10*)
4M	12 (3***)	16 (17)	23** (16)
5M	14 (11)	18 (13)	23** (10*)
6M	9* (18)	3*** (16)	18 (9*)
7M	7** (12)	22** (17)	25*** (16)
10M	14 (1***)	26*** (17)	25*** (20*)
11M	11 (18)	18 (13)	18 (17)

Note. Numbers in parentheses are the numbers of correct string selections. Significant differences from the random level (binomial test): $*p < 0.05$; $**p < 0.01$; $***p < 0.001$.

DISCUSSION

In tasks involving pulling a string attached to a bait, animals were able to understand their logical structure, i.e., to follow the connection between the string and the bait or to use a simpler strategy consisting of pulling the string whose end was located opposite the bait [21, 26]. The second of these strategies could be performed successfully if all the strings were positioned perpendicularly to the front wall of the cage (or the perch, if the task was presented in the vertical plane). However, this strategy did not produce the desired result when the strings were positioned such that the bait was opposite the end of an "empty" string (see Table 1, tasks 3, 4, and 5) or when the bait was attached to both strings but one had a break (see Table 1, task 6). Solution of these tests allows determination of whether animals understand the logical structure of the task.

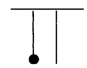
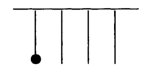
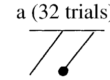
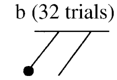
In our experiments, seven of the nine crows and two of the four ravens coped with complex tasks (3a, 5, 6). Only one bird (crow 1M) solved all tasks of these types. The other birds coped only with some of the tasks, though different birds solved different combinations of tasks.

It should be noted that previous studies of the task in which the bait was suspended from the perch on a single string also showed that not all birds solved it [1]. Ravens 1B, 2B, and 3B and crows 3M, 4M, and 6M coped with this task and birds 4B, 1M, 2M, 5M, and 7M did not solve it. It is interesting that crow 1M, which could not solve the task consisting of pulling the bait suspended from the perch on a single string, successfully coped with three complex tasks involving multiple strings (3a, 5, 6). This variability is probably associated with the fact that the birds' behavior in the experiment was influenced by a complex set of external factors which are beyond control: weather conditions, noises penetrating the experimental room from the street, etc. Furthermore, food deprivation could have different effects on the bird (depending on the initial level of fitness or the presence of parasites or undetected diseases).

Stereotypical activity expressed as preference for the string on a particular side was regarded as a measure of neurosis-like behavior in the birds, mainly apparent during solution of very complex tasks. In fact, the preferences of the birds for strings placed on a particular side was often seen during solution of complex tasks (3a, 4, 5, and 6), while this behavior was not seen during solution of the simple task (1). Those crows which used the simpler strategy (selecting the string whose end was positioned opposite the bait) showed no such preference.

Tasks in which the bait was located opposite the end of the "incorrect" string and the strings did not cross (experiments 3a and 5) are successfully solved by primates (which coped with the other versions of the task) [6, 24], keas [25], and some budgerigars [14]. In Heinrich's experiments [20], some ravens also successfully solved this task. Dogs in this situation generally pulled the strong whose end was located opposite the bait [21]. In our experiments using version 3a (see Table 1), one raven and two of four crows coped successfully, and five of eight crows coped with task 5 (see

TABLE 4. Numbers of Correct Solutions in Tasks 1, 2, and 3 by Common Ravens

Raven No.	Task 1 (32 trials) 	Task 2 (32 trials) 	Task 3 a (32 trials) 	Task 3 b (32 trials) 
1B	25*** (13)	25***	19 (27***)	29*** (19)
2B	27*** (13)	27***	20 (26***)	31*** (17)
3B	20 (18)	13*	22* (18)	30*** (14)
4B	25*** (19)	18***	14 (12)	28*** (12)

Note. Numbers in parentheses are the numbers of correct string selections. Significant differences from the random level (binomial test): *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 1) (tasks 4–6 were not presented to crows). Thus, in terms of the ability to follow the connection of the string with the bait, both of the corvid species tested here were similar to primates and psittacines and performed better than carnivorous mammals (as in other cognitive tests [3]).

Task 4 (with two crossing strings) was not solved by any of the crows. The fact that the analogous task in Heinrich's experiments [20] was solved by only one of five ravens leads to the conclusion that it is in fact complex for corvids. Parrots also experience difficulty in solving this task [14, 22]. Thus far, the only birds demonstrated to have the ability to solve this task stably (over several tens of presentations) are keas [25]. We suggest that laying strings on top of each other increases the perceptual complexity of the task (birds may perceive crossing strings as a single unit) but without complicating its logical structure, by which this task is not significantly different from tasks 3a and 5, in which the bait was also positioned closer to the end of the "empty" string.

We have provided the first demonstration that corvids can solve a task in which the bird has to identify that the string consisting of two fragments is not suitable for pulling the bait (task 6), with which six of eight crows coped. Anthropoids successfully cope with an analogous task [6, 7, 24], as do some psittacines (hyacinth macaws, Lear's macaws, but not amazons) [22]. A similar task was also presented to keas and tamarins (pieces of tissue carrying bait were used instead of strings): keas immediately coped successfully with the task [10], while only some tamarins solved it without additional training [19]. Thus, in terms of the results obtained from solving this task, which is based on the ability to follow the connection between the string and the bait and assess the value of the string, crows also showed no difference from primates and psittacines.

The absence of significant differences in the levels of correct solutions in the first and second halves of the presentations of each task suggests that clear trial-and-error learning did not occur.

The use of different types of tasks allows the role of transfer of experience in solving one task to another to be minimized. In addition, birds to which tasks 1–3 were not presented performed complex tasks 5 and 6 as successfully as birds with experience of solving the simpler tasks 1 and 2, which is also evidence for the absence of transfer of task-solving experience.

CONCLUSIONS

Overall, the data obtained here provide evidence that not only common ravens, but also hooded crows are able, without prior training, to solve tasks with multiple strings successfully. The results from solution of "complex" tests, in which the bait was located closer to the end of the "empty" string or one of the strings consisted of two fragments and was unsuitable for pulling the bait, showed that birds were in fact able to follow the connection of the string and the bait and to evaluate the value of the string, i.e., the logical structure of these tasks. In terms of solving these tasks, corvids, like psittacines, are significantly more able than carnivorous mammals and are at least comparable with lower monkeys [5–7, 17, 18, 20, 21, 25].

Our results supplement existing data showing that corvids have a whole series of higher cognitive functions [3], including the ability to use and even make tools [12, 23].

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REFERENCES

1. M. S. Bagotskaya. A. A. Smirnova, and Z. A. Zorina, "Comparative studies of the abilities of corvids to solve tasks involving procurement of suspended baits," *Zh. Vyssh. Nerv. Deyat.*, **60**, No. 2, 208–216 (2010).
2. V. Keler, *Studies of Intellect in Humanoid Monkeys* [in Russian], Komakademiya, Moscow (1930).
3. V. M. Konstantinov, V. A. Ponomarev, L. N. Voronov, Z. A. Zorina, D. A. Krasnobaev, I. G. Lebedev, V. A. Margolin, I. I. Rakhimov, A. G. Rezanov, and A. S. Rodimstev, *The Hooded Crow (Corvus cornix) in the Manmade Landscapes of the Paleoartic (questions of synanthropization and urbanization)* [in Russian], Moscow State Pedagogical University, Moscow (2007).

4. N. N. Ladygina-Kots, *Constructive and Tool-Using Activity in Higher Monkeys* [in Russian], USSR Academy of Sciences Press, Moscow (1959).
5. S. L. Novoselova, *Development of the Intellectual Bases of Activity in Primates* [in Russian], NPO MODEK, Voronezh (2001).
6. G. Z. Roginskii, *Skills and Rudiments of Intellectual Activity in Anthropoids (Chimpanzees)*, Nauka, Leningrad (1948).
7. G. Z. Rozinskii, *Development of the Brain and Mental Activity* [in Russian], Lenizdat, Leningrad (1948).
8. K. E. Fabri, *Tool-Using Activity of Animals* [in Russian], Znanie, Moscow (1980).
9. D. K. Adams, "Experiments studies of adaptive behavior in cats," *Comp. Psychol. Monogr.*, **6**, No. 1, 1–128 (1929).
10. A. M. Auersperg, G. K. Gajdon, and J. Huber, "Kea (*Nestor notabilis*) consider special relationships between objects in the support problem," *Biol. Lett.*, **5**, No. 4, 455–458 (2009).
11. J. Balasch, P. Sabater, and T. Padrosa, "Perceptual learning ability in *Mandrillus sphinx* and *Cercopithecus nictitans*," *Rev. Espanol. Fisiol.*, **30**, 15–20 (1974).
12. L. A. Bluff, A. A. S. Weir, C. Rutz, J. H. Wimpenny, and A. Kacelnik, "Tool-related cognition in new Caledonian crows," *Comp. Cogn. Behav. Rev.*, **2**, 1–25 (2007).
13. J. Cha and J. E. King, "The learning of patterned strings problems by squirrel monkeys," *Anim. Behav.*, **17**, 65–67 (1969).
14. G. Ducker and B. Rensch, "Solution of patterned string problems by birds," *Behaviour*, **62**, No. 1–2, 164–173 (1977).
15. G. Finch, "The solution of patterned string problems by chimpanzees," *J. Comp. Physiol.*, **32**, 83–90 (1941).
16. G. J. Fischer and S. L. Kitchener, "Comparative learning in young gorillas and orang-utans," *J. Gen. Psychol.*, **107**, 337–348 (1965).
17. L. G. Halsey, B. M. Bezerra, and A. S. Souto, "Can wild common marmosets (*Callithrix jacchus*) solve the parallel strings task?" *Anim. Cogn.*, **9**, 229–233 (2006).
18. H. F. Harlow and P. H. Settlage, "Comparative behavior of primates. VII. Capacity of monkeys to solve patterned string tests," *J. Comp. Psychol.*, **18**, 423–435 (1935).
19. M D. Hauser, J. Kralik, and C. Botto-Mahan, "Problem solving and functional design features: experiments on cotton-top tamarins, *Sanguinus oedipus oedipus*," *Anim. Behav.*, **57**, 5656–582 (1999).
20. B. Heinrich, "An experimental investigation of insight in common ravens (*Corvus corax*)," *The Auk*, **112**, 994–1003 (1995).
21. B. Osthaus, S. Lea, and A. Slater, "Dogs (*Canis lupus familiaris*) fail to show understanding of means-end connections in a string-pulling task," *Anim. Cogn.*, **8**, 37–47 (2005).
22. C. Schuck-Paim, A. Borsari, and E. B. Ottoni, "Means to an end: Neotropical parrots manage to pull strings to meet their goals," *Anim. Cogn.*, **12**, 287–301 (2009).
23. A. H. Taylor, G. R. Hunt, F. S. Medina, and R. D. Gary, "Do New Caledonian crows solve physical problems through causal reasoning?" *Proc. Biol. Sci.*, **276**, 247–254 (2009).
24. M. Tomasello and J. Call, *Primate Cognition*, Oxford University Press, New York (1997).
25. D. Werdenich and L. Huber, "A case of quick problem solving in birds: string pulling in keas, *Nestor notabilis*," *Anim. Behav.*, **71**, 855–863 (2006).
26. E. Whitt, M. Douglas, B. Osthaus, and I. Hocking, "Domestic cats (*Felis catus*) do not show causal understanding in a string-pulling task," *Anim. Cogn.*, **12**, No. 5, 739–743 (2009).