

Investigating Physical Cognition in Rooks, *Corvus frugilegus*

Amanda M. Seed,¹ Sabine Tebbich,¹ Nathan J. Emery,² and Nicola S. Clayton^{1,*}

¹Department of Experimental Psychology
University of Cambridge
Downing Street
Cambridge, CB2 3EB
United Kingdom

²Sub-Department of Animal Behaviour
Department of Zoology
University of Cambridge
High Street, Madingley
Cambridge, CB3 8AA
United Kingdom

Summary

Although animals (particularly tool-users) are capable of solving physical tasks in the laboratory [1–7], the degree to which they understand them in terms of their underlying physical forces is a matter of contention. Here, using a new paradigm, the two-trap tube task, we report the performance of non-tool-using rooks. In contrast to the low success rates of previous studies using trap-tube problems [1–4], seven out of eight rooks solved the initial task, and did so rapidly. Instead of the usual, conceptually flawed [8] control, we used a series of novel transfer tasks to test for understanding. All seven transferred their solution across a change in stimuli. However, six out of seven were unable to transfer to two further tasks, which did not share any one visual constant. One female was able to solve these further transfer tasks. Her result is suggestive evidence that rooks are capable of sophisticated physical cognition, if not through an understanding of unobservable forces [3, 9], perhaps through rule abstraction. Our results highlight the need to investigate cognitive mechanisms other than causal understanding in studying animal physical cognition.

Results and Discussion

Many studies of cognition reveal that animals are capable of solving physical tasks in the laboratory [1–7]. Explanations for this ability have traditionally fallen into two main categories: a low-level model based on associative learning, in which cause and effect are linked through exposure to their contiguity; and a high-level cognitive model in which the tasks are solved through an understanding of their underlying causal structure. Associative learning based on an arbitrary cue results in the formation of a task-specific solution. However, an understanding of causality may allow an animal to transfer what it has learned in one task to a novel one based on the same principles, an ability thought to be

evolutionarily favored in animals living in complex environments (e.g., the Environmental Complexity Thesis [10, 11]). Much of the evidence suggests that animals do not have a human-like appreciation of causal regularities, leading some theorists to posit that animals are incapable of reasoning about the unobservable forces underlying events [3, 9].

The trap-tube task (in which an animal must use a tool to extract a food reward from a horizontal tube, which has a “trap” along its length into which the food will drop if pulled or pushed over it, Figure 1) has become the benchmark test for causal understanding in the physical domain, and it has been used to test a variety of tool-users. There is no convincing evidence to suggest that any animal tested with this paradigm has shown an understanding of its causal properties [12]. We tested rooks (*Corvus frugilegus*) on a modification of the trap-tube task to investigate whether this non-tool-using bird could solve this task, and if so, whether its solution would be best explained by the low-level or high-level model.

Eight naive rooks were tested on the modified “two-trap tube” task. In Experiment 1, we presented four rooks with Tube A and four with Tube B (Figure 2). Both of these designs feature two traps along a horizontal tube with a piece of food positioned between them. One is functional—food will fall into it and be trapped. The other is nonfunctional— if it is to be retrieved, the food must be moved toward this trap. In order to test a non-tool-using species, we adapted the task so that the tool was already inside the apparatus: a stick with two clear discs, which enclose the food, attached to it, such that moving the stick will move the food. In Tube A, the food could be pulled across the top of the non-functional trap, and in Tube B it could fall through it and be recovered from below. The birds were each given one block of ten trials per day, with the left-right orientation of the tube randomized so that the functional trap occurred an equal number of times on both sides. The birds were deemed to have solved the problem if they made 15 or more correct responses over two consecutive blocks of ten trials (a result that is significant according to a Binomial test with α set at 0.05). If after 150 trials the bird had not reached the threshold, then testing ended.

As seen in Figure 3, seven of the eight rooks learned the initial problem, although the number of trials required to achieve significance varied considerably among individuals.

The traditional control used to assess how an animal has solved the trap-tube task is the use of an inverted trap tube such that the trap is above the tube and no longer effective (Figure 1). This control is based on the premise that animals that have understood the causal nature of the task should no longer avoid an ineffective trap. However, because there is no cost to doing so, we cannot be sure that an animal that does so has understood nothing about causality. Recent findings by

*Correspondence: nsc22@cam.ac.uk

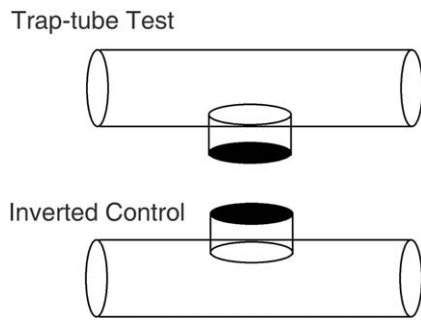


Figure 1. The Trap-Tube Test, Which Has Been Used to Test a Variety of Tool-Using Animals, and the Control Task Used in a Number of these Studies to Test for Understanding

Silva et al. have shown that even adult humans will unnecessarily avoid an ineffective trap [8]. These authors also point out that predicting a null effect in this way is a weaker test of a hypothesis than predicting a specific behavioral outcome. We adopted a different approach and used transfer tasks, in which the causal properties of the task remain the same but the appearance of the arbitrary stimulus differs, in order to address this problem, an approach advocated by Heyes [13] and adopted to investigate understanding in other paradigms (e.g., [7]).

In Experiment 2, we tested birds that had solved Tube A on Tube B, and vice versa, to assess whether or not they could transfer (respond significantly correctly within the first 20 trials) to this new task. All of the birds that had learned the initial two-trap tube task were able to do this, and all were correct on their first trial (Figure 3). Furthermore, when retested on ten trials of their original task, all seven performed significantly better than chance (5 out of 10 correct). This immediate transfer

from one physical task to a novel one, based on the same causal principles, could be explained by the formation of an understanding of the underlying causal structure of the task. Alternatively, both of these tasks could have been solved by avoiding the feature they had in common, the functional trap with a black disc at the bottom (see Figure 2).

In the third experiment, we precluded the use of a rule based on this cue present in Tubes A and B (the black disc at the bottom of one of the traps), by using two further transfer tasks. Each design featured the two previously nonfunctional traps within the same tube (Figure 2). However, the tube was manipulated such that one of these would now trap the food. The cue common to Tubes A and B was absent. In Tube C, the “pass-across” trap was made functional, because bungs were placed in the tube ends to prevent the food from passing through the open end of the tube. Once the stick had been pulled one way, it disappeared behind the bung on the other side, so that if a bird made the wrong response, it could not correct its mistake. In Tube D, the “drop-down” trap was made functional, because the whole tube was lowered such that the food could no longer be retrieved from below. Critically, the visual stimulus that could have been used as an arbitrary cue to solve these tasks, namely, the position of the black disc at the top of one of the traps, was the same in both tasks, but each task required the *opposite response* (pull away from the black disc in Tube C, pull toward it in Tube D). Subjects could not, therefore, solve both tasks through the use of a single procedural rule based on the configuration of the black disc. We gave the birds two blocks of ten trials in which to achieve significance according to a binomial test (9 or 10 correct out of 10, or 15 or more correct out of 20).

Six of the birds failed to transfer in Experiment 3 (Figure 4). They appeared to perform somewhat better on

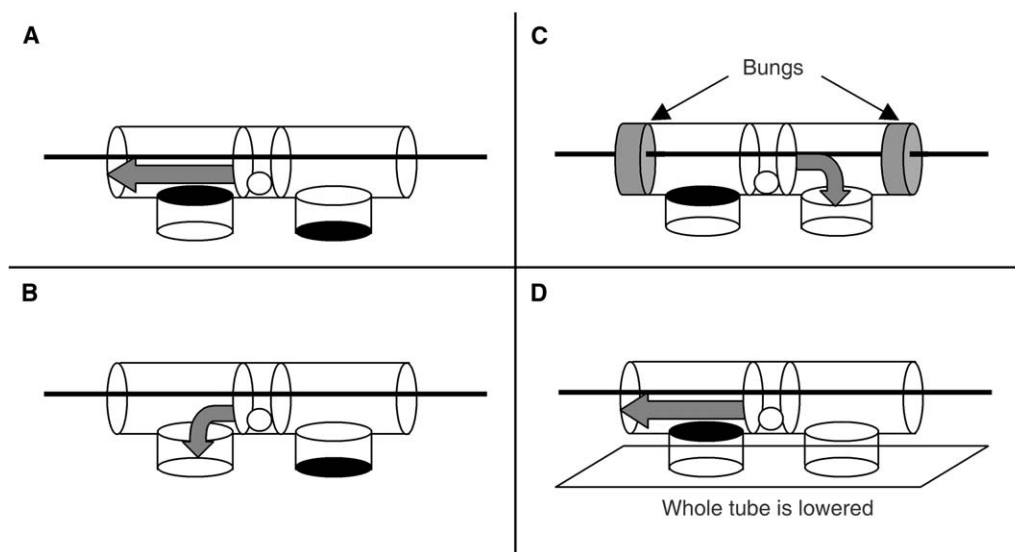


Figure 2. Experimental Apparatus

Tubes A and B were used in Experiments 1 and 2, and Tubes C and D were used in Experiment 3. A stick is already inserted into the tube at the start of the trial, and the food is enclosed by clear Perspex discs such that it will move with the stick whichever way it is pulled. Each tube has two “traps” along its length, and each has different solutions depending upon the position of horizontal black discs at the top or bottom of these traps. The arrow shows the path the food will take on a successful trial.

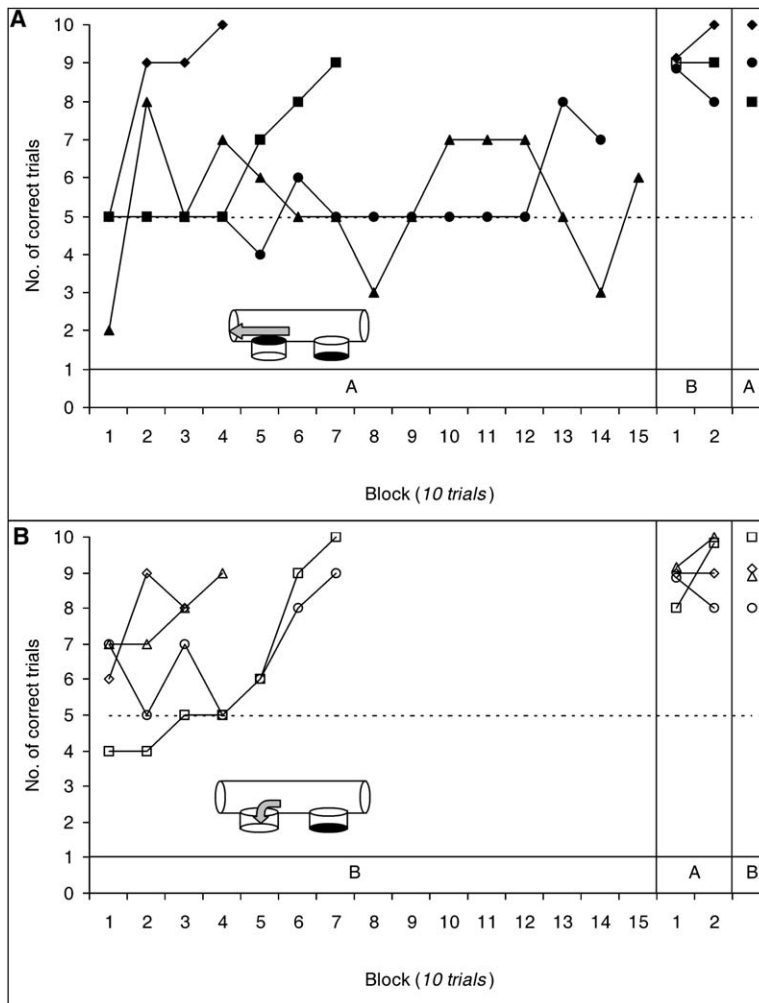


Figure 3. Results of Experiments 1 and 2
Panel (A) shows those birds that received Tube A in Experiment 1 and Tube B in Experiment 2 (subjects shown by closed symbols: Selvino = diamond, Fonteyn = triangle, Fry = square, and Callas = circle); Panel (B) shows those that received Tube B first (subjects shown by open symbols: Cooper = diamond, Curie = triangle, Guillem = square, and Cooper = circle). The horizontal dotted line in each graph shows chance performance (5 out of 10 trials correct). The vertical lines separate results from different tubes, and the boxes above the x axis show which of the tubes were used.

Tube C than Tube D, but this difference was not significant (paired t test, $n = 6$, $p = 0.13$). Learning to pull toward one type of nonfunctional trap in the first experi-

ment (i.e., pass-across in Tube A, drop-down in Tube B) did not facilitate performance on the transfer in which they had to pull toward the same type (i.e., pass-across

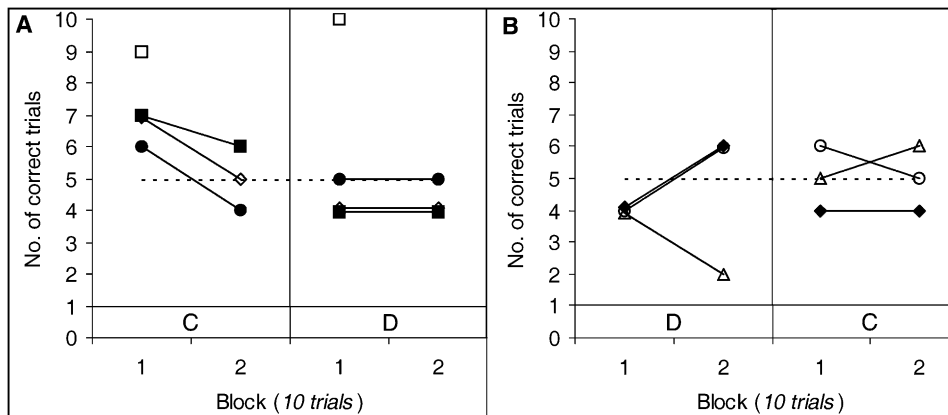


Figure 4. Results of Experiment 3

Panel (A) shows those birds that received Tube C and then Tube D; Panel B shows those that received Tube D first. Subjects are shown by the same symbols as used in Figure 3, so that closed symbols show subjects that received Tube A in Experiment 1 and open symbols show subjects that received Tube B. Fonteyn did not learn the first task in 150 trials and therefore did not continue to these transfers. The horizontal dotted line in each graph shows chance performance (5 out of 10 trials correct). The vertical lines separate results from different tubes, and the boxes above the x axis show which of the tubes were used.

in D, drop-down in C) (paired t test, $n = 6$, $p = 0.46$). Remarkably, one bird, Guillem, passed both Tubes C and D within the first block of ten trials, scoring 9 out of 10 in the former and 10 out of 10 in the latter, a result that is significant according to a binomial test. This striking performance could not be based on a simple procedural rule, as explained above.

These experiments have demonstrated that rooks are capable of solving a physical problem at least as complicated as any previously solved by tool-using primates. They solve these tasks surprisingly fast as compared to any of the tool-using species so far tested on related problems. One possibility for this is the fact that, although they are not tool-users, rooks are the only corvids reported to cache food by digging a hole before placing the food inside it and then covering it over [14]. Given that the traps are effectively holes, it may be that learning what constitutes a functional hole is an ecologically relevant problem for a rook. Corvids are also opportunistic generalists [14] for whom rapid learning is likely to confer a high survival advantage.

Other possible explanations for this difference may be considered: Shettleworth [15] has pointed out that many of the primates used in similar experiments (e.g., [3]) have participated in a variety of other physical tasks (unlike our rooks), which could have interfered with their learning; secondly, the rooks were not required to insert a tool, and this could also potentially facilitate learning on the task; lastly, it is possible that pulling food toward oneself is a more natural behavior for animals than pushing it away, and this improvement in “external validity” [16] may also be a facilitatory factor. We suggest that future studies on primates could investigate these alternative hypotheses by employing the methodology used in this study.

Given that six of the seven rooks failed to transfer to Tubes C and D, which had no visual features in common with the first task, it seems unlikely that they had an understanding of the unobservable causal properties of the task at their disposal. However, it is possible that the novel features of the transfer tasks made them difficult to solve; perhaps the problem appeared too different. This is one of the limitations of using transfer tests, in which one must change the appearance of the tasks.

The surprising performance of Guillem, who solved all four tasks despite the lack of a constant arbitrary visual cue, deserves further attention. A possible account of Guillem’s performance is that she had understood the unobservable features of the task, a result that would contradict the hypothesis that animals are incapable of learning about such features [3, 9]. However, the proponents of this hypothesis have suggested that sophisticated cognition may be possible without this ability, through the formation of “concepts” or “representations” based on observable features of problems. In this task, Guillem could have abstracted a rule based on the observable features of the task, such as surface continuity and the inability of objects to pass through barriers. These kinds of concepts have been described as constituting a simple form of knowledge about objects, one that arises earlier in human child development than more complex causal reasoning about unobservable forces, such as the notion of gravity [17, 18]. The ability of corvids to abstract rules has been documented

in other tasks, such as matching and oddity learning [19], learning set formation [20, 21], spatial learning [22], tests of episodic-like memory [23, 24], and transitive inference [25].

However, the result of one bird in seven must be interpreted with caution, and at present we cannot distinguish between these hypotheses. Guillem’s result in the third experiment highlights the fact that there is more to physical cognition than reasoning about unobservable forces. Rule abstraction and the formation of representations based on observable features is one possible reason why some animals (such as primates and corvids) have the ability to form sophisticated cognitive solutions to physical problems in the absence of causal understanding of unobservable forces. The adoption of transfer tasks, as opposed to control tests that probe for an all-or-nothing possession of causal understanding, might allow us to form a better understanding of how animals process their physical world.

Experimental Procedures

Study Animals and Housing

The subjects were eight rooks: Selvino (f), Curie (f), Cooper (f), Fry (f), Cook (m), Guillem (f), Callas (f), and Fonteyn (f). None of them had taken part in any previous cognitive experiments. They are part of a group of 15 hand-raised rooks that were collected from two colonies in Cambridge on April 16th and 17th, 2003, and housed at the time of testing in a climate-controlled indoor aviary with a 12:12 hr light:dark schedule. Test subjects were housed in pairs in two side aviaries (both 2 m by 1 m) of the main housing aviary and were tested almost daily for the duration of the study. During testing, an opaque partition separated each individual so that they were visually isolated from the other. Food and water were supplied ad libitum outside trial periods. The daily feed included pasta, potatoes, meat, eggs, seeds, nuts, and fresh fruit. Food was removed 1 hr prior to testing, and preferred foods (e.g., bacon, pork pie, pancakes, and meal worms), which were used as rewards, were not given as part of the regular feed.

Experimental Procedures and Apparatus

Tubes A–D were Plexiglas tubes (175 mm long \times 40 mm wide), fixed horizontally onto a wooden block (200 mm long \times 25 mm high) between two vertical Perspex panels, which were fixed to the wooden block 150 mm apart and held the tube at an elevation of 140 mm (measured from the base of the wooden block to the top of the tube). A tool was inserted into the tube. It consisted of wooden dowel with two Perspex discs attached to it, positioned in the center of the dowel and 20 mm apart (Figure 1). A food reward was placed in the center of the tube between the two discs. To obtain the food reward, rooks had to pull the tool toward them. Subjects were tested between June and October of 2004. Subjects were tested in blocks of ten trials and never received more than one block of trials a day. During a trial, an experimenter baited the apparatus, placed it on a shelf in front of the bird, and left the room. The trial was then scored from live video feed as either successful (the subject obtained the food reward) or unsuccessful. The apparatus was left in for periods of 10 min, or until the subject was successful at obtaining the food by pulling the stick. If no response was made within 10 min, the apparatus was removed for a short time and then replaced in the same orientation.

Data Analysis

Subjects were deemed to have solved the tasks if they approached the correct side and successfully retrieved the food in 15 or more trials within two consecutive blocks. We used a binomial test to assess the statistical significance of the performance in test trials [26], and we used paired t tests for post-hoc comparisons of performance. Alpha was set at 0.05.

Authorization for Use of Experimental Animals

Rook nestlings were collected under English Nature licence. This work adhered to University of Cambridge policies on animal husbandry and welfare.

Acknowledgments

A. Seed was supported by a Biotechnology and Biological Sciences Research Council (BBSRC) postgraduate studentship, S. Tebbich by a Marie Curie Fellowship of the European Union under contract number HPMF-CT-2002-01599, and N. Emery by a Royal Society University Research Fellowship. The work was funded by the BBSRC, the Royal Society, and the University of Cambridge. We thank J. Call for discussion, and we also thank R. McCarthy and P. Miedl for help with collecting the birds, S. de Kort and K. Kluck for help with hand rearing, C. Donovan for her care of them, and I. Millar for constructing the apparatus. Thanks also go to N. Mackintosh, L. Salwiczek, and A. Helme for comments on an earlier draft of the manuscript.

Received: January 20, 2006

Revised: February 13, 2006

Accepted: February 14, 2006

Published: April 3, 2006

References

1. Visalberghi, E., and Limongelli, L. (1994). Lack of comprehension of cause-effect relations in tool-using capuchin monkeys (*Cebus apella*). *J. Comp. Psychol.* *108*, 15–22.
2. Limongelli, L., Visalberghi, E., and Boysen, S.T. (1995). The comprehension of cause-effect relations in a tool-using task by chimpanzees (*Pan troglodytes*). *J. Comp. Psychol.* *109*, 18–26.
3. Povinelli, D.J. (2000). *Folk Physics for Apes* (New York: Oxford University Press).
4. Tebbich, S., and Bshary, R. (2004). Cognitive abilities related to tool use in the woodpecker finch, *Cactospiza pallida*. *Anim. Behav.* *67*, 689–697.
5. Chappell, J., and Kacelnik, A. (2002). Tool selectivity in a non-primate, the New Caledonian crow (*Corvus moneduloides*). *Anim. Cogn.* *5*, 71–78.
6. Chappell, J., and Kacelnik, A. (2004). Selection of tool diameter by New Caledonian crows *Corvus moneduloides*. *Anim. Cogn.* *7*, 121–127.
7. Hauser, M.D., Kralik, J., and Botto-Mahan, C. (1999). Problem solving and functional design features: Experiments in cotton-top tamarins. *Anim. Behav.* *57*, 565–582.
8. Silva, F.J., Page, D.M., and Silva, K.M. (2005). Methodological-conceptual problems on the study of chimpanzees' folk physics: How studies with adult humans can help. *Learn. Behav.* *33*, 47–58.
9. Tomasello, M., and Call, J. (1997). *Primate Cognition* (New York: Oxford University Press).
10. Godfrey-Smith, P. (2001). Environmental complexity and the evolution of cognition. In *The Evolution of Intelligence*, R. Sternberg and J. Kaufman, eds. (Mahwah, New Jersey: Lawrence Erlbaum Associates).
11. Sterelny, K. (2003). *Thought in a Hostile World* (Oxford: Blackwell Publishing).
12. Call, J. (2000). Representing space and objects in monkeys and apes. *Cogn. Sci.* *24*, 397–422.
13. Heyes, C.M. (1994). Reflections on self-recognition in primates. *Anim. Behav.* *47*, 909–919.
14. Goodwin, D. (1986). *Crows of the World* (London: British Museum (Natural History) Press).
15. Shettleworth, S.J. (1998). *Cognition, Evolution and Behavior* (New York: Oxford University Press).
16. Hare, B. (2001). Can competitive paradigms increase the validity of experiments on primate social cognition? *Anim. Cogn.* *4*, 269–280.
17. Spelke, E.S. (1994). Initial knowledge: Six suggestions. *Cognition* *50*, 431–445.
18. Spelke, E.S., Katz, G., Purcell, S.E., Ehrlich, S.M., and Breinlinger, K. (1994). Early knowledge of object motion: Continuity and inertia. *Cognition* *51*, 131–176.
19. Wilson, B., Mackintosh, N.J., and Boakes, R.A. (1985). Transfer of relational rules in matching and oddity learning by pigeons and corvids. *Q. J. Exp. Psychol. B* *37*, 313–332.
20. Kamil, A.C., Lougee, M., and Shulman, R.I. (1973). Learning-set behavior in the learning-set experienced blue-jay (*Cyanocitta cristata*). *J. Comp. Physiol. Psychol.* *82*, 394–405.
21. Kamil, A.C., Jones, T.B., Pietrewicz, A., and Mauldin, J.E. (1977). Positive transfer from successive reversal training to learning set in blue jays (*Cyanocitta cristata*). *J. Comp. Physiol. Psychol.* *91*, 79–86.
22. Kamil, A.C., and Jones, J.J. (2000). Geometric rule learning by Clark's nutcrackers (*Nucifraga columbiana*). *J. Exp. Psychol. Anim. Behav. Process.* *26*, 439–453.
23. Clayton, N.S., Yu, K., and Dickinson, A. (2001). Scrub-jays (*Aphelocoma coerulescens*) form integrated memory for multiple features of caching episodes. *J. Exp. Psychol. Anim. Behav. Process.* *27*, 17–29.
24. Clayton, N.S., Yu, K.S., and Dickinson, A. (2003). Interacting cache memories: Evidence for flexible memory use by scrub jays. *J. Exp. Psychol. Anim. Behav. Process.* *29*, 14–22.
25. Paz-Y-Mino, C.G., Bond, A.B., Kamil, A.C., and Balda, R.P. (2004). Pinyon jays use transitive inference to predict social dominance. *Nature* *430*, 778–781.
26. Siegel, S., and Castellan, N.J. (1988). *Nonparametric Statistics for the Behavioral Sciences*, 2nd edition. (New York: McGraw-Hill).