Current Biology 17, 1504–1507, September 4, 2007 ©2007 Elsevier Ltd All rights reserved DOI 10.1016/j.cub.2007.07.057

Report

Spontaneous Metatool Use by New Caledonian Crows

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Summary

A crucial stage in hominin evolution was the development of metatool use—the ability to use one tool on another [1, 2]. Although the great apes can solve metatool tasks [3, 4], monkeys have been less successful [5–7]. Here we provide experimental evidence that New Caledonian crows can spontaneously solve a demanding metatool task in which a short tool is used to extract a longer tool that can then be used to obtain meat. Six out of the seven crows initially attempted to extract the long tool with the short tool. Four successfully obtained meat on the first trial. The experiments revealed that the crows did not solve the metatool task by trial-and-error learning during the task or through a previously learned rule. The sophisticated physical cognition shown appears to have been based on analogical reasoning. The ability to reason analogically may explain the exceptional tool-manufacturing skills of New Caledonian crows.

Results and Discussion

Metatool use was one of the major innovations in human evolution [1, 2]. The use of simple stone tools to make more complex tools may reflect the "cognitive leap" that initiated technological evolution in hominins [2]. Metatool use has three distinct cognitive challenges. First, an individual must recognize that tools can be used on nonfood objects. This recognition may require analogical reasoning abilities [2]. Second, an individual must initially inhibit a direct response toward the main goal of obtaining food, a reaction that both children and primates find difficult to suppress [8–10]. Third, an individual must be capable of hierarchically organized behavior [11, 12]. That is, they must be able to flexibly integrate newly innovated behavior (tool → tool) with established behaviors as a subgoal in achieving a main goal (tool → tool → food). Such flexible, hierarchical organization of behavior has been suggested to follow a recursive pattern and to require cognitive processing similar to language production [13].

In early hominins, the transfer of a thrusting percussion technique from breaking nuts to knapping cutting tools was likely part of longer behavioral sequences in which tool materials and food were acquired separately [2]. Metatool use, therefore, probably involved considerable behavioral organization in space and time. Tests for metatool use in great apes and monkeys have typically followed an experimental design where a small stick can be used to retrieve a nearby longer stick that can then be used to gain otherwise inaccessible food. The close proximity of the tools and the food in these tests eliminates tool transport and facilitates assessment of the relevant requirements of the task. It also makes it relatively easy to accidentally touch the long tool with the short tool in normal exploratory behavior, and thereby chance upon the solution. Increased distance between tools and the food source has been suggested to increase the cognitive demands of a tool task [3, 14].

Striking evidence is now emerging that Corvidae have convergently evolved cognitive abilities that rival those of our primate relatives [15]. Evidence for convergent evolution include the impressive tool-manufacturing skills of New Caledonian crows (*Corvus moneduloides*) [16–21] and complex physical cognition in non-tool-using rooks (*Corvus frugilegus*) [22]. To test whether New Caledonian crows (crows hereafter) are capable of metatool use, we used an experimental design similar to the standard design used with great apes [3, 4]. We modified the design to give a greater degree of spatial and temporal separation between the tools and the food. In our experiments, food (meat) was placed in a 15 cm deep horizontal hole 1.75 m away from two identical "toolboxes" (Figure 1). The front of each toolbox consisted of vertical bars that allowed a crow to insert its bill but not its head. We placed an 18 cm long stick tool 4 cm inside one toolbox. This tool was long enough to extract the meat but out of reach of a crow's bill. In the other toolbox, we placed a stone in a similar position. The positions of the stone and tool were randomized between the toolboxes across trials. Presenting both a relevant and an irrelevant object controlled for random probing of the toolboxes leading to a solution by trial and error. In front of the toolboxes, we placed a 5 cm long tool (Figure 1). This tool was too short to extract the meat but could be used to extract the long tool from the tool box. Successful completion of the task required a crow to use the short stick to extract the long stick from the box and then transport the long stick to the hole and extract the food.

All seven crows developed metatool use and extracted the food (Figure 2). Icarus, Luigi, and Gypsy spontaneously produced the correct behavioral sequence in the first trial (Gypsy's and Icarus's first trial are shown in Movies S1 and S2, respectively, in the Supplemental Data available online). This was despite the requirement to transport tools and the difficulty in obtaining a tool from behind the bars. Joker also successfully solved the problem on the first trial, but made the error of taking the short tool to the hole after a first attempt at extracting the long stick (Figure 2). Colin, Lucy, and Ruby first extracted food in the 5th, 19th, and

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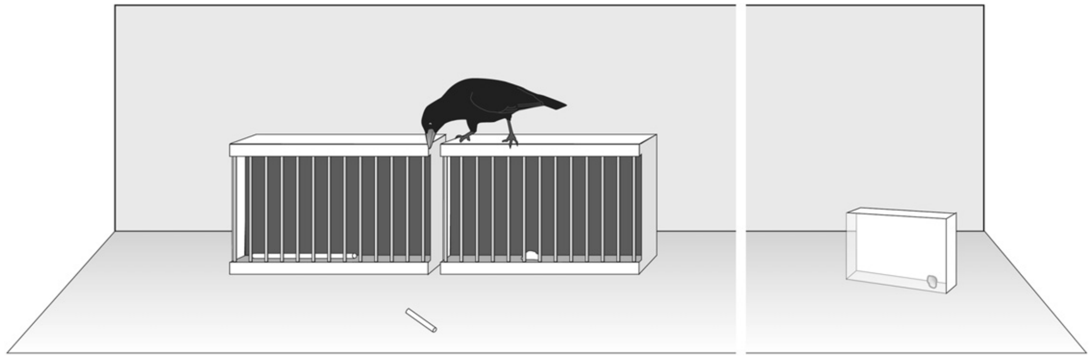

Figure 1. The Metatool-Use Task

The experimental apparatus consists of a long, functional tool in one toolbox, a stone in the second toolbox, a short, nonfunctional tool in front of both toolboxes, and a 15 cm deep horizontal hole in which meat was placed. The distance between the hole and the toolboxes was 1.75 m but is reduced in the image to save space.

23rd trial, respectively. Significantly, the first use of the short stick by six of the seven crows was either successful metatool use or a failed attempt to extract the long tool. This performance is comparable with that of the great apes [3, 4]. In the first trial, five out of six gorillas and three out of five orangutans used a tool as a metatool [3]. However, only three out of five chimpanzees (*Pan troglodytes*) developed metatool use, and these individuals first made the error of attempting to use the small, nonfunctional stick tool to obtain the food [4]. Monkeys have been less successful. One out of two capuchins (*Cebus apella*) performed at a similar level to gorillas and developed metatool use on the first trial [5]. In another study, only one out of six capuchins used tools as metatools and this individual succeeded in less than 50% of trials [7]. Despite receiving considerable training on tool use, Japanese macaques (*Macaca fuscata*) did not attempt metatool use on the first trial and required more than 50 trials to achieve a 75% success rate [6].

Initial use of the nonfunctional tool in an attempt to get the food frequently occurs in primate metatool-use studies [3, 4]. In our experiment, only Lucy made the error of first taking the nonfunctional stick to the hole. Four crows (Ruby, Joker, Luigi, and Colin) occasionally attempted to use the nonfunctional tool to get food in later trials, but only after unsuccessfully trying to extract the long tool with the short tool. These crows appeared to have had difficulty extracting the long tool from the barred toolbox. They may have then taken the nonfunctional short tool to the hole because of problems inhibiting tool use when no other course of action was available.

The task could have been solved by trial-and-error learning if crows had initially used tool-related exploratory behavior toward the toolboxes and stumbled across the solution. However, the crows did not randomly probe the toolboxes. The first toolbox probed by all seven crows was the one with the long stick rather than the stone. In fact, only Ruby ever probed the toolbox containing the stone; she did so once, several trials after successful metatool use. This suggests that metatool use did not develop through trial-and-error learning during the experiment. The use of a previously learned behavioral rule by the crows is also unlikely. Familiarization training with the apparatus did not involve metatool use, and we have never seen this behavior in the wild in

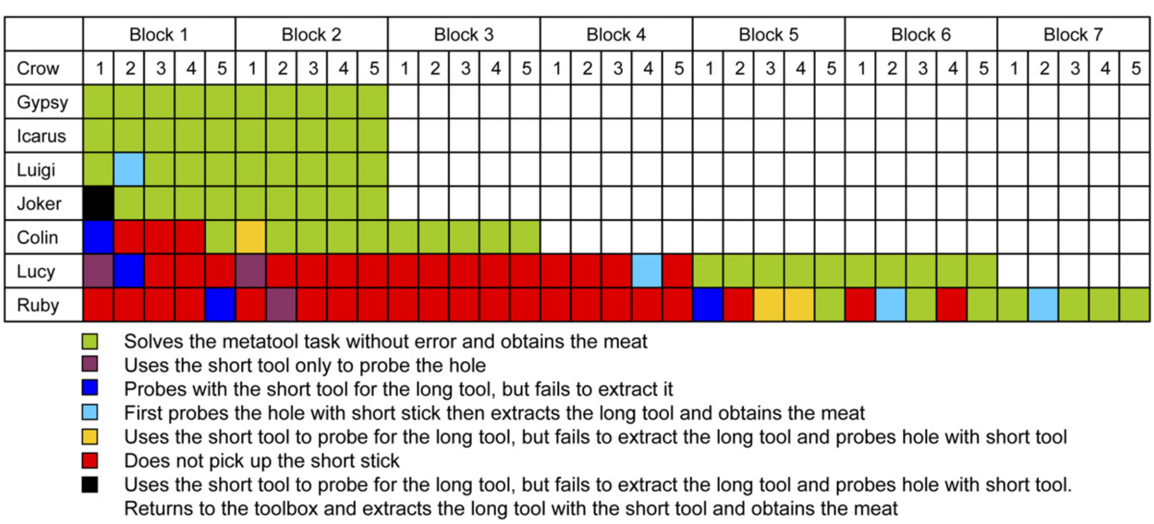

Figure 2. Trial-by-Trial Description of Experiment One

The long, functional tool was in a toolbox and the short, nonfunctional tool was in front of the toolboxes.

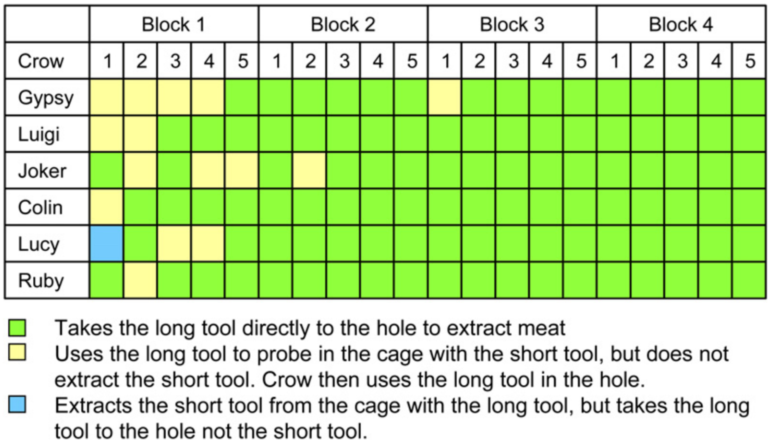

Figure 3. Trial-by-Trial Description of Experiment Two

The positions of the long and short tools were reversed; the short, nonfunctional tool was in a toolbox and the long, functional tool was in front of the toolboxes. Icarus did not participate in these trials.

more than 3 years of observing crows on Maré. The spontaneous development of metatool use therefore required cognition more complex than simple learning mechanisms.

One possibility is that the crows solved the metatool task by analogical reasoning. Successfully constructing an analogy requires that an individual maps experience from previous problems onto a structurally similar, novel problem [23–25]. One language-trained chimpanzee has been reported to have solved both figural and conceptual analogy problems [26]. The crows may have solved the metatool-use task by perceiving the shared causal relationship between the task and normal tool use, namely that a tool can access out of reach objects. Children's performance with causal analogies depends in part on knowledge of the relevant causal properties of the task [27–29]. Causal understanding is indicated by the spontaneous correction of mistakes in an appropriate, goal-directed way [30, 31]. If the crows had understood the relevant causal relationship in this experiment, we would expect them to use this knowledge to avoid making errors based on tool type.

To see whether crows were sensitive to the causal aspects of the food extraction task, we carried out a second experiment where the positions of the short and long tools were reversed. The long tool was now freely available so that metatool use was not required to extract the food. In the first block of five trials, all six crows tested initially inserted the long tool into the toolbox containing the short tool, but this generally occurred in the first block of five trials (Figure 3). This behavior usually lasted momentarily and there was often no contact with the short tool. In the only exception, Lucy extracted the short stick from the toolbox in her first trial but did not take it to the hole. No crow took the short stick to the hole. The insertion of the long tool appeared to be due to the difficulties in deviating from habitual behavior [32]. The crows may have routinely probed the toolbox with the long tool because they had been rewarded in the previous ten metatool-use trials for probing the box. The crows rapidly rectified this mistake, suggesting that they were sensitive to the causal relationship between the tools and the final goal.

Our findings provide experimental evidence that New Caledonian crows can spontaneously solve a metatool task. On their first attempt to solve the problem, six out of seven crows used the short tool to probe the toolbox with the long tool. This appropriate spontaneous behavior and the quick correction of causal errors suggest that the crows used analogical reasoning to solve the metatool task. Analogical reasoning may be the crucial factor in the exceptional tool-manufacturing skills of New Caledonian crows.

Experimental Procedures

We carried out the experiments with seven wild New Caledonian crows captured on Maré Island, New Caledonia. We housed up to three crows at a time in a 2-cage outdoor aviary at the location of capture; each cage was 4 m × 2 m × 3 m high. After capture, a crow was left to get accustomed to the aviary and human presence for 3 days before the experimental procedures began. During the experimental work, crows were held in one cage and the experimental apparatus was in the second cage; crows could not see between the cages. All crows were released at their site of capture after the experiment.

Each crow was given 10 familiarization trials in each of the following tasks before testing began: (1) extracting meat from the 15 cm deep horizontal hole with an 18 cm long stick that we provided; (2) withdrawing an 18 cm long stick from the toolbox and extracting meat from the hole (one end of the stick extended out between the bars, making it easy for crows to see and extract it); and (3) using a nonfunctional 5 cm long stick to try and extract meat from the 15 cm deep hole. The familiarization trials were carried out in blocks of five, in the following sequence: (1), (2), (3), (1), (2), and (3).

Before the first trial in the testing phase, each crow was given a 5 min familiarization period with the experimental setup without the short tool present. The short tool was placed in front of the toolboxes at the start of all trials. The trials were 10 min long and in blocks of five. To ensure that birds were exposed to the problem for standardized blocks of time, the position of the short stick was reset if a bird moved and then discarded it before the 10 min trial period ended. Testing continued until a crow had solved the task in 80% of trials across two consecutive 5-trial blocks or until 35 trials had been completed.

Supplemental Data

Two movies are available at http://www.current-biology.com/cgi/content/full/17/17/1504/DC1/.

Acknowledgments

The authors thank W. Wardrobert and his family for access to their land. This work was supported by a Commonwealth Doctoral Scholarship (to A.H.T.) and a grant from the New Zealand Marsden Fund (to G.R.H. and R.D.G.). We are grateful to M. Corballis for helpful advice about the methodology and V. Ward for drawing Figure 1.

Our work was carried out under University of Auckland Animal Ethics Committee approval R375.

Received: June 27, 2007
Revised: July 24, 2007
Accepted: July 25, 2007
Published online: August 16, 2007

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