

Learning generalization in problem solving by a blue-fronted parrot (*Amazona aestiva*)

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Abstract Pepperberg (The Alex studies: cognitive and communicative abilities of gray parrots. Harvard University Press, Cambridge; 1999) showed that some of the complex cognitive capabilities found in primates are also present in psittacine birds. Through the replication of an experiment performed with cotton-top tamarins (*Saguinus oedipus oedipus*) by Hauser et al. (Anim Behav 57:565–582; 1999), we examined a blue-fronted parrot's (*Amazona aestiva*) ability to generalize the solution of a particular problem in new but similar cases. Our results show that, at least when it comes to solving this particular problem, our parrot subject exhibited learning generalization capabilities resembling the tamarins'.

Keywords Problem solving · Learning generalization · Parrots · *Amazona aestiva*

Introduction

Some cognitive abilities previously attributed only to primates seem to be present in other taxa, such as corvids (Emery and Clayton 2004), and psittacine birds (Pepperberg 1999). Pepperberg's subject, for example (Alex, an African Gray parrot), could use sounds from spoken English to identify, request, refuse, or quantify objects of various colors, shapes and materials, as well as understand the relational concepts of "same" and "different", and has also achieved the same level as a chimpanzee on tests of

object permanence (review in Pepperberg 1999), whereas Emery and Clayton (2004) describe tool use and manufacture by New Caledonian crows and cache recovery by scrub jays and Clark's nutcrackers.

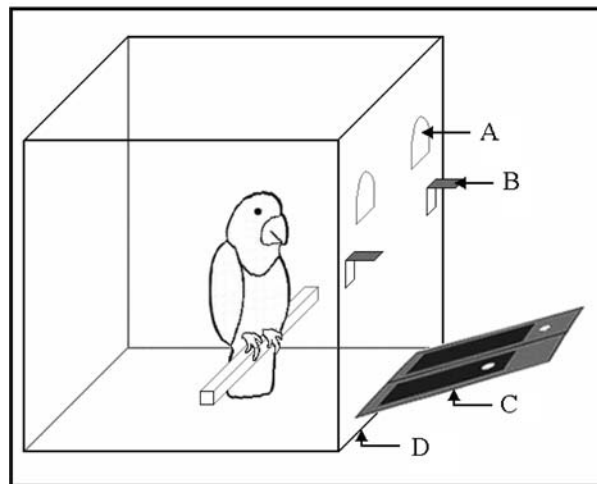
Complex sociality can be a selective pressure for complex cognitive abilities. This hypothesis comes from primatology (Jolly 1966; Humphrey 1976; Byrne and Whiten 1988) and has been extended to other taxonomic groups (de Waal and Tyack 2003); if so, we should expect Psittacids to be particularly well-endowed with cognitive abilities, since they live in large groups and are monogamous (Emery et al. 2007). Moreover, they have a relatively large pallid area in the brain, which, in birds, is responsible for complex cognitive processes (analogous to the mammalian neocortex; Jarvis et al. 2005). Wright (1996) and Sauters (1983) suggested that parrots have the ability to recognize individuals (group members or mates) by their vocalizations.

Learning sets (Harlow 1949) allow an organism to adjust to changes in the environment through generalization of previous learning, instead of depending on new learning processes. Therefore, after an animal is trained to solve a specific problem, it can readily solve new but conceptually similar problems if it can distinguish the relevant (and unchanged) from the irrelevant features of the context. This enables an animal, to generalize, for instance, the technique it learned to open a given species of nut to other, similar species of encapsulated fruit. Problems in nature seldom come in exactly the same form—even when they can be solved through already-learned procedures.

Hauser et al. (1999) developed a two-choice experimental paradigm to test cotton-top tamarins' (*Saguinus oedipus oedipus*) capacity of generalizing the solutions to two problems involving in the access to out-of-reach food items: in the "On" problem, the correct choice was pulling a piece of

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Fig. 1 Experimental cage. *A* openings; *B* support for the tray during the “access position”; *C* tray in “observation position”; *D* the Plexiglas wall. Photos: *I* the bird looks at the tray in the observation position; *II* experimenter showing the tray in the access position; *III* the subject reaches through one of the openings to pull the cloth with the reward on it



cloth on which the food reward laid (as opposed to another piece of food, inaccessible, set beside its corresponding cloth), while in the “Connected” problem, the correct choice was pulling a single piece of cloth with a reward on it (the other option being two “disconnected” pieces of cloth, with the inaccessible food on the farther one).

In the current study, we tested the ability of a blue-fronted parrot to generalize the solution of the “On” problem developed by Hauser et al. If the parrot is capable of solving this problem, as did the tamarins, it would be another indication of convergent evolution in the cognitive abilities underlying learning generalization.

Methods

Subject and housing

Our subject was an adult male blue-fronted-parrot (*Amazona aestiva*). The animal was housed in a 3.3×2.9 m room during the day, and spent the night in a $0.91 \times 0.54 \times 1.0$ m cage. Other experiments (laterality preference, comprehension of labels, ability of matching-to-sample and object permanence) were being conducted with that subject at the same time, but none of them explicitly involved learning generalization.

The animal was usually fed fruit in the morning and seeds with parrot’s chow in the evening. During this exper-

iment a feeding restriction was imposed: bananas were excluded from the subject’s diet, since they were to be used as rewards, and, in the night before the experiment, he received less seed and chow than usual.

Apparatus

During the experimental sessions, the subject was kept in a 0.4×0.4 m cage with a perch positioned next to the door (Fig. 1). The front of the cage was replaced by a Plexiglas wall that allowed the animal to see the tray (28×28 cm) attached to it; two side-by-side openings in the board, at the same height as the parrot’s head, allowed the bird to reach each side of the tray with his beak. On the tray, two pieces of cloth (16×7 cm) were positioned, one in front of each opening. On one of these, there was a piece of banana (weighting approximately 0.7 g), which could be reached by pulling the cloth. On the other side of the tray, the reward was not accessible, since it was not on the cloth. Both pieces of food were beyond the subject’s direct reach, thus the only way to obtain a piece of banana was to pull the appropriate cloth with its beak.

Habituation

Four sessions of habituation were conducted before starting the experiment. The subject was placed in the apparatus, and the tray was presented in the “observation” position

(see details below) for 3 s, then lifted to the “access” position. There was only one reward on the tray, always within reach, and no pieces of cloth. We verbally encouraged the parrot to get the reward, putting his head through the openings in the Plexiglas board. Once the reward was eaten, the procedure was repeated. A session ended when the parrot obtained the reward five times.

Test procedure

Each trial presentation consisted of two steps. First, the tray was positioned out of the subject’s reach (“observation” position) (Fig. 1), in a lower level than the “access” position. This way the subject could have a general view of the tray from above, through the Plexiglas board. The parrot was allowed to look at it for 3 s after which the tray was lifted to the “access” position, where the cloth pieces were within his reach. The tray was removed after the subject pulled one of the pieces of cloth, or spent more than 10 s without trying to pull any of them (in this case the trial was presented again at the end of the session, twice at the most). Soon after that, a new trial was presented, with an inter-trial interval of approximately 5 s. To minimize possible cues, throughout the procedure the experimenter did not look directly at the subject or at the tray, which was prepared out of the sight of the subject (behind the experimenter). In addition, a condition where a different experimenter was in charge was performed (condition K).

The experiment consisted of 11 conditions. The first one (A) was the training condition. In this condition, the problem was presented in seven trial types, each presented twice, with the reward being accessible one time on the right and the other on the left side of the tray. The presentation of these 14 trials (plus 6 “control” trials—see below) in random order constituted a session. We ran one session per day, twice a week, due to motivational limitations of the subject.

Condition A also included three types of “control” trials in which there was no correct choice. Each type was presented twice, in mirror image. The presentations were randomly ordered in the sessions, interspersed with the test trials.

Hauser et al. (1999) established an accuracy of 92% of correct choices per session (or 13 correct choices in 14 trials) in five consecutive sessions (control trials not included) as a criterion for learning in condition A. Such a high criterion was required to ensure that eventual mistakes in subsequent conditions would not be due to difficulties already present in condition A (being therefore related to the subsequent test manipulations). This criterion was maintained in condition B of their study to ensure that performance had stabilized. On subsequent conditions, the criterion of accuracy was lowered (75% in two consecutive sessions) due to

difficulties of some monkeys to reach it in the second condition. In the current study, we adopted the same criteria for the sake of comparison. Notice though that 75% of accuracy, here, is still significantly above chance.

The following conditions (B–K) were probe conditions—to determine if the subject solved the task based on the relevant relationship, in which case irrelevant manipulations should not significantly affect performance. Probe conditions involved irrelevant changes¹ in size, shape, distance, and color of the reward and cloth. These configurations are depicted in Fig. 2.

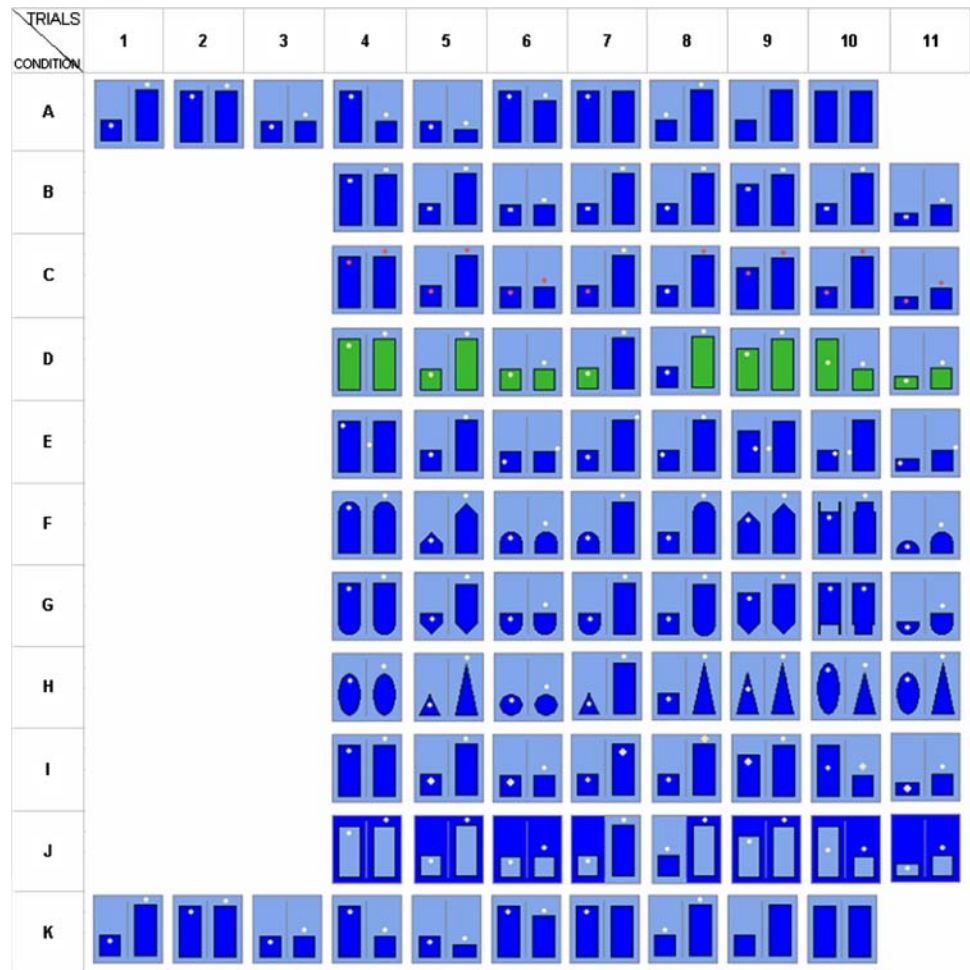
All probe conditions involved eight trial types, each presented twice so that the reward was available on both sides of the tray for each trial type. In addition, during each probe condition session, the first three condition A trial types were repeated to compare the parrot’s general performance across conditions (to make sure eventual difficulties were not due to other contextual factors that might cause the subject to perform poorly even on these now “easy”, previously learned cases—see Table 1). Therefore, 22 trials (16 probe and 6 condition-A trials) were presented randomly to the subject in each session.

Some modifications had to be made in the methodology developed by Hauser et al. due to attention problems exhibited by our subject in the habituation phase and in the beginning of the experimental phase (condition A): the experiment was always conducted in the morning (beginning at 8 am); the time the tray stayed in both positions was increased (from 3 to 15 s in the “observation” position, and from 10 to 15 s in the “access” position); an additional cost was added, consisting of an extra latency of 20 s for the presentation of a new trial, after the subject made a mistake; the parrot was allowed to get the pieces of cloth from both sides of the tray when control trials were presented; he was also allowed to manipulate them between trial presentations.

To avoid the possibility of incomplete training, Hauser et al.’s condition B was postponed in our experiment, and became here condition I. The tamarins in that study had a peculiar difficulty in condition B, choosing at first the bigger reward’s side, independently of its accessibility. Those authors proposed two hypotheses: (1) this was the first condition presented after the training condition, so the subjects still had not fully learned to solve the problem, or (2) the monkeys could not refrain from the tendency of trying to obtain the bigger food reward even when it was not accessible. This last hypothesis was suggested by Boysen and Berntson (1995) study, in which chimpanzees trained with

¹ Hauser et al. defined condition E as a relevant change in the problem. However, we considered it here “irrelevant”, since the problem rule does not change: the correct choice is still the side where the reward is ON the cloth.

Fig. 2 Pictograms of trial types presented (columns 1–11) in each condition (lines A–K)



Arabic numerals were given a choice between two trays with different amounts of candy. The apes had active or passive roles: the active chimp would choose a tray, the contents of which would then go to the passive ape, and the active chimp would receive the contents of the other tray. These animals were incapable of making the best option (to pick the tray with less candy). However, once the food items were replaced with the numerical symbols (to be later exchanged for the corresponding amount of candy), the chimps readily learned to choose the tray with tokens displaying the lower numerals.

In condition B (change in reward shape) we could not make the same kind of change made by Hauser et al. on trays 5 and 7, so these two trays were identical in our study (#7 is there just to make an equal number of trays in every condition). In Hauser et al. work the different reward was triangular so they could point the triangle up or down, however, in our case the different reward was a rectangle (although the representation of our regular reward on the pictograph is circular, its actual form was something like a triangle—a pizza slice) so we could not make these trials different.

Results

Hauser's et al. tamarins took fewer sessions to reach criterion (see "Methods") in condition A than our subject. The parrot had to perform 46 training sessions (condition A) before moving on to the next condition. The parrot's performance did not monotonically increase, but rather had several "ups and downs" (which could be attributed to motivational variations, i.e. the subject's willingness to participate in the experiment or not—see Table 1, "% refused trials"). It is worth reminding that some changes were unavoidable during this phase of the experiment (see "Methods").

The ability to quickly reach criterion in each probe condition (75% accuracy in two consecutive sessions, except in condition B in which 92% accuracy in five consecutive sessions was required) was considered evidence of generalization of the problem solution, learned in condition A (or the formation of a Learning Set).

Table 1 shows the performance of the subject on the "On" problem; he took fewer sessions (no more than 7) to reach the pre-established criterion in probe conditions

Table 1 Methodology and results for different conditions

Conditions	Irrelevant changes	Criterion	% Correct choices 1st session (all together) 1	% Correct 1st session (trials condition A) 2	% Correct choices 1st session (new trials) 3	No. of sessions to reach criterion	Departures Hauser et al.'s methodology	% Refused trials	Correct on first presentation 4
A	–	92% Correct in 5 Consecutive sessions	42.9	–	–	46	None	3.7	Yes (4 E)
B	Shape of the reward (rectangular)	92% Correct in 5 Consecutive sessions	90.9*	100.0*	93.7*	5	Hauser et al.'s condition C	2.3	No (10 D)
C	Reward color (painted in red)	75% Correct in 2 Consecutive sessions	77.3*	83.3	75.0*	3	Hauser et al.'s condition D	0.0	Yes (10 E)
D	Cloth color (green)	75% Correct in 2 Consecutive sessions	90.9* (81.8*)	100.0* (100.0*)	87.5* (75.0*)	2 (–)	Blue to green instead of blue to yellow	9.0 (0.0)	Yes (9 D)
E	Relative position of reward and cloth (closer to each other)	Consecutive sessions 75% Correct in 2	90.9*	100.0*	87.5*	2	Hauser et al.'s condition F	4.5	Yes (2 E)
F	Shape of the upper portion of the cloth (distal)	Consecutive sessions 75% Correct in 2	100.0*	100.0*	100.0*	2	Hauser et al.'s condition G	6.8	Yes (8 E)
G	Shape of the upper portion of the cloth (proximal)	Consecutive sessions 75% Correct in 2	100.0*	100.0*	100.0*	2	Hauser et al.'s condition H	0.0	Yes (8 E)
H	Overall shape of the cloth (oval, triangular or round)	Consecutive sessions 75% Correct in 2	95.5*	83.3	100.0*	2	Hauser et al.'s condition I	0.0	Yes (5 E)
I	Reward size (three times bigger) in one of the sides and its distance to the subject	Consecutive sessions 75% Correct in 2	85.5*	66.6	92.8*	2	Hauser et al.'s condition B	6.8	Yes (6 E)
J	Reverse color of tray and cloth	Consecutive sessions 75% Correct in 2	59.1	83.3	50.0	7	None	5.1	No (7 D)
K	The experimenter presenting the trials	Consecutive sessions 75% Correct in 2	85.7*	100.0*	85.7*	2	Extra control, not used in Hauser et al.	2.5	Yes (2 D)

(1) Considering all trials presented; (2) considering only trials from condition A (1–3); (3) considering only trials types from the condition mentioned (without those from condition A; (4) correct choices on the first tray of a condition and, in parenthesis, the trial type and the side were the reward was in each case. Values in parentheses are for the four sessions of condition D using yellow cloth

* Shows values significantly above chance (binomial test, $P < 0.05$)

(B–K) than in the training condition A (46 sessions). We do not believe the above-mentioned methodological changes could have caused these differences in performance since, after them—still in condition A—the subject needed several sessions yet to reach criterion, and no more than the minimum number of sessions was necessary, in most cases, to reach it in the subsequent conditions (B–K).

Accuracy in the first session in each condition is shown in Table 1 in two ways: all together—considering all trials presented in the session, including the ones from condition A (following Hauser et al.); and separately—with one column showing the percentage of correct choices on trials from condition A (to compare the parrot's general performance across conditions) and another column showing only correct choices on the probe trials. In the beginning of the experiment (condition A), the subject performed near chance, whereas, after reaching criterion in condition A and moving on to the probe phase, the percentage of correct choices in the first session in each condition was significantly above chance (binomial test, $P < 0.05$) in every condition except J ($P = 0.523$). The choice made by the subject on the first presentation of each new condition is also presented in Table 1.

The control trials in condition A showed that our subject, unlike Hauser et al.'s, did not gradually start to refrain from pulling the cloth when no reward was available: getting the cloth seemed rewarding in itself. On these trials, the parrot inhibited his response in only 21.5% of the presentations, getting the cloth, and playing with it in the remaining 78.5% of them. The rationale behind this control trials was that if the subject recognized the necessity of a causal effect between the intermediary and the target object (in this experiment the cloth and the reward) it should pull the cloth when the reward was on it but not when the reward was off it, although, differently from Hauser et al. tamarins—as well as the Japanese macaques, crab-eating macaques, gorillas and capuchins tested by Spinozzi and Poti (1989) in a similar task—parrots seem to be very manipulative, being quite fond of biting and gnawing objects with their beaks.

On the conditions where the changed feature was related to color (C, D and J), the subject took more than the two minimum necessary sessions for reaching criterion (Table 1). Condition C involved a change in the color of the reward (dyed red), whereas condition J consisted of a change of cloth color (from light blue to dark blue) and tray color (from dark to light blue). We compared the choices between the red piece of banana and the one in natura (see Fig. 2, condition C, trays 7 and 8), as well as the choices made on tray 7 in condition J between reward available on the light blue side or on the dark blue side of the tray. No bias due to color preference was found in either condition (binomial test: condition C, $P = 0.109$; condition J, $P = 0.145$). In condition D, the irrelevant feature changed was

cloth color. Like Hauser et al. did, we changed the cloths from light blue to yellow, but our subject just kept looking at the cloth without taking any action (an unusual reaction). Believing that the difficulty was due to the lack of contrast between the cloth and the banana (both yellow) we changed the cloths color again (from yellow to green)² in the fourth session of that condition—after which the subject readily reached criterion. One could think that tray type 10 involved an extra difficulty, since it was the first time the reward was in the middle of the cloth. Although we do not know if this new setting was a source of increased difficulty for the subject, the fact that the parrot readily reached criterion once we redefined the cloth's color (from yellow to green) leads us to believe that cloth color was a greater source of difficulty in the initial sessions of that condition.

Differently from Hauser et al.'s tamarins, our subject reached criterion immediately when the size of one of the rewards was changed (condition I); and, importantly, no effect of experimenter change (condition K) was found.

Discussion

Although it took several sessions for the subject to reach learning criterion for the original problem, the generalization of the solution was clearly shown in every probe condition besides condition J and the initial sessions of condition D. The fact that our subject was able to generalize the solution of the “On” problem puts him, at least concerning this task, in the same cognitive level as the monkeys tested by Hauser et al.

Weir and Kacelnik (2006), testing generalization versus trial-and-error learning by a new Caledonian crow in a series of tasks involving the production of tools (hooks) from new materials, hypothesized that a slow and gradual increase in proficiency would indicate the subject's reliance on within-task trial-and-error learning, whereas immediate or step-wise acquisition—as exhibited by our subject—would suggest generalization from concepts formed during earlier experience in related tasks.

The precise kind of learning generalization exhibited by our subject remains, to a certain extent, an open question: a steeper learning curve would suggest the formation of a learning set, whereas correct responses in the first trials for each new condition, as observed here for 9 out of 10 conditions (Table 1), is more adequately construed as “true generalization”. However, the experimental design is not adequate to compare these two possibilities, since it consisted in a binary choice, with a 50% probability of random

² Please note that on the line concerning condition D in Table 1 is the data from the four sessions with the yellow cloth (in parentheses) and from the two final sessions with the green cloth.

success in any given trial. Our subject's "learning curves", though, suggest rather a true generalization of the problems solution with delays to reach criterion due to distractions and/or lack of motivation.

It is interesting to notice that unlike observed by Hauser et al., our subject did not exhibit any difficulties in the condition where the size of one of the rewards was bigger. This could be because the parrot was more used to the task by the time this condition was presented, or because food size, in this experimental setting, was not so prominent a feature to him.

Conditions D and J, both involving irrelevant color changes, apparently presented an extra difficulty, since it took the parrot more sessions to reach criterion. In condition C, the food reward was dyed red, and previous experiments showed our subject's preference for this color (Sestini, unpublished data), but the statistical test on trials pitting the red versus the natural colored piece of banana ruled out the hypothesis that he was choosing the red reward independently of its accessibility. Meanwhile, in condition J there were color inversions between tray (from light to dark blue) and cloth (from dark to light blue). The longer latency to reach criterion could be due to some heuristic used by the subject to solve the previous forms of the problem, such as "banana on light blue = accessible banana" (in this case he would pull the light blue cloth even if the banana was not on it) or "banana on dark blue = not accessible banana" (in this case he would not pull the dark blue cloth even if the banana was on it). However, again, the statistical test directly comparing the light and dark blue color combinations (tray 7, condition J) did not confirm this hypothesis (although perhaps because of our small sample size).

These results lead us to consider that, in contrast to Hauser et al.'s subjects, ours did not have problems with the reward size, but with its color. Parrots have highly developed color vision (Bowmaker et al. 1997). The above-mentioned attraction to certain colors might explain why our subject performed differently in conditions D and J. These perceptual/motivational particularities could, perhaps, also explain the different difficulties exhibited in the same task by the tamarins and our parrot. These comparisons are complicated, though, since tamarins exhibit a range of individual differences in color vision (the alleles coding for visual pigments allow three kinds of trichromacy and three kinds of dichromacy, according to Pessoa et al. (2005)).

In any case, the delay to reach criterion in conditions C, D and J (3, 6 and 7 sessions, respectively) was not comparable to the 46 sessions needed for our subject to reach criterion in condition A, suggesting that the parrot was able to generalize the solution readily to novel exemplars of the problem. Our overall results, in short, show that, at least

when it comes to the solution of this particular problem (and bearing in mind that we cannot generalize this single individual's performance for the species as a whole), our parrot subject exhibited learning capabilities resembling the tamarins', suggesting convergent evolution in the cognitive abilities underlying learning generalization.

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