

Supplementary materials

Tracking Changes of Hidden Food: Spatial Pattern Learning in Two Macaw Species.

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Note S1 Housing

The birds were group-housed in 5 semi-outdoor aviaries (4 aviaries each Length x Width x Height: 1.8 x 6 x 3 m and one aviary 2 x 6 x 3 m), divided by species into two groups of six individuals. These aviaries were interconnected by windows (L x W: 1 m x 1 m), which could be opened and closed when needed (but were kept open other than to separate individuals for feeding and testing). Each aviary was open to the outside at the back, so it followed Tenerife's natural light schedule and kept to the ambient outdoor temperature. They were additionally lit with Arcadia Zoo Bars (Arcadia 54W Freshwater Pro and Arcadia 54W D3 Reptile lamp) to ensure sufficient exposure to UV light. The aviaries were all within the same building as the testing rooms (described below). The parrots' health was monitored at least twice a week (e.g., individual weighing). To regulate each individual's weight, the quantity of seeds (Versele Laga Ara seed-mix) provided during their daily feeding was adjusted according to their intake during testing.

Note S2 Habituation (Pre-training phase)

In the pre-training phase, we gave the parrots a habituation period that aimed to minimise their neophobic responses to the poke box, as well as to train them to tear and peel the paper covering the wells. The parrots received 3 trials per day, 6 days a week. The three habituation trials lasted a maximum of 30 minutes per day. A trial started when a parrot entered the test room after the experimenter lowered the connecting board and ended when the parrot left the test room and re-entered the cage. Before trials, each parrot entered the transporting cage voluntarily which ensured high motivation levels during testing. In each trial, sunflower seeds were placed in the middle of each well, followed by the whole box being covered by two sheets of white A4 paper. The habituation phase included several 'stages': 1) an open-well stage, in which the parrots did not have to tear the paper but could freely obtain the seeds from the wells; 2) a half-open well stage, in which the wells were half covered and the parrots had to tear a bit of paper to enlarge the opening in order to obtain the seeds from the wells; 3) a quarter-open well stage, in which the parrots needed to tear more paper in order to obtain the seeds from the wells; 4) a one-cut well stage, in which the wells were fully covered with paper, but a single line cut was made across each well, and so the parrots had to tear the paper in half or completely to obtain the seeds from wells; and, 5) a closed-well stage in which the wells were fully covered by paper and the parrots had to tear the paper on their own. If a parrot struggled to tear the paper in any of these stages (frequently seen in the one-cut well stage and closed-well stage, we applied a ring of water on the edge of the paper over each well; this prevented the parrots moving onto another well (and thus not representing their 'true' choice). The main training phase started on an individual based criteria: over 2 consecutive days, a parrot 1) tore and peeled paper; 2) opened at least 10 (out of 12) wells; and 3) were comfortable to be alone in the test room.

Note S3 Learning performance

In this poke box design, there were 6 correct and 6 incorrect choices for each pattern. We focused on the search order to calculate a q value (e.g., Bamber, 1975; Herrnstein et al., 1976). This q value has a tight relationship with the U value of the Mann–Whitney U test. For each trial, a U value can be calculated by recording the number of incorrect choices remaining unopened, whenever a parrot made a correct choice. For example, considering a search order being C(correct)-In(correct)-C-In-C-C-C-In-In-In-In, the first correct choice left 6 incorrect wells unopened, the second correct choice left 5 incorrect wells unopened, the third to the last correct choices each left 4 incorrect wells unopened. Hence, a parrot received $U = 6, 5, 4, 4, 4, 4 = 27$. This U value can then be divided by the product of the total number of possible correct and incorrect choices ($6, 6, 6, 6, 6, 6 = 36$) to obtain a q value that is ranged between 0 and 1. In this case, $q = 27/36 = 0.75$.

That is to say, q was calculated as such

$$\rho = \frac{1}{n^2} \sum_{i=1}^k c(n - e_k)$$

e_k = the number of errors at the current point in the sequence

n = the total number of possible correct choices

n^2 = divide the U value by the product of the total number of possible correct and incorrect choices (n^2)

c = correctness of choice ($c = 0$ if incorrect and $c = 1$ if correct)

References:

Bamber, D. (1975). The area above the ordinal dominance graph and the area below the receiver operating characteristic graph. *Journal of Mathematical Psychology* 12, 387–415.

Herrnstein, R.J., Loveland, D.H., and Cable, C. (1976). Natural Concepts in Pigeons. *Journal of Experimental Psychology: Animal Behavior Processes* 2, 18.

Note S4 Search time analyses

We analysed the mean time (seconds) to open a well using a Generalised Linear Model with a Gaussian distribution. Species (BT or GG), pattern (A or B) and their interaction were included as fixed effects whereas the mean time to open a well was included as a response variable. Results showed that only species had a main effect on the mean time to open a well (species: $\chi^2_1 = 9.64$, $P = 0.002$; pattern: $\chi^2_1 = 1.52$, $P = 0.218$; species*pattern: $\chi^2_1 = 0.004$, $P = 0.947$). This result indicates that regardless of which pattern, the Blue-throated Macaws showed less time to open a well than the Great Green Macaws.

Note S5 Search order analyses

To determine whether a macaw showed some signs of learning pattern A, for example, whether the macaws opened one well to indicate which pattern it would be for that trial, or whether they perceived pattern A as two separated columns, we conducted additional analysis: as there was a maximum number of six correct responses, we categorised an order of responses as 'alternative' (e.g., correct-incorrect-correct-incorrect) or 'consecutive' (e.g., 'incorrect-incorrect-correct-incorrect'). Based on this categorisation, we obtained the frequency of consecutive correct responses a macaw made (ranged from 1-6, with 1 indicated a macaw only made one correct response and 6 indicated the macaw made 6 consecutive responses). We also counted the number of trial that a macaw made consecutive correct responses (2 or more). For example, if a macaw opened one well to indicate which pattern it would be for that trial, it may make an incorrect choice but followed by consecutive correct responses. Accordingly, in either case, we expected that there would be consecutive correct responses made (3 or more).

Table S1. Result of a Generalized Linear Mixed Model with the effect of species (GG or BT), pattern (A or B), and training session on learning performance across training sessions (mean ρ value for each session across sessions of the unadjusted criterion ($\rho \geq 0.8\%$). This table contains estimates, standard errors (S.E), and Z and P values.

	Estimate	S.E	Z	P
Species: GG	-0.20	0.49	-0.41	0.680
Pattern: A	5.07	0.33	15.27	<0.001
Training session	0.02	<0.01	3.69	<0.001

Table S2. Pattern B: Results of Generalized Linear Models with a Poisson log link distribution that includes the effect of species (GG or BT) on the unadjusted learning criterion, ($\varrho \geq 0.8$), (A) and the two adjusted learning criterion, $\varrho \geq 0.75$ (B) and $\varrho \geq 0.7$ (C). This table contains estimates, standard errors (S.E), χ^2 and P values.

Number of individuals that passed the learning criterion		ϱ	Estimate	S.E	χ^2	P
GG (N = 6)	BT (N = 6)	Species: BT				
4	4	(A) 0.8	0.29	0.11	7.46	0.006
6	4	(B) 0.75	0.52	0.10	24.18	<0.001
6	6	(C) 0.7	0.86	0.11	60.21	<0.001

Table S3. Results of the Generalized Linear Model with a Gaussian distribution that includes the effect of species (GG or BT) on the mean time (seconds) to open a well (A), to complete a trial (B), to explore after a change of pattern on the first week (C), spent on the table (D), as well as the mean correct responses made in the first six choices for pattern A (E) and pattern B (F). This table contains estimates, standard errors (S.E), χ^2 and P values.

	Estimate	S.E	χ^2	P
Species: BT				
(A) Open a well	-1.39	0.45	9.77	0.002
(B) Complete a trial	-16.13	4.95	10.60	0.001
(C) Exploration time after a change of pattern	-10.02	4.80	4.35	0.037
(D) Spent on the table	-15.81	5.69	7.72	0.005
(E) Mean correct responses made in the first six choices for pattern A	-3.17	0.14	5.17	0.023
(F) Mean correct responses made in the first six choices for pattern B	0.12	0.12	0.95	0.329