

SUPPLEMENTARY INFORMATION

The temporal dependence of exploration on neotic style in birds

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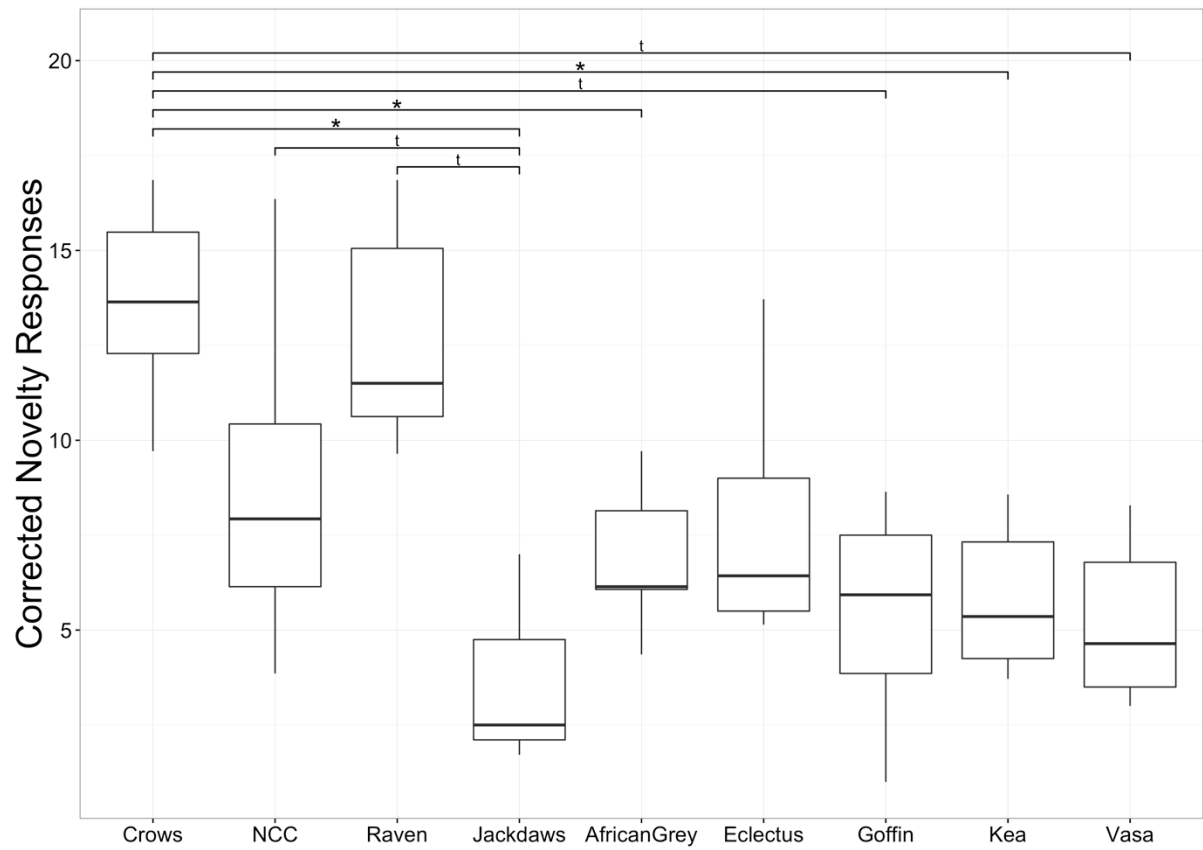


Figure S1. Boxplots of corrected novelty responses for all species; bold horizontal lines indicate median values, boxes span the first to third quartiles and whiskers represent 95% confidence intervals; horizontal lines indicate age group comparisons; Significance codes: '***' for $p < 0.001$, '**' for $p < 0.01$, '*' for $p < 0.05$, 't' for $p < 0.1$ (alpha adjusted for multiple comparisons; see Table S1 for detailed test statistics).

Table S1. Multiple comparisons of means for novelty responses, corrected for association strength in each session, of all species. P values are adjusted for multiple comparisons.

Model: *Corrected Novelty Responses* ~ *Sum of errors* + *Species*

Significance codes: '****' for $p < 0.001$; '**' for $p < 0.01$; '*' for $p < 0.05$; '.' for $p < 0.1$

	Estimate	Std. Error	t value	P	Sig.
AfricanGrey vs Crows	0.628	0.206	3.049	0.028	*
AfricanGrey vs Eclectus	0.219	0.236	0.929	0.482	
AfricanGrey vs Goffin	0.004	0.254	0.015	0.988	
AfricanGrey vs Jackdaws	-0.482	0.350	-1.377	0.310	
AfricanGrey vs Kea	-0.059	0.237	-0.249	0.904	
AfricanGrey vs NCC	0.359	0.231	1.551	0.257	
AfricanGrey vs Raven	0.416	0.223	1.868	0.185	
AfricanGrey vs Vasa	-0.042	0.276	-0.153	0.930	
Crows vs Eclectus	-0.408	0.202	-2.022	0.155	
Crows vs Goffin	-0.624	0.229	-2.722	0.058	.
Crows vs Jackdaws	-1.109	0.329	-3.374	0.014	*
Crows vs Kea	-0.687	0.204	-3.364	0.014	*
Crows vs NCC	-0.269	0.197	-1.365	0.310	
Crows vs Raven	-0.212	0.171	-1.239	0.337	
Crows vs Vasa	-0.670	0.253	-2.643	0.059	.
Eclectus vs Goffin	-0.216	0.237	-0.912	0.482	
Eclectus vs Jackdaws	-0.701	0.341	-2.057	0.155	
Eclectus vs Kea	-0.278	0.225	-1.239	0.337	
Eclectus vs NCC	0.139	0.220	0.635	0.653	
Eclectus vs Raven	0.196	0.227	0.866	0.497	
Eclectus vs Vasa	-0.262	0.261	-1.005	0.454	
Goffin vs Jackdaws	-0.485	0.345	-1.408	0.310	
Goffin vs Kea	-0.063	0.232	-0.270	0.904	
Goffin vs NCC	0.355	0.229	1.553	0.257	
Goffin vs Raven	0.412	0.266	1.550	0.257	
Goffin vs Vasa	-0.046	0.255	-0.181	0.930	
Jackdaws vs Kea	0.423	0.339	1.245	0.337	
Jackdaws vs NCC	0.840	0.336	2.498	0.064	.
Jackdaws vs Raven	0.898	0.348	2.580	0.059	.
Jackdaws vs Vasa	0.439	0.362	1.215	0.337	
Kea vs NCC	0.418	0.218	1.916	0.181	
Kea vs Raven	0.475	0.232	2.046	0.155	
Kea vs Vasa	0.017	0.257	0.065	0.976	
NCC vs Raven	0.057	0.224	0.255	0.904	
NCC vs Vasa	-0.401	0.253	-1.583	0.257	
Raven vs Vasa	-0.458	0.287	-1.599	0.257	

Factors Effecting Learning

Responses to unrewarded baseline stimuli were significantly affected by the amount of corrected novelty responses (GLM: $F_{1,39} = 8.24$, $p = 0.007$), indicating that individuals that responded more often to novel stimuli chose the unrewarded stimulus more often in baseline trials ($\beta = 0.08$, $SE = 0.03$, $p = 0.039$; see Fig. S2). Additionally, species had an effect on the amount of incorrect first choices in baseline trials (GLM: $F_{8,39} = 2.83$, $p = 0.014$), with Goffin's cockatoos choosing the unrewarded stimulus significantly less often than African Grey parrots ($\beta = -1.26$, $SE = 0.38$, $p = 0.032$) and ravens ($\beta = 1.27$, $SE = 0.40$, $p = 0.041$). Also vasa parrots exhibited less incorrect first choices than African Grey parrots ($\beta = -1.21$, $SE = 0.43$, $p = 0.048$) and tended to perform better than ravens ($\beta = -1.21$, $SE = 0.45$, $p = 0.056$; see Fig. S3). Other factors, such as neotic style (GLM: $F_{3,31} = 0.11$, $p = 0.95$) or sex (GLM: $F_{1,38} = 1.80$, $p = 0.19$), did not affect learning performance. Age revealed no significant effect in a parallel model (GLM: $F_{2,45} = 1.05$, $p = 0.36$) and was discarded in favour of a model structure including species as a fixed effect.

While noetic style did not seem to influence learning ability, we did find a positive correlation of the amount of novelty responses with the number of unrewarded choices in baseline trials. The fact that overall greater exploration indicated more responses to unrewarded stimuli may reflect general impaired associative skills, especially in young birds. As we controlled for associative strength of the rewarded stimulus in instances of novelty trials, and age did not affect learning ability, this explanation seems unlikely. Another possibility would be that more explorative individuals are less coherent in their choices and frequently 'revisit' the known unrewarded stimuli. Interestingly, this result stands in stark contrast to previous studies that found a positive effect of exploration on discrimination learning¹.

¹ Guillette, L. M., Hahn, A. H., Hoeschele, M., Przyslupski, A. M. & Sturdy, C. B. Individual differences in learning speed, performance accuracy and exploratory behaviour in black-capped chickadees. *Anim. Cogn.* 165–178 (2014). doi:10.1007/s10071-014-0787-3

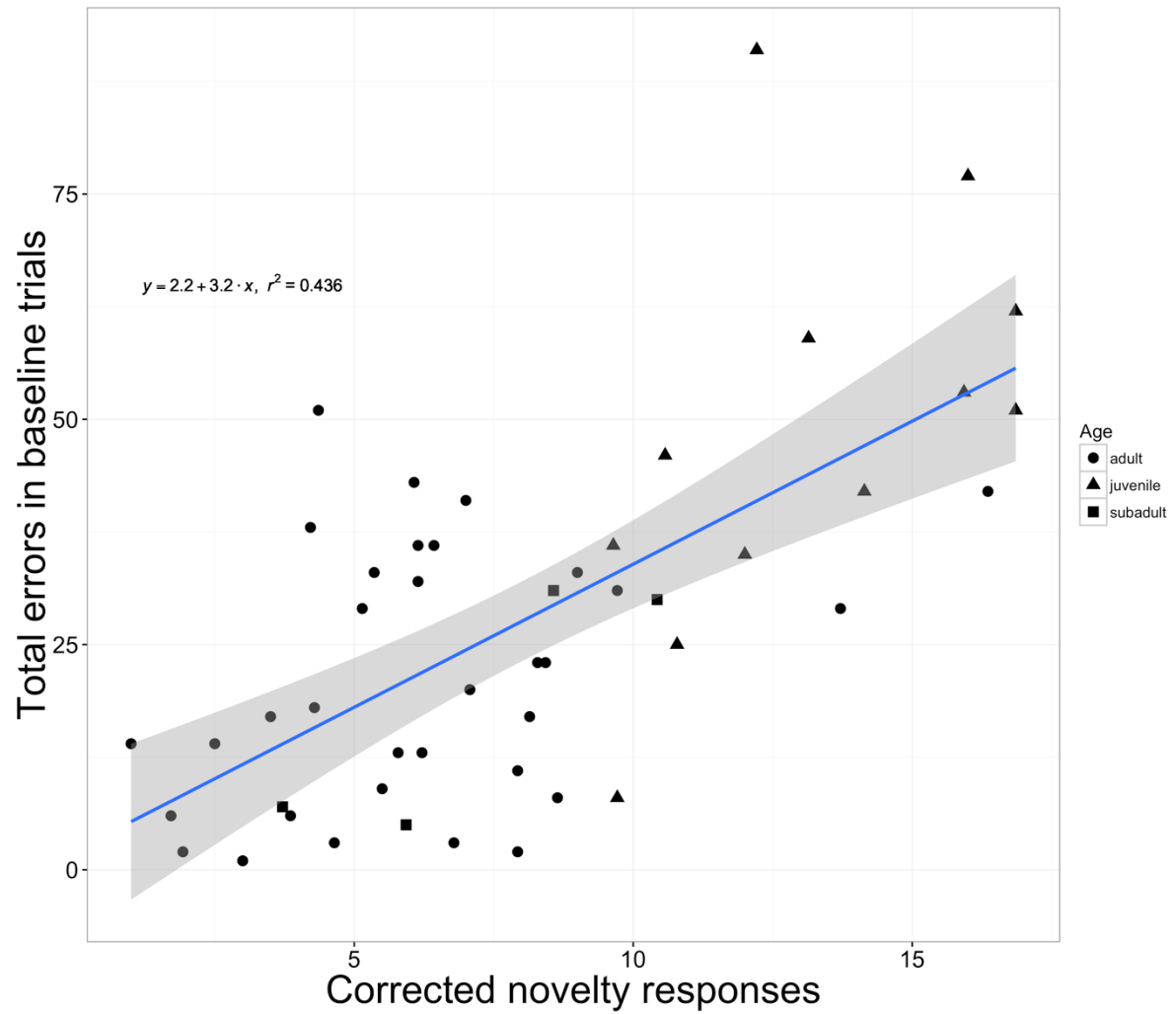


Figure S2. The relationship of learning performance, determined by the number of incorrect first choices in baseline trials, and total amount of corrected novelty responses in the task for individual birds; shape of points represents different age groups; blue line indicates assumed linear fit; grey area denotes 95% confidence interval.

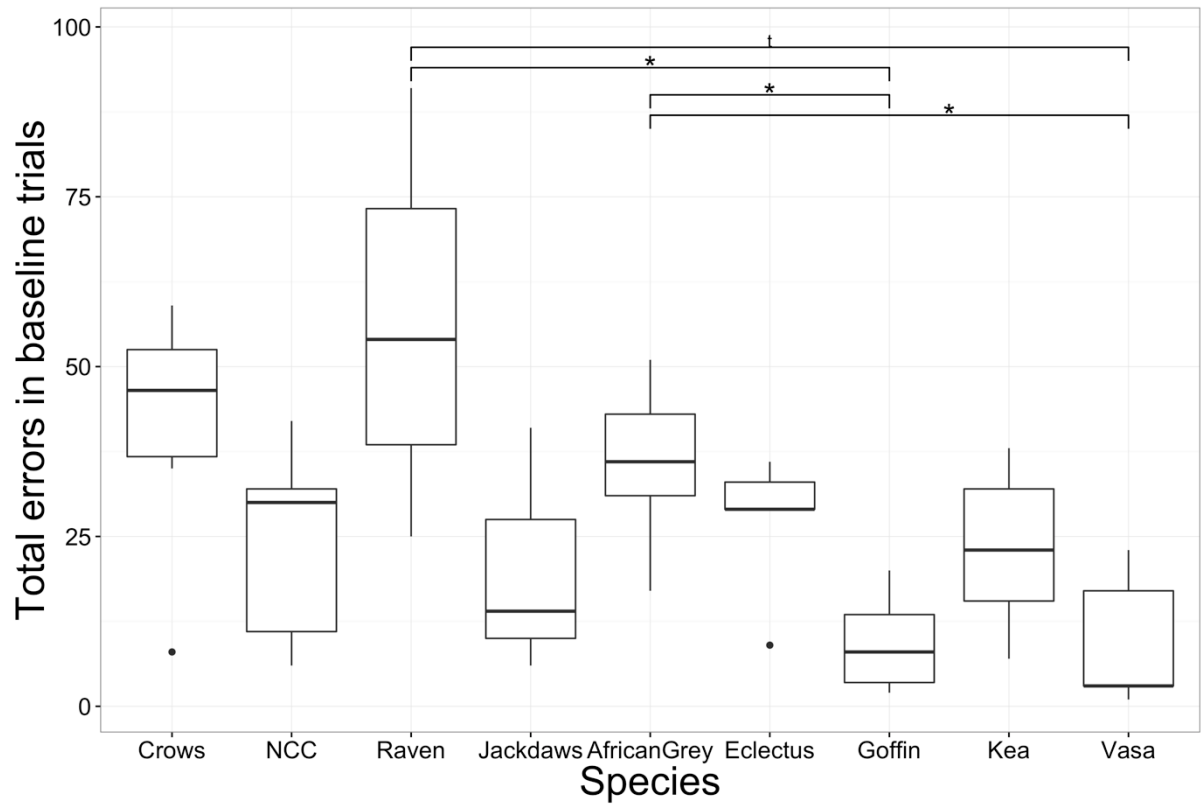


Figure S3. Boxplots of total amount of novelty responses, corrected for associative strength with the rewarded stimulus in each session, for all species; bold horizontal lines indicate median values, boxes span the first to third quartiles and whiskers represent 95% confidence intervals; horizontal lines indicate species comparisons; Significance codes: '***' for $p < 0.001$, '**' for $p < 0.01$, '*' for $p < 0.05$, 't' for $p < 0.1$ (alpha adjusted for multiple comparisons).

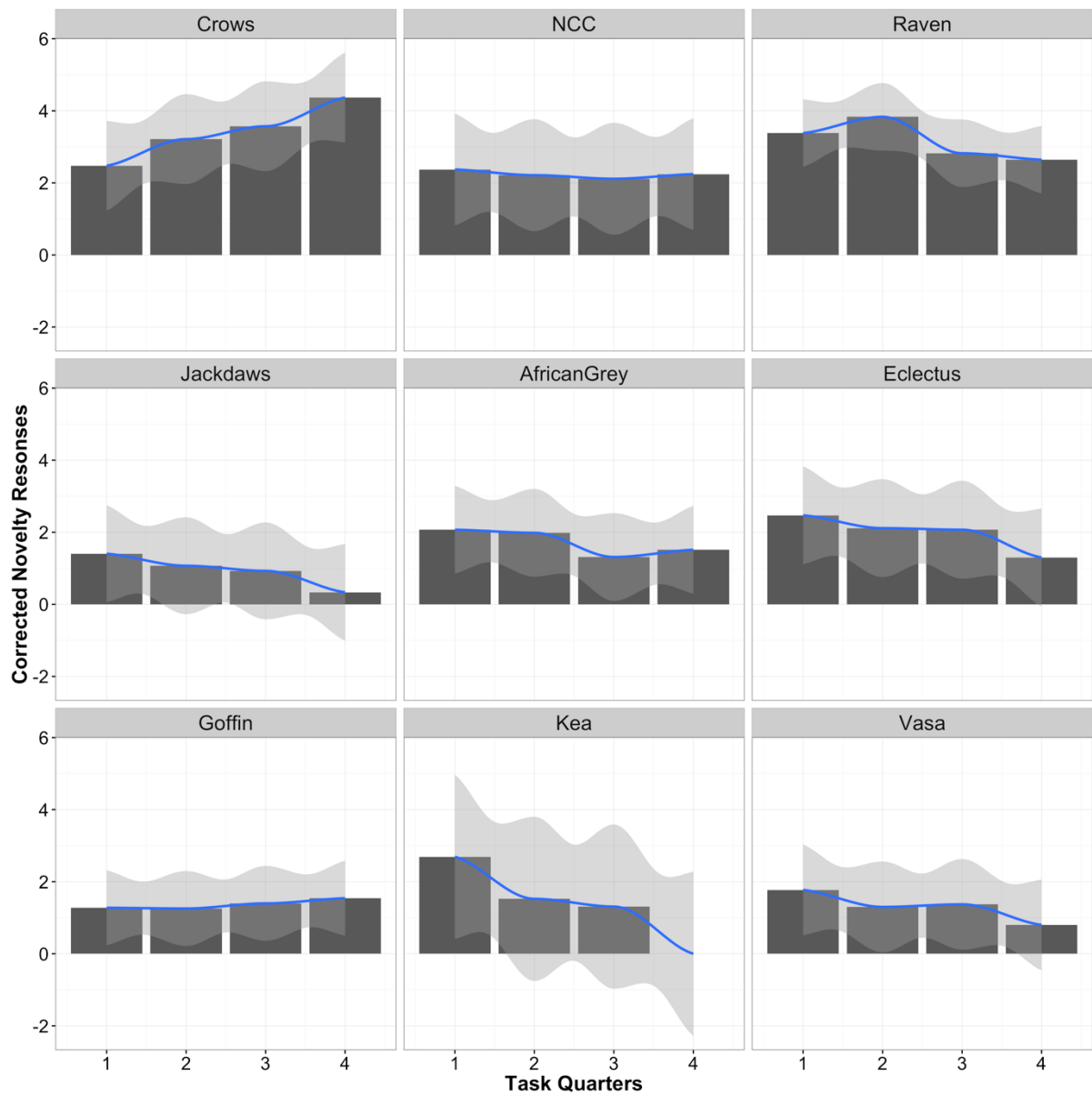


Figure S4. Bars show mean expressed exploration, as corrected novelty responses, in each of the four task quarters for different species; blue line indicates the smoothed slope by local polynomial regression fitting (locally weighted scatterplot smoothing-loess); shaded areas represent 95% confidence intervals.

Table S2. Multiple comparisons of slopes for the novelty responses, corrected for association strength

in task quarters of all species. P values are adjusted for multiple comparisons. Significance codes:

‘***’ for $p < 0.001$; ‘**’ for $p < 0.01$; ‘*’ for $p < 0.05$; ‘.’ for $p < 0.1$

Model: *Corrected Novelty Responses in TaskQuarters* ~ *NeoticStyle*TaskQuarters* +

*Species*TaskQuarters* + (*1 + TaskQuarter* | *Individual*)

	Estimate	Std. Error	t value	P	Sig.
AfricanGrey vs Crows	0.910	0.353	2.576	0.090	.
AfricanGrey vs Eclectus	0.117	0.376	0.310	0.801	
AfricanGrey vs Goffin	0.270	0.321	0.839	0.640	
AfricanGrey vs Jackdaws	-0.305	0.410	-0.745	0.640	
AfricanGrey vs Kea	-0.459	0.399	-1.149	0.531	
AfricanGrey vs NCC	0.389	0.351	1.108	0.533	
AfricanGrey vs Raven	0.017	0.348	0.049	0.961	
AfricanGrey vs Vasa	-0.160	0.347	-0.461	0.796	
Crows vs Eclectus	-0.793	0.337	-2.353	0.128	
Crows vs Goffin	-0.640	0.318	-2.012	0.199	
Crows vs Jackdaws	-1.215	0.402	-3.025	0.045	*
Crows vs Kea	-1.368	0.412	-3.322	0.032	*
Crows vs NCC	-0.521	0.359	-1.451	0.407	
Crows vs Raven	-0.892	0.388	-2.302	0.128	
Crows vs Vasa	-1.070	0.374	-2.863	0.050	.
Eclectus vs Goffin	0.153	0.351	0.436	0.796	
Eclectus vs Jackdaws	-0.422	0.437	-0.965	0.602	
Eclectus vs Kea	-0.575	0.424	-1.358	0.449	
Eclectus vs NCC	0.272	0.370	0.735	0.640	
Eclectus vs Raven	-0.099	0.408	-0.244	0.831	
Eclectus vs Vasa	-0.277	0.401	-0.690	0.654	
Goffin vs Jackdaws	-0.575	0.379	-1.518	0.389	
Goffin vs Kea	-0.728	0.387	-1.884	0.238	
Goffin vs NCC	0.119	0.336	0.355	0.801	
Goffin vs Raven	-0.252	0.337	-0.748	0.640	
Goffin vs Vasa	-0.430	0.328	-1.310	0.457	
Jackdaws vs Kea	-0.153	0.470	-0.327	0.801	
Jackdaws vs NCC	0.694	0.431	1.612	0.385	
Jackdaws vs Raven	0.323	0.432	0.747	0.640	
Jackdaws vs Vasa	0.145	0.412	0.352	0.801	
Kea vs NCC	0.847	0.397	2.135	0.168	
Kea vs Raven	0.476	0.396	1.203	0.515	
Kea vs Vasa	0.299	0.406	0.736	0.640	
NCC vs Raven	-0.371	0.345	-1.077	0.533	
NCC vs Vasa	-0.549	0.362	-1.515	0.389	
Raven vs Vasa	-0.177	0.346	-0.512	0.783	

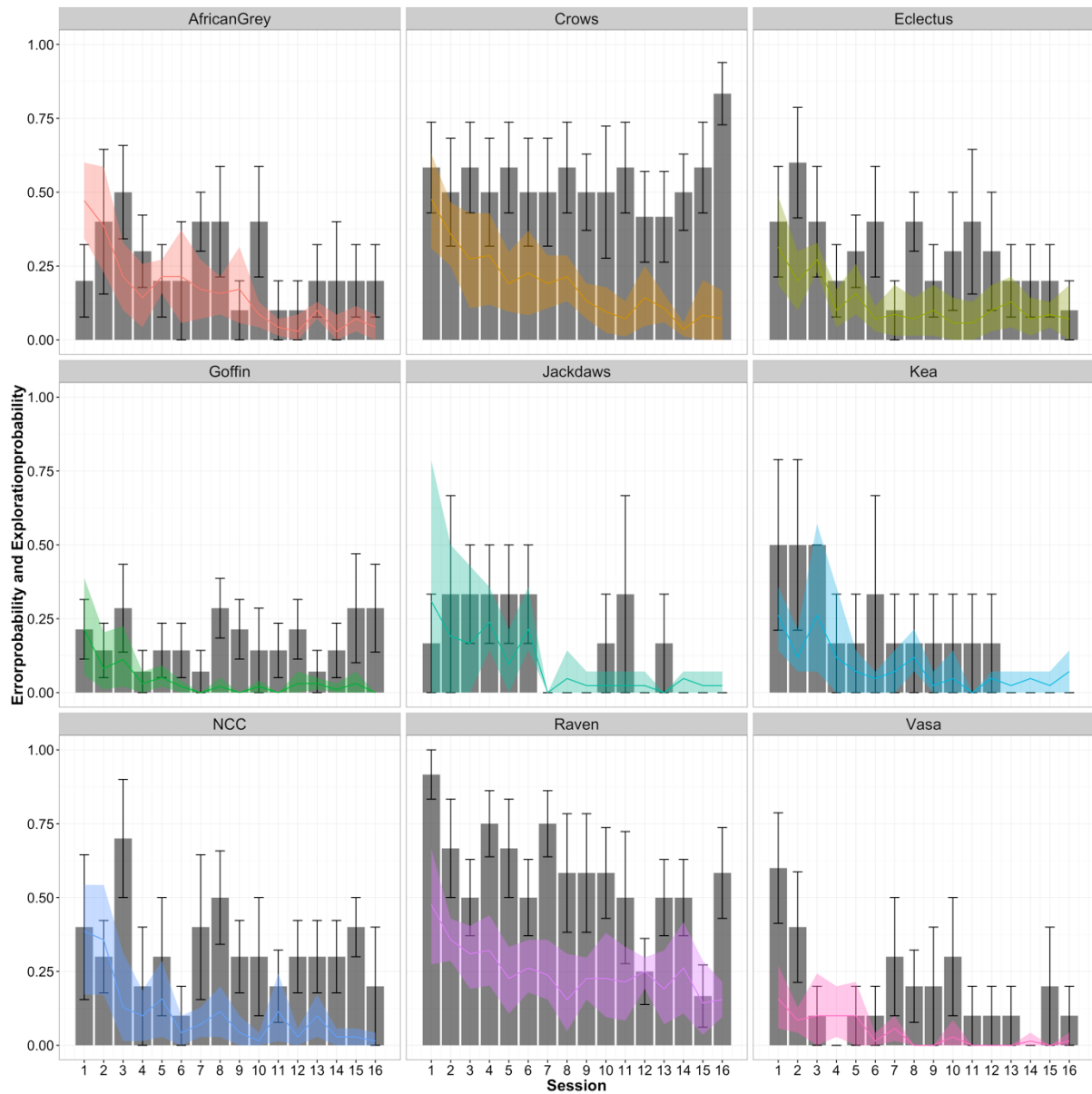


Figure S5. Bars show the mean observed corrected probability to respond to novel stimuli in each session, with whiskers representing SE; coloured lines indicate learning curves as mean probability of committing an error in baseline trials, with shaded areas representing 95% confidence intervals for different species.

Table S3. Multiple comparisons of slopes for the novelty responses, corrected for association strength in task quarters of all species. P values are adjusted for multiple comparisons. Significance codes:

‘***’ for $p < 0.001$; ‘**’ for $p < 0.01$; ‘*’ for $p < 0.05$; ‘.’ for $p < 0.1$

Model: *Corrected Novelty Responses in TaskQuarters* ~ *NeoticStyle*TaskQuarters* + *Age*TaskQuarters* + (*1 + TaskQuarter* | *Individual*)

	Estimate	Std. Error	t value	P	Sig.
Very Fast Approach vs Fast Approach	-0.261	0.244	1.070	0.355	
Very Fast Approach vs Slow Approach	0.314	0.238	1.316	0.339	
Very Fast Approach vs Very Slow Approach	0.552	0.242	2.282	0.058	.
Fast Approach vs Slow Approach	0.575	0.258	2.233	0.058	.
Fast Approach vs Very Slow Approach	0.813	0.258	3.151	0.015	*
Slow Approach vs Very Slow Approach	0.238	0.237	1.004	0.355	
Adult vs Juvenile	0.489	0.200	2.446	0.058	.
Subadult vs Juvenile	-0.119	0.335	-0.356	0.722	
Adult vs Subadult	0.370	0.323	1.147	0.355	

Stimulus Generation

For this study a total of 48 stimuli were generated and divided into 12 simple habituation stimuli, 18 straight line stimuli, 18 curved stimuli (see Fig. S6 for examples). For the discrimination task each individual was randomly assigned a specific baseline pair of a positive (rewarded) and negative (non rewarded) stimulus. The baseline pairs contained one straight lined and one curved stimulus.

Additionally, for each positive Stimulus 16 similar stimuli were created (differing slightly in colour and shape from the original positive stimulus). The colours of the stimuli were assigned randomly from a scale, differing in their RGB-scale by 20 steps from one colour to the next, but not in brightness. First the positive stimulus was randomly assigned to a colour, saving five colours above and below on the scale for the similar stimuli. Then the negative stimulus was assigned the most distant colour from the positive stimulus colour, excluding the six colours above and below the negative one. The remaining colours were then randomly assigned to the remaining stimuli.

Procedure

Pre-training

In order to pre-train the animals to use the touchscreen computer they were presented with a simple geometric figure (circle, triangle, square or star) that was centred on the screen. Individuals were shaped to reliably touched the stimulus and received the reward by moving the mouse cursor around the stimulus or in case of limited approach the screen was introduced in a group setting.

After this initial phase and once the stimulus was touched reliably by the animals, the stimulus was then presented in a random position. This phase consisted of two sessions with 35 trials each. Inter-trial-intervals (ITI) were set to one second, during this time the screen was blank.

Discrimination training

In this phase, each individual was given one additional stimulus, which was not rewarded when responded to. Additionally, a correction inter-trial-interval (CITI) of 1.3 seconds was introduced. The two stimuli were presented next to each other, with the rewarded stimulus (S_0+) displayed randomly on either the right or left side on a horizontal axis on the screen. The height of the stimuli was adapted

for each species to ensure the stimuli would appear at head height. If the subjects pecked the unrewarded stimulus (S_0^-) the birds received a correction trial (CT), which was repeated until the S_0^+ was selected. Pecking a stimulus resulted in differential acoustic feedback being played (depending on the stimulus that was being pecked).

Discrimination training consisted of two sessions with 16 trials each. The computer program recorded the retention latency (latency from onset of the trial until a peck occurred), correct first choices and number of correction trials, as well as pecks on the screen in other locations than where the stimuli were.

	S+	S-
Habituation stimuli		
Discrimination pair		
Novelty stimuli (identical)		
Novelty stimuli (similar)		

Figure S6. Examples of generated stimuli used throughout the task. Habituation stimuli were used during habituating birds to the setup, Discrimination pair exemplifies stimuli used for the main discrimination task, Novelty stimuli were used during novelty test trials with the rewarded stimulus remaining the same as in the basic discrimination task (identical) or being slightly altered in colour and shape (similar); S+ indicates the rewarded stimuli, S- lists the unrewarded stimuli.

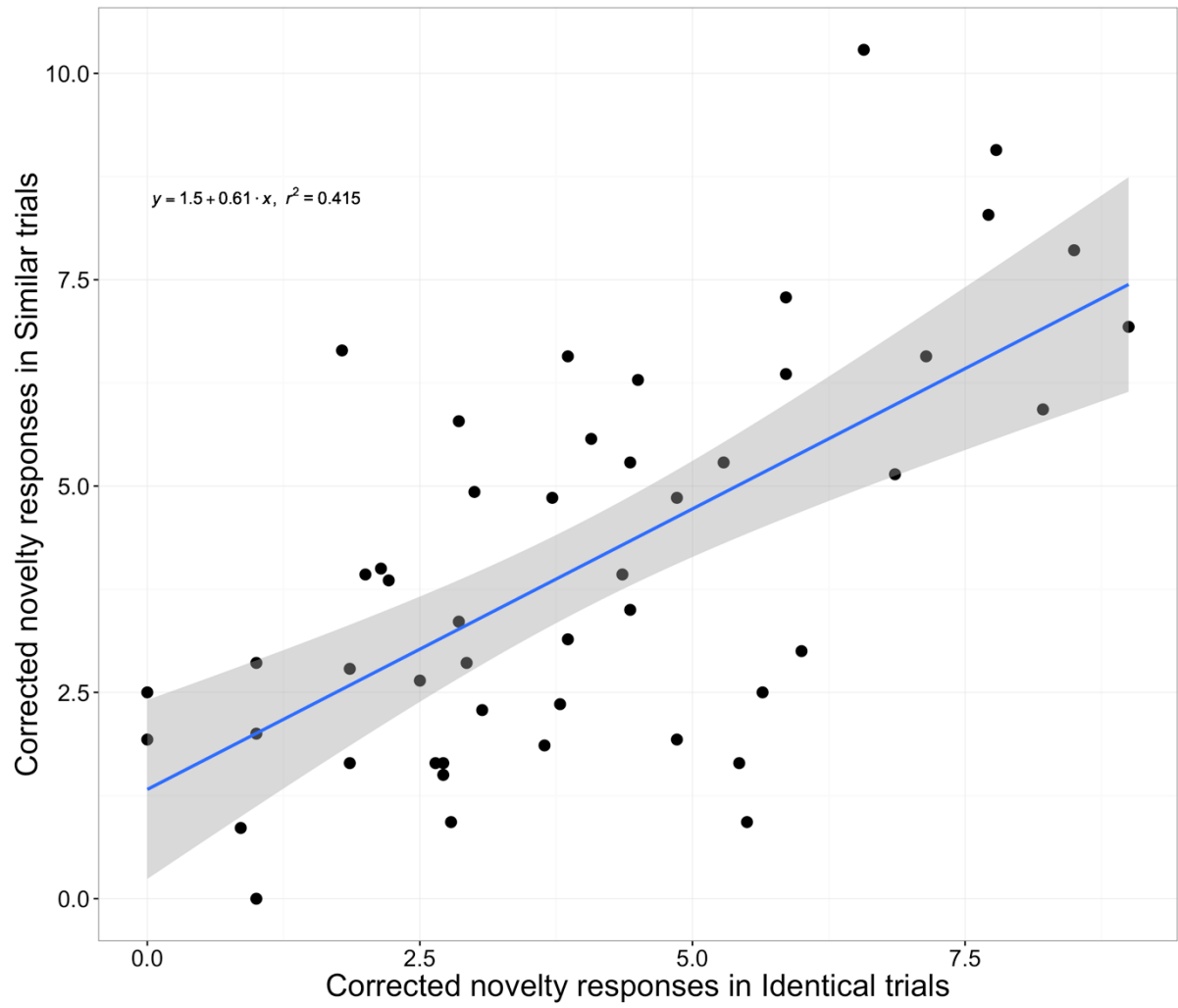


Figure S7. The relationship of novelty responses in 'Identical' and 'Similar' trials; blue line indicates assumed linear fit; grey area denotes 95% confidence interval.