

Supplemental materials

Validation of a Battery of Inhibitory Control Tasks Reveals a Multifaceted Structure in Non-Human Primates

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Training phases

Training phase 1

As none of the macaques had experience with touchscreen experiments prior to the beginning of the data collection, all the macaques had to complete two training phases. The first training phase used a rectangular transparent Plexiglas sheet (42 x 30 cm) with a plastic red square target (10 x 12 cm) moved by hand. Monkeys were progressively rewarded for approaching the Plexiglas sheet, touching the target as it moved. This phase was judged as complete if the macaques followed the target 20 times in a row. Two females did not complete this training stage as they gave birth during the training period, two males could not reach the success criterion.

Training phase 2

After completion of the first training phase, the touchscreen was introduced. The aim of training phase 2 was to be trained to touch a target on the screen.

Stimuli

The target was a red (RGB 255, 0, 0) rectangle of a maximum of 1200 x 1000 pixels (ca. 32 x 26 cm) and was gradually reduced to 360 x 500 pixels (ca. 10 x 13 cm).

Procedure

When the program was launched, the experimenter entered the name of the individual, the number of trials per session, the size of the target and the time limit to complete the task. Every session was initiated by the subject touching a red cross located in the centre of the screen, starting the time recording. Then, the target was displayed in the middle of a white background (RGB 255, 255, 255). For the first 30 trials a picture of peanuts was displayed inside the target to motivate the macaques to touch it. Once the subject touched the target, a high-pitched chime (composed of 3 sound frequencies: 800, 1300 and 2000 Hz) was played, the timer was stopped, and the reward was given. After an inter-trial of 2000 ms, with only the white background displayed, the next trial was presented. Based on a pilot study (N = 4 subjects), we set up a maximum response time of 35 s.

If the subject left the testing area or was not focusing attention on the screen the session was aborted. If the target was not touched within the time limit (35 s), the timer was paused, a red cross appeared in the centre of the screen until the session was resumed by touching it. The size of the target was gradually reduced to 360 x 500 pixels (ca. 10 x 13 cm).

Once the macaques performed successfully 20 times in a row with the target in the centre of the screen, the target was displayed randomly at the far left or right of the screen. This phase was judged as complete if the macaque followed the target 20 trials in a row. If the subject stayed inactive for more than 5 min the session was stopped and continued the next testing day, if the subject did not participate for three testing days in a row the subject was excluded from the task. The training phase 2 was completed by 21 subjects (12 males, 9 females) who therefore progressed to the experimental phase. Five subjects abandoned this training phase as they stayed at distance from the screen or gave birth in the meantime.

Training phase 3

Subjects

The 21 subjects who progressed from the training phase 2 participated in this last training phase. This resulted in a sample of 9 females and 12 males (age ranging from 3 to 17 years old, mean age in years $M \pm SD = 8.85 \pm 4.38$, $N = 21$).

Procedure

After the initiation of the session a red rectangle target (360 x 500 pixels, c.a. 10 x 13 cm) was randomly displayed at the left or right of the screen. The subjects had a time limit of 15s to complete the task (i.e. touch the red rectangle). Three sessions of 20 trials were repeated at time point 1 and time point 2 (average days between the time points $M \pm SD = 14.38 \pm 5.30$, $N = 21$; depending on the availability of the subjects).

Rank calculations

Calculated ranks by David's Scores:

Ranks obtained from David's Scores (DS) were calculated in 2016. They were also based on agonistic interactions recorded ad libitum. Agonistic behaviours included threats (e.g. open mouth threat), displacements (i.e. a macaque approaches another who departs immediately), chases, and physical conflict (e.g. bite, slaps). These calculated ranks were regularly monitored and updated during observations and training sessions by caretakers. After a regression analysis all calculated ranks were found significant.

Total Number of conflicts: 734

Number of conflicts: [48-136]

Number of observations: [4-14]

Observed ranks:

To confirm the calculated ranks at the time our experiments were conducted we coded agonistic behaviour with a focus on the studied subject. A blind observer recorded agonistic interactions (winner/loser) between a focal individual and other members of the group during the training and test sessions. Agonistic behaviours included threats (e.g. open mouth threat), displacements (i.e. a macaque approaches another who departs immediately), chases, and physical conflict (e.g. bite, slaps). If the male never lost, he was considered as high ranked. If

the female never lost against other females, she was considered as high ranked (H), otherwise she was considered low ranked (L).

Females

name	loser (suppl/threat)	winner (suppl/threat)	No observati ons	Se x	Observed rank	Rank from DS
Ylang	18	30	26	F	L	L
Adele	32	13	23	F	L	L
Rach	0	21	32	F	H	H
Ybbi	0	8	18	F	H	H
Blossom	0	33	27	F	H	H
Tes	1	7	12	F	L	L
Aqua	4	5	10	F	L	L
Saphy	0	8	7	F	H	H
Talula	0	34	27	F	H	H

Males

name	loser (suppl/threat)	winner (suppl/threat)	No observati ons	Se x	Observed rank	Rank from DS
Yew	0	6	22	M	H	H
Yorkie	0	34	39	M	H	H
Yosser	0	3	40	M	H	H
Zazy	0	2	36	M	H	H
Sol	0	81	19	M	H	H
Vincent	0	16	26	M	H	H
Abbott	0	14	28	M	H	H
Sequel	0	14	22	M	H	H
Nodon	0	41	31	M	H	H
Star	0	23	29	M	H	H
Plum	0	31	18	M	H	H
Yeti	5	0	15	M	L	L

Supplementary results

The Distraction task:

CONTENT VALIDITY

Table S1

Results of LMMs for the log transformation of the response latency in the Distraction task. Confounding factors were divided in individual (sex, age, rank and experience with picture) and experimental determinants (session and time point). All full models included the individual

ID as a random factor. The Estimates (representing the change in the dependent variable relative to the baseline category of each predictor variable), Standard Error, t-value and p-value using maximum likelihood method. The variables in bold stimulus, age, trial and time point had a significant effect on the models. 4094 data points were analysed.

<i>log(response latency) on a trial</i>				
Predictor	Estimate	Std. Error	t-value	p-value
(Intercept)	8.223	0.213	38.526	0.000
Stimulus picture	0.112	0.035	3.189	0.001
Picture Object vs face	0.018	0.025	0.753	0.452
Picture Threat vs neutral	-0.058	0.043	-1.350	0.177
Sex male	0.120	0.150	0.801	0.436
Age	0.043	0.018	2.296	0.035
Rank low vs high	0.196	0.154	1.273	0.220
Experience picture	-0.084	0.097	-0.862	0.388
Trial	0.000	0.002	0.069	0.944
Session	-0.035	0.017	-2.20	0.027
Time point	-0.534	0.032	-16.877	0.000

Note. Number of subjects 21

Likelihood-ratio test comparing the best fitted model (with session, time point and age as explanatory variables) with the null model : $\chi^2_4 = 296.02$, $p < 0.0001$.

The subjects had a longer response latency as they get older ($\chi^2_1 = 9.086$, $p < 0.01$), and their response latency were shorter as session ($\chi^2_1 = 4.798$, $p < 0.05$) and time point ($\chi^2_4 = 276.165$, $p < 0.0001$) increased.

Go/No-go task:

Table S2

Results of GLMMs for the success in the Go/No-go task. Confounding factors were divided in individual (sex, age and rank) and experimental determinants (session and time point). All full models included the individual ID as a random factor. The Estimates (representing the change in the dependent variable relative to the baseline category of each predictor variable), Standard Error, z-value and p-value using maximum likelihood method. The type of stimulus (Go or No-go) and session had a significant effect on the models. 7783 data points were analysed.

<i>Success on a trial</i>				
Predictor	Estimate	Std. Error	t-value	p-value
(Intercept	6.824	0.671	11.072	0.000
)				

Stimulus	-7.098	0.413	-17.196	0.000
No-Go				
Sex	-0.300	0.200	-1.5000	0.134
female				
Age	-0.004	0.037	-0.111	0.911
Rank low	0.023	0.364	0.065	0.948
vs high				
Trial	0.001	0.004	0.173	0.862
Session	0.081	0.033	2,456	0.014
Time	0.091	0.093	0.972	0.331
point				

Note. Number of subjects 20

Likelihood-ratio test comparing the best fitted model (with type of stimulus and session as explanatory variables) with the null model: $\chi^2_2 = 3335.6$, $p < 0.0001$.

The success on a trial was higher as the number of the session increased: $\chi^2_1 = 6.172$, $p < 0.05$.

Table S3

Results of LMMs for the log transformation of the response latency in the Go/No-go task. Confounding factors were divided in individual (sex, age and rank) and experimental determinants (session and time point). All full models included the individual ID as a random factor. The Estimates (representing the change in the dependent variable relative to the baseline category of each predictor variable), Standard Error, t-value and p-value using maximum likelihood method. Only the variable in bold stimulus had a significant effect on the models. 7783 data points were analysed.

<i>log(response latency) on a trial</i>				
Predictor	Estimate	Std. Error	z-value	p-value
(Intercept)	7.638	0.160	47.800	0.000
Stimulus	0.509	0.020	24.969	0.000
No-Go				
Sex female	-0.041	0.042	-0.967	0.334
Age	0.006	0.012	0.555	0.579
Rank low vs	0.115	0.116	0.999	0.331
high				
Trial	-0.001	0.001	-0.969	0.332
Session	0.010	0.006	1.640	0.101
Time point	0.001	0.018	0.068	0.946

Note. Number of subjects 20

Likelihood-ratio test comparing the best fitted model (with type of stimulus as explanatory variables) with the null model: $\chi^2_1 = 600.73$, $p < 0.001$.

Table S4

Results of GLMMs for the success in the Reversal learning task. Confounding factors were divided in individual (sex, age and rank) and experimental determinants (session and time point). All full models included the individual ID as a random factor. The Estimates (representing the change in the dependent variable relative to the baseline category of each predictor variable), Standard Error, z-value and p-value using maximum likelihood method. The variables in bold rule, trial and session had a significant effect on the models. 6686 data points were analysed.

Success on a trial				
Predictor	Estimate	Std. Error	z value	p-value
(Intercept)	0.797	0.272	2.885	0.004
Ruverse rule	-0.099	0.069	-1.437	0.150
Sex female	-0.185	0.157	-1.183	0.237
Age	-0.025	0.016	-1.607	0.108
Rank low vs high	-0.025	0.149	-0.170	0.897
Trial	0.005	0.002	2.047	0.041
Session	0.056	0.017	3.377	0.001
Time point	-0.088	0.072	-1.233	0.218

Note. Number of subjects 19

Likelihood-ratio test comparing the best fitted model with the null model: $\chi^2_4 = 27.74$, $p < 0.001$.

The success on a trial was higher as the trials ($\chi^2_1 = 4.101$, $p < 0.05$) and session increased ($\chi^2_1 = 11.687$, $p < 0.05$).

TEMPORAL REPEATABILITY

Table S5

Results of LMMs for the Distraction control score (the Distraction task). Confounding factors were divided in individual (sex, age, rank and experience with picture) and experimental determinants (session and time point). All full models included the individual ID as a random factor. The Estimates (representing the change in the dependent variable relative to the baseline category of each predictor variable), Standard Error, t-value and p-value using maximum likelihood method. Only the variables in bold sex, session and time point had a significant effect on the models. 346 data points were analysed.

Distraction control score

Predictor	Estimate	Std. Error	t-value	p-value
(Intercept)	-185.419	683.239	-0.271	0.786
Sex male	-1368.504	631.269	-2.172	0.045
Age	-102.284	103.125	-0.986	0.334
Rank low vs high	-1211.880	619.867	-1.955	0.068
Experience with pictures	317.939	856.463	0.371	0.715
Trial	6.374	9.807	0.649	0.517
Session	455.514	124.249	3.666	0.0003
Time point	2019.521	205.8753	9.815	0.000
Type picture Object	-117.94	245.685	-0.484	0.628
Type picture Threat	66.953	249.686	0.266	0.790

Table S6

Results of LMMs for the Action Control Score (Go/No-go). Confounding factors were divided in individual (sex, age and rank) and experimental determinants (session and time point). All full models included the individual ID as a random factor. The Estimates (representing the change in the dependent variable relative to the baseline category of each predictor variable), Standard Error, t-value and p-value using maximum likelihood method. None of the variables had a significant effect on the models. 120 data points were analysed.

<i>Action control score</i>				
Predictor	Estimate	Std. Error	t-value	p-value
(Intercept)	47.742	13.653	3.497	0.001
Sex male	-10.487	9.604	-1.092	0.292
Age	0.744	1.061	0.701	0.494
Rank low vs high	-3.680	9.857	-0.373	0.714
Session	4.631	2.851	1.646	0.103
Time point	3.062	4.370	0.631	0.523

Reversal learning task:

Table S7

Results of GLMMs for the Rule Control Score (Reversal learning task). Confounding factors were divided in individual (sex, age, rank) and experimental determinants (session and time point). The Estimates (representing the change in the dependent variable relative to the

baseline category of each predictor variable), z-value and p-value using maximum likelihood method. None of the variables had a significant effect on the model. 38 data points were analysed.

Rule control score

Predictor	Estimate	Std. Error	t-value	p-value
(Intercept)	40.211	68.579	0.586	0.566
Sex male	-109.509	65.719	-1.666	0.118
Age	6.471	8.011	0.808	0.4323
Rank low vs high	-18.676	72.299	-0.258	0.799
Time point	-2.001	13.721	-0.146	0.887

CONTEXTUAL REPEATABILITY

Table S8

Contextual unadjusted repeatability estimates of the scores of executive function and inhibitory control. Distraction control score (Distraction task), Action control score (Go/No-go) and Rule control score (Reversal Learning) are represented

✓ indicates that the individual's performances are significantly repeatable between tasks.

* p < 0.05, ** p < 0.01, *** p < 0.001

Contextual R for the scores	Distraction control	Action control	Rule control
Distraction control	1	-	-
Action control	✓ 0.166 (p = 2.69e-05)***	1	-
Rule control	✓ 0.212 (p = 9.46e-04) ***	✓ 0.138 (p = 0.012)*	1

Table S9

Results of LMMs for the Distraction task (Distraction control scores) and the Go/No-go task (Action Control Score). Confounding factors were divided in individual (sex, age and rank) and experimental determinants (session and time point). The Estimates (representing the change in the dependent variable relative to the baseline category of each predictor variable t-value and p-value using maximum likelihood method. The variables in bold session and time point had a significant effect on the models. 237 data points were analysed.

Predictor	Estimate	Std. Error	t-value	p-value
(Intercept)	-0.241	0.226	-1.065	0.282
Task Go/No-go	0.012	0.096	0.128	0.898

Sex male	-0.381	0.162	-2.338	0.032
Age	0.007	0.020	0.320	0.752
Rank low vs high	0.051	0.156	0.330	0.741
Session	0.126	0.058	2.160	0.032
Time point	0.268	0.096	2.809	0.006

Table S10

Results of LMMs for the Go/No-go (Action control scores) and the Reversal learning task (Rule Control Score). Confounding factors were divided in individual (sex, age and rank) and experimental determinants (session and time point). All full models included the individual ID as a random factor. The Estimates (representing the change in the dependent variable relative to the baseline category of each predictor variable) t-value and p-value using maximum likelihood method. Only the variable in bold sex had a significant effect on the model (when comparing with the full model). 158 data points were analysed.

Predictor	Estimate	Std.Error	t-value	p-value
(Intercept)	-0.325	0.367	-0.890	0.375
Task	0.183	0.219	0.838	0.404
Reversal learning				
Sex male	-0.528	0.218	-2.494	0.023
Age	0.030	0.025	1.230	0.221
Rank low vs high	-0.108	0.226	-0.447	0.656
Session	0.163	0.112	1.457	0.148
Time point	0.122	0.162	0.751	0.454

Table S11

Results of LMMs for the Distraction task (Distraction control scores) and the Reversal learning task (Rule Control Score). Confounding factors were divided in individual (sex, age and rank) and experimental determinants (session and time point). All full models included the individual ID as a random factor. The Estimates (representing the change in the dependent variable relative to the baseline category of each predictor variable), Standard Error, t-value and p-value using maximum likelihood method. The variable in bold had a significant effect on the models. 155 data points were analysed.

Predictor	Estimate	Std. Error	t-value	p-value
(Intercept)	-0.325	0.365	-0.890	0.375
Task	0.173	0.217	0.792	0.425
Reversal learning				
Sex male	-0.416	0.133	-3.140	0.023

Age	0.006	0.016	0.396	0.206
Rank low vs high	-0.108	0.224	-0.478	0.633
Session	0.166	0.11	1.430	0.128
Time point	0.1209	0.165	0.759	0.448
