

1 **Supplementary Materials:**

2
3 **The influence of stress hormones and aggression on cooperative behaviour in subordinate**
4 **meerkats**

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24	This file contains:
25	
26	Supplementary Materials, Methods, and Results
27	Figs. S1 to S5
28	Tables S1 to S12
29	

Supplementary Materials, Methods & Results

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31

(a) Validating methods to manipulate subordinate cortisol levels

32 We provisioned subordinate meerkats with either cortisol (10 mg/kg, hydrocortisone,
33 Sigma H4126), mifepristone (40 mg/kg, Sigma M8046), or oil vehicle (100% coconut oil). We
34 chose these dosages based upon previous studies in meerkats and other species and our own pilot
35 studies reported herein (Figs. S1-S3). We based our dosage of cortisol on a previous study in
36 meerkats (64) that showed that an injection of ~20 mg/kg caused plasma cortisol levels to be
37 ~11x higher than individuals injected with saline (they were sampled ~2 hours after injection).
38 We cut the dosage by 50% (10 mg/kg) in order to produce a less steep increase in circulating
39 glucocorticoid concentrations. Our pilot experiments confirmed that this dosage caused a
40 significant, but less severe, increase in plasma glucocorticoid (cortisol) concentrations (Fig. S2)
41 in addition to a long-term elevation in faecal glucocorticoid metabolite concentrations (Fig. S3).
42 We based our dosage of mifepristone on previous studies in mammals (30 mg/kg: 70; 50 mg/kg:
43 71) and birds (10 or 50 mg/kg in birds: 72) that used similar dosages of mifepristone. These
44 studies show that these mifepristone dosages could affect behaviour (73), antagonize the
45 glucocorticoid receptor (GR) but not cause toxicity (74), but are sufficient to bind to GRs as
46 evident by their effects on raising circulating glucocorticoid levels (by exerting negative
47 feedback on the hypothalamic-pituitary-adrenal axis: 70,74).

48
49 To prepare the dosages, cortisol (70 mg each time) or mifepristone (28 mg) was weighed
50 on an analytical balance, and 100% coconut oil was added to achieve a standardized
51 concentration for cortisol (0.07 mg/1 μ l of coconut oil) and mifepristone (0.14 mg/ μ l), the
52 solutions were vortexed to suspend the cortisol or mifepristone, and then stored at 4° C prior to

53 use. New dosages were made at least every 7 d. Prior to provisioning meerkats with the dosages,
54 we thoroughly vortexed and then injected 100 µl of the emulsions into the thorax of a dead
55 scorpion (*Opisthophthalmus* spp.), and fed the meerkats the scorpions. Meerkats were fed in the
56 morning soon after foraging started. Control treatments were just 100 µL of 100% coconut oil.

57 *Effects of treatments on plasma glucocorticoid levels*

58 To assess how our treatments affected plasma glucocorticoid levels, we obtained blood
59 samples from subordinates prior to starting and during the treatments and measured plasma
60 glucocorticoid (cortisol) levels using established protocols (7, 12, 15). Meerkats sampled during
61 the treatment period were blood sampled 1-5 hours after they consumed the treatments (mean =
62 3.45 hrs). We confirmed that there were no statistically significant differences in plasma
63 glucocorticoid (cortisol) levels prior to treatment (Fig. S2) and that subordinate meerkats fed
64 cortisol had significantly higher plasma glucocorticoid levels than those fed mifepristone or the
65 controls sampled on the same day that they were provisioned with their treatment (Fig. S2).

66 *Effects of treatments on faecal glucocorticoid metabolite levels*

67 We measured the effects of the treatments on faecal glucocorticoid metabolite (fGCM)
68 levels, which represent an average level of circulating glucocorticoid levels experienced over a
69 ~24-48 hr period (6, 75). Faecal samples (n=26) for fGCM monitoring were collected from 15
70 subordinate meerkats over the course of the experimental treatment period (range = 1-10 days
71 after the treatments started, median = 4.5 d). Samples were taken immediately after the animal
72 left the defecation spot, placed on wet ice, and stored frozen within 2-6 h after collection at -20°
73 C until further processing. For fGCM extraction, carried out at the Endocrine Research
74 Laboratory, Faculty of Veterinary Science, University of Pretoria, South Africa, frozen faeces
75 were lyophilized, subsequently pulverized and fGCMS extracted from 0.10–0.11 g of faecal

76 powder using 3 ml 80% methanol in water (full details provided in 76). One ml of the extract
77 was oven dried over night at 55 to 58° C (77) and shipped to the Endocrinology Laboratory of
78 the German Primate Centre, Göttingen, Germany, for hormone analysis.

79 Faecal extracts were measured for immunoreactive 11 β -hydroxyetiocholanolone, a major
80 metabolite of cortisol in meerkats (75). Its measurement has been validated and proven reliable
81 in reflecting adrenocortical activity in meerkats (75). Prior to assay, dried faecal extracts were
82 reconstituted in 0.5 ml 80% methanol in water by sonication in a water bath for 5 minutes,
83 followed by 30 seconds of vortexing (77-78). Reconstituted extracts, diluted 1:10 to 1:300
84 (depending on concentration) in assay buffer, were then taken to assay according to the
85 procedure described elsewhere (79). Sensitivity of the assay was 1 pg/well. Intra-assay
86 coefficients of variation (CV) determined by repeated measurements of high and low value
87 quality controls were 5.3% and 7.0%, respectively, and inter-assay CV values were 11.0% and
88 16.4% (n=2 assays). All fGCM concentrations reported are expressed as ln ng/g dry faecal matter.

89 During the treatment period, fGCM levels of subordinates fed cortisol were significantly
90 higher than those fed mifepristone or the controls (Fig. S3). Taken together, these results indicate
91 that the dosages of cortisol we fed to subordinate meerkats entered their bloodstream and
92 elevated plasma glucocorticoid levels (Fig. S2) and that meerkats fed cortisol experienced
93 significantly higher overall exposure to glucocorticoids than those fed mifepristone or the
94 controls (Fig. S3). This is similar to previous studies in other mammal species where
95 provisioning individuals with exogenous glucocorticoids each day for 6-28 continuous days
96 caused sustained elevations in plasma glucocorticoids (80-82) or fGCM levels (81) during the
97 treatment period. Finally, we confirmed that these experimental increases in cortisol levels were

98 not causing abnormal changes in meerkat behaviour, as indicated by the lack of treatment effects
99 on meerkat activity levels (Fig. S5).

100 *Validation of mifepristone dosage*

101 We performed a separate set of experiments to confirm that mifepristone affected the
102 expression of behaviours stimulated by exogenous cortisol, likely by antagonizing the GR and
103 therefore lowering GR activity. To do this, we fed subordinate males cortisol (10 mg/kg, n=9),
104 cortisol (10 mg/kg) plus mifepristone (40 mg/kg, n=4), or oil vehicle (n=7) for one day and then
105 assessed the effects of these treatments on their foraging success during that day of treatment.
106 Subordinates fed cortisol by itself had significantly higher foraging success compared to the
107 controls on day 1 of treatment (Fig. S1) but meerkats fed cortisol along with mifepristone
108 exhibited foraging success that was similar to the controls (Fig. S1) and lower but not
109 significantly lower than those fed cortisol by itself (Fig. S1). Administration of mifepristone by
110 itself for 10 continuous days during either babysitting or pupfeeding also lowered foraging
111 success compared to those fed cortisol (Fig. S4). These results are consistent with previous
112 studies that show that experimental increases in glucocorticoid concentrations promote food-
113 seeking behaviour or food-intake (83-86) and that administration of mifepristone by itself can
114 reduce food-seeking behaviour or food-intake (72,87). Overall, this indicates that our dosages of
115 mifepristone reduced the activity of the glucocorticoid receptor and caused behavioural changes.

116 Mifepristone is a potent glucocorticoid receptor antagonist, but it is also a progesterone
117 receptor antagonist (73,88). Although we cannot rule out the possibility that the effects of
118 mifepristone on babysitting or pupfeeding behaviour were caused by its anti-progesterone
119 receptor effects rather than its anti-glucocorticoid receptor effects, we think this is unlikely for
120 the following reasons. First, experimental administration with cortisol increased food-intake but

121 co-administration with mifepristone prevented this change in behaviour (Fig. S1) and
122 administration of mifepristone by itself reduced food-intake compared to those fed cortisol (Fig.
123 S4). This indicates that mifepristone altered food-seeking behaviour that is known to be
124 influenced by the activity of glucocorticoid receptors (see 72-73). Second, we had *a priori*
125 evidence in subordinate males that there should be a negative association between increased
126 glucocorticoid receptor activity and babysitting (15) but a positive association between
127 glucocorticoid receptor activity and pupfeeding (12). We found support for these associations
128 when we reduced glucocorticoid receptor activity with mifepristone. Finally, if mifepristone
129 caused changes in behaviour due to its anti-progesterone effects, we would expect that its effects
130 would be most obvious in pregnant females. We only conducted our experiments in subordinate
131 females that were not pregnant and subordinate males. Consequently, the behavioural
132 consequences of mifepristone on babysitting and pupfeeding behaviour were most likely caused
133 by a reduction in glucocorticoid receptor activity rather than a reduction in progesterone receptor
134 activity.

135 The dosages of mifepristone we used (40 mg/kg) were within the range that has been
136 used in other species (see above) and also not known to be toxic (73). Nonetheless, we confirmed
137 that our mifepristone dosages were not causing abnormal changes in behaviour by documenting
138 subordinate behaviour during focal behavioural observations. In Fig. S5, we show that treating
139 subordinates with mifepristone did not cause abnormal changes in their activity levels. Our own
140 observations (B. Dantzer, pers. obs.) also indicated that these dosages did not cause observable
141 sickness behaviour or vomiting.

142

143 **(b) Additional Details of Statistical Analyses**

145 We first used an information-theoretic approach (51) to examine the degree of support
146 among different models to explain variation in 1) babysitting contributions (generalized linear
147 mixed-effects model [GLMM] with binomial errors), 2) the probability that pupfeeding occurred
148 during our focal observations (GLMM with binomial errors), and 3) the proportion of biomass
149 that was found by subordinates and subsequently fed to pups foraging with the group (GLMM
150 with binomial errors). We included sex and treatment and, in some models, an interaction term
151 between sex of the subordinate and treatment to identify if there were sex-specific effects of the
152 treatments on babysitting or pupfeeding. Although we aimed to provision all subordinates their
153 treatments prior to starting the focal observations (focals), in some cases this was not possible
154 and focals were conducted ≥ 24 hrs after the last treatment in 64 of 230 total focals. Consequently,
155 in the two pupfeeding models (probability of pupfeeding during focals and the proportion of
156 biomass found that was fed to pups), we also included a binary covariate for whether the
157 subordinate was fed or not prior to the focals occurring and, in some models, an interaction term
158 between treatment and whether the subordinate was fed prior to the focals. We did not include
159 this latter covariate in the babysitting models because we used the average relative babysitting
160 contribution over the entire treatment period as the response variable.

161 Group size, litter size, and age of the subordinate may affect subordinate contributions to
162 babysitting (36) and pupfeeding (35, 36, 42). Foraging success and body mass may also
163 influence babysitting and pupfeeding (35, 36). In some of our initial babysitting models (Table
164 S1), we included a covariate for the average age-corrected body mass of treated subordinates
165 during the treatment period. Average age-corrected body mass during the treatment period were
166 the residuals from a general linear model containing average morning body mass during the

167 treatment period as the response variable and average age during the treatment period as the
168 independent variable. In the initial models for the probability of observing pupfeeding during the
169 behavioural focals (Table S2), we included a covariate for the total biomass of food found during
170 the focal session. We included some of these variables in our initial model selection procedures
171 shown in Tables S1-S3. Relatedness is not associated with variation in pupfeeding (35) or
172 babysitting (36) and including it in these models would have restricted our sample sizes (we did
173 not have full relatedness information for all individuals) so we did not include it in our models
174 shown in Tables S1-S3. Our model selection procedures revealed that the best model (with
175 lowest AIC_c shown in Tables S1-S3) for babysitting and pupfeeding was the null model that did
176 not contain any biological predictor variables. Because we were interested in the effects of the
177 experimental treatments on babysitting and pupfeeding, we only report results from models
178 (Tables S1-S3) containing biological predictor variables with the lowest AIC_c (model in bold
179 face font in Tables S1-S3) in the main text and use these results for our interpretations. Because a
180 second model containing biological predictor variables (i.e., not the null model) was within
181 $\Delta AIC_c < 2$ in Tables S1-S3, we also include results from model averaging (53) from these top
182 models in Tables S10-S12 (using the zero method: 90).

183 *Causes of variation aggression directed at subordinates*

184 We used AIC_c model selection procedures to identify the top model of those considered
185 to explain variation in aggression by dominant females directed at subordinate meerkats (Table
186 S7). In these GLMMs (Poisson error structure), we included characteristics of the individual (sex,
187 age at sampling [days of age], age-corrected body mass), social group (group size, group size²,
188 proportion of adult group members (>12 months of age) that were females [group sex ratio]),
189 potential causes of conflict between the dominant female and subordinates (whether or not the

190 dominant female was pregnant), and a 4-level categorical variable to indicate whether there were
191 pups at the burrow being babysat, pups foraging with the group, no pups in the group and the
192 dominant female was pregnant, or no pups in the group and the dominant female was not
193 pregnant. We also included a fixed effect for relatedness between the subordinates and dominant
194 female defined as whether the dominant female was either the mother or full sister of the
195 subordinate or not (two-level categorical variable). Group size was the total number of
196 individuals in the group and group sex ratio was the proportion of females in the group during
197 the *ad libitum* behavioral observation session. To identify if there were sex-specific effects of the
198 dominant female pregnancy status or the presence of pups at the burrow or foraging with the
199 group on aggression directed at subordinates, we included an interaction term between sex and
200 the dominant female's pregnancy status and an interaction term between sex and the presence of
201 pups in the group (no pups and dominant female not pregnant, no pups but dominant female
202 pregnant, pups at burrow being babysat, pups foraging with the group). In some models, we also
203 included interactions between sex and age and sex and age-corrected body mass to investigate
204 whether aggression directed at subordinates was elevated in older or heavier females but not
205 males. We included a covariate for season to indicate whether the amount of aggression directed
206 at subordinates differed between the summer (September-April) or winter (May-August) months
207 and, in some models, an interaction between sex and season. All models included an offset for
208 the total amount of time of the behavioral observation session (time was ln transformed) as the
209 total amount of time we observed each subordinate or dominant was variable.

210 *Associations between babysitting and pupfeeding and aggression received*

211 We also used AIC_c model selection procedures to identify the top model of those
212 considered to examine associations between the amount of aggression subordinates received

213 from dominant females and their 1) babysitting contributions (Table S8) and 2) the probability
214 that pupfeeding occurred during our *ad libitum* behavioral observations (Table S9). In these
215 GLMMs (binomial error structure), we included characteristics of the individual (sex, age, age-
216 corrected body mass), social group (group size, total number of pups foraging with the group and
217 being pupfed), and the amount of aggression per hour that the subordinate received from the
218 dominant female over the previous month ($\ln+1$ transformed, see above). In some models, we
219 also included interactions between sex and age, age-corrected body mass, group size, or the
220 amount of aggression received. The response variable in these models was either the relative
221 proportion of babysitting contributions provided by that individual or a binary response variable
222 to indicate whether pupfeeding did or did not occur in the behavioral observation sessions. The
223 model for the effects of dominant female aggression on subordinate pupfeeding behaviour
224 included an offset for the total amount of time observing the group as there was variation in how
225 much time we observed each subordinate.
226

227 **Supplementary References**

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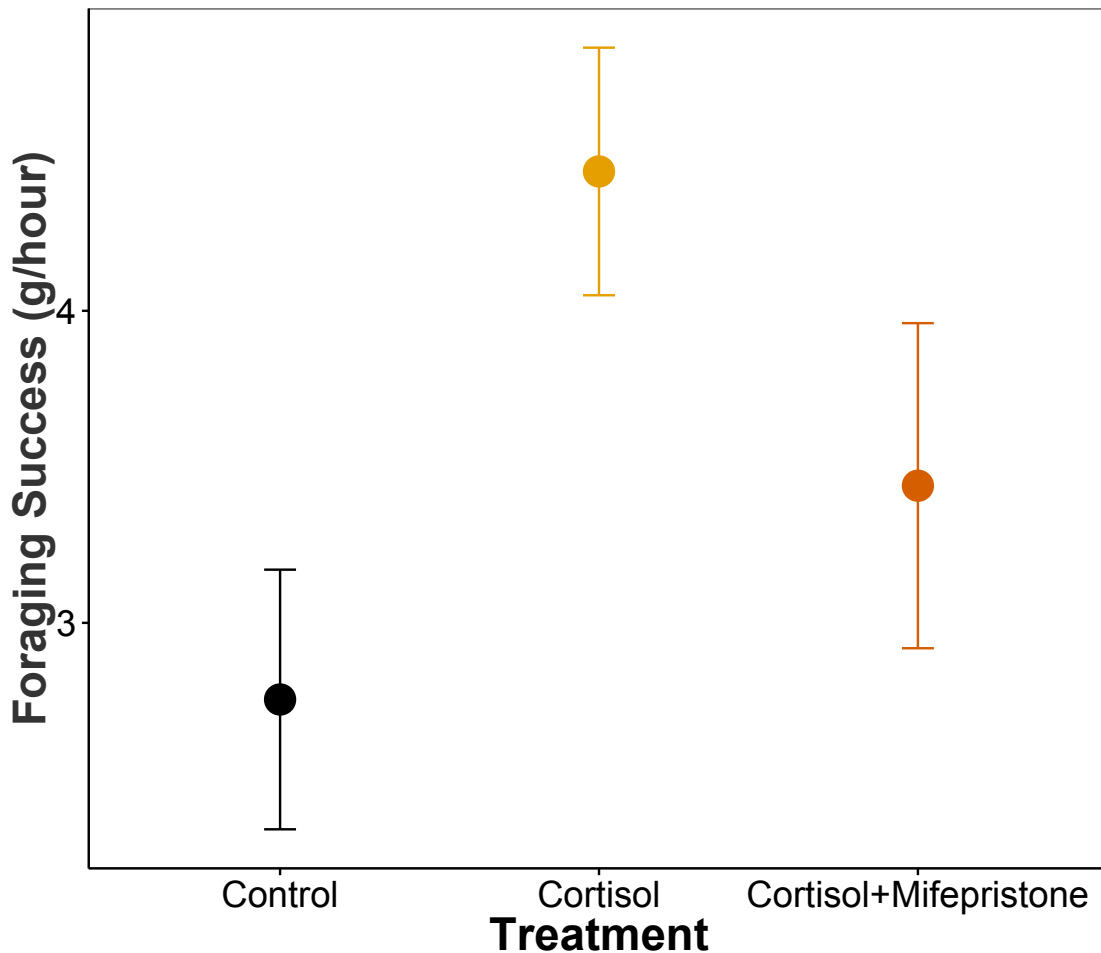
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298 **Supplementary Figures S1-S5 and Tables S1-S12**

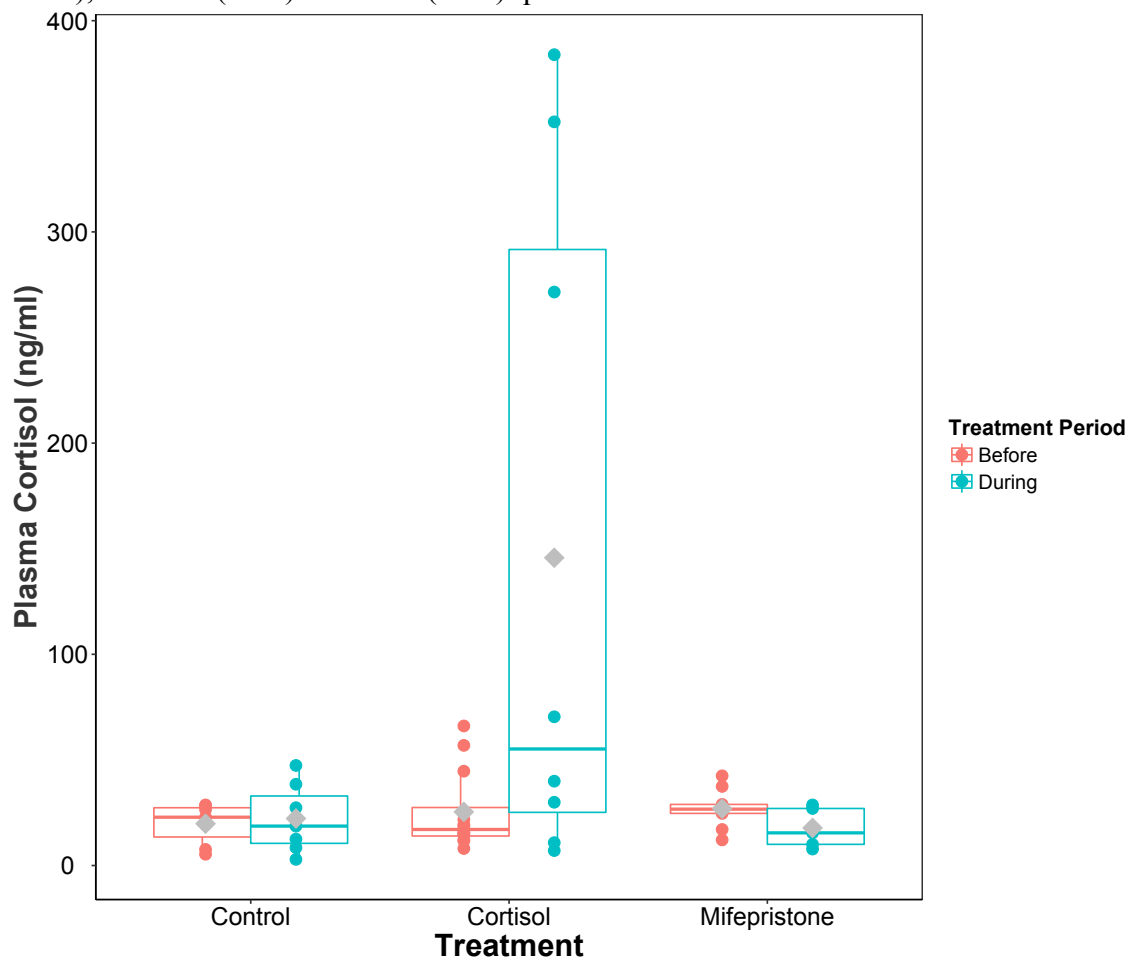
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300 **Figure S1.** We confirmed that mifepristone was antagonizing glucocorticoid receptors by
301 conducting a separate set of experiments where we fed subordinate male meerkats cortisol,
302 cortisol plus mifepristone, or oil vehicle for one day and assessed their effects on food-intake
303 (foraging success during the day of treatment). Subordinates that were fed cortisol (n=8) had
304 significantly higher foraging success (grams of prey biomass consumed per hour) than controls
305 fed oil vehicle (n=6, $t=-2.92$, $P=0.01$) but subordinates fed cortisol along with mifepristone did
306 not have higher foraging success than the controls (n=4, $t=-0.99$, $P=0.34$). Subordinates fed
307 cortisol by itself had slightly higher foraging success than those fed cortisol plus mifepristone
308 ($t=-1.53$, $P=0.15$). Together, these data indicate that our dosages of mifepristone lowered the
309 activity of the glucocorticoid receptor because they prevented exogenous glucocorticoids from
310 increasing food-seeking behaviour (as was observed in those fed cortisol). Data are from an
311 experiment separate from those shown in Fig. S4 where subordinate males were treated with one
312 of the three treatments (treated for 1 d) and their foraging success on the day of treatment was
313 quantified by weighing them in the morning prior to the treatments starting and when foraging
314 commenced and in the evening when foraging ended. We quantified foraging success as the
315 evening body mass minus the morning body mass and estimated the number of grams gained of
316 food consumed per hour as we had the time of each body mass measure. Results are from a
317 general linear model with foraging success as the response variable (grams of prey biomass
318 consumed per hour) and treatment as the independent variable.
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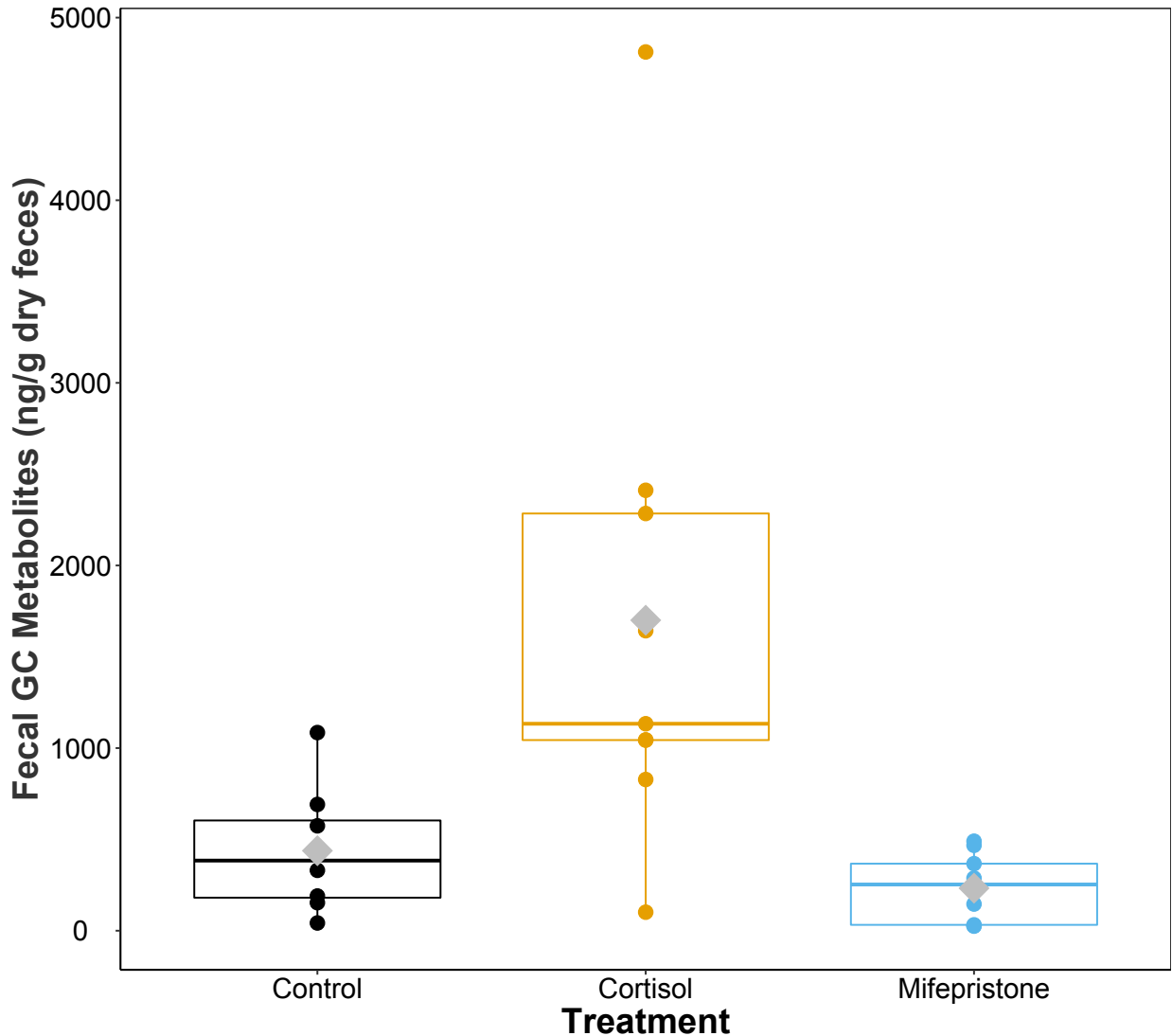
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321 **Figure S2.** Prior to the treatments starting (“Before”), plasma glucocorticoid (cortisol) levels
 322 from subordinate meerkats that were to be treated with cortisol (n=12) were similar to those from
 323 subordinates that were to be treated with mifepristone (n=9, t=0.85, P=0.39) or oil vehicle
 324 (controls, n=7, t=-0.47, P=0.38). Plasma cortisol levels in subordinates that were to be treated
 325 with mifepristone did not differ compared to the controls (t=1.21, P=0.23). During the treatment
 326 period (“During”), subordinates fed cortisol (n=8) had significantly higher plasma cortisol levels
 327 compared to those fed mifepristone (n=5, t=-3.05, P=0.004) and the controls (n=7, t=-3.62,
 328 P=0.001). Plasma cortisol levels in subordinates being fed mifepristone did not differ compared
 329 to those from the controls (t=0.41, P=0.68). Meerkats sampled during the treatment period were
 330 blood sampled 1-5 hours after they consumed the treatments (mean = 3.45 hrs). Results are from
 331 a general linear mixed-effects model that contained treatment (mifepristone, control, cortisol),
 332 treatment period (before or during treatment), sex, sample acquisition time (ranging from 1-7
 333 min, median=4 min), and a two-way interaction between treatment and treatment period. We also
 334 included random intercept terms for individual identity and group because we had repeated
 335 samples on the same individuals from the same groups (48 samples from 36 individuals in 11
 336 different groups). A separate model that included an interaction term between sex, treatment, and
 337 treatment period confirmed that there were no sex-specific effects of the treatments on plasma
 338 cortisol levels prior to or during the treatments (interaction between sex x treatment x treatment
 339 period, $F_{1,33} = 0.03$, P=0.86). Boxplots show median (solid horizontal line), mean (grey
 340 diamonds), and first (25%) and third (75%) quartiles.



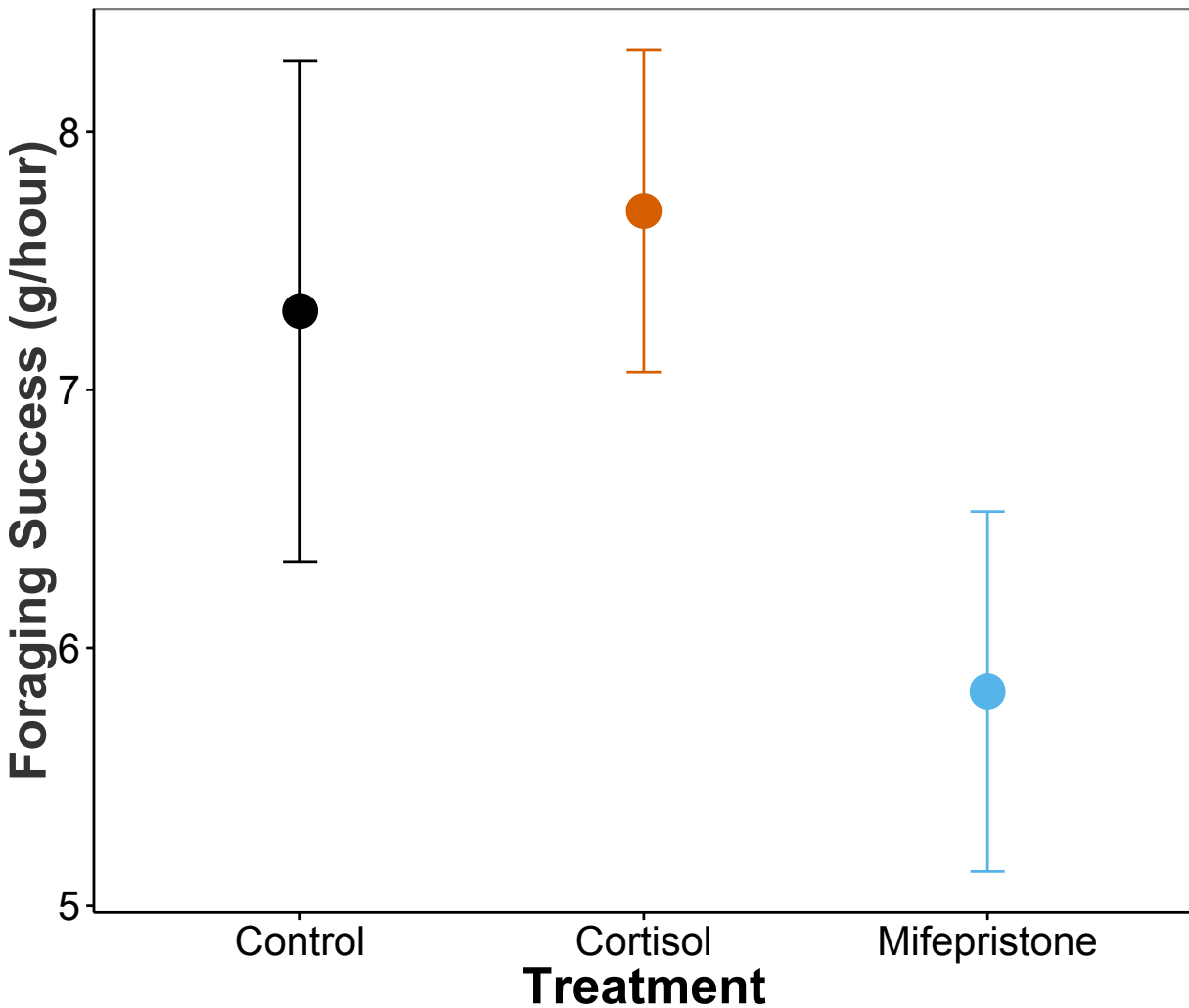
341

342 **Figure S3.** Subordinates that were being treated with cortisol (n=9) had significantly higher
343 faecal glucocorticoid metabolite levels than those fed mifepristone (n=9, $t=-5.74$, $P<0.0001$) and
344 the controls (n=8, $t=-4.34$ $P=0.0003$). There were no differences between subordinates that were
345 being treated with mifepristone and the controls ($t=-1.44$, $P=0.17$). The increase in faecal
346 glucocorticoid metabolites for those treated with cortisol was within the biologically-relevant
347 range in meerkats (89). Results are from a general linear mixed-effects model that included
348 treatment, sex, and a 3-level categorical variable for the time of day the sample was collected
349 (see 58) and random intercept terms for individual identity and group (26 samples from 15
350 individuals in 8 groups). A separate model that included an interaction term between treatment
351 and sex confirmed that there were no sex-specific effects of the treatments on faecal
352 glucocorticoid metabolite levels ($F_{2,19} = 0.52$, $P=0.6$). Boxplots show median (solid horizontal
353 line), mean (grey diamonds), and first (25%) and third (75%) quartiles.



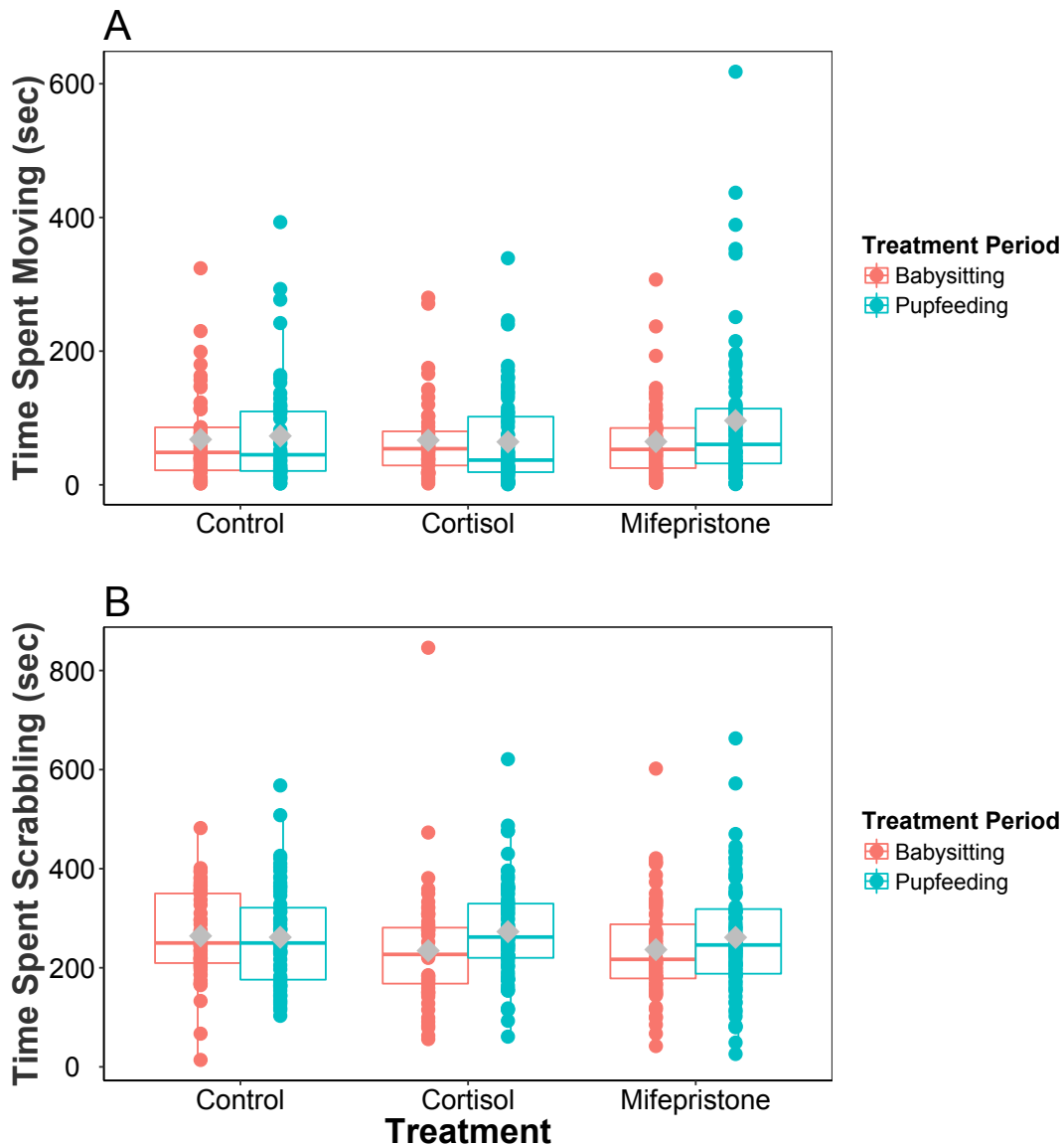
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355

356 **Figure S4.** Subordinate meerkats fed mifepristone (n=20) during babysitting or pupfeeding
357 tended to have lower foraging success than those fed cortisol (n=21, $t=1.92$, $P=0.06$) but not
358 controls fed oil vehicle (n=16, $t=1.32$, $P=0.19$). Foraging success did not differ between
359 subordinates fed cortisol and the controls ($t=-0.47$, $P=0.64$), suggesting that although short-term
360 increases in plasma cortisol levels increased foraging success (Fig. S1), treatment with cortisol
361 for 10 days did not. Values on y-axis represent average foraging success (change in body mass
362 from morning to mid-afternoon divided by the number of hours) over the entire treatment period.
363 Results are from a general linear mixed-effects model with foraging success (grams of prey
364 biomass consumed per hour) as the response variable, sex and treatment as fixed effects, and
365 individual identity as a random intercept term because of repeated observation on the same
366 individuals.



367
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370 **Figure S5.** Our experimental treatments did not affect the average amount of time subordinate
371 meerkats spent (A) moving ($F_{2,232} = 2.3$, $P=0.11$) or (B) scrabbling for food ($F_{2,203} = 0.87$,
372 $P=0.42$) during 20 min continuous focal behavioural observations collected during the
373 babysitting and pupfeeding treatment periods. Results are from a general linear mixed-effects
374 model with time spent moving or scrabbling as the response variable (ln transformed), sex,
375 treatment, treatment period (babysitting, pupfeeding), and interaction terms between sex and
376 treatment or treatment period as fixed effects, and individual identity as a random intercept term
377 because of repeated observation on the same individuals. There was no evidence of sex-specific
378 effects of the treatments on the behaviours or that the effects of the treatments on the behaviours
379 depended upon whether the meerkats were treated during the babysitting or pupfeeding treatment
380 periods as indicated by the lack of significant interactions between treatment and period
381 (babysitting or pupfeeding) in any of these comparisons (P-value at least >0.21 for all interaction
382 terms). Sample sizes were the following: mifepristone (3140 min focal behavioural data on 27
383 individuals), cortisol (2840 min on 22 individuals), controls (2480 min on 23 individuals).
384



385

386 **Table S1.** AIC_c model selection for identifying the effects of the treatments on relative
 387 babysitting contributions exhibited by subordinate meerkats fed cortisol (n=9), mifepristone
 388 (n=9), or oil vehicle (controls, n=8). All models were generalized linear mixed-effects models
 389 (binomial errors) that were fit by maximum likelihood and included a random intercept terms for
 390 litter (L) and an observation level random effect (obs). Results from the model presented in the
 391 main text shown in bold. Model averaging results for the two top models (italicized) containing
 392 biological variables with <2 ΔAIC_c are shown in Table S10.

Fixed Effects	Random Effects	K	AIC_c	ΔAIC_c
Null	L, obs	3	130.1	0
<i>S+T</i>	<i>L, obs</i>	6	<i>133.2</i>	<i>3.07</i>
<i>GS+S+T</i>	<i>L, obs</i>	7	<i>134.8</i>	<i>4.74</i>
S+T+S*T	L, obs	8	136.8	6.65
A+BM+S+T	L, obs	8	139.5	9.42
GS+S+T+S*T	L, obs	9	140.7	10.59
GS+A+BM+S+T	L, obs	9	141.6	11.52
GS+S+T+S*GS+S*T	L, obs	10	144.3	14.21
A+BM+S+T+S*T	L, obs	10	145.3	15.24
A+BM+S+T+S*A+S*BM+S*T	L, obs	12	156.7	26.62
GS+A+BM+S+T+GS*S+S*A+S*BM+S*T	L, obs	14	165.5	35.42

393 “S” is sex of the subordinate, “A” is age of the subordinate, “T” is treatment, “GS” means group
 394 size during the babysitting period, “BM” is the age-corrected body mass.
 395

396 **Table S2.** AIC_c model selection for identifying the effects of the treatments on the probability
 397 that pupfeeding occurred during our behavioural focal observations. All models were generalized
 398 linear mixed-effects models (binomial errors) that were fit by maximum likelihood and included
 399 random intercept terms for identity of the subordinate meerkat (ID), litter identity (L), and
 400 observer that collected the behavioural data (O). Results from the model presented in the main
 401 text shown in bold. Model averaging results for the two top models (italicized) containing
 402 biological variables are shown in Table S11.

Fixed Effects	Random Effects	<i>K</i>	AIC_c	ΔAIC_c
Null	ID, L, O	4	306.3	0
<i>F+S+T+S*T</i>	<i>ID, L, O</i>	<i>10</i>	<i>311.6</i>	<i>5.35</i>
<i>F+S+T</i>	<i>ID, L, O</i>	8	313.1	6.84
F+S+LS+S+T+S*T	ID, L, O	12	314.1	7.85
F+A+FS+S+T	ID, L, O	10	314.8	8.51
F+S+T+F*T+S*T	ID, L, O	12	315	8.69
F+S+T+F*T	ID, L, O	10	316.5	10.21
F+GS+LS+S+T+F*T	ID, L, O	12	317.1	10.78
F+GS+LS+A+FS+S+T+F*T	ID, L, O	14	317.2	10.89
F+A+FS+S+T+F*T+S*T	ID, L, O	14	317.5	11.24
F+GS+LS+S+T+F*T+S*T	ID, L, O	14	317.7	11.39
F+A+FS+S+T+F*T	ID, L, O	12	318.4	12.17
F+GS+LS+A+FS+S+T+F*T+S*T	ID, L, O	16	319.2	12.96

403 “F” indicates whether the subordinate was fed or not on the same day of the behavioural
 404 observations, “S” is sex of the subordinate, “A” is age of the subordinate, “T” is treatment, “GS”
 405 means group size during the pupfeeding period, “LS” is the litter size of pups that were foraging
 406 with the group, “FS” is the foraging success of the subordinate during the focal observation
 407 session (total grams of prey biomass found). Sample sizes for each treatment were as follows:
 408 controls (n=7 females, n=7 males), cortisol (n=10 females, n=4 males), and mifepristone (n=8
 409 females, n=7 males) whose behaviour was recorded for 400-1200 min (see main text).
 410

411 **Table S3.** AIC_c model selection for identifying the effects of the treatments on the proportion of
 412 biomass that was found by subordinates and subsequently fed to pups foraging with the group
 413 (“generosity”) during our behavioural focal observations. All models were generalized linear
 414 mixed-effects models (binomial errors) that were fit by maximum likelihood and included a
 415 random intercept term for identity of the subordinate meerkat (ID), litter identity (L), and
 416 observer (O). Results from the model presented in the main text shown in bold. Model averaging
 417 results for the two top models (italicized) containing biological variables are shown in Table S12.

Fixed Effects	Random Effects	K	AIC_c	ΔAIC_c
Null	ID, L, O	4	257.4	0
<i>F+S+T+S*T</i>	<i>ID, L, O</i>	<i>10</i>	<i>263.2</i>	<i>5.8</i>
<i>F+S+T</i>	<i>ID, L, O</i>	8	264.6	7.2
F+A+S+T	ID, L, O	9	265.3	7.9
F+S+T+F*T+S*T	ID, L, O	12	265.4	8.0
F+GS+LS+S+T+S*T	ID, L, O	12	265.6	8.2
F+S+T+F*T	ID, L, O	10	266.4	9.0
F+GS +LS+S+T+F*T+S*T	ID, L, O	13	266.9	9.5
F+A+S+T+F*T	ID, L, O	11	267.2	9.8
F+GS+LS+S+T+F*T+S*T	ID, L, O	14	267.9	10.5
F+GS+LS+A+S+T+F*T+S*T	ID, L, O	15	269.5	12.1
F+GS+LS+S+T+F*T	ID, L, O	12	269.7	12.3
F+GS+LS+A+S+T+F*T	ID, L, O	13	270	12.6

418 Variable abbreviations are the same as described for Tables S1 and S2. Sample sizes for each
 419 treatment were as follows: controls (n=7 females, n=7 males), cortisol (n=10 females, n=4
 420 males), and mifepristone (n=8 females, n=7 males) whose behaviour was recorded for 400-1200
 421 min (see main text).
 422

423 **Table S4.** AIC_c model selection for identifying the causes of variation in the amount of
 424 aggression subordinate meerkats received from the dominant female. All models were
 425 generalized linear mixed-effects models (Poisson error structure) that were fit by maximum
 426 likelihood and included random intercept terms for identity of the subordinate meerkat (I), social
 427 group (G), dominant female (DF), year (Y), and the *ad libitum* behavioural observation session
 428 (SS). Models included an offset for observation time. Results from top model (in bold) presented
 429 in Table S7.

Fixed Effects	Random Effects	K	AIC_c	ΔAIC_c
S+A+BM+GST+R+SR+GS+GS²+SN+S*A+S*B M+S*GST	I, G, DF, Y, SS	22	18690.2	0
S+A+BM+GST+R+SR+GS+GS ² +SN+S*A+S*BM	I, G, DF, Y, SS	19	18693.3	3.0
S+A+BM+GST+R+SR+GS+GS ² +SN+S*A+S*BM +S*GST+S*R+S*SR+S*GS+S*GS ²	I, G, DF, Y, SS	26	18694.9	4.7
S+A+BM+GST+R+SR+GS+GS ² +SN+S*GST+S*R +S*SR+S*GS+S*GS ²	I, G, DF, Y, SS	24	18762.4	72.1
S+A+BM+GST+R+SR+GS+GS ² +SN	I, G, DF, Y, SS	17	18771.5	81.2
S+A+BM	I, G, DF, Y, SS	10	18806.4	116.2
S+A+BM+GST+R+SR+GS+GS ² +SN+S*GST	I, G, DF, Y, SS	20	18847.1	156.9
S+GST+R+SR+GS+GS ² +SN	I, G, DF, Y, SS	15	19250.9	560.7
Null	I, G, DF, Y, SS	6	19343.1	652.9

430 “S” is sex of the subordinate, “A” is age of the subordinate, “BM” is the age-corrected body
 431 mass, “GST” or group stage is a 4-level-level categorical variable to indicate whether there were
 432 pups at the burrow being babysat, pups foraging with the group that were being pupped by
 433 subordinates, no pups in the group and the dominant female was pregnant, or no pups in the
 434 group and the dominant female was not pregnant, “R” is relatedness of the subordinate to the
 435 dominant female, “SR” is the proportion of females in the group (group sex ratio), “GS” means
 436 group size during the pupfeeding period and “GS²” is a quadratic term for group size, and “SN”
 437 is season. Data used in these analyses were collected from >110,483 hours of behavioural data
 438 collected over 19 years that provided us with rates of aggression by 98 dominant females
 439 towards 1520 subordinates (713 females, 807 males) in 40 different groups.
 440

441 **Table S5.** AIC_c model selection for identifying how the amount of aggression subordinate
 442 meerkats received from the dominant female affected their relative babysitting contributions. All
 443 models were generalized linear mixed-effects models (binomial error structure) that were fit by
 444 maximum likelihood and included random intercept terms for identity of the subordinate meerkat
 445 (I), litter (L), dominant female (DF), and year (Y). Results from top model presented in Table S8.

Fixed Effects	Random Effects	K	AIC_c	ΔAIC_c
S+A+BM+GS+Agg+S*A+S*BM+S*GS+S*Agg	I, L, DF, Y	15	39188.3	0
S+A+BM+GS+Agg+S*Agg	I, L, DF, Y	12	39338.2	149.9
S+A+BM+GS+Agg	I, L, DF, Y	11	39343.3	155
S+A+BM+Agg+S*A+S*BM	I, L, DF, Y	12	39618.1	429.8
S+A+BM+Agg+S*Agg	I, L, DF, Y	11	39759.1	570.8
S+A+BM+Agg	I, L, DF, Y	10	39762.7	574.4
S+GS+Agg+S*GS+S*Agg	I, L, DF, Y	11	40404.5	1216.2
S+GS+Agg+S*Agg	I, L, DF, Y	10	40439.9	1251.6
S+GS+Agg	I, L, DF, Y	9	40449.6	1261.3
S+Agg+S*Agg	I, L, DF, Y	9	40724.5	1536.2
S+Agg	I, L, DF, Y	8	40731.5	1543.2
Null	I, L, DF, Y	5	40789.4	1601.12

446 Variable abbreviations are the same as described for Table S4 except here “Agg” is the amount
 447 of aggression the subordinate received from the dominant female (number of assertions received
 448 over observation time). Data used in these analyses are from 9410 estimates of babysitting
 449 contributions from 1487 subordinate meerkats during 639 different litters produced by 96
 450 different dominant females over the 19 years.
 451

452 **Table S6.** AIC_c model selection for identifying how the amount of aggression subordinate
 453 meerkats received from the dominant female affected the probability of pupfeeding during *ad*
 454 *libitum* behavioural observations. All models were generalized linear mixed-effects models
 455 (binomial error structure) that were fit by maximum likelihood and included random intercept
 456 terms for identity of the subordinate meerkat (I), litter (L), dominant female (DF), and year (Y).
 457 Models included an offset for observation time. Results from top model presented in Table S9.

Fixed Effects	Random Effects	K	AIC_c	ΔAIC_c
LS+S+A+BM+GS+Agg+S*A+S*BM+S*GS+S*Agg	I, L, DF, Y	15	6460.8	0
LS+S+A+BM+GS+Agg+S*Agg	I, L, DF, Y	12	6466.1	5.27
LS+S+A+BM+GS+Agg	I, L, DF, Y	11	6467.1	6.28
LS+S+A+BM+Agg+S*A+S*BM	I, L, DF, Y	12	6500.2	39.42
LS+S+A+BM+Agg+S*Agg	I, L, DF, Y	11	6507.6	46.78
LS+S+A+BM+Agg	I, L, DF, Y	10	6508.9	48.13
LS+S+GS+Agg+S*Agg	I, L, DF, Y	10	6813.2	352.41
LS+S+GS+Agg	I, L, DF, Y	9	6815.0	354.21
LS+S+GS+Agg+S*GS+S*Agg	I, L, DF, Y	11	6815.1	354.3
LS+S+Agg+S*Agg	I, L, DF, Y	9	6840.7	379.86
LS+S+Agg	I, L, DF, Y	8	6842.8	381.98
Null	I, L, DF, Y	5	7101.0	640.16

458 Variable abbreviations are the same as described for Table S5 but here “LS” refers to the litter
 459 size or number of pups that were foraging with the group. Data used in these analyses were from
 460 7619 estimates of the probability of exhibiting pupfeeding by 1626 subordinates towards pups
 461 from 544 different litters produced by 92 dominant females over 20 years.
 462

463 **Table S7.** Results from a generalized linear mixed-effects model to examine the causes of
 464 variation in the amount of aggression subordinate meerkats received from the dominant female.
 465 This model (Poisson error structure) included random intercept terms for identity of the
 466 subordinate meerkat, litter, dominant female, year, and the *ad libitum* behavioural observation
 467 session. An offset for observation time was included. Reference for the categorical variables
 468 described below and in parentheses where applicable. Significant variables in bold.

Fixed Effect	b ± SE	z	P-value
Intercept	-9.6 ± 0.12	-77.8	<0.0001
Sex (Male)	-0.8 ± 0.09	-8.5	<0.0001
Age	0.77 ± 0.04	19.2	<0.0001
Body mass	0.34 ± 0.03	9.53	<0.0001
Group stage			
Babysitting groups	-0.59 ± 0.19	-3.1	0.002
Pupfeeding groups	-0.23 ± 0.11	-2.01	0.044
Dom. Fem. Not Pregnant, No Pups	-0.54 ± 0.15	-3.7	0.0002
Dom. Fem. Mom or Sister? (No)	0.08 ± 0.08	-1.02	0.31
Sex ratio	-0.05 ± 0.05	-0.88	0.38
Group size	0.08 ± 0.21	0.39	0.69
Group size²	-0.45 ± 0.22	-2.06	0.039
Season	0.08 ± 0.09	0.8	0.42
Sex (Male) x Age	-0.49 ± 0.05	-8.9	<0.0001
Sex (Male) x Body mass	-0.11 ± 0.05	-1.92	0.055
Sex (Male) x Group stage			
Sex (Male) x Babysitting groups	0.55 ± 0.2	2.73	0.006
Sex (Male) x Pupfeeding groups	0.16 ± 0.11	1.53	0.13
Sex (Male) x Dom. Fem. Not Preg., No Pups	0.27 ± 0.16	1.69	0.09

469 “Dom. Fem. Not Pregnant, No Pups”, “Babysitting groups”, and “Pupfeeding groups” described
 470 the group stage (GST in Table S4) where the reference level was that the dominant female was
 471 pregnant and there were no pups in the group. “Dom. Fem. Mom or Sister?” was a two-level
 472 categorical variable to indicate whether the dominant female in the group where the subordinate
 473 was observed was either the mom or sister of the subordinate (reference level was that the
 474 dominant female was not the mother or full sister). “Season” was a two-level categorical variable
 475 to indicate whether the behavioural data were collected in the summer or winter months
 476 (reference level was summer). Reference level for “Sex” was female. The results from this model
 477 are based upon 58568 estimates of the amount of aggression 1520 subordinates received from 98
 478 dominant females in 40 different social groups over 19 years during 5120 *ad libitum* behavioural
 479 observation sessions.

480

481 **Table S8.** Results from a generalized linear mixed-effects model to examine how the amount of
 482 aggression subordinate meerkats received from the dominant female affected their babysitting
 483 contributions. This generalized linear mixed-effects model (binomial error structure) included
 484 random intercept terms for identity of the subordinate meerkat, litter, dominant female, and year.
 485 Reference for the categorical variables described below and in parentheses where applicable.
 486 Significant variables in bold.

Fixed Effect	b ± SE	z	P-value
Intercept	-2.49 ± 0.04	-60.8	<0.0001
Sex (Male)	-0.31 ± 0.03	-11.2	<0.0001
Age	0.36 ± 0.02	20.2	<0.0001
Body mass	0.26 ± 0.02	14.6	<0.0001
Group size	-0.39 ± 0.02	-21.2	<0.0001
Aggression received	-0.003 ± 0.007	-0.48	0.63
Sex (Male) x Age	-0.21 ± 0.02	-10.4	<0.0001
Sex (Male) x Body mass	-0.06 ± 0.02	-2.9	0.004
Sex (Male) x Group size	-0.03 ± 0.02	-1.96	0.049
Sex (Male) x Aggression received	-0.013 ± 0.01	-0.94	0.34

487 Reference level for sex was female. “Aggression received” is the amount of aggression the
 488 subordinate received from the dominant female (number of assertions received over observation
 489 time). The results from this model are based upon 9410 estimates of babysitting contributions
 490 from 1487 subordinate meerkats during 639 different litters produced by 96 different dominant
 491 females over the 19 years.
 492

493 **Table S9.** Results from a generalized linear mixed-effects model to examine how the amount of
 494 aggression subordinate meerkats received from the dominant female affected the probability of
 495 observing pupfeeding during *ad libitum* behavioural observations. This generalized linear mixed-
 496 effects model (binomial error structure) included random intercept terms for identity of the
 497 subordinate meerkat, litter, dominant female, and year. An offset for observation time was
 498 included. Reference for the categorical variables described below and in parentheses where
 499 applicable. Significant variables in bold.

Fixed Effect	b ± SE	z	P-value
Intercept	1.8 ± 0.36	4.98	<0.0001
Litter size	0.32 ± 0.1	3.28	0.001
Sex (Male)	-0.62 ± 0.1	-5.9	<0.0001
Age	-0.02 ± 0.09	-0.26	0.79
Body mass	1.02 ± 0.09	11.91	<0.0001
Group size	-0.68 ± 0.12	-5.57	<0.0001
Aggression received	-0.01 ± 0.04	-0.26	0.8
Sex (Male) x Age	0.26 ± 0.1	2.57	0.01
Sex (Male) x Body mass	-0.23 ± 0.09	-2.44	0.014
Sex (Male) x Group size	-0.03 ± 0.09	-0.33	0.74
Sex (Male) x Aggression received	0.14 ± 0.09	1.59	0.11

500 Reference level for sex was female. “Aggression received” is the amount of aggression the
 501 subordinate received from the dominant female (number of assertions received over observation
 502 time). The results from this model are based upon 7619 estimates of the probability of exhibiting
 503 pupfeeding by 1626 subordinates towards pups from 544 different litters produced by 92
 504 dominant females over 20 years.
 505

506 **Table S10.** Results from model averaging from the two models containing biological predictor
 507 variables with the lowest AIC_c from Table S1 regarding the treatment effects on babysitting
 508 behaviour. These generalized linear mixed-effects models included random intercept terms for
 509 identity of the litter and an individual-level for observation. Reference for the categorical
 510 variables described below. Significant terms in bold and based upon whether 95% CI overlaps 0.

Fixed Effect	b ± SE	95% CI
Intercept	-1.69 ± 0.14	-1.97 - -1.4
Sex (Male)	0.16 ± 0.18	-0.23 - 0.54
Treatment		
Control	-0.46 ± 0.23	-0.93 - 0.02
Cortisol	-0.47 ± 0.18	-0.9 - -0.04
Group size	-0.04 ± 0.07	-0.29 - 0.05

511 “Treatment” was a three-level categorical variable to indicate whether the behavioural data were
 512 collected from control individuals or individuals treated with cortisol or mifepristone (reference
 513 level). Reference level for “Sex” was female.
 514

515 **Table S11.** Results from model averaging from the two models containing biological predictor
 516 variables with lowest AIC_c from Table S2 regarding the treatment effects on the probability of
 517 pupfeeding behaviour. These generalized linear mixed-effects models included random intercept
 518 terms for identity of the subordinate meerkat, litter, and observer. Reference for the categorical
 519 variables described below. Significant terms in bold and based upon whether 95% CI overlaps 0.

Fixed Effect	b ± SE	95% CI
Intercept	0.37 ± 0.59	-0.8 – 1.54
Treated prior to focal?	0.04 ± 0.36	-0.66 – 0.75
Sex (Male)	-1.35 ± 0.83	-2.99 – 0.29
Treatment		
Control	-0.79 ± 0.69	-2.16 – 0.56
Cortisol	-0.84 ± 0.75	-2.33 - 0.64
Sex (Male) x Treatment		
Sex (Male) x Control	-0.49 ± 1.0	-0.49 – 3.22
Sex (Male) x Cortisol	1.59 ± 1.35	0.45 – 4.25

520 “Treatment” was a three-level categorical variable to indicate whether the behavioural data were
 521 collected from control individuals or individuals treated with cortisol or mifepristone (reference
 522 level). Reference level for “Sex” was female.

523
 524

525 **Table S12.** Results from model averaging from the two models containing biological predictor
 526 variables with lowest AIC_c from Table S3 regarding the treatment effects on the proportion of
 527 biomass that was found by subordinates and subsequently fed to pups foraging with the group
 528 (“generosity”) during our behavioural focal observations. These generalized linear mixed-effects
 529 models included random intercept terms for identity of the subordinate meerkat, litter, and
 530 observer. Reference for the categorical variables described below. Significant terms in bold and
 531 based upon whether 95% CI overlaps 0.

Fixed Effect	b ± SE	95% CI
Intercept	-2.66 ± 0.58	-3.81 – -1.51
Treated prior to focal?	0.2 ± 0.32	-0.42 – 0.83
Sex (Female)	0.41 ± 0.68	-0.93 – 1.76
Treatment		
Control	0.37 ± 0.49	-0.58 – 1.33
Cortisol	1 ± 0.67	-0.32 - 2.33
Sex (Female) x Treatment		
Sex (Female) x Control	-0.36 ± 0.64	-1.96 – 0.89
Sex (Female) x Cortisol	-1.2 ± 1.05	-3.31 – -0.29

532 Variable descriptions as in Table S11. Reference level for “Sex” was male.
 533