

1 **Social influences on delayed gratification in New Caledonian**  
2 **crows and Eurasian jays**

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4 Rachael Miller <sup>1,2\*</sup>, James R. Davies <sup>2\*</sup>, Martina Schiestl <sup>3</sup>, Elias Garcia-Pelegriñ <sup>4</sup>, Russell D. Gray <sup>5,9</sup>,  
5 Alex H. Taylor <sup>5-8</sup>, Nicola S. Clayton <sup>2</sup>

6  
7 <sup>1</sup> School of Life Sciences, Anglia Ruskin University, Cambridge, UK

8 <sup>2</sup> Department of Psychology, University of Cambridge, Cambridge, UK

9 <sup>3</sup> Faculty for Veterinary Medicine, University of Veterinary Science, Brno, South Moravia, Czech  
10 Republic

11 <sup>4</sup> Department of Psychology, National University of Singapore, Singapore

12 <sup>5</sup> ICREA, Barcelona, Spain

13 <sup>6</sup> Institut de Neurociències, Universitat Autònoma de Barcelona, Barcelona, Spain

14 <sup>7</sup> School of Biological Sciences, University of Canterbury, Christchurch, New Zealand

15 <sup>8</sup> School of Psychology, The University of Auckland, Auckland, New Zealand

16 <sup>9</sup> Max Planck Institute for the Science of Human History, Max Planck Society, Jena, Germany

17

18 \*Corresponding authors

19 E-mail: [rh87@aru.ac.uk](mailto:rh87@aru.ac.uk) (RM); [jd940@cam.ac.uk](mailto:jd940@cam.ac.uk) (JD)

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21 <sup>†</sup> RM and JD are Joint First Authors

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24 **Abstract**

25

26 Self-control underlies goal-directed behaviour in humans and other animals. Delayed gratification - a  
27 measure of self-control - requires the ability to tolerate delays and/or invest more effort to obtain a reward  
28 of higher value over one of lower value, such as food or mates. Social context, in particular, the presence  
29 of competitors, may influence delayed gratification. We adapted the 'rotating-tray' paradigm, where  
30 subjects need to forgo an immediate, lower-quality (i.e. less preferred) reward for a delayed, higher-quality  
31 (i.e. more preferred) one, to test social influences on delayed gratification in two corvid species: New  
32 Caledonian crows and Eurasian jays. We compared choices for immediate vs. delayed rewards while alone,  
33 in the presence of a competitive conspecific and in the presence of a non-competitive conspecific. We  
34 predicted that, given the increased risk of losing a reward with a competitor present, both species would  
35 similarly, flexibly alter their choices in the presence of a conspecific compared to when alone. We found  
36 that species differed: jays were more likely to select the immediate, less preferred reward than the crows.  
37 We also found that jays were more likely to select the immediate, less preferred reward when a competitor  
38 or non-competitor was present than when alone, or when a competitor was present compared to a non-  
39 competitor, while the crows selected the delayed, highly preferred reward irrespective of social presence.  
40 We discuss our findings in relation to species differences in socio-ecological factors related to adult  
41 sociality and food-caching (storing). New Caledonian crows are more socially tolerant and moderate  
42 cachers, while Eurasian jays are highly territorial and intense cachers that may have evolved under the  
43 social context of cache pilfering and cache protection strategies. Therefore, flexibility (or inflexibility) in  
44 delay of gratification under different social contexts may relate to the species' social tolerance and related  
45 risk of competition.

46

47 **Introduction**

48  
49 Self-control underlies decision-making and future planning, ensuring individuals are able to perform goal-  
50 directed behaviours. This process is important for humans and other animals [1, 2]. Self-control is  
51 influenced by socio-environmental factors in humans. For instance, it correlates with behavioural  
52 problems like substance abuse [3], and with measures of success, like social and academic competence  
53 [4]. It is also influenced by socio-environmental factors in other animals, such as sociality [5]. One  
54 measure of self-control is the ability to delay gratification, i.e. to tolerate a delay and/or invest more effort  
55 to obtain a reward of higher value over one of lower value, such as food or mates [6]. It has been tested  
56 comprehensively using various paradigms in many species, including primates and birds [7-13]. For  
57 instance, in the exchange paradigm, subjects may choose to swap rewards with a conspecific or  
58 experimenter for a more preferred reward [14].

59 However, the role of social context on self-control is still relatively unexplored. In humans, the  
60 presence and behaviour of others can influence our own decisions [15]. For example, children engage  
61 higher cognitive control when competing or cooperating with another person [16] and are less likely to  
62 delay gratification when the experimenter behaves in an unreliable/ untrustworthy manner [17].  
63 Flexibility in self-control is likely to be important in a social context in non-human animals too, for  
64 instance, refraining from approaching food or a potential mate while in the presence of a competitor [18,  
65 19]. There are few delayed gratification studies that require interaction and co-operation with a  
66 conspecific, mostly using the token-exchange paradigm in primates [20, 21]. For example, high-ranking  
67 capuchin monkeys quickly acquired token exchange behaviour in social contexts, though low-ranking  
68 ones did not display this behavior [22]. There is therefore scope for developing tasks that explore the  
69 influence of social context and the behaviour of others on self-control.

70 Corvids (members of the crow family) have been found to differ in their ability to delay gratification  
71 [10, 23]. Corvids differ in sociality, i.e. living in a variety of different social systems [24]. For example,  
72 some corvids, such as Eurasian jays (E jays: *Garrulus glandarius*), are most often found alone or within a  
73 (socially) monogamous pair, who fiercely protect their own individual territories [24]. At the other

74 extreme are the highly social corvids, such as rooks (*Corvus frugilegus*) and Western jackdaws (*Coloeus*  
75 *monedula*), who form large aggregations of up to 60,000 individuals [24], in which there can be a strong  
76 social hierarchy and colonial breeding [25]. Other species, such as New Caledonian crows (NC crows:  
77 *Corvus moneduloides*), common ravens (*Corvus corax*) and carrion crows (*Corvus corone*), show more  
78 flexibility in their sociality depending on season and age [26]. They sometimes remain within mating  
79 pairs or otherwise form larger family groups with overlapping territories and even showing some  
80 instances of cooperative breeding [24].

81 Studies suggest that corvids possess complex cognitive abilities, such as the ability to plan for the  
82 future [27, 28], mentally represent problems [29, 30], make inferences [31-33], and learn abstract  
83 information [34, 35]. In the social domain, corvids show evidence for co-operative behaviors [36]; [37,  
84 38] and seem to be aware of what other individuals can see and flexibly adjust their behaviour in  
85 response. For example, ravens differentiate between knowledgeable and ignorant conspecifics [39] even  
86 after controlling for observable behavioural cues [19, 40]. Furthermore, Western scrub jays (*Aphelocoma*  
87 *californica*) re-cache their food if they have been observed by a potential pilferer during caching, but not  
88 after caching in private [41] or when observed by their mate [42]. Importantly, this re-caching only occurs  
89 when the caching jays have themselves had experience of pilfering other individuals' caches [41].

90 Western scrub jays (*Aphelocoma californica*) are able to keep track of which birds were watching  
91 them during caching, as they only defend caches against subordinates and are tolerant to their partner  
92 sharing food [42]. Like scrub-jays, Eurasian jays have also demonstrated the use and flexible deployment  
93 of various cache-protection strategies [43-46] (although see [47]). Jays cached more behind an occluder  
94 [43] and at a distance [44] when observed by a conspecific than when alone, preferentially cached less in  
95 a 'noisy' substrate when a conspecific could hear but not see them (but not when they could hear and see  
96 them) [45].

97 There is variation across species in the socio-cognitive abilities of corvids. Some evidence suggests  
98 that these abilities vary with the species' natural sociality. For example, when comparing highly social  
99 pinyon jays (*Gymnorhinus cyanocephalus*) with less social Western scrub-jays on two complex tasks

100 related to tracking and assessing social relationships, the pinyon jays learned more rapidly and were  
101 significantly more accurate than the scrub jays [48]. Additionally, the ability to remember the locations of  
102 conspecific made caches (observation spatial memory) in order to take them later, seems to vary in line  
103 with a species' sociality, with social Mexican jays (*Aphelocoma ultramarina*) out-performing less social  
104 Clark's nutcrackers (*Nucifraga columbiana*) [49].

105 Clark's nutcrackers, considered to be relatively solitary in the wild, are also able to perform a variety  
106 of cache protection strategies in the presence of a conspecific [50]. Moreover, other recent evidence  
107 suggests that variation in observational spatial memory is more related to a species' dependence on  
108 caches than their degree of sociality, as less social but frequent-caching ravens performed above chance  
109 levels in an observational spatial memory task, whereas highly social but rarely-caching jackdaws did not  
110 [51]. Therefore, the degree to which a corvids' social system influences their socio-cognitive abilities  
111 remains unclear. That said, recent research investigating the behavioral flexibility of (highly social)  
112 pinyon jays and (less social) Clark's nutcrackers under different social contexts, in which subjects were  
113 tested on their caching strategies whilst alone, observed by a conspecific, or observed by a heterospecific,  
114 suggests that each species uses different cache protection behaviors. These behaviors seem to be elicited  
115 by different social cues, which can be explained in relation to the species' social organization [52].  
116 However, very few studies have explored delayed gratification abilities in a social context, particularly in  
117 taxa that differ in sociality.

118 We aimed to test the flexibility of delayed gratification in a social context in two corvid species -  
119 New Caledonian crows (NC crows) and Eurasian jays (E jays) - exploring their choices for immediate vs  
120 delayed rewards (varying in quality and preference) while alone compared with in the presence of  
121 conspecific(s). We selected these two species as they differ in adult sociality, as outlined above, and they  
122 also differ in intensity with which they cache food (NC crows: moderate, i.e. cache variety of food types  
123 through-out the year, not entirely dependent on caches for survival; E jays: specialized cachers, i.e. hide  
124 large amounts of predominately one food type, usually seasonally available) [24, 53]. Furthermore, both  
125 species delay gratification in previous studies, though not tested comparatively with the same paradigm or

126 in a social context. Schnell et al [54] found that delay of gratification correlated with measures of general  
127 intelligence in Eurasian jays. Miller et al [55] found that New Caledonian crows are better able to delay  
128 gratification when rewards varied in quality over quantity and struggled when rewards (immediate or  
129 delayed) were not visible compared with being visible.

130 We used an adapted automatic rotating tray delayed gratification paradigm first introduced in a  
131 capuchin (*Cebus apella*) study by Bramlett et al. [56], which we have used previously to test New  
132 Caledonian crows and young children by Miller et al. [55], where subjects were required to choose  
133 between an immediate reward or wait for a delayed one. The advantage of this paradigm is that it requires  
134 minimal pre-training (compared to exchange paradigm) and does not require interaction with an  
135 experimenter. While the rotating tray paradigm has not been used in Eurasian jays previously, this species  
136 has been tested using other delay of gratification paradigms (inter-temporal delay maintenance task:  
137 Schnell et al., [54]). We used a within-subject, repeated measures design and rewards that differed in  
138 quality.

139 We tested whether corvids can flexibly alter their decision as to whether to wait for a better reward in  
140 response to current social conditions, specifically, whilst alone, in a competitive situation (e.g. dominant  
141 conspecific), vs a non/less competitive one (subordinate conspecific). We compared behavioural choices  
142 between conditions on the individual and species level, and where possible, compared performance  
143 between species. Based on our hypothesis that delayed gratification will vary under different social  
144 contexts, we predicted that both species may alter their behaviour in the presence of a conspecific  
145 compared to being alone, particularly when the conspecific was a competitor. We expected that the birds  
146 may wait for the higher-quality (i.e. more preferred) reward when alone (as in Miller et al., [55]) and  
147 potentially with a non-competitor conspecific, but may choose the lower-quality, immediate reward (even  
148 though less preferred) when a competitor was present (Table 1), as waiting would risk losing the reward  
149 to a competitor, leaving the focal bird with nothing. We tested whether there was a difference in  
150 performance between species, as their socio-ecological backgrounds (i.e., NCC: more socially tolerant,  
151 moderate cachers; EJ: less socially tolerant, specialized cachers) may influence levels of flexibility in

152 delay of gratification across social contexts. However, given the expected increased risk of losing a  
153 reward when a competitor was present, we predicted that both species would similarly alter their  
154 behaviour in the presence of a competitive conspecific compared to being alone.

155

156 **Table 1. Predicted selections by condition (social context)**

Condition	Prediction for test trial selection
Alone (i.e. baseline)	Delayed; higher-quality reward
Non/less-competitor	Delayed; higher-quality reward
Competitor	Immediate; higher or lower-quality reward

157

## 158 **Materials and methods**

159

### 160 **Subjects**

161

#### 162 **New Caledonian crows**

163 Eleven New Caledonian crows (NC crows) were caught from the wild (at location 21.67°S 165.68°E) on  
164 Grand Terre, New Caledonia, for temporary holding in captivity on the Island for non-invasive behavioural  
165 research purposes from April to August 2019, of which six were available for inclusion in this study. The  
166 other five birds were not available as they were engaged in other parallel experiments at the field site, with  
167 data collection period limited by season length and experimenter availability. There were three males and  
168 three females, based on sexual size dimorphism [57], of which one was adult, two were in their second year  
169 (not breeding, remaining in their family group) and three were juveniles (less than 1 year old) (S1 Table).

170 The birds were identifiable with leg-rings (crows were ringed post-capture). During the field season, all  
171 crows took part in several experiments, including making forced 2-choices (e.g. between 2 tools or food  
172 types) and interacting with artificial apparatuses (e.g. [55]). The birds were housed in a ten-compartment  
173 outside aviary, with compartments differing in size, though all at least 2 x 3 x 3m, containing a range of  
174 natural enrichment materials like logs, branches and pinecones. Subjects were tested individually in  
175 temporary visual isolation from the group, while willingly participating in the study for food rewards to  
176 enhance their motivation. The birds were not food deprived and their daily diet consisted of meat, dog food,  
177 and fruit, with water available *ad libitum*. The birds maintained at or above capture weights during their  
178 stay in captivity. The birds were acclimatized to the aviaries in April and habituated to the experimental  
179 apparatus in May, completing the study in August 2019. At the end of their research participation, birds  
180 were released at their capture sites. Hunt [58] indicated that New Caledonian crows housed temporarily in  
181 a similar situation as the present study successfully reintegrated into the wild after release.

182

### 183 **Eurasian jays**

184 Eight Eurasian jays (E jays; four males; four females; all adults: S1 Table) participated in this study from  
185 September 2022 to May 2023, of which five jays reached criterion for testing. All jays were hand-reared at  
186 10 days old from wild eggs collected by a registered breeder under a Natural England License to NSC  
187 (20140062) in 2015. The jays were housed together within a large outdoor aviary (20 m long × 10 m wide  
188 × 3 m high) at the Sub-Department of Animal Behaviour, University of Cambridge, Madingley,  
189 Cambridgeshire, UK. One end of the aviary was divided into smaller subsections (6 × 2 × 3 m), used to  
190 separate mate pairs during the breeding season. Hatch doors connected these subsections to separate indoor  
191 testing compartments (each 2 x 1 x 2 m) and could be opened or closed to isolate individuals. Subjects were  
192 identified using unique leg-ring color combinations. The jays had *ad libitum* access to water (including  
193 during testing) and were fed a mixture of soaked dog or cat biscuits, boiled eggs, boiled vegetables, seeds,  
194 and fruit, twice a day. During test days, this food was removed from the aviary approximately 1 hour before

195 testing to increase the birds' motivation to come inside the testing compartments and to participate in  
196 experimental trials. The birds were only food restricted for a maximum of 4 hours in one day, although as  
197 they habitually cache food, they may have had access to non-test foods during this time. All subjects  
198 participated on a voluntary basis (to maximize motivation) and were separated from the group once they  
199 entered the testing compartment (by closing the hatch door). When interacting with the birds, the  
200 experimenter stood by a window in one of the test compartments.

201

## 202 **Materials**

203

### 204 **Apparatus**

205 The main apparatus used in this experiment was the same as that deployed in Miller et al., [55]. This  
206 consisted of a 38 cm diameter raised disk, fitted on top of a rotation device (moving at a speed of 68 s per  
207 revolution) which was operated using a remote control (Fig 1). The rotating disk was enclosed within a  
208 transparent Perspex box (41 cm × 34 cm × 14 cm) with a rectangular opening at one side (29 cm × 7 cm),  
209 to prevent the birds from accessing the rewards until they were positioned directly in front of the subjects.  
210 Two small upturned, transparent plastic cups (with a string attached to facilitate cup flipping) covered the  
211 rewards and were positioned at two standardized locations on the disk, so that the first reward reached the  
212 subject after 5 s (the immediate reward), whereas the second reward reached the subject after 15 s (the  
213 delayed reward). Both cups were baited simultaneously. To standardize the position of the birds at the  
214 beginning of the trial, the tray was only started once the bird moved to be in front of the tray. The bird made  
215 a choice by touching the cup and flipping it to access the reward. Once contact was made with either of the  
216 cups, the rotating tray was stopped, meaning they were only allowed to make one choice.

217

### 218 **Procedure**

219

## 220 **Pretraining**

221 **Food preference.** Before the main training stage, the relative preference for each food type was established  
222 per individual. To do this, both food types (high-quality: meat, low-quality: apple for NC crows; and high-  
223 quality: mealworm, low-quality: bread for E jays) were presented simultaneously in front of each subject  
224 (individually isolated in the test compartment). The bird was then allowed to choose one reward and was  
225 subsequently prevented from obtaining the other food item. This was repeated for 10 trials per session until  
226 the bird reached the criterion of choosing the high-quality reward 17/20 times (in two consecutive sessions).  
227 The position (right or left) of the high-quality reward was pseudorandomized so that it was not in the same  
228 location more than twice in a row. We intended to exclude a bird if it did not pass criterion within 10  
229 sessions. However, all six NC crows passed within 2 sessions, and all eight E jays passed within 7 sessions  
230 (ranging from 2-7).

231

232 **Habituation.** To habituate the birds to the apparatus, they were gradually exposed to the apparatus in  
233 multiple phases; progressing each phase when they began taking food comfortably. First, the tray remained  
234 turned off (and so not moving) with the food placed near it. Then, the apparatus was switched on (moving)  
235 with food again placed near it. Next, the food was placed on top of the moving tray. Finally, the food was  
236 placed on top of the moving tray and the experimenter turned the tray off and on again (after each piece of  
237 food was collected) to habituate the birds to the sound the tray makes when stopping and to tray movement.  
238 Each phase was done as a group (with each individual free to leave the compartment) and then subsequently  
239 as an individual (separated from the group within the compartment).

240

241 **Forced choice training.** For the birds to learn that they could only make one choice of food (causing the  
242 tray to stop) in each trial, they were given trials in which only one cup was baited and the other remained  
243 empty. As such, if the food was in the delayed position, and the bird selected the immediate cup, then they

244 did not receive a reward. In one session of 10 trials, the rewarded cup was placed at the immediate location  
245 5 times and at the delayed location 5 times, in a pseudorandomized order (so that the reward was not in the  
246 same location more than twice consecutively). The birds passed criterion for this phase when they chose  
247 the food in the delayed position in 9/10 trials across two consecutive sessions. If they failed to pass this  
248 criterion within 15 sessions (i.e., 150 trials) then they were discounted from the experiment. However, all  
249 six NC crows passed within 2 sessions, and all eight E jays passed within 14 sessions (ranging from 6-14).

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250  
251 **Food monopolization.** Before being tested in the test conditions, food monopolization tests were conducted  
252 to assess the relative dominance relationships between pairs of individuals to inform the assignment of non-  
253 focal birds (competitor/non-competitor) in these trials (S1 & S2 Tables). This was always done between  
254 two individuals isolated from the rest of the group. Choices of which birds to test as non-focal birds were  
255 informed by general observations of displacement and other competitive behaviors under non-test  
256 conditions. As we tested relative dominance, a single individual could be both a competitor and a non-  
257 competitor observer depending on the identity of the focal bird that they were paired with. To confirm the  
258 dominance ranking within the pair in food monopolization trials, the experimenter baited a cup on a  
259 platform whilst both birds observed, then simultaneously allowed both birds access to the baited cup. If the  
260 focal bird took the food without being displaced, then the non-focal bird was considered to be a non-  
261 competitor, but if the focal bird was displaced or did not attempt to obtain the food, then the non-focal bird  
262 was considered to be a competitor. Food monopolization trials were sometimes repeated (for the jays)  
263 immediately before test trials if observations suggested that the dominance relationships may have changed  
264 and non-focal birds re/assigned accordingly.

265

## 266 **Testing**

267 Upon successful completion of the forced choice phase and food monopolization trials, the birds began the  
268 test phase. This phase was made up of trials in three different conditions: 'alone', 'non-competitor', and

270 'competitor'. Each bird received 2 sessions per test condition (totaling to 20 trials each). In each session,  
271 8/10 trials were 'test' trials (in which the high-quality reward was in the delayed position, and the low-  
272 quality reward was in the immediate position) and the remaining 2/10 trials were 'control' trials (in which  
273 the high-quality reward was in the immediate position, and the low-quality reward was in the delayed  
274 position). Each individual received both alone sessions first, then the remaining two social conditions. The  
275 order in which the birds received the non-competitor and competitor sessions was counterbalanced across  
276 individuals. The stimulus birds were selected opportunistically and in accordance with the relationships  
277 determined by the food monopolization tests, and so occasionally varied between replicates (note that what  
278 is important here is not the identity of the stimulus bird, but their relationship with the focal bird). The  
279 conditions were then alternated every session for each bird (e.g., non-competitor, competitor, non-  
280 competitor, competitor). A choice was made once the bird touched either cup and were recorded as an  
281 immediate choice (Fig 1. a-c; S5 Resource a), a delayed choice (i-iii; S5 Resource b), or no choice (as the  
282 non-focal bird took either reward before the focal bird could or displaced the focal bird; no choices =  
283 competitor trials: n = 19, non-competitor trials: n = 1; S5 Resource 4c). During the social conditions, while  
284 the rotating tray was baited with food rewards, the competitor/ non-competitor observer bird remained in  
285 an adjacent compartment with the conjoining door shut. Before the immediate option became available to  
286 the focal bird, the observer bird was also allowed access to the rotating tray, and the focal bird's choice  
287 (immediate or delayed reward) was recorded. A timeline of the pretraining and testing phases can be found  
288 in S4 Fig. By design, there was a minimum and maximum of two sessions each for the competitor and non-  
289 competitor conditions.

290

291 **Figure 1. Diagram representing the potential choices the focal bird could make in test trials. (a-c),**  
292 **choosing the immediate option (less preferred choice); (i-iii), choosing the delayed option (more preferred**  
293 **choice). a) / i), Focal bird observes as the rotating tray is baited with both food types (at an equal distance**  
294 **from them) while the competitor observer bird remains in an adjacent compartment with the conjoining**  
295 **door shut. b) Just before the first option becomes available, the door between the compartments is opened,**

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298 allowing the non-focal bird access to the rotating tray. The focal bird then can either choose the immediate  
299 option (c) or ignore it as it passes (ii) and choose the delayed option once it becomes available (iii).

300

301 **Alone.** The birds first received alone trials to assess their baseline ability to delay gratification in a non-  
302 social context, as in these trials the bird was alone in the testing compartments. The six NC crows selected  
303 the high-quality reward in the 13/16 test choices within 2 sessions (S3 Table). However, the E jays required  
304 additional training to successfully complete these baseline trials and therefore E jays' sessions were  
305 repeated until an individual made 13/16 test choices (high-quality reward was at the delayed position) to  
306 the delayed reward in two consecutive sessions. These last two sessions were then used as the alone test  
307 condition. However, if the E jays did not reach this criterion in 15 sessions, they were excluded from the  
308 experiment. Five (three females; two males) of eight jays met this criterion (ranging from 3-8 sessions). We  
309 calculated 'learning speed' based on the number of trials to reach criterion in the alone condition (S3 Table).

310

311 **Non-competitor.** In these trials, the focal birds were tested with a non-competitor conspecific (determined  
312 by the food monopolization trials – see earlier) in an adjacent compartment. The non-focal bird was allowed  
313 access to the main test compartment (with the apparatus) just before the immediate reward became  
314 accessible (Fig 1). A trial was terminated once the focal bird made a choice.

315

316 **Competitor.** In these trials, the focal birds were tested with a conspecific competitor (determined by the  
317 food monopolization trials) in an adjacent compartment. The non-focal bird was allowed access to the main  
318 test compartment (with the apparatus) just before the immediate reward became accessible (Fig 1). A trial  
319 was terminated once the focal bird made a choice or was displaced by the non-focal bird (no choice).

320

321 **Data analysis**

322 We recorded the choice per trial for each subject as ‘immediate’ (1) or ‘no choice/ delayed’ (0), with  
323 proportion over total number of trials (control and test trials). All test sessions were coded live as well as  
324 being video recorded. Example trials can be found in S5 Resource.

325 We conducted Linear Mixed Models (LMM: [59] with binomial distribution using R (version  
326 2023.03.0+386, [60]) to assess which factors influenced choices in the New Caledonian crows and Eurasian  
327 jays. Choice was a binary variable indicating whether the subject selected immediate (1) or delayed/ no  
328 reward (0) per trial and was entered as a dependent variable in the model. For the model, we included the  
329 random effect of subject ID and fixed effects of species (NC crows, E jays), condition (alone, competitor,  
330 non-competitor), with interaction effects of species\*condition. We used the test trial data (high-quality  
331 reward in delayed position; low-quality reward in immediate position). In control trials, all subjects selected  
332 the immediate, high-quality reward irrespective of condition (100% of trials). We used Tukey comparisons  
333 for post-hoc comparisons (package multcomp, function dlht ()) and the DHARMA package [61] to test  
334 model assumptions. The model did not fail to converge, with a confidence interval of 97.5%. Model  
335 assumption checks showed no deviation from expected distribution. For individual-level analysis, we used  
336 exact two-tailed Binomial tests of choices (delayed) per condition (SPSS version 28).

337

### 338 **Ethics statement**

339 The study methods were conducted in accordance with relevant guidelines and regulations. The Eurasian  
340 jay study was reviewed and approved by the University of Cambridge Animal Welfare Ethical Review  
341 Body (AWERB) and was conducted under a non-regulated license (NR2022/82). The New Caledonian  
342 crow research was conducted under approval from the University of Auckland Animal Ethics Committee  
343 (reference number 001823) and from the Province Sud with permission to work on Grande Terre, New  
344 Caledonia, and to capture and release crows.

345

## 346 **Results**

347

## 348 **Group-level performance: testing effects of condition and species**

349

350 At the group level, selection of the low-quality, immediate option differed between species (LLM:  $\chi^2 =$   
351 168.75, d.f = 2,  $p < 0.0001$ ), by condition ( $\chi^2 = 52.49$ , d.f = 1,  $p < 0.0001$ ) and within condition by species  
352 interaction ( $\chi^2 = 60.36$ , d.f = 2,  $p < 0.0001$ ). The jays were more likely to select the low-quality, immediate  
353 reward than the crows (Tukey contrasts: E jays - NC crows,  $z = 2.66$ ,  $p = 0.00782$ ). The jays were also more  
354 likely to select the low-quality, immediate reward when they were with a non-competitor than when alone  
355 ( $z = 2.676$ ,  $p = 0.00745$ ), but the difference was stronger when a competitor was present than when they  
356 were alone (Tukey contrasts:  $z = 7.270$ ,  $p < 0.0001$ ), as well as with a competitor than a non-competitor ( $z$   
357 =  $-4.616$ ,  $p < 0.0001$ : Fig 2). The crows were not more likely to select the low-quality, immediate reward  
358 depending on condition, i.e. they selected the delayed, high-quality reward irrespective of condition (Tukey  
359 contrasts: alone - competitor,  $z = -0.196$ ,  $p = 0.845$ ; alone - noncompetitor,  $z = -1.040$ ,  $p = 0.298$ ; noncompetitor  
360 vs competitor,  $z = -0.864$ ,  $p = 0.388$ ).

361

362 **Figure 2. Proportion of choices of the immediate (low-quality) reward per condition for Eurasian**  
363 **jays (EJ) and New Caledonian crows (NCC).** \*\*  $p > 0.01$ ; \*\*\*  $p > 0.001$ .

364

## 365 **Individual-level performance: selection of high-quality, delayed** 366 **reward by condition**

367

368 On an individual level, all six NC crows selected the high-quality, delayed reward over the low-quality,  
369 immediate reward in all three conditions (Table 2). In contrast, while all five E jays selected the high-  
370 quality, delayed reward while alone, no jays significantly chose the delayed reward while a competitor or

Deleted:

372 non-competitor was present. Rather, the E jays changed their behaviour by selecting the low-quality,  
 373 immediate reward in some trials (Table 2). One jay (Stuka) switched strategy entirely when a competitor  
 374 was present - significantly selected the immediate over the delayed reward.

375

376 **Table 2. Delayed choices per individual across conditions for test trials only (high-quality reward in**  
 377 **delayed position).**

ID	Species	Choice	Alone (out of 16)	Competitor (out of 16)	Non-competitor (out of 16)	% Overall
Birute	NC crows	Delayed	16	16	16	100
		p-value	<0.0001	<0.0001	<0.0001	
Fossey	NC crows	Delayed	16	16	16	100
		p-value	<0.0001	<0.0001	<0.0001	
Irene	NC crows	Delayed	16	16	16	100
		p-value	<0.0001	<0.0001	<0.0001	
Konrad	NC crows	Delayed	16	16	16	100
		p-value	<0.0001	<0.0001	<0.0001	
Leakey	NC crows	Delayed	16	16	16	100
		p-value	<0.0001	<0.0001	<0.0001	
Marie	NC crows	Delayed	15	15	16	95.83
		p-value	0.0005	0.0005	<0.0001	
Godot	E jays	Delayed	13	7	12	

		p-value	<b>0.0213</b>	0.804	0.0768	68.75
Homer	E jays	Delayed	15	5	12	68.75
		p-value	<b>0.0005</b>	0.210	0.0768	
Penny	E jays	Delayed	13	9	9	64.58
		p-value	<b>0.0213</b>	0.804	0.804	
Sojka	E jays	Delayed	14	5	11	62.5
		p-value	<b>0.0042</b>	0.210	0.2101	
Stuka	E jays	Delayed	13	2	10	52.08
		p-value	<b>0.0213</b>	<i>0.004</i>	0.455	

378 Binomial exact two-tailed test:  $p < 0.05$  highlighted in bold. NC crows = New Caledonian crow; E jays =  
379 Eurasian jay. In one case, Stuka made a majority of immediate choices highlighted in italics as significant  
380 immediate, low-quality reward choice.

381

## 382 Discussion

383

384 We tested the flexibility of the ability to employ delayed gratification, i.e. to wait for a delayed, higher-  
385 quality reward over an immediate, lower-quality one, in different social conditions in two corvid species  
386 that differ in sociality and food-caching, New Caledonian crows and Eurasian jays, using the rotating-tray  
387 paradigm. We found species and condition differences on choices to select an immediate, but lower-quality  
388 reward over a delayed, higher-quality one. Specifically, jays were more likely to select the immediate, low-  
389 quality reward than crows. Jays, though not crows, were also more likely to alter their choices while alone  
390 compared with when a competitor or a non-competitor was present. Crows continued to forgo the

391 immediate, lower-quality reward for the delayed, higher-quality one irrespective of condition. Our findings  
392 highlight that the ability to delay gratification in Eurasian jays is influenced by the presence of conspecifics,  
393 depending on their identity (competitor/ non-competitor), suggesting flexibility in their delayed  
394 gratification abilities. On the other hand, the crows continue to delay gratification even with a competitor  
395 present, reflecting stability (or inflexibility) in their delayed gratification abilities. Furthermore, both  
396 species were capable of delaying gratification in this paradigm, comparable with young children and other  
397 New Caledonian crows in a previous study [55] (S6 Resource), as well as capuchin monkeys (*Cebus Apella*)  
398 [56].

399 The species difference was unexpected, with the crows selecting the delayed, high-quality reward  
400 regardless of social condition, while the jays altered their choices when competitors or non-competitors  
401 were present. Both species were able to reliably delay gratification while alone, which was expected, given  
402 New Caledonian crows delayed gratification using the rotating tray paradigm in a previous study [55]. We  
403 note the jays took longer to train than the crows (crows: 2 sessions; jays 3-8 sessions to pass criterion) and  
404 three other jays did not pass criterion to proceed to testing (despite having 15-34 sessions of 10-trials per  
405 session). It is possible that training length was influenced by neophobia differences between species, as the  
406 jays are typically more neophobic than the crows [53]. Future research may expand on samples and data  
407 set size to explore potential differences in species' learning speed.

408 It is also possible that species differences were related to limitations of the study set-up or subject  
409 sourcing. Although both species were originally sourced in the wild, the jays had been hand-reared and  
410 housed long-term in captivity, whereas the crows were parent-reared and only temporarily held in captivity  
411 (~4 months). Both species received adequate habituation and were required to pass comparable criterion  
412 prior to testing. Furthermore, although the crows were more recently sourced from the wild, they were  
413 tested and showed high performances in several other cognitive experiments during this field-season (e.g.  
414 [55]), indicating they were well habituated for testing before participating in the current study. The jays  
415 were all adults, while the crows ranged in age (juvenile to adult). Whilst we are not aware of any studies  
416 investigating the development of delay of gratification in corvids, an experiment with human children, using

417 the same rotating-tray task, shows evidence for age-related improvements in delay of gratification ability  
418 across cultures [62]. Therefore, development may also play a role in the birds' performance in this task.  
419 However, there were no differences in choices between individual crows (Table 2) and we do not have  
420 sufficient variation in the jay performance to test for age effects.

421 The type of competitor/ non-competitor was as comparable as possible between species. All subjects  
422 were familiar with their observing, non-focal conspecifics (NC crows caught together so potentially a  
423 family unit) although the prior interactions of the NC crows were unknown (being wild caught) (S1 Table).  
424 However, in the jays, the non-focal/ observer bird (competitor/ non-competitor) was not always the same  
425 individual across all trials, partly due to practical issues of encouraging the focal and non-focal to participate  
426 in each trial and partly due to more fluid dominance relationships. With the jays, it appeared that the  
427 dominance relationships varied between some pairs across the 6-month period of this study, hence, we  
428 conducted repeated food monopolization trials and assigned the non-focal accordingly (S1 and S2 Table).  
429 We also note that many of the jay breeding pairs in this captive colony change year-by-year. For both  
430 species, the food monopolization trials supported the distinction of a competitor versus non-competitor  
431 status for the non-focal bird in relation to the focal bird. The food monopolization trials for the crows were  
432 limited to the group and conducted prior to testing due to field season time pressures. The crow test  
433 compartments were around twice the size of the jay compartments, so it is possible that the crow non-focal  
434 took longer to reach the platform, thereby potentially less likely to directly compete for rewards. The focal  
435 and non-focal (both species) were released simultaneously though to remedy this issue. Furthermore, we  
436 incorporated the requirement for the focal to lift a small lid to obtain the reward, once chosen, which created  
437 a short time delay between selection and eating/hiding the reward in their bill.

438 The species differed from one another in adult sociality (NC crows: family groups; E jays: territorial  
439 pairs) and food caching (NC crows: moderate; E jays: specialised cachers) [24, 53]. We selected adult  
440 sociality as it is more consistent than at the juvenile/ subadult stages and our sample consists primarily of  
441 adults. These socio-ecological factors could impact choices relating to food selection and responses to  
442 competition. We interpret these findings as a caching specialist with territorial pair living (E jays) showing

443 flexibility or perhaps struggling to delay gratification when there is social competition, while a moderate  
444 caching and family-group living species (NC crows) continues to delay gratification - suggesting stability  
445 (or inflexibility) in behaviour regardless of social context. This flexibility by the E jays may relate to this  
446 change in behaviour being a more adaptive response to take any reward available immediately (even if less  
447 preferred), rather than risk waiting and end up without any reward at all, as the competitor may take it.

448 With regard to caching, the jays - being specialised cachers - have evolved under the social context of  
449 cache pilfering and development of cache protection strategies [46]. With sociality, the jays may be less  
450 tolerant of potential competitors, being more likely to actively displace conspecifics and defend territories,  
451 than the crows. Although not a highly social corvid species, the New Caledonian crows may form temporary  
452 aggregations of small groups [63] and will tolerate conspecifics outside of their family groups - largely  
453 juveniles and sub-adults (2-years old) - with rarely observed aggressive interactions [64]. Juvenile crows  
454 have been observed showing submissive displays when in the presence of non-family adults [64]. It is  
455 possible that stable hierarchies exist with the crows [64], similar to carrion crows (*Corvus corone*) [65].  
456 This is less likely with the Eurasian jays, given the variation observed in the food monopolization trials and  
457 continuous changing of breeding pairs suggesting non-linear hierarchies (S2 Table), as well as the generally  
458 dyadic and territorial nature of Eurasian jays in the wild [24]. Species differences in responses to novel food  
459 and objects (i.e. neophobia) may influence testing performance [53], however, this is unlikely due to  
460 habituation and both species demonstrating a reliable ability to delay gratification in the alone condition  
461 (Table 2).

462 The condition effect in the Eurasian jays was largely in line with our expectations. The jays flexibly  
463 altered their choices depending on the social context, being more likely to take the immediate reward, even  
464 though of lower quality, rather than risk losing it to a competitor. They were more strongly influenced by a  
465 competitor than a non-competitor on the group-level. However, on the individual level, all five jays did not  
466 show significant differences between competitor and non-competitor trials as they still chose the immediate,  
467 low-quality reward in some trials in both conditions (Table 2). These findings may relate to a higher risk of  
468 being displaced and losing the reward to any conspecific.

469        These captive jays were hand-reared socially and live most of the time (outside of breeding season,  
470 when they live in pairs to reduce risk of aggression) in a large social group. This social setting is quite  
471 different to their natural behaviour in the wild, where when adult, they will largely defend territories in  
472 pairs [24]. Furthermore, in captivity, they are provided with adequate food for all individuals, distributed  
473 through-out the large aviary to reduce any competition. Whether or not jays living in the wild would also  
474 show this flexibility in behaviour in response to social context requires future focus. Regardless of these  
475 aspects of the captive setting, the jays appear to pay attention and respond to the presence and identity of  
476 others while delaying gratification, while the crows do not adjust their choices according to social  
477 competition. These findings are in line with previous studies on Eurasian jays testing flexibility of other  
478 behaviours in social contexts. For example, they are able to switch caching and pilfering behaviour  
479 depending on whether they are more subordinate or dominant than a conspecific present [46]. In addition,  
480 evidence suggests that Eurasian jays are also capable of desire state attribution towards both their partners  
481 and competitors [36, 66, 67] (although see [47]).

482        Future research can expand on species comparisons to explore social influences on self-control and  
483 other aspects of decision-making. For instance, using the rotating tray paradigm or other delayed  
484 gratification paradigms in non-human primates and human children, or in highly social/tolerant species  
485 compared with less social/ tolerant ones within taxa. Expanding on the length of delay, as this study utilised  
486 only a short delay (15 seconds), the quantity (as we only tested using quality differences) and visibility of  
487 rewards provides several avenues for future work. Furthermore, it would be worthwhile to expand on the  
488 identity of the observer, for instance, to see whether familiarity or age influences choices in delayed  
489 gratification tests, in particular, whether NC crow delayed gratification is influenced by presence of other  
490 types of observers.

491

## 492 **Conclusion**

493 In conclusion, we explored the effect of social influences on delayed gratification in two corvid species -  
494 New Caledonian crows and Eurasian jays - highlighting both species and condition (alone, competitor, non-  
495 competitor) differences in performance. Both species were able to delay gratification. The jays did so  
496 flexibly depending on the social context, while the crows remained stable in their choices for delayed  
497 rewards. These findings contribute to our understanding of self-control and the factors influencing delayed  
498 gratification in non-human animals. In particular, flexibility (or inflexibility) in delay of gratification varies  
499 under differing social contexts, which may relate to the species' social tolerance and related risk of  
500 competition.

501

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506

## 507 **Additional information**

508 The authors declare no competing interests.

509

## 510 **Author contributions**

511 R.M. conceived and designed the experiments. Data collection was conducted by: 1) crow testing: M.S.  
512 and E.G-P. with supervision by R.M, A.H.T. and N.S.C; and 2) jay testing: J.R.D. and E.G-P. with  
513 supervision by R.M and N.S.C. R.M. and J.R.D. planned, analysed and interpreted the data, and prepared  
514 the figures and tables. R.M. and J.R.D. wrote the first draft of the manuscript, with subsequent drafts being  
515 reviewed by all the other authors. R.M, A.H.T., R.D.G. and N.S.C provided direct funding support and  
516 coordinated the wider NC crows field season (A.H.T, R.D.G) and E jays Clayton's Comparative Cognition

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520

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528

## 529 **Data availability**

530 The full data set and R script is available on Figshare: [10.6084/m9.figshare.23514828](https://figshare.com/s/10.6084/m9.figshare.23514828), (private link:  
531 <https://figshare.com/s/3a6adfae2cb31f707659>)

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697

698 **Supporting information**

699

700 **S1 Table: Subject Information.** \*Change in relative dominance between sessions (see S2 Table).

701

702 **S2 Table: Food monopolization results for the Eurasian jays.** \*Change in relative dominance between  
703 two specific individuals.

704

705 **S3 Table. ‘Learning speed’ per individual and species: number of trials and sessions to reach**  
706 **criterion and complete test trials (last 2 sessions counted) in alone condition.** Three of eight jays did  
707 not reach criterion within 15 sessions (\*) so were excluded from further testing. NC crows = New  
708 Caledonian crows; E jays = Eurasian jays.

709

710 **S4 Fig. Timeline of pretraining and testing phases.** Coloured arrows show the different test condition  
711 sequences that individuals were assigned to for sessions one through to four (S1-S4). The dotted line shows  
712 a possible repeat of the food monopolization phase if relative dominance relationships were perceived to  
713 change mid-test sequence (jays only).

714

715 **S5 Resource. Example video trials for both species**

716

717 **S6 Resource. Comparison of baseline to Miller et al. 2020 [55]**

718