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1 Exclusion in the field: wild brown skuas find hidden food in the absence of  
2 visual information

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25 **Abstract**

26 Inferential reasoning by exclusion allows responding adaptively to various environmental  
27 stimuli when confronted with inconsistent or partial information. In the experimental context,  
28 this mechanism allows selecting correctly between an empty option and a potentially  
29 rewarded one. Recently, the increasing reports of this capacity in phylogenetically distant  
30 species have led to the assumption that reasoning by exclusion is the result of convergent  
31 evolution. Within one largely unstudied avian order, i.e. the Charadriiformes, brown skuas  
32 (*Catharacta antarctica ssp lonnbergi*) are highly flexible and opportunistic predators.  
33 Behavioural flexibility, along with specific aspects of skuas' feeding ecology, may act as  
34 influencing factors in their ability to show exclusion performance. Our study aims to test  
35 whether skuas are able to make choice by exclusion in a visual two-way object-choice task.  
36 Twenty-six wild birds were presented with two opaque cups, one covering a food reward.  
37 Three conditions were used: 'full information' (showing the content of both cups),  
38 'exclusion' (showing the content of the empty cup), and 'control' (not showing any content).  
39 Skuas preferentially selected the rewarded cup in the full information and exclusion  
40 condition. The use of olfactory cues was excluded by results in the control condition. Our  
41 study highlights the cognitive potential of this predatory seabird and opens new  
42 investigations for testing further its cognition in the wild.

43

44 **Keywords:** avian cognition · Charadriiformes · cups task · exclusion performance ·  
45 inferential reasoning

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## 50 **Introduction**

51 The capacity of nonhuman animals to choose via exclusion has recently received  
52 considerable interest (e.g. Paxton et al. 2018; Nawroth et al. 2014; Petit et al. 2015; Subias et  
53 al. 2019). This cognitive mechanism, which refers to ‘the ability to understand that if there  
54 are only two possibilities and if it is not A, it must be B’ (O’Hara et al. 2016), is typically  
55 explored through the use of a two-way object-choice paradigm i.e. the *cups task* (Call 2004;  
56 Mikolasch et al. 2012; Pepperberg et al. 2013; Plotnik et al. 2014; Subias et al. 2019). In the  
57 visual version of this test, a food reward is hidden underneath one of two identical opaque  
58 cups (Darmaillacq et al. 2018). In the crucial phase, the experimenter lifts the empty cup  
59 only. The subject is able to choose via exclusion if it excludes the presented empty cup and  
60 selects the potentially rewarded, non-lifted one.

61 Successful performance on this task can be achieved through the use of low- and/or high-  
62 level cognitive strategies (Call 2004; Penn and Povinelli 2007; Watanabe and Huber 2006).  
63 Subjects may solve the task by learning to *avoid* the empty cup, without acquiring any  
64 knowledge about the other rewarded container (i.e. low-level strategy). Other individuals,  
65 however, may be able of *inferring* the logical presence of the food under the non-lifted  
66 container (i.e. high-level strategy). Although both mechanisms are not mutually exclusive,  
67 e.g. one subject can follow a mixed strategy (e.g. Jelbert et al. 2015), choosing by avoiding  
68 the incorrect option is less cognitively challenging than inferential reasoning *per se*  
69 (Mikolasch et al. 2012), and may be present in more individuals.

70 The ability to choose by exclusion has been found in various animals such as elephants  
71 (Plotnick et al. 2014), dogs (Aust et al. 2008; Erdőhegyi et al. 2007), goats (Nawroth et al.  
72 2014), or non-human primates (Hill et al. 2011; Sabbatini et al. 2008; Schmitt et al. 2009). In  
73 birds, mainly in Corvids and Parrots, some species pass the cups task (e.g. carrion crows  
74 *Corvus corone*, Mikolasch et al. 2012; Clark’s nutcracker, *Nucifraga Columbiana*, Tornick

75 and Gibson 2013; red-tailed black cockatoo *Calyptorhynchus banksii*, Subias et al. 2019),  
76 whereas others demonstrate marked difficulties (e.g. Eurasian Jays, *Garrulus glandarius*,  
77 Shaw et al. 2013; jackdaws, *Corvus monedula*, Schloegl 2011; keas, *Nestor notabilis*,  
78 Schloegl et al. 2009, but see O’Hara et al. 2016).

79 Whilst some researchers have supported hypotheses about ecological factors promoting  
80 the emergence of exclusion in specific animal orders (e.g., ‘the adapted intelligence  
81 hypothesis’ in food-caching corvids e.g. Mikolasch et al. 2012; Schloegl et al. 2009; Schloegl  
82 2011, but see Shaw et al. 2013; ‘social complexity’ in primates e.g. Petit et al. 2015), others  
83 have proposed this ability to be a fundamental cognitive capacity (‘general intelligence’;  
84 Pepperberg et al. 2013), or, lately, to be of higher importance in flexible foraging species  
85 (Nawroth et al. 2014).

86 A good way to further understand the possible drivers favouring the emergence and  
87 evolution of exclusion is to expand the spectrum of species studied with this paradigm in  
88 species possessing traits associated with this ability (Marsh et al. 2015; Mikolasch et al.  
89 2011; Schloegl et al. 2009). Moreover, experiments with free-living animal populations are  
90 crucial to understand how exclusion performance – and cognitive processes more generally –  
91 operates under natural conditions (Byrne and Bates 2011; Cauchoix et al. 2017; Völter and  
92 Call 2017).

93 However, as testing individuals in the wild is often prohibitively challenging (Shaw et al.  
94 2015), we still lack studies about the use of exclusion in wild individuals. For instance,  
95 species can show high neophobia (preventing their willingness to participate in the task), be  
96 non-territorial (struggling with locating individuals when several trials need to be  
97 administrated), or live in groups (making difficult their isolation from conspecifics; Shaw et  
98 al. 2015). To our knowledge, only two captive exclusion experiments have been conducted

99 with wild birds brought into captivity (New Caledonian crows, *Corvus moneduloides*: Jelbert  
100 et al. 2015; Clark's nutcrackers: Tornick and Gibson 2013).

101 This study aims to assess exclusion performance in a new avian model: the wild brown  
102 skua (*Catharacta antarctica* ssp *lonnbergi*). This large gull-like seabird frequents Antarctic  
103 Peninsula and Subantarctic islands of Atlantic, Indian and Pacific Oceans (Carneiro et al.  
104 2014, 2015; Furness et al. 2018). Skuas are top marine predators that display a wide range of  
105 feeding techniques i.e. aerial and terrestrial hunting, cannibalism, fishing, kleptoparasitism,  
106 and scavenging (Moncorps et al. 1998; Mougeot et al. 1998; Schreiber and Burger 2002).  
107 When spatial or seasonal fluctuations in prey availability occur, these birds exhibit high  
108 degree of flexibility by adjusting their movements and switching to different resources  
109 (Burton 1968; Carneiro et al. 2015). Moreover, skuas can be locally highly selective in their  
110 prey intakes and show preferences for hunting specific seabird species (e.g. blue petrel,  
111 *Halobaena caerulea*), while others seem to be avoided (e.g. diving petrels, *Pelecanoides*  
112 *urinatrix*; Mougeot et al. 1998). Both previous characteristics, behavioural flexibility and  
113 selectivity, have been suggested as explanatory factors for exclusion skills in animals  
114 (Nawroth et al. 2014). Indeed, some highly flexible species may show higher aversion to  
115 losses through the avoidance of the empty container (Nawroth et al. 2014).

116 Regarding one species' feeding ecology may also provide significant insights on the  
117 occurrence of exclusion performance under natural conditions (Völter and Call 2017). In the  
118 Kerguelen archipelago, some populations (e.g. skuas at Cape Ratmanoff) predate and  
119 scavenge mainly on king penguin chicks and eggs (*Aptenodytes patagonicus*; Furness 1987).  
120 In this environment, a penguin egg covered by its incubating parent's fold of skin is often  
121 hardly visible (FB, JCC, AN: personal observations). In this context, being able to locate prey  
122 without directly perceiving it could be highly adaptive for skuas, which may have favoured  
123 the appearance of exclusion performance in the wild (Marsh and Levendoski 2015).

124 Noteworthy, similarly to other birds endemic to isolated islands (e.g. kea, *Nestor notabilis*,  
125 Gadjon et al. 2006; wild robin, *Petroica longipes*, Garland et al. 2014), the skua is highly  
126 explorative and shows very low neophobia (Furness et al. 2018). It is also highly territorial  
127 during the breeding season, forming breeding pairs and establishing a territory that is fiercely  
128 defended against conspecific intruders or potential predators (Hahn and Peter 2003;  
129 Trivelpiece et al. 1980). Such aspects of this species' feeding ecology, along with complex  
130 foraging flexibility and territoriality, make the skua a promising model for exclusion  
131 experiments in the field (Gadjon et al. 2006).

132 In this study, we aimed to assess whether wild brown skuas were capable to use exclusion  
133 to find hidden food in a visual two-way object choice task. According to the species' feeding  
134 ecology, we predict skuas to be able to solve the task.

## 135 **Methods**

### 136 Study population

137 Between Feb 2010 – and Mar 2012, 26 wild brown skuas were tested at Cape Ratmanoff,  
138 Courbet Peninsula, Kerguelen Island (48°25'-50°00'S; 68°27'-70°35'E). All birds had a  
139 minimum age of 1 year (i.e. colour pattern, uniformity, distinct wing flashes of the body  
140 plumage, Furness et al. 2018). Eighteen subjects were individually identified based on leg  
141 bands coloured by Darvik©, 2 based on temporary coloured dye sprays (Porcimark©,  
142 Langeskov, Denmark, 22 Feb 2010 – 3 Mar 2010), and 6 based on specific aspects of their  
143 appearance (i.e. body plumage, presence/absence of scars on the feet' webbing, 2 Mar 2012 –  
144 10 Mar 2012). In both field seasons, trials were performed between 7 a.m. and 5 p.m. and  
145 each subject was tested separately (a second experimenter prevented conspecifics from  
146 entering the test area, by approaching and making the intruders leave within approximately 5  
147 meters radius of the setup). Prior to the current study, no skua had ever been tested in any  
148 exclusion task.

149 Experimental setup and Materials

150 Two identical opaque plastic cups (13 cm in height and 11 cm in diameter) with a piece of  
151 string forming a loop on the top (braided sisal cord, 3 mm in diameter and 6 cm in length)  
152 were set up on the ground, 25 cm apart (Fig. 1). Both cups and string loops were coated with  
153 fish flesh to avoid birds to use any smell-related clue. Depending on the procedure (see  
154 below), two (training phase) or one container (test phase) held a motivating food reward (a  
155 fresh fish piece of *Salmo trutta*, ca. 3 g). At the onset of each trial during all 3 conditions, an  
156 opaque blind (a flat wooden board, 30 x 40 cm) was placed vertically between the subject and  
157 the cups (3 cm before the containers) to prevent subjects from seeing under which cup the  
158 experimenter hid the food reward.

159 < Fig. 1 about here >

160 Procedure

161 ***Familiarization phase.***

162 The free-ranging 26 subjects were initially familiarized with the experimental apparatus.  
163 When a skua was sufficiently close to the apparatus ( $\leq 1$  meter), the experimenter showed  
164 two food rewards and placed one under each cup. Skuas were then allowed to touch the cups.  
165 Once a subject successfully retrieved the rewards by lifting the cups (4 times within 2 min),  
166 we considered that it was familiarized with the apparatus.

167 ***Test phase.***

168 Three conditions were presented to all birds in the following order: full information,  
169 exclusion, and control. In all conditions, the position of the reward was pseudo-randomized  
170 and balanced equally on the left/right side in each condition (i.e. Control: left = 93/right = 94;  
171 Exclusion: left = 255/right = 263; Full information: left = 124/right = 126). The subject's  
172 choice was considered as correct when the bird lifted the cup and retrieved the reward. The  
173 order in which birds participated every day was randomly assigned through the subjects'



174 voluntary participation. If a bird left the test area during the test and did not return within 1  
175 minute, the trial was performed again from the beginning later in the day. During the whole  
176 procedure, the experimenter stayed approximately 0.5 m behind the cups, looking straight  
177 ahead.

178 *Full information condition.* In this condition, we wanted the birds to learn that they would  
179 have to make a choice. For that purpose, one reward was hidden under one cup by the  
180 experimenter behind the blind. Then, the experimenter removed the blind and both cups were  
181 simultaneously lifted so the subject could locate visually which cup contained the food. After  
182 3 sec, both containers were put down in same places and the skua could choose between one  
183 of them (see S1 in supplementary material). If the subject lifted the rewarded cup, it was  
184 allowed to consume the food. Conversely, if the subject chose the unrewarded cup, the  
185 experimenter stopped the trial to prevent the bird from obtaining the food. Each subject  
186 received 10 trials in total (60 sec each, max. 10 per day, between 10 sec-1 min apart).

187 *Exclusion condition.* Same procedure as in *Full information condition* was followed,  
188 except that after baiting, only the empty cup was lifted while the experimenter  
189 simultaneously touched the rewarded cup (see S1 in supplementary material). This was made  
190 to prevent the reliance on enhancement effects (e.g. the tendency to choose the cup that is  
191 manipulated last, Mikolasch et al. 2012; Nawroth et al. 2014). Each subject received 20 trials  
192 in total (60 sec each, max. 20 per day, between 10 sec-1 min apart).

193 *Control condition.* We assessed whether the subjects' choices were influenced by the use  
194 of olfactory or any other uncontrolled cues. Here, one cup still contained the reward, but  
195 subjects had no information about food position i.e. the experimenter did not lift the cups but  
196 touched them simultaneously. Each subject received 10 trials in total (60 sec each, max. 10  
197 per day, between 10sec-1 min apart).

198 Analysis

199 All trials were coded live. When the weather allowed (no strong winds, nor flying sand), we  
200 also recorded trials using a video camera mounted on a tripod. Inter-observer reliability was  
201 not calculated as the subjects' choice in each trial was unambiguous (binary response:  
202 success or failure). We modelled birds' success probability at trials as a random variable  
203 following a binomial distribution. To compare birds' performance depending on test  
204 condition and to assess the possible effects of lateralization and learning, the probability to  
205 find the reward was modelled as a function of test condition (full information, exclusion,  
206 control), position of the food (right/left), and trial number (or ID\_trial), in a generalized linear  
207 mixed-effects model (GLMM). To account for individual differences in probability to pass  
208 the test, we set individual identity as a random effect with a Gaussian distribution in the error  
209 structure of the model. We implemented generalized linear mixed-effects model trees  
210 (Fokkema et al. 2019) to identify relevant clusters and effects. The algorithm finds subgroups  
211 (or terminal nodes) that differ in their success rate, while taking into account the nested  
212 structure of the dataset (individuals). The algorithm evaluates the stability of model  
213 parameters (i.e. stability of the intercept coefficient) at each node. The node becomes  
214 terminal (stable) if  $p > 0.05$  for all splitting variable of the model.

215 As position of the food (right or left cup) was not available for all testing sequences, we  
216 implemented two trees. Model tree I was based on a reduced dataset with only individuals for  
217 whom we had full information on the position of food (left/right) within the 3 conditions ( $n =$   
218 19). This first model was implemented with test condition and food position effects in  
219 interaction. Model tree II was implemented on the complete dataset including all the  
220 individuals ( $N = 26$ ). We back transformed coefficients from the logit scale to get success  
221 probabilities on the response scale. We refer to these transformed coefficients as probability  
222 of success ( $P_s$ ).  $P_s$  is reported with 95% confidence intervals. All the analyses were carried

223 out with R version 3.6 (R Core Team, 2019), and glmertree package (Fokkema et al. 2019)  
224 was used to perform the analysis.

## 225 **Results**

### 226 Model tree I: test conditions and food position

227 With the model accounting for food position, we identified a difference in success probability  
228 between each of the 3 experimental conditions (control, exclusion and full information), as  
229 well as an effect of food position on success during control tests. Results are shown in Fig. 2.

230 < Fig. 2 about here >

231 There was a difference in performance between the control condition and the exclusion/full  
232 information condition ( $p < 0.001$ ; Node 1). Food position had an effect on success probability  
233 but only within the control condition ( $p = 0.023$ ; Node 2): birds' success probability was  $P_s =$   
234  $0.43$  [95% IC:  $0.32 - 0.54$ ] when food was on the left (Node 3), and  $P_s = 0.62$  [95% IC:  $0.47$   
235  $- 0.75$ ] when the reward was located on the right (Node 4). Thus, there was a mean side bias  
236 towards the right container during this condition. At the individual scale, we could detect  
237 birds 100% lateralized (Left side:  $N = 1$ , right side:  $N = 3$ ). Skuas were on average more  
238 successful in the full information condition ( $P_s = 0.74$  [95% IC:  $0.63 - 0.83$ ]) than in the  
239 exclusion condition ( $P_s = 0.64$  [95% IC:  $0.53 - 0.74$ ]) ( $p = 0.024$ ; Node 5).

### 240 Model tree II: test conditions and learning

241 With the model accounting for trial number (complete dataset), we identified a difference  
242 between each of the 3 experimental conditions (control, exclusion and full information), as  
243 well as an effect of trial number (ID\_trial) during exclusion tests. Results are shown in Fig. 3.

244 < Fig. 3 about here >

245 There was a difference in performance between the control condition and the exclusion/full  
246 information condition ( $p < 0.001$ ; Node 1). Mean success probability during the control  
247 condition (Node 2) was  $P_s = 0.51$  [95% IC:  $0.43 - 0.59$ ]. The model tree procedure identified

248 a difference between the exclusion and full information condition ( $p = 0.021$ ; Node 3).  
249 During the exclusion condition, there was a difference between the first 12 trials and the last  
250 8 trials ( $p = 0.021$ ; Node 4), with an average success probability  $P_s = 0.58$  [95% IC: 0.49 –  
251 0.67] during the first 12 trials (Node 5), and an average success probability  $P_s = 0.71$  [95%  
252 IC: 0.62 – 0.79] during the last 8 trials (Node 6). Thus, there was a learning effect emerging  
253 over the course of the exclusion condition. During the full information condition (Node 7),  
254 mean success probability was  $P_s = 0.72$  [95% IC: 0.64 – 0.80].

## 255 **Discussion**

256 Overall, our results demonstrate that free-living skuas are capable of showing exclusion  
257 performance. Subjects succeeded above the level expected by chance in the full information  
258 and exclusion conditions, and their performances confirm that they did not use olfactory cues  
259 (smell of the hidden food reward) in the control condition. This experiment is the first to  
260 reveal exclusion skills in Charadriiformes within a natural setting.

261 When no information was available (control condition), most birds failed in locating the  
262 baited cup above chance. This result is not surprising when we refer to the species' biological  
263 and behavioural features. Skuas possess small olfactory bulbs and display no reaction when  
264 faced to striking odour changes of a same food item (Furness et al. 2018). Noteworthy, a  
265 mean side bias emerged over trials in the control condition with a mean preference to select  
266 the right cup in tested individuals. At the individual level, four subjects chose constantly the  
267 same side (three skuas selected the right one, one the left one). This behaviour is not  
268 uncommon when subjects are confronted with two-way object-choice tasks (e.g. Danel et al.  
269 2018; Gagne et al. 2012; Ketchaisri et al. 2019), and represents a useful strategy when  
270 environmental stimuli are unpredictable, such as in our control condition (Jacobs and Osvath  
271 2015; Ketchaisri et al. 2019; Plotnik et al. 2013; Tebbich et al. 2007). In contrast, skuas were  
272 able to derive relevant information from the full information and exclusion conditions

273 without displaying any side bias, probably because both conditions were predictable.

274 Similarly to other avian species (e.g., African grey parrots, Mikolasch et al. 2011,  
275 Pepperberg et al. 2013, Schloegl et al. 2012; carrion crows, Mikolasch et al. 2012; Clark's  
276 nutcrackers, Tornick and Gibson 2013; Eurasian jays, Shaw et al. 2013; jackdaws, Schloegl  
277 et al. 2011; keas, Schloegl et al. 2009; ravens, Schloegl et al. 2009; red-tailed black  
278 cockatoos, Subias et al. 2019), skuas chose significantly more the rewarded cup over the  
279 unrewarded one in the full information condition (success probability  $P_s = 0.72$  [95% IC:  
280  $0.64 - 0.80$ ]). Our results indicate that this species was able to rely on direct visual  
281 information for solving the task. We also suggest that skuas showed spontaneous object  
282 permanence (Piaget 1954), i.e. the understanding that hidden objects do not cease to exist  
283 (Pepperberg et al. 2013), as they successfully selected the opaque container covering the food  
284 reward.

285 Crucially, this species was also able to use indirect information (i.e. the view of the empty  
286 cup) to choose substantially more the baited cup over the unbaited one in the critical  
287 exclusion condition (success probability  $P_s = 0.64$  [95% IC:  $0.53 - 0.74$ ]). Unlike other  
288 captive avian species (e.g., Schloegl et al. 2009), skuas in this experiment did not require  
289 extensive training and all birds were naive to experimental testing. In this case, the subjects  
290 may not have had the time to learn the causal cues (low-level explanation i.e. avoidance of  
291 the empty cup) required to solve the task (Nawroth et al. 2014; Shaw et al. 2013; Schloegl  
292 2011; Schloegl et al. 2009). Moreover, exclusion performance might not normally require  
293 elementary associative learning when a limited number of tests is proposed (Darmaillacq et  
294 al. 2018; Shaw et al. 2013). However, we found a progressive amelioration in subjects'  
295 performance over trials within the exclusion condition. We therefore cannot rule out the  
296 possibility that subjects have used a non-costly cognitive strategy through the avoidance of  
297 the empty cup in the following trials (Call 2006; Paukner et al. 2009; Mikolasch et al. 2012;

298 Schmitt and Fischer 2009). Only a further study with proper controls will clarify the use of  
299 low-level strategies in this species (e.g. see the different tests used in Call 2006 and in  
300 Mikolasch et al. 2011, with the procedure pioneered by Premack and Premack 1994; or the  
301 follow-up conditions of the modified *tubes task* employed by Jelbert et al. 2015). Future  
302 experiments may also assess whether wild skuas still show success when they are confronted  
303 with an increased number of containers, such as in the 3-cups object choice task (Grether and  
304 Maslow 1937). This version may provide contrasting results and is considered more complex  
305 than the binary cups task (Marsh et al. 2015).

306 At first glance, our results support the adaptive specialisation hypothesis (De Kort and  
307 Clayton 2006), which suggests that cognitive abilities may vary depending on specific  
308 aspects of one species' feeding ecology. Referring to this assumption, Nawroth et al. (2014)  
309 recently found a link between highly selective feeding behaviour and exclusion performance  
310 in small ruminants. Although it would be tempting to propose similar mechanisms operating  
311 in our model species, only a comparative approach may reveal the potential role behavioural  
312 flexibility plays in exclusion. For instance, further experiments may test exclusion  
313 performance in skuas' genetically related species that possess different feeding ecologies, e.g.  
314 specialist predators such as long-tailed skuas (*Stercorarius longicaudus*, Sitter et al. 2011).

315 Naturally, predatory animals might be highly attentive and sensitive to the sound emitted  
316 by their preys (Grant and Samways 2015; Rice 1982; Schmitt and Fischer 2009). Although  
317 vision seems to play a significant role in skuas' ecology, this species relies also on acoustic  
318 information during foraging (Furness 1987). For instance, on Mayès Island, Kerguelen  
319 archipelago, acoustic information helps specialized skuas in finding burrow-nesting birds at  
320 night (Mougeot and Bretagnolle 2000). Thus, in order to determine potential variations in  
321 levels of exclusion performance across sensory modalities, further experiments should assess  
322 skuas' capacity to locate hidden food when given acoustic information.

323 In conclusion, wild brown skuas are capable of showing exclusion performance in the  
324 visual domain. Although the role ecological traits play in the emergence of exclusion  
325 performance must be the object of further research, our results corroborate the hypothesis that  
326 this capacity has emerged in distantly related taxa through convergent evolution (O'Hara et  
327 al. 2015). Skuas possess life history and ecological traits that are commonly linked to  
328 enhanced cognition (Morand-Ferron et al. 2007; Ricklefs 2004) e.g. late sexual and physical  
329 maturity, longevity, high innovation rate, kleptoparasitism, and generalism (Chester 1993;  
330 Furness et al. 2020; Spear et al. 1999). However, to date, we are aware of only one previous  
331 experimental cognitive work showing the capacity of skuas to recognize human faces (Lee et  
332 al. 2016). Research is needed to explore further the cognitive abilities of this promising new  
333 model system. We also hope this study will encourage future field comparative work on this  
334 capacity across taxonomic groups, so as to enhance our current view of the distribution of  
335 exclusion skills in avian phylogeny.

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481 **Figure captions**

482 **Fig. 1** Schematic representation of the conditions and the experimental setup for a typical  
483 exclusion test trial. **(a)** The ‘full information’, ‘exclusion’, and ‘control’ conditions are  
484 presented from left to right, respectively **(b)** Two identical opaque cups are simultaneously  
485 showed on a wooden platform. In the sketch, the reward is located under the *right* cup. The  
486 subject is watching a human experimenter lifting the empty left cup. To solve the task, the  
487 skua must exclude the left cup (low-level explanation) and/or infer that the right cup covers  
488 the reward (high-level explanation), by raising this container accordingly.

489 **Fig. 2** Model tree I: test conditions and food position. The Tree shows skuas’ estimated mean  
490 success probabilities in each of the terminal nodes during the different test conditions,  
491 including the potential effect of food position during the control condition. The black bars  
492 show 95% confidence intervals associated with estimated means. Dots show the observed  
493 performance of each individual during the different tests between 0 and 1 (0 to 100%  
494 success), dots’ colour include transparency so that darker dots show that multiple individuals  
495 performed with the same success rate.

496 **Fig. 3** Model tree II: test conditions and learning. The Tree shows skuas’ estimated mean  
497 success probabilities in each of the terminal nodes during the different test conditions,  
498 including the potential effect of learning through trial number (ID\_trial) during the exclusion  
499 condition. The black bars show the 95% confidence intervals associated with estimated  
500 means. Dots show the observed performance of each individual during the different tests  
501 between 0 and 1 (0 to 100% success), dots’ colour include transparency so that darker dots  
502 show that multiple individuals performed with the same success rate.

503 **Electronic supplementary material**

504 **S1.** Video of test trial examples in the full information and the exclusion conditions,

505 respectively.







