
The use of social information in vulture flight decisions

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Abstract :

Animals rely on a balance of personal and social information to decide when and where to move next in order to access a desired resource. The benefits from cueing on conspecifics to reduce uncertainty about resource availability can be rapidly overcome by the risks of within-group competition, often exacerbated toward low-ranked individuals. Being obligate soarers, relying on thermal updraughts to search for carcasses around which competition can be fierce, vultures represent ideal models to investigate the balance between personal and social information during foraging movements. Linking dominance hierarchy, social affinities and meteorological conditions to movement decisions of eight captive vultures, *Gyps* spp., released for free flights in natural soaring conditions, we found that they relied on social information (i.e. other vultures using/having used the thermals) to find the next thermal updraught, especially in unfavourable flight conditions. Low-ranked individuals were more likely to disregard social cues when deciding where to go next, possibly to minimize the competitive risk of social aggregation. These results exemplify the architecture of decision-making during flight in social birds. It suggests that the environmental context, the context of risk and the social system as a whole calibrate the balance between personal and social information use.

Keywords : griffon vulture, hierarchy, movement decision, landscape exploration, social information, unpredictable resource

43 1. Introduction

44 Animals must constantly decide where and when to move next in order to find resources
45 such as food, water, shelter, or a mate, necessary for life. To make these decisions, they can
46 rely on two sources of information: personal information and social information. Personal
47 information includes knowledge of the spatiotemporal patterns of resource distribution that
48 individuals may perceive or have memorised from previous encounters [1]. For example, food-
49 storing birds are able to return to locations where they stored or saw food in the past, based on
50 prior expectation of the resource availability [2]. Social information, on the other hand, is
51 obtained by observing the behaviour of others [3–5]. Feeding, fleeing, or mating individuals
52 provide discrete information about the availability and locations of food, predators, or potential
53 mates.

54 For resources that are heterogeneously distributed in the environment, ephemeral and
55 unpredictable, using only personal information for movement decisions may be prone to
56 inaccuracies, either because the knowledge is erroneous per se and/or because previous
57 experience has been too limited [6]. In such conditions, social animals may benefit from
58 companions' knowledge and may follow the dominant or oldest individual(s) considered as
59 knowledgeable (e.g. homing pigeons, *Columba livia*, or elephants, *Loxodonta africana*, [7,8]),
60 follow the largest group through shared decision-making [9], or stay with preferred affiliates
61 [10–12]. Because using social information can considerably reduce uncertainty in finding
62 resources, individuals should favour this source of information to achieve cost-efficient
63 movement [13–15]. However, relying heavily on social information can also lead individuals
64 to aggregate on resources. While this aggregation could potentially facilitate early detection of
65 predators [16] and access to resources (e.g. in seabirds preying on fish schools [17]), it could
66 also induce competition by exploitation or interference if the resource is monopolizable and
67 depletable [18]. Since both social and personal information are often available to social animals
68 and may differ in their quality and quantity [1], they need to balance their relative importance,
69 depending on the availability and predictability of the resource. When deciding on the next
70 movement step, social animals must trade-off the decreased uncertainty of locating a resource
71 through social information, with the potential increase in competition risk. Such a balance may
72 be dictated by the immediate needs of the individual and its risk sensitivity [19] but also by the
73 group social organisation. For example, low-ranked individuals are known to suffer more from
74 within-group competition compared to high-ranked individuals [20]. To minimise future
75 interactions for food with their conspecifics (and certainly high-ranked individuals), low-

76 ranked individuals should forage on their own and be reluctant to use social information which
77 may trigger aggregation [21].

78 Vultures rely on two unpredictable resources: carcasses to feed and thermal updrafts
79 (i.e. masses of hot air rising from heated surfaces) to move. During foraging flights, these large
80 soaring birds gain altitude by circling into thermal updrafts and glide across the landscape to
81 the next updraft while scanning the ground for carcasses [22]. Although some topographic
82 features are clearly favourable to updrafts presence [23], at the individual level, challenging
83 local meteorological conditions (e.g. high wind speed, low temperature, high cloudiness) can
84 make thermal locations and availability hard to predict [24]. If they fail to detect an updraft,
85 vultures may be forced to switch to flapping flight, or worse to land and take-off again,
86 significantly increasing their energy expenditure [25,26]. While both thermals and carcasses
87 are relatively unpredictable, the use of thermals by individuals does not impact their availability
88 to other birds contrary to carcasses, which are a depletable resource. When a vulture discovers
89 a carcass, its sharp drop in altitude while circling before landing is used as a signal by
90 conspecifics, dragging tens of individuals to the food source in a few minutes [27,28]. As the
91 number of vultures around the carcass increases (up to 100-120 individuals, [29,30]), individual
92 feeding rates decrease due to reduced access to the resource, resource depletion by competitors,
93 and increased agonistic interactions [29]. Therefore, in these social birds, individuals should
94 have to balance the advantage of conspecific presence to locate thermal updrafts (as
95 demonstrated in [31]) with the ultimate cost of competition around the carcasses that can be
96 fierce [32–35]. As such, vultures are ideal models to investigate the role of conspecifics in
97 shaping their foraging movement decisions.

98 While the role of conspecifics in attracting individuals once a carcass is found has been
99 well documented in vultures [36,37], the role they may play on individuals' movement during
100 carcass search is far less known in this soaring bird. Using a group of captive but freely-flying
101 'griffon' vultures, *Gyps fulvus* and *Gyps rueppellii*, tagged with high-resolution GPS loggers,
102 we studied how conspecifics' presence shapes individuals' movement decisions during
103 foraging flights. Despite being trained birds released for public shows, these individuals
104 sometimes detected and fed on carcasses at surrounding farms (5 times in the 24 days of data
105 collection). We therefore consider these flights comparable to natural flights [38] whose
106 patterns are mostly driven by food search given the opportunistic behaviour of these birds.
107 Focusing on the movement steps from thermal to thermal, we first assessed when do individuals
108 preferentially discover new thermals (i.e. use of personal information) compared to using
109 thermals already discovered by conspecifics (i.e. use of social information). We expected that

110 vultures would favour the use of social information when unfavourable meteorological
111 conditions increased thermal unpredictability and when flight conditions (e.g. low altitude)
112 increased risks of landing [1]. Furthermore, given the hierarchy in vulture groups, we expected
113 low-ranked individuals to be more prone to use personal information than high-ranked
114 individuals to try to find the food source first, in order to avoid large aggregation [39,40]. As a
115 result, low-ranked individuals would explore the environment and high-ranked individuals
116 would prioritise following low-ranked ones. Second, we investigated the drivers underlying
117 thermal selection when individuals had to choose between simultaneously available thermals.
118 We expected individuals to select thermals providing the maximal positive vertical speed (i.e.
119 climb rate) as it may provide a reliable proxy of the thermal current strength helping them
120 maximise their height gain [31]. To decrease uncertainty about resource finding and risks
121 mentioned above, we expect that individuals should favour thermals hosting the maximum
122 number of individuals to maintain cohesion and secure the possibility to cue on as many
123 conspecifics as possible [31]. Finally, social preferences may also influence decision, with
124 individuals preferentially moving together with preferred affiliates [12,41,42], as it could
125 reduce competition due to familiarity between individuals [43].

126 2. Material and methods

127 2.1 Study site, vultures housing conditions and experimental settings

128 The study was carried out in 2021 and 2022 at the Rocher des Aigles falconry centre,
129 Rocamadour, France, and divided between winter and summer periods each year. During
130 winters, vultures were housed within an aviary (6.7 x 6 x 6 m) equipped with four perches:
131 three of them measuring 3.10 m, and one of the full width of the aviary (Figure S1). This setting
132 was used to estimate vulture social bonds (see Social bond estimation). In addition, besides
133 being fed daily on small pieces of meat to prevent conflicts, five feeding events (one each week
134 during a five-week period) were organised in the aviary on a butchery carcass occurring after
135 a one-day fasting (to motivate feeding). These feeding events were used to assess dominance
136 hierarchy within the group (see Hierarchy estimation). In summer, these trained vultures were
137 kept perching on individual logs, released several times per day to execute free flight shows
138 for the public within a landscape composed of plateaus interspaced by canyons, similar to
139 “Causses” landscape typically used by french wild vultures [44]. The falconry centre is located
140 near a 120 m-deep canyon and offers natural soaring conditions for raptors, making this study
141 site a great place to investigate natural group flight behaviour (see Group flights) [26].

142 We used GPS data and visual observations to characterise the social and flight
143 behaviour of eight captive vultures (7 Eurasian griffon vultures, *Gyps fulvus*, and 1 closely-
144 related Rüppell's vulture, *Gyps rueppellii*), including five females and three males (Table S1).
145 Each year, we conducted experiments on a group of six individuals (two griffon vultures were
146 replaced in 2022, Table S1). Experiments followed the animal ethical guidelines of France and
147 the Centre National de la Recherche Scientifique. Handling of birds to fit GPS loggers followed
148 the protocol of telemetry study of vultures authorised in the Programme Personnel 961,
149 coordinated by OD, under the supervision of the French ringing centre, CRBPO, Paris.
150 Furthermore, experiments, observations, handling, and flight events were systematically
151 performed under the guidance of the head of animal caretakers, BN.

152 2.1.1 Social bond estimation

153 During five weeks in both years (December/January 2020-2021 and
154 November/December 2021), we recorded pictures of vultures in the aviary from 8:00 to 19:00
155 (local time) at 5 minutes interval, using three camera traps (Wosport Big Eye D3 and Reconyx
156 HyperFire HC600).

157 We identified birds using repeated colours on plastic rings and marks on the ruff and
158 backhead feathers, using harmless colour sticks (Raidex GmbH, Figure 1A). We removed
159 pictures on which we observed agonistic interactions, and then processed the remaining ones
160 to extract the individuals' ID and location based on their bill/head location to estimate inter-
161 individual distances with a purpose-built image annotation program in Julia software, JuliaHub
162 Inc., [45]. For subsequent analyses, we relied on R software (v 4.2.2, R software, 2022, [46]).

163 We considered the social bond between a dyad of individuals i and j based on spatial
164 proximity following the Simple Ratio association Index (SRI, equation 1, [47,48])

$$165 \text{ Equation 1: } SRI_{i,j} = SRI_{j,i} = \frac{n_{tog}}{n_{tot}},$$

166 where n_{tog} is the number of pictures in which individuals i and j were on the same perch at a
167 Euclidean distance of less than 1.55 m and n_{tot} is the total number of pictures in which
168 individuals i and j were both detected on the same perch. SRI values varied between 0 and 1,
169 where 0 represented dyads that were never seen associated and 1 represented dyads that were
170 always observed sitting at less than 1.55 m from each other. The distance of 1.55 m was chosen
171 as matching to the mode of the inter-individual distances distribution (Figure S2). This was
172 also consistent with the aviary setting, as it corresponded to half the length of most available
173 perches, and was biologically relevant (as it matches with the maximum distance (a step

174 forward, body tilted toward the opponent and neck extended) at which an individual can attack
175 and bite another one). Our analyses were robust to choices of a lower distance threshold (see
176 Supplementary Material, ESM01).

177 2.1.2 Hierarchy estimation

178 Each winter, we estimated hierarchy within the vulture group by monitoring feeding
179 interactions during the five carcass-based feeding events in the aviary (10 in total, Figure 1B)
180 using a remotely-controlled video camera (GoPro Hero 4, GoPro Inc.) fixed at 2 m height on
181 the aviary wall. These feeding events lasted on average 34 min (SD \pm 4 min).

182 We computed individuals' rank relying on the randomised Elo-rating approach [49,50],
183 which accounts for potential temporal instability of the rank using permutations in the agonistic
184 interaction series ('elo_scores' function, *aniDom* package, [50,51]; using 1000 randomisations
185 and fixing the rank adjustment speed along the series, *K*-factor, to 200). The interaction series
186 consisted in identifying the "wins" and "losses" during agonistic interactions [52] with other
187 individuals recorded ad libitum from video footage of feeding events (annotated with BORIS
188 video analysis software, [53]). We used the ethograms from Bose & Sarrazin (2007, [32]) and
189 Valverde (1959, [54]) to characterise griffon vulture feeding behaviour and between-individual
190 interactions. An individual won the interaction when it interrupted another individual's feeding
191 bout (by pecking it, displacing it or engaging in a fight), and finally accessed the carcass before
192 its opponent. In other cases, the interaction was considered as a "loss" for the initiator. We
193 assessed the reliability of the dominance hierarchy through individual Elo-rating repeatability
194 ('estimate_uncertainty_by_repeatability' function, *aniDom* package, [50]).

195 2.1.3 Group flights

196 We recorded vulture flights decisions during 42 flight sessions (21 sessions each year,
197 Table S2) in the vicinity of the Rocher des Aigles. In general, birds were released for a flight
198 session three times per day (in rare occasions from 2 to 4 times), at around 11:00, 14:30 and
199 16:00 (local time) for a mean duration of 26.03 min (SD \pm 14.15 min) of flight. Once released,
200 the birds were not forced to fly and no food was placed in the landscape to attract them. They
201 only received a meagre reward (ca. 60 g) at the end of the show (as they are fed at the end of
202 the day; see Supplementary Material ESM02 for details on captive vulture daily life). These
203 captive vultures were trained to fly freely, searching for thermals, gaining altitude and coming
204 back to their trainers (Supplementary Video 1). After about 20 to 25 minutes of free flight, the
205 birds were signalled by their caretakers to return to the Rocher des Aigles. It could take several

206 minutes for them all to return, with a longer delay if the flying conditions were particularly
207 good and when birds were more motivated to remain in flight. Vultures were equipped with a
208 high-resolution GPS logger (4 Hz, TechnoSmart, models Gipsy 1, Gipsy 5 or Axytreck)
209 positioned at their lower back using a Teflon leg-loop harness (Figure 1C, [55]). They were
210 released in two groups of three individuals. The second group was released 2-min after the first
211 group. The groups were built according to social preferences, with the three most socially-
212 bonded birds together, and the composition of these groups remained stable across all flight
213 sessions of the same year. Release order alternated between consecutive days. For each flight
214 session, we recorded and considered as stable the cloudiness (i.e. the proportion of clouds
215 covering the sky, on a scale from 0 - no clouds - to 8 - sky fully covered by clouds), horizontal
216 wind speed (four categories estimated locally from the Beaufort scale) and temperature
217 (extracted from meteofrance.com).

218 To further investigate how vulture thermal choices were shaped by personal and social
219 information, we pre-processed flight tracks in three consecutive steps. We subsampled
220 individuals' tracks from 4 to 1 GPS fix per second by taking the first record, and segmented
221 their flight behaviour into gliding, linear soaring and circular soaring. We then created spatio-
222 temporally dynamic maps of thermal availability based on the spatial clustering of individual's
223 circular soaring phases. Leaning on these maps, we retraced the history of thermal use/choice
224 by individuals.

225 2.1.3.1 Thermal use identification

226 To segment vulture flight between circular soaring, linear soaring and gliding flight we
227 first calculated turning angle and vertical speed between consecutive locations using the *move*
228 R package [56]. We applied a moving window of 30 s to calculate the absolute cumulative sum
229 of the turning angles (hereafter cumulative turning angle) and a moving window of 5 s to
230 calculate the average vertical speed. We then applied a k-means approach ($k = 2$, 'kmeans'
231 function, *stats* R package) on the smoothed vertical speed (positive speed when flying upwards,
232 negative when flying downwards) to distinguish between soaring (ascending flight) and gliding
233 (descending flight, [57,58]). We further classified soaring locations into circular soaring
234 (indicating use of thermal updrafts) and linear soaring (also called slope soaring, expected to
235 occur outside of thermals), with circular soaring being associated with a cumulative turning
236 angle ≥ 300 degrees. A result of segmentation is illustrated in Figure 2B. Finally, we inferred
237 the use of a thermal when the individual engaged in circular soaring for more than 30 s, with
238 no interruption of more than 5 s of gliding (Table S1).

239 2.1.3.2 Dynamic mapping of available thermals

240 Within each flight session, we created a dynamic map of thermals (Figure 3). First, we
241 spatially clustered vulture circular soaring locations (reflecting the use of the same thermal
242 updraft) independently of time by using a 3D density-based spatial clustering approach
243 ('*dbscan*' function, *dbscan* R package, [59]). This algorithm relies on a spherical
244 neighbourhood to perform density-based neighbour joining, i.e. clustering (Figure 2C). We
245 assumed this neighbourhood to be of a 40-m radius, and a minimum number of five locations
246 within this range for the algorithm to consider the neighbourhood further. This 40 m threshold
247 corresponded to the largest 4-nearest-neighbour distance observed when considering locations
248 attributed to thermal use only ('*kNNdistplot*' function, *dbscan* R package) and matched with
249 empirical expectations of radius during circular soaring phases [60].

250 We then made those maps dynamic in time by considering the lifetime of each thermal.
251 We considered a thermal as "available" from the moment when the first individual entered it
252 until the last individual left it (Figure 3). Note that using vulture tracks for this mapping may
253 induce limits such as the underestimation of the real lifetime of a thermal but also the lack of
254 detection of thermals never used by vultures.

255 2.2 Statistical analyses

256 We defined collective flight events as any time of a flight session when at least two
257 individuals were flying. For each of these events, we first analysed the use of social information
258 (the tendency to join thermals already discovered by conspecifics) as a function of external
259 (meteorological) and internal drivers (individual traits). We then used step selection functions
260 to define, at each movement step, which drivers determined the selection of the chosen next
261 location (thermal updraft) relative to other potential locations.

262 2.2.1 Drivers of social information use

263 We investigated the effect of local meteorological context, individual traits and flight
264 mechanics on the use of social information, defined here as the tendency to join thermals
265 already discovered by conspecifics. We considered that an individual discovered a thermal
266 when it was the first, among all individuals, to adopt circular soaring flight into it. For the
267 analysis, we discarded the discovery of the first thermal in each flight session (as this thermal
268 was necessarily discovered).

269 To investigate the drivers underlying the use of social information we modelled the
270 probability to join a thermal already discovered by others (binary response: 0 if the selected

271 thermals has not been previously discovered by a conspecific, 1 otherwise) using generalised
272 linear mixed models (GLMMs) with binomial error structure and a logit link function [61]. Our
273 full model contained the following ten fixed effects: **meteorological variables** with the (i)
274 wind speed (categorical predictor, 4 categories with null (Beaufort 0-1), low (Beaufort 2),
275 medium (Beaufort 3) and high (Beaufort ≥ 4)), (ii) cloudiness and (iii) temperature (both
276 continuous predictors); **social variables** with (iv) the age (continuous predictor) and (v) rank
277 in the dominance hierarchy of the individual (ordinal categorical predictor, with the dominant
278 individual ranked 1st), and variables related to the **mechanic of flight** with (vi) the glide-ratio
279 (horizontal distance travelled during a 1-m altitude loss, only measured on glides with
280 straightness > 0.95 in each flight), (vii) the altitude of and (viii) the 3D distance to the exit
281 location from the previous thermal used (all continuous predictors). We also added (ix) the
282 group in which individuals have been released (first or second group released for the flight)
283 and (x) the time elapsed since the first individual take-off (continuous predictor) as control
284 variables. Individual ID was considered as a random factor. We predict that the use of social
285 information should increase with thermals unpredictability (i.e. higher wind speed, lower
286 temperature), increase with inexperience and competitive abilities (i.e. younger and higher-
287 ranked individuals), and increase with flight challenge and landing risk (i.e. lower glide ratio,
288 lower previous thermal exit altitude and larger distance from previous thermal).

289 To compare the relative importance of the fixed effects we scaled all non-categorical
290 variables to use their estimate as dimensionless effect size [62]. We examined the significance
291 of each variable by comparing the goodness of fit of models with and without the variable of
292 interest using a likelihood ratio test ('drop1' function, *stats* R package). Assumptions required
293 for these statistical approaches (homoscedasticity, Gaussian distribution of residuals) were
294 checked with plot diagnosis (histogram of residuals, residual Q-Q plot, distribution of residuals
295 vs fitted values, *DHARMA* R package, [63]). We also tested for the presence of outliers, and
296 calculated the variance inflation factor (VIF) to test for collinearity (VIF values ≥ 3 suggesting
297 a strong collinearity [64]). We did not detect collinearity in our predictors (VIF_{max} = 1.74)
298 (Figure S3). Furthermore, we extracted the marginal coefficient of determination (R_m^2) and the
299 conditional coefficient of determination (R_c^2) which describe, respectively, the proportion of
300 variance explained by fixed effects and by the fixed and random effects combined [65]. Finally,
301 as the flight time period, and the tested individuals differed, we cross-compared models fitting
302 on the two years separately (see Supplementary Material ESM01).

303 2.2.2 Drivers of thermal updraft selection

304 To study the drivers underlying thermal selection, we embedded our work in the Step
305 Selection framework [66] in which we investigated the determinants of vulture movement
306 decisions to fly from a thermal to another specific one among all simultaneously available at
307 this time (i.e., during a “step”. In practice, we considered the series of thermals used by each
308 individual. In that series, we focused on movement steps involving a flight to a thermal
309 previously (or currently) used by a conspecific when other thermals were available. Using a
310 conditional logistic regression, we compared the “chosen” thermal characteristics to those
311 “available” but not chosen. The conditional logistic regression included seven predictors,
312 respectively characterising the **thermal profitability** with (i) the distance to it and (ii)
313 maximum vertical speed reached in the thermals by any individual since the focal individual
314 has been released in the flight session (continuous predictors), **individual personal experience**
315 considering whether (iii) the thermal was previously used by the focal individual (binary
316 predictor), and **social information** with (iv) the presence of the focal individual’s preferred
317 affiliates in the thermal or not (binary predictor), (v) the number of individuals present in the
318 thermal, (vi) the weighted mean (by the number of previous visits to the thermal) of the social
319 bond with individuals that used the thermals, and (vii) the negative cubed difference of ranks
320 between the focal individual and those in the thermals (all continuous predictors, set to 0 for
321 the two latter if no individuals used it/were present). We used the negative cubed difference to
322 consider an attraction-repulsion effect. In cases where the difference in rank is large, high-
323 ranked individuals should be attracted to conspecifics (i.e. higher probability to join the thermal
324 in which the difference of ranks is large and positive), while low-ranked individuals should be
325 repulsed (i.e., lower probability to join the thermal in which the difference of ranks is large and
326 negative). When the difference of rank is weak, this should have a close to null effect on the
327 probability of selecting a thermal. To model this effect, and because the dominant individual is
328 rank 1, the negative cubed difference of ranks was used. For example, following the curve of
329 the negative cube function, if the difference of rank was five (e.g. the focal individual is ranked
330 6th - a low rank, a conspecific in another thermal is ranked 1st - a high rank) the probability that
331 the focal individual joined the conspecific should be drastically decreased, mimicking a
332 repulsion effect. We predict that individuals should select the thermal with the highest
333 profitability (i.e. closest in distance and the one with largest positive vertical speed), the most
334 familiar (i.e. if previously used), with the most valuable social information (i.e. hosting the

335 most and preferred affiliates), and minimising competition risk (i.e. when the cube rank
336 difference is the largest).

337 Also for this model, we scaled all non-categorical variables to better compare their
338 relative importance. We fitted the conditional regression considering all individuals together,
339 yet considering data stratified at the individual-step level. We finally reported the relative
340 selection strength (RSS) of significant variables which provides the magnitude of estimated
341 selection coefficients, holding all other covariates fixed at their mean value [67,68].

342 3. Results

343 Vulture dominance hierarchy was steep (Figure S4) and reliably inferred (individual
344 Elo-rating repeatability = 0.82 and 0.83 in 2021 and 2022 respectively). The rank orders among
345 individuals present in both years were relatively consistent and uncorrelated to sex or age
346 (Wilcoxon test: $w = 6$, $p = 0.70$ and $w = 3$, $p = 0.80$, Pearson's correlation coefficient [95%
347 confidence interval]: $\rho = -0.19$ [-0.87, 0.73], $p = 0.71$ and $\rho = 0.72$ [-0.21, 0.97], $p = 0.11$
348 respectively for sex and age in both years, Table S1). During the 21 flight sessions performed
349 each year, we identified a total of 520 and 578 thermalling events in 2021 and 2022
350 respectively. On average, 63% (SD \pm 7%, Table S1) of these circular soaring behaviours took
351 place in thermals discovered by a conspecific.

352 3.1 Flight risks and hierarchy shapes the use of social information

353 Our model was significantly better than the null model (considering only control
354 effects; $\chi^2_{10} = 195.3$, $p < 0.001$, AIC = 1237.4 and 1412.7 respectively) and explained 30% of
355 the variance (Table S3). The probability for an individual to use a thermal previously
356 discovered by a conspecific decreased with temperature (from 0.74 at 17°C to 0.43 at 31°C,
357 Figure 4A, Figure 5A, Table S3), but tended to increase with cloudiness and wind speed (Figure
358 4A, Table S3). This probability dropped also with the distance from the previous thermal and
359 the altitude at which the bird left it (from 0.63 when being at a distance of 12 m from the last
360 thermal used to 0.16 at a distance of 6776 m and from 0.76 when exiting the last thermal at an
361 altitude of 195 m to 0.039 at 1574 m of altitude, Figure 4A, Figure 5B, C, Table S3). Individuals
362 lower in the dominance hierarchy were approximately twice as likely to discover new thermals
363 than high-ranked individuals (Figure 4A, Figure 5D). We did not detect significant effects of
364 age and glide-ratio on the probability to use thermal previously discovered by conspecifics
365 (Figure 4A, Table S3). Fitting the same model structure on 2021 and 2022 data separately

366 yielded the same overall results, suggesting that the observed pattern was robust to changes in
367 hierarchy and between-year conditions (Figure S5, Table S3).

368 3.2 Vultures select thermal updrafts hosting the most conspecifics

369 We identified 178 movement steps where an individual entered a thermal while at least
370 one other thermal was available simultaneously. In these movement steps, individuals were
371 approximately 28 times more likely (RSS [95% confidence interval] = 27.94 [5.99, 131.63],
372 Figure 4B, Table S4) to select a thermal hosting the largest number of conspecifics compared
373 to a thermal hosting only one individual. On the contrary, the probability to choose a thermal
374 tended to decrease when the preferred affiliate was using it. The distance to the previous
375 thermal, the maximal vertical speed reached in the thermal, and whether individuals used this
376 thermal in the past did not significantly affect thermal selection (Figure 4B, Table S4). At time
377 of decision (i.e. when individuals decided to move from one thermal to another), the difference
378 in dominance ranks as well as the presence of its preferred affiliate did not drive the individual's
379 probability of selecting the thermal. This pattern was consistent when considering only
380 movement steps where individuals had to choose between thermals currently used by other
381 vultures at time of decision (N = 61, Figure S6, Table S4). Furthermore, considering all
382 decision events, the sensitivity analysis on the inter-individual distance threshold for the social
383 bond strength estimation yielded the same results (i.e. 1.55 m, 1.30 m and 1 m; see
384 Supplementary Material ESM01, Figure S7, Table S5).

385 4. Discussion

386 Using a combination of high-resolution tracking and social structure monitoring, we
387 identified contextual drivers for the differential weighting of personal and social information
388 in movement decisions. We showed that vultures' movement decisions predominantly relied
389 on social information, especially in unfavourable flight conditions that increased thermal
390 unpredictability or put individuals at risk of undesired landing. Overall, individuals
391 preferentially joined thermals with the largest number of conspecifics. However, the use of
392 social information depended on the individual social status: low-ranking individuals were more
393 inclined to use personal information and discovered more thermals on their own than high-
394 ranking individuals.

395 We found that low-ranked individuals, likely the ones suffering the most from
396 interference competition, had higher probabilities of discovering new thermals, thus likely

397 exploring their environment more intensively than the high-ranked individuals. Such flight
398 strategy would enable subdominant individuals to reach carcasses first, or at least to arrive at
399 the beginning of the feeding event when the rate of interference is lower [29] hence avoiding
400 lost opportunities due to conformity with conspecific behaviour [69]. From this may emerge a
401 producer-scrounger dynamic [70,71] wherein the use of personal information from low-ranked
402 individuals to arrive at food sources with lower competition levels would be exploited by
403 dominant individuals to reduce their own searching effort [18,71,72]. This is coherent with
404 previous observations of low-ranked vultures being “pioneers”: the very first individuals to
405 land and feed on the carcasses before being displaced by high-ranked individuals arriving
406 afterwards [29]. This influence of dominance on foraging tactics where low-ranked individuals
407 explore and find food while dominant profit has also been observed in other social bird species
408 such as common cranes, *Grus grus*, oystercatcher, *Haematopus ostralegus*, house sparrows,
409 *Passer domesticus*, and barnacle goose, *Branta leucopsis* [20,72–74]. Eviction of subordinates
410 from food patches has even recently been identified as a trigger for collective movements in
411 vulturine guineafowl, *Acryllium vulturinum* [75]. In contrast, in activities where individuals do
412 not experience competition, such as tool-use learning in chimpanzees, naïve individuals will
413 generally copy dominant (and knowledgeable) individuals [76]. Because individuals likely to
414 suffer a cost (low-ranked) were reluctant to follow other individuals, while the reverse was not
415 true, our study hence stands as a clear-cut illustration of the “copy when asocial learning is
416 costly” rule [77]. The vulture position in the dominance hierarchy, through the costs it imposes
417 on access to food, seems to calibrate the balance between the use of personal and social
418 information in foraging movements. In some cases, however, trading personal information in
419 favour of social information is inevitable.

420 When the environment is largely unpredictable or whenever using error-prone personal
421 knowledge can be energetically costly, individuals should tend to eavesdrop, and rely more on
422 information provided by conspecifics to reduce uncertainty about resources availability
423 [15,78]. Here, we evidenced both cases. First, vultures prioritised the use of social information
424 when the temperature was low and tended to do so also when cloudiness and wind speed
425 increased (Table S3). These weather conditions may translate into fewer and weaker thermals,
426 drifting into the wind, making them less predictable [79–83]. Second, they also favoured social
427 information when the altitude at which they left their previous thermal was low. When exiting
428 a thermal at low altitude, individuals have limited time to glide to the next thermal before
429 having to shift to flapping flight to stay aloft, or else landing in an undesired place, which both
430 would add high energetic cost associated with flapping and take-off [25,26,84,85]. Reaching

431 high altitudes quickly to avoid this risk may also explain why vultures used more thermals
432 previously discovered by conspecifics if those were close to the last thermal they used. While
433 vultures are able to cope with difficult flight conditions (e.g. turbulence and strong wind) by
434 adjusting their banking angles [60], anticipating such risky events may remain the most
435 efficient way to maximise the trade-off between time, energy, and risk, which largely dictates
436 their flight strategy [38].

437 Adult individuals, through experience, are generally better at coping with difficult flight
438 conditions [86], yet we did not find evidence of an effect of age relative to the use of social
439 information, as observed in other group living species (e.g. [87]). More than age *per se*, the
440 familiarity of individuals with a given situation might shape their tendency to rely or not on
441 social knowledge (e.g. in spider monkeys, *Ateles geoffroyi*, during collective foraging [88]).
442 The captive individuals tested in this experiment are all adults and fly in the same landscape
443 every day since their birth, thus they are probably very familiar with the areas favourable to
444 thermal emergence. This could explain why we did not detect any effect of age on the use of
445 social information, but also indicates that the relative importance of this source of information
446 is probably underestimated due to the birds' familiarity with the surroundings.

447 When faced with a choice between simultaneously available thermals, the previous
448 experience of individuals (i.e. whether the thermal was used previously or not by the focal) or
449 current expertise of the group (i.e. relative age/hierarchy difference) impacted very little vulture
450 movement decisions compared to other social cues (i.e. number of conspecifics present in the
451 thermals, and affiliation status). This result contrasts with previous findings from insects to
452 mammals, including birds [89–93]. In the current system, ascending currents can be very
453 ephemeral phenomena, sometimes only lasting a few minutes [94,95]. Certainly, a “live report”
454 is therefore better provided by the accumulation of convergent information sources (i.e.
455 numerous conspecifics, [96]) rather than relying on a unique individual source (i.e. the
456 individual itself or one reference individual). In that line, and surprisingly, the presence of one
457 preferred affiliate in a thermal tended to reduce the probability to join it. There is evidence that
458 social bonds assessed “on the ground” are often unrelated to association in flight [97]. It
459 therefore questions whether collective flights might be used by vultures to strengthen initially
460 weak social bonds. Maintaining association in flight can indeed be important, as evidenced in
461 the migratory behaviour of other soaring bird species to enable accurate collective mapping of
462 the distribution of uplifts [98,99]. Furthermore, for soaring birds, the presence of conspecifics
463 should provide not only information on the location and strength of updrafts [22,99] but could
464 also indicate flight speed and circling radius needed to optimise climb rate, by remaining close

465 to the centre of the thermal where uplift is highest [60]. Yet, the maximum speed reached by
466 individuals using the thermal little affected vulture decision choices. Possibly, climb rate or
467 individual speed are not as easy to assess at a distance, compared to the number of conspecifics.
468 In other words, vultures tended to favour quantity signals (with the number of conspecifics)
469 over quality signals (maximal vertical speed) [100]. The “power of the group” may indeed in
470 turn drive cohesion, which could itself make social information even more profitable [100,101].

471 The aforementioned observations relied on an experimental setting involving captive
472 birds. While moving and foraging stand as engrained behaviours underpinning animals’ life
473 (see [78] for definition), and are thus likely to be naturally expressed, especially in a long-lived
474 species only recently brought to captivity (2-3 generations). Yet, natural foraging conditions
475 can still be very different from those occurring in captivity. This may affect the described
476 dynamic, amplifying or reducing the challenge and necessity of finding food. For example, the
477 studied birds are fed every day (although with limited amounts to keep them lean and
478 responsive to caretakers), thus certainly less motivated in finding food than their wild
479 counterparts which regularly face food-deprived periods and need to adjust their foraging
480 strategy as a consequence [102]. The shift in movement pattern as a result of hunger level may
481 as well affect the balance between personal and social information. Hungry individuals facing
482 energetic emergency may specifically prioritise the use of social information (e.g. in house
483 sparrows [103,104]). In addition, natural feeding events can aggregate up to 100-120 vultures
484 [29] creating conditions in which both the competition and the social information load are much
485 higher than the ones in our experiments. Natural conditions may therefore likely exacerbate the
486 competition and social effect highlighted in this study.

487 Altogether, our results provide insights into the architecture of decision-making
488 during movement in a social bird. It highlighted the trade-offs between personal and social
489 information these birds have to consider in order to optimise both their flying efficiency and
490 their foraging success. As a first approximation, we considered social cues as coming from
491 “conspecifics”. Strictly speaking however, our study included two species, Griffon vulture and
492 Rüppell’s vulture, albeit phylogenetically close and with similar biology. The one Rüppell’s
493 vulture in fact, used social information provided by surrounding vultures and did not stand out
494 as an outlier in its behaviour. Despite being from another species, this individual had a stable
495 dominance rank between years and was not the lowest ranked, it also developed a range of
496 affinities similar to other individuals. In this line, in West Africa, both species are commonly
497 seen together in foraging groups. It is known that even phylogenetically distant individuals
498 could be an important source of social information, not only about the presence of carcasses

499 [105], but also about the availability of thermals when sharing the same airspace (e.g. from
500 black kites, *Milvus migrans*, or common swifts, *Apus apus*, [106,107]). Interactions with
501 heterospecifics can indeed drastically affect animals' daily life [108], up to shaping the
502 cognitive machinery underpinning their foraging decisions [109]. How heterospecific cues are
503 used when foraging remains clearly overlooked. Future studies in this direction could provide
504 valuable insights into understanding the fundamental rules dictating how animals decide where
505 to go.

506 CRediT authors' contributions

507 **Yohan Sassi:** Conceptualization, Methodology, Software, Investigation, Formal Analysis,
508 Visualization, Writing - original draft, Writing - Review & Editing

509 **Basile Nousières:** Investigation, Resources

510 **Martina Scacco:** Software, Writing - Review & Editing

511 **Yann Tremblay:** Conceptualization, Writing - Review & Editing

512 **Olivier Duriez:** Conceptualization, Investigation, Supervision, Writing - Review & Editing

513 **Benjamin Robira:** Conceptualization, Methodology, Software, Visualization, Validation,
514 Supervision, Writing - original draft, Writing - Review & Editing

515 Declaration of competing interest

516 The authors declare to have no conflict of interest

517 Data availability

518 Data, scripts and supplementary video are available here:

519 <https://data.indores.fr/privateurl.xhtml?token=95fda53c-378d-48f0-970e-1e7b5d62bd6e>

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530

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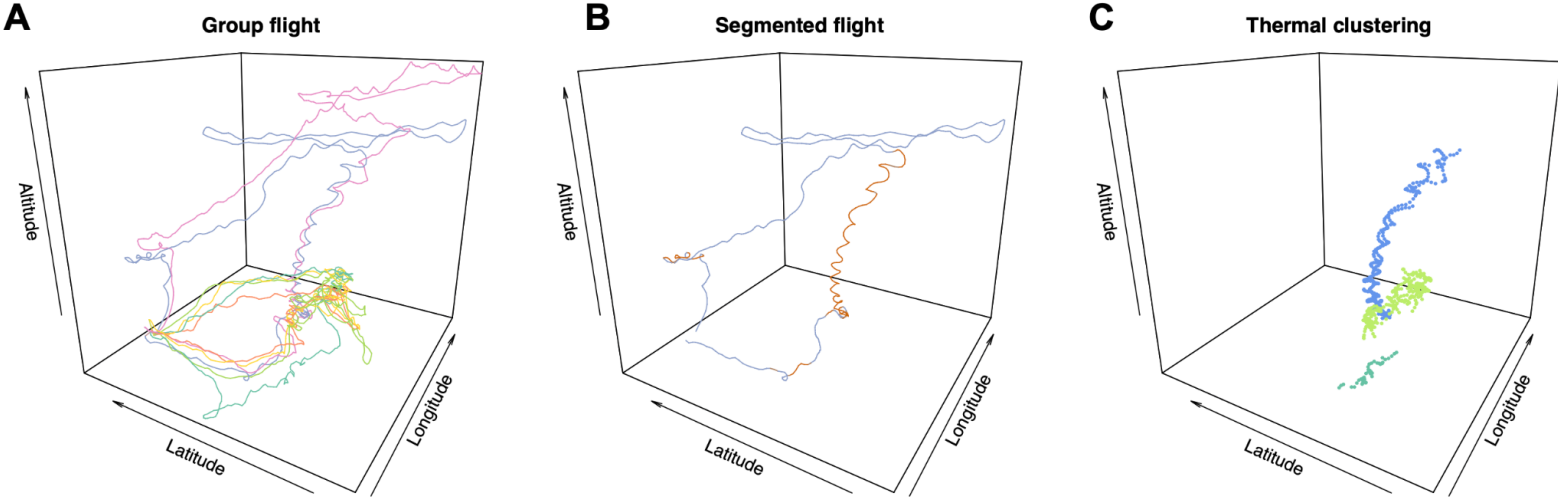
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835 Main text figures



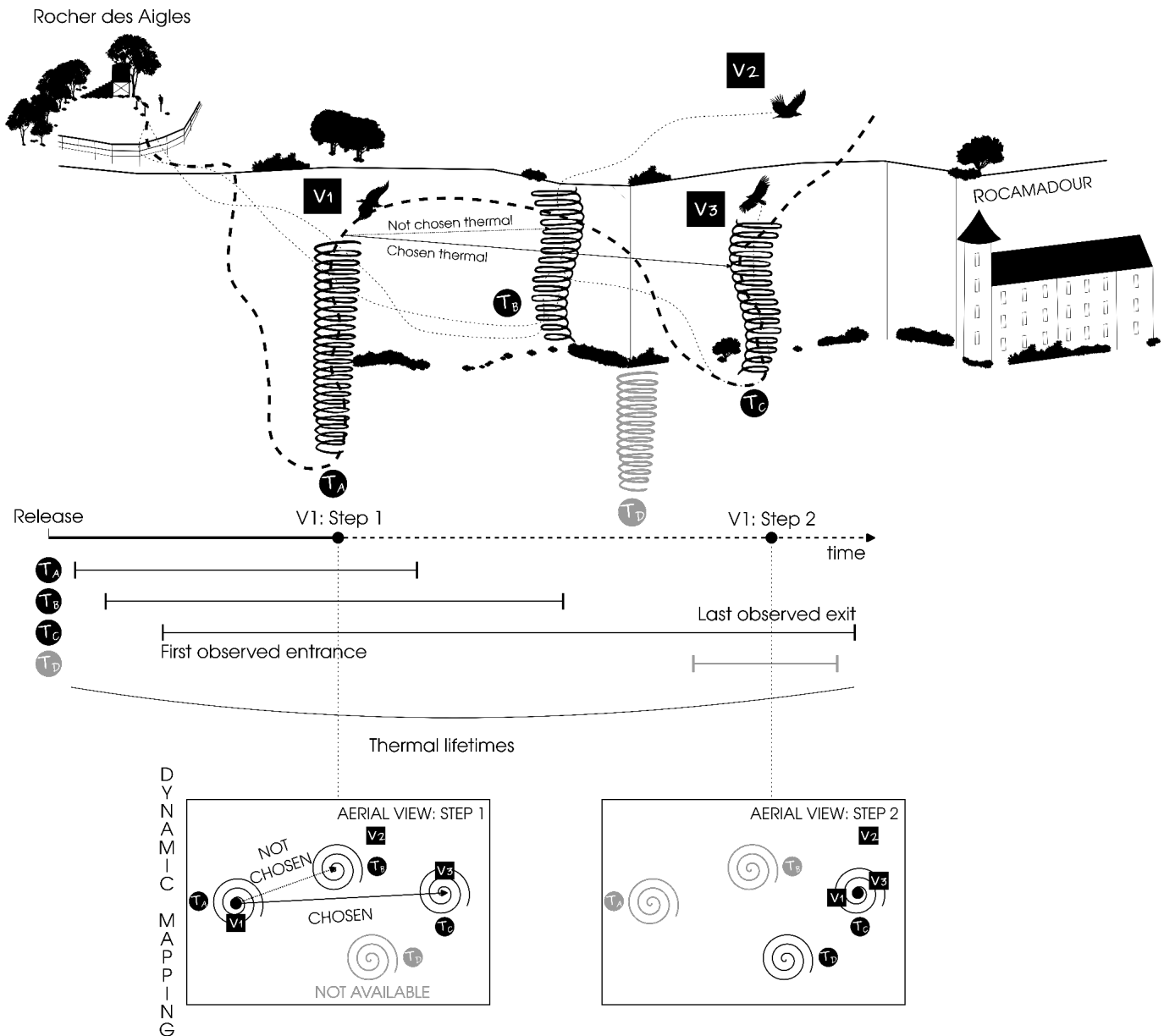
836 **Figure 1. Data collection.** (A) Perched vultures. Distance between vultures during perching
837 events were used to estimate social-bond strength. (B) Feeding event around a butchery carcass.
838 Agonistic interactions during those feeding events were used to estimate dominance hierarchy.
839 (C) Flying vulture. Vultures were released for free flight into a 120-m canyon, equipped with
840 high-resolution GPS loggers.



841

842 **Figure 2. Flight data pre-processing.** Pre-processing steps of group flight GPS data, example
 843 of one flight session. The altitude ranges from 200 m to 600 m. (A) shows a group flight (see
 844 Supplementary Video 1), with colours corresponding to each individual. (B) illustrates the
 845 segmentation of an individual's flight (blue individual in (A)), with the orange segments
 846 corresponding to circular soaring phases. (C) illustrates the 3D density-based spatial clustering
 847 of individuals circular soaring phases, with colours indicating the three thermals identified in
 848 this flight session.

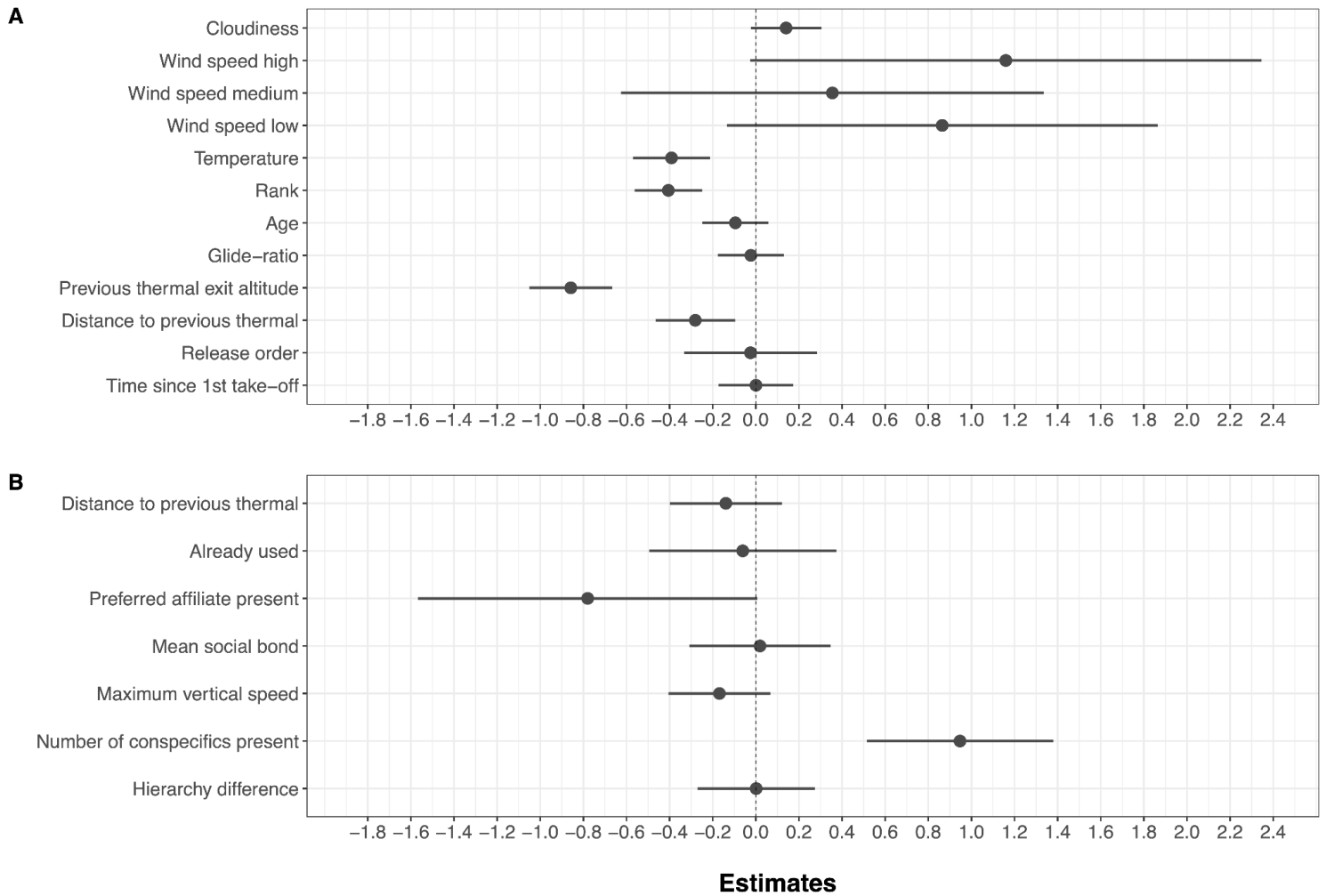
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850 **Figure 3. Illustration of the step selection framework used to investigate thermal**
 851 **selection.** We focused on the movement of vultures released from the Rocher des Aigles when
 852 flying from thermal to thermal (i.e. a step). To do this, we mapped each thermal used during a
 853 flight session based on movement segmentation and clustering (see method section) to create
 854 dynamic maps of thermal availability over the flight session (as represented by the aerial
 855 views). The illustrated example focuses on the decision of a vulture (V_1 ; step 1) when leaving
 856 the thermal (T_A) and having to choose between two available thermals (T_B , close but not
 857 currently used by another vulture, and T_C , further away but currently used by another
 858 individual). T_D was not available until step 2, when it was discovered and used by another
 859 individual, and is therefore shown in grey at step 1. At step 2, V_1 joined V_3 in T_C and both

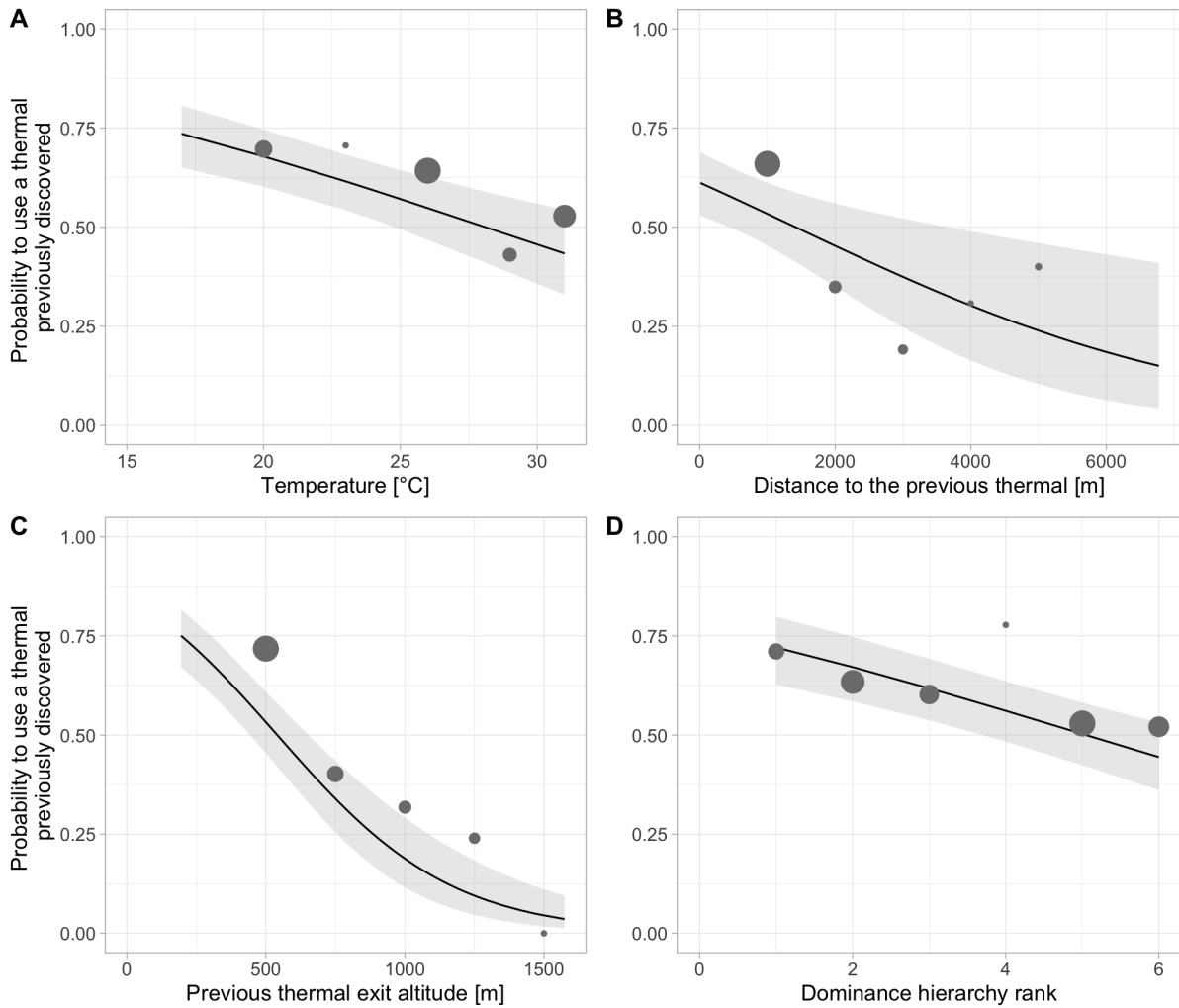
860 thermals T_A and T_B were no longer available. A thermal was available from the moment when
861 the first individual entered it until the last individual left it. Therefore, the number of available
862 thermals could change during the flight session (see differences between maps in step 1 and 2).

863



864 **Figure 4. Estimates of models investigating the drivers of social information use (A) and**
 865 **thermal selection (B).** Rows correspond to each predictor, with positive values indicating
 866 increased probability to discover a thermal (A) or to move to the thermal (B). For their
 867 biological meaning in (A) and (B), see Material and methods sections 2.2.1 and 2.2.2
 868 respectively. Each point represents the standardised estimate value. Segments give the
 869 associated 95% confidence intervals.

870



871

872 **Figure 5. The probability to use a thermal already discovered by conspecifics decreases**
 873 **with temperature, distance to the thermal, flight altitude and hierarchy rank.** This is the
 874 visual representation of significant variable effects presented in Figure 4A. Points represent the
 875 probability of using a thermal already discovered by a conspecific, estimated on the raw data.
 876 Their size is relative to the number of thermals used. Because vultures were encouraged to
 877 leave the Rocher des Aigles to perform free flights, but not forced to, and can fly for different
 878 lengths of time, some differences in the number of thermals used by individuals can appear
 879 (e.g. small sample size for individuals of rank 4 in panel D). To estimate the probability in (A),
 880 (B) and (C), predictors were binned in six bins. Black lines with grey shades show the GLMM
 881 estimated probability with its 95% confidence interval (N = 1098 thermals).

882

883 Supplementary materials

884 ESM01: Sensitivity analysis

885 To assess the robustness of our inference to variability in the social composition of the
886 group and flight conditions between years and other “arbitrary” analytical decisions, we
887 repeated the analysis based on different choices.

888 Drivers of social information used in movement decisions were investigated on all data
889 combined to increase sample size. Yet, we evaluated the effect of years by refitting the full
890 model structure on 2021 and 2022 data separately.

891 To study the drivers of thermal selection, we investigated the influence of social bond
892 strength between individuals on thermal choice. Social bond strength was calculated
893 considering spatial proximity on perches (≤ 1.55 m) between individuals as a sign for social
894 bond. We repeated the model fit (see main text, Drivers of thermal updraft selection) using a
895 distance threshold of 1.30 m (half the average wingspan of griffon vultures, [1]), and 1 m.

896 Furthermore, in the main text, to analyse thermal updraft choices, we considered all
897 choices independently of whether vultures had to choose between thermals with and potentially
898 without conspecifics. To verify whether the “presence” only of conspecifics influenced the
899 choice, we repeated the analysis considering only choice events implying that currently
900 available thermal updrafts were all used by conspecifics.

901 All these investigations revealed high robustness of our inference (Figure S5-7, Table
902 S3-5). Therefore, we presented in main text the models which were the most complete and
903 based on the most parsimonious rationale.

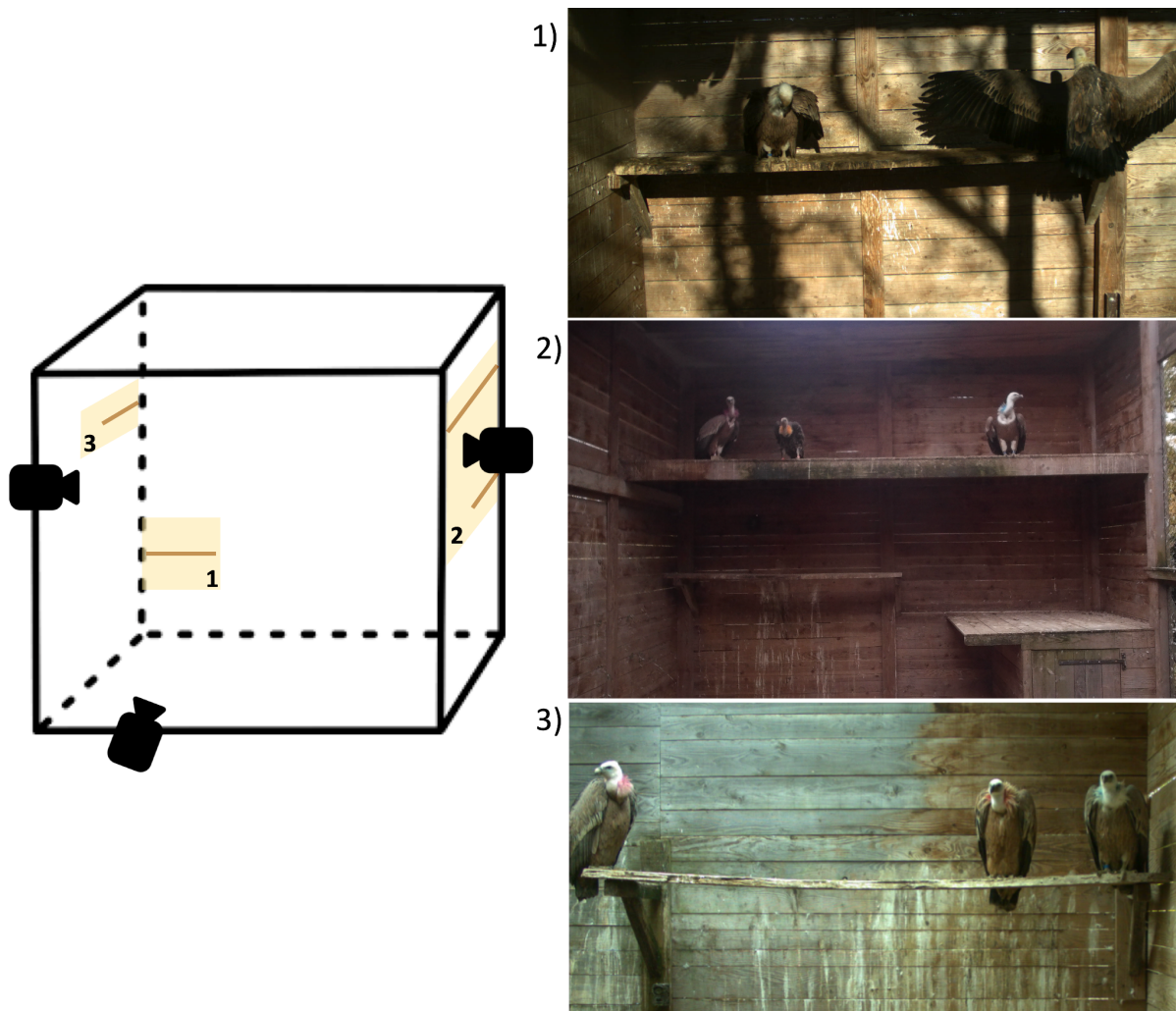
904 ESM02: The captive life of vultures under study

905 In winter vultures are housed into a large collective aviary (6.7 x 6 x 6 m) equipped
906 with four perches: three perches measuring 3.10 m, placed at 1.7, 2.6 and 3.5 m from the
907 ground, and one perch measuring the full width of the aviary at 4 m height. Birds have ad-
908 libitum access to water, within a pond, and are fed daily with small pieces of meat. Every bird
909 receives approximately 400-450 g of meat per day. Once a week during the experiment periods,
910 every other week in normal conditions, a feeding event with a butchery carcass is organised
911 after a day of fasting. Individuals’ weight is measured when placed in the aviary at the end of
912 the flight season, and one month before the start of the new flight season.

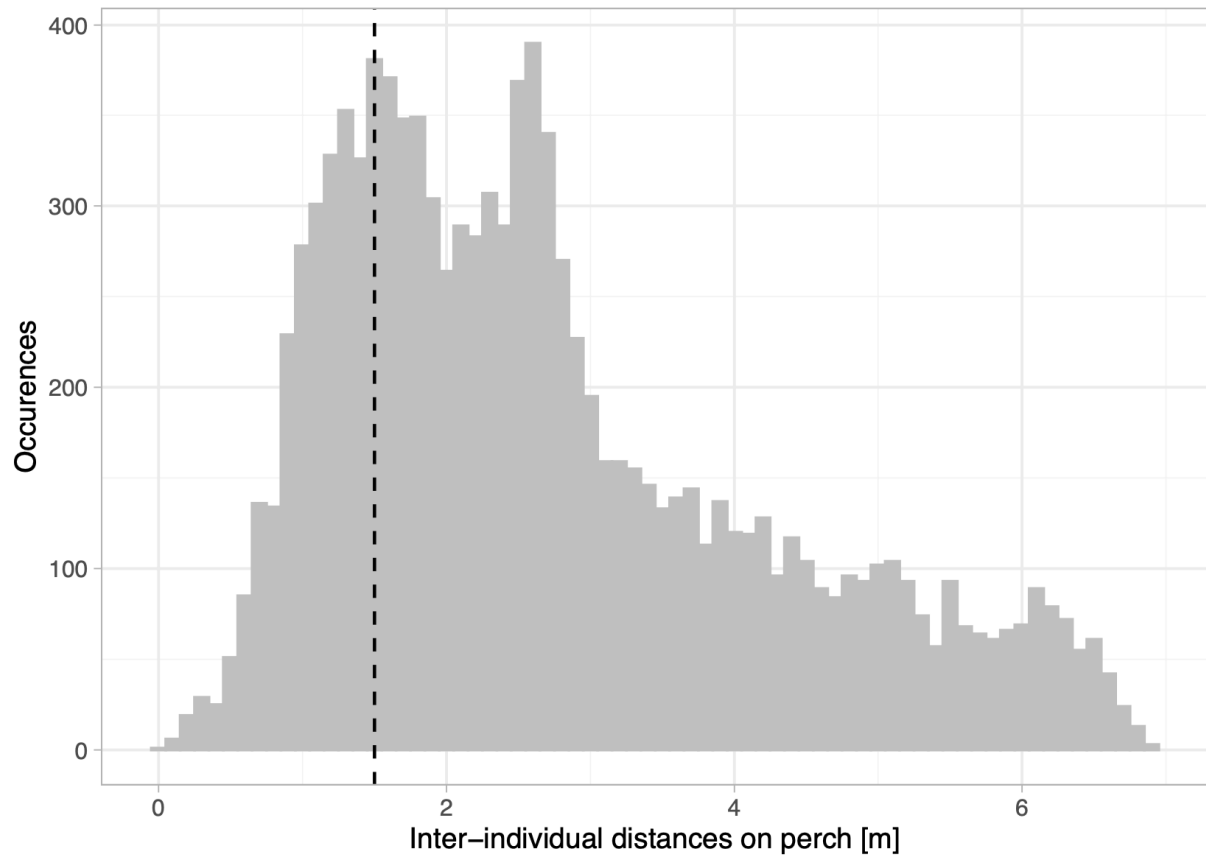
913 In summer, birds are individually kept in aviaries or on tree logs. They are released in
914 general three times a day for public free flight shows in the Canyon de l'Alzou. Once released,
915 birds are free to take off and dive into the canyon to explore the surroundings, or stay with
916 caretakers in the show area. Birds are neither forced to fly (just encouraged vocally by
917 caretakers), nor lured with food at certain places of the countryside to attract them. After 20 to
918 25 minutes, caretakers raise their fist as a visual signal for vultures to come back and land at
919 the Rocher des Aigles. When doing so, birds receive a few pieces of meat (around 60 g) as a
920 reward on the way back to their aviary. At the end of the day, after all flight sessions, each bird
921 receives an additional piece of meat to complement its daily meal to reach 450 g per day. Birds
922 are weighted once a week to ensure stability.

923

924 **Supplementary Video 1** is accessible, with data and scripts, at [doi:10.48579/PRO/WYKS5A](https://doi.org/10.48579/PRO/WYKS5A)

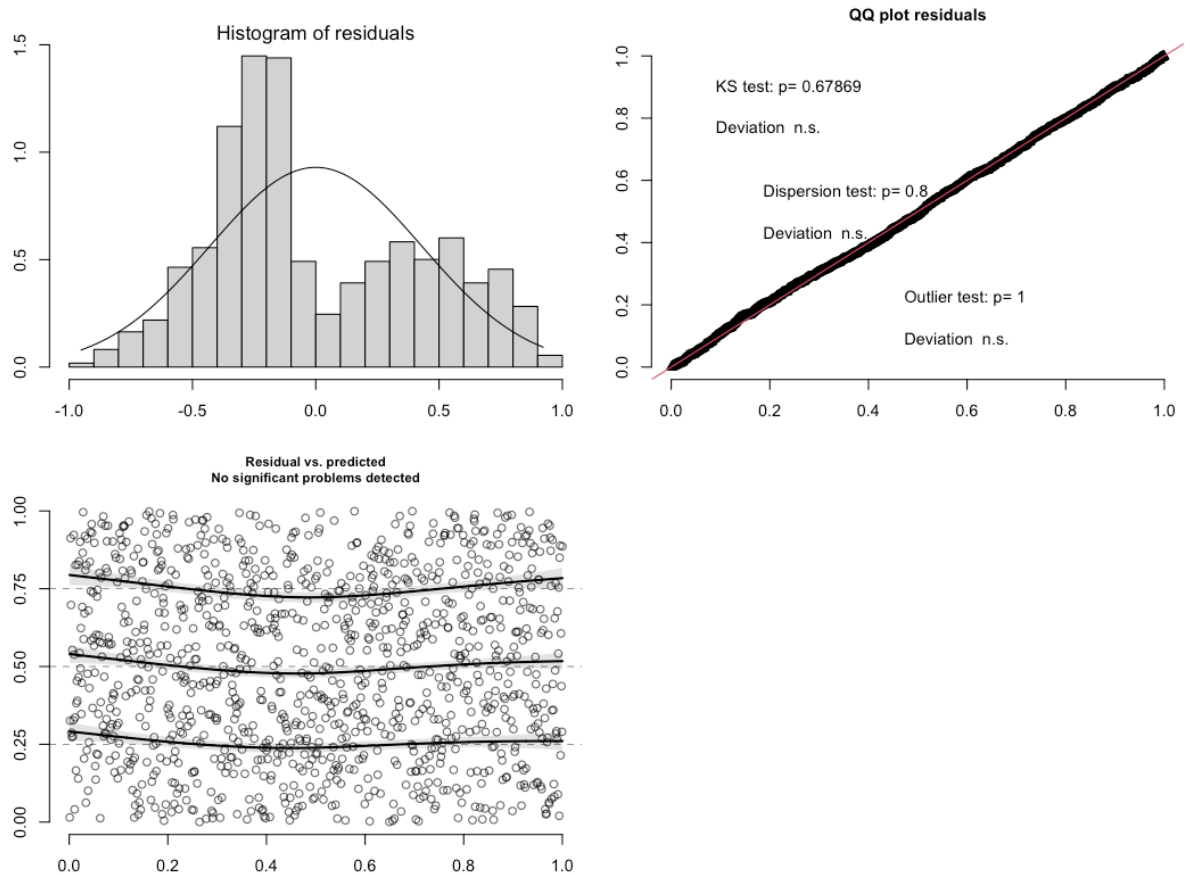


925 **Figure S1. Schematic view of the wintering aviary and camera angles.** Brown lines refer to
 926 perches. Camera icons show their location in the aviary, and the yellow area in front of each
 927 camera indicates the area photographed every 5 minutes. Pictures provide examples for each
 928 corresponding number in the yellow areas.



929

930 **Figure S2. Distribution of the Euclidean inter-individual distances between birds on**
931 **perches.** Distances have been measured based on pictures taken in the wintering aviary. Every
932 bin corresponds to 10 cm. The vertical black dotted line represents a distance of 1.55 m.

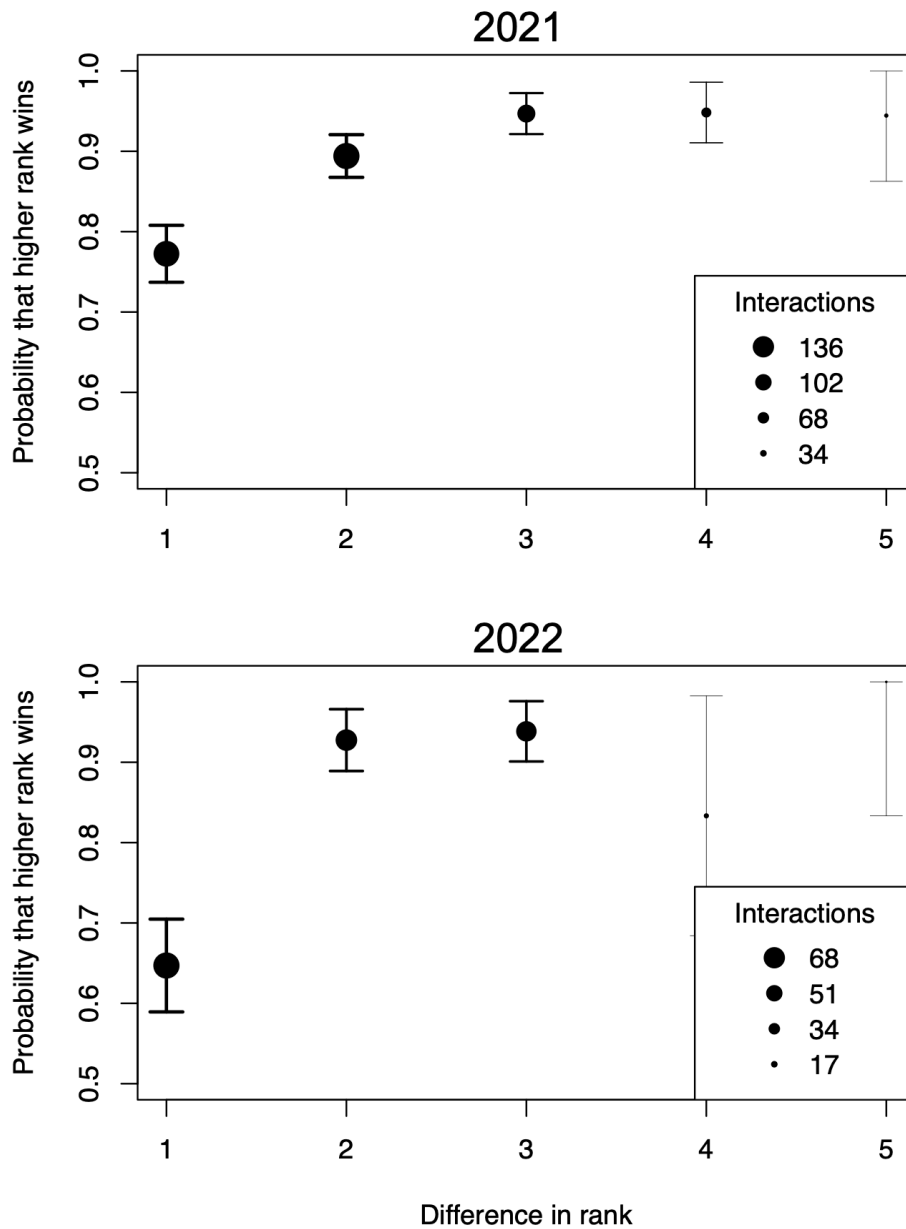


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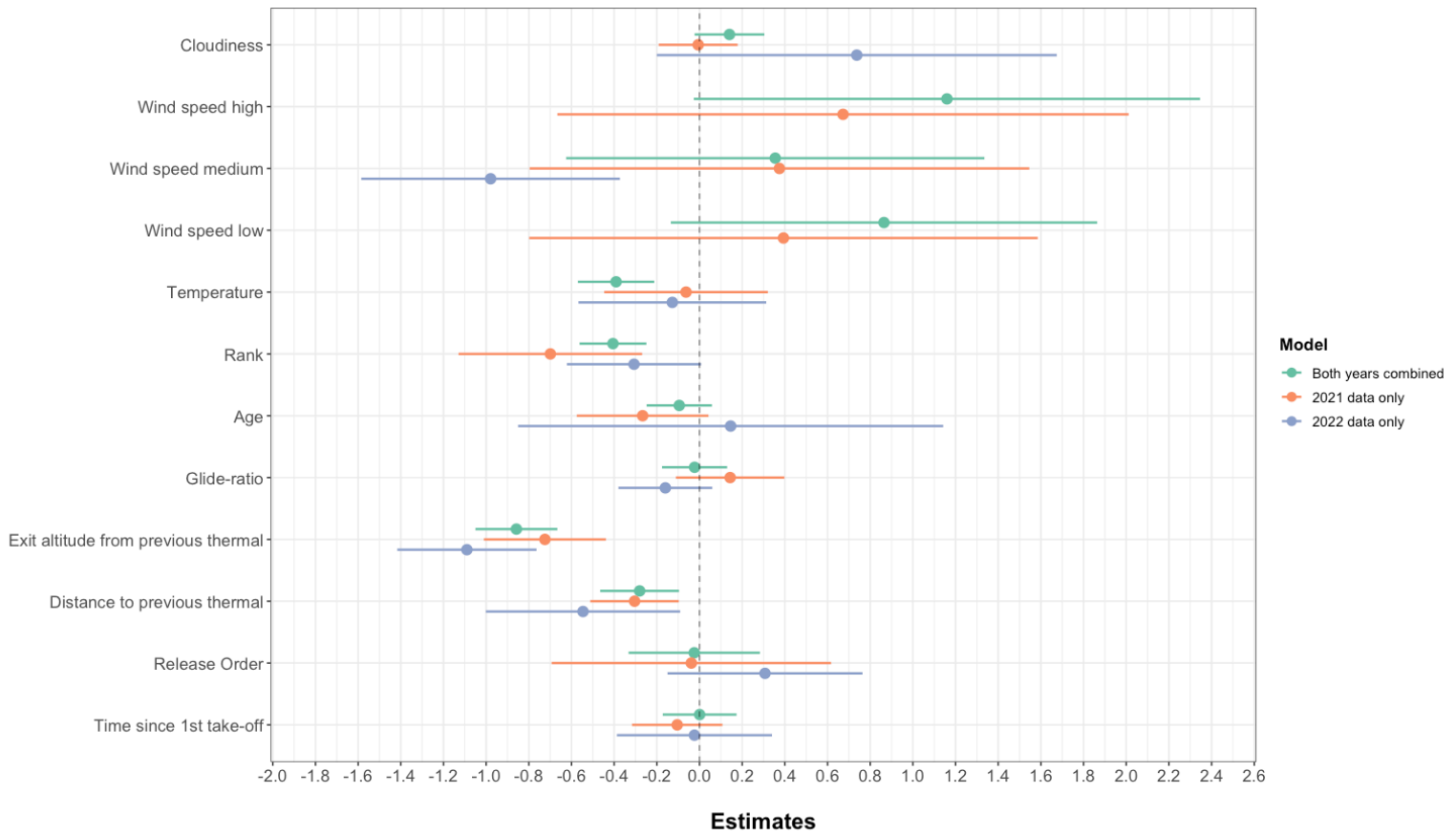
934 **Figure S3. Diagnostic plot of the model investigating the drivers of social information use.**

935 The histogram of residuals is shown, as well as the Q-Q plot (adapted for the modelled
 936 distribution; with test for deviation of the distribution - Kolmogorov-Smirnov, KS, outliers and
 937 overdispersion) and the scatter plot of the fitted values vs. the residuals. Plots were based on
 938 the DHARMA package [2].

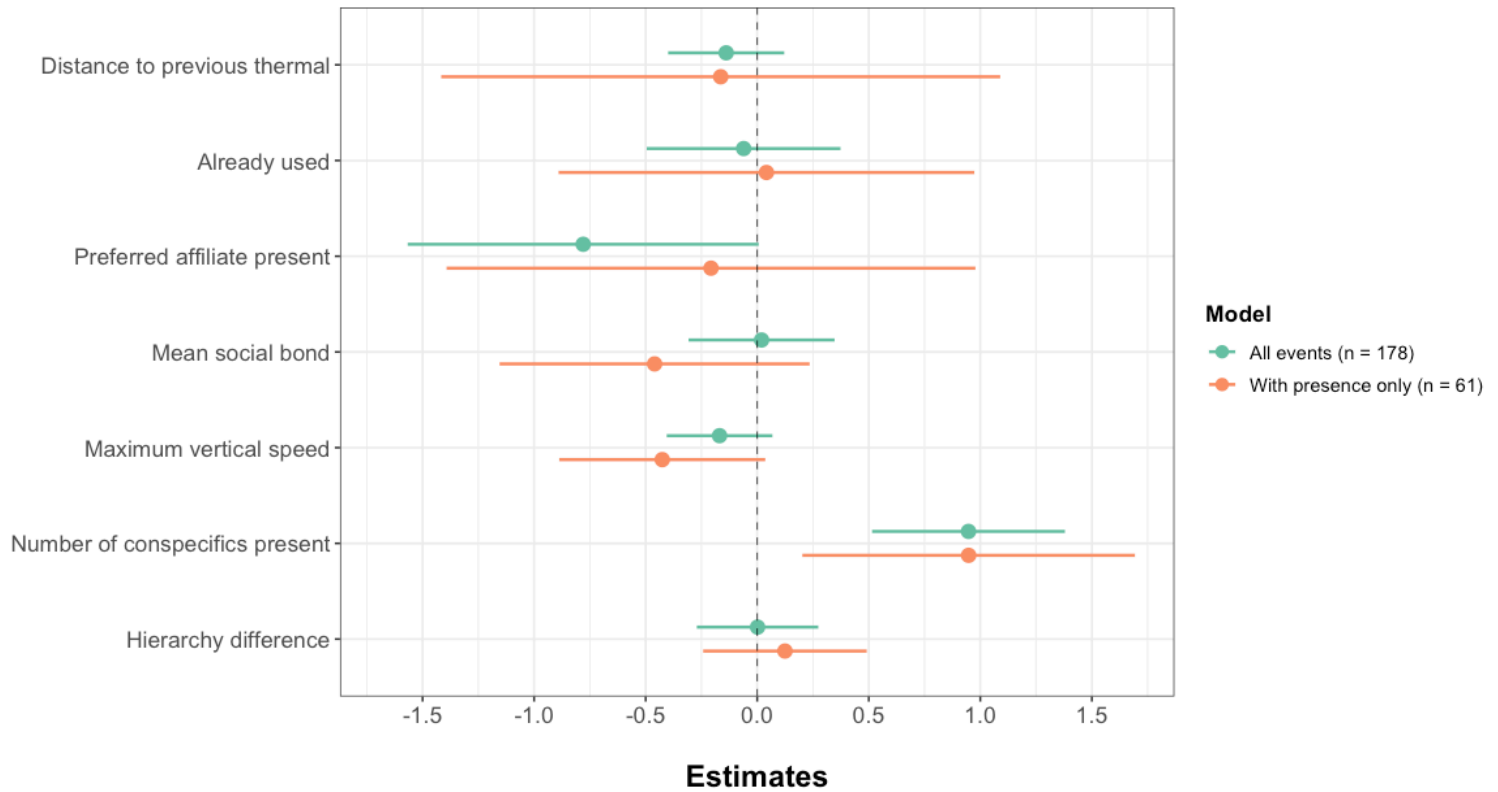
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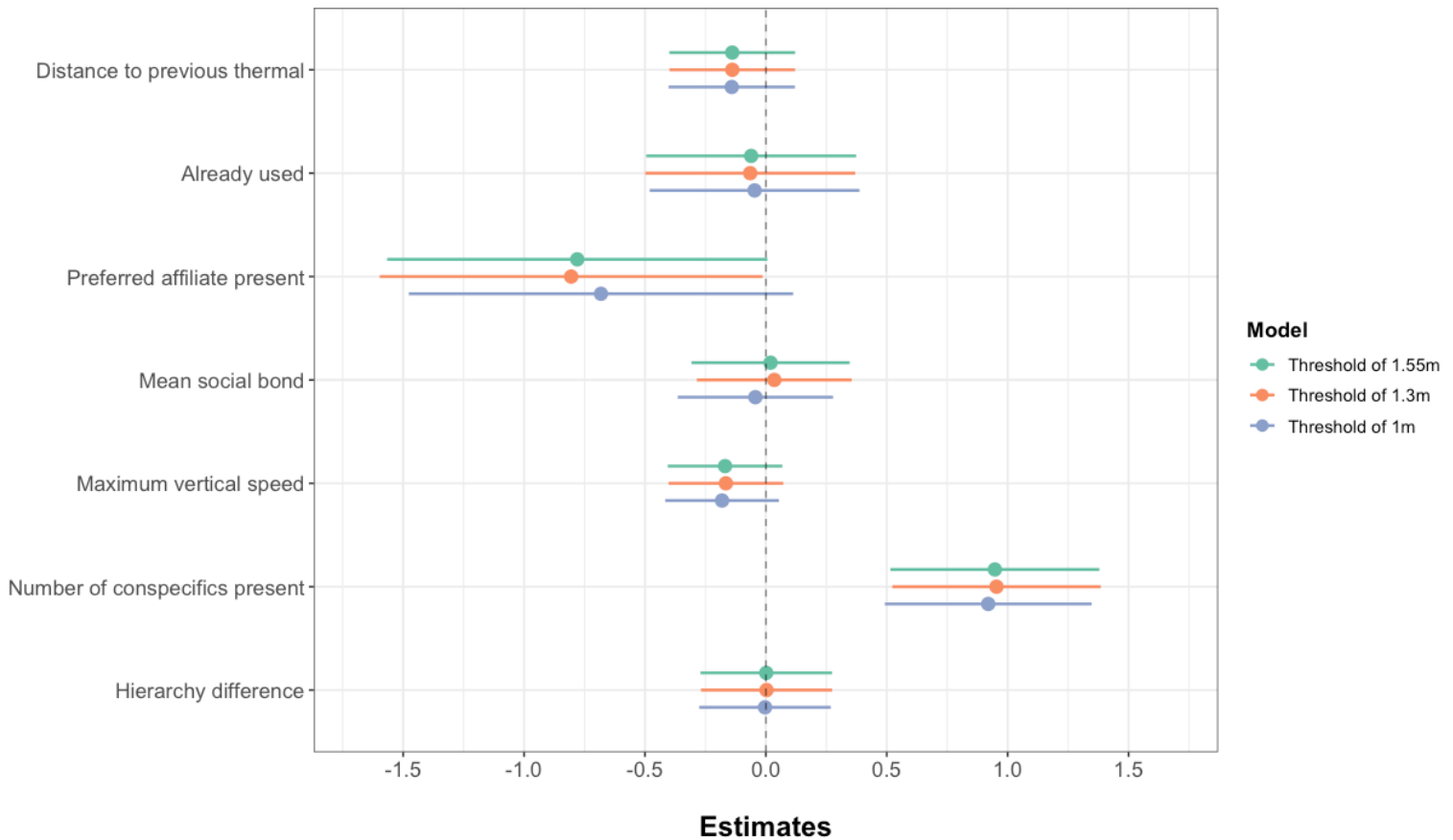
940 **Figure S4. Dominance hierarchy steepness in vulture groups.** Points represent the
 941 probability that the higher ranked individual wins an agonistic interaction as a function of the
 942 difference in rank. The size of the point is relative to the sample size. Segments give the 95%
 943 confidence interval.



944 **Figure S5. Estimates of models investigating the drivers of thermal discovery.** Rows
 945 correspond to each predictor. Each point represents the (standardised) estimate value. Segments
 946 give the associated 95% confidence intervals. Models were fitted considering data of both years
 947 (green), only 2021 (orange) or only 2022 (blue).



948 **Figure S6. Estimates of models investigating the drivers of thermal selection.** Rows
 949 correspond to each predictor. Each point represents the (standardised) estimate value. Segments
 950 give the associated 95% confidence intervals. “All events” refers to the model considering
 951 decision events where available thermals previously used but potentially empty at time of
 952 choice were considered. “With presence only” refers to the model focusing on decision events
 953 where vultures had to choose only between thermals currently used by conspecifics.



954 **Figure S7. Estimates of models investigating the drivers of thermal selection.** Rows
 955 correspond to each predictor. Each point represents the (standardised) estimate value. Segments
 956 give the associated 95% confidence intervals. “Threshold 1.55m” refers to the model
 957 considering an inter-individual distance threshold of 1.55m in the estimation of social bonds,
 958 which is the threshold considered in the analysis. The other levels are part of the sensitivity
 959 analysis.

960 **Table S1. Summary table of vultures under study.** For ranks, (-) means that for the
 961 considered year the rank of the individual was not estimated. The frequency of socially
 962 informed thermal use corresponds to the percentage of thermals used by each individual that
 963 was previously discovered by a conspecific.
 964

Individuals	Species	Sex	Age	Year of presence	Rank (in 2021 / 2022)	Frequency of socially informed thermal use	Number of thermalling events
Henry	<i>G. fulvus</i>	F	25	2021	3 / -	0.654	78
Gregoire	<i>G. fulvus</i>	M	11	2021	1 / -	0.716	81
Hercule	<i>G. fulvus</i>	F	10	2022	- / 4	0.667	27
Kazimir	<i>G. fulvus</i>	M	8	2021 / 2022	6 / 6	0.521	190
Bulma	<i>G. fulvus</i>	F	8	2021 / 2022	4 / 3	0.652	138
Kirikou	<i>G. rueppelli</i>	F	8	2021 / 2022	5 / 5	0.529	291
Leon	<i>G. fulvus</i>	M	6	2021 / 2022	2 / 2	0.634	246
Mathilda	<i>G. fulvus</i>	F	4	2022	- / 1	0.702	47

965

966 **Table S2. Summary table of flight sessions used in the study.** Number of flight sessions
967 represent all flight sessions per Dates that were exploitable to fit our models on (after data
968 treatment and filtering detailed in Material and methods section).

969

Dates	Number of flight sessions
27-05-2021	2
28-05-2021	2
07-07-2021	3
08-07-2021	3
09-07-2021	3
10-07-2021	3
11-07-2021	3
30-09-2021	2
04-07-2022	2
05-07-2022	3
06-07-2022	2
07-07-2022	4
08-07-2022	4
09-07-2022	3
10-07-2022	3

971 **Table S3. Outputs of models investigating the drivers of social information use.** Estimates for continuous variables are scaled and provided
 972 with their 95% confidence intervals (95% CI), hence can be used as a dimensionless effect size. For the categorical predictor wind speed, the level
 973 without wind (i.e. wind speed null) is included in the intercept. ID gives the percentage of variance explained by the individual names (random
 974 effect), with N_{ID} the number of individuals considered. (-) indicates missing data preventing estimation of the considered parameters. Scaled
 975 variables are indicated by an asterisk.

<i>Predictors</i>	Use of already discovered thermal								
	<i>Both year combined</i>			<i>2021 data</i>			<i>2022 data</i>		
	<i>Estimates</i>	<i>95% CI</i>	<i>p</i>	<i>Estimates</i>	<i>95% CI</i>	<i>p</i>	<i>Estimates</i>	<i>95% CI</i>	<i>p</i>
(Intercept)	-0.24	[-1.18, 0.71]	-	0.61	[-0.54, 1.77]	-	0.52	[-0.40, 1.44]	-
Cloudiness *	0.14	[-0.02, 0.30]	0.089	-0.01	[-0.19, 0.18]	0.947	0.74	[-0.20, 1.67]	0.120
Wind speed high	1.16	[-0.03, 2.35]		0.67	[-0.67, 2.01]		-	-	
Wind speed medium	0.35	[-0.63, 1.34]	0.011	0.37	[-0.80, 1.55]	0.792	-0.98	[-1.59, -0.37]	0.001
Wind speed low	0.86	[-0.13, 1.86]		0.39	[-0.80, 1.59]		-	-	
Temperature *	-0.39	[-0.57, -0.21]	<0.001	-0.06	[-0.45, 0.32]	0.747	-0.13	[-0.57, 0.31]	0.570
Dominance rank *	-0.41	[-0.56, -0.25]	0.003	-0.70	[-1.13, -0.27]	0.017	-0.31	[-0.62, 0.01]	0.054
Age *	-0.09	[-0.25, 0.06]	0.247	-0.27	[-0.58, 0.04]	0.134	0.15	[-0.85, 1.14]	0.774
Glide-ratio *	-0.02	[-0.18, 0.13]	0.767	0.14	[-0.11, 0.40]	0.266	-0.16	[-0.38, 0.06]	0.158

Previous thermal exit altitude *	-0.86	[-1.06, -0.66]	<0.001	-0.72	[-1.01, -0.44]	<0.001	-1.09	[-1.42, -0.76]	<0.001
Distance to previous thermal *	-0.28	[-0.47, -0.10]	0.002	-0.30	[-0.51, -0.10]	0.003	-0.55	[-1.00, -0.09]	0.012
Release order [2]	-0.02	[-0.33, 0.28]	0.875	-0.04	[-0.69, 0.62]	0.908	0.31	[-0.15, 0.76]	0.186
Time since 1 st take-off	0.00	[0.17, 0.17]	0.994	-0.10	[-0.32, 0.11]	0.339	-0.02	[-0.39, 0.34]	0.898

Random Effects

ID	0.00			0.18			0.00		
N _{ID}	8			6			6		
Observations	1098			520			578		
Marginal R ² / Conditional R ²	0.304 / -			0.269 / 0.308			0.406 / -		

* Mean + SD prior to scaling

Cloudiness	1.07 + 1.73			1.98 + 2.13			0.24 + 0.43		
Temperature	25.43 + 4.14			22.00 + 2.86			28.50 + 2.22		
Dominance rank	3.66 + 1.72			3.55 + 1.76			3.75 + 1.67		
Age	8.86 + 4.71			10.60 + 6.23			7.28 + 1.40		
Glide-ratio	11.68 + 4.05			12.40 + 4.21			11.10 + 3.80		
Previous thermal exit altitude	463.81 + 250.78			448.13 + 241.39			477.91 + 258.33		
Distance to previous thermal	653.11 + 932.68			683.40 + 1070.37			625.86 + 788.52		

977 **Table S4. Outputs of models investigating the drivers of thermal selection.** Estimates for
 978 continuous variables are scaled and provided with their 95% confidence intervals (95% CI),
 979 hence can be used as a dimensionless effect size. “All events” refers to the model considering
 980 decision events where available thermals previously used but potentially empty at time of
 981 choice while “Presence only” indicates the model focusing on decision events where vultures
 982 had to choose only between thermals currently used by conspecifics, with their respective
 983 sample size in brackets. Scaled variables are indicated by an asterisk.
 984

<i>Predictors</i>	<i>All events (N = 178)</i>			<i>Presence only (N = 61)</i>		
	<i>Estimates</i>	<i>95% CI</i>	<i>p</i>	<i>Estimates</i>	<i>95% CI</i>	<i>p</i>
Distance to previous thermal *	-0.14	[-0.40, 0.12]	0.295	-0.16	[-1.42, 1.08]	0.798
Thermal already used	-0.06	[-0.49, 0.37]	0.784	0.04	[-0.90, 0.96]	0.931
Preferred affiliate present	-0.78	[-1.56, 0.007]	0.052	-0.21	[-1.37, 1.00]	0.732
Mean social bond *	0.02	[-0.31, 0.35]	0.907	-0.46	[-1.14, 0.24]	0.194
Maximum vertical speed *	-0.17	[-0.40, 0.07]	0.163	-0.42	[-0.87, 0.05]	0.071
Number of conspecifics present *	0.95	[0.51, 1.38]	<0.001	0.95	[0.20, 1.68]	0.013
Hierarchy difference *	-0.001	[-0.27, 0.27]	0.991	0.12	[-0.25, 0.48]	0.506

* *Mean + SD prior to scaling*

Distance to previous thermal	754.81 + 1220.90	562.49 + 991.70
Mean social bond	0.13 + 0.09	0.13 + 0.09
Maximum vertical speed	2.57 + 0.94	2.42 + 0.91
Number of conspecifics present	0.73 + 0.83	1.16 + 0.79
Hierarchy difference	- 2.34 + 27.78	- 3.03 + 39.93

985

986 **Table S5. Outputs of models investigating the drivers of social information use.** Estimates for continuous variables are scaled and provided
 987 with their 95% confidence intervals (95% CI), hence can be used as a dimensionless effect size. Scaled variables are indicated by an asterisk.
 988

<i>Predictors</i>	<i>Threshold of 1.55 m</i>			<i>Threshold of 1.30 m</i>			<i>Threshold of 1 m</i>		
	<i>Estimates</i>	<i>95% CI</i>	<i>p</i>	<i>Estimates</i>	<i>95% CI</i>	<i>p</i>	<i>Estimates</i>	<i>95% CI</i>	<i>p</i>
Distance to previous thermal *	-0.14	[-0.40, 0.12]	0.295	-0.14	[-0.40, 0.12]	0.294	-0.14	[-0.40, 0.12]	0.290
Thermal already used	-0.06	[-0.49, 0.37]	0.784	-0.06	[-0.50, 0.37]	0.770	-0.04	[-0.48, 0.39]	0.833
Preferred affiliate present	-0.78	[-1.56, 0.007]	0.052	-0.80	[-1.59, -0.01]	0.046	-0.68	[-1.48, 0.11]	0.093
Mean social bond *	0.02	[-0.31, 0.35]	0.907	0.03	[-0.28, 0.35]	0.831	-0.04	[-0.36, 0.28]	0.791
Maximum vertical speed *	-0.17	[-0.40, 0.07]	0.163	-0.16	[-0.40, 0.07]	0.172	-0.18	[-0.42, 0.05]	0.130
Number of conspecifics present *	0.95	[0.51, 1.38]	<0.001	0.95	[0.52, 1.38]	<0.001	0.92	[0.49, 1.34]	<0.001
Hierarchy difference *	-0.001	[-0.27, 0.27]	0.991	0.003	[-0.27, 0.27]	0.984	-0.003	[-0.27, 0.27]	0.980

* *Mean + SD prior to scaling*

Distance to previous thermal	754.81 + 1220.90	754.81 + 1220.90	754.81 + 1220.90
Mean social bond	0.13 + 0.09	0.13 + 0.10	0.12 + 0.10
Maximum vertical speed	2.57 + 0.94	2.57 + 0.94	2.57 + 0.94

Number of conspecifics
present

$0.73 + 0.83$

$0.73 + 0.83$

$0.73 + 0.83$

Hierarchy difference

$- 2.34 + 27.78$

$- 2.34 + 27.78$

$- 2.34 + 27.78$

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