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► To cite this version:

Vitor Hugo Bessa Ferreira, Benoît Peuteman, Flore Lormant, Mathilde Valenchon, Karine Germain, et al.. Relationship between ranging behavior and spatial memory of free-range chickens. *Behavioural Processes*, 2019, 166, pp.103888. 10.1016/j.beproc.2019.103888 . hal-02629384

HAL Id: hal-02629384

<https://hal.inrae.fr/hal-02629384>

Submitted on 26 Oct 2021

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1 **RELATIONSHIP BETWEEN RANGING BEHAVIOR AND SPATIAL MEMORY OF FREE-**
2 **RANGE CHICKENS**

3

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29 **ABSTRACT**

30
31 Different personalities may lead to different ways of processing environmental information; however,
32 the relationship between personality and cognition is not fully understood as studies on diverse species
33 present contrasting results. As there is great within-flock variability of outdoor ranging behavior in
34 free-range broiler chickens, we tested whether and how ranging behavior impacts on individual spatial
35 memory abilities. The experiment was conducted on one flock (n=200) reared in the same conditions
36 throughout the study, to simulate on-farm situations. As the ranging behavior was stable over time, we
37 compared two distinct groups of male chickens: one that visited the range more (High rangers) and
38 one that was more prone to staying in the poultry house (Low rangers). To test the spatial memory,
39 individuals (n=30) went through two main phases in an arena with 8 cups. For the familiarization
40 phase, individuals were submitted to one trial per day, for seven days, to a situation where all eight
41 cups were baited with mealworms. Animals had to reach a criterion of 5 cups **visited** out of 8 to
42 advance to the next phase. For the spatial test, only four cups were baited and systematically placed at
43 the same location. This last phase comprised two trials per individual per day, for nine days. During
44 these two phases, latency to visit cups and the number of visits and revisits of all cups were recorded.
45 Low ranger chickens took less time to attain the pre-established threshold of visiting 5 cups out of 8,
46 over the familiarization phase. During the spatial test, the latency to visit four cups decreased between
47 the within-day trials for low ranger chickens and increased for high ranger chickens. Moreover, in the
48 within-day trial analysis, low ranger chickens exhibited an improvement on spatial memory and better
49 spatial memory compared to high ranger chickens. Different speed-accuracy trade-offs may explain
50 these differences between low and high ranger chickens and the way individuals **interact and solve the**
51 **task**. Our study strengthens the scientific evidence relating consistent individual differences in
52 behavior, **with** the ranging behavior of free-range chickens, and cognitive performance during a spatial
53 memory task.

54
55 **Keywords:** birds; **broiler**; free-range chicken; **cognition**; personality.
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1. INTRODUCTION

60

61 In the last decades, the interdisciplinary approach of individual consistent differences in
62 behavior is flourishing among the scientific community as scientists realize that **such** behavioral
63 differences are ubiquitous in the animal kingdom (Gosling, 2001). The fact that a group of animals
64 shows between-individual variation and within-individual consistency that persist through time and
65 different situations (i.e. animal personality) brings theoretical and practical inquiries, since individuals
66 from the same group or population will interact with their social and physical environment in different
67 ways (Dall et al., 2004; Réale et al., 2007; Sih et al., 2004).

68 Empirical research has highlighted a link between learning performance and personality
69 focusing on diverse personality and behavioral traits, however, the relationship between these traits
70 and cognition is not fully understood, as studies on diverse species present contrasting results
71 (Dougherty et al., 2018). An important animal personality trait believed to influence cognition is
72 known as Exploration-Avoidance. As proposed by Réale et al. (2007) this trait can be seen when the
73 individual interacts with new situations (unknown conspecifics, new habitat, new food, new objects).
74 For cognitive scientists, the link between exploration and cognition (learning performances, mainly) is
75 expected since more explorative individuals are more prone to be in contact with what is to be learned
76 (Carere and Locurto, 2011; Sih and Del Giudice, 2012). For example, individual black-capped
77 chickadees (*Poecile atricapillus*) entering a novel arena more quickly had a better performance during
78 an acoustic discrimination task than slower individuals (Guillette et al., 2009). However, for other
79 species, such as the red junglefowl, this relationship is age and task-dependent: more explorative
80 chicks and less explorative adult females were faster to learn a reversal task (Zidar et al., 2018).
81 Pheasants (*Phasianus colchicus*), on the contrary, show a different pattern with slow explorers (when
82 chicks) being slow reversers (when adults) (Madden et al., 2018).

83 A recent meta-analysis by Dougherty et al. (2018) showed that the direction of the
84 personality/cognition relationship is highly variable and the current hypothesis that exploration is
85 consistently linked to cognitive performance was not supported. Therefore, even if a link between

86 different personality traits, such as exploration, and cognition may exist for a given species or
87 population, assumptions of the direction and dynamics of this relationship need to be reassessed
88 through further work and made cautiously.

89 Free-range domestic chickens, the contemporary of the junglefowl, show great variability in
90 range use, when the outdoor range access is finally available (Chielo et al., 2016). Extrinsic factors
91 such as indoor/outdoor stocking density (Campbell et al., 2017a), position of pop-holes (Rault and
92 Taylor, 2017), the access and placement of the poultry house, the availability of shelters and trees
93 (Dawkins et al., 2003), and the internal roosting location (Pettersson et al., 2018) were all potential
94 candidates for explaining this inconsistency at the group-level. Intrinsic factors such as sex, age or the
95 breed/strain (Hegelund et al., 2005; Mahboub et al., 2004; Nielsen et al., 2003; Stadig et al., 2017) are
96 also important variables to take into account when studying the interactions between chicken groups
97 and range use.

98 A less studied feature of chickens and range interactions is that individual chickens have
99 different personality profiles (Garnham and Løvlie, 2018), and these profiles may, in turn, be related
100 to important cognitive processes. For juvenile and adult red **junglefowl**, for example, personality,
101 mainly high shyness/fearfulness and low exploration, impacts positively how fast the individuals
102 learned a reversal task (Zidar et al., 2018).

103 A similar personality/cognition interaction dynamic may be impacting individual chickens in
104 their spatial learning and memory when using the range (Campbell et al., 2018). When foraging or
105 exploring a new environment, animals, such as mammals and birds, use their spatial memory, also
106 called reference memory (White and McDonald, 2002), based on the formation of a complex spatial
107 map that includes cues present in the surrounding environment as well as their relationships (Packard
108 & Cahill, 1995; White & McDonald, 2002). Free-range chickens can be a suitable animal model for
109 the integration of personality and cognition studies as individuals within the same flock vary in
110 visiting the range or not. This potentially exposes birds to different levels of environmental complexity
111 and different ways to navigate this environment. On the one hand, some individuals may require more
112 spatial information processing, since their interaction with the surrounding environment is higher
113 (Campbell et al., 2018). On the other hand, as suggested by Guillette et al. (2017), some individuals

114 may be slower when processing environmental information, resulting in less exploratory individuals
115 that are not prone to switch between different and potentially new environments, until acquiring
116 sufficient information on one particular area.

117 In the current work, we studied the relationship between ranging behavior and spatial memory
118 of free-range chickens. We aimed to verify two main predictions. The first one was that individuals
119 could be characterized based on their ranging behavior, to corroborate findings of consistent ranging
120 behavior on laying hens and broilers chickens (Campbell et al., 2017b; Hartcher et al., 2015; Larsen et
121 al., 2017; Pettersson et al., 2018; Taylor et al., 2017). The second prediction was that ranging behavior
122 is linked to different spatial cognitive performances, based on the recent literature and findings of red
123 junglefowl personality and cognition (Zidar et al., 2018, 2017), we hypothesized that low ranger
124 chickens would perform better than high ranger ones. To test behavioral consistency within-
125 individuals, we initially checked for the stability of individual range visits. Then, according to their
126 placement in the number of range visits continuum, the chickens on the extremes were selected: the
127 highest rangers and the lowest rangers to undergo a spatial cognitive test. To test whether the level of
128 ranging behavior is related to changes in processing spatial information, mainly reference memory, we
129 used a cohort of individuals that were trained to find the constant location of four rewarded black cups
130 among 8 identical black cups.

131

132 2. METHODS

133

134 This study was conducted at the experimental unit UE 1206 EASM of INRA, France, from
135 February to May 2015. All applicable international, national and/or institutional guidelines for the care
136 and the use of animals followed the 1964 Helsinki declaration and its later amendments or comparable
137 ethical standards. Animal care and experimental treatments complied with the guidelines of the French
138 Ministry of Agriculture for animal experimentation and European regulations on animal
139 experimentation (86/609/EEC).

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142

143 **2.1. SUBJECTS**

144

145 For this experiment, the free-range system consisted of a poultry house (4 m x 5 m) giving
146 access to an outdoor range (27 m x 27 m) through one pop-hole. A flock of 200 *naked neck* broiler
147 chicks (S757N, males and females mixed) was placed at day-old in the poultry house, all chicks being
148 identified one week later with a wing tag. Birds had indoor *ad libitum* access to feed and water. During
149 the first three days from placement, artificial lighting was provided continuously, then from day 4 to
150 day 14 it was gradually decreased, until total use of natural lighting. The indoor ambient temperature
151 was maintained at 28°C during the first week and decreased 1°C each week, until reaching 23° at the
152 age of 38 days.

153 At day 31, 120 chickens were chosen randomly and equipped around the neck with a plastic
154 poncho labelled with a unique acronym for easy identification. From day 38, when feathering was
155 complete, birds were allowed free access to the outdoor range (meadow-like, open space with vegetal
156 cover, without trees or shelters available), day and night. The initial stocking density in the poultry
157 house was 10 chickens/ m², and 3.7 m²/chicken in the outdoor range. Birds' sex was determined at 65
158 days of age.

159

160 **2.2. RANGING BEHAVIOR**

161

162 The chickens carrying a poncho were observed by scan sampling. Six interspaced scans per
163 day at four different ages (D44, D49, D57, and D64) were performed. The experimenter, using
164 binoculars, counted the marked birds from a high chair placed outside the range, to minimize
165 disturbance. For each scan, the location of each chicken was noted on one of the 16 range zones,
166 previously delimited with small wood stakes, or inside the poultry house (Figure 1). As some animals
167 preferred to stay close to the building's edges, Zones A to C were gradually longer, except for zone D
168 (A = 4m, B = 9m, C = 14m, and D = 2m). This range division allowed us to have a more

169 heterogeneous distribution of the individuals and differentiate chickens who ranged near the poultry
170 house from those who went further on the range.

171

172 Figure 1 about here

173

174 These observations made it possible to determine the number of times the chickens were seen
175 on the range (number of range visits) and to calculate an individual distance index. When an animal
176 was seen in a given zone, we considered it walked the equivalent of **the** half-length of this zone plus
177 the total length of already crossed zones, in **the** case of zones B, C or D. For example, when a given
178 individual was seen in zone B, we considered it walked the 4 meters of zone A plus 4.5 m (half-
179 length) of zone B. The distance index was then calculated as follows:

180

181 **Individual distance index** = number of times seen in zone A*2 + number of times seen in
182 zone B*8,5 + number of times seen in zone C*19 + number of times seen in zone D*26

183

184 The distance index integrated the 'number of range visits' with the distance that individuals
185 moved away from the poultry house, adapted to incorporate the size of the range zones. A high
186 distance index corresponded with a high level of ranging behavior.

187 The 120 birds were classified according to their total number of range visits and their
188 individual distance index. Those placed at the extremities of this continuum were called *low rangers*
189 or *high rangers*, the former meaning an individual with a low number of range visits, and the latter an
190 individual with a high number of range visits. When individuals presented the same number of range
191 visits, those presenting a higher distance index, in the case of high rangers, or a lower distance index,
192 in the case of low rangers, were chosen for testing in a spatial memory task.

193

194 **2.3. SPATIAL MEMORY TASK**

195

196 From 66 to 88 days of age, 30 chickens underwent a series of cognitive tests. These
197 individuals were selected among the 120 animals, according to two criteria: sex (only males were
198 selected in order to control for sex influences on cognition - [Bushby et al., 2018](#)) and ranging behavior
199 level 'high rangers'/'low rangers' (after group observations on the range).

200 Following classification of ranging behavior, 15 healthy individuals from either extreme, i.e.
201 the 15 highest rangers and the 15 lowest rangers, were selected for the spatial memory task. The group
202 was then divided in two subgroups, equally balanced in the number of high rangers and low rangers
203 chickens, to be tested throughout the day (morning and afternoon). The first subgroup was caught in
204 the morning and kept in crates without food placed in the test room for at least 1 hour before the
205 beginning of the cognitive task. As soon as all chickens from this subgroup finished the cognitive
206 tests, they were released back into the poultry house. In the afternoon, we proceeded in the same way
207 with the second subgroup. The testing order of the individuals, as well as the testing order of the
208 subgroups, was similar throughout the experiment.

209 The apparatus used for this task was a wooden square structure (l : 1.6m, w : 1.6, h : 0.7m,
210 Figure 2), with a yellow plastic floor and illuminated by a linear fluorescent lamp. The walls were
211 opaque, with a curtain **surrounding** the apparatus to both prevent animals from escaping and
212 homogenize all the sides of the arena. Black visual cues of different shapes were placed on each wall
213 of the apparatus and on the surrounding curtain. Eight identical cups were placed at equidistance in
214 this structure. Cues on the wall were not associated with specific cups. The height and depth of these
215 cups could be manually adjusted, depending on the task phase. All behavioral data were recorded
216 using a digital video camera recorder.

217

218 Figure 2 about here

219

220 **2.3.1. FAMILIARIZATION**

221

222 During the first stage of the familiarization (Figure 3), **with the test set up**, pairs of chickens
223 (one low ranger and one high ranger) were placed in the apparatus and were allowed to explore it for

224 10 minutes. Familiarization in pairs was used to facilitate exploration of the arena and reduce the
225 stress of the social isolation (Fontana et al., 2016; Weldon et al., 2016), the new environment
226 (apparatus structure, cups) and the new food (mealworms). The 8 cups in the apparatus were 10 cm
227 high and 2 cm deep. This setup allowed individuals to easily see the inside of the cup. Each cup was
228 baited with one mealworm. The height and the depth of each cup was chosen in order to motivate
229 exploration and to encourage individuals to put their heads in the cup and eat the mealworm. Each pair
230 of chickens underwent, in this stage, one familiarization trial once a day on four occasions (between
231 D66 and D72). By the end of the 4 days, all birds were actively moving in the arena and eating the
232 mealworms.

233 For the second stage of the familiarization (Figure 3), all 8 cups (15 cm high and 5 cm deep)
234 were baited with one mealworm. The new dimensions of cups were used to prevent animals from
235 easily seeing the reward in the cup and to motivate them to approach the cups one by one. Each animal
236 was individually introduced into the apparatus and allowed to explore the cups until all mealworms
237 were eaten or up to a maximum trial duration of 10 minutes. Each animal was submitted to one trial
238 per day for 7 days (D73 to D79). At the beginning of each trial, the individual could be placed in one
239 of two possible entrances, randomly chosen and alternated from trial to trial.

240 We pre-defined a familiarization threshold of 5 cups visited out of the 8. Since the number of
241 baited cups during the next phase (spatial test) was 4, it was important that the animals visited more
242 than 4 cups. Birds that did not meet this criterion did not advance to the next phase. For each trial, the
243 number of cups visited (number of times the chicken placed its head above the cup and ate the
244 mealworm) and the latency to visit at least 5 baited cups was recorded.

245

246 Figure 3 about here

247

248 2.3.2. SPATIAL TEST

249

250 The same apparatus and cup dimensions used during the second stage of the familiarization
251 were used for this learning task but only 4 out of 8 cups were baited (Figure 3). The location of the

252 baited cups was permanent for all individuals and trials. Thus to solve the test, birds needed to learn
253 the spatial location of the 4 baited cups. Birds were individually introduced in the apparatus and
254 allowed to explore it until all mealworms were eaten or after a maximum time of 5 minutes. Each
255 animal underwent two trials (inter-trial interval of 1h15min) per day for 9 days (D80 to D88). As for
256 the familiarization task, chickens were introduced in the apparatus from two different entrances, from
257 trial to trial. The aim of this alternation was to prevent a stimulus-response behaviour or the use of
258 egocentric strategies, requiring individuals to rely solely on intra and extra-maze cues.

259 For each trial, the total number of visited cups, the number of visited baited cups (the chicken
260 placed its head above the cup and ate the mealworm) and non-baited cups, the latency to visit all
261 baited cups, the number of revisited baited cups, the total number of revisited cups (baited and not
262 baited) were recorded. Through these data it is possible to calculate an index relating to reference
263 spatial memory:

264

265 Index to assess spatial reference memory: $\frac{\text{visits and revisits to baited cups}}{\text{visits to all cups}}$

266

267 This reference memory index measures the chicken's ability to discriminate between baited
268 cups and non-baited cups (Nordquist et al., 2011; Tahamtani et al., 2015). The index results are
269 between 0 and 1, with 1 being the best possible score.

270

271 3. STATISTICS

272

273 3.1. RANGING BEHAVIOR

274

275 The stability of the ranging behavior (number of range visits) between 4 days of observations
276 was analyzed by Spearman correlation, due to non-normality of the data. In order to avoid multiple
277 correlations, we combined the data for days 44 and 49 and for days 57 and 64 for each chicken (both

278 **sexes**), then the correlation between the two periods (days 44 + 49 and days 57 + 64) for the number of
279 visits were tested.

280 The variable “number of range visits” and “distance index” were then calculated by adding all
281 visits on the outdoor range for each chicken at the four ages of observations in order to **characterize**
282 the ranging **behavior** level of each chicken. The sex effect for these variables was analyzed on the
283 pooled data of four observation ages using a Mann-Whitney test. Of the 120 individuals with a
284 poncho, 113 could be studied throughout the study (n = 62 females, and n = 51 males). The losses
285 were due to predation and/or lost ponchos.

286

287 **3.2. SPATIAL MEMORY TASK**

288

289 **3.2.1. FAMILIARIZATION (SECOND STAGE)**

290

291 A general linear model with repeated measures was performed on the variables “number of
292 cups visited” and “latency to visit 5 cups”. The ranging behavior level (low or high ranger) was
293 included as the between-subject factor and the day (D1 to D7) as the within-subject factor.
294 Greenhouse-Geisser corrections were applied when the assumptions of sphericity were violated. When
295 main effects or interactions were significant, analyses were followed by multiple comparisons
296 corrected by Tukey’s HSD. **Ranging behaviour level (low or high ranger) effects on** ‘Days to criterion’
297 variable **(number of days to reach the threshold of 5 cups visited out of the 8)** was analyzed through a
298 Mann-Whitney test.

299 At the end of the familiarization period, two individuals (one low ranger and one high ranger)
300 did not meet the criterion for inclusion in the next phase of the task. The total number of chickens for
301 the next phase was n = 28.

302

303 **3.2.2. SPATIAL TEST**

304

305 The variables ‘latency to visit 4 cups’ and the ‘reference memory index’ were analyzed by a
306 general linear model with repeated measures. The between-subject factor was the ranging behavior
307 level (low or high ranger) and the within-subject factors were the trial (1 or 2) and the day (D1 to D9).
308 Day and trial were included separately in order to verify changes in performance within and between
309 days, since memory within and between-days are mediated by different subregions of the
310 hippocampus and could be potentially different (Kesner et al., 1993; Kesner and Hunsaker, 2010).
311 Greenhouse-Geisser corrections were applied when the assumptions of sphericity were violated. When
312 main effects or interactions were significant, analyses were followed by multiple comparisons
313 corrected by Tukey’s HSD.

314 At the end of the spatial test period, four chickens (one low ranger and three high rangers)
315 were excluded because they did not visit more than 2 cups (with or without mealworms). The number
316 of chickens included in the analyses was $n = 24$.

317 All statistical analyses were performed using IBM SPSS Statistics 21 and using R version
318 3.5.3 with the ‘R commander’ package. Statistical significance was accepted at $p \leq 0.05$, while
319 tendency was considered for $0.05 < p < 0.09$. Data are presented as means or estimated marginal
320 means \pm SD.

321

322 **4. RESULTS**

323

324 **4.1. RANGING BEHAVIOR**

325

326 There was a tendency for the total number of range visits to be higher for males than for
327 females (4.33 ± 2.71 and 3.38 ± 2.37 , respectively, $U = 1271$, $p = 0.071$, $\eta_p^2 = 0.02$). Moreover, the
328 distance index was significantly higher for males than for females (24.70 ± 24.77 and 15.16 ± 15.27 ,
329 respectively, $U = 1158.5$, $p = 0.015$, $\eta_p^2 = 0.05$).

330 The number of range visits and the distance index which characterized the groups as low
331 ranger or high ranger are presented in Table 1 for the 113 labelled chickens and the 30 males used for

332 the tests of cognitive performance. The number of range visits during D44+D49 was positively and
333 significantly correlated with the number of range visits during D57 + D64 ($r_s = 0.307$, 95% CI = 0.13
334 to 0.47, $p = 0.002$). The total number of range visits was positively and significantly correlated with the
335 distance index ($r_s = 0.795$, 95% CI = 0.70 to 0.87, $p < 0.001$).

336

337

Table 1 about here

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4.2. SPATIAL MEMORY TASK

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4.2.1. FAMILIARIZATION

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For the variable ‘number of cups visited’ the interaction of Day x Ranging behavior level was not significant (Greenhouse-Geisser corrected- $F_{3,219, 90.142} = 1.467$, $p = 0.227$, $\eta_p^2 = 0.050$), however there was a significant increase in the number of cups visited by individuals from both groups over the days (effect of day: Greenhouse-Geisser corrected- $F_{3,219, 90.142} = 17.67$, $p < 0.001$, $\eta_p^2 = 0.387$; effect of ranging behavior level: $F_{1, 28} = 3.04$, $p = 0.092$, $\eta_p^2 = 0.098$), which indicated they became habituated to the task.

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Similarly, there was no interaction of Day x Ranging behavior level for the latency to visit 5 baited cups (Greenhouse-Geisser corrected- $F_{2,894, 81.020} = 1.033$, $p = 0.381$, $\eta_p^2 = 0.036$). The latency to visit 5 baited cups decreased significantly over days for both groups equally (effect of day: Greenhouse-Geisser corrected- $F_{2,894, 81.020} = 12.68$, $p < 0.001$, $\eta_p^2 = 0.312$; effect of ranging behavior level: $F_{1, 28} = 2.67$, $p = 0.113$, $\eta_p^2 = 0.087$). Low ranger chickens needed, however, significantly fewer days to reach the criterion of 5 visited baited cups among the 8 baited cups than high ranger chickens (1.46 ± 1.26 and 3.06 ± 2.49 , respectively, $U = 64$, $p = 0.023$, $\eta_p^2 = 0.17$).

4.2.2. SPATIAL TEST

For the latency to visit four baited cups there was no Day x Trial x Ranging behavior level interaction (Greenhouse-Geisser corrected- $F_{5,041, 110,911} = 1.085$, $p = 0.373$, $\eta_p^2 = 0.047$). There was a significant interaction of Trial x Ranging behavior level for the latency to visit the 4 baited cups (Greenhouse-Geisser corrected- $F_{1, 22} = 9.89$, $p = 0.005$, $\eta_p^2 = 0.310$). Separated analyses, showed that low ranger chickens took significantly less time between trials to visit the four baited cups ($F_{1, 12} = 6.076$, $p = 0.030$, $\eta_p^2 = 0.336$, Figure 4), while between-trial latency increased significantly from trial 1 to trial 2 for high ranger chickens ($F_{1, 10} = 5.134$, $p = 0.047$, $\eta_p^2 = 0.339$, Figure 4).

The latency decreased significantly over test days in the same way for chickens of both high and low ranging behavior levels (effect of day: Greenhouse-Geisser corrected- $F_{5,173, 113,812} = 3.28$, $p = 0.008$, $\eta_p^2 = 0.130$; effect of trial: $F_{1, 22} = 2.046$, $p = 0.167$, $\eta_p^2 = 0.085$; effect of day x trial: Greenhouse-Geisser corrected- $F_{5,041, 110,911} = 0.690$, $p = 0.700$, $\eta_p^2 = 0.030$; effect of ranging behavior level: $F_{1, 22} = 0.082$, $p = 0.77$, $\eta_p^2 = 0.004$; effect of day x ranging behavior level: Greenhouse-Geisser corrected- $F_{5,173, 113,812} = 0.947$, $p = 0.45$, $\eta_p^2 = 0.041$).

Figure 4 about here

4.2.3. REFERENCE MEMORY INDEX

There was no day x trial x ranging behavior level interaction for the reference memory index ($F_{8, 176} = 1.174$, $p = 0.317$, $\eta_p^2 = 0.051$), however the trial x ranging behavior level interaction was significant ($F_{1, 22} = 13.169$, $p = 0.001$, $\eta_p^2 = 0.374$). The reference memory index increased significantly between the trial 1 and 2 for low ranger chickens (0.732 ± 0.175 and 0.819 ± 0.176 , for low ranger trial 1 and 2, respectively, $p = 0.002$), whereas it was similar between the 2 trials for high ranger chickens. Moreover, the reference index of low ranger chickens for the second trial was

384 significantly higher when compared to high ranger chickens' two trials (0.745 ± 0.2 , $p = 0.023$ and
385 0.734 ± 0.209 , $p = 0.005$, for high rangers' trial 1 and 2, respectively, Figure 5).

386 The reference memory index increased significantly over test days in the same way for
387 chickens of both high and low ranging behavior levels (effect of day: $F_{8, 176} = 3.102$, $p = 0.003$, $\eta_p^2 =$
388 0.124 , Figure 6; effect of day x trial: $F_{8, 176} = 1.076$, $p = 0.382$, $\eta_p^2 = 0.047$; effect of ranging behavior
389 level: $F_{1, 22} = 0.642$, $p = 0.43$, $\eta_p^2 = 0.028$; effect of day x ranging behavior level: $F_{8, 176} = 1.280$, $p =$
390 0.257 , $\eta_p^2 = 0.055$).

391

392 Figure 5 about here

393 Figure 6 about here

394

395 5. DISCUSSION

396

397 Our study strengthens the scientific evidence relating consistent individual differences in
398 behavior, with the ranging behavior of free-range chickens, and cognitive performance during a spatial
399 memory task. Low ranger chickens took less time to attain the pre-established threshold of visiting 5
400 cups out of 8, over the familiarization phase. During the spatial task, the latency to visit four cups
401 decreased between the within-day two trials for low ranger chickens and increased for high ranger
402 chickens. Moreover, in the within-day trial analysis, low ranger chickens exhibited an improvement on
403 spatial memory and a better spatial memory index compared to high ranger chickens.

404 Behaviorally, males and females differed in the number of visits to the range and how far they
405 ranged, with males visiting the range on more occasions and travelling farther from the poultry house.
406 These results support what was evidenced by other studies in domestic chickens: males and females
407 differ in social attachment and social reinstatement patterns, with females being more sociable, and
408 therefore less prone to be in social isolation, than their male counterparts (Vallortigara, 1992;
409 Vallortigara et al., 1990). Males also show weak physiological and behavioral responses during social
410 isolation when compared to females (Weldon et al., 2016). Social isolation may be a common situation

411 in the range since there is a negative relationship between stocking density (animal/m²) and distance
412 from the poultry house that results in low individual proximity to social partners. (Chielo et al., 2016).

413 The number of range visits was significantly correlated between the two periods of
414 observations (D44+49 and D57+64), showing a certain stability over time. When looking at the
415 individuals on the extremities of the ranging behavior continuum, high rangers did visit the range more
416 frequently than low ranger chickens, suggesting the existence of personality traits (i.e. between-
417 individual differences and within-individual consistency - (Dall et al., 2004)) even in domestic species
418 as chickens, strongly selected for production (Finkemeier et al., 2018; Richter and Hintze, 2018).
419 These findings support previous studies reporting that chickens can exhibit individual differences in
420 multiple features, such as environmental preferences (Nicol et al., 2009) and fear responses (Campbell
421 et al., 2016). Moreover, chickens' movement patterns (Rufener et al., 2018) and range use (Campbell
422 et al., 2017b; Hartcher et al., 2015; Larsen et al., 2017; Taylor et al., 2017) were already demonstrated
423 to vary consistently between individuals.

424 During the familiarization phase of the spatial memory task, low ranger individuals were faster
425 to attain our familiarization threshold (five cups visited) when compared to high rangers. Moreover,
426 during the spatial test, low ranger chickens exhibited an improvement on spatial memory index and a
427 decrease in the latency to reach the four baited cups between trials compared to high ranger chickens.
428 Campbell et al. (2018), using a similar framework, compared the relationship between spatial
429 cognition and range use in free-range laying hens. However, contrary to our results, the authors found
430 that individuals presenting more visits to the range were faster to reach the learning criterion and find a
431 food reward in one arm of a T-maze. These conflicting results may be linked to that, even if aiming to
432 study spatial cognition, the tasks proposed presented different levels of complexity, the T-maze being
433 simpler when compared to our arena with multiple cups. As Campbell et al. (2018) tested only females
434 and, in our study, we tested only males, an alternative explanation is that cognitive abilities are linked
435 to sex. For example, male Vanajara chickens cognitively tested on Y and T mazes had a better overall
436 performance than females, however from day 84 of age, both sexes performed equally (Panigrahy et
437 al., 2017). On the contrary, females chicks of the red junglefowl learned a reversal task faster than
438 males (Zidar et al., 2018). Sex influences on cognitive abilities have also been seen in other species

439 such as guppies (Lucon-Xiccato and Bisazza, 2017) and lizards (Carazo et al., 2014). For great tits
440 (*Parus major*), for example, personality and learning performance interacts in a sex-dependent way:
441 fast-exploring males outperform slow males, but slow-exploring females outperform fast females
442 (Titulaer et al., 2012).

443 Our results are, however, in line with the coping styles literature (Coppens et al., 2010;
444 Koolhaas et al., 1999) where slow-exploring, reactive animals perform better under variable and
445 unpredictable situations than fast-exploring, proactive individuals. Reactive juvenile red **junglefowl**,
446 more fearful in a tonic immobility test, were quicker to explore a new color cue in response to an
447 alteration of rewarded stimulus, showing high behavioral flexibility (Zidar et al., 2017).

448 The latency to visit the cups during the spatial test (four rewarded cups out of eight) showed
449 no differences over days between groups, however, high ranger and low ranger chickens exhibited
450 different patterns in the between-trial analysis, with low ranger chickens decreasing and high ranger
451 chickens increasing their time to reach the rewarded cups. **High ranger chickens may be faster during**
452 **their first trials due to internal motivation to explore the test arena, however these individuals seem to**
453 **be more oblivious to their surroundings. On the other hand, low ranger chickens may be more accurate**
454 **and, in turn, take more time to create an effective spatial map.** These results agree with White et al.
455 (2017) and their study of individual differences in brook trout (*Salvelinus fontinalis*) spatial learning
456 ability: bold fish are less attentive to environmental cues and explore their environment randomly,
457 which in turn results in more time to execute the task. Fast-exploring mallard ducks (*Anas*
458 *platyrhynchos*) were slower than slow-exploring individuals to reach the final compartment when in a
459 maze, **possibly** because they engaged in other activities, such as foraging, and therefore paid less
460 attention to spatial cues (Bousquet et al., 2015).

461 **In the spatial test,** low ranger individuals also showed an improvement of reference memory
462 index between trials within the same day, and not between different days when compared to high
463 ranger individuals. As this occurred within trials of the same day, on an interval of approximately
464 1h15min, it may suggest that a short-term memory was being improved over long-term memory (i.e.
465 reference memory). Nordquist et al. (2011), in the first work using a holeboard task in chickens,

466 suggest that long and short term memories are not fully independent in chickens, mainly during
467 acquisition phases, and this may be the case for the chickens in our study.

468 From an ecological point of view, [Sih and Del Giudice \(2012\)](#) suggest that there is a trade-off
469 between speed and accuracy, with fast-explorers animals favoring short-term gains and therefore being
470 more inaccurate in their decision process. Contrarily, slow-exploring individuals prefer to gather more
471 environmental information and take time to make a decision ([Chittka et al., 2009](#)). This speed-
472 accuracy hypothesis is further supported by our result showing that the main difference between our
473 high ranger and low ranger chickens within the spatial test phase can be seen through analyses of the
474 reference memory index between trials, with low ranger chickens showing a better performance when
475 compared to high ranger chickens.

476 Currently, when providing a range to chickens, the individual variability is rarely considered.
477 However, through this work, we have shown there is not only high variability in terms of ranging
478 behavior, but also that the ranging behavior level can impact individuals' abilities during a spatial
479 memory task, therefore free-range chicken cognition. The variation in the individual x environment
480 interaction could be the source of different cognitive abilities, as is the case for juvenile Atlantic
481 salmon (*Salmo salar*) exposed to enriched conditions and presenting improved neural plasticity in the
482 forebrain and better learning ability assessed in a spatial task ([Salvanes et al., 2013](#)). The same was
483 observed in laying hens exposed to different housing conditions (battery cages, littered pens or free
484 range) as they exhibit distinct brain morphologies, probably linked to the contrasting spatial
485 complexity of these systems ([Patzke et al., 2009](#)).

486

487 **6. CONCLUSION**

488

489 To further improve our knowledge of the impact of ranging behavior and cognitive
490 performances in free-range chickens, it is necessary to bear in mind two main points: the first one is
491 that memory is not a single faculty and the relationships between ranging behavior and cognitive
492 performances may be dependent on the memory system (short vs long term) considered.

493 The second point is that our measure of ranging behavior was based on a **single** variable
494 (number of range visits). Range use can potentially be a part of three of the five major animal
495 personality traits proposed by Réale et al. (2007), which can be also applied to free-range chickens:
496 shyness-boldness, exploration-avoidance or activity, however, it was outside of the scope of the
497 present study to present a convergent validity and include ranging behavior as a part of one of these
498 three major personality traits through multiple tests. Nonetheless, it is important to note that our
499 variable did show time repeatability between different ages, **an important step to be considered as a**
500 **component of a major personality trait** (Bell et al., 2009).

501 From an interdisciplinary perspective, all that information can provide a better knowledge
502 about animals' inner perceptions and their own interactions with the physical (e.g., food source,
503 predation) and social environment (Réale et al., 2007), contributing to improvements of their quality
504 of life, mainly for those under human care, such as wild captive animals and livestock (Boissy and
505 Lee, 2014).

506

507 **7. FUNDING**

508

509 This experiment was funded by Yncréa Hauts-de-France and the French National Institute for
510 Agricultural Research (INRA).

511

512 **8. ACKNOWLEDGEMENTS**

513

514 We are grateful to all members of the unit EASM of INRA Magneraud, especially the animal
515 caretakers, for their help beyond animal care, in the construction of the test device and practical
516 advices. We thank F. Cornilleau for practical assistance. The authors are also grateful to the editor and
517 three anonymous reviewers from the journal for helpful comments.

518

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673

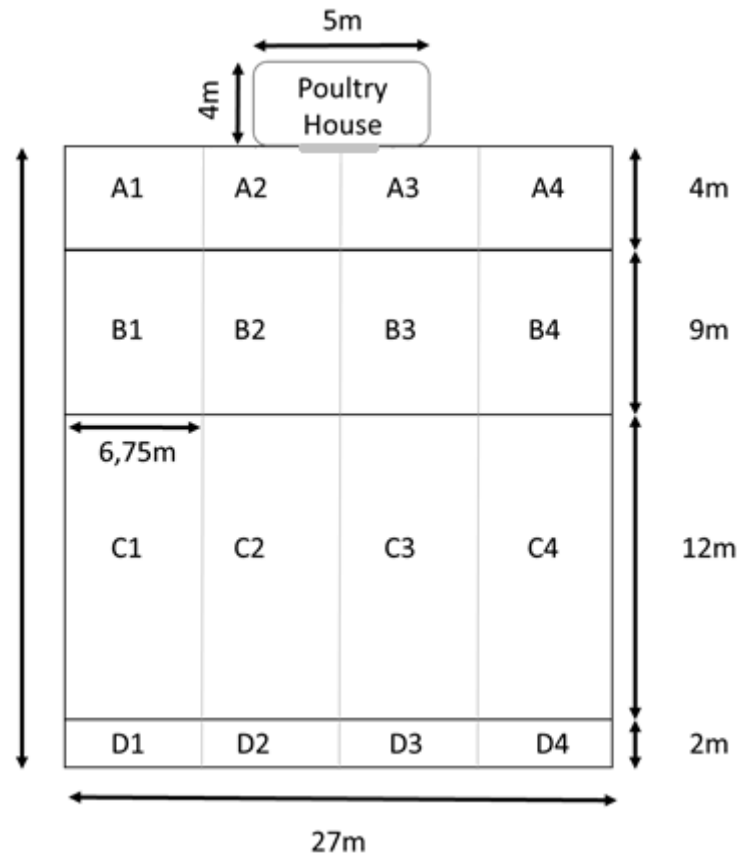


Figure 1 – Schematic figure of the poultry house and the outdoor range divided virtually in 16 different zones. Zones A to C were gradually longer, except for zone D (A = 4m, B = 9m, C = 14m, and D = 2m). This range division allowed a more heterogeneous distribution of the individuals and to differentiate chickens who ranged near the poultry house from those who went further on the range. The pop-hole giving access to the outdoor range is placed between zone A2 and A3 (grey bar).

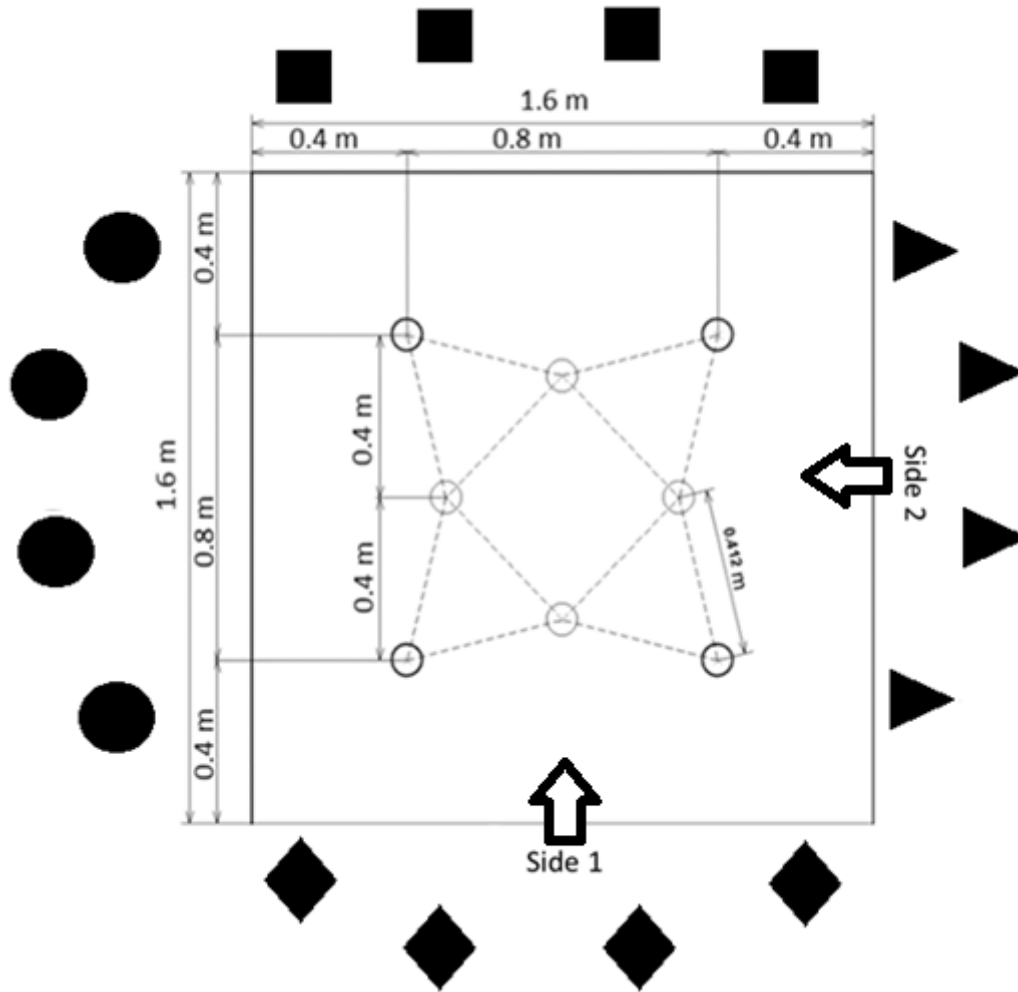


Figure 2 – Schematic figure of the apparatus used to test spatial memory. Circles represent the eight cups within the arena where mealworms were placed as a reward. Chickens could enter the arena from two different sides (dark arrows). Black patterns around the arena walls and on the surrounding curtain were available to chickens to rely on spatial guidance.

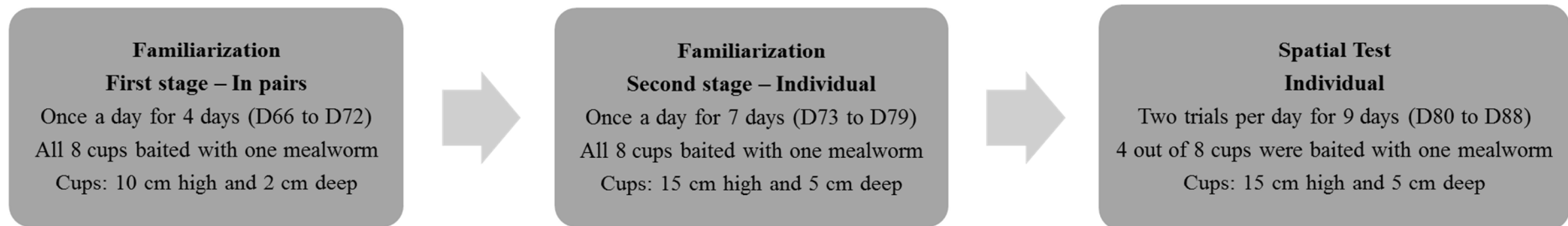


Figure 3 - Summary of the spatial memory task, describing each of the phases, and trials within phases, **the birds** underwent from familiarization to spatial test.

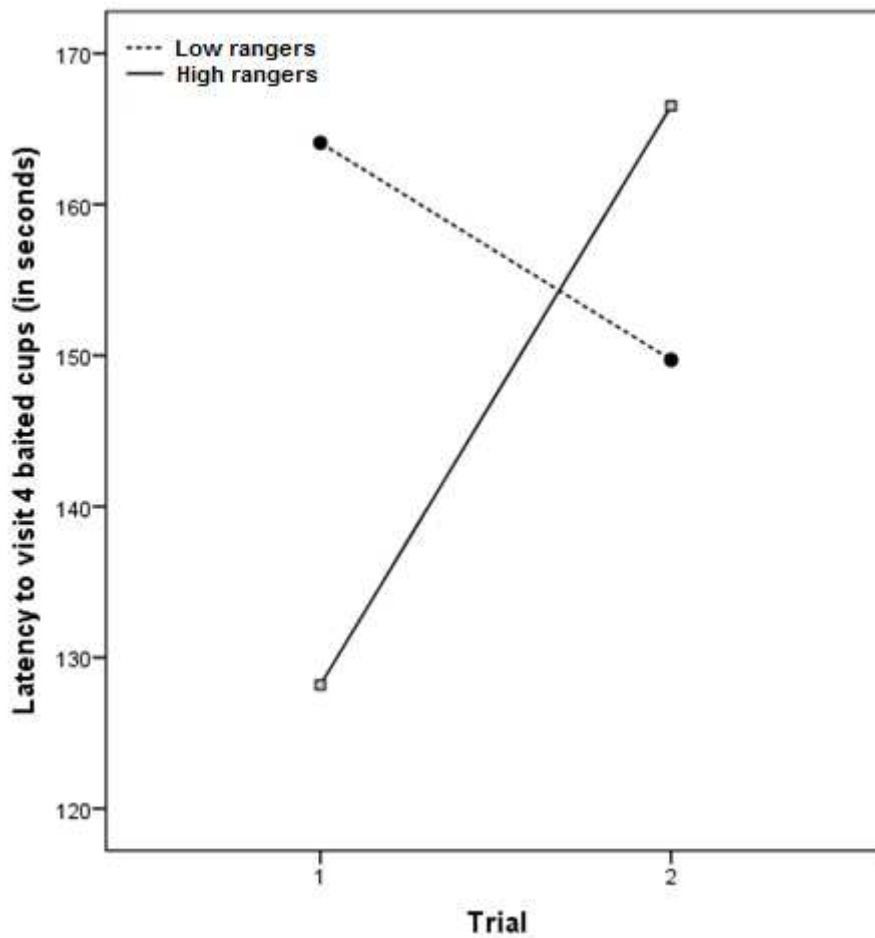


Figure 4 - Latency to visit four baited cups (in seconds) from trial 1 to trial 2 during the spatial training for low ranger (N = 13) and high ranger (N = 11) chickens. The location of the baited cups was permanent for all individuals and trials. Data are presented as estimated marginal means.

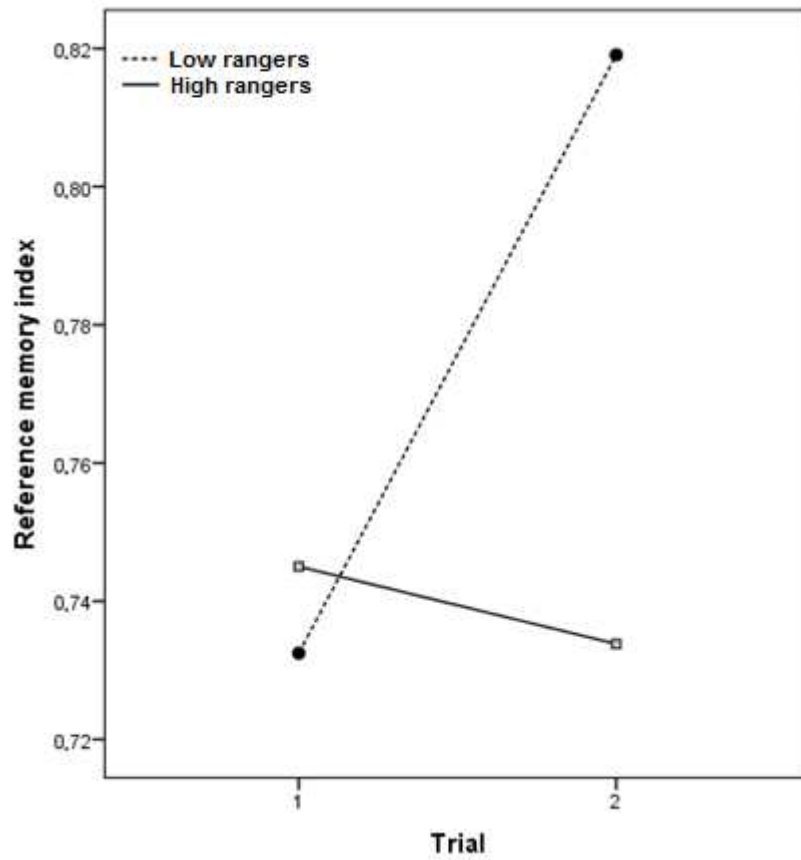


Figure 5 - Reference memory index from trial 1 to trial 2 during the spatial test for low ranger (n = 13) and high ranger (N = 11) chickens. This reference memory index measures the chicken's ability to discriminate between baited cups and non-baited cups. The index results are between 0 and 1, with 1 being the best possible score. Data are presented as estimated marginal means.

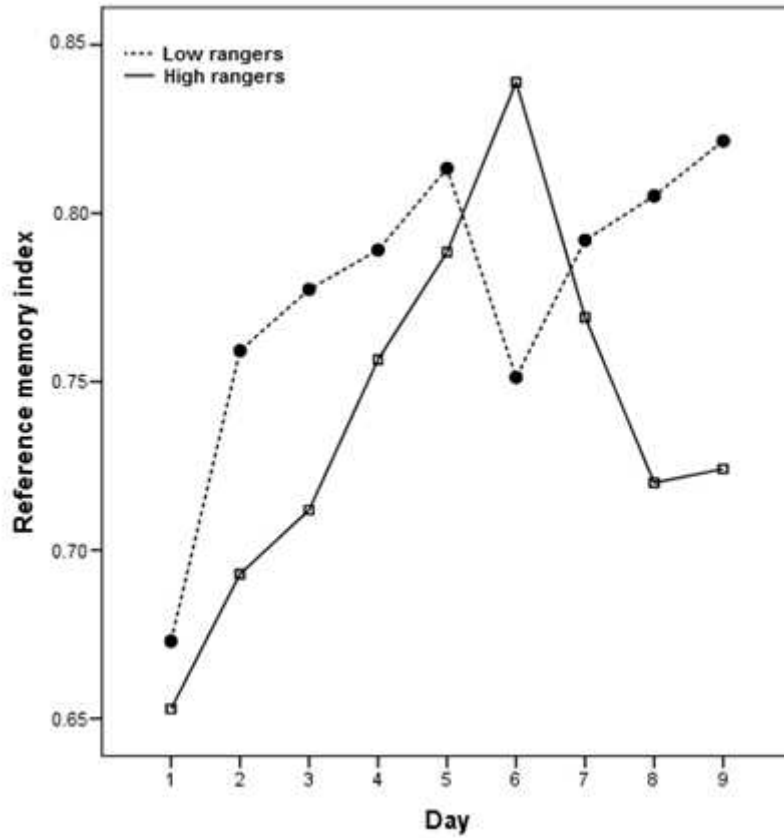


Figure 6 - Reference memory index over days of the spatial training for low ranger (N = 13) and high ranger (N = 11) chickens. This reference memory index measures the chicken's ability to discriminate between baited cups and non-baited cups. The index results are between 0 and 1, with 1 being the best possible score. Data are presented as estimated marginal

Table 1 - Number of range visits and distance index for 113 chickens (males and females) and 30 male chickens who underwent the spatial memory task according to their ranging behavior level: high rangers (n=15) and low rangers (n=15). Data are presented as mean \pm SD.

	Number of range visits	Distance index
Males (n=51)	4.33 \pm 2.71	24.70 \pm 24.77
Females (n=62)	3.38 \pm 2.37	15.16 \pm 15.27
High rangers (n=15)	6.8 \pm 2.30	42.80 \pm 34.49
Low rangers (n=15)	2.8 \pm 0.77	16.68 \pm 8.64