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The OpenFeeder: a flexible automated RFID feeder to measure inter and intraspecies differences in cognitive and behavioral performance in wild birds

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32 **Abstract**

33 1. Understanding the ecology and evolution of personality and cognition requires the
34 development of new tools to measure individual and species differences in behavioral
35 and cognitive performances in wild populations. Furthermore, such tools should
36 facilitate collection of large sample sizes, evaluate the repeatability of measured traits
37 and allow direct comparison of species performances across a variety of behavioural
38 tasks.

39 2. Here we present a RFID-based feeder (OpenFeeder) designed to run visual cognitive
40 tasks in wild animals. We illustrate the flexibility of the tool showing performances of
41 three wild passerine species (*Parus major*, *Cyanistes caeruleus* and *Poecile palustris*)
42 in an associative learning task.

43 3. We recorded performances of a large number of individuals (>300) in the wild and
44 showed both inter and intraspecific differences in associative learning. We also found
45 moderate to high repeatability in individual differences in associative learning in each
46 species.

47 4. We show that the OpenFeeder is a flexible tool to record performance in multiple
48 cognitive and behavioural tasks in free ranging animals across a variety of passerine
49 species. The design, firmware, and software are open source to facilitate use in a wide
50 variety of species and thus allow continuous improvement of the system and
51 development of new behavioural and cognitive tasks. In doing so, we hope that this tool
52 will be used by a large community of cognitive ecologists and comparative
53 psychologists for both within and across species studies. Furthermore, our system
54 should facilitate replication of results across populations along large-scale
55 environmental gradients to improve our understanding of the role ecology plays in the
56 evolution of cognitive traits.

57 **Keywords**

58 Individual difference, cognition, behavior, RFID feeder, associative learning

59

60 **1) INTRODUCTION**

61 Interest in the evolution of cognitive abilities has experienced rapid growth as a field
62 leading to increased attention placed on measurement of cognitive performance in wild
63 animals (Cauchoix & Chaine, 2016; Cauchoix et al., 2017; Morand-Ferron et al., 2016;
64 Pritchard et al., 2016). However, most studies are usually conducted in captivity which
65 can constrain sample sizes of any single species and even more so on different species
66 where differences in husbandry among species can add an extra challenge. Testing
67 animal cognition directly in the wild (Boogert et al., 2018; Cauchoix & Chaine, 2016;
68 Morand-Ferron et al., 2016; Pritchard et al., 2016) can reduce the need for husbandry
69 and maintenance of large numbers of individuals in captivity and the stress of animals
70 performing cognitive tasks, thereby improving measures and conducting more ethical
71 research (Daneshian et al., 2015; Monamy, 2017).

72

73 A major challenge for studies on the ecology and evolution of cognition in the wild is
74 gathering accurate and repeatable measures on a variety of cognitive tasks in a
75 sufficiently large sample size in the wild (Cauchoix et al., 2018). While existing systems
76 that automatically identify individuals hold promise for gathering behavioral and
77 cognitive data on large samples of individuals in the wild, (Aplin et al., 2015; Cauchoix
78 et al., 2017; Croston et al., 2016; Morand-Ferron et al., 2015; Reichert et al., 2020),
79 these systems are not easily adapted to test different cognitive abilities (Aplin et al.,
80 2015; Cauchoix et al., 2017; Croston et al., 2016; Morand-Ferron et al., 2015; Reichert
81 et al., 2020). Here, we present the OpenFeeder, a new flexible open-source feeder that
82 aims to compensate for limitations of existing systems and encourage studies of
83 cognitive abilities and behavioral tests in wild animals. We describe the potentiality and
84 the flexibility of the Openfeeder through a case study measuring associative learning in
85 the wild in three species of european tits.

86

87 **2 METHODS**

88 General OpenFeeder design principles

89 Our goal was to design a flexible automated cognitive testing device that could be easily
90 adopted by a wide range of different research groups working on a variety of species.

91 As such, we had five guiding principles that played an important role in determining our
92 design:

93 1) We wanted individuals to be identified to track performance of individuals through
94 trials and tasks and provide the ability to link that information to other life history traits.
95 Barcode or photo re-identification (Alarcón-Nieto et al., 2018; Ferreira et al., 2020)
96 approaches are promising, but still require considerable development to put in place, so
97 we based our system on Radio Frequency identification (RFID) tags as these can
98 currently be used across a broad array of species with little additional development
99 (Bonter & Bridge, 2011; Bridge et al., 2019).

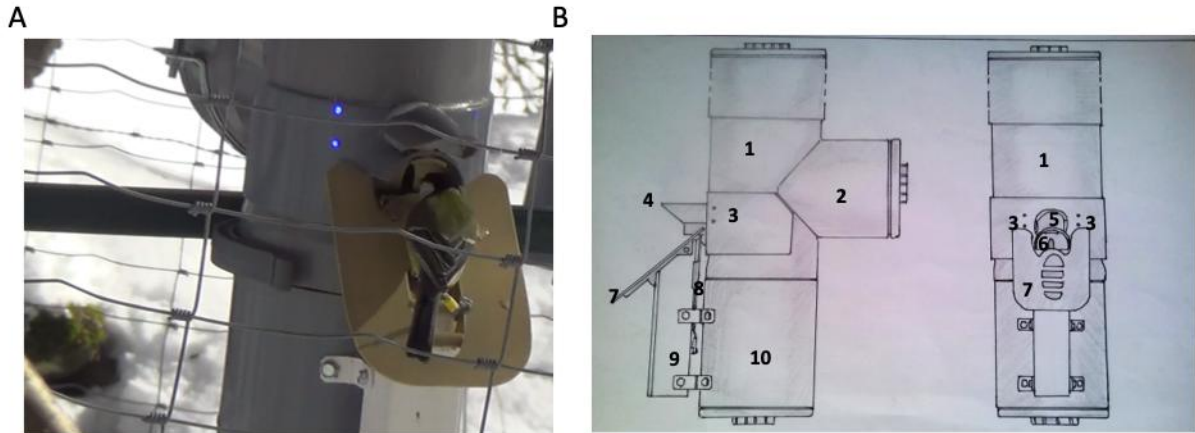
100 2) We wanted feeder systems to be able to conduct a large number of trials which
101 meant the ability to have a large reward reservoir and function autonomously for a
102 number of days or more.

103 3) To encourage participation of a large number of individuals, we chose to focus on a
104 simple design to produce tasks that require only perching as a response, but has the
105 ability to measure a broad variety of cognitive abilities with this paradigm. To do this, we
106 set initial tests with LED lights to present stimuli and provide software to easily construct
107 new cognitive tests.

108 4) To allow for new tests in the future, we kept a number of open input/output ports for
109 electronic components that could allow for expansion either through different testing
110 paradigms (e.g. touchscreen, sound), additional measures (video, environmental
111 measures), and remote data transfer (e.g. Global System for Mobile (GSM)
112 communication).

113 5) We also sought to keep the cost down to make the OpenFeeder accessible to more
114 research teams by providing software under an open-source license (Creative
115 Commons Attribution ShareAlike 3.0. CC BY-SA 3.0) and plans for our initial feeder
116 design using common materials for the main body with a few 3D printed components.
117 Firmware (see SI), software and 3D printed files can be found on
118 <https://github.com/OpenFeeder>.

119



120
 121 **Figure 1: The OpenFeeder device.** (A) A great tit equipped with a yellow pit passive
 122 integrated transponder (PIT) tag band performing a rewarded trial in the ON/OFF
 123 associative learning task (Supplemental information (SI)), the devices are protected
 124 from cattle by a surrounding mesh (B) OpenFeeder container design: (1) Reward/food
 125 storage container, (2) Electronic board compartment, (3) Four Light-Emitting Diode
 126 (LED) displays, (4) feeding hole protective cap, (5) Passive infrared (PIR) sensor, (6)
 127 Feeding hole, (7) 3D printed perch containing the RFID antenna, (8) 3D printed door to
 128 control access to the feeding hole, (9) Servomotor compartment, (10) battery
 129 compartment.

130
 131 OpenFeeder container design and microcontroller

132 The OpenFeeder housing is entirely made of standard polyvinyl chloride plastic (PVC)
 133 pipe available in most hardware and plumbing stores (Figure 1 and Figure S1). It
 134 is composed of 3 main sections: a reward/food storage container, an electronics
 135 container, and a battery container. This is achieved using a T-pipe (turned 90 degrees)
 136 with additional pipe sections and components for each of the containers. A large and
 137 modular food container (100 mm standard PVC) to hold sunflower seeds as a reward
 138 was placed in the upper portion of the T. Below the food container, we placed a battery
 139 compartment held in place with a screw cap pierced to reduce condensation. We used a
 140 12V 9A lead battery (~25 €, <https://www.battery-direct.fr/Batterie-HR9-12.html>) to
 141 power the entire system (~5 days autonomy with the most energy intensive cognitive
 142 test scenario). To control the OpenFeeder, a peripheral interface controller (PIC)

143 microcontroller was the best choice to produce a reliable, low-cost and low energy
144 consumption device when we started developing this system in 2015. Recently,
145 Raspberry or Arduino (Jolles 2021; Bridge et al. 2019), have been shown to be good
146 tools for behavior and cognitive testing in the wild too. Those systems permit video
147 recording and embedded artificial intelligence which hold great promise for non-invasive
148 species or individual recognition in the field (Ferreira et al. 2020; Zualkernan et al. 2022)
149 but with higher energy consumption.

150

151 Food access and RFID Perch design

152 Birds were given access to food through a 20mm by 8mm oval opening at the bottom of
153 the food container. This design allows birds to fit their beak into the food storage
154 section, but not their entire head to remove the risk of the door closing on the bird's
155 head. The only way to obtain the food reward is to perch on a 3D printed perch,
156 containing an RFID antenna, specially designed to force birds to perch in an optimal
157 position for passive integrated transponder (PIT) tag detection
158 (<https://github.com/OpenFeeder/mechanics>, Figure 1, Figure S1 and SI).

159

160 Stimuli for cognitive and behavioural tests

161 Cognitive and behavioural tasks rely on response to specific stimuli and we chose a
162 simple paradigm where stimuli could be seen from a distance and the response was
163 simply perching on the feeder at the right time. Our stimuli were four Light-Emitting
164 Diode (LED) lights spaced evenly around the feeding hole. These LEDs were brought to
165 the feeder surface using light guides and enabled display of RGB signals provided by
166 four independently controlled RGB LEDs (called attractive LED). Each light could be
167 turned on or off and made any color depending on the experimental paradigm. This
168 simple system allows for a large variety of cognitive or behavioural tests (called
169 *scenarios* parameterized in a configuration file) commonly used in the field of visual,
170 attentional and memory psychophysical studies. Although future tests on how luminosity
171 affects perception of the stimuli should be done, the fact that birds do learn the task
172 suggests that they are visible most of the time.

173

174 Cognitive test scenario software

175 We created a user-friendly Matlab interface (<https://github.com/OpenFeeder/software>,
176 Figure S13) to enable programming of different scenarios which produces a
177 configuration file (CONFIG.INI) stored on the USB drive which is also used to write and
178 store OpenFeeder data. The current interface allows the user to flexibly define: multiple
179 deep sleep periods, multiple door opening periods, which LED lights to turn on to create
180 the spatial pattern of the stimulus, the color of each light (RGB combination for each
181 LED), and the temporal pattern of lights turning on including both the duration and
182 frequency of display, which LED patterns lead to a response such as providing a reward
183 by opening the door to all individuals or only to specific individuals based on a list of PIT
184 tag numbers, or which PIT tags open the door regardless of LED display, the probability
185 that the door opens given a correct response (100% if always rewarded at a given LED
186 display), the time between bird detection and door opening, the duration of the door
187 staying open, how much the door opens (e.g. $\frac{1}{4}$ open, $\frac{1}{2}$ open, fully open) and the
188 speed of door movement, and the duration of punishment defined as the time LED
189 stimuli are switched off with no access to the food after perching during a non-rewarded
190 stimuli. Through the combination of these parameters, we have implemented ten
191 different cognitive tasks to date (see SI).

192
193 Among those tasks, neophobia (habituation to door movement or to LED lights) and
194 visual associative learning tasks (association of LED spatial pattern and reward) have
195 been tested in our entire population. Performances in associative learning are
196 presented as a case study in the present paper (Figure 2). In this task, the four LEDs
197 were switched on in blue for 5s and the timing of lights turning on was determined at
198 random with a probability of 0.25 such that the feeder would reward birds one quarter of
199 the time and these reward periods were signaled by blue LED lights being on. Birds are
200 rewarded by a 1s door opening only if they perched while LEDs were on. To assess
201 repeatability of learning performance individuals also performed a LEFT/RIGHT
202 discrimination learning task (SI).

203

204 We also use a collection of Matlab scripts that produces subtitles from log files that can
205 be useful for quality control (i.e. estimating RFID detection rate) when responses are
206 paired with video recordings of other behavior in the vicinity of feeders. Finally, we
207 developed a third Matlab interface to allow serial communication between OpenFeeder
208 boards and a laptop (Figure S14). This interface can be used for debugging and offers a
209 number of other functionalities including uploading test scenarios, downloading data,
210 OpenFeeder/PC timing synchronisation, assessing battery charge level and RFID
211 frequency (Figure S13).

212

213 **3 RESULTS**

214

215 We tested the OpenFeeder in four different wild populations previously equipped with a
216 PIT tag (see SI, Figures S2 to S12 and Table S1 to S9 for detailed methods and
217 results). Each site was equipped with an array of four OpenFeeders (Figure S1).
218 Using 4,5 hours of video from the 4 sites taken on 6 different OpenFeeders, we found
219 that 98.3% of visits performed by tagged birds perched on the RFID antenna were
220 detected.

221

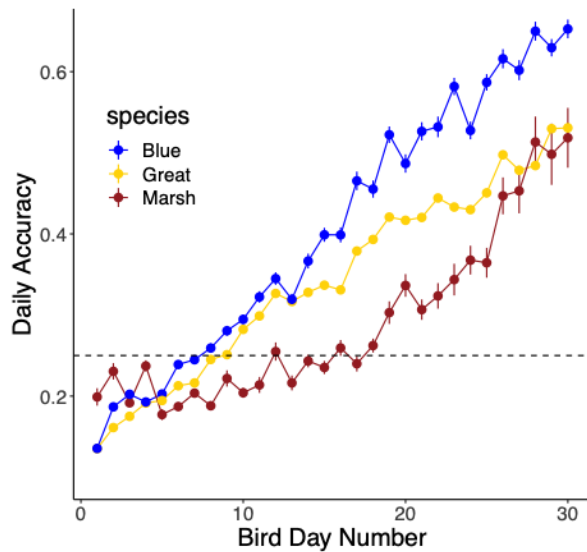
222 During 79 consecutive days, the Openfeeder recorded 1.3 million trials (number of visits
223 at the feeder) done by a large sample of individuals (N= 332 birds) of three species of
224 tits (great tits: N=179, mean=4909 trials; marsh tits: N=50, mean=4641 trials and blue
225 tits: N=103, mean= 2645 trials, Table S8).

226

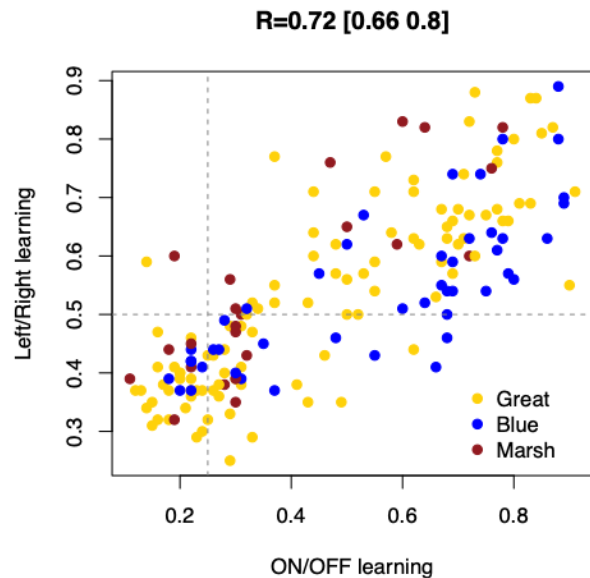
227 The OpenFeeder allows us to robustly measure cognitive performance such as
228 associative learning (Figure 2) at both the species and individual level, in the wild (see
229 SI and Figures S3 to S12 and Table S1 to S9 for detailed methods and results). We
230 found both inter and intraspecific significant differences in associative learning.
231 Analyses of repeatability demonstrate strong individual differences in associative
232 learning in each species ($R=0.72$; Figure 2B and SI).

233

A. Interspecies differences in learning



B. Intraspecific differences in learning



234
235 **Figure 2. Results from the case study.** Blue tits are represented in blue, great tits in
236 gold and marsh tits in brown. (A) Daily accuracy (number of correct responses divided
237 by total number of responses done during a day) is represented according to bird day of
238 the ON/OFF task. “Bird Day number” refers to the number of days each bird has visited
239 the feeders from the beginning of each learning experiment excluding days during which
240 the bird did not visit the feeder (see Supplemental Information). (B) Repeatability in
241 cognitive performances across associative learning tasks: ON/OFF (x axis) and
242 LEFT/RIGHT (y axis) tasks. Dotted line indicates chance level (0.25 in the ON/OFF task
243 and 0.5 in the LEFT/RIGHT task).

244 245 DISCUSSION

246 In this paper we present a new open-source tool for cognitive ecologists, behavioural
247 ecologists or comparative psychologists interested in measuring cognitive performance
248 of wild animals directly in their natural environment. The OpenFeeder relies on
249 individual identification using RFID technology, self-administered tasks, weatherproof
250 electronic and mechanical components as well as a flexible software environment to
251 program multiple behavioral and cognitive tasks. Providing this new flexible cognitive
252 testing device to work directly on wild animals, we hope to advance research in the

253 ecology and evolution of cognition while prioritizing animal welfare and cognitive tests in
254 natural environments.

255 Automated cognitive testing devices that allow large sample sizes, such as the
256 OpenFeeder, also provide an important tool for studies of contemporary selection on
257 cognitive performance within species (Cauchoix & Chaine, 2016; Morand-Ferron et al.,
258 2016; Thornton et al., 2014) as they allow us to link individual variation in cognition to
259 fitness (Branch et al., 2019; Sonnenberg et al., 2019). Indeed, we found high
260 repeatability of learning performance across the two tasks, a hallmark of consistent
261 individual differences necessary for studies of selection (Cauchoix et al., 2018) the large
262 number of trials performed by individuals on the OpenFeeder would allow more detailed
263 analyses of performance measures including learning curves over time (Donner &
264 Hardy, 2015; Hartz et al., 2001; Leibowitz et al., 2010; Smith et al., 2004).

265

266 The OpenFeeder can be adapted to measure a broad range of cognitive abilities or
267 behaviors in many bird species in the wild or in captivity. It allows animals to use their
268 natural behaviour of perching on the RFID antenna to respond instead of learning a new
269 behavioural pattern (Aplin et al., 2015; Cauchoix et al., 2017; Morand-Ferron et al.,
270 2015) and is associated with a large food container (see also Croston et al., 2016)
271 eliminating logistic constraints resulting from reward provisioning in some existing
272 systems (Cauchoix et al., 2017; Morand-Ferron et al., 2015). While we only describe
273 results associative learning here, more behavioural and cognitive tasks have already
274 been implemented in the OpenFeeder system including spatial learning and memory,
275 neophobia, color associative learning, color or spatial reversal learning and delayed
276 gratification tasks (SI). As other RFID systems it can also be used to measure social
277 abilities (Aplin et al., 2012; Firth et al., 2015). All these tasks can be programmed simply
278 by changing configuration file parameters with our Matlab interface (Figure S13) or
279 directly in a text editor. Open access to the code and building plans along with the low
280 cost (<150€/device) and the easy user interface for programming experiments will allow
281 researchers interested in measuring cognition in the wild to use the OpenFeeder and to
282 develop their own behavioural and cognitive tasks. By doing so we hope to build an
283 OpenFeeder international community sharing similar cognitive tasks, run on a common

284 platform adapted to morphological and motor abilities of each species with a common
285 web-space for exchanges and troubleshooting (e.g. slack channel). Such widespread
286 multi-species international collaborative projects have the potential to tackle important
287 comparative questions, such as understanding past evolution of cognitive traits using
288 comparative analysis of cognition (MacLean et al., 2012, 2014).

289

290 **Author Contributions**

291 MC, ASC and JMF designed the study. AB and VG designed the electronics. VG
292 produced the electronics. JB and AB coded the firmware. JB coded the software
293 (Matlab scripts) and designed 3D printed parts. DL designed and built the feeders. NE
294 collected the data. MC analyzed the data and wrote the first version of the article. ASC,
295 GBJ, JMF and AB corrected and improved the manuscript.

296

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300 MC, NE, DL, JB, AB, GBJ, and ASC declare no conflict of interest.

301 VG is the director of SelectDesign company that designed and produced the
302 OpenFeeder board.

303

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310

311 **Data availability**

312 Data will be available on dryad.

313

314 **Ethical statement**

315 All our methods were carried out in accordance with published guidelines of the Animal
316 Behavior Society, Association for the Study of Animal Behaviour, and the Ornithological
317 Council. All experimental procedures were conducted under permits to A. Chaine from
318 the French bird ringing office (CRBPO; n°13619) and animal care permits from the state
319 of Ariège (Préfecture de l'Ariège, Protection des Populations, n°A09-4 for experimental
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321

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