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Non-human animals detect the rhythmic structure of a familiar tune

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Alexandre Celma-Miralles^{1,*} and Juan M. Toro^{1,2}

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¹ Universitat Pompeu Fabra, C. Ramon Trias Fargas, 25-27, 08005, Barcelona, Spain

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² Institució Catalana de Recerca i Estudis Avançats (ICREA), Pg. Lluís Companys, 23, 08019,

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Barcelona, Spain

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* Corresponding author: alexandre.celma@upf.edu

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c\ Ramon Trias Fargas, 25-27, 24.326

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08005, Barcelona (Spain)

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Telephone: +34 935421381

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21 **Abstract**

22 The musical motives of a song emerge from the temporal arrangement of discrete tones. These
23 tones normally have few durational values, and are organized in structured groups to create
24 metrical patterns. In the present study we show that the ability to detect the rhythmic structure
25 of a song, while ignoring surface changes, is already present in other species. We familiarized
26 rats (*Rattus norvegicus*) with an excerpt of the Happy Birthday song. During test, we presented
27 the animals with (i) the same excerpt of the familiarization, (ii) a constant-pitch version of the
28 excerpt that reduced melodic intervals to only one tone (i.e. isotonic) but preserved rhythmic
29 structure, and (iii) a rhythmically scrambled version of the excerpt that preserved the melodic
30 intervals. The animals discriminated the rhythmically scrambled version from the versions that
31 preserved the original rhythm. This demonstrates that rats were sensitive to at least some parts
32 of the rhythmic structure of the tune. Together with previous findings, the present set of
33 results suggests that the emergence of rhythmic musical universals might be based in principles
34 shared with other species.

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37 **Keywords:**

38 Temporal perception; Song discrimination; Rhythm; Comparative cognition, Rats

39

40 **Introduction**

41 Music organizes a set of tones over time, creating musical phrases or motives. While the tones
42 of a motive can vary in features like pitch range, timbre or intensity, the rhythmic organization
43 of the tones and their durations can mainly vary in relation to the tempo of the beat and its
44 metrical structure. In fact, two music universals that appear across cultures are that the sounds
45 used to build motives have few durational values (mainly, their duration is set to 2- to 3-beat
46 subdivisions) and that they are organized in metrical hierarchies (Savage, Brown, Sakai and
47 Currie, 2015). The combination of these 2 factors leads to the rhythmic structure of any
48 musical excerpt. Here we will explore if the cognitive architecture required for the processing
49 of these structural features in music has deep biological roots that can be traced to other
50 species. More explicitly, we will study if a distantly related mammal, the rat (*Rattus norvegicus*),
51 can detect the rhythmic structure of a song while ignoring changes in other features, such as
52 pitch. Other fundamental aspects of rhythm processing, such as beat entrainment or regularity
53 detection, have fruitfully been studied with birds, pinnipeds and primates (for a review, see
54 Kotz, Ravignani and Fitch, 2018; Wilson and Cook, 2018; ten Cate, Spierings, Hubert and
55 Honing, 2016). Here, however, we will focus on the exploration of a more complex aspect of
56 rhythmic cognition: whether non-human animals can extract the temporal organization of
57 three durational values that define the rhythmic structure of a tune.

58 Rodents can correctly process some salient aspects of musical sequences. For instance,
59 rats are able to discriminate between excerpts of Bach and Stravinsky (Otsuka, Yanagi and
60 Watanabe, 2009) or between Mozart and the Beatles (Okaichi and Okaichi, 2001). They also
61 succeed in discriminating structured tunes based on surface features, such as intensity, octave,
62 timbre and melodic organization (d'Amato and Salmon, 1982, 1984; Poli and Previde, 1991).
63 However, more important for musical structure is how tones are organized in temporal

64 patterns (Kotz, Ravignani and Fitch, 2018). It is not clear whether non-human animals can
65 detect this temporal information in order to integrate the structural and perceptual features of
66 the complex auditory signal. Rats are sensitive to at least some aspects of the rhythmic
67 organization in acoustic sequences, as they can detect isochrony, discriminating regular from
68 irregular tone sequences (Celma-Miralles and Toro, 2019). They also group sound sequences
69 following the principles described by the iambic-trochaic law (de la Mora, Nespors and Toro,
70 2013; Toro and Nespors, 2015). In the present study, we want to go further, by exploring
71 whether rats can detect the underlying temporal pattern of a complex auditory signal
72 independently of changes in surface features (such as pitch).

73 In our experiment, we tested whether rats can use rhythm (defined by the durations of
74 the composing tones in relation to the tempo of the beat) to discriminate a familiar song from
75 similar melodies. We familiarized the animals with an excerpt of the Happy Birthday song.
76 After familiarization, the animals were presented with three types of test items: the same
77 musical excerpt, a version of the excerpt that preserves the rhythm but not the melodic
78 intervals, and versions of the excerpt that scramble the rhythmic but not the melodic intervals.
79 If the animals can in fact detect the underlying rhythmic structure of the tune, they should be
80 able to recognize it independently of melodic changes. If, on the contrary, the animals are
81 focusing on the melody of the tune, they should not detect rhythmic variations when melodic
82 intervals are preserved.

83 **Materials and Methods**

84 *Subjects*

85 Subjects were 40 female Long-Evans rats (4 months of age). They were caged in pairs. Rats
86 were exposed to a light–dark cycle of 12h/12h in a pathogen-free room. They were food-

87 deprived until they reached 85%-90% of their free-feeding weight, but they had access to water
88 ad libitum. Food was always administered after each training session.

89 *Stimuli*

90 For the familiarization, we used the second half of the “Happy birthday” song (see Figure 1a).
91 This tune is composed by 13 tones, contains all the pitches of the Western major musical scale,
92 and the tonic (C6) occupies a centric position in the frequency range of the sounds. The tones
93 were synthesized with MuseScore 2.3.2 (www.musescore.org) with the timbre of an acoustic
94 piano. Every tone had a 20 ms fade-in ramp and it fade out during the rest of the tone
95 duration. The tones were eight different pitches: G5 (783.9 Hz), A5 (880 Hz), B5 (987.8 Hz),
96 C6 (1046.5 Hz), D6 (1174.7 Hz), E6 (1318.5 Hz), F6 (1396.9 Hz) and G6 (1568.0 Hz). The
97 frequencies of these pitches fall in the hearing range of rats, which goes from approximately
98 200 Hz to 80-90 kHz (Fay, 1988). Each sequence of 13 tones lasted 5.156 seconds and
99 contained three kinds of rhythmic figures (the notes could have 3 different durations): 1 half
100 note (857.14 ms), 8 quarter notes (428.5 ms) and 4 eighth notes (214.28 ms). The tempo of the
101 beat (every quarter note) occurred at the frequency of 2.33 Hz, that is, at the metronomic 140
102 BPM.

103 For the test, we used two kinds of unfamiliar stimuli: the isotonic rhythm excerpt and
104 the rhythmically-scrambled excerpt. The isotonic rhythm was obtained by replacing the tones
105 of the familiarization song by the pitch C6 (Figure 1b). We thus eliminated the melodic
106 intervals of the musical excerpt, creating a constant-pitch version, while preserving its rhythmic
107 organization. The rhythmically-scrambled excerpt was obtained by randomly switching the
108 rhythmic figures inside the song. That is, by interchanging the duration of the composing

109 tones (Figure 1c). Thus, the rhythmically-scrambled excerpt preserved the melodic intervals of
110 the song but distorted its rhythmic organization.

111 *Apparatus*

112 We used modular response boxes (reference LE1005; Panlab S. L., Barcelona, Spain), equipped
113 with a pellet feeder. There was a photoelectric detector that registered the nose-poking
114 responses of the rats attached to the feeder. We presented the auditory stimuli using Electro
115 Voice (s-40) speakers located next to the boxes. The intensity of the sound was approximately
116 68 dB. Each box was isolated within a bigger soundproof box. A custom-made program
117 (RatboxCBC v.2) controlled the presentation of stimuli, recorded the nose-poking responses
118 and provided the food reward (sugar pellets; F0021-D, Bilaney Consultants) during the study.

119 *Procedure*

120 Before the experiment began, rats were trained to put their nose into the feeder to obtain food
121 pellets. They learned this behavior within the first session. After this first day, we used a
122 familiarization procedure to repeatedly present to the animals the target song. We thus
123 familiarized the animals with the “Happy birthday” excerpt during 26 sessions (1 session per
124 day). In each session, rats were placed individually in a response box. The familiar excerpt was
125 presented 40 times per session. There was an 8 seconds silent interval between excerpts.
126 During this time interval, rats received food pellets if they introduced the nose into the feeder.
127 One pellet was delivered after each nose-poking response. After the familiarization, we ran a
128 test session. In the test session, we presented 42 sequences. Half of the sequences were familiar
129 excerpts. As during familiarization, the animals received reinforcement for responses after
130 these sequences. The other half of the sequences were test sequences, including 7 familiar
131 excerpts, 7 isotonic rhythm versions and 7 rhythmically-scrambled versions of the excerpt. No

132 reinforcement was delivered after the presentation of these test sequences. The presentation of
133 the sequences was semi-randomized within the test session, so that there were no more than
134 two items of the same type in a row. We also avoided the alternation of the three types of
135 stimuli. All the experimental procedures were conducted in accordance with Catalan, Spanish
136 and European guidelines and received the necessary approval by the ethical committee from
137 the Universitat Pompeu Fabra and the Generalitat de Catalunya (protocol number 9068).

138 **Results**

139 A Repeated Measures ANOVA with the within factor Test Stimuli (familiar song, isotonic
140 rhythm, rhythmically-scrambled song) was applied to the number of responses rats gave to the
141 three stimuli. Shapiro-Wilk test revealed that the nose-poking responses to each test stimuli
142 were normally distributed (all $p > .05$) and Mauchly's Sphericity test revealed no violations of
143 variances of the differences between possible pairs ($p > .05$). The animals responded
144 differently to the 3 types of test stimuli ($F_{(2,78)}=9.885, p < .001, \eta^2 = .202$; see Figure 2). *Post hoc*
145 pairwise comparisons with the Bonferroni alpha correction revealed a higher mean number of
146 nose-poking responses for the rhythmically-scrambled excerpts ($M=31.57, SD=9.33$)
147 compared to the familiar song ($M=24.75, SD=7.35$; $MD=6.82, p < .001, 95\% CI [3.60, 10.05]$)
148 and to the isotonic rhythm excerpts ($M=27.52, SD=9.76$; $MD=4.05, p=.035, 95\% CI [0.22,$
149 $7.89]$). The mean number of responses after the isotonic rhythm excerpts and the familiar song
150 did not differ ($MD=2.77, p=.376, 95\% CI [-1.66, 7.21]$). Thus, the animals discriminated the
151 rhythmically-scrambled rhythm from the two excerpts that maintained the rhythmic
152 organization of the song. In contrast, they did not discriminate between the 2 excerpts that
153 differed in their melodic intervals but that kept the same rhythmic structure.

154 To explore possible individual differences in the cues used to discriminate the test items,
155 we classified the rats according to their responses to the unfamiliar stimuli. By far, the majority
156 of the rats (N=30) responded more to the rhythmically-scrambled stimuli than to the isotonic
157 rhythm stimuli. However, a group of animals (N=8) showed the opposite pattern, and
158 responded more to the isotonic rhythm stimuli than to the rhythmically-scrambled stimuli.
159 Only 2 rats gave the same number of responses to both types of unfamiliar stimuli (see
160 Supplementary Figure 1). The difference between the number of animals responding
161 differently to the rhythmically-scrambled and the isotonic rhythm stimuli was significant
162 ($X^2=24.26$, $p<0.005$). A Mixed-Design ANOVA with the within factor Test Stimuli (familiar
163 song, isotonic rhythm, rhythmically-scrambled song) and the between factor Preference
164 (rhythmically-scrambled, isotonic, indifferent) was applied to the rats' responses. Greenhouse-
165 Geisser corrections were applied to sphericity violations found in Mauchly's test ($p = .013$),
166 and Bonferroni alpha corrections were applied to *post hoc* paired *t*-tests. Shapiro-Wilk test
167 revealed that each group nose-poking responses to the test stimuli were normally distributed
168 (all $p > .05$). Levene's test for equality of variances was not violated in any group (all $p > .05$).
169 We observed no significant main effects but a significant interaction between Test Stimuli and
170 Preference ($F_{(3,29,60,93)}=10.17$, $p < .001$, $\eta^2 = .355$; see Figure 3). The 8 rats that gave more
171 responses to the isotonic test excerpts (M=37.25, SD=10.11) significantly discriminated them
172 from the rhythmically-scrambled (M=27.00, SD=10.93; MD=10.25, $p < .001$, 95% CI [4.62,
173 15.88]) and from the familiar excerpts (M=22.38, SD=6.80; MD=14.88, $p < .001$, 95% CI
174 [6.37, 23.39]). However, this group of animals did not discriminate the rhythmically-scrambled
175 from the familiar stimuli (MD=4.63, $p = .316$, 95% CI [-2.36, 11.61]). This suggests that these
176 rats were focusing on the melodic organization of the tune instead of its rhythmic structure.
177 The opposite pattern is observed in the group of 30 animals that produced more responses to

178 the rhythmically-scrambled ($M=33.37$, $SD=8.61$) than to the familiar ($M=25.27$, $SD=7.66$;
179 $MD=8.10$, $p < .001$, 95% CI [4.50, 11.71]) and the isotonic stimuli ($M=25.23$, $SD=8.40$;
180 $MD=8.13$, $p < .001$, 95% CI [5.23, 11.04]), without discriminating the isotonic from the
181 familiar stimuli ($MD=-0.03$, $p = 1.000$, 95% CI [-4.43, 4.36]). The 2 rats that gave the same
182 number of responses to the isotonic stimuli ($M=23.00$, $SD=1.41$) and the rhythmically-
183 scrambled stimuli ($M=23.00$, $SD=1.41$; $MD=0.00$, $p = 1.000$, 95% CI [-11.26, 11.26]) could
184 not discriminate the familiar ($M=26.50$, $SD=4.95$) from neither the isotonic stimuli ($MD=3.50$,
185 $p = 1.000$, 95% CI [-13.52, 20.52]) nor the rhythmically-scrambled stimuli ($MD=3.50$, $p =$
186 1.000 , 95% CI [-10.48, 17.48]).

187 **Discussion**

188 We explored whether rats could discriminate a familiar song from a version that preserved the
189 rhythm but not the melody, and from a version that preserved the melody but not the rhythm.
190 The results suggest that most animals successfully discriminated among the complex auditory
191 sequences by focusing on their underlying rhythmic structure. In the main analysis, we
192 observed no differences between the original excerpt and its constant-pitch version (the
193 isotonic rhythm excerpt). In contrast, we did observe differences between them and the
194 version that disrupted the rhythmic organization of the song. Importantly, we observed some
195 individual differences in the cues on which the animals focused to process the tune. Although
196 the majority of the rats focused on the rhythmic structure of the tune to discriminate among
197 the unfamiliar stimuli, 8 out of 40 animals seem to have focused on the melodic organization
198 of the tunes. This suggests that there might be individual differences in the strategies to
199 process complex auditory signals and discriminate musical tunes. Nevertheless, the general
200 tendency we observed is to focus on the rhythmic structure of the song rather than on its
201 melodic organization.

202 Previous studies reported that rats found it difficult to discriminate sequential patterns
203 of notes (d'Amato and Salmon, 1984) and a tune from its reversed sequence (Poli and Previde,
204 1991). In these studies, the rodents seem to have focused on a single pitch of the sequences or
205 in a difference in timbre rather than on their underlying structure to perform their
206 discrimination. In our study, however, the order of the pitches and the timbre were identical
207 between the familiar song and its rhythmically-scrambled version. The only difference between
208 these two excerpts was the duration pattern of the tones that composed them. Under these
209 conditions, our rats seem to have focused on the rhythmic structure, rather than on the
210 melodic organization of the song, to discriminate among the excerpts. It is an open-question,
211 however, whether the group of rats that did not discriminate the rhythmically-scrambled from
212 the familiar stimuli was paying attention to the whole frequency contour or just to a single
213 pitch, as in the Experiment 3 by d'Amato and Salmon (1984). If they were focusing on certain
214 tones, the rats that did not discriminate any stimuli could have been basing their responses
215 only on the pitch C6, present in both unfamiliar stimuli.

216 Our study suggests that rats are sensitive to the rhythmic structure of a familiar tune.
217 One possibility could be that, to discriminate the stimuli, rats may have used the metrical
218 organization of the three different durational values that the tones composing the excerpts
219 could take. This may mean that they were sensitive to the temporal changes in the tune
220 regardless the pitch of the tones. In fact, they did not discriminate the familiar tune from the
221 version in which all notes were transposed to a single tone (the constant-pitch version). This
222 suggests that when the underlying structure of an auditory sequence provides enough
223 information, rodents can compensate for changes in absolute frequency (e.g. Crespo-Bojorque
224 and Toro, 2016). Another possibility could be that rats just focused on the first or the last few
225 durational values of the unfamiliar excerpts to detect whether they matched or mismatched

226 with those of the familiar song. This alternative implies that rats can discriminate the temporal
227 organization of few durational values but without requiring the processing of higher metrical
228 structures. Indeed, this is a limitation of this study, because we cannot disentangle whether rats
229 focused on the whole rhythmic structure or just the temporal organization of the few first or
230 last tones. A way to solve this conundrum would be by testing rats with unfamiliar excerpts
231 that uniquely scramble the beginning, the middle or the end of the tune.

232 Despite this limitation, and in contrast with the findings reported in Poli and Previde
233 (1991), our main results indicate that rats' discriminative behavior might go beyond the surface
234 features of the musical excerpts (such as fundamental frequency or timbre) and is based on the
235 structured rhythm of the tunes (or part of them). This suggests striking abilities in rodents
236 regarding the processing of complex auditory signals, which would be interesting to explore
237 using more naturalistic and biologically-meaningful stimuli. Interestingly, we observed that the
238 rodents responded more (produced more nose-poking responses) to the unfamiliar excerpts
239 than to the familiar ones. A similar preference for novel stimuli has also been reported in rats
240 in the domain of taste (Kalat, 1974; Welker and King, 1974) and in the spatial rearrangement
241 of objects (Pisula and Siegel, 2005; Pisula, Stryjek and Nalecz-Tolak, 2006), as well as in new-
242 born chicks during difficult tasks (Bateson and Jaeckel, 1976; Santolin, Rosa-Salva, Vallortigara
243 and Regolin, 2016). The animals in our experiment were, therefore, responding to the novel
244 durations of the tones composing the tune.

245 The fact that the ability to detect the rhythmic organization of tones in a sequence -be
246 the whole sequence or part of it- is present in a distantly-related mammal suggests that certain
247 musicality features may have evolved independently across species to process the relevant
248 sensory information of their environment. More importantly, it suggests that the cognitive
249 architecture required for the processing of core aspects of music universals (i.e. temporal

250 organization [metrical hierarchies] of few durations constrained to 2- to 3-subdivisions of the
251 beat, Savage et al., 2015) might have deep biological roots shared across species. In fact,
252 studies with avian species suggest strong rhythmic processing abilities probably linked to their
253 natural vocalizations (Slabbekoorn and ten Cate, 1999; Hoeschele, Merchant, Kikuchi, Hattori
254 and ten Cate, 2015). Beyond the temporal organization of rhythms that we attested here, other
255 universal properties of music might be spread in the animal kingdom (e.g. Hauser and
256 McDermott, 2003; Fitch, 2006; Honing, ten Cate, Peretz and Trehub, 2015), such as pitch
257 identification or melodic organization, which opens the door to a better understanding of the
258 phylogenetic origins of music.

259 **Open Practices Statement**

260 *The data and materials for the experiment are available as online Supplementary Materials, and the*
261 *experiment was not preregistered.*

262 **References**

- 263 Bateson, P. P. G., & Jaeckel, J. B. (1976). Chicks' preferences for familiar and novel
264 conspicuous objects after different periods of exposure. *Animal Behavior*, 24, 386-390.
- 265 Celma-Miralles, A., & Toro, J. M. (2019). Regularity discrimination in rats (*Rattus norvegicus*) and
266 humans (*Homo sapiens*). *Journal of Comparative Psychology*, in press.
267 <http://dx.doi.org/10.1037/com0000202>
- 268 Crespo-Bojorque, P., & Toro, J. M. (2016). Processing advantages for consonance: A
269 comparison between rats (*Rattus norvegicus*) and humans (*Homo sapiens*). *Journal of*
270 *Comparative Psychology*, 130, 97.
- 271 d'Amato, M. R., & Salmon, D. P. (1982). Tune discrimination in monkeys (*Cebus apella*) and
272 in rats. *Animal Learning and Behavior*, 10(2), 126-134.
- 273 d'Amato, M. R., & Salmon, D. P. (1984). Processing of complex auditory stimuli (tunes) by rats
274 and monkeys (*Cebus apella*). *Animal Learning and Behavior*, 12, 184-194.
- 275 de la Mora, D., Nespore, M., & Toro, J. M. (2013). Do humans and nonhuman animals share
276 the grouping principles of the iambic–trochaic law? *Attention, Perception, & Psychophysics*, 75,
277 92-100.
- 278 Fitch, W. T. (2006). The biology and evolution of music: A comparative
279 perspective. *Cognition*, 100, 173-215.
- 280 Hauser, M. D., & McDermott, J. (2003). The evolution of the music faculty: A comparative
281 perspective. *Nature Neuroscience*, 6, 663.

282 Hoeschele, M., Merchant, H., Kikuchi, Y., Hattori, Y., & ten Cate, C. (2015). Searching for the
283 origins of musicality across species. *Philosophical Transactions of the Royal Society B* 370:
284 20140094.

285 Honing, H., ten Cate, C., Peretz, I., & Trehub, S. E. (2015). Without it no music: cognition,
286 biology and evolution of musicality. *Philosophical Transactions of the Royal Society B* 370:
287 20140088.

288 Kalat, J. W. (1974). Taste salience depends on novelty, not concentration, in taste-aversion
289 learning in the rat. *Journal of Comparative and Physiological Psychology*, 86, 47.

290 Kotz, S. A., Ravignani, A., & Fitch, W. T. (2018). The evolution of rhythm processing. *Trends*
291 *in Cognitive Science*, 22, 896-910.

292 Okaichi, Y., & Okaichi, H. (2001). Music discrimination by rats. *Japanese Journal of Animal*
293 *Psychology*, 51, 29-34.

294 Otsuka, Y., Yanagi, J., & Watanabe, S. (2009). Discriminative and reinforcing stimulus
295 properties of music for rats. *Behavioral Processes*, 80, 121-127.

296 Pisula, W., & Siegel, J. (2005). Exploratory behavior as a function of environmental novelty
297 and complexity in male and female rats. *Psychology Reports*, 97, 631-638.

298 Pisula, W., Stryjek, R., & Nalecz-Tolak, A. (2006). Response to novelty of various types in
299 laboratory rats. *Acta Neurobiologiae Experimentalis*, 66, 235.

300 Poli, M., & Previde, E. P. (1991). Discrimination of musical stimuli by rats (*Rattus*
301 *norvegicus*). *International Journal of Comparative Psychology*, 5.

302 Santolin, C., Rosa-Salva, O., Vallortigara, G., & Regolin, L. (2016). Unsupervised statistical
303 learning in newly hatched chicks. *Current Biology*, 26, R1218-R1220.

304 Savage, P. E., Brown, S., Sakai, E., & Currie, T. E. (2015). Statistical universals reveal the
305 structures and functions of human music. *Proceedings of the National Academy of*
306 *Sciences*, 112(29), 8987-8992.

307 Slabbekoorn, H., & Ten Cate, C. (1999). Collared dove responses to playback: slaves to the
308 rhythm. *Ethology*, 105, 377-391.

309 ten Cate, C., Spierings, M., Hubert, J., & Honing, H. (2016). Can birds perceive rhythmic
310 patterns? A review and experiments on a songbird and a parrot species. *Frontiers in*
311 *Psychology*, 7, 730.

312 Toro, J. M., & Nespore, M. (2015). Experience-dependent emergence of a grouping bias. *Biology*
313 *Letters*, 11, 20150374.

314 Welker, W. I., & King, W. A. (1962). Effects of stimulus novelty on gnawing and eating by
315 rats. *Journal of Comparative and Physiological Psychology*, 55, 838.

316 Wilson, M., & Cook, P. F. (2016). Rhythmic entrainment: why humans want to, fireflies can't
317 help it, pet birds try, and sea lions have to be bribed. *Psychonomic Bulletin & Review*, 23, 1647-
318 1659.

319

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323 **AUTHORS' CONTRIBUTIONS**

324 ACM and JMT designed the study. ACM ran the experiment and analyzed the data. ACM and
325 JMT wrote the manuscript.

326 **ETHICAL APPROVAL**

327 All experimental procedures were approved by the ethical committee from the Universitat
328 Pompeu Fabra and the Generalitat de Catalunya (protocol number 9068).

329 **ACKNOWLEDGEMENTS**

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331 Bojorque for her insights in the familiarization procedure.

332 **DATA ACCESSABILITY**

333 The data supporting this article has been included as Supplementary Material.

334 **COMPETING INTERESTS**

335 We declare no competing interests.

336

337

338 **Figure Captions**

339

340 **Figure 1**

341 The music score and the sound envelope (in amplitude and time) are depicted for each excerpt
342 used in the experiment. The isotonic rhythm excerpt preserved the rhythmic structure of the
343 original tune but reduced the melodic organization to one pitch (C6). The rhythmically-
344 scrambled excerpt maintained the melodic organization but scrambled the rhythmic structure.

345

346 **Figure 2**

347 Individual and mean number of nose-poking responses (and standard error bars) to the 3 types
348 of test stimuli. The filled dots represent each rat responses to the test stimuli. The significance
349 level of the paired t-tests is marked with asterisks: n.s. indicates $p > .05$, * indicates $p \leq .05$, and
350 *** indicates $p \leq .001$.

351

352 **Figure 3**

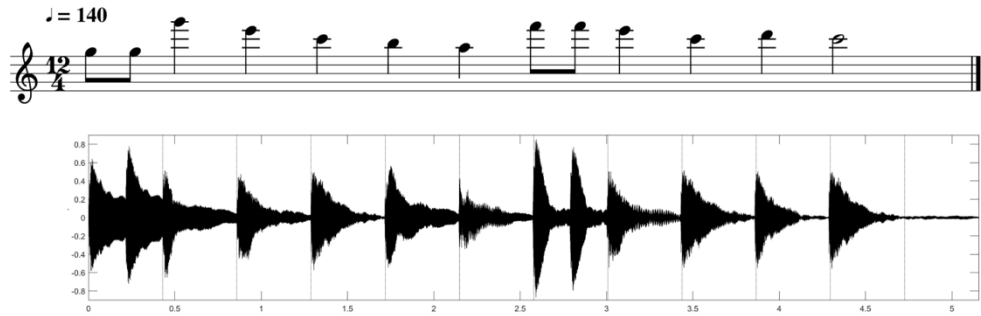
353 Mean number of responses (and standard error bars) to familiar, isotonic and rhythmically-
354 scrambled stimuli grouped by response patterns. The significance level of the paired t -tests is
355 marked with asterisks: n.s. indicates $p > .05$, and *** indicates $p \leq .001$.

356

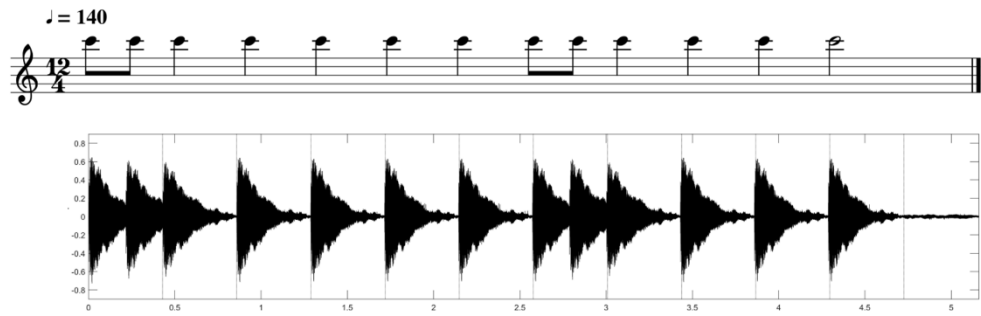
357 Figure 1

358

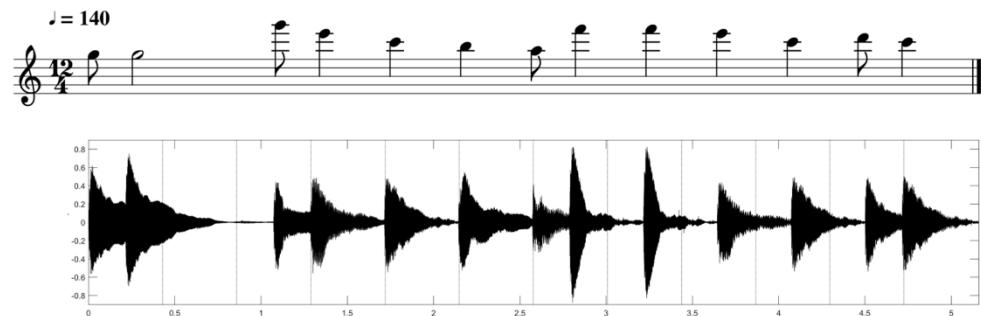
a) Familiar



b) Isotonic



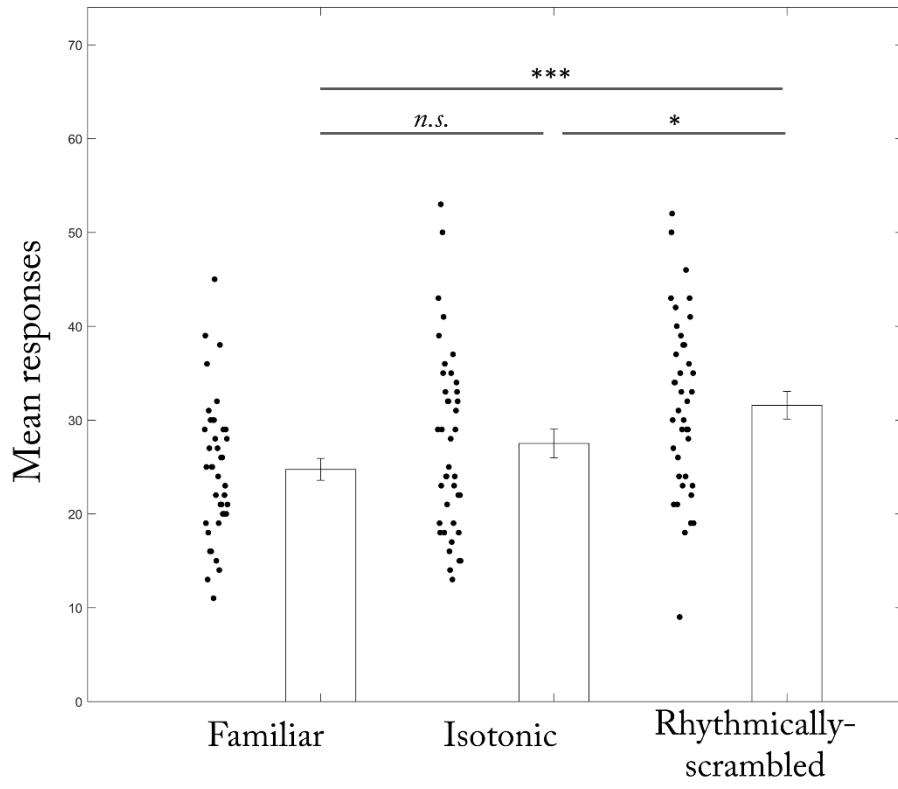
c) Rhythmically-scrambled



359

360 Figure 2

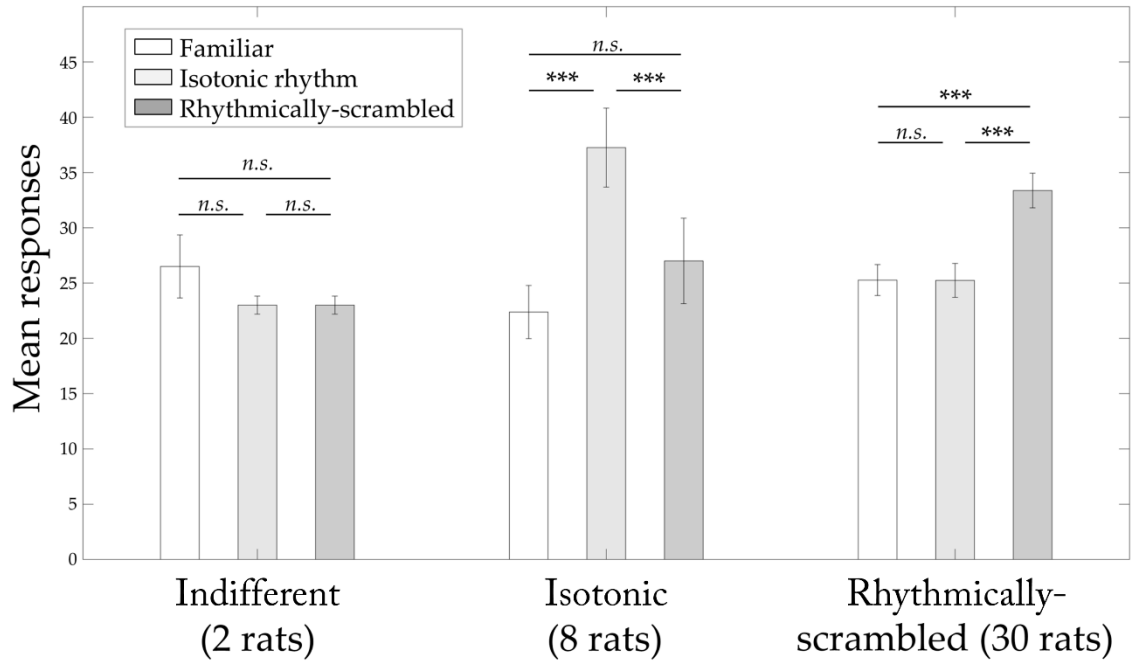
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362

363 Figure 3

364



365

366

367

SUPPLEMENTARY MATERIAL

368

Animal	FAMILIAR	ISOTONIC	RHYTHMIC-SCRAMBLED
1	21	15	19
2	28	22	35
3	20	15	23
4	29	18	33
5	23	22	22
6	22	32	19
7	20	33	41
8	29	34	43
9	20	31	36
10	26	29	28
11	21	24	29
12	26	23	32
13	21	19	29
14	38	37	46
15	14	13	24
16	19	17	18
17	24	35	38
18	27	28	30
19	32	14	38
20	15	16	23
21	22	25	29
22	28	32	33
23	45	32	39
24	30	21	35
25	11	24	9
26	30	24	24
27	25	33	31
28	25	36	26
29	16	18	21
30	30	41	40
31	16	35	37
32	27	50	42
33	31	29	34
34	18	23	34
35	13	53	21
36	36	18	27
37	25	19	30
38	19	39	52
39	39	43	50
40	29	29	43

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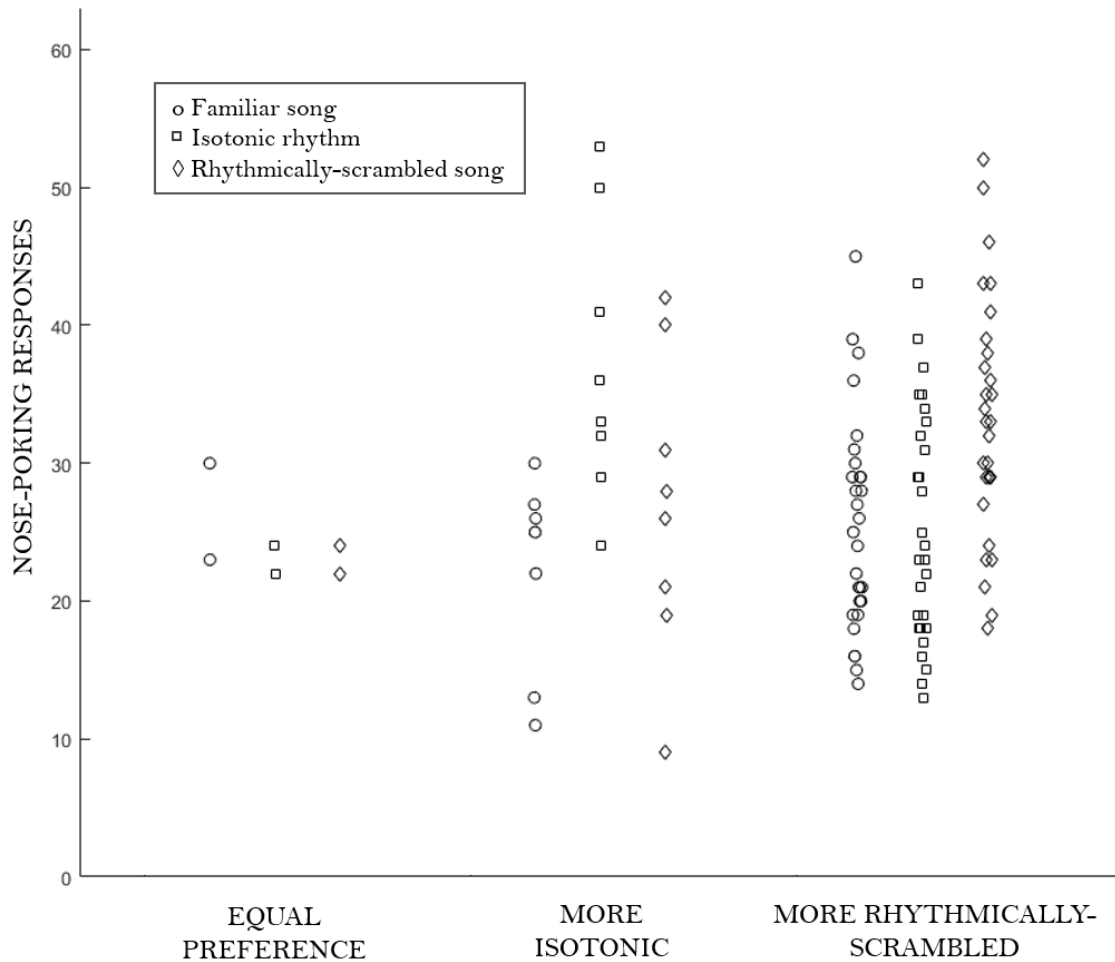
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Table 1. Mean number of responses from each individual animal (N=40) to the 3 types of test items: the familiar song excerpt, the isotonic version of the excerpt and the rhythmic-scrambled version of the excerpt.



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376 **Supplementary Figure 1**

377 Individual number of nose-poking responses grouping the rats depending on their

378 responses to the unfamiliar stimuli. There were rats (N=2) that responded equally

379 to the unfamiliar items, rats (N=8) that responded more to the isotonic rhythms

380 and rats (N=30) that responded more to the rhythmically-scrambled rhythms.

381 Circles stand for responses to the familiar song, squares stand for responses the

382 isotonic rhythms, and diamonds stand for the rhythmically-scrambled rhythms.