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Crossmodal pitch-luminance correspondence in human and non-human primates: a failed replication of Ludwig et al. (2011) in baboons (*Papio papio*)

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Abstract

Humans spontaneously and consistently map information coming from different sensory modalities. Surprisingly, the phylogenetic origin of such cross-modal correspondences has been under-investigated. A notable exception is the study of Ludwig et al (2011) which reports that both humans and chimpanzees spontaneously map high-pitched sounds to bright objects and low-pitched sounds to dark objects. Our pre-registered study aimed to directly replicate this research on both humans and baboons (*Papio papio*), an old world monkey which is more phylogenetically distant from humans than chimpanzees. Following Ludwig et al., participants were presented with a visual classification task where they had to sort black and white square (low and high luminance), while background sounds (low or high-pitched tones) were playing. Whereas we replicated the finding that humans' performance on the visual task was affected by congruency between sound and luminance of the target, we did not find any of those effects on baboons' performance. These results question the presence of a shared iconic pitch-luminance mapping in other non-human primates.

Keywords: crossmodal correspondence; comparative cognition; iconicity

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72 Humans tend to form automatically cross-modal correspondences, i.e., associations  
73 between modality-specific features [1]. For instance, they associate certain sound  
74 frequency to shape properties: a high-pitched tone will be preferably associated to  
75 objects that are small, spiky and bright, whereas a low-pitched tone would be generally  
76 associated to objects that are big, round, and dark [2]. Such cross-modal biases have  
77 been demonstrated experimentally across a wide range of modalities: between odors  
78 and visual stimuli [3], sound and taste [4], and taste and touch [5], among many others  
79 [6].

80

81 Cross-modal biases have been proposed as a key mechanism underlying  
82 multisensory integration and language evolution. In perception, cross-modal  
83 correspondences may help to constrain the cross-modal binding problem (i.e., the  
84 problem of knowing which of many perceptual information should be bound together)  
85 [7]. In language: cross-modal biases to associate sounds with other sensory  
86 modalities may have triggered the evolution of spoken language by facilitating the  
87 expression of sensory experiences through a unique auditory channel [8,9].  
88 Surprisingly though, despite the potential evolutionary importance of cross-modal  
89 correspondences, the investigation of their phylogenetic origins remains very limited.

90

91 One possibility is that cross-modal correspondences may be limited in non-human  
92 animals because they are rooted in linguistic experience. For instance, the pitch-  
93 luminance mapping [10] –where higher frequencies are associated to bright stimuli –  
94 might derive from the usage in English of the same adjectives to refer to luminance  
95 and pitch, namely ‘high’ and ‘low’. Alternatively, because non-human species would  
96 similarly benefit from cross-modal correspondences to facilitate the integration of  
97 multisensory inputs coming from their environment [11], these proclivities may be the  
98 result of a natural, structural, feature of our perceptual system that may be shared  
99 across species. For example, for the pitch-luminance mapping, both visual high  
100 luminance and acoustic high frequency have a shared increase in stimulus intensity  
101 which is suggested to be encoded by the same brain structure dedicated to magnitude  
102 [12].

103

104 Comparative studies provide an immediate way to tease apart these different  
105 possibilities. To our knowledge, only few studies tested the existence of these  
106 mappings in other animals, and report evidence for a pitch-elevation mapping [13] –  
107 where higher frequencies are associated to high spatial positions-- , and a pitch-size  
108 mapping in domestic dogs [14], a space-luminance mapping [15] –where right  
109 positions are associated to brighter stimuli-- but not a pitch-luminance mapping in  
110 chicks [16], and finally a pitch-luminance mapping in chimpanzee [10]. Some of these  
111 correspondences could be learn from their co-occurring regularities in the environment.  
112 The pitch-elevation correspondence might be explained by environmental statistics of  
113 auditory scenes as higher frequency sounds originate from elevated sources [5].  
114 Similarly the pitch-size correspondence might arise from the observation that large  
115 objects tend to produce low frequency sounds (e.g., when dropped) while small  
116 objects produce high-pitched sounds [17]. Yet, evidence from the pitch-luminance and  
117 the space-luminance mappings in non-human animals would suggest that some of  
118 these mappings have a non-linguistic, structural origin.

119

120 Of special interest is pitch-luminance correspondence, which is well established in  
121 humans [18-20], that triggered different findings in chicks and chimpanzees. Critically,  
122 this is the only study reporting the existence of a cross-modal correspondence that  
123 cannot be extracted statistically from the environment, in a non-human primate  
124 species. In that study, 6 chimpanzees and 33 human participants were trained in a  
125 visual speeded classification task on a touch screen, where they had to match a  
126 sample square (black or white) to the matching stimulus (i.e., identical black or white  
127 square). During testing, both species performed the same task while passively  
128 listening to background sounds (i.e., high and low-pitched tones), which were  
129 crossmodally either congruent or incongruent to the luminance of the sample square.  
130 Both species showed better performance when the frequency of the sound matched  
131 the luminance of the sample square – white square congruent with the high-pitched  
132 tone and black square with the low-pitched tone.

133

134 Other attempts on testing sound-shape mappings (i.e., mapping the ‘round’ vs ‘sharp’  
135 sounding nonwords, such as ‘bouba’ and ‘kiki’, to a curved and ‘sharp’ shapes,  
136 respectively [21, 22]) in great apes (i.e., gorillas, chimpanzees and bonobos) failed to

137 show any cross-modal effects in these species. Based on the weak experimental  
138 evidence on cross-modal mapping in non-human primates, in the current pre-  
139 registered study, we aimed to carry out a direct replication of Ludwig et al. (2011)'s  
140 study on the pitch-luminance correspondence, by testing a group of humans and  
141 baboons (*Papio papio*) following the original methods and analyses as closely as  
142 possible. Baboons and humans were trained on a visual speeded classification task,  
143 where they had to classify squares based on their luminance. During the testing phase,  
144 both species repeated the same speeded classification task, while background sounds  
145 (e.g., low vs high pitched tones) were presented. We examined whether sound  
146 congruency, following a pitch-luminance mapping, would affect the performance of  
147 both species on the visual classification task.

148

## 149 Methods

150

151 The methods, design and analysis were pre-registered at: <https://osf.io/vsnp4>.

152 All the data and stimulus material are openly available at:  
153 [https://osf.io/ng6y3/?view\\_only=b3797de197744bb79a1bcc544f0cf69a](https://osf.io/ng6y3/?view_only=b3797de197744bb79a1bcc544f0cf69a).

154 All methods for the human study were approved by the Ethics Committee of Aix-  
155 Marseille University and for the baboon study received approval from the French  
156 Ministère de l'Education Nationale (approval no. APAFIS-2717-2015111708173794-  
157 V3).

158

159 Human testing: Twenty-seven, right-handed human adults (21 females, age  $M=22.70$   
160  $\pm 5.55$ ) participated in the study. The task was a visual speeded classification task  
161 involving the matching of a sample square (black or white) to one of the two  
162 alternatives which is identical to the sample (identity matching-to-sample procedure).  
163 During the test trials, a tone, either high or low-pitched, was played while participants  
164 were performing the same task. The design was identical to the one described in  
165 Ludwig et al. (2011) [10], with the sole difference on the feedback screens (see  
166 supplementary Figure S1.b). In the present study, we used visual feedback, instead  
167 of audio feedback as in Ludwig et al., 2011, since that group of baboons was already  
168 used to be trained with visual feedback when performing touch-screen tasks [22]. After  
169 a correct response, a black screen appeared for 3s combined with food reward only

170 for the baboons, whereas after an incorrect response a green screen appeared for 3  
171 s plus a black screen of 3s.

172

173 Before starting with the task, participants received written instructions and were asked  
174 to be as fast and accurate as possible in performing the visual speeded classification  
175 task. The experiment was divided into two phases, a training and a testing phase.  
176 During the training, participants performed 16 matching-to-sample trials without any  
177 background sound (for details see supplementary material). By the end of this phase,  
178 participants had to reach a performance of 100%, in order to continue to the testing  
179 phase. These 16 trials were repeated once in case of mistakes. Two participants did  
180 not reach a 100% performance at the first training and repeated the procedure. Once  
181 the training was completed, the testing phase followed. Participants received written  
182 instructions to focus on the visual speeded classification task, even though sounds  
183 would be played in the background. The testing phase started with 4 trials including  
184 sounds, which were excluded from the analysis. Then, two blocks of 80 trials each  
185 (160 trials in total) followed, with a break in-between. Humans were tested in one  
186 single session of 30 minutes.

187

188 Baboon testing: Fifteen Guinea baboons (*Papio papio*), (12 females, age  $M=11.4 \pm$   
189  $5.64$ ) completed the study. Baboons were tested at the CNRS Primatology center in  
190 Rousset-sur-Arc, France where they live in two social groups and had *ad libitum*  
191 access to 13 ALDMs (Automated Computer Learning devices) [23]. Each device has  
192 a food dispenser, a touchscreen and two speakers. The speakers are facing down  
193 inside each test chamber. A radio-frequency identification of the subjects by the  
194 system facilitated testing, as it doesn't require capturing of the subjects [24]. The  
195 baboons have voluntary access to all the devices. Baboons performed the same visual  
196 speeded classification task as humans, and were exposed to the same training  
197 procedure (for details on the training see supplementary material). All baboons  
198 completed the testing in three consecutive days. Each day comprised a testing  
199 session. During a session, the monkeys completed a block of 16 trials without any  
200 background noise, where they had to achieve a performance of at least 80% in both  
201 categories (i.e., black/white) (White:  $M=0.80\%$ ;  $SE=0.02\%$ , Black:  $M=0.88\%$ ;  
202  $SE=0.02$ ). The block was repeated until the criterion was reached (number of  
203 averaged training blocks  $=2.71$ ;  $min=1$ ;  $max=11$ ;  $SE=0.31$ ). After that, baboons

204 performed 4 practice trials with background sounds. Then, a block of 160 testing trials  
205 followed. In total, baboons completed 480 testing trials. All trials and conditions  
206 between samples and sounds were equally counterbalanced, following the description  
207 by [10] (for details on the training see supplementary material).

208

## 209 Results

210

211 We conducted the analysis described by Ludwig et al., (2011) [10]. We first looked at  
212 the mean median RT and the error rates for congruent and incongruent trials in both  
213 species. Our results confirm the findings of Ludwig et al. (2011) [10] on humans but  
214 not on non-human primates. Specifically, in the original study, chimpanzees made  
215 more errors in incongruent than in congruent trials, while, in baboons, no differences  
216 were observed on the mean error rates between congruent ( $M = 10.58\%$ ,  $SD =$   
217  $3.16\%$ ) and incongruent trials ( $M = 10.58\%$ ,  $SD = 4.16\%$ ). Yet, similarly to the original  
218 study, there was also no difference on the mean median RTs between congruent ( $M$   
219  $= 653\text{ms}$ ,  $SD = 97.6\text{ms}$ ) and incongruent trials ( $M = 657\text{ms}$ ,  $SD = 102.4\text{ms}$ ;  $t(14) =$   
220  $1.31$ ,  $p = 0.20$ ,  $r = 0.33$ ).

221 Humans had no significant difference in the mean error rates between congruent ( $M$   
222  $= 0.18\%$ ,  $SD = 0.04\%$ ) and incongruent trials ( $M = 0.46\%$ ,  $SD = 0.06\%$ ;  $t(26) =$   
223  $-0.94$ ,  $p = 0.35$ ,  $r = 0.18$ ). Yet, they were faster for congruent trials ( $M = 544\text{ms}$ ;  $SD = 71.8\text{ms}$ )  
224 than for incongruent trials ( $M = 560\text{ms}$ ,  $SD = 69.8\text{ms}$ ;  $t(26) = -4.88$ ,  $p < 0.001$ ,  $r = 0.69$ ).  
225 These findings parallel the results reported in humans by Ludwig et al. (2011).

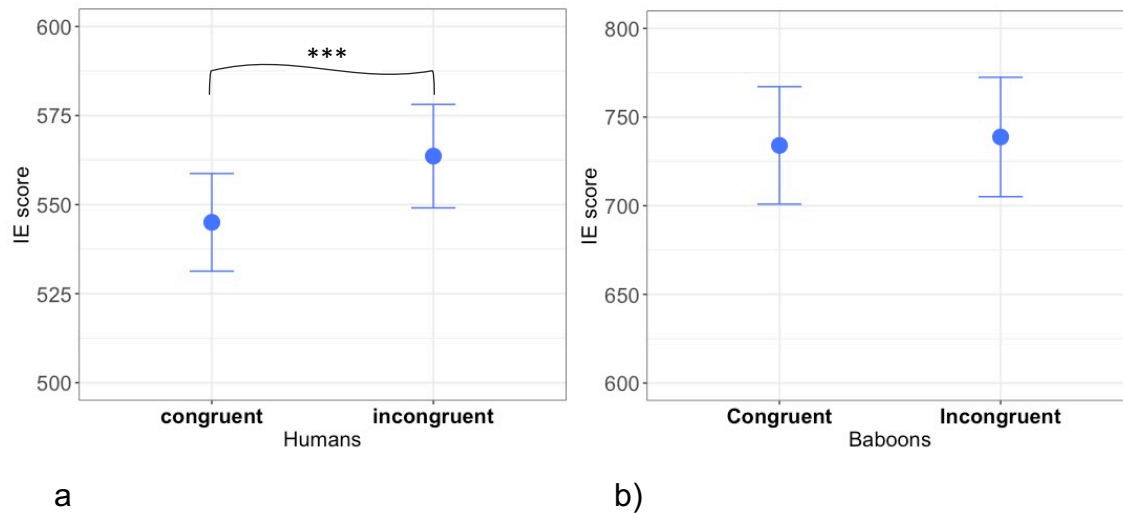
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227 Following Ludwig et al., we then calculated the speed-accuracy trade-off for congruent  
228 and incongruent trials in both species, by calculating the Inverse Efficiency score (IE)  
229 [25]. To calculate the IE scores, for each participant we divided the median RT by the  
230 proportion correct, for the two conditions. A paired sample t-test showed that humans  
231 had a significantly lower IE score (i.e., indicating better performance) ( $t(26) = -4.15$ ,  
232  $p < 0.001$ ;  $r = 0.69$ ) for congruent (IE = 545,  $SD = 71.2$ ) than for incongruent trials (IE =  
233 564,  $SD = 75.5$ ; ). In contrast to the findings of Ludwig et al. (2011) on chimpanzees,  
234 the results on the baboons revealed no significant difference ( $t(14) = -0.53$ ,  $p > 0.10$ ) on  
235 the IE score between congruent (mean IE: 734,  $SD = 128$ ) and incongruent trials  
236 (mean IE: 738,  $SD = 130$ ) (see Fig.1). Based on these findings, we replicated the  
237 findings of Ludwig et al. (2011) [10] in humans on pitch-luminance congruency



238 crossmodal effects, but not in baboons (for details see results in supplementary  
239 material).

240



241

242

243

244 Figure 1. Mean IE scores for congruent and incongruent trials in a) humans and b)  
245 baboons. Blue circles and errors bars represent the means and standard errors for  
246 each condition (SE). Asterisks indicate significant differences between the two  
247 conditions ( $p < 0.001$ ).

248

## 249 Discussion

250

251 Following the protocol of Ludwig et al. (2011) [10], we tested the pitch-luminance  
252 crossmodal correspondence in a group of humans and baboons. In the original study,  
253 humans showed longer reaction times when the sound was incongruent to the  
254 luminance of the sample stimulus, whereas in chimpanzees an interference effect was  
255 observed only on the proportion of error rates. Chimpanzees did more errors for  
256 incongruent than congruent trials. In the present replication study, although we  
257 replicated the human results, our results did not show any evidence of sound  
258 interference effects on the visual speeded classification task in baboons.

259

260 How to account for the difference between chimpanzees [10] and the current baboons  
261 result? Certainly, primate species differences might suggest that the mapping of pitch-  
262 to-luminance is unique to chimpanzees and humans, but does not extend to more  
263 phylogenetically distant relatives such as the Old World monkeys, including the

264 baboons. According to this hypothesis, such a cross-modal correspondence might  
265 thus have emerged and be inherited from the last common ancestor of the Hominini  
266 tribe. Yet, another possibility is that the absence of any systemic pitch-to-luminance  
267 correspondence in baboons, questions the existence of this mapping not only in this  
268 species but also in any other nonhuman species. There are several reasons to doubt  
269 on the robustness of the chimpanzee's result. First, while the study of Ludwig et al.  
270 (2011) showed a pitch interference effect in a visual speeded classification task in  
271 chimpanzees, this effect was based on a 2.7% difference between mean error rates  
272 for congruent and incongruent trials but was not visible on median response times,  
273 contrary to human participants. Second, the size of the chimpanzee sample was  
274 relatively low (N=6) compared to the present baboon study (N=15). Third, whether the  
275 chimpanzees tested in the Ludwig et al., (2011) [10] had previous experiences on  
276 auditory discrimination between high- and low-pitched tones, is not specified in the  
277 original study. Any such previous experience could have increased sensitivity to the  
278 auditory stimuli of the present paradigm. This is of particular importance as testing  
279 non-human primates on auditory paradigms is not a trivial task [26, 27].

280

281 Our results are consistent with previous results showing no evidence of crossmodal  
282 mappings in non-human primates [21,22] or in other animals such as chicks [16]. This  
283 suggests that some crossmodal correspondences might not be shared with other  
284 nonhuman species. As we noted, the absence of any crossmodal effects in these  
285 species could have plausibly resulted from attention or discriminatory troubles on  
286 auditory stimuli. In addition, factors such as previous habituation to visual tasks,  
287 training history, protocol design, or age of the individuals appear to play an important  
288 role in testing the performance of nonhuman primates on tasks including auditory  
289 stimuli [28].

290

291 To conclude, evidence of the presence of a pitch-luminance mapping in other  
292 nonhuman species appears to be weak, suggesting that language, culture or human-  
293 specific neuro-anatomical features may be fundamental for the emergence of this non-  
294 statistically learned mapping. Future studies will be necessary to investigate the  
295 reliability of this hypothesis.

296

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