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On the role of interference in sequence learning in Guinea baboons (*Papio papio*)

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27 Abstract

28 It is nowadays well-established that decay and interference are two main causes of
29 forgetting. In the present study, we specifically focus on the impact of *interference* on
30 memory forgetting. To do so, we tested Guinea baboons (*Papio papio*) on a visuo-motor
31 adaptation of the Serial Reaction Time task in which a target sequence is repeated, and a
32 random sequence is interposed between repetitions, a similar situation as the one used in the
33 Hebb repetition paradigm. In this task, one three-item sequence, the repeated sequence, was
34 presented every second trial and interleaved with random sequences. Interference was
35 implemented by using random sequences containing one item that was also part of the
36 repeated sequence. In a first condition, the overlapping item was located at the same position
37 as the repeated sequence. In a second condition, the overlapping item was located at one of
38 the two other positions. In a third condition, there was no overlap between repeated and
39 random sequences. Contrary to previous findings, our results reveal similar learning slopes
40 across all three conditions, suggesting that interference did not affect sequence learning in the
41 conditions tested. Findings are discussed in the light of previous research on sequence
42 learning and current models of memory and statistical learning.

43 **Keywords:** *statistical learning, sequence learning, memory, forgetting, interference*

44 According to the influential model of statistical learning PARSER (Perruchet &
45 Vinter, 1998), when a to-be-learned sequence of items is not frequently repeated, the memory
46 trace of this percept rapidly vanishes as a consequence of *spontaneous decay* and *interference*
47 *with similar material*. In the present study, we specifically focus on the impact of *interference*
48 on the learning of sequential material. In other words, we examine whether and how
49 similarities between random and repeated visuo-spatial sequences induce interference in
50 active representations in working memory and in the creation of sequential long-term memory
51 representations. Indeed, when learning sequences in everyday life (e.g., sequencing
52 movements in typing or sports, when playing an instrument, or sequencing sounds in speech),
53 there is generally more or less overlap between the to-be-learned items composing a sequence
54 (e.g., movements or sounds), which is likely to induce interference between sequences and
55 consequently to affect learning.

56 The effect of interference on sequence learning has been studied in humans by Page et
57 al. (2013) with the Hebb repetition paradigm. In that study, the authors examined to what
58 extent item-overlap is likely to affect learning in adults. Participants were presented with a
59 repeated Hebb sequence of seven single-syllable words which were interposed by either non-
60 overlapping or fully overlapping filler sequences. The fully overlapping filler sequences were
61 composed of exactly the same items as those contained in the Hebb sequence, but in different
62 orders (e.g., Hebb sequence = “flea, vase, disc, moss, shed, curb, soup”; filler sequence =
63 “shed, disc, flea, soup, moss, curb, vase”), while the non-overlapping filler sequences did not
64 share any item with the Hebb sequence (e.g., Hebb sequence = “flea, vase, disc, moss, shed,
65 curb, soup”; filler sequence = “cow, cart, wink, seam, coin, arch, grown”). Results revealed
66 reliable learning in the non-overlapping condition, while no learning was observed in the fully
67 overlapping condition, suggesting that interference significantly affected learning. However,
68 in our view, full overlap between items is very rare in natural learning situations. Taking the

69 example of vocabulary acquisition in infants, not all words of a given language are anagrams
70 of each other (e.g., *eat* and *tea*) and rather do, in many cases, share at most some phonemes
71 only (e.g., /kɒpi/ [copy] versus /kɒfi/ [coffee]). As a consequence, mouth movements
72 during speech production of different words are not systematically permutations of the same
73 movements. The same is true for the acquisition of non-linguistic sequences such as
74 sequences of movements when tapping out a phone number, learning to drive a car, or when
75 playing an instrument.

76 As far as we know, only one study in humans used a semi-overlapping design,
77 meaning that random and repeated sequence shared some but not all items (Saint-Aubin et al.,
78 2015). However, the aim of that study being different from ours, the degree of item-overlap
79 between sequences was not controlled for and therefore does not allow to draw conclusions
80 about the effect of interference on sequence learning.

81 The aim of the present study is thus to examine the impact of interference on
82 sequential statistical learning by proposing a semi-overlapping design, which is more similar
83 to what is usually observed in natural learning situations. To do so, we created an adaptation
84 of the Serial Reaction Time task (Nissen & Bullemer, 1987) combined with the advantage of
85 the Hebb repetition paradigm allowing to measure the impact of interference by inserting
86 semi-overlapping random sequences between repeated sequences. In the present study, we
87 tested a population of Guinea baboons in order to examine the impact of interference on
88 sequence learning by controlling for language-related refreshing mechanisms, which are
89 absent in non-human primates. Baboons were presented with sequences of three target
90 locations on the touch screens. One random sequence was inserted between the presentations
91 of the repeated sequence. In a first condition (Condition 1), the random sequences contained
92 one location that was part of the repeated sequence, and this location was always presented at
93 the same position (e.g., repeated sequence = 7 6 2, random sequence = 7 9 1 or 9 6 1 or 1 9 2,

94 etc., random sequences were presented in random order). In a second condition (Condition 2),
95 random sequences again contained one item of the repeated sequence but this time, it was
96 located at one of the two remaining positions compared to the repeated sequence (e.g.,
97 repeated sequence = 7 6 2, random sequence = 9 7 1 or 9 1 7, etc., and the same for the two
98 other locations 6 and 2, again presented in random order). In the third condition (Condition 3),
99 we used a non-overlapping design, meaning that different locations were used for the repeated
100 and the random sequences (e.g., repeated sequence = 7 6 2, random sequence = 4 9 1). In the
101 present study, we hypothesize that the representation of the items of the repeated sequence
102 and the connections between these items within the sequence (Burgess & Hitch, 2006) may
103 interfere with the item representations of the overlapping random sequences (in Condition 1
104 and 2) as a consequence of overwriting of features shared by these sequences (Oberauer &
105 Kliegel, 2006). More precisely and according to previous studies (Page et al., 2013; Smalle et
106 al., 2016), we expected to observe weaker or even no reliable learning in the two overlapping
107 conditions but reliable learning in the non-overlapping condition. Moreover, we expected
108 stronger interference in the “same-position” condition (Condition 1) compared to Condition 2.
109 Indeed, imagine the following repeated sequence: 7 6 2, the co-occurrence between e.g., 7 and
110 6 should be more affected when being alternately presented with the following random
111 sequence: 7 1 9 (condition 1) compared to e.g., 1 9 7 (condition 2), because 7 at the first
112 position can here be associated to 6 or to 1, leading to an unstable representation of this
113 association.

114 **Method**

115 **Participants**

116 We tested 25 Guinea baboons (*Papio papio*, 16 females) living in a social group at the
117 CNRS primate facility in Rousset (France). The baboons were housed in a 700 m² outdoor
118 enclosure with access to indoor housing.

119 Apparatus

120 Baboons had free access to fourteen Automated Learning Devices for Monkeys
121 (ALDM, Fagot & Bonté, 2010; Fagot & Paleressompoulle, 2009) equipped with touch
122 screens and a food dispenser. When entering the ALDM test box, baboons were identified by
123 microchips implanted in each arm. The system saved the last trial the baboon had achieved
124 before leaving the box, allowing him to continue the task later on where it had stopped. The
125 experiment was controlled by E-Prime 2.0 software (Psychology Software Tools, Pittsburgh,
126 PA). All the baboons were familiar with touch screen experimentation.

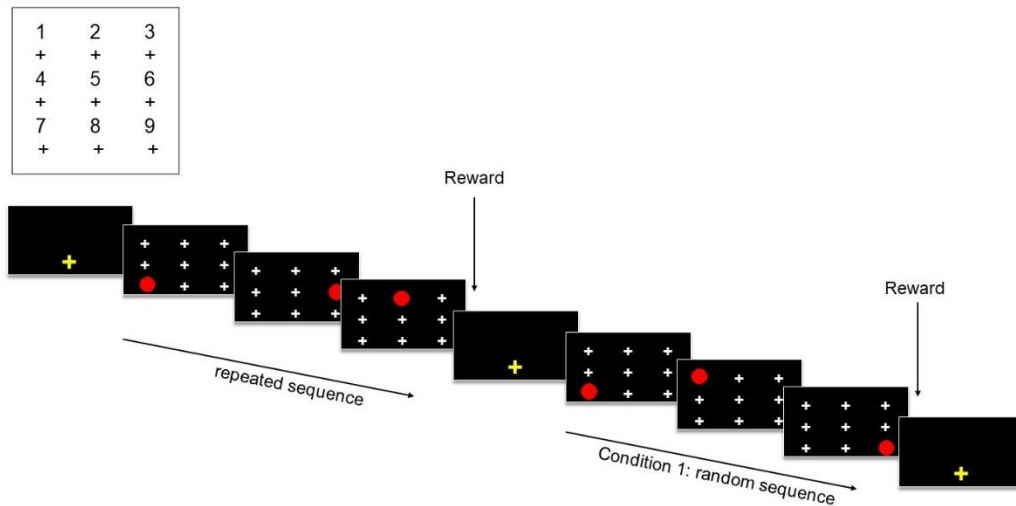
127 Materials and procedure

128 To begin a trial, baboons must press the yellow fixation cross¹ centered at the bottom
129 of the screen. After pressing the cross, they saw a black screen that was divided into an
130 invisible matrix of (3x3) cells, each containing a white cross in their center (see Figures 1A
131 and 1B). In this task, baboons needed to touch sequentially one red circle that moved on the
132 screen in sequences of three target locations. When the baboon touched the first target
133 position, it disappeared and was replaced by the white cross. The red circle then appeared at
134 the second position and must again be touched before being presented with the last position of
135 the sequence, where a last touch was required. Reward (grains of dry wheat) was delivered at
136 the end of each sequence of three correct touches. In case of an error (i.e., the participant
137 touched another location than the target one or failed to touch the screen within 5,000 ms), a
138 green screen was displayed for 3,000 ms as a marker of failure.

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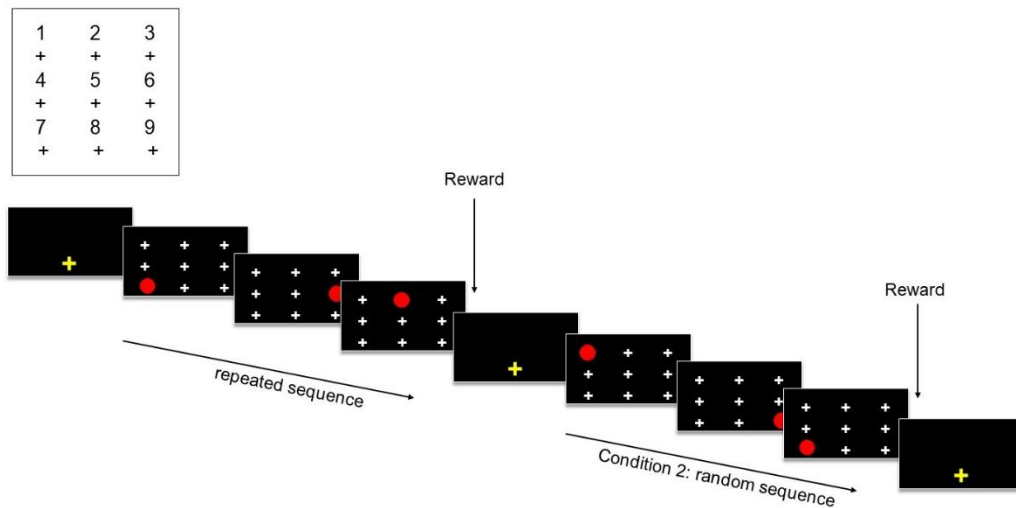
¹ Thus, the inter-stimulus-interval depends on the moment the baboon decides to press the yellow fixation cross. As the length of the inter-stimulus-interval can help subjects to separate trials and eventually help to minimize interference between trials, it is important to mention that we deliberately decided to let the baboons initiate the next trials in order to make sure that they are alert after having been rewarded with the grains. For a video, see https://osf.io/7h8cd/?view_only=ec264f23c01f4b94b4571543b494d867

139 **Figure 1A.** Representation of the touch screen with the nine locations and example of
 140 the experimental display and stimuli presentation for repeated and random sequences in
 141 Condition 1 (overlap at the same position).



142

143 **Figure 1B.** Representation of the touch screen with the nine locations and example of
 144 the experimental display and stimuli presentation for repeated and random sequences in
 145 Condition 2 (overlap at a different position).



146

147 The experiment was therefore composed of three conditions: Two overlapping
 148 conditions (Condition 1 and 2) and one non-overlapping condition (Condition 3). Each
 149 baboon completed all three conditions and the order of Conditions 1 and 2 was randomized.
 150 Thirteen baboons began with the first condition and subsequently completed the second one,

151 while twelve baboons completed the second and then the first condition. The non-overlapping
152 condition was part of a previous study conducted in our lab (Ordonez Magro et al., revision
153 submitted). Each condition began with a random phase during which baboons were presented
154 with three blocks of 100 random sequences of three positions. This phase was used as a
155 familiarization phase at the beginning of the experiment as well as a phase allowing to “clean
156 up” the memory trace of the previously learned repeated sequence to avoid interference
157 between to-be-learned repeated sequences across conditions. The test phase began when the
158 baboon achieved a performance higher than 80% correct within three consecutive blocks of
159 100 random trials. Response times (RTs) between the appearance of the red circle and the
160 participant’s touch of each of the three positions for each sequence was recorded and served
161 as a dependent variable. The present task follows a 1-filler design, meaning that the
162 presentations of the repeated sequence were spaced by one random sequence (i.e., random-
163 *repeated-random-repeated-...*). Baboons performed 5 blocks of 100 trials, resulting in 250
164 presentations of the repeated sequence plus 250 presentations of the random sequence. To
165 perform the 500 trials, baboons visited the test boxes in Condition 1 about 8.70 times in
166 average, with an average of 65.96 trials per visit. In Condition 2, they visited the test boxes
167 about 7.35 times with an average of 74.35 trials per visit. Finally, in Condition 3, baboons
168 visited the test boxes about 8.12 times with an average of 69.85 trials per visit.

169 To avoid learning effects across conditions, participants were presented with a
170 different repeated sequence in each condition (see Table 1 for an example). Repeated
171 sequences were matched across positions for motor difficulty. To do so, a random phase of
172 sequence production of six positions for 1,000 trials was conducted on thirteen baboons.
173 Based on these random trials, a baseline measure for all possible transitions from one location
174 to another was computed by calculating mean RTs for each transition (e.g., from position 1 to
175 9), leading to a 9x9 matrix of mean RTs (see Appendix A).

176 In this experiment, and in accordance with the serial recurrent network (SRN; Elman,
177 1990) model, learning was measured by comparing RTs between the three positions of the
178 sequence. In a repeating three-position sequence such as e.g., 7 6 2, location 7 is always
179 followed by location 6 and location 6 is always followed by location 2. Thus, location 7
180 (Position 1) is less predictable over trials, because of the previously presented random
181 sequences, compared to locations 6 (Position 2) and 2 (Position 3) which benefit from the
182 systematic presence of 7 or 7 6 presented just before. Thus, if learning takes place, we should
183 observe faster RTs for Positions 2 and 3 compared to Position 1.

184 To be able to assess learning accurately, the mean RTs of the transition between
185 Position 1 and 2 (transition 1) and the transition between Position 2 and 3 (transition 2) of the
186 repeated sequences should be comparable. In our previous, study (Ordonez Magro et al.,
187 revision submitted), we created our repeated sequences by computing the RTs for the first and
188 the second transition of all possible 504 triplets of the matrix and retained the triplets with the
189 smallest difference of RTs (going from 2.06 ms to 15.55 ms), by making sure to choose
190 sequences that were not too similar to each other (e.g., avoiding that all sequences begin with
191 the same location). For the present study, we used novel sequences and thus retained the next
192 five triplets of the list with the smallest difference of RTs (going from 6.97 ms to 18.22 ms),
193 again making sure that they are not too similar too each other.

194 To create the random sequences of Condition 1, we computed, for each location, all
195 sequences containing the given location at the same position and retained only those which
196 did not contain the two remaining locations. For example, taking the repeated sequence 7 6 2,
197 we computed all sequences starting with 7 and retained those which did not contain 6 and 2.
198 We did the same for the location 6 and the location 2. This gave us a total of 90 different
199 random sequences for Condition 1. Regarding Condition 2, we computed, for each location,
200 all sequences that did contain the given location but at a different position and again retained

201 those which did not contain the two remaining locations of the repeated sequence. Taking the
 202 example of the repeated sequence 7 6 2, we computed all random sequences containing the
 203 location 7 at position two or three and retained those which did not contain 6 and 2. We did
 204 the same for locations 6 and 2. This gave us a total of 180 different random sequences for
 205 Condition 2. The presentation order of the random sequences was randomized across trials.

206 **Table 1.** Example of sequences presented in the three conditions for a given
 207 participant. Digits correspond to the nine screen locations. Repeated sequences are bolded,
 208 and the underlined digits correspond to the overlapping items.

Participant	Condition 1	Condition 2	Condition 3
Participant 1	<u>6</u> -3-2	9-1- <u>6</u>	1-4-6
	6-9-4	7-6-2	5-8-3
	<u>6</u> -1-2	4-9- <u>7</u>	7-9-4
	6-9-4	7-6-2	5-8-3
	3-5- <u>4</u>	1-8- <u>7</u>	9-7-2
	6-9-4	7-6-2	5-8-3
	3- <u>9</u> -7	8- <u>2</u> -1	2-6-4
	6-9-4	7-6-2	5-8-3
...	

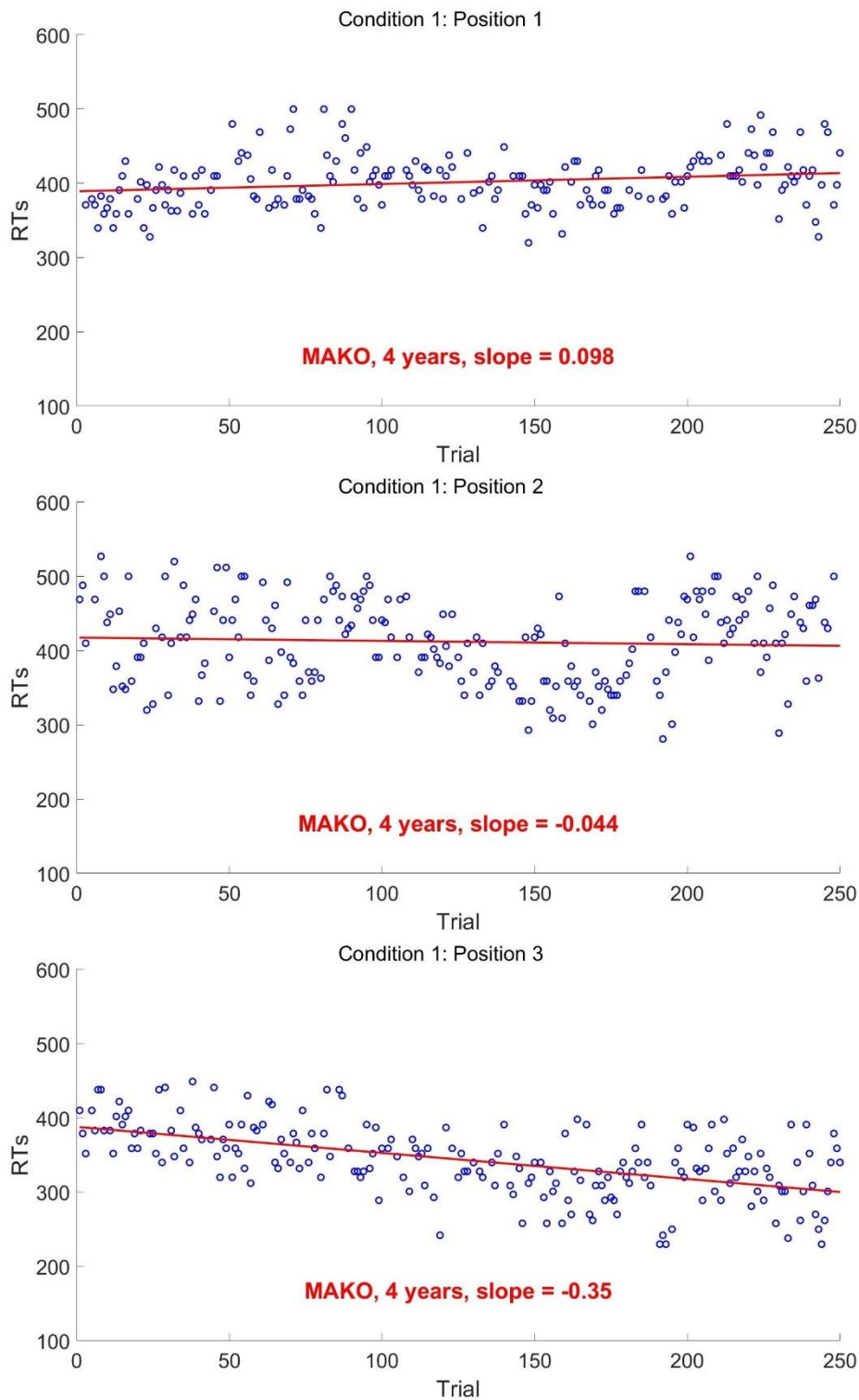
209

210 **Analyses**

211 The ability of monkeys to learn the sequence was assessed by looking at the evolution
 212 of RTs on the three positions by computing linear regression analyses. The slope of the
 213 repeated sequence for the less predictable Position 1 and the mean slope of the predictable
 214 Positions 2 and 3 of the linear regression was used as an index of learning (see Figure 2 for an
 215 example. To see the learning slopes for each baboon, each position, and each condition, see
 216 https://osf.io/6cpfm/?view_only=35017b02cc2947688636ee7620e1906f).

217

218 **Figure 2.** Evolution of RTs for all three positions of the repeated sequence and mean
219 slopes for one individual (Mako) across the 250 trials for Condition 1.



220

221

222 **Results**

223 We retained the seventeen baboons (13 females, age range 3.58 - 25.16 years) who
224 completed all three conditions (for the full data set, see
225 https://osf.io/6cpfm/?view_only=35017b02cc2947688636ee7620e1906f). Like in previous
226 studies on regularity extraction in non-human primates (Malassis et al., 2018; Minier et al.,
227 2016; Rey et al., 2019, 2022; Tosatto et al., in press), analyses were only conducted on the
228 repeated sequences (but see Appendix C, for some analyses on the random sequences). For
229 these sequences, baboons obtained a mean accuracy level of 99.0% ($SD=19.0\%$) in Condition
230 1 (item-overlap at the same position), of 99.1% ($SD=15.8\%$) in Condition 2 (item-overlap at a
231 different position), and of 98.4% ($SD=15.7\%$) in Condition 3 (no overlap)². Incorrect trials
232 were removed from the data set. We then removed RTs greater than 800 ms and subsequently
233 conducted a recursive trimming procedure excluding RTs greater than 2 standard deviations
234 from the mean for each of the three possible positions in a block of 50 trials and for each
235 baboon (see Appendix B for the mean RTs for both repeated and random sequences as a
236 function of block and condition). To measure learning of the repeated sequence, we looked at
237 the evolution of RTs at each of the three positions in the sequence. Previous studies have
238 shown that learning of the sequence leads to faster RTs on the predictable positions (i.e.,
239 Positions 2 and 3) compared to the less predictable position (i.e., Position 1) due to stronger
240 contextual information (Elman, 1990; Malassis et al., 2018; Minier et al., 2016; Rey et al.,
241 2019, 2020).

242 More precisely, as a measure of learning we computed, for each baboon, a slope on the
243 RTs for each of the three positions of the repeated sequence and for each condition. We
244 averaged the slopes of Position 2 and 3 for which learning was possible and compared them

2

As this condition was the same as in our previous study, we only retained the 500 first trials in order to compare the results across experiments.

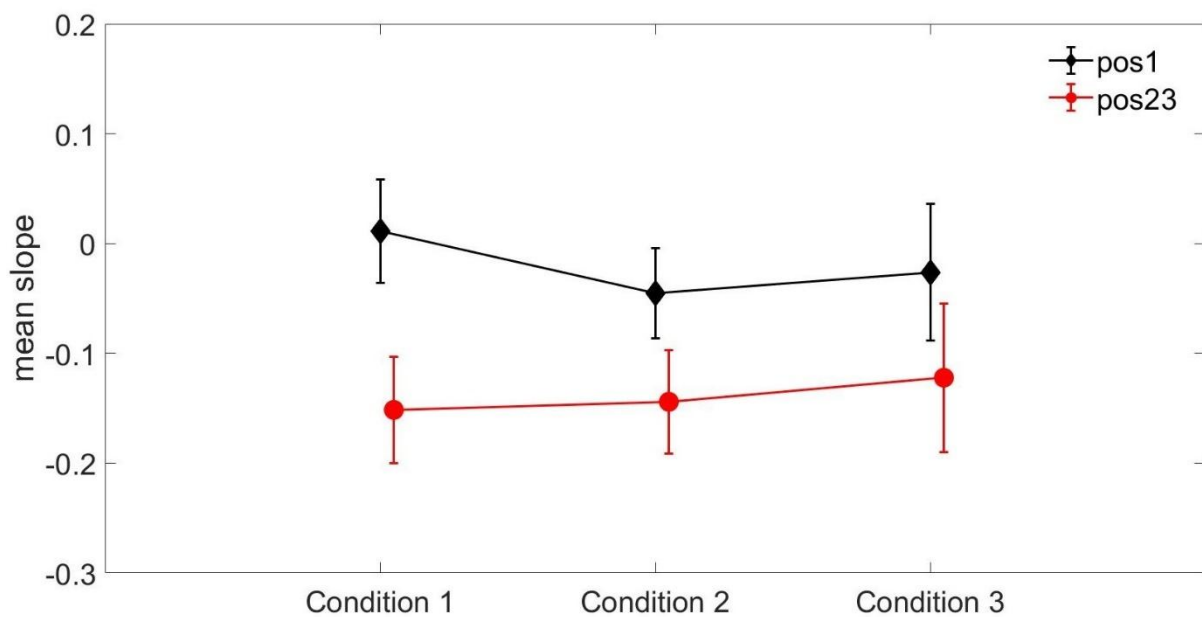
245 with the slope of the less predictable Position 1³. We ran a 3 (Condition: Condition 1,
 246 Condition 2, and Condition 3) x 2 (Position: Position 1 *versus* mean of (Position 2 + 3))
 247 repeated measures ANOVA on the learning slopes (see Figure 3). Bayesian Factors (BF) are
 248 also reported, as a major advantage of a Bayesian statistical framework is that it allows to
 249 quantify evidence in favor but also against the presence of an effect, and hence both positive
 250 and null effects can be reliably interpreted (Kruschke et al., 2012; Wagenmakers, 2007). The
 251 Bayesian model comparison approach directly compares the null hypothesis to the alternative
 252 hypothesis (i.e., the effect of interest) and assesses evidence for the null effect and the effect
 253 of interest simultaneously (Dienes, 2014). Results are interpreted using the Bayes factor (BF),
 254 which reflects the likelihood ratio of two compared models. The BF_{10} is used to determine the
 255 likelihood ratio of the alternative model relative to the null model. A $BF_{10} > 3$ provides
 256 anecdotal evidence; a $BF_{10} > 10$ provides strong evidence, and a $BF_{10} > 100$ provides decisive
 257 evidence for the alternative hypothesis, while a $BF_{01} < 0.33$ provides anecdotal evidence; a
 258 $BF_{01} < 0.10$ provides strong evidence, and a $BF_{01} < 0.01$ provides decisive evidence for the
 259 null hypothesis (Jeffreys, 1961). The analyses were conducted with the JASP software
 260 package (JASP Team., 2021), using default settings for Cauchy prior distribution and the
 261 Monte Carlo Markov Chain Method for parameter estimation (Wagenmakers et al., 2018).
 262 Analyses revealed no significant main effect of Condition ($F(2,32) = 0.367, p = .696, \eta^2 =$
 263 $.022, BF_{01} = 0.12$), a significant main effect of Position ($F(1,16) = 27.184, p < .001, \eta^2 = .629,$
 264 $BF_{10} > 100$) with a steeper mean learning slope for Positions 2 and 3 (Mean = $-.139, SD =$
 265 $.114$) compared to Position 1 (Mean = $-.020, SD = .108$), and no significant interaction
 266 between Condition and Position ($F(2,32) = 1.599, p = .218, \eta^2 = .091, BF_{01} = 0.33$). Thus, our

 3

³ We compared the learning slope of Position 1 with the mean slope of Position 2 + 3 because if learning takes place, we should observe a steeper learning slope for the predictable Positions 2 and 3 compared to the less predictable Position 1. Moreover, averaging both predictable positions allowed us to obtain more data points and thus more robust results.

267 findings showed faster mean RTs for the predictable Positions 2 and 3 compared to the less
 268 predictable Position 1 for all three conditions, and crucially, the mean RTs of the predictable
 269 Positions 2 and 3 were significantly different from zero (Condition 1: Mean = -0.151, CI [-
 270 0.103, -0.199]; Condition 2: Mean = -0.144, CI [-0.097, -0.191]; Condition 3: Mean = -0.122,
 271 CI [-0.055, -0.189]), while this was not the case for Position 1 (Condition 1: Mean = 0.011, CI
 272 [0.058, -0.036]; Condition 2: Mean = -0.045, CI [0.004, -0.086]; Condition 3: Mean = -0.026,
 273 CI [0.036, -0.088]). Thus, findings revealed that learning occurred for all three conditions and
 274 the absence of a main effect of Condition as well as of an interaction between Condition and
 275 Position indicates that learning was similar across all conditions. In sum, it seems that
 276 interference did not affect learning significantly in the conditions tested in the present study
 277 using a semi-overlapping design.

278 **Figure 3.** Mean slopes for Positions 1 and the average for Positions 2 and 3 for each
 279 condition: Condition 1 (overlapping item located at the same position), Condition 2
 280 (overlapping item located at a different position), and Condition 3 (no overlap between
 281 random and repeated sequences). Error bars represent 95% confidence intervals.



282

283 **Discussion**

284 In the present study, we examined the impact of interference on the learning of item
285 sequences. According to the influential model of statistical learning PARSER (Perruchet &
286 Vinter, 1998) and previous experimental studies on sequence learning (Page et al., 2013;
287 Smalle et al., 2016), the learning of sequences of items is significantly hindered in situations
288 in which interference is caused by the presentation of similar sequences. Note that most
289 studies in humans use either fully overlapping random and repeated sequences (e.g., Attout et
290 al., 2020; Bogaerts et al., 2016; Hebb, 1961; Szmalec et al., 2011), meaning that random
291 sequences contain all items of the repeated sequence, but in a different order, or non-
292 overlapping sequences (e.g., Hitch et al., 2009; Ordonez Magro et al., 2018, 2020, 2021; Page
293 et al., 2013; Smalle et al., 2016), meaning that the repeated and the random sequences are
294 composed of different items. To our knowledge, only one study in humans uses a semi-
295 overlapping design, meaning that random and repeated sequence share some but not all items
296 (Saint-Aubin et al., 2015). Moreover, previous studies in non-human primates examining the
297 nature of regularity extraction in sequence learning (Malassis et al., 2018; Minier et al., 2016;
298 Rey et al., 2019, 2022; Tosatto et al., in press) usually use a design similar to the one
299 introduced by Saffran et al. (1996), where baboons are repeatedly exposed to one and the
300 same sequence of locations. This design however does not allow researchers to measure the
301 impact of interference on sequence learning. The present study therefore proposes a learning
302 paradigm mixing repeated and random sequences with a semi-overlapping design in non-
303 human primates. In our semi-overlapping design, repeated and random sequences shared only
304 one item, either located at the same position (Condition 1) or on one of the two other positions
305 (Condition 2). This design is, in our opinion, more representative of what generally occurs in
306 natural learning situations like, for instance, learning to play an instrument, the acquisition of
307 sports, learning to drive a car, sequencing speech sounds, etc. Moreover, the present study is

308 the first one to use a semi-overlapping learning paradigm in non-human primates, allowing us
309 to measure interference in memory while controlling for language-related factors.

310 In contrast to previous studies (Page et al., 2013; Smalle et al., 2016) and to what we
311 predicted on the basis of these studies, we did not observe a negative impact of interference
312 on sequence learning. Indeed, our analyses showed that learning slopes were comparable
313 across conditions. One potential explanation for this finding may be the fact that we used a
314 semi-overlapping design rather than a fully overlapping design used in the previous studies.
315 Indeed, a full overlap between all items of a sequence undeniably causes more interference as
316 compared to partial overlap. However, our findings, even if unexpected, are not totally
317 surprising, given that such interference would be a major handicap for learning in natural
318 situations (for a discussion, see also Page et al., 2013).

319 Moreover, according to PARSER (Perruchet & Vinter, 1998), the impact of
320 interference may become practically negligible for a percept, once it has been encountered
321 repeatedly and its representation in long-term memory has become relatively robust. Thus,
322 our finding that interference does not affect learning is compatible with the predictions of
323 PARSER and with what is observed in natural learning situations involving a high level of
324 interference.

325 The absence of a significant difference in learning the semi-overlapping repeated
326 sequences (Conditions 1 and 2) compared to the non-overlapping repeated sequences
327 (Condition 3) can also be explained in terms of frequency of occurrence. Indeed, in our semi-
328 overlapping conditions the random sequences contained an item that was also part of the
329 repeated sequence, which certainly increased the frequency of occurrence (during the
330 experiment) of this given overlapping item. Thus, it is possible that the repetition of the same
331 item in the random sequence might have strengthened its representation in long-term memory,
332 which in turn would have facilitated the learning of item-item associations (i.e., co-

333 occurrences between the three positions), via associative learning mechanisms (Majerus et al.,
334 2012; Perruchet & Pacton, 2006; Perruchet & Vinter, 1998). This hypothesis is in line with
335 sequence learning models (Page & Norris, 1998; Perruchet & Vinter, 1998), according to
336 which learning is strongly dependent on repetition, a major component determining
337 consolidation in long-term memory. There is indeed some evidence in our data that supports
338 this hypothesis (see Figure 3). Even if the difference between conditions is not significant,
339 there was a slightly steeper learning slope for Positions 2 and 3 for the overlapping conditions
340 (Condition 1 and 2, -0.151 and -0.141, respectively) compared to the non-overlapping
341 condition (Condition 3, -0.122) suggesting that the presentation of an overlapping item in the
342 random sequences may rather have facilitated than perturbed the learning of the repeated
343 sequence. Moreover, the observed absence of interference between random and repeated
344 sequences can also be explained in terms of context signals. Indeed, according to the model of
345 long-term learning proposed by Burgess and Hitch (2006), each new sequence is associated
346 with a new set of context nodes, while a repeated sequence is associated with its own set of
347 context signals and these connections are further strengthened with each repetition. Based on
348 this, our random and repeated sequences, even if they had one item in common, might have
349 been associated with different context nodes, consequently limiting the interference between
350 random and repeated sequences.

351 Finally, our observations are in line with several previous studies on non-human
352 primates, showing that monkeys like tamarins, macaques, and baboons can extract regular
353 patterns from continuous sequences allowing them to learn predictable motor sequences by
354 using statistical cues (Hauser et al., 2001; Heimbauer et al., 2012; Locurto et al., 2010, 2013;
355 Malassis et al., 2018; Minier et al., 2016; Procyk et al., 2000; Rey et al., 2019, 2022; Tosatto
356 et al., in press; Wilson et al., 2013, 2015).

357 In sum, the present study used a semi-overlapping design to examine the influence of
358 interference on memory forgetting in conditions that better mimic natural learning conditions
359 compared to prior studies. In the present work, we observed that interference has not such a
360 deleterious impact on sequence learning as would be expected based on the results of prior
361 research. In contrast to the observation of previous studies, suggesting that no learning is
362 possible when interference occurs (Page et al., 2013; Smalle et al., 2016), our findings are
363 easy to reconcile with what is observed in natural sequence learning situations, where learning
364 still takes place in an interfering environment.
365

366 **Declarations**

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- 369 • **Conflicts of interest:** The authors have no conflicts of interest to declare that are
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- 371 • **Ethics approval:** This research adhered to the applicable French rules for ethical
372 treatment of research animals and received ethical approval from the French Ministry
373 of Education (approval APAFIS#2717-2015111708173794 10 v3).
- 374 • **Consent to participate:** Not applicable.
- 375 • **Consent for publication:** Not applicable.
- 376 • **Availability of data and materials:** The datasets generated and analyzed during the
377 current study are available in the OSF repository,
378 https://osf.io/6cpfm/?view_only=35017b02cc2947688636ee7620e1906f.
- 379 • **Code availability:** Not applicable.
- 380 • **Authors' contributions:** **Laura Ordonez Magro** conceptualized the design, collected
381 the data, conducted the data analyses, and wrote the paper; **Joël Fagot** conceptualized
382 the design; **Jonathan Grainger** helped writing the paper; **Arnaud Rey**
383 conceptualized the design, conducted data analyses, and helped writing the paper.

384 **Open Practices Statements**

385 The data and materials for all experiments are available on
386 https://osf.io/6cpfm/?view_only=35017b02cc2947688636ee7620e1906f and none of the
387 experiments was preregistered.

388

389 **References**

- 390 Attout, L., Ordonez Magro, L., Szmalec, A., & Majerus, S. (2020). The developmental neural
 391 substrates of Hebb repetition learning and their link with reading ability. *Human Brain*
 392 *Mapping, n/a(n/a)*. <https://doi.org/10.1002/hbm.25099>
- 393 Bogaerts, L., Szmalec, A., De Maeyer, M., Page, M. P. A., & Duyck, W. (2016). The involvement of
 394 long-term serial-order memory in reading development : A longitudinal study. *Journal of*
 395 *Experimental Child Psychology, 145*, 139-156. <https://doi.org/10.1016/j.jecp.2015.12.008>
- 396 Burgess, N., & Hitch, G. J. (2006). A revised model of short-term memory and long-term learning of
 397 verbal sequences. *Journal of Memory and Language, 55*(4), 627-652.
 398 <https://doi.org/10.1016/j.jml.2006.08.005>
- 399 Dienes, Z. (2014). Using Bayes to get the most out of non-significant results. *Frontiers in Psychology,*
 400 *5*. <https://doi.org/10.3389/fpsyg.2014.00781>
- 401 Elman, J. L. (1990). Finding Structure in Time. *Cognitive Science, 14*(2), 179-211.
 402 https://doi.org/10.1207/s15516709cog1402_1
- 403 Fagot, J., & Bonté, E. (2010). Automated testing of cognitive performance in monkeys : Use of a
 404 battery of computerized test systems by a troop of semi-free-ranging baboons (*Papio papio*).
 405 *Behavior Research Methods, 42*(2), 507-516. <https://doi.org/10.3758/BRM.42.2.507>
- 406 Fagot, J., & Paleressompouille, D. (2009). Automatic testing of cognitive performance in baboons
 407 maintained in social groups. *Behavior Research Methods, 41*(2), 396-404.
 408 <https://doi.org/10.3758/BRM.41.2.396>
- 409 Hauser, M. D., Newport, E. L., & Aslin, R. N. (2001). Segmentation of the speech stream in a non-
 410 human primate : Statistical learning in cotton-top tamarins. *Cognition, 78*(3), B53-64.
 411 [https://doi.org/10.1016/s0010-0277\(00\)00132-3](https://doi.org/10.1016/s0010-0277(00)00132-3)
- 412 Hebb, D. (1961). Distinctive features of learning in the higher animal. In J. F. Delafresnaye, *Brain*
 413 *mechanisms and learning*. Oxford, UK: Blackwell.

- 414 Heimbauer, L. A., Conway, C. M., Christiansen, M. H., Beran, M. J., & Owren, M. J. (2012). A Serial
415 Reaction Time (SRT) task with symmetrical joystick responding for nonhuman primates.
416 *Behavior Research Methods*, *44*(3), 733-741. <https://doi.org/10.3758/s13428-011-0177-6>
- 417 Hitch, G. J., Flude, B., & Burgess, N. (2009). Slave to the rhythm : Experimental tests of a model for
418 verbal short-term memory and long-term sequence learning. *Journal of Memory and*
419 *Language*, *61*(1), 97-111. <https://doi.org/10.1016/j.jml.2009.02.004>
- 420 JASP Team. (2021). *JASP (Version 0.16)[Computer software]*.
- 421 Jeffreys, H. (1961). *Theory of probability (3 ed.)* (Oxford University Press, Clarendon Press.).
- 422 Kruschke, J. K., Aguinis, H., & Joo, H. (2012). The time has come : Bayesian methods for data analysis
423 in the organizational sciences. *Organizational Research Methods*, *15*(4), 722-752.
424 <https://doi.org/10.1177/1094428112457829>
- 425 Locurto, C., Dillon, L., Collins, M., Conway, M., & Cunningham, K. (2013). Implicit chaining in cotton-
426 top tamarins (*Saguinus oedipus*) with elements equated for probability of reinforcement.
427 *Animal Cognition*, *16*(4), 611-625. <https://doi.org/10.1007/s10071-013-0598-y>
- 428 Locurto, C., Gagne, M., & Natile, L. (2010). Characteristics of implicit chaining in cotton-top tamarins
429 (*Saguinus oedipus*). *Animal Cognition*, *13*(4), 617-629. [https://doi.org/10.1007/s10071-010-](https://doi.org/10.1007/s10071-010-0312-2)
430 [0312-2](https://doi.org/10.1007/s10071-010-0312-2)
- 431 Majerus, S., Martinez Perez, T., & Oberauer, K. (2012). Two distinct origins of long-term learning
432 effects in verbal short-term memory. *Journal of Memory and Language*, *66*(1), 38-51.
433 <https://doi.org/10.1016/j.jml.2011.07.006>
- 434 Malassis, R., Rey, A., & Fagot, J. (2018). Non-adjacent Dependencies Processing in Human and Non-
435 human Primates. *Cognitive Science*, *42*(5), 1677-1699. <https://doi.org/10.1111/cogs.12617>
- 436 Minier, L., Fagot, J., & Rey, A. (2016). The Temporal Dynamics of Regularity Extraction in Non-Human
437 Primates. *Cognitive Science*, *40*(4), 1019-1030. <https://doi.org/10.1111/cogs.12279>
- 438 Nissen, MJ., & Bullemer, P. (1987). Attentional requirements of learning : Evidence from performance
439 measures. *Cognitive Psychology*, *19*(1), 1-32. [https://doi.org/10.1016/0010-0285\(87\)90002-8](https://doi.org/10.1016/0010-0285(87)90002-8)

- 440 Ordonez Magro, L., Attout, L., Majerus, S., & Szmalec, A. (2018). Short-and long-term memory
441 determinants of novel word form learning. *Cognitive Development, 47*, 146-157.
442 <https://doi.org/10.1016/j.cogdev.2018.06.002>
- 443 Ordonez Magro, L., Fagot, J., Grainger, J., & Rey, A. (revision submitted). The limits of forgetting in
444 sequential statistical learning. *Cognitive Science*.
- 445 Ordonez Magro, L., Majerus, S., Attout, L., Poncelet, M., Smalle, E. H. M., & Szmalec, A. (2020). The
446 contribution of serial order short-term memory and long-term learning to reading
447 acquisition : A longitudinal study. *Developmental Psychology, 56*(9), 1671-1683.
448 <https://doi.org/10.1037/dev0001043>
- 449 Ordonez Magro, L., Majerus, S., Attout, L., Poncelet, M., Smalle, E. H. M., & Szmalec, A. (2021). Do
450 serial order short-term memory and long-term learning abilities predict spelling skills in
451 school-age children? *Cognition, 206*, 104479.
452 <https://doi.org/10.1016/j.cognition.2020.104479>
- 453 Page, M. P. A., Cumming, N., Norris, D., McNeil, A. M., & Hitch, G. J. (2013). Repetition-spacing and
454 item-overlap effects in the Hebb repetition task. *Journal of Memory and Language, 69*(4),
455 506-526. <https://doi.org/10.1016/j.jml.2013.07.001>
- 456 Page, M. P. A., & Norris, D. (1998). The Primacy Model : A New Model of Immediate Serial Recall.
457 *Psychological Review, 105*(4), 761-781.
- 458 Perruchet, P., & Pacton, S. (2006). Implicit learning and statistical learning : One phenomenon, two
459 approaches. *Trends in Cognitive Sciences, 10*(5), 233-238.
460 <https://doi.org/10.1016/j.tics.2006.03.006>
- 461 Perruchet, P., & Vinter, A. (1998). PARSER : A Model for Word Segmentation. *Journal of Memory and*
462 *Language, 39*(2), 246-263. <https://doi.org/10.1006/jmla.1998.2576>
- 463 Procyk, E., Ford Dominey, P., Amiez, C., & Joseph, J. P. (2000). The effects of sequence structure and
464 reward schedule on serial reaction time learning in the monkey. *Brain Research. Cognitive*
465 *Brain Research, 9*(3), 239-248. [https://doi.org/10.1016/s0926-6410\(00\)00002-1](https://doi.org/10.1016/s0926-6410(00)00002-1)

- 466 Rey, A., Bogaerts, L., Tosatto, L., Bonafos, G., Franco, A., & Favre, B. (2020). Detection of regularities
467 in a random environment. *Quarterly Journal of Experimental Psychology*.
- 468 Rey, A., Fagot, J., Mathy, F., Lazartigues, L., Tosatto, L., Bonafos, G., Freyermuth, J.-M., & Lavigne, F.
469 (2022). Learning higher-order transitional probabilities in nonhuman primates. *Cognitive*
470 *Science*, 46(4).
- 471 Rey, A., Minier, L., Malassis, R., Bogaerts, L., & Fagot, J. (2019). Regularity Extraction Across Species :
472 Associative Learning Mechanisms Shared by Human and Non-Human Primates. *Topics in*
473 *Cognitive Science*, 11(3), 573-586. <https://doi.org/10.1111/tops.12343>
- 474 Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science*
475 *(New York, N.Y.)*, 274(5294), 1926-1928. <https://doi.org/10.1126/science.274.5294.1926>
- 476 Saint-Aubin, J., Guérard, K., Fiset, S., & Losier, M.-C. (2015). Learning multiple lists at the same time in
477 the Hebb repetition effect. *Canadian Journal of Experimental Psychology/Revue canadienne*
478 *de psychologie expérimentale*, 69(1), 89-94. <https://doi.org/10.1037/cep0000030>
- 479 Smalle, E. H. M., Bogaerts, L., Simonis, M., Duyck, W., Page, M. P. A., Edwards, M. G., & Szmalec, A.
480 (2016). Can Chunk Size Differences Explain Developmental Changes in Lexical Learning?
481 *Frontiers in Psychology*, 6, 1925. <https://doi.org/10.3389/fpsyg.2015.01925>
- 482 Szmalec, A., Loncke, M., Page, M. P. A., & Duyck, W. (2011). Order or disorder ? Impaired Hebb
483 learning in dyslexia. *Journal of Experimental Psychology. Learning, Memory, and Cognition*,
484 37(5), 1270-1279. <https://doi.org/10.1037/a0023820>
- 485 Tosatto, L., Fagot, J., Nemeth, D., & Rey, A. (in press). The evolution of chunks in sequence learning.
486 *Cognitive Science*.
- 487 Wagenmakers, E.-J. (2007). A practical solution to the pervasive problems of p values. *Psychonomic*
488 *bulletin & review*, 14(5), 779-804.
- 489 Wagenmakers, E.-J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Selker, R., Gronau, Q. F.,
490 Dropmann, D., Boutin, B., Meerhoff, F., Knight, P., Raj, A., van Kesteren, E.-J., van Doorn, J.,
491 Šmíra, M., Epskamp, S., Etz, A., Matzke, D., ... Morey, R. D. (2018). Bayesian inference for

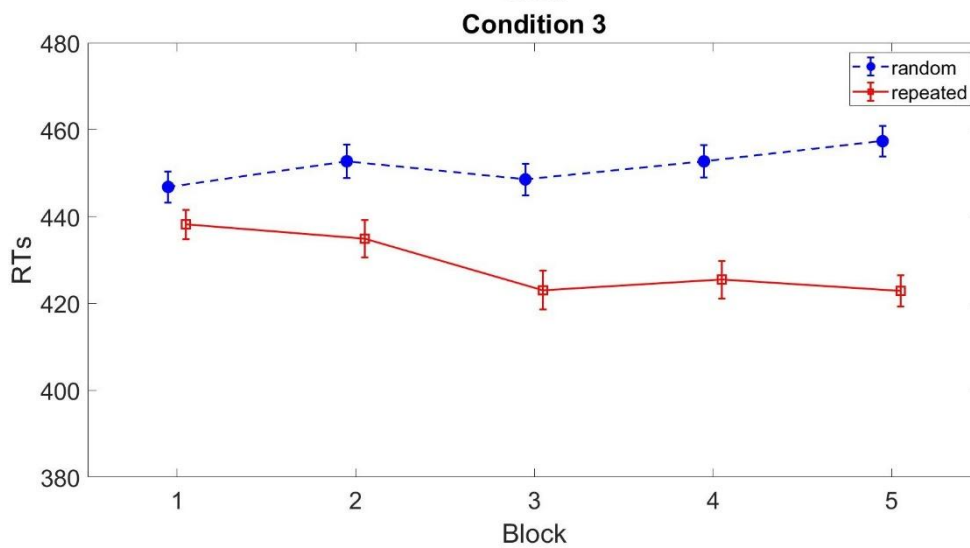
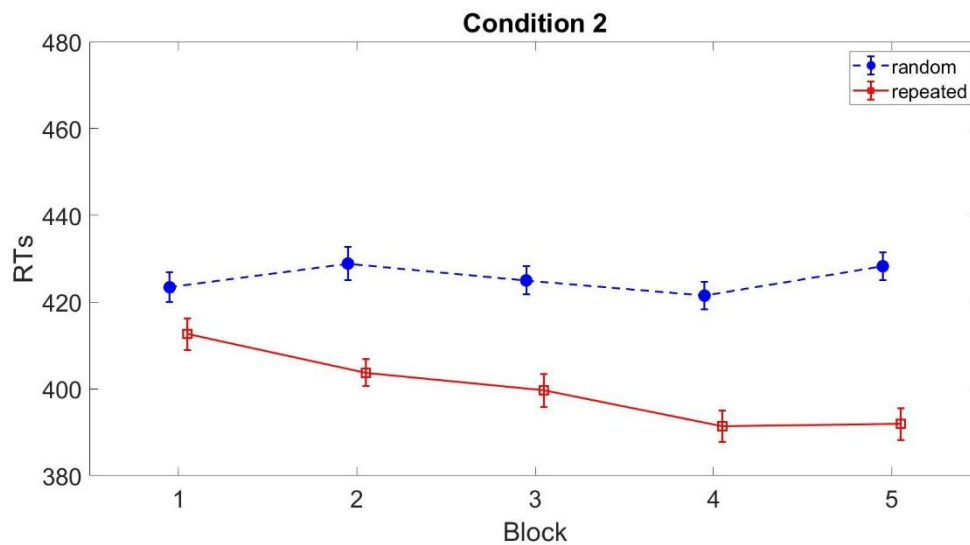
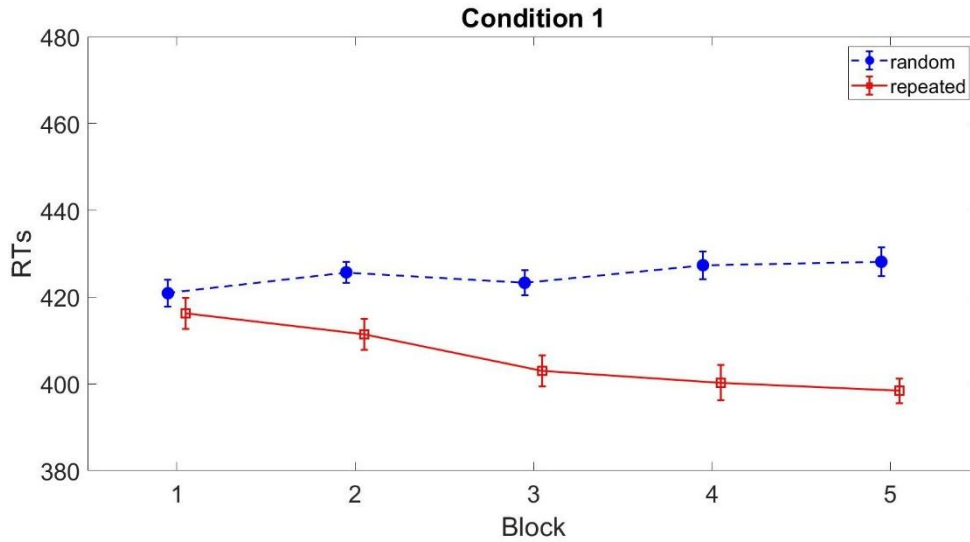
- 492 psychology. Part II : Example applications with JASP. *Psychonomic Bulletin & Review*, 25(1),
493 58-76. <https://doi.org/10.3758/s13423-017-1323-7>
- 494 Wilson, B., Slater, H., Kikuchi, Y., Milne, A. E., Marslen-Wilson, W. D., Smith, K., & Petkov, C. I. (2013).
495 Auditory artificial grammar learning in macaque and marmoset monkeys. *The Journal of*
496 *Neuroscience: The Official Journal of the Society for Neuroscience*, 33(48), 18825-18835.
497 <https://doi.org/10.1523/JNEUROSCI.2414-13.2013>
- 498 Wilson, B., Smith, K., & Petkov, C. I. (2015). Mixed-complexity artificial grammar learning in humans
499 and macaque monkeys : Evaluating learning strategies. *The European Journal of*
500 *Neuroscience*, 41(5), 568-578. <https://doi.org/10.1111/ejn.12834>
- 501
- 502

503 **Appendix A**

504 **Mean response times over a group of 13 baboons for each of the 72 possible transitions**
 505 **calculated from 1,000 random trials. For example, consider the transition [4-8] from**
 506 **Position 4 to 8 (4 being the first position of the transition and 8 being the second**
 507 **position). When the red circle was on Position 4, baboons touched it and the target**
 508 **moved to Position 8. The mean response times for that transition [4-8], i.e., 482 ms,**
 509 **corresponds to the time baboons took on average to move from Position 4 to Position 8**
 510 **(i.e., from the baboon's touch on Position 4 to the baboon's touch on Position 8).**

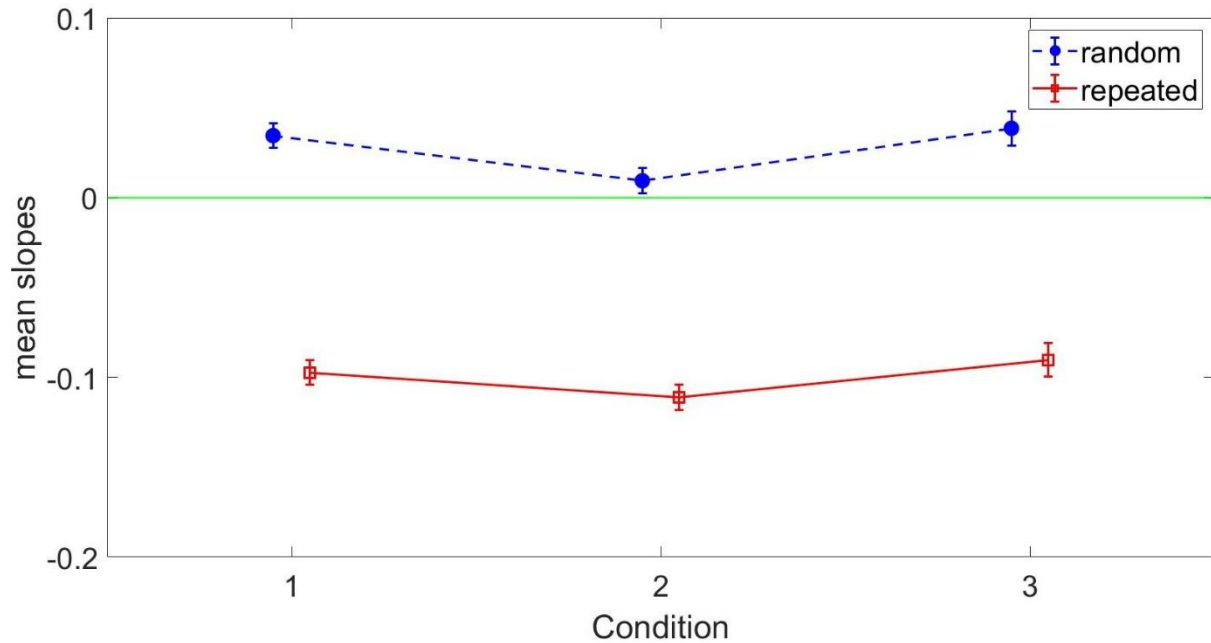
1 st position in Transition	2 nd position in Transition								
	1	2	3	4	5	6	7	8	9
1		426	421	438	365	360	447	359	371
2	506		457	411	377	393	391	365	393
3	502	435		443	368	353	439	372	365
4	486	423	448		366	374	434	339	358
5	485	408	378	444		345	449	392	380
6	477	383	379	426	344		448	384	418
7	472	424	435	423	370	381		374	371
8	445	388	401	396	342	367	443		396
9	487	403	410	425	334	361	437	362	

511

512 **Appendix B**513 **Mean response times (RTs) per block for both random and repeated sequences and for**514 **each condition. Error bars represent 95% confidence intervals.**

518 **Appendix C**

519 **Mean slopes for both random and repeated sequences and for each condition. Error bars**
 520 **represent 95% confidence intervals.**



521

522 Note that, paired t-test on the *regression slopes* showed steeper regression slopes for
 523 repeated compared to random sequences for the three conditions, confirming our analyses that
 524 learning takes place in all three conditions.

525 Condition 1: $t(16) = -6.87, p < .001$

526 Condition 2: $t(16) = -6.06, p < .001$

527 Condition 3: $t(16) = -4.84, p < .001$

528 Moreover, paired t-tests showed that the regression slopes for the random sequences
 529 are all positive and significantly larger than zero for Conditions 1 and not significantly
 530 different from zero for Condition 2 and 3, indicating that learning did not take place for the
 531 random sequences. As to the repeated sequences, analyses show that the slopes for all three
 532 conditions are negative and significantly smaller than zero, indicating that learning took place
 533 for the repeated sequences.

534

INTERFERENCE IN SEQUENCE LEARNING

	<i>t</i>	<i>df</i>	<i>p</i>
<i>Random sequences</i>			
Condition1	2.353	16	<.05
Condition2	0.705	16	0.491
Condition3	1.930	16	0.072
<i>Repeated sequences</i>			
Condition1	-4.703	16	<.001
Condition2	-6.832	16	<.001
Condition3	-3.122	16	<.01

535