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**IN PRESS/ Learning & Behavior**

**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 m<sup>2</sup> 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**

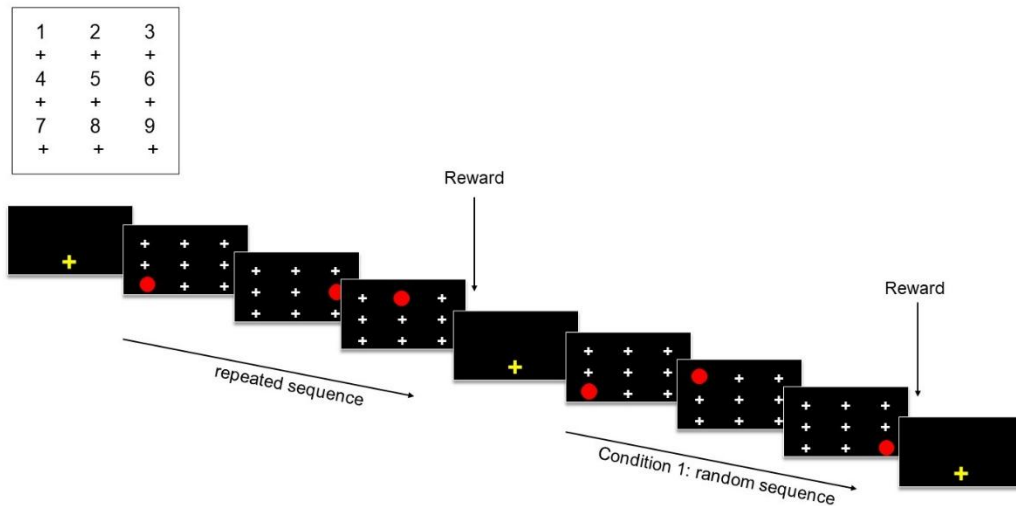
128 To begin a trial, baboons must press the yellow fixation cross<sup>1</sup> centered at the bottom  
129 of the screen. After pressing the cross, they saw a black screen that was divided into an  
130 invisible matrix of (3x3) cells, each containing a white cross in their center (see Figures 1A  
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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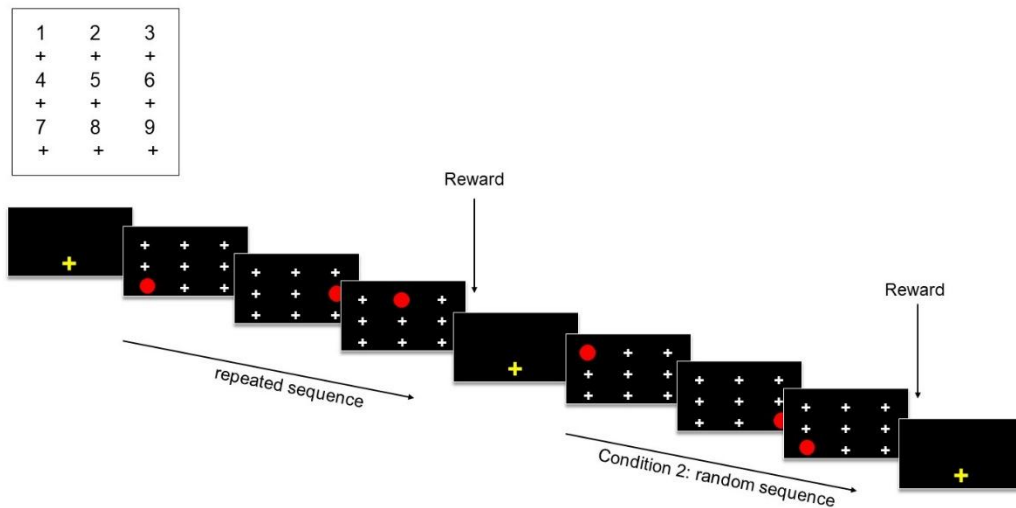
<sup>1</sup> Thus, the inter-stimulus-interval depends on the moment the baboon decides to press the yellow fixation cross. As the length of the inter-stimulus-interval can help subjects to separate trials and eventually help to minimize interference between trials, it is important to mention that we 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](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
	<b>6-9-4</b>	<b>7-6-2</b>	<b>5-8-3</b>
	<u>6</u> -1-2	4-9- <u>7</u>	7-9-4
	<b>6-9-4</b>	<b>7-6-2</b>	<b>5-8-3</b>
	3-5- <u>4</u>	1-8- <u>7</u>	9-7-2
	<b>6-9-4</b>	<b>7-6-2</b>	<b>5-8-3</b>
	3- <u>9</u> -7	8- <u>2</u> -1	2-6-4
	<b>6-9-4</b>	<b>7-6-2</b>	<b>5-8-3</b>
...	...	...	

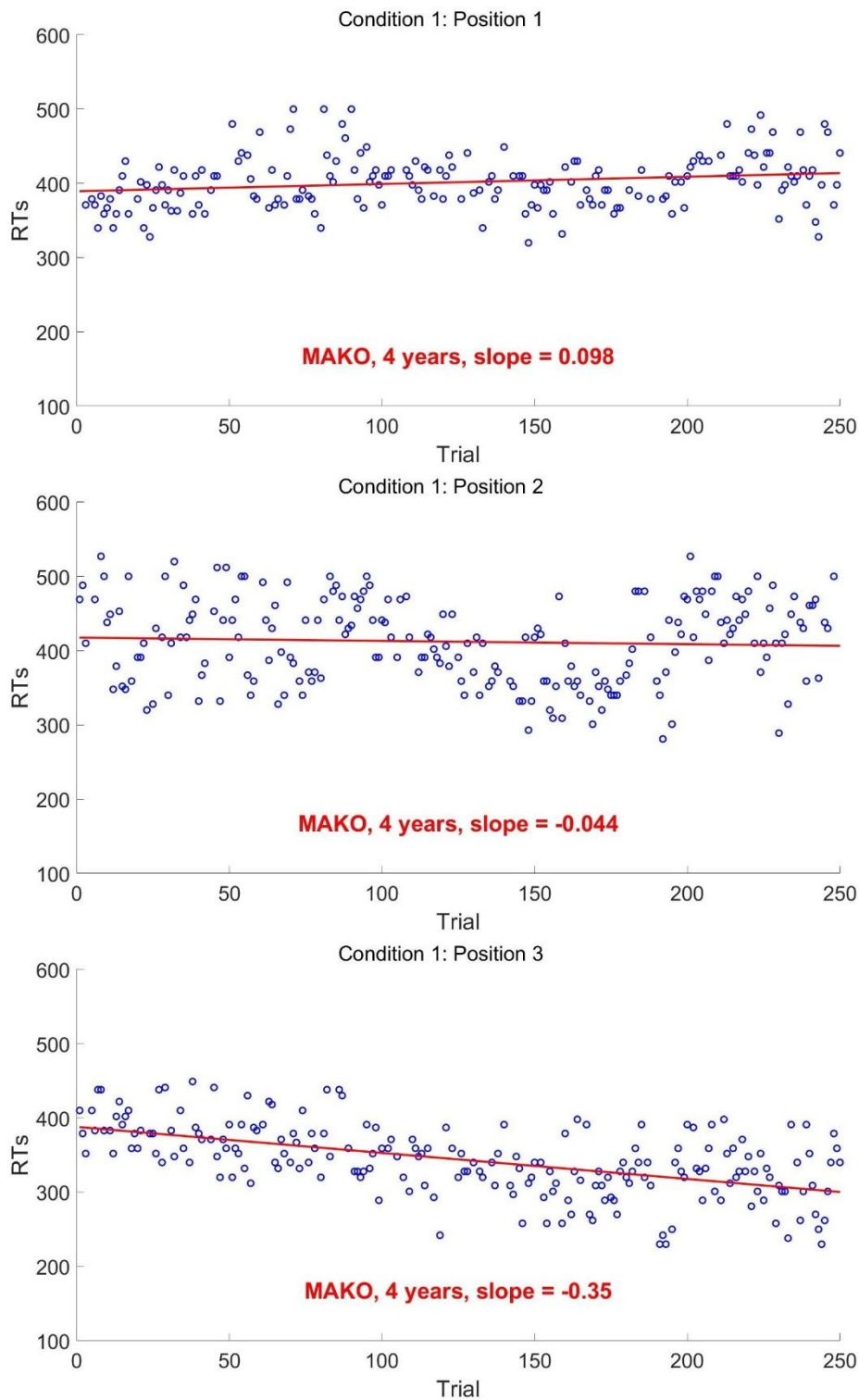
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## 210 **Analyses**

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](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](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)<sup>2</sup>. 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

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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 1<sup>3</sup>. 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

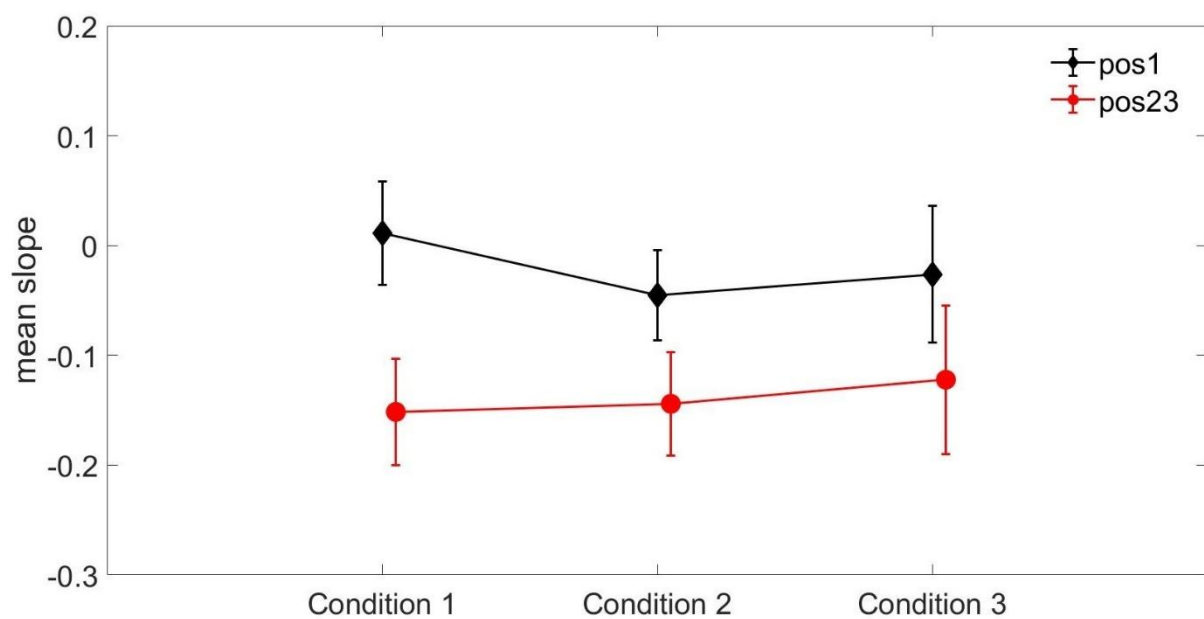
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<sup>3</sup> We compared the learning slope of Position 1 with the mean slope of Position 2 + 3 because if learning takes place, we should observe a steeper learning slope for the predictable Positions 2 and 3 compared to the less predictable Position 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  
370 relevant to the content of this article.
- 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](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](https://osf.io/6cpfm/?view_only=35017b02cc2947688636ee7620e1906f) and none of the  
387 experiments was preregistered.

388

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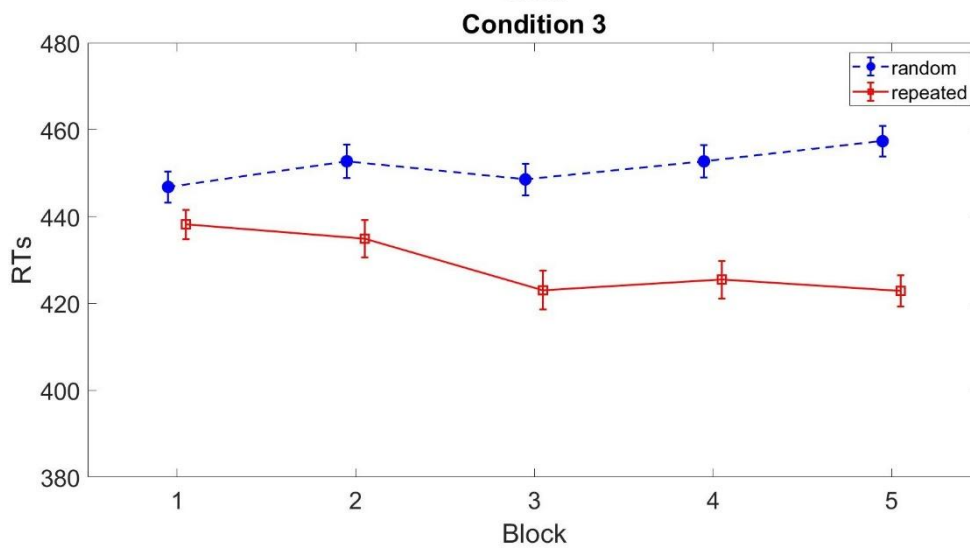
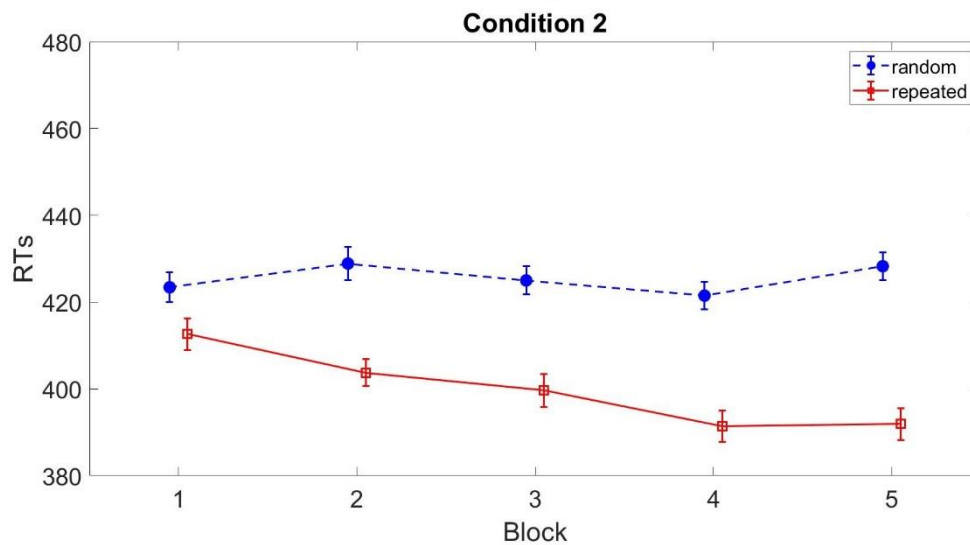
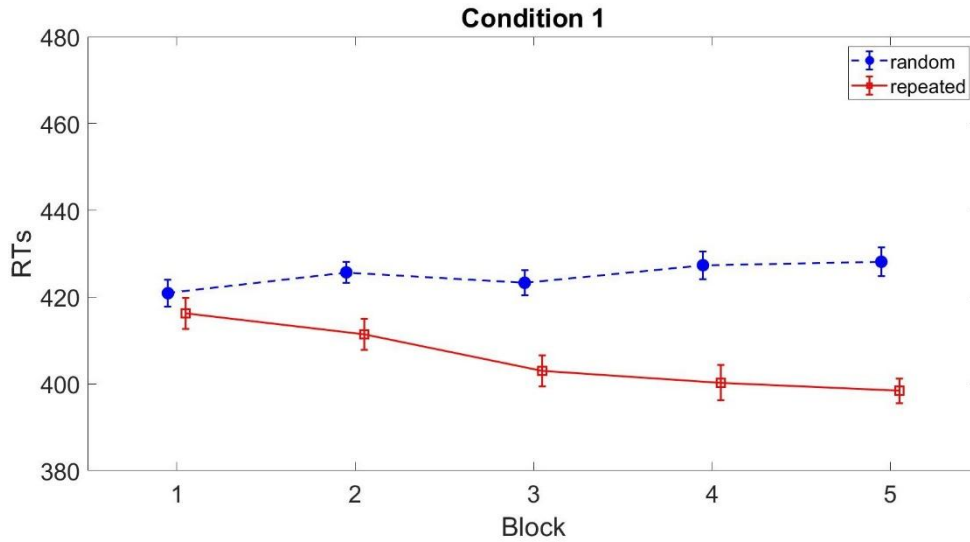
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- 501
- 502

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).**

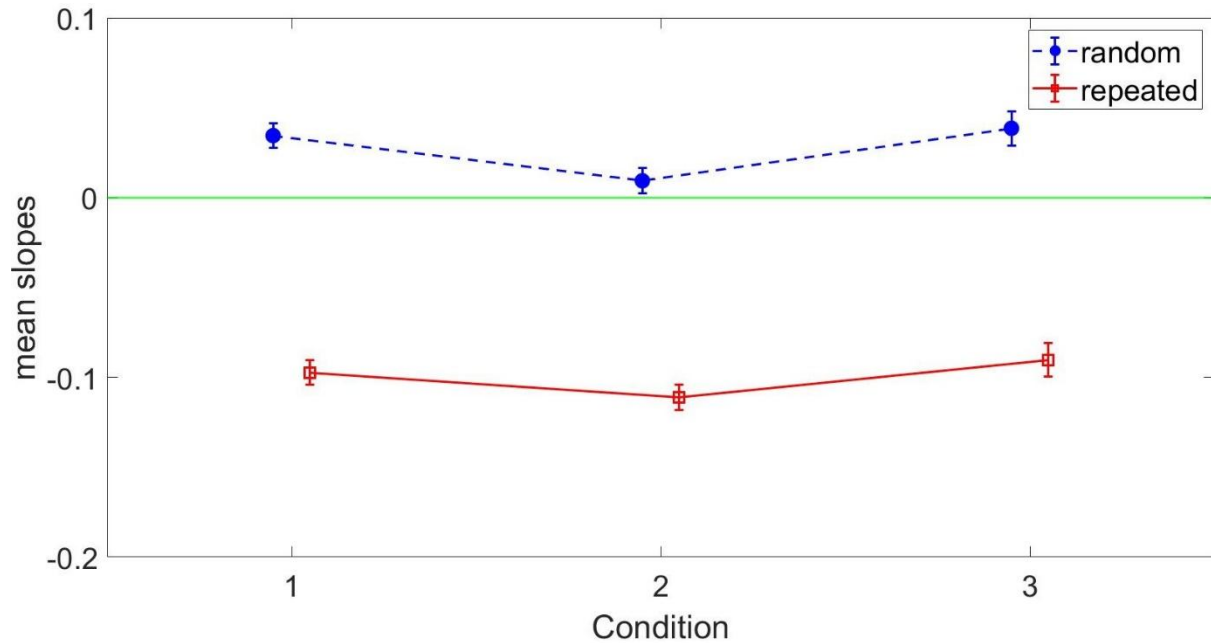
1 <sup>st</sup> position in Transition	2 <sup>nd</sup> position in Transition								
	1	2	3	4	5	6	7	8	9
1		426	421	438	365	360	447	359	371
2	506		457	411	377	393	391	365	393
3	502	435		443	368	353	439	372	365
4	486	423	448		366	374	434	339	358
5	485	408	378	444		345	449	392	380
6	477	383	379	426	344		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>
<b><i>Random sequences</i></b>			
Condition1	2.353	16	<.05
Condition2	0.705	16	0.491
Condition3	1.930	16	0.072
<b><i>Repeated sequences</i></b>			
Condition1	-4.703	16	<.001
Condition2	-6.832	16	<.001
Condition3	-3.122	16	<.01

535