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

Laura Ordonez Magro¹, Joël Fagot^{1,2}, Jonathan Grainger¹, & Arnaud Rey¹

¹Laboratoire de Psychologie Cognitive & CNRS & Aix-Marseille Université, 13331

Marseille, France

²Station de Primatologie-Celphedia, 13790 Rousset, France

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Correspondence concerning this article should be addressed to Laura Ordonez Magro,
Laboratory of Cognitive Psychology, CNRS, Aix-Marseille Université, 3, place Victor Hugo,
Case D, 13331 Marseille Cedex 03, France. Telephone number: +33 (0)6 09 79 84 50. E-mail:
laura.ordonezmagro@gmail.com

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*

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

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

Apparatus

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

Materials and procedure

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

1

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

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

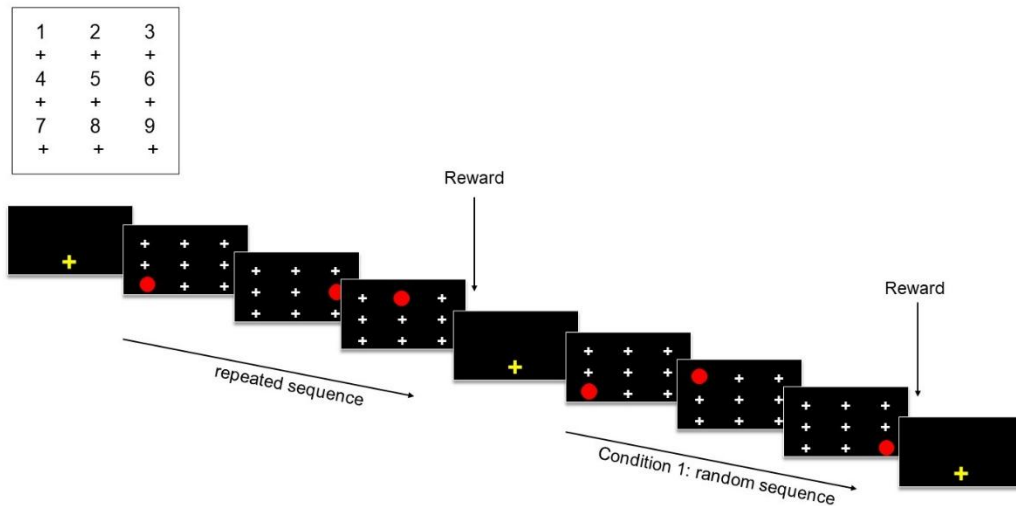
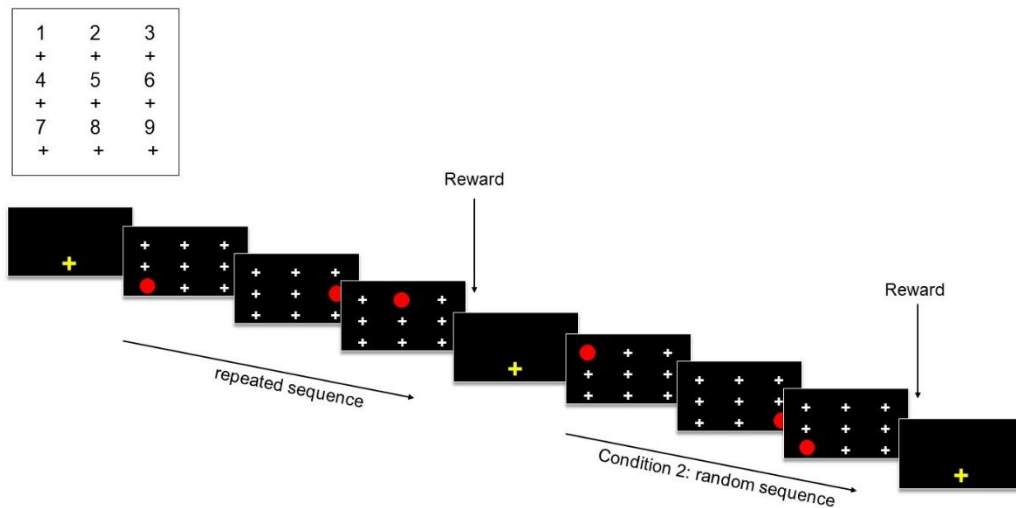


Figure 1B. Representation of the touch screen with the nine locations and example of the experimental display and stimuli presentation for repeated and random sequences in Condition 2 (overlap at a different position).



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

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

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

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

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

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

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

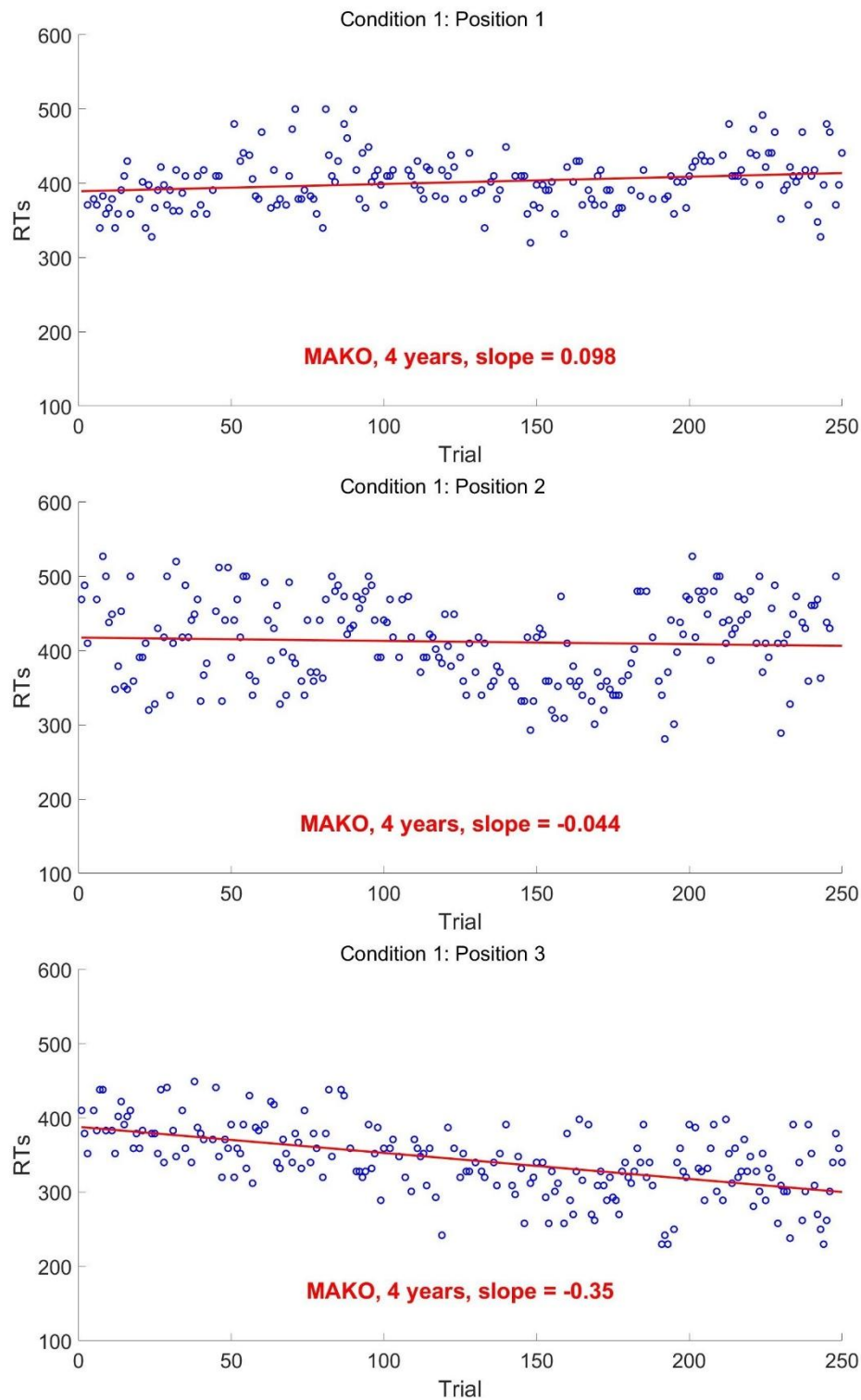
Table 1. Example of sequences presented in the three conditions for a given participant. Digits correspond to the nine screen locations. Repeated sequences are bolded, and the underlined digits correspond to the overlapping items.

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

Analyses

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

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



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.

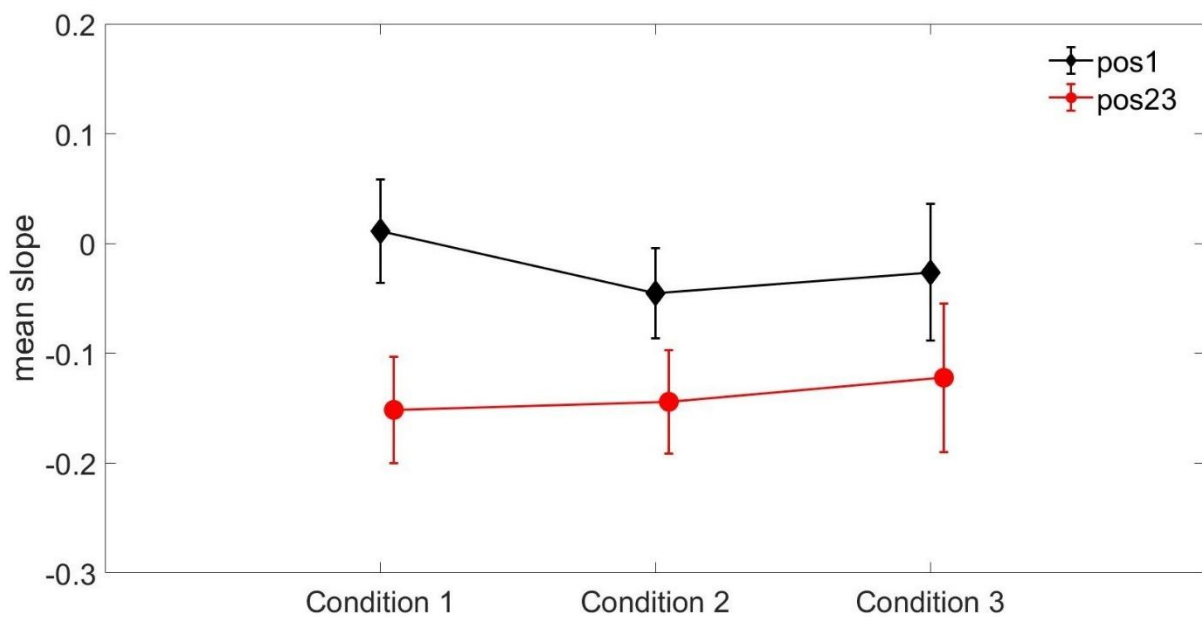
245 with the slope of the less predictable Position 1³. We ran a 3 (Condition: Condition 1,
 246 Condition 2, and Condition 3) x 2 (Position: Position 1 *versus* mean of (Position 2 + 3))
 247 repeated measures ANOVA on the learning slopes (see Figure 3). Bayesian Factors (BF) are
 248 also reported, 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.

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

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



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

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

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

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

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

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

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

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

Declarations

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

Open Practices Statements

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

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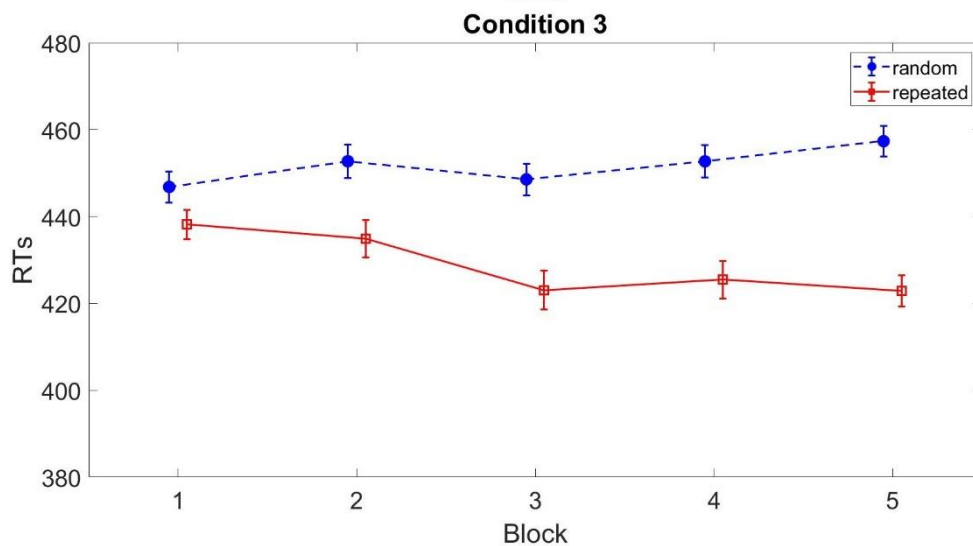
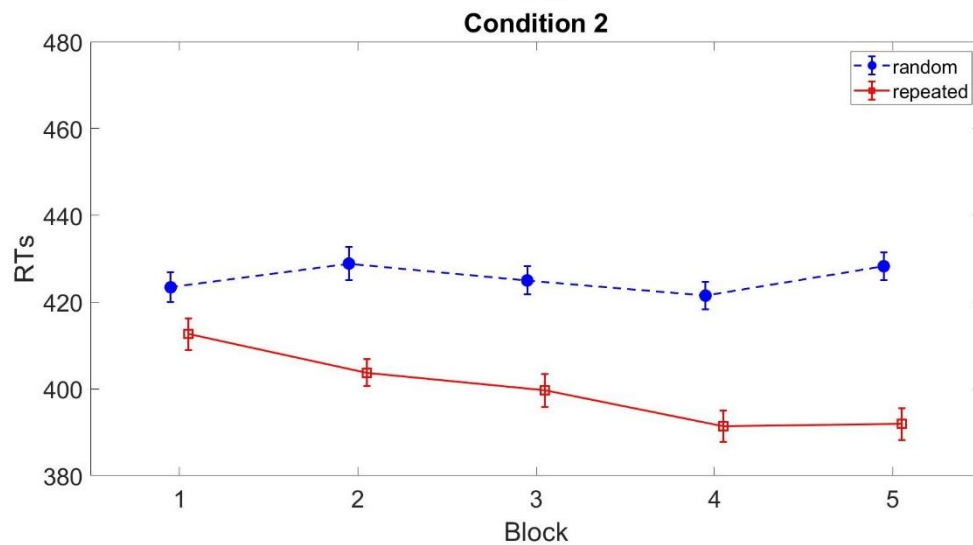
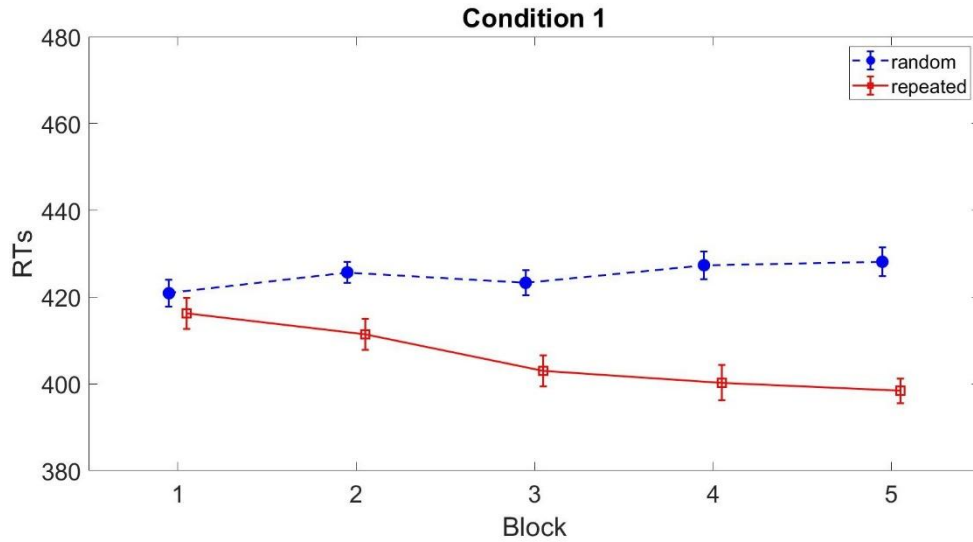
Appendix A

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

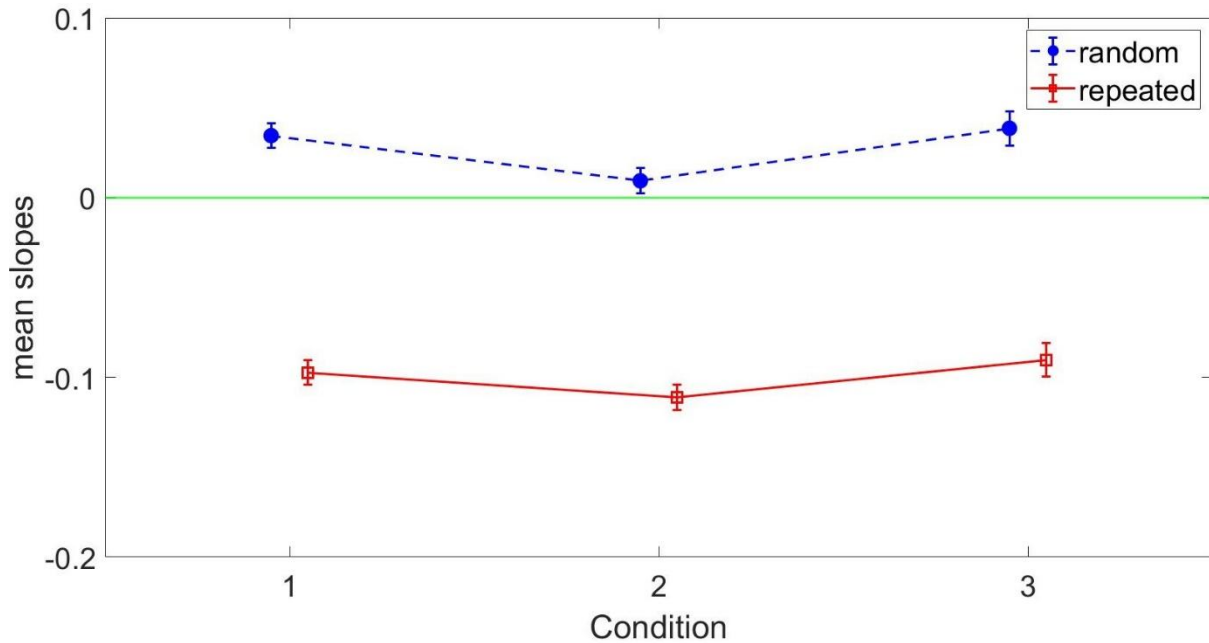
Appendix B

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



Appendix C

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



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

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

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

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

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

	<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