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# Overt language production plays a key role in the Hebb repetition effect

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## Abstract

When asked to recall verbatim a short list of items, performance is very limited. However, if the list of items is repeated across trials, recall performance improves. This phenomenon, known as the Hebb repetition effect (Hebb, 1961; Brain Mechanisms and Learning: A Symposium, pp. 37–51), is considered a laboratory analogue of language learning. In effect, learning a new word implies the maintenance of a series of smaller units, such as phonemes or syllables, in the correct order for a short amount of time before producing them. The sequence of smaller units is typically presented more than once. In the present study, we investigated the role of overt language production in language learning by manipulating recall direction. If the learning of a repeated list of items relies on overt language production processes, changing list production order by manipulating recall direction should impact the learning of the list. In Experiment 1, one list was repeated every third trial, and recall direction of the repeated list changed on the ninth repetition. In Experiment 1a, the repeated list changed from a forward to a backward order recall, where participants had to recall the items in reverse presentation order. In Experiment 1b, the repeated list changed from a backward to a forward order recall. Results showed a cost in recall performance for the repeated list when recall direction switched from forward to backward recall, whereas it was unaffected by the change from backward to forward recall. In Experiment 2, we increased the number of trials before introducing the change from a backward to a forward order recall. Results showed a decrement in recall performance for the repeated list following the change in recall direction, suggesting that language production processes play a role in the Hebb repetition effect.

**Keywords** Hebb repetition effect · Sequence learning · Overt language production · Backward recall

In Hebb's (1961) original experiment, the experimenter read aloud a list of digits, and at the end of the presentation participants were asked to repeat them in the exact same order. Unknown to the participants, one list of digits was repeated every third trial. Hebb observed that recall performance for the repeated list increased gradually over repetitions compared with the nonrepeated lists. This gradual learning of a repeated list is known as the Hebb repetition effect (Hebb, 1961). Given their many similarities, researchers consider the Hebb repetition paradigm to be a laboratory analogue of language learning (Mosse & Jarrold, 2008; Page & Norris, 2009; Saint-Aubin & Guérard, 2018; Saint-Aubin, Guérard, Fiset, & Losier, 2015; Szmalec, Duyck, Vandierendonck, Mata, & Page, 2009). For instance, after seeing *Mary Poppins*, imagine you try to learn the word *supercalifragilisticexpialidocious*. Typically, you will listen to the word and try to produce it immediately after. In order to do so, you have to maintain the word's phonemes or syllables in the correct order until you produce it. You are also likely to need more than one attempt to master this new word. With enough repetitions, you should be able to produce it without errors, and once mastered, this knowledge should be long-lasting.

Despite the spike in interest in the Hebb repetition effect in recent years, the role played by language production in Hebb learning is still ambiguous. Some studies have suggested that the production of the repeated list is mandatory to induce its long-term learning (Cohen & Johansson, 1967; Cunningham, Healy, & Williams, 1984). Other studies, however, have shown that production processes play a negligible role (Hitch, Flude, & Burgess, 2009; see also Burgess & Hitch, 2006; Page & Norris, 2009). For example, Hitch et al. (2009) investigated the role of language production during a Hebb repetition paradigm by adding an articulatory suppression

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requirement. Under articulatory suppression, participants repeated aloud "the, the, the . . . " during both presentation of the lists and written recall. Articulating the irrelevant sequence solicited language production processes making them unavailable for the to-be-remembered items. Hitch et al. found that articulatory suppression interfered with immediate serial recall performance, but not with the learning of the repeated list (see also Page, Cumming, Norris, Hitch, & McNeil, 2006). In other words, overall recall performance was lower under suppression than in the control silent condition. However, in both conditions, performance increased similarly over repetitions.

Hitch et al.'s (2009) results are in line with the idea that processes other than production—such as perceptual processes—underlie the long-term learning of serial order information (Burgess & Hitch, 2006; Page & Norris, 2009). For example, it has been found that changes during the perception of the lists, such as a change in the grouping pattern during list presentation, disrupted the Hebb repetition effect (Bower & Winzenz, 1969; Hitch et al., 2009; Schwartz & Bryden, 1971). Those findings fit well with Burgess and Hitch's (2006) implementation of the phonological loop suggesting that the long-term learning of a sequence mostly relies on its repeated perception. However, the primacy model (Page & Norris, 2009) offers an alternative view. Within this view, perception also plays a key role in the long-term learning of the repeated list, but when the memory task requires the production of the items, production processes would also contribute in the learning of the repeated list. Essentially, this would happen during an immediate serial recall task.

Although Hitch et al. (2009) offered an elegant demonstration, it can be argued that articulatory suppression did not block all production processes. In effect, participants performed written recall, and it is known that writing calls upon language production processes (Ferreira, 2010). What is more, empirical effects related to language production processes, such as the word-length effect and phonological recoding, have been observed under suppression (see, e.g., Norris, Butterfield, Hall, & Page, 2018; Romani, McAlpine, Olson, Tsouknida, & Martin, 2005). Consequently, without denying the powerful interference effect of suppression on language production processes, it can be argued that it may not block all of them. This problem was overcome in studies in which production processes were manipulated with an all-or-none methodology (Cunningham et al., 1984; Mechanic, 1964; Sanders, 1961). For example, Cohen and Johansson (1967) used a typical Hebb repetition paradigm and presented participants with a repeated list every third trial. Cohen and Johansson added a further manipulation. During the first phase of the experiment, participants did not recall all presented lists. Following each list presentation, be it a repeated list or not, a cue indicated whether or not the list was to be recalled. Unknown to participants, in the critical condition during the first phase of the experiment, the repeated list was never cued for recall. Following this first phase, participants were warned that in the next phase, all trials ought to be recalled. There were four trials: one with the repeated list and three with nonrepeated lists. During this final phase, recall performance of the repeated list was equivalent to recall performance of the three nonrepeated lists. They concluded that the recall of the repeated list was essential for the emergence of a Hebb repetition effect (see also Oberauer & Meyer, 2009).

Although interesting, Cohen and Johansson's (1967) demonstration must be interpreted with caution. First, recall performance for the repeated list was only assessed once in the final phase. It is well known that performance varies across trials, which can mask learning with only one assessment. Second, one must be careful when assessing learning in trials where no recall is required since there is no data available to examine learning rate throughout the task. Third, there is also the possibility that the retrieval of the items and the production processes might already have been activated by the time the participants were instructed not to recall the list. It can thus be argued that production processes were not rigorously controlled throughout Cohen and Johansson's experiment.

To circumvent the above-mentioned problems, Guerrette, Guérard, and Saint-Aubin (2017) manipulated recall direction during a Hebb repetition paradigm. Recall direction of the repeated list varied randomly across repetitions, with some trials to be recalled in a forward typical order and others to be recalled in backward order. Backward serial recall is a variant of the typical serial-recall task, where participants must recall the items in reverse order, from the last presented item to the first. (The possible mechanisms underlying the Hebb repetition effect in backward recall will be addressed in the General Discussion.) Recall order varied across repetitions so that it was not possible for participants to predict recall direction on a given trial. The rationale behind this study was that if Hebb learning relies on overt language production, then manipulating overt production order of the repeated list should impair its learning. Guerrette's et al.'s results showed the typical Hebb learning, and it was of the same magnitude for forward and backward recall. Randomly changing recall direction did not impair learning of the repeated list, thus suggesting that overt language production plays a limited role in the Hebb repetition effect.

Regardless, one possibility is that the methodology used by Guerrette et al. (2017) did not allow them to uncover the role of production processes. For instance, within the primacy model (Page & Norris, 2009), learning of the repeated list involves both perception and production processes. If recall direction of the repeated list changed constantly, the production processes are likely to be associated to two distinct production lists: one for forward recall and one for backward recall. As a result, switching recall direction could happen at no apparent cost. Then, the null effect does not entirely suggest that production processes are not involved in the learning of the repeated list. To reveal the contribution of production processes, it would be necessary to first allow the development of strong associations between perceptual and production processes before switching recall direction. If production processes are indeed not involved in the learning of the repeated list, the switch in recall direction should be done at no cost, as found previously by Guerrette et al. (2017). Contrarily, if production processes do contribute to the learning of the repeated list, given the development of stronger association between perceptual and production processes, recall performance of the repeated list should be affected by the switch in recall direction. Furthermore, it is important to keep tasks as similar as possible to what was done in previous studies to produce convincing evidence and rule out alternative hypotheses calling upon different strategies. Consequently, although recall direction of the repeated sequence was constant—except for the critical change in the middle of the experiment—recall direction of the nonrepeated lists changed randomly across trials. With this procedure, from the participants' perspective, the current experimental design was the same as in Guerrette et al.'s study.

The objective of the present study was to evaluate the role of overt language production in the Hebb repetition effect when task characteristics support the use of production processes for learning the repeated list. We achieved this aim by keeping production order for the repeated list constant during a Hebb repetition paradigm, as it is usually the case, and then changing recall direction once during the experiment. Therefore, in the following experiments, one repeated list was presented every third trial. In Experiment 1, recall direction of the repeated list was kept constant for the first half of the 16 presentations and changed on the 9th repetition from a forward to a backward recall (Experiment 1a), and from a backward to a forward recall (Experiment 1b). To increase the reliability of our results, we included the same number of trials before and after the change in recall direction. As mentioned above in the presentation of Cohen and Johansson (1967), learning must be assessed with multiple trials. Experiment 2 involved more trials before changing recall direction, with 16 backward recall presentations of the repeated list before changing to a forward recall on the 17th presentation. Recall direction varied randomly for nonrepeated trials. If overt language production processes play a role in the Hebb repetition effect when output order of the repeated list remains constant, the change in recall direction for the repeated list should produce a decrement in recall performance. This pattern of results would nicely complement previous studies abolishing the Hebb repetition effect by prohibiting overt recall (Cohen & Johansson, 1967; Cunningham et al., 1984; Mechanic, 1964; Sanders, 1961). According to this hypothesis, recall performance should drop following the change in recall direction. Conversely, if previous results observed when recall direction of the repeated list varied randomly across repetitions occurred because the Hebb repetition effect exclusively relies on perceptual processes, then the recall direction switch should be done at no cost (Guerrette et al., 2017).

## Experiment 1

Experiment 1 was split into two separate experiments. In Experiment 1a, participants were asked a forward order recall during the first eight presentations of the repeated list before recall direction changed to a backward order recall on the ninth repetition. Experiment 1b required the opposite: Participants first recalled the repeated list in backward order, before recall direction of the repeated list changed to a forward order recall on the ninth repetition. We compared recall performance before and after the switch in recall direction to evaluate the role of overt language production on sequence learning when production order of the repeated list remains constant during a Hebb repetition paradigm. If Hebb learning relies at least partly on overt language production processes, then changing the output production order of the repeated list halfway through the experiment should produce a decrement in recall performance for the repeated list immediately following the switch in recall direction.

### Method

**Participants** Experiments 1a and 1b both included 20 participants. All participants ($N = 40$) were French-speaking students from Université de Moncton, and all volunteered to take part in the experiment. All participants were naïve to the purpose of the experiment.

**Materials** The experiment was presented on a PC computer using E-Prime (Version 2.0; Psychology Software Tool, Inc.). The stimuli were 36 nonsense syllables created from the combination of 16 consonants and 11 vowels (see Guerrette et al., 2017). All syllables consisted of one onset consonant phoneme followed by one offset vowel phoneme. The syllables were digitally recorded with VRS Recording System (NCH Software, Version 5.48) and edited with Soundforge Audio Studio system (Sony Corporation, Version 10.0). No syllable was to sound like a genuine French word.

At the beginning of the experiment, the program generated one repeated list and 34 nonrepeated lists. Each list was made of seven nonsense syllables randomly drawn from the pool of 36 syllables. No syllable repeated itself within a list. The experiment included a total of 50 trials. Starting on the third trial, the repeated list was presented every three trials for a total of 16 repetitions. The last two trials of the experiment consisted of nonrepeated lists. Trial 2 to Trial 49 were divided into eight blocks of six trials. Each block contained two repeated lists and four nonrepeated lists. To ensure that there was an equal number of lists recalled in forward and backward order, within each block, one of the four nonrepeated lists was randomly selected and assigned the recall direction of the repeated list. The other three nonrepeated lists were assigned the other recall direction. The repeated lists in Experiment 1a were to be recalled in forward order from Block 1 to Block 4 and in backward order from Block 5 to Block 8. In Experiment 1b, the repeated lists were to be recalled in backward order from Block 1 to Block 4 and in forward order from Block 5 to Block 8. The first and last experimental trials both involved nonrepeated lists, one of which was assigned to the forward recall condition and the other to the backward recall condition. A digital voice recorder was used to record the participants' answers.

**Procedure** Participants were tested individually. The experiment began with a familiarization phase during which the 36 nonsense syllables were presented both aurally and visually on the computer screen, at a rate of one item per 1,500 ms. Following the familiarization phase, participants undertook the memory task. In each trial, seven syllables were presented successively through loudspeakers at a rate of one syllable per 1,000 ms. Immediately following the presentation of each list, participants were asked to recall out loud the seven syllables either in forward or in backward order. If the instruction *Normal* [Forward] appeared on the screen, participants were required to recall the seven syllables in their presentation order. If the instruction *Inversé* [Backward] appeared on the screen, participants were required to recall the seven syllables in reverse order, from the last syllable to the first syllable presented. Participants were instructed to say *Passe* [Pass] for every syllable they could not recall. Participants pressed the space bar to initiate the next trial. The experimental task lasted approximately 25 minutes.

## Results

Responses were scored using a strict serial recall criterion: A syllable had to be recalled in its correct serial position as determined by recall direction to be scored as correct. For all analyses, a .05 level of significance was adopted and the Greenhouse–Geisser correction was applied when the sphericity criterion was not met. For each trial, we computed the mean proportions of correct recall. Each block represents the mean score of two repeated lists and their yoked nonrepeated list matching in recall direction. We analyzed the gradients of improvement over repetitions and compared recall performance between Block 4 and Block 5, where the repeated list changed in recall direction.

**Experiment 1a** Recall performance for the two repeated lists and their associated nonrepeated list as a function of block is presented in the top panel of Fig. 1. Blocks 1 to 4 only include forward-recalled trials, whereas Blocks 5 to 8 only include backward-recalled trials. With linear regressions, the gradients of improvement—the slopes—were computed across the first four blocks and across the last four blocks separately to compare the learning rate before and after the switch in recall direction. Recall performance for the repeated list increased by .066 per block in the forward-recalled trials (Blocks 1 to 4) and by .045 per block in the backward-recalled trials (Blocks 5 to 8). Conversely, recall performance for the nonrepeated lists decreased by .023 per block in the forward-recalled trials (Blocks 1 to 4) and by .012 per block in the backward-recalled trials (Blocks 5 to 8). A 2 (repetition: repeated, nonrepeated) × 2 (recall direction: forward, backward) repeated-measures analysis of variance (ANOVA) was performed on the gradients of improvement obtained by computing a linear regression for each participant in each condition. The analysis revealed a significant main effect of repetition, $F(1, 19) = 47.46$, $p < .001$, $\eta_p^2 = .71$, with the repeated lists showing a higher learning rate than nonrepeated lists. The main effect of recall direction as well as the interaction between repetition and recall direction were not significant (all $F$s < 1).

Although the learning rate was similar between forward and backward repeated trials, Fig. 1 suggests a decrease in

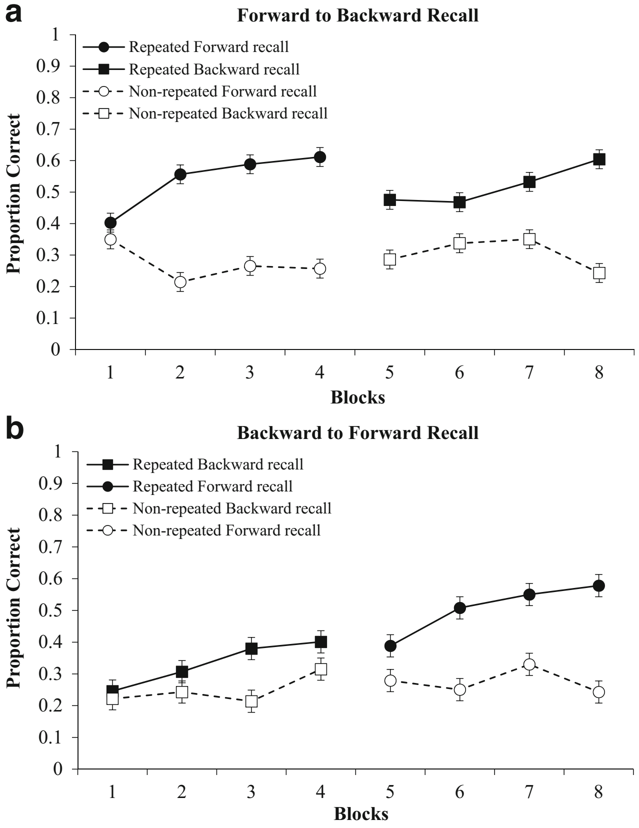

**Fig. 1** Proportion of correct recall as a function of block for the repeated and nonrepeated lists in the forward-recalled and backward-recalled trials. The top panel show results for Experiment 1a and the bottom panel show results for Experiment 1b. Error bars represent 95% confidence intervals (Masson & Loftus, 2003)

recall performance between Block 4 and Block 5. To examine if recall performance was affected by the change in recall direction, we compared the proportions of correct responses in Block 4 before the change in recall direction and Block 5 immediately after the change in recall direction. A 2 (block: 4, 5) × 2 (repetition: repeated, nonrepeated) repeated-measures ANOVA performed on the proportions of correct responses showed no significant main effect of block, $F(1, 19) = 1.58$, $p = .224$, $\eta_p^2 = .08$. The analysis revealed a significant main effect of repetition, $F(1, 19) = 26.31$, $p < .001$, $\eta_p^2 = .58$. Importantly, the interaction between block and repetition was significant, $F(1, 19) = 4.48$, $p = .048$, $\eta_p^2 = .19$, suggesting that the difference between repeated and nonrepeated lists was greater in Block 4 than in Block 5. Paired-samples *t* tests confirmed that the repeated lists were significantly better recalled than were the nonrepeated lists in Block 4, $t(19) = 5.49$, $p < .001$, $d = 1.23$, as well as in Block 5, $t(19) = 2.83$, $p = .011$, $d = .63$. In addition, the repeated list was better recalled in Block 4 than in Block 5, $t(19) = 2.19$, $p = .021$, $d = .50$, whereas recall performance for the nonrepeated list remained similar between Blocks 4 and 5, $t(19) = .55$, $p = .591$, $d = .15$. This suggests that recall performance for the repeated list was affected by the change in recall direction.

**Experiment 1b** Recall performance for the two repeated lists and their yoked nonrepeated list as a function of block is presented in the bottom panel of Fig. 1. Blocks 1 to 4 contain backward-recalled trials and Blocks 5 to 8 contain forward-recalled trials. Recall performance for the repeated list during backward-recalled trials increased by .054 per block from Block 1 to Block 4, and by .061 per block from Block 5 to Block 8 in the forward-recalled trials. Recall performance for the nonrepeated lists increased by .025 per block in the backward-recalled trials (Blocks 1 to 4), whereas it decreased by .004 per block during the forward-recalled trials (Blocks 5 to 8). A 2 (repetition: repeated, nonrepeated) × 2 (recall direction: forward, backward) repeated-measures ANOVA revealed a significant main effect of repetition, $F(1, 19) = 5.33$, $p = .032$, $\eta_p^2 = .22$, with the repeated lists showing a greater rate of improvement than nonrepeated lists. The main effect of recall direction ($F < 1$), as well as the interaction between repetition and recall direction, $F(1, 19) = 1.25$, $p = .278$, $\eta_p^2 = .06$, were not significant.

To examine if recall performance for the repeated list was affected by the change in recall direction, we compared recall performances between Block 4 and Block 5 using a 2 (block: 4, 5) × 2 (repetition: repeated, nonrepeated) repeated-measures ANOVA performed on the proportions correct. The analysis revealed a significant main effect of repetition, $F(1, 19) = 6.67$, $p = .018$, $\eta_p^2 = .26$, but neither the main effect of block, nor the interaction were significant (both *F*s < 1). This suggests that recall performance was not affected when recall direction changed from a backward to a forward order recall. Paired-samples *t* tests showed that the repeated lists were better recalled than nonrepeated lists in Block 4, $t(19) = 2.11$, $p = .048$, $d = .49$, but not in Block 5, $t(19) = 1.71$, $p = .104$, $d = .51$. In addition, recall performance did not significantly differ between Block 4 and Block 5 for the repeated, $t(19) = .21$, $p = .834$, $d = .07$, and nonrepeated lists, $t(19) = .78$, $p = .447$, $d = .18$.

### Discussion

In Experiment 1a, the repeated list suffered a decrease in recall performance when recall direction changed from a forward to a backward order recall, whereas no decrease was observed when recall direction changed from a backward to a forward order recall during Experiment 1b. Such patterns suggest that overt language production processes play a role in Hebb learning, but only when the repeated list is recalled in a constant forward order. This is in line with other studies that also used forward recalls and suggested that response production during recall plays an important role during Hebb learning (Cohen & Johansson, 1967; Cunningham et al., 1984; Oberauer & Meyer, 2009).

Despite the clarity of results in Experiment 1 and before discussing the theoretical implications of the selective cost of switching recall direction, the apparent costless transition for the repeated list when recall direction changed from backward to forward order warrants further exploration. As is shown in Fig. 1, although learning occurred during the first four backward-recalled blocks in Experiment 1b, recall performance at the fourth block was much lower than recall performance at the fourth forward-recalled block in Experiment 1a (.40, and .61, respectively), backward recall being a generally harder task and starting from a lower baseline performance level than was forward recall. A more convincing demonstration would require an equivalent performance level in forward and backward recall before switching recall direction. Accordingly, in Experiment 2, we increased the initial number of backward-recalled trials for the repeated list before switching to a forward order recall.

## Experiment 2

We increased the number of repeated trials in backward recall to ensure that before switching recall direction, backward recall performance for the repeated list in Experiment 2 would be equivalent to forward recall performance in Experiment 1a. Based on a linear extrapolation of Experiment 1b's results, we estimated that 16 backward recall repetitions of the repeated list (eight blocks) would produce an equivalent performance level to that observed in Experiment 1a after eight forward recall repetitions (four blocks). Therefore, in Experiment 2, the repeated list was presented 24 times: 16 consecutive backward order recalls, followed by eight forward order recalls. In addition, we increased the sample size to achieve enough statistical power to uncover the potential cost of switching direction. We compared recall performance before and after the switch in recall direction to evaluate the role of overt language production on sequence learning when production order of the repeated list remains constant during a Hebb repetition paradigm. If Hebb learning during backward recall is not at least partly production based, then increasing the number of repeated trials in backward recall should still render no decrement in recall performance for the repeated list following the switch in recall direction. If Hebb learning during backward recall is at least partly production based, then a decrement in recall performance for the repeated list should be observed following the switch in recall direction, as observed in Experiment 1a.

## Method

**Participants** Thirty French-speaking students from Université de Moncton volunteered to take part in the experiment. All participants were naïve to the purpose of the study; no participants had taken part in Experiment 1.

**Materials and procedure** The materials used in Experiment 2 were the same as in Experiment 1, except that Experiment 2 included a total of 74 trials. At the beginning of the experiment, the program generated one repeated list and 50 nonrepeated lists. The repeated list was still presented every third trial, for a total of 24 presentations over the course of the experiment. The first and last trials consisted of nonrepeated lists, one of which was assigned to the forward recall condition and the other to the backward recall condition. Trial 2 to Trial 73 were divided into 12 blocks of six trials each. Each block contained two repeated lists and four nonrepeated lists. One of the four nonrepeated lists was randomly selected and assigned the same recall condition as the repeated lists; the other three nonrepeated lists were assigned to the other recall direction. From Block 1 to Block 8, the repeated list was to be recalled in backward order, whereas from Block 9 to Block 12, the repeated list was to be recalled in forward order. The procedure used in Experiment 2 was the same as in Experiment 1. The recall direction appeared on the computer screen after the presentation of the list. The experimental task lasted approximately 35 minutes.

## Results

For each trial, we computed the mean proportions of correct recall. Each block represents the mean score of two repeated lists and their associated nonrepeated list matching in recall direction. As in Experiment 1, we analyzed the gradients of improvement over repetitions and compared recall performance between Block 8 and Block 9, where the repeated list changed in recall direction.

Figure 2 illustrates recall performance for the two repeated lists and their associated nonrepeated list as a function of block. From Block 1 to Block 8, the repeated and nonrepeated lists are only recalled in backward order; from Block 9 to Block 12, they are only recalled in forward order. Using linear regressions, gradients of improvement were calculated separately across the first eight blocks and across the last four blocks to compare learning rates before and after the switch in recall direction. Recall performance for the repeated list increased by .037 per block during the backward-recalled trials (Block 1 to Block 8), and by .034 per block during the forward-recalled trials (Block 9 to Block 12). For the nonrepeated lists, recall performance remained constant across blocks for backward-recalled and forward-recalled trials (both *b*s = .000). A 2 (repetition: repeated, nonrepeated) × 2 (recall direction: forward, backward) repeated-measures ANOVA conducted on the gradients of improvement revealed a significant main effect of repetition, $F(1, 29) = 11.81$, $p = .002$, $\eta_p^2 = .29$, reflecting the higher learning rate for repeated than nonrepeated lists. Neither the main effect of recall direction, nor the interaction between repetition and recall direction were significant (both $F$s < 1).

As observed in Experiment 1a, Fig. 2 suggests a decrease in recall performance for the repeated list between Block 8 and Block 9. To evaluate if the change in recall direction affected the repeated list's recall rate, we compared the proportions of correct responses between Block 8 and Block 9 using a 2 (block: 8, 9) × 2 (repetition: repeated, nonrepeated) repeated-measures ANOVA. The analysis revealed a significant main effect of repetition, $F(1, 29) = 27.58$, $p < .001$, $\eta_p^2 = .49$, but the main effect of block was not significant ($F < 1$). The interaction between block and repetition was significant, $F(1, 29) = 4.33$, $p = .046$, $\eta_p^2 = .13$, reflecting the greatest difference in

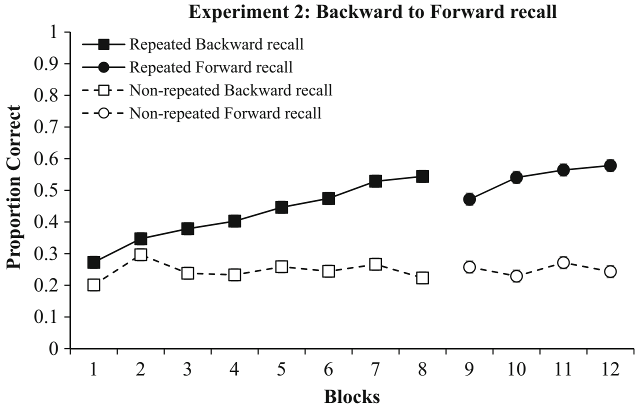

**Fig. 2** Proportion of correct recall as a function of block for the repeated and nonrepeated lists in the backward-recalled and forward-recalled trials of Experiment 2. Error bars represent 95% confidence intervals (Masson & Loftus, 2003)

recall performance between repeated and nonrepeated lists in Block 8 than in Block 9. By using paired-samples *t* tests, we ensured that repeated lists were significantly better recalled than nonrepeated lists in Block 8, $t(29) = 5.72$, $p < .001$, $d = 1.04$, and in Block 9, $t(29) = 3.69$, $p = .001$, $d = .68$. In addition, the repeated list in Block 8 was better recalled than in Block 9, $t(29) = 2.24$, $p = .023$, $d = .27$, while recall performance remained similar for the nonrepeated lists between Block 8 and Block 9, $t(29) = .75$, $p = .460$, $d = .18$. Overall, this indicates that recall performance for the repeated list was affected by the change in recall direction.

Compared with Experiment 1, in Experiment 2, we doubled the number of trials (eight blocks instead of four blocks) before switching recall direction. This increase was implemented to ensure that when switching recall direction, backward recall performance for the repeated list in Experiment 2 would be equivalent to forward recall performance in Experiment 1a. Results revealed that the manipulation was successful: Backward recall performance of the repeated list at Block 8 in Experiment 2 was similar to the forward recall performance of the repeated list at Block 4 in Experiment 1a. A one-way ANOVA on the proportion of correct recall at Block 4 in Experiment 1a and Block 8 in Experiment 2 confirmed those trends ($F < 1$).

### Discussion

Experiment 2 allowed more recall opportunities for cumulative learning of the repeated list in backward order before switching to forward order recall. As shown in Fig. 2, our manipulation was successful with an average recall performance of .54 at Block 8 for the repeated list before the transition to a forward order recall. This value is similar to the average recall performance of .61 for the repeated list at Block 4 in Experiment 1a before the transition to a backward order recall. With a higher level of recall in Experiment 2 than in Experiment 1b (.40), recall performance of the repeated list dropped following the transition from a backward to a forward order recall. Such pattern is similar to what has been found in Experiment 1a when recall direction switched from forward to backward recall. Taken in conjunction with Experiment 1, our results suggest that overt language production does play a role in Hebb learning when recall order of the repeated list remains constant across repetitions.

## General discussion

The objective of the current study was to evaluate the role of overt language production in Hebb learning when overt production order remained constant during a Hebb repetition paradigm. In Experiment 1, recall direction of the repeated list was kept constant for the first four blocks (eight repetitions) before changing to the opposite direction on the fifth block. The results showed a decrease in recall performance for the repeated list when recall direction changed from a forward to a backward recall (Experiment 1a), but not when it changed from a backward to a forward recall (Experiment 1b). However, the level of performance for the repeated list was much lower at the fourth block in the backward than in the forward recall condition. To circumvent this issue, in Experiment 2 we increased the number of trials so the repeated list was recalled in backward order for eight blocks (16 repetitions) before recall direction changed to a forward order recall. As in Experiment 1a, a decrement in recall performance was observed after changing recall direction of the repeated list. This suggests that overt language production plays a role in Hebb learning when the repeated list is recalled in a constant order. This pattern of results is in accordance with previous studies using only one recall direction and manipulating overt recall processes by manipulating the recall requirement (Cohen & Johansson, 1967; Cunningham et al., 1984; Oberauer & Meyer, 2009).

Overall, our results showed similar recall performances for forward and backward recall of nonrepeated lists. This finding is in line with previous studies. In effect, although it is generally believed that recall performance is superior in forward than in backward recall, many studies showed no difference between both recall directions (e.g., Anderson, Bothell, Lebiere, & Matessa, 1998; Beaudry, Saint-Aubin, Guérard, & Pâquet, 2018; Bireta et al., 2010, Experiments 1–2; Farrand & Jones, 1996; Guérard, Saint-Aubin, Burns, & Chamberland, 2012; Guerrette et al., 2017; Li & Lewandowsky, 1995, Experiments 1–2; Madigan, 1971; Thomas, Milner, & Haberlandt, 2003).

The key finding of the current study is the cost of switching from one recall direction to the other one. Given sufficient learning of the repeated list, this cost was observed when transitioning both from forward to backward recall and when transitioning from backward to forward recall. This clearly suggests that overt language production processes are involved in the Hebb repetition effect. How can this finding be reconciled with our previous demonstration suggesting a limited role of production processes? Guerrette et al. (2017) used a design similar to the current experiments, except that recall direction of the repeated list varied randomly from trial to trial. They found similar learning rates in forward and backward recall and no learning cost for varying recall direction. Guerrette et al.'s findings can suggest that overt production processes play a limited role in the Hebb repetition effect or that participants learned concurrently two distinct production lists: one for forward recall and one for backward recall. The former hypothesis would be reminiscent of O'Shea and Clegg (2006), who also suggested that Hebb learning can be based either on perceptual or production processes, depending on the context during which sequences are presented. To adjudicate between those two explanations, in the current experiment, consistency of recall direction of the repeated list was the key factor. If production processes were not involved in the Hebb repetition effect, our manipulation should have produced the same results as in Guerrette et al.: Switching recall direction would be done at no cost. However, since production processes are involved and were masked in our previous study because participants learned two production lists concurrently, a decrement is observed here, in Experiments 1 and 2, where dual learning was impossible.

In addition to the cost associated with switching recall direction, it is worth noting that recall performance of the repeated sequence did not return to the baseline level in Experiments 1a and 2. This residual learning observed after switching recall direction is coherent with O'Shea and Clegg's (2006) suggestion about the involvement of perceptual processes in Hebb learning (see also Bower & Winzenz, 1969; Hitch et al., 2009; Schwartz & Bryden, 1971). As such, our results reflect both a contribution of language production and of perceptual processes in learning the repeated sequence. In another line of thought, since the repeated list was recalled in a constant order across repetitions, either in forward or backward order, participants could have relied on the production of articulatory sequences during recall (Jones, Hughes, & Macken, 2006; Jones, Macken, & Nicholls, 2004). The repeated list would then have benefited from more practised coarticulation between items, leading to better recall performance (see Woodward, Macken, & Jones, 2008).

Our results fit well with the primacy model (Page & Norris, 1998, 2009), which accounts for both the Hebb repetition effect and backward recall. The primacy model suggests four layers of representations. In the occurrence layer, units fire to signal the occurrence of their corresponding items in the word. The activation in the occurrence layer is forwarded to the recognition layer, where units compete for activation. When a unit wins the competition, the item is recognized and the activation is forwarded to the order layer, where items are associated with a primacy gradient of activation. The primacy gradient represents the level of activation of successive list items, which decays exponentially for each successive unit. During recall, the production layer selects the most activated unit from the order layer and then suppresses that unit to prevent its repeated output.

According to the primacy model, the Hebb repetition effect takes place in the occurrence layer: The units and their primacy gradients are copied back from the order layer to the occurrence layer, and this feedback would create a chunk over repeated presentations. Subsequent presentations of the same list allow the engaged chunk to gain additional activation from the order layer, and, after several presentations, the chunk becomes committed to the repeated list. Once a chunk is committed to the repeated list, activation of the chunk alone is sufficient to allow recall of the repeated list. Hebb learning is thus the result of repeated presentations allowing new information to be committed to chunks. This architecture allows the primacy model to account for learning in the absence of list production, as when list recognition rather than list recall is required (Page & Norris, 2009). However, when list production is necessary, the production layer would also be involved. More specifically, the production layer unit changes some of its outgoing weights in the direction of the primacy gradient. Over repetitions, an output representation would be learned and linked to the occurrence layer. As a result, in a memory task involving response production, such as an immediate serial recall task, recall performance would improve over repetitions.

Moreover, because of the primacy gradient, each item can only be retrieved after the retrieval of its predecessor. Therefore, within the primacy model, backward serial recall is assumed to be a series of covert forward recalls (Page & Norris, 1998). Such use of covert forward recalls during backward recall is reflected by the pattern of response times (Guerrette et al., 2017; Thomas et al., 2003; but see Bireta et al., 2010). Under this view, overt production of a sequence is not necessary for the emergence of the Hebb repetition effect.

The primacy model can account for current results in a straightforward manner. Before switching recall direction, the recall improvement of the repeated list would reflect the joint action of the occurrence and production layers. When recall direction switched—provided sufficient learning occurred during the first phase—recall performance dropped but did not return to its baseline level. This decrement would reflect the contribution of the production layer: Recall performance decreased because the involvement of the production layer would differ in forward and backward recall. Following the switch from forward to backward recall, a learned stimulus list will be recognized, which will facilitate covert forward recalls, from which the reversed response is then derived. However, the transfer is incomplete, as the learned output representation is not deployed to the same extent (i.e., as a fluent, learned, overt response). The same logic would apply in Experiment 2, when switching from backward to forward recall.

In sum, our results show that when a repeated list is recalled in a constant order, a sudden change in its production order leads to a decrement in recall performance. This suggests the involvement of overt language production processes in the Hebb repetition effect. The relation between the Hebb repetition effect, backward recall and trial organization can be accounted for by the primacy model (Page & Norris, 2009).

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