Visual Hebb repetition effects survive changes to both output order and concurrent articulation

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Abstract

Building upon the work of Guerrette et al. (2017), we examine the effect of output order on the visual Hebb repetition effect. We limit the opportunities for forward recall at test by using a novel positional recall procedure, employing non-verbal visual stimuli, and requiring participants to undertake concurrent articulation (CA). During the encoding phase, participants received sequences of six unfamiliar-faces. For every third sequence, participants received the same faces in the same serial order (i.e. the Hebb sequence). For the remaining trials, the sequence items were presented in a random order (i.e. the filler sequences). At test, participants were required to either select the faces in their order of original presentation (SR) or recall the serial position of each individually re-presented face tested in a randomised order (PR). For both recall conditions, the Hebb repetition effect was evident, and this persisted with CA. The findings demonstrate that the Hebb repetition effect is not dependent upon forward recall and is consistent with the view that the effect is underpinned by perceptual processing rather than repeated retrieval.

175 words

Keywords: Hebb repetition effects; visual memory; short-term memory; serial order reconstruction; output order; concurrent articulation

Introduction

The Hebb repetition effect refers to the gradual acquisition of memory for a sequence of items following repeated surreptitious re-presentation of that sequence (Hebb, 1961). In the classic Hebb repetition procedure, participants undertake a series of trials requiring serial-order recall of the preceding sequence. The experimental trials comprise unique non-repeated sequences (known as filler sequences) and a repeated Hebb sequence. The Hebb repetition effect is demonstrated by improved recall for the Hebb sequence as a function of repetition number. This improvement is above that of general practice-based enhancements and is, therefore, evidenced by greater learning for the Hebb sequences relative to the filler sequences.

Recently, the Hebb repetition effect has experienced renewed interest as a possible candidate mechanism that enables the transfer of short-term memories (STM) for phonemic sequences into long-term memory (LTM) as words (e.g. Cumming, Page, & Norris, 2003; Kalm & Norris, 2016; Mosse & Jarrold, 2008; Norris, Page, & Hall, 2018; Page, Cumming, Norris, McNeil, & Hitch, 2013; Smalle et al., 2016; Szmalec, Duyck, Vandierendonck, Mata, & Page, 2009; Szmalec, Loncke, Page, & Duyck, 2011; Szmalec, Page, & Duyck, 2012). It has been suggested that following repeated presentation of the Hebb sequence, the items therein form a unified ‘chunk’ within memory (Page & Norris, 2009) and that this is analogous to how a sequence of phonemes combine to become a word within LTM. It is, however, worth noting that whilst linked to language acquisition, the Hebb repetition effect is clearly not confined to verbal stimuli, with the effect found across a range of stimulus types including unfamiliar faces (Horton, Hay, & Smyth, 2008; Johnson, Dygacz, & Miles, 2017; Johnson & Miles, 2019), visuo-spatial stimuli (Couture & Tremblay, 2006; Guérard, Saint-Aubin, Boucher, & Tremblay, 2011; Tremblay & Saint-Aubin, 2009; Turcotte, Gagnon, &

Poirier, 2005), abstract matrices (Johnson & Miles, 2019), auditory-spatial stimuli (Lafond, Tremblay, & Parmentier, 2010; Parmentier, Maybery, Huitson, & Jones, 2008), odours (Johnson, Cauchi, & Miles, 2013), and touches (Johnson, Shaw, & Miles, 2016).

Learning of the repeated (Hebb) sequence has typically been tested by serial recall, i.e. recalling the list in the order of original presentation. In past studies, researchers have employed either: (1) immediate serial recall (ISR), where participants generate the items in the order of original presentation (e.g. Cohen & Johansson, 1967; Hebb, 1961; McKelvie, 1987; Oberauer & Meyer, 2009), or (2) serial order reconstruction (SOR), where the preceding sequence items are re-presented at test and participants are required to select those items in the order of original presentation (e.g. Couture & Tremblay, 2006; Horton et al., 2008; Parmentier, et al., 2008). The one notable exception is a recent study (Guerrette, Guérard, and Saint-Aubin, 2017) that examined directly the impact of backward recall on the Hebb repetition effect. Participants received sequences of seven nonsense French syllables and, at test, were required to recall the sequences in either forward or backward order, with a repeated Hebb sequence presented every third trial. Results demonstrated that the Hebb repetition effect was immune to both the direction of recall (Experiment 1) and alternating recall direction for the Hebb sequence across the experiment (thereby halving the recall opportunities for the repeated sequence in each given direction: Experiment 2). The authors conclude that learning of the repeated Hebb sequence persists when output order is inconsistent with input order and, therefore, argue that the Hebb repetition effect does not rely exclusively upon the repeated retrieval of items in the same order. Nevertheless, despite overt backward retrieval of the sequences, it remains possible that participants engaged in some covert forward serial recall. Indeed, analysis of response times indicated that participants did engage in some covert forward recall of groups of items during backward recall. Specifically, Guerrette et al. (2017) reported longer response times for earlier outputted items with backward compared to forward recall. Since under backward recall the first outputted items would have been the latter list items at the encoding stage, Guerrette et al. argue that these longer latencies for backward recall are consistent with participants performing covert forward recall of the list.

Since the response time data in Guerrette et al. (2017) suggests some covert forward recall in the backward output condition, one might argue that the study has failed to demonstrate the Hebb repetition effect following non-forward recall. One possible explanation for the Guerrette et al. (2017) finding is, therefore, that forward recall is a requirement for the Hebb repetition effect to be detected. Alternatively, it is possible that learning of the repeated sequence is not linked to output order with the Hebb repetition effect instead a result of a repeated perceptual process, rather than repeated retrieval of the Hebb sequence. Whilst an early study suggested that participants needed to be repeatedly tested on the Hebb sequence for a recall benefit to be observed (Cunningham, Healy, & Williams, 1984), more recent studies point to the contrary. For instance, in Oberauer and Meyer (2009) participants were required to recall or discard each 9-digit sequence. Following a learning block, recall was assessed for both repeatedly recalled and discarded Hebb sequences, relative to the non-repeated filler sequences. Whilst recall for discarded Hebb sequences was inferior to that for the recalled Hebb sequences, recall accuracy was still higher than that for the filler sequences. This finding suggests that repeated encoding alone is sufficient to produce the Hebb repetition effect (although their findings also suggest an additive effect of repeated retrieval). Moreover, Kalm and Norris (2016) argued that the use of a strict serial-recall scoring protocol underestimated learning of the sequence. They used the Levenshtein (1966) scoring metric (rather than testing absolute positional recall accuracy) to assess string similarity between the presented sequence and the outputted sequence. This analysis assesses the number of changes (i.e. edit distance) needed to transform the recalled sequence into the to-be-remembered sequence. This scoring procedure takes into account the relative order of items at output and is therefore a more sensitive measure of sequence learning than absolute scoring. This analysis showed that whilst repeated presentation of the Hebb sequence improved learning, there was no difference in improvement for the Hebb sequence based upon the number of times the repeated sequence had been overtly recalled.

Whilst the studies of Kalm and Norris (2016) and Oberauer and Meyer (2009) point to, at least some, perceptual learning following repeated exposure to the Hebb sequence, the extent to which output order might affect learning is unclear. Indeed, as highlighted by Guerrette et al. (2017), it is possible that even when backward recall is required, participants covertly recalled groups of items in forward order and then reversed the order of those items for overt output. In the present experiment, we disrupt the opportunity for forward recall to test more directly whether the Hebb repetition effect survives non-forward retrieval and, in addition, whether the Hebb repetition effect is found when output order of the list differs across repetitions. Whilst the Hebb repetition effect has been shown to develop in the absence of sequence retrieval (Kalm & Norris, 2016; Oberauer & Meyer, 2009), we build on the work of Guerrette et al. (2017) and examine whether learning can be disrupted when recalling the Hebb sequence under concurrent articulation and/or in a different order to that of presentation. Given the potential for some covert forward retrieval in Guerrette et al. (2017), we further limit the opportunity for forward ordered recall by using non-verbal stimuli (unfamiliar-faces) instead of the syllables as used in previous studies. The rationale for these methodological controls is outlined below.

With respect to our recall task, we employ a novel procedure (adapting the task described by Oberauer, 2003) such that, at test, the items from the preceding list are individually and sequentially re-presented in a random order, with participants required to state the serial position of each item. Specifically, at test, a single item is presented on the screen above a row of boxes labelled 1-*n* (where *n* represents the number of items within that sequence). Participants are required to click on the box which corresponds to the position of that item in the preceding sequence. Following the response, another item is displayed from the preceding sequence and the participant must identify the position of this item in the sequence. This positional recall (PR) process continues until all sequence items have been re-presented in a randomised order. As a result, the sequence is outputted in a non-forward order. Whilst this procedure disrupts the opportunity for recalling the list in the order of original presentation, another important element of the task is that output order varies across trials. Our task randomises the order in which items are re-presented at test, which means that for the Hebb sequence participants are not able to learn a repeated response pattern at test.

Whilst this novel serial position recall task appears to deconfound presentation order and testing order (as in Oberauer, 2003), participants could, conceivably, perform the task by sub-vocally outputting the list in full (or parts of the list if broken into sub-chunks) to recall the position of each individually tested item. That is, a de facto serial order recall for each tested item, and, similar to that described for Guerrette et al. (2017). To counter this possibility, we employ hard-to-name stimuli (unfamiliar-faces, Ellis, 1975) and include a secondary CA task. Indeed, it is possible that the use of verbal stimuli (nonsense syllables) in Guerrette et al. (2017) increased the opportunity for forward recall. We argue that employing face stimuli restricts the possibility for sub-vocal articulation, and consequently makes it harder for participants to use a serial recall strategy in the positional recall procedure. Nevertheless, it remains possible that participants may attempt to verbally label the faces. Successful verbal re-coding should (1) result in the task being characteristic of verbal, rather than visual, repetition learning, and (2) presumably increase the ease with which a covert serial recall strategy could be used for the PR trials. In order to minimise verbal re-coding of the face stimuli, participants undertake CA throughout both the learning and output stages of each trial (see Baddeley, Lewis, & Vallar, 1984; Saito, Logie, Morita, & Law, 2008).

In this experiment we examine the Hebb repetition effect for sequences of unfamiliar faces comparing serial recall (SR) and positional recall (PR) under conditions of both quiet and CA, with participants undertaking four blocks of trials: quiet SR, quiet PR, SR with CA, and PR with CA. Evidence for the Hebb repetition effect follows a steeper learning gradient for the Hebb (repeated) sequence relative to the filler (unrepeated) sequence. However, if the non-forward recall of the PR task disrupts the Hebb repetition effect, then method of reconstruction should interact with sequence type (Hebb and filler), such that a reduced difference in learning gradient between Hebb and filler trials should be found following PR. If CA disrupts the Hebb repetition effect, then secondary task should interact with sequence type, such that a reduced difference in learning gradient between Hebb and filler trials should be found following CA. Finally, if the Hebb repetition effect survives PR through covert forward recall for each probed item, we predict a 3-way interaction between sequence type, reconstruction task, and secondary task, such that the Hebb repetition effect is reduced for PR but only under CA due to a disruption of covert forward recall.

Method

Participants. Twenty-four Bournemouth University Psychology undergraduates (mean age = 20.21 years; 6 male and 18 female), participated in exchange for research participation credits. Ethical approval was obtained from the Bournemouth University Ethics Committee.

Materials. Sequences of six unfamiliar-faces were presented on a 23-inch (58.4cm) Hewlett-Packard (Palo Alto, USA) Elite Display E231 monitor using the experimental software E-prime 2.0 (Psychology Software Tools, Inc.). For each block of the experiment, the unfamiliar faces were selected at random, and without replacement, for each participant from a corpus of 60 faces (taken from Facial Recognition Technology, FERET, database, Phillips, Wechsler, Huang & Rauss, 1998). Each face comprised 52mm x 64mm frontal images of Caucasian males lacking both facial hair and eye-wear. Images were greyscale and elliptically cropped to remove hair and ears.

Previous research has shown the Hebb repetition effect to be accentuated when the Hebb and filler trials comprise different items (i.e. no-stimulus-overlap, Johnson et al., 2017; Page et al., 2013; Smalle et al., 2016). Therefore, we employed no-stimulus-overlap between the Hebb and filler condition. Consequently, for each 30-trial experimental block, 18-upright faces were selected at random, for each participant. Without replacement, six faces were selected to construct the Hebb sequence, 6 were selected to construct one filler sequence, and 6 were selected to construct the other filler sequence.

Design. A 5-factor (2x2x2x10x6) within-participants design was employed. The first factor was secondary task (quiet versus CA), the second factor was method of reconstruction (SR and PR), the third factor was sequence type (filler and Hebb), the fourth factor was experimental epoch (1-10), and the fifth factor was serial position (1-6). Each experimental epoch comprised 3 trials; 1 Hebb and 2 filler trials. The presentation order of the four combinations of reconstruction task and secondary task (i.e. SR quiet, SR CA, PR quiet, and PR CA) was fully counterbalanced.

The dependent variable was serial position reconstruction accuracy.

Procedure. Participants were tested individually in a quiet laboratory booth and sat facing the computer at a distance of 60cm. Participants completed 4 blocks of 30 trials, each preceded by 5 practice trials. Each trial was initiated by a keyboard press and comprised the sequential presentation of 6 faces, each displayed for 1000ms with a 1000ms inter-stimulus-interval. Following a 1000ms retention interval (RI) the test phase commenced. In the blocks employing CA, participants were instructed to repeat aloud the digits “1, 2, 3, 4” at a rate of 2-3 digits per second during both the presentation and test phase. The experimental procedure for the SR and PR trials differed and is described below.

SR: The 6-faces from the preceding sequence were re-presented simultaneously on the screen in a circular array. The positioning of each face in the test array was randomised across trials and across participants. At recall, participants were required to reconstruct the presentation order of the preceding sequence by clicking on each stimulus. Once selected, the stimulus acquired a blue border signifying stimulus selection, and participants were unable to either change or repeat a selection.

PR: At test a target face from the preceding sequence was selected at random and displayed on the screen. Beneath the target face were 6 boxes positioned horizontally and labelled 1-6. Participants were required to select the box that corresponded to the position of that target face in the preceding sequence. Once selected, the box acquired a blue border and could not then be re-selected within that trial. Following the response, the target face was succeeded by a new target face selected at random from the remaining faces presented in the preceding trial. Participants were required to select the box number that corresponded to the position of the face in the preceding sequence. This process was repeated until all six faces had been tested. Participants could not alter their responses nor could a box (i.e. the same serial position) be selected more than once within a trial.

Across all blocks, the test-phase was self-paced and successive trials did not commence until the six stimuli from the previous sequence had been selected. The experiment lasted approximately 60-minutes.

Results

A strict scoring criterion was adopted such that a response was recorded as correct only if the correct item was recalled in the correct serial position, with analysis computed using JASP (JASP Team, 2018). Figure 1(a-d) shows the acquisition gradients for both SR and PR as a function of experimental epochs. The quiet condition is shown in Figures 1a and b, and CA is shown in Figures 1c and d. Hebb learning was assessed by fitting the data to a least squares linear regression model for each participant in order to compute an acquisition gradient for both the filler and Hebb trials; gradients across conditions are then compared.

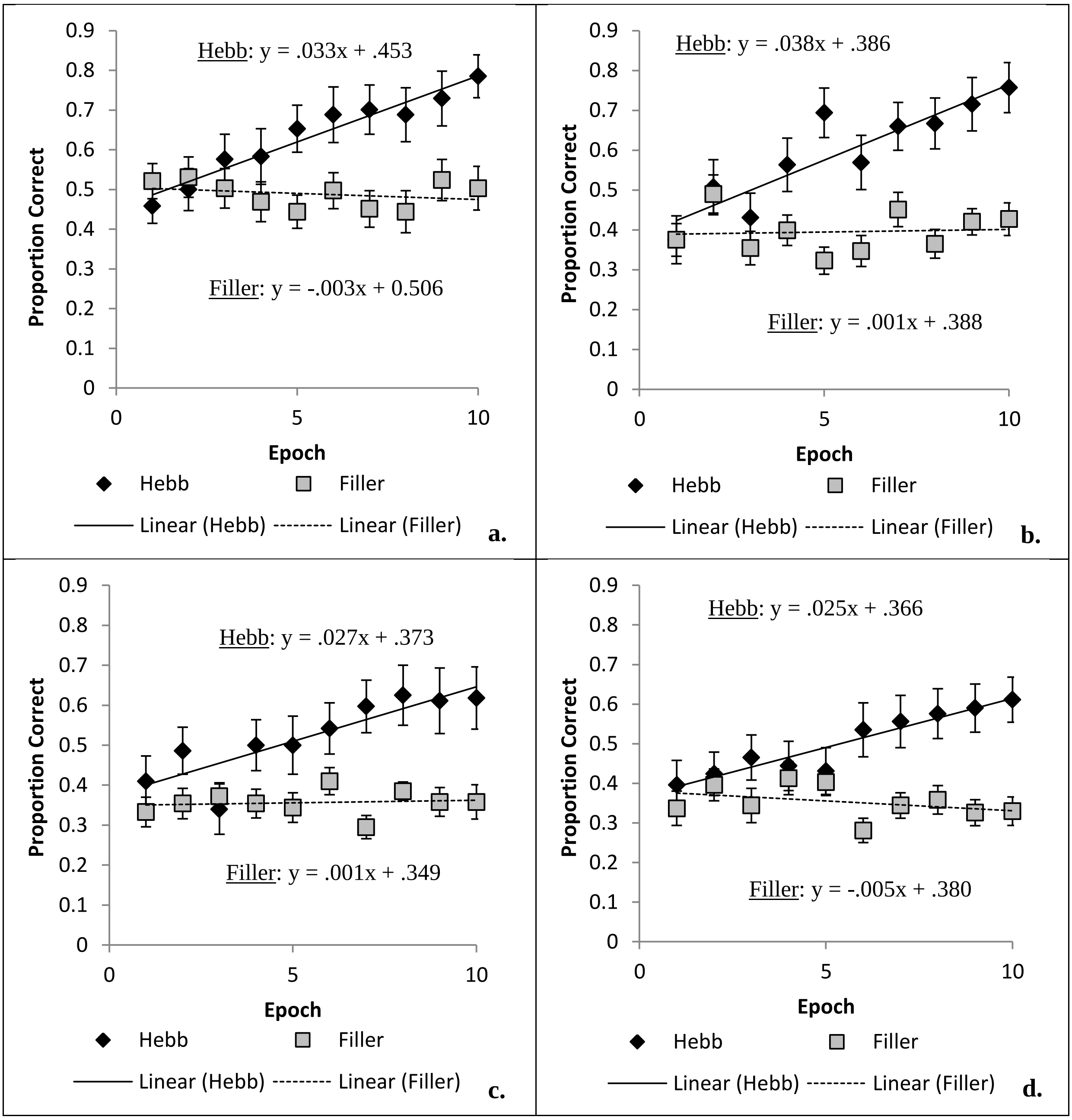

Figure 1(a-d). Mean proportion correct recall scores for the filler and Hebb sequences as a function of experimental epoch (1-10) for the (a) SR trials under quiet conditions, (b) PR trials under quiet conditions, (c) SR trials under conditions of CA, and (d) PR trials under conditions of CA. Line of best fit depicts the learning gradient for both sequence types. Error bars denote the mean standard error.

Learning gradients: Data was fit to a least squares linear regression model for each participant in order to compute acquisition gradients for each condition. The acquisition gradients produced by each participant for the filler and Hebb trials were computed and examined via a 3-factor (2x2x2) within-participants ANOVA, with the factors secondary task (quiet and CA), reconstruction task (SR and PR), and sequence type (filler versus Hebb). The main effects of both secondary task ($F(1,23) = 1.443$, $p = .242$, $\eta_p^2 = .059$) and reconstruction task ($F(1,23) = 0.005$, $p = .946$, $\eta_p^2 < .001$) were non-significant. Importantly, the main effect of sequence type was significant ($F(1,23) = 55.142$, $p<.001$, $\eta_p^2 = .706$; mean gradient for the filler and Hebb sequences = -.001 and .031, respectively). All interactions were non-significant; this included the two-way interactions between secondary task and method of reconstruction ($F(1,23) = 1.411$, $p = .247$, $\eta_p^2 = .058$), secondary task and sequence type ($F(1,23) = 1.365$, $p = .255$, $\eta_p^2 = .056$), and method of reconstruction and sequence type ($F(1,23) = 0.004$, $p = .948$, $\eta_p^2 < .001$); and the three-way interaction between secondary task, method of reconstruction, and sequence type ($F(1,23) = 0.041$, $p = .842$, $\eta_p^2 = .002$). The analysis demonstrates that there was superior learning for the repeated sequence but that this Hebb repetition effect did not significantly differ for the SR and PR recall conditions under both conditions of quiet and CA.[1]

Discussion

The present experiment examined the Hebb repetition effect when forward serial recall of sequences is disrupted. We reduced the opportunity for forward recall via three

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[1] Bogaert, Siegelman, Ben-Porat, and Frost (2018) note that the Hebb repetition effect has poor test re-test reliability at the individual level. One explanation for this unreliability is that “spurious (high) performance” (p.12) in the first trial may serve to mask learning due to elevating the start point of the acquisition gradient. To dilute the possible effect of serendipitously high performance at the start of the task, we re-analysed our data comparing performance on the first and second half of the task (an approach outlined by Mosse & Jarrold, 2008, 2010). We computed a 4-factor (2x2x2x2) ANOVA with the factors secondary task, method of reconstruction, sequence type, and experimental stage. The results were consistent with the regression analysis, wherein we reported a significant two-way interaction between sequence type and experimental stage ($F(1,23) = 42.730$, $p<.001$, $\eta_p^2 = .650$). This interaction was underpinned by a significant improvement in the second half of the task for the Hebb but not filler sequences.

methodological controls: (1) using a novel non-forward positional recall (PR) procedure, (2) using non-verbal stimuli (unfamiliar-faces), and (3) employing a secondary verbal task during the trials (CA). Despite these controls, the Hebb repetition effect was evident (see Figure 1). Specifically, whilst we replicated the Hebb repetition effect following SR of faces (Horton et al., 2008; Johnson et al., 2017; Johnson & Miles, 2019), the rate of learning for the Hebb sequence was unaffected by PR. Furthermore, consistent with Horton et al. (2008), the Hebb repetition effect following both SR and PR survived CA.

Whilst previous research has shown that the Hebb repetition effect survives backward recall (Guerrette et al., 2017), the present study was designed to further test the role of output order on the Hebb repetition effect. We argue that a combination of random order probed positional recall, the employment of unfamiliar-faces as to-be-remembered stimuli, and concurrent articulation minimised the possibilities for participants to employ covert forward recall strategies. That we find equivalent sequence learning following SR and PR in the present experiment is consistent with Guerrette et al. (2017) and the interpretation that acquisition of the Hebb sequence follows repeated perceptual exposure (see also Kalm & Norris, 2016; Oberauer & Meyer, 2009; cf. Cunningham et al., 1984). To be clear, we argue that the order in which items are outputted at test does not affect rate of learning for the repeated sequence. Moreover, it is worth noting that in the PR condition, the order in which items are probed in the Hebb sequence varies across trials. This prevents participants from learning a repeated response pattern at test. Despite variation in the order of output, learning of the Hebb sequence persisted; further evidence that it is perceptual learning, rather than retrieval which is important in the Hebb repetition effect.

Whilst we report an overall detrimental effect of CA on recall accuracy, there is no evidence that CA impaired the rate of improvement for the Hebb sequence (consistent with that reported by Horton et al., 2008). As stated earlier, we argue that CA increases the difficulty with which participants can employ forward recall. However, more generally, survival of the Hebb repetition effect for faces under CA (a manipulation that purportedly disrupts verbal recoding of visual stimuli, e.g. Baddeley et al., 1984) adds weight to the proposition that the Hebb repetition effect is a common feature of memory that is not confined to verbal memory per se. Moreover, that the Hebb repetition effect for non-verbal visual stimuli survived non-forward recall mirrors that found with verbal stimuli following backward recall (Guerrette et al., 2017). Our present data, therefore, suggest that the visual Hebb repetition effect is also underpinned by the perceptual and encoding process, and adds weight to the proposed commonality of the Hebb repetition effect across stimulus types (e.g. Couture & Tremblay, 2006; Johnson et al., 2013, 2016; Page et al., 2006; Parmentier et al., 2008).

Our findings can be accommodated by existing models of the Hebb repetition effect despite these models being initially developed to accommodate verbal memory. For example, in the primacy model (Page & Norris, 1998, 2009) items are encoded along an exponentially declining primacy gradient. Following repeated exposure to the Hebb sequence, a chunk is formed containing the items and their respective primacy gradients. Guerrette et al. (2017) note that the primacy gradient used in the model necessitates that each item can only be retrieved following recall of the predecessor. They, therefore, suggest that the backward recall in their study followed covert forward recall. One might argue that our experimental design (PR with non-verbal stimuli and CA) prevents covert forward recall in order to identify the serial position of each tested item. If so, the Primacy Model cannot account for the ability to perform the PR task. However, during the review process it was suggested that participants might still employ the primacy gradient in order to recall the position of the test items. Since each sequence item would possess an activation level based upon its position along the exponentially declining primacy function, this activation level could be used to estimate the serial position of the test item. This activation signal would become an increasingly reliable positional marker following repeated exposure to the Hebb sequence.

The present data can also be interpreted via the positional model outlined by Burgess and Hitch (2006). In this model the associations between items and context signals (which include positional information) become stronger following repeated presentation. Recall of items in the PR condition could reflect the positional signal associated with each tested item, with the reliability of this signal increasing following repetitions of the Hebb sequence (however, it should be noted that positional models of the Hebb repetition effect have faced problems, Cumming et al., 2003; Hitch, Fastame, & Flude, 2005).

It is worth re-emphasising that both models described above were developed for verbal serial order memory. It is however, conceivable that the principles of these models could be applied to non-verbal stimuli, especially considering the growing evidence for order memory functional similarity across stimulus types. As demonstrated in the present experiment, the Hebb repetition effect is evident for non-verbal stimuli, illustrating the commonality of this effect (see also Couture & Tremblay, 2006; Johnson et al., 2013, 2016; Parmentier et al., 2008; Page et al., 2006). Similarly, when task constraints are consistent across stimuli, order memory serial position functions have been shown to be qualitatively equivalent cross-modally both in respect to accuracy (e.g. Avons, 1998; Guérard & Tremblay, 2008; Parmentier & Jones, 2000; Ward, Avons, & Melling, 2005) and error distributions (e.g. Guérard & Tremblay, 2008; Smyth, Hay, Hitch, & Horton, 2005). With evidence increasingly pointing towards analogous order memory processes (Hitch, Flude, & Burgess, 2009; Vandierendonck, 2016), models of order memory should consider the extent to which they are applicable cross-modally.

In conclusion, the present study has shown that the Hebb repetition effect persists when forward recall is constrained through a combined use of a novel positional recall procedure, employment of non-verbal stimuli, and CA. This suggests that the visual Hebb repetition effect, analogous to that found with verbal memory, is underpinned via repeated perceptual learning and not learning at output. The findings provide further support for the commonality of the Hebb repetition effect across visual and verbal stimuli.

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