Replication of Couture's et al. (2008)

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***Abstract*—The concept of error learning in the Hebb repetition effect, proposed by Couture and colleagues, constitutes an interesting new aspect for studies on human memory and learning. By replicating this paper, we hope to further your knowledge on the topics and verify the validity of error learning by testing its reproducibility and its applicability to other types of stimuli. Therefore, while the immediate serial recall task in the original paper presented letters auditorily as items to be recalled, we added a visual immediate serial recall task with emojis to test our hypothesis. Our results, despite suggesting error learning qualitatively, could not replicate Couture et al.'s results. Nevertheless, further studies need to be undertaken to conscientiously arbitrate about the validity of the error leaning effect.**

Keywords—Hebb repetition effect, sequence learning, serial recall, implicit memory, error analysis, response-based learning

I. INTRODUCTION

The Hebb repetition effect consists of the cumulative learning of a sequence when presented in a surreptitious and recurrent manner. First reported by Donald O. Hebb in an already considered classical experiment (1961), this form of implicit learning has been instrumental in the study of sequence memory and learning. The typical procedure for studying the Hebb repetition effect involves the presentation of a series of immediate serial recall (ISR) trials, in which participants must recall the correct order a sequence of items has appeared. Within a series, among unique non-repeating sequences, and unbeknownst to the subject, a specific sequence is repeated every n^{th} trial. With this setting, the Hebb repetition effect is evidenced when there is a gradual improvement in the recall of repeated sequences relative to the recall of non-repeated sequences.

ISR tasks have been largely used to study cumulative learning of Hebbian-like sequences. The classic way of measuring the serial recall performance in ISR tasks –and therefore detecting whether there is a Hebb repetition effect– is to consider the proportion of correct responses. However, it is of relevance to highlight the work of Estes (1991), who observed how certain errors were recurrent across trials in ISR tasks.

Following this line of research, Couture, Lafond & Tremblay (2008) aimed to investigate the role of error learning in the Hebb repetition effect. Since the standard way of measuring recall performance was not suitable for the study of error learning, they proposed an analysis of individual response probabilities that depended on the number of past occurrences of each given response. The observed results revealed that, for both correct answers and errors, the probability of producing a specific response increased with the number of its prior occurrences. Hence, two forms of cumulative learning seemed to occur: learning of correct answers –corresponding to the classical Hebb repetition effect– and learning of erroneous answers. Together, these effects were suggested to be response learning.

There is no doubt that the Hebb repetition effect is a valid and highly general phenomenon of memory for serial recall, and for that reason it has been used as an explanatory target for several computational models (see Burgess & Hitch, 1999, 2006; Page & Noris, 2009). Despite this, there has been a lot of discussion around the nature and the scope of its validity. A crucial point that still lingers on is its role and validity as a model of phonological word-form learning. (e.g. Page et al., 2013; Page & Noris, 2009a; Page et al., 2006; Szmalec et al., 2009).

When considering the different nature of the stimuli to which Hebb effect applies, there is some research, although also no single conclusion. The Hebb repetition effect has been tested primarily with verbal information, such as digits or letters in both auditory (Hebb, 1961; McKelvie, 1987; Melton, 1963) and visual (Hitch, Fastame & Flude, 2003) modalities. Nevertheless, Hebb effect has also been studied with other types of stimuli, e.g., visual-spatial locations (Couture & Tremblay, 2006; Turcote, Gagnon & Poirier, 2005; Milner, 1971), faces (Horton et al, 2008) and pictures (Page, Cumming, Norris Hitch & McNeil, 2006).

While studying the Hebb effect with faces, Horton et al. (2008) concluded that the way the faces were presented had a significant effect on the Hebb learning effect, especially that it depends on how distinguishable list items are visually (see also Melton, 1967). On another topic, Parmetier and colleagues (2008) postulated that a lack of perceptual never coherence gives rise to an absence of learning (see also Hughes & Jones. 2004).

Lafond, Tremblay and Parmentier (2010), taking the Couture and colleagues error learning hypothesis as a premise, provided evidence that undetected Hebb learning, as in the case of Horton et al. (2008) and the one of Parmentier et al. (2008), could be error learning that hasn't been accounted for. Furthermore, there is empirical evidence from memory experiments (like word list learning) that eliciting incorrect answers has a greater and detrimental influence on recall than repeating presentations of the correct responses (Baddeley & Wilson, 2001). Although, it is also worth taking into consideration that some researchers suggested that, in the context of serial recall, recall errors are mostly short-lived (Cumming et al., 2003; Henson, 1998; McNicol, 1978). Another key aspect of error learning in the Hebb effect is its influence in learning, more precisely learning by practicing. McClelland (2001) considers that Hebbian learning, by reinforcing incorrect answers, is likely \to hinder the beneficial effects of practice and rote learning in memory (see also Johnson & Proctor, 2017).

As stated before, research on the Hebb repetition effect is still far from a final answer. In this line of though, it is interesting to consider that the Hebb repetition effect is almost always studied using the same set of items for repeating and filler sequences, but that Page and colleagues (2013) see a week or almost nonexistent Hebb learning for experiments in which the items to be recalled (repeating and non-repeating) were drawn from the same set of item, while in experiments where items came from a different set a strong Hebb effect was detected. In the paper, they posit that "recalling many lists containing the same items in different orders can interfere with the learning of the order in a repeating list." (p. 511) And that "the interference seems to be confined to learning; there was no buildup of what one might call proactive interference between (non-repeating) lists in general." (p. 511) Moreover, their results suggest that this Hebb learning is fast and long lasting. Learning needs to begin from the first presentation and all lists need to be learned to some extent (including non-repeating sequences), because when first presented, it is unknown if they will be repeated in future.

These are just a few of the examples that show how the Hebb repetition effect, and the new angle of the error repetition effect must be analyzed from a wide range of perspectives to be able to draw significant conclusions. For instance, error learning, as reported by Couture and his team, has not yet been tested in stimuli other than the auditory-verbal.

While analyzing the paper from Couture and his colleagues, we considered some improvements. As mentioned before, testing if error learning would also apply to stimuli of a different nature, like the classical Hebb repetition effect does. Another improvement that we thought about is taking into account the initial ability of each participant for an ISR task and its possible influence in the results in the classical Hebb effect and error learning. Furthermore, besides many other considerations, we contemplated restricting the randomness of the filler sequences to avoid those sequences would be very similar, specially to the repeated one.

Reproducibility, the ability to run an experiment and reach the same results as another person doing the same experiment, is an important feature of scientific research, nonetheless, currently, it is uncertain how much research results are replicable. Having this in mind, the concept of error learning constitutes an important new issue for studies on human memory, theoretical models of serial recall, and conceptualizations of implicit memory. And, by replicating this paper we hope to further your knowledge on the topic and verify the validity of error learning by testing its reproducibility.

In the attempt to push this discussion, forward we sought to further investigate in the visual domain the role of error learning as described by Couture and colleagues (2008). We propose an extension of that experiment in which we will investigate the extent of error learning in a visual ISR task. We use input sequences of emojis of fruit and vegetables, used in this context as pictograms, simple symbolic visual stimuli, that are easily reconnected to their corresponding physical object. This choice was based on three main points: firstly, visually representing letters would be the same type of serial recall only presented in a different way; secondly, we wanted a visual stimuli that would have some immediate meaning for the participant viewing it, as letters have; and thirdly, we wanted to avoid having to big of a change in stimuli that could hamper our results, namely, by using visual-spatial stimuli.

The aim of this experiment is to test if assumptions about the Hebb repetition effect, and error learning, will hold true regardless of the type of stimulus presented. We hypothesize that, like in the classical Hebb repetition effect, error learning will be present also with visual symbolic stimuli. Nevertheless, we expect to observe significant differences in the learning slopes between the two types of stimuli. We also hope that our findings –more importantly the qualitative differences between the predominant type of learning observed between the classical verbal ISR task and our extension– will pose new questions about the nature of cumulative learning of correct and incorrect responses in the recalling of repeated sequences. As will be shown in detail in the discussion section, some of the results obtained in this replication differ from those obtained in the experiment of Couture et al. (2008).

II. Methods

As stated before, the present paper is a replication of the study conducted by Couture and his team (2008), titled "Learning correct responses and errors in the Hebb repetition effect: two faces of the same coin". Consequently, its methodology is largely based on the one used in the original paper, even for the variations introduced.

A. Participants

The original paper had 24 participants from the Université Laval, Québec, Canada that received a small honorarium in exchange for the participation. The small sample size can be justified because for the effect being studied in this paper, the degrees of freedom reflect the number of trials of each participant and not the number of participants and, accordingly, increasing the sample size would not impact the power of the calculations.

For this replication, participants were selected by convenience and data was collected from non-native english speakers, 14 men and 14 women with ages between 19 and 36, in majority students from University Pompeu Fabra.

B. Experimental Design

The experiment described in this paper consisted of two parts with a break of 2 to 5 minutes in between. One part of the experiment was the replication of the target paper –a verbal ISR task. And the other part was our variation –a visual ISR task. To counterbalance the possible effects of fatigue caused by the experiment, half of the participants took the verbal IRS task first and the other half took the visual task first.

C. Setup and Procedure

The task of this experiment consisted of recalling a sequence of 9 items that were presented by clicking in the right order on the items shown on the screen after each presentation. The items presented on the original paper were a set of monosyllabic letters (D, F, G, H, K, L, N, Q, and R) in different orders presented auditorily. And in the extension, to test if error learning would also occur in a visual ISR task, the items used were emojis of fruits and vegetables presented on the screen (see Fig. 1).

Each experiment consisted of 2 practice trials followed by 48 trials. These 48 trials consisted of 12 blocks of 3 randomly generated sequences plus 1 repeated sequence that was chosen randomly at the beginning of each experiment. After the presentation of each sequence, the items were presented horizontally on the screen in a random order, so the participants could give their response by clicking on the items with the mouse. And after each item was selected, it changed its color. In the case of the letter from black to green and in the case of the emoji from colors to a black silhouette.

Participants were asked to memorize the presented items and to strive to reproduce the correct sequence in the recall phase, without having any further instructions, nor receiving any type of feedback for their answers.

The ISR task was designed following the one created by Couture et al. However, despite having access to the programmed task of the original paper, since it was compiled in Java there was the necessity to program a new one that would include the extension added to it. The task for this replication was programmed in Love.

Fig. 1 Random sequence of emojis captured from the recall phase of the visual ISR task of the experiment.

Fig. 2 Random sequence of letters captured from the recall phase of the auditory ISR task of the experiment.

D. Analysis of Data

As previously mentioned, the classical Hebb repetition effect is normally studied by calculating the proportion of correct responses for repeated and novel sequences. Every item recalled in their correct serial position is considered correct. Afterwards, the two average learning slopes are compared. The first average learning slope represents the change in proportion of correct answers on presentation 1 to 12 of the repeated sequence, and the second slope represents the change in proportion of correct responses for the 12 corresponding blocks of three non-repeated sequences.

Adapting the error analysis approach used by Estes (1991), the authors of the paper being replicated posit a new way to calculate the error learning that can also be used to study the classical Hebb effect. As in most classical studies (see Hebb, 1961), a closed pool of to-be-remembered items was used in the original study, so the error analysis was constrained to the examination of protrusions. These errors refer to the incorrect production of an item from the closed pool of to-be-remembered items at its serial position of preceding trials. Error learning in the Hebb repetition effect is studied thus by calculating the proportion of new and repeated errors in the 12 repeated sequences. Responses not recalled in their proper serial positions were classified as erroneous responses. And these erroneous responses were classified in two types: if the same erroneous answer was given in the same serial position in previous presentations, the error was considered repeated; otherwise, the error was considered new. Repeated errors were furthermore decomposed into repetitions from the last repeated presentation (n – 1) or repetitions from an earlier presentation (n – 2+).

To calculate the error learning, one first needs to calculate the probabilities for the nine correct responses (one for each serial position) and 16 transposition errors (p – 1 and p + 1) - the ones more likely to be learned. The authors of the original paper argue that "if learning takes place on the basis of responses made (correct or incorrect), then the probability of producing a given response should increase as a function of the number of times the same response had previously been recalled (referred to as the number of past occurrences)" (Couture et al., 2008: 527). For each repetition, probabilities are calculated by dividing the number of past occurrences (a response recalled at the relevant serial position) by the number of opportunities (the number of presentations between the –last time this answer was given and the current one i.e., the number of presentations in which the answer being evaluated could have been produced). Subsequently, the learning slopes obtained through this method were compared.

Following the calculation of probabilities, a within-subjects repeated measures ANOVA was performed on the obtained probabilities to compare the effect of previous occurrences of a specific response –in the repeated series at the same position– to the probability of producing the same response. It is important to note that only the estimated probabilities for repetitions 1 to 4 were considered since certain errors were not repeated beyond the fourth occurrence, so it was no longer possible to calculate and compare the following probabilities (for more information about the error analysis, please see original paper).

Subsequently, a two-tailed paired t-test was conducted to compare the serial recall performance for both correct answers and errors in lexical auditory stimulus and symbolic visual stimulus.

It is important to note that, in the original experiment, a simulation was designed to test a null model which assumed that there was only correct repetition learning and no error learning. The simulated data validated that the error learning measures were valid and not biased in any way. However, we did not have access to that data in our replication, so an analysis between-subjects using a mixed ANOVA was not possible.

III. Results

The first part of the statistical analysis will focus on the mere replication of the experiment conducted by Couture and his team (2008) –that is, the analysis of serial recall performance in both correct answers and errors exclusively on the auditory-verbal part. For the second part, we will analyze the serial recall performance in both correct answers and errors with symbolic visual stimuli. Our extension will also examine whether there are differences in the learning slopes between the two types of stimuli.

The probabilities for each correct response and transposition, as a function of the number of past occurrences, are listed in Table 2 and Table 3. For each response, the slope of the estimated probabilities for Repetitions 1 to 4 was calculated. A positive slope suggests that learning occurred.

Table 1. Observed Response Probabilities and Slopes for Correct Responses on the Repeated Sequence as a Function of Prior Occurrences of That Response (Repetitions 1–4)

	Prior occurrences				
Serial Position	1	2	3	4	Slope
1	.70	.69	.79	.79	.74
2	.61	.65	.70	.82	.70
3	.57	.62	.65	.64	.62
4	.47	.53	.70	.74	.61
5	.47	.44	.56	.53	.50
6	.28	.37	.44	.54	.41
7	.37	.32	.43	.45	.39
8	.36	.38	.54	.49	.44
9	.45	.53	.56	.72	.56
M	.48	.50	.60	.64	.55

Table 2. Observed Response Probabilities and Slopes for p – 1 or p + 1 Transposition Errors on the Repeated Sequence as a Function of Prior Occurrences of That Response (Repetitions 1–4)

	Prior occurrences				
Transpo-sition	1	2	3	4	Slope
T_1+1	.09	.06	.00	-	.05
T_2–1	.01	.21	.05	.00	.08
T_2+1	.01	.17	.12	.33	.18
T_3–1	.16	.08	.20	.38	.20
T_3+1	.10	.09	.60	.25	.26
T_4–1	.12	.09	.20	.00	.10
T_4+1	.01	.37	.44	.54	.13
T_5–1	.10	.13	.07	1.00	.33
T_5+1	.11	.18	.13	.00	.10
T_6–1	.12	.19	.11	.00	.11
T_6+1	.17	.18	.41	.21	.24
T_7–1	.17	.15	.27	.29	.22
T_7+1	.19	.15	.16	.11	.15
T_8–1	.20	.19	.25	.27	.23
T_8+1	.13	.28	.24	.10	.19
T_9–1	.12	.25	.31	.14	.21
M	.13	.16	.20	.22	.17

A. *Replication of Couture's et al. (2008)*

To study the classical Hebb Effect for the auditory part, that is, the correct answers learning for auditory lexical stimulus, a repeated measures ANOVA was performed to compare the changes in proportion of correct responses on Presentation 1 to 12 for the repeated sequences. There was a statistically significant difference in the probability of producing a specific correct response for the repeated sequences ($F(24) = 8.20$, $p < 0.000$).

For the error learning, a repeated measures ANOVA was also performed to compare the changes in proportion of erroneous responses on Presentation 1 to 12 the repeated sequences. There was no statistically significant difference in the probability of producing a specific erroneous response for the repeated sequences ($F(39) = 2.72$, $p = 0.057 > 0.05$).

The key outcome of this analysis is summarized in Figure 2.

B. *Visual ISR task*

To study the classical Hebb Effect in the visual part, that is, the correct answers learning for symbolic visual stimuli, a repeated measures ANOVA was performed to compare the changes in proportion of correct responses on Presentation 1 to 12 for the repeated sequences. There was a statistically significant difference in the probability of producing a specific correct response for the repeated sequences ($F(24) = 6.76$, $p < 0.002$).

For the error learning, a repeated measures ANOVA was performed to compare the changes in proportion of erroneous responses on Presentation 1 to 12 the repeated sequences. There was no statistically significant difference in the probability of producing a specific erroneous response for the repeated sequences ($F(33) = 0.31$, $p = 0.82 > 0.05$).

The key outcome of this analysis is summarized in Fig 3.

C. *Type of Stimuli*

A paired samples t-test was performed to compare the average correct slopes for both parts. There was no significant difference in the average slope for correct answers between the auditory part ($M = 0.07$, $SD = 1.13$) and the visual part ($M = 0.05$, $SD = 1.13$); $t(68) = 0.49$, $p = 0.62 > 0.05$.

On the other side, a paired samples t-test was also performed to compare the average error slopes for the auditory and visual parts. In this case there was a significant difference in the average slope for incorrect answers between the auditory part ($M = 0.08$, $SD = 1.13$) and the visual part ($M = 0.003$, $SD = 1.13$); $t(124) = 2.85$, $p = 0.004 > 0.01$.

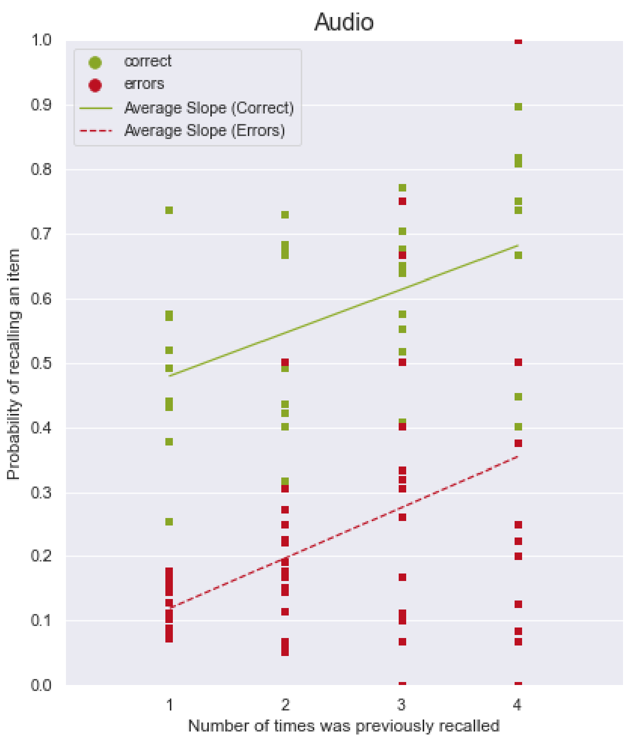

Fig. 3 Mean learning slopes for the auditory data showing the probability of recalling an item as a function of the number of times this item was previously recalled. The slope for correct answers is the average learning slope for the nine correct responses (one for each serial position). The slope for errors is the average learning slope for the 16 errors studied in the present analysis (p — 1 or p + 1 transpositions).

IV. Discussion

One of the main reasons we decided to replicate and propose an extension for Couture's et al. (2009) was understanding how consistently the classical Hebb repetition effect and the observed error learning phenomenon would scale up to more complex stimuli. Studying prior research on the matter led us to many open questions that we felt vital to address to better understand how this learning process works.

For the replication of Couture's paper, classical Hebb repetition effect is observed, that is, a serial recall learning for auditory-verbal beyond mere task practice, for correct answers. A classical visual Hebb effect, that is, a serial recall learning of symbolic visual stimulus is also found in the proposed extension. These results are within expectations, as the Hebb effect has been demonstrated in different occasions and conditions.

On the other hand, no significant error learning was found in either the replication or the proposed extension. However, the results for the error learning in auditory-verbal stimulus, however, tends to significance. Considering the limited research examining the degree to which error learning contributes to the memory processes related to the Hebb repetition effect, future research is needed.

Finally, a significant difference is found in the slopes of the error learning curves, but not for the correct answers learning. This somehow supports our initial expectations, in the sense that the processing of different types of stimuli were expected to affect the way in which the different dimensions of the Hebb effect are manifested.

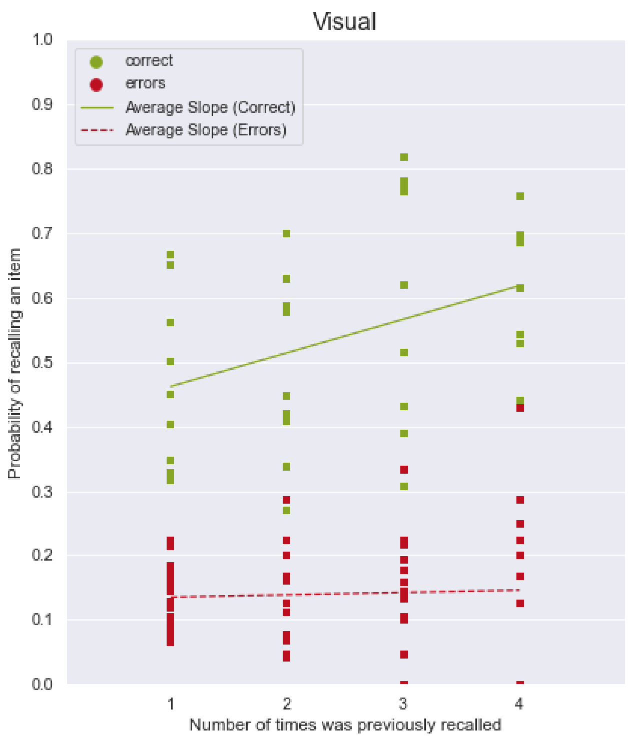

Fig. 4 Mean learning slopes for the visual data showing the probability of recalling an item as a function of the number of times this item was previously recalled.

In any case, it should be noted that, despite these differences being detected, no significant error learning occurred in either type of stimulus. Rather than drawing premature conclusions, we consider it more appropriate at this stage to consolidate new questions that would help confront aspects of this experiment that we think, if more deeply investigated, could lead to new understanding of Hebb learning and error learning. We could not tackle possible biases of the ecological validity type, but we considered a first important step towards a more realistic scenario to experiment with different categories and complexity of stimuli. As for the differences with respect to the original experiment, it should be noted that the recordings used for the auditory part were in English, and the subjects who participated, even though they had a good command of English, were mostly Spanish speakers.

On a qualitative level, another important factor that was reported by many of our subjects is how tiring the task they had to perform was. We were not able to rule out this as a biasing characteristic of this (and similar) experiments. We could not help but ask ourselves if the experiment itself was inflicting on our subjects the same cognitively narrowing "overdose of repetitions" that Edward C. Tolman (1948) thought to be the reason for stereotypical behaviors in rats involved in behaviorists experiments. On the other hand we also received spontaneous feedback on the emergence of a varied palette of recalling strategies by the subjects. We think these are focal points that should be part of future considerations in this category of experiments.

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