Introduction

The term "testing effect" refers to the finding that, when it comes to long-term retention of a piece of information, retrieving that information from memory trumps restudying it (Adesope, Trevisan, & Sundararajan, 2017; Glover, 1989; Roediger III & Butler, 2011; Roediger III & Karpicke, 2006a, 2006b; Rowland, 2014). It is generally recognised that testing can have two types of effects — *direct* and *indirect* (Arnold & McDermott, 2013b; Roediger III & Karpicke, 2006a). Direct effects refer specifically to the increased retention that ensues from repeatedly *successfully* retrieving the target information — a process which is, presumably, reactivated at the time of a later test. A typical demonstration of the testing effect entails an initial learning phase, followed by a period during which participants either restudy the same material, engage in a memory test involving the studied material, or are not exposed to the original material at all. Finally, after a retention interval, an additional memory test reveals that the group subjected to a memory test during the intervening period has a distinct advantage over the other two groups.

On the other hand, indirect effects are brought about by some other process or processes besides the act of taking the test (Roediger III & Karpicke, 2006a; but for a different view, see Kornell, Klein, & Rawson, 2015). For example, *unsuccessful* retrieval attempts (which are not followed by feedback) can, through subsequent repeated encoding, also generate a testing effect, namely *test-potentiated (re)learning* (Arnold & McDermott, 2013a, 2013b; Izawa, 1966, 1970; Kornell, Hays, & Bjork, 2009; Wissman & Rawson, 2018). With the aim of disentagling test-potentiated (re)learning from the testing effect, Arnold and McDermott (2013b) let participants learn a list of 25 word pairs. One group completed nine cycles comprising a single test and a restudy session, while another completed three cycles. In order to isolate the effect of unsuccessful from successful retrieval attempts, they focused their analysis only on words not recalled on a test preceding a restudy episode. Results showed that, compared to taking fewer tests, taking more tests produces a greater increase in the proportion of *newly* retrieved items (i.e. words that were not retrieved on a pretest) in a test immediately following a restudy episode — a veritable potentiation of learning.

Test-potentiated new learning

Juxtaposed to the well established finding that attempting to recall studied material compared to restudying it, facilitates the long-term retention of *that* material, stand the results of a decade of research showing that retrieving previously studied information can even facilitate the acquisition of *new* information (Chan, Meissner, & Davis, 2018; Yang, Potts, & Shanks, 2018). If each additional study episode in the paradigm used to demonstrate test-potentiated learning contains *new* materials (giving a now standard blocked design; Chan, Manley, Davis, and Szpunar (2018)), one still observes that testing the memory of those new materials after each learning episode, compared to restudying the same materials, yields a greater number of correct responses and a decrease of proactive interference on a test administered to all subjects after the final learning episode (e.g. Szpunar, Khan, & Schacter, 2013; Szpunar, McDermott, & Roediger, 2008; Wissman, Rawson, & Pyc, 2011). Following the reasoning of Chan, Meissner, and Davis (2018), in this paper we will use the term "test-potentiated *new* learning" (TPNL) to denote this effect.

In one of the earliest studies showing the effect of TPNL, Darley and Murdock (1971) observed that, when recalling studied lists of words, participants systematically produce more prior-list intrusions when probed for a given list, if their memory of a prior list had not been tested before they proceeded to study the given list. These findings were corroborated by Tulving and Watkins (1974). Building on these results, Szpunar et al. (2008) conducted a study using a blocked design wherein they told their subjects to study five lists of items in anticipation of a final cumulative test. All subjects were tested immediately after studying the final list, but they engaged in different intermittent activities between studying the first four lists. One group was tested on each list after studying it, another group restudied each list, and a third group completed a mathematical distractor task. Participants whose memory was tested after each list produced more correct responses and fewer prior-list intrusions on the immediate test administered after studying the last list. The authors explained the found benefit of testing in terms of a segregation mechanism that prevents overburdening of retrieval cues, which, in the absence of testing, causes a build-up of proactive interference. The following decade has seen a renewal of interest in TPNL (Chan, Meissner, & Davis,

2018; Pastötter & Bäuml, 2014; Yang et al., 2018), with studies mainly using the multilist learning paradigm to delineate the scope of the effect with respect to various moderating variables: the type of study materials, varieties of study designs (blocked vs. interleaved), and populations, to name a few.

Theoretical overview

Recently, Chan, Meissner, and Davis (2018) provided a meta-analytic analysis and comprehensive overview of the literature, identifying four *nonconflicting* theoretical frameworks which were put forth throughout the years as viable explanations for TPNL. *Resource theories* generally posit that testing increases cognitive resources, but they propose different mechanisms by which this is achieved: (1) proactive interference reduction (e.g. Nunes & Weinstein, 2012; Szpunar et al., 2008; Wahlheim, 2015; Weinstein, McDermott, & Szpunar, 2011), (2) restoration of encoding/attentional resources (e.g. Pastötter, Schicker, Niedernhuber, & Bäuml, 2011), or (3) alteration of mind wandering patterns (e.g. Jing, Szpunar, & Schacter, 2016; Szpunar, Khan, & Schacter, 2013; Szpunar, Moulton, & Schacter, 2013). Whereas resource theories focus on the amount of deployable cognitive resources, *metacognitive theories* emphasise the optimisation of encoding strategies induced by retrieval attempts (e.g. Chan, Manley, et al., 2018; Cho, Neely, Crocco, & Vitrano, 2017). For example, in a recent investigation, Chan, Manley, et al. (2018) found that, compared to untested groups, the group whose memory for the first three word lists was subjected to interpolated testing displayed superior semantic organisation across lists. These findigs reflect a similar pattern obtained for the testing effect, where a greater number of tests is associated with improved organisation of output displayed upon testing (Karpicke, 2012; Zaromb & Roediger, 2010).

The key idea underlying the third framework – *context theories* – is that, apart from storing the studied information themselves, people store the related contextual information as well (e.g. Lehman, Smith, & Karpicke, 2014). Afterwards, the accessibility of this contextual information can affect the likelihood of successful retrieval of target information. Furthermore, the claim is that, unlike restudying, attempting retrieval causes an internal context change relative to the study context (Jang & Huber, 2008; Sahakyan & Kelley, 2002), and recalled

items may be updated with contextual information from the retrieval attempt, while newly encountered information is still associated only with the study context. Therefore, recalling new-learning items is limited to only those items associated exclusively with the study context, providing them with the advantage observed upon testing. While this circumscription of separate learning episodes is at the core of both resource and context accounts, its effect on learning is supposedly different. According to the former, isolating a learning episode through attempts at recall increases resources for subsequent learning by preventing *encoding-based* proactive interference. On the other hand, the latter place the emphasis on later *retrieval* processes, whereby isolating an earlier learning episode reduces the memory search set for retrieval.

Finally, *integration theories* advance the notion that interpolated testing facilitates the integration of the new-learning material either with its retrieval cues or with the original-learning material. On one account, testing increases the likelihood of spontaneous covert retrieval of original-learning items during the study of new items, fostering their integration, thereby increasing conceptual organisation (e.g. Jing et al., 2016) and the effectiveness of retrieval cues (Pyc & Rawson, 2010). For example, Jing et al. (2016) found that interpolated testing increased the clustering of related information that is acquired across different segments within a video-recorded lecture.

Nonepisodic recall

One of the more curious findings in the field is that TPNL can arise not only after retrieving the previously studied material (episodic retrieval), but also after retrieval of information unrelated to the studied material from semantic memory (Divis & Benjamin, 2014; Pastötter et al., 2011), or from short-term memory (Pastötter et al., 2011), although there have been unsuccessful attempts at replication (e.g. Weinstein, McDermott, Szpunar, Bäuml, & Pastötter, 2015).

Pastötter et al. (2011) let their participants learn five lists of 20 words while engaging in varied interlist activities. They either restudied the lists, recalled the words from the list, generated as many words as they could from one of four semantic categories (e.g. professions),

engaged in a 2-back short-term memory task, or counted backwards from a random three-digit number. They found that all three forms of retrieval induced TPNL. In their first experiment, Divis and Benjamin (2014) adapted the procedure from Pastötter et al. (2011), using only the semantic generation and distractor (counting backwards) tasks, and found that interleaved semantic retrieval enhanced performance for final list recall. They replicated and extended these findings in their second experiment by using complex learning materials: lists of words were replaced by texts related to animals, while learning was evaluated with short-answer and multiple-choice questions.

The argument these two groups of authors invoke to explain their results is that nonepisodic retrieval tasks sufficiently alter participant's internal context. Because the last study session is not affected by an additional context shift, a beneficial segregation of the final study context from the previous ones is produced. However, summarising their results, Chan, Meissner, and Davis (2018) highlighted resource and integration theories as accounts which have thus far garnered more empirical support, giving a slight upper hand to integration theories, while stating that context theories are least supported by extant research.

Feedback

Although corrective feedback is known to augment the testing effect (Roediger III & Butler, 2011), there is a paucity of research into the effect of feedback on TPNL, especially when considering studies that have implemented the blocked design. Feedback is particularly important for recognition test such as multiple-choice tests since the usual benefit testing confers might turn into a disadvantage in case the test-taker selects a lure (Marsh, Roediger, Bjork, & Bjork, 2007; Roediger & Marsh, 2005). Moreover, evidence points to the timing of feedback being a relevant variable when gauging its influence on learning, with delayed feedback showing superior effects compared to immediate feedback (Butler, Karpicke, & Roediger, 2007; Butler & Roediger, 2008; Metcalfe, Kornell, & Finn, 2009; Smith & Kimball, 2010). For example, participants in a study by Butler and Roediger (2008) read prose passages and then either took or did not take an initial multiple-choice test. If they took the test,

corrective feedback was either not given, given immediately after each answer was provided, or given in bulk after the entire test. A final test administered one week after the initial test revealed (1) that taking an initial test alone tripled the success rate on the final test relative to studying, (2) that giving immediate feedback increased performance for another 10%, and (3) that delayed feedback increased performance even further by 11%.

The variable of corrective feedback may be a fruitful avenue for research because resource and integration theories provide conflicting predictions regarding its effects on TPNL (Chan, Meissner, & Davis, 2018). Providing corrective feedback should increase the likelihood of intrusions during new learning, which are deemed beneficial from the standpoint of integration theories, but detrimental from the point of view of resource theories. Thus, feedback should reduce TPNL according to resource theories, but increase it according to integration theories.

Present study

Our study had two main goals. Firstly, we sought to replicate the TPNL effect in an ecologically valid setting, by using complex learning materials and standard multiple-choice items. Secondly, guided by the analysis of gaps in the field provided by Chan, Meissner, and Davis (2018), who identified a relative dearth of studies using nonepisodic retrieval and recognition (e.g. multiple-choice items) for the interpolated activity, and furthermore a lack of studies introducing feedback in a blocked study design, we attempted to expand the existing body of literature by employing a novel combination of variables, in order to examine their effects and interactions in the context of TPNL.

In particular, we assumed that retrieval could be the active component in interpolated activities that have been shown to give rise to TPNL. To test this, apart form using rereading as a control comparison task, we formed two memory tests, one of which tapped into episodic (assessing memory of the studied materials) while the other tapped into semantic (i.e. nonepisodic) memory (assessing general knowledge). Following the reasoning of Chan, Meissner, and Davis (2018), in order to pit integration and resources accounts of TPNL against each other, participants either were or were not given feedback upon completing an interpolated activity episode. Bearing in mind the necessity of systematically assessing

the impact of proactive interference on participants' performance, we used multiple-choice questions designed to assess memory both in terms of correct answers and susceptibility to intrusions.

Based on the preceding discussion, we predicted the following:

H1: Compared to the rereading group, participants in the retrieval groups will have a significantly higher average total score on the final test. Furthermore, we expect to find no difference between the two groups having different types of retrieval.

H2: Participants in the episodic retrieval condition will display the lowest susceptibility to proactive interference, followed by participants in the semantic retrieval condition, and finally by the participants in the rereading condition. We expect all three differences to be statistically significant.

H3: When looking at the two retrieval groups, we expect to find a significant main effect of feedback on the average number of correctly answered questions.

H4: We expect to find an interaction effect between feedback presentation and type of interpolated activity. Specifically, we assume that presenting feedback will have a positive effect on the average number of correctly answered questions, but only for the participants in the content-related test condition. The remaining three groups will not differ.

H5: There will be a main effect of feedback on the level of proactive interference. Participants receiving feedback will have a significantly higher average number of intrusions than participants receiving no feedback.

H6: Finally, we expect to find an interaction effect of activity type and feedback presentation on the number of intrusions, but cannot set a specific prediction regarding its pattern.

To anticipate the results, only episodic recall was found to be effective in generating TPNL, while providing feedback was found to be of no consequence for TPNL.

Methods

The analysis plan was preregistered on GitHub, which also serves all project materials, data and analyses scripts, together with the whole project history. The repository can be found at `[URL]`.

Participants and design

Undergraduate and graduate phonetics and psychology students (80.8% female, median age = 21, IQR = 3, range = [18, 31], total $N = 207$) participated in the study in exchange for course credit. We employed a 2 (interpolated activity: episodic vs semantic recall) x 2 (feedback: given vs not given) between-subjects design. Rereading served as a comparison interpolated activity, which was given to an additional control group. In total, this amounts to five separate groups, to which the participants were randomly assigned.

Materials and procedure

Participants read an expository text about weeds, drawn from a chapter in a university-level textbook. Some sentences and passages were slightly modified, so as to avoid odd language constructions; terms from the binomial nomenclature were translated, and, taking into account the characteristics of the target participant population, some plant names were removed from the text to make it more approachable. The text was divided into three interrelated parts (874, 754, and 835 words) constituting an integrated body of knowledge. Additionally, a practice text (768 words), not directly related to any of the other three parts, was taken from the same chapter. The materials were presented on a PC, in an application constructed using the open source *oTree* framework (version 2.1.35, Chen, Schonger, & Wickens, 2016) for the *Python* programming language (version 3.6.4, October 20, 2018).

For the interpolated activity, participants either (i) answered ten multiple choice questions related to the content of the part they have previously read (episodic recall, hereafter referred to as content-related testing), (ii) answered ten general knowledge multiple choice questions

(semantic recall, hereafter referred to as general-knowledge testing) or (iii) reread the same part of the text they have previously read.

Further, we have manipulated whether or not participants received feedback on their accomplishment on the interpolated tests. Feedback was presented on a separate screen which listed the questions, the participant's answers, and the correct answers in a tabular format. Incorrectly answered questions were highlighted in red, and correctly answered questions in green. After 40 seconds elapsed, a "Next" button appeared, allowing participants to proceed to the next part. By setting this cooldown period, by emphasising that there would be a cumulative test, and through written instructions, we wanted to encourage our participants to carefully examine the feedback. The feedback was presented for maximally 60 seconds, after which the application proceeded to the next part.

The general procedure is shown in Figure 1. Participants were first given a brief introduction to the study, and were encouraged to carefully read and follow the written instructions. Then, they were led to a computer which was running a fullscreen instance of the *oTree* application with a randomly chosen experimental condition. There, participants read the informed consent form and, in case there were no questions, started the experiment.

After entering their personal information, participants were presented with the instructions for their first task, which was to read the practice text at a speed that comes naturally to them. Unbeknownst to the participants, the time they took to read the practice text was recorded, and used as the basis for determining the reading time limits for the remaining texts. However, the lowest possible time limit was set to 5 minutes, and the longest to 8 minutes.

Next, participants were familiarised with the interpolated activity they were going to perform during the main part of the procedure. The content-related test group answered four questions based on the practice text, the general-knowledge test group answered four general knowledge questions, and the rereading group reread the practice text (this time with the time limit applied). Subjects in the rereading and general knowledge conditions also answered the four questions related to the practice text, in order to familiarise themselves with the scope and specificity level of the questions they will receive after reading the final text.

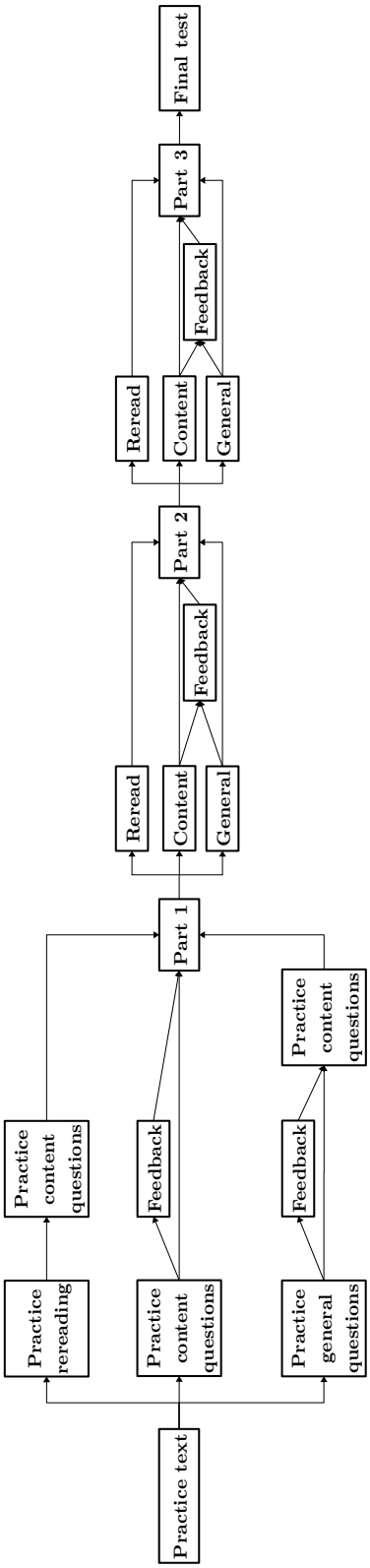

Figure 1. A flowchart depicting the experimental procedure.

Participants assigned to the feedback condition also received feedback on their interpolated activity practice test achievement.

After the practice round, participants proceeded to the main part of the study, engaging in the interpolated activities they were assigned. Depending on the condition they were assigned to, they also received feedback after every interpolated test.

All participants were told that there would be a cumulative test after the final part of the text, examining their knowledge of all three parts. In reality, the final test examined only the knowledge of the final part. Participants were presented with twenty questions examining their knowledge of that part. No feedback was presented after the final test, irrespective of the experimental condition. The computer recorded whether a participant correctly answered a question and whether the participant chose an intrusive distractor. This allowed us to compute our dependent variables — the total number of correct answers and the total number of intrusive distractors chosen.

In total, forty-four content related questions with four response options were generated from the presented parts of the text. Four questions were presented after the practice text, ten after each of the first two parts (only to the participants in the content related test condition), and twenty after the third part of the text (to all participants). Starting from the second ten-question-set, the distractor options were chosen so that (a) two distractors were plausible, but unrelated to the text, and (b) one distractor was a term or concept mentioned in the previous part of the text — this was considered to be the "intrusive" distractor (sometimes reffered to as the "intrusor" in the rest of this article). Further, twenty-four general knowledge questions were generated. These questions were presented to participants in the general-knowledge test condition, after the first two parts of the text and after the practice text.

Table 1

Descriptive statistics for the DVs broken down by experimental condition.

Measure	Condition	n	M	SE_M	SD	min	max
Total correct	Content, feedback	41	13.22	0.508	3.25	2	19
	Content, no feedback	42	12.79	0.465	3.02	7	19
	General, feedback	40	10.97	0.533	3.37	1	17
	General, no feedback	40	10.47	0.449	2.84	5	16
	Rereading	40	10.88	0.443	2.80	4	17
Total intrusors	Content, feedback	41	3.15	0.258	1.65	0	7
	Content, no feedback	42	3.38	0.257	1.67	0	7
	General, feedback	40	4.17	0.318	2.01	0	8
	General, no feedback	40	4.58	0.288	1.82	1	9
	Rereading	40	4.62	0.350	2.21	1	10

Results

Exclusion criteria

Prior to analysing the data, we have excluded participants based on a priori set criteria. Participants who have spent less than or equal to 90 seconds on the practice text were excluded (1 exclusion). Further, we wanted to exclude participants who have had no correct answers on the final test (0 exclusions). Finally, we have excluded participants who have stated that they have reading deficits (3 exclusions). This left us with a total sample of 203 participants. The descriptives for the sample are shown in Table 1.

Interpolated activity effect

Our first two hypotheses are concerned with the effects of different interpolated activities on the total number of correct answers and total number of intrusive distractors chosen. To test these hypotheses, we have focused only on the groups which have not received feedback (n = 122). This was done because there was no feedback option for the rereading group, and we did not want to treat the feedback and no-feedback general-knowledge and content-related testing groups as equivalent without strong evidence supporting that assumption. We conducted

a one-way MANOVA with interpolated activity as the independent variable and the total number of correct and intrusive options chosen as dependent variables. The correlation between our DVs calculated on the whole sample is $r(201) = -.707$ (95% CI: [-.77, -.63], $p < .0001$).

Pillai's V for the analysis is .126, $p = .004$ (Wilks' $\Lambda = .875$, $p = .003$). The effect size, calculated as $\omega^2_{mult} = .109$ (bootstrap median[1] = .132, BC_α 95% CI = [.012, .201]). To further inspect the relationship of the interpolated activities with our dependent variables, we have conducted a Roy-Bargmann stepdown analysis, as suggested by Tabachnick and Fidell (2012; a linear discriminant analysis with the same aim is available in the supplementary materials). The total number of correct answers was a priori chosen to be the higher priority variable. According to Tabachnick and Fidell (2012), the higher priority variable can be chosen based on theoretical or practical grounds. Since, the total number of correct answers is the criterion that determines a student's success in a testing context, we have chosen this dependent variable as the higher priority one. Therefore, we first conducted an ANOVA with interpolated activity type as the independent variable and the total number of correct answers as the dependent variable.

As could be expected, the ANOVA points to an interpolated activity effect, with $F(2, 119) = 7.541$, $p = .001$. Following the ANOVA, we conducted an ANCOVA, with the total number of correct answers as the covariate, and the total number of intrusors as the dependent variable. The results imply a main effect of the total number of correct answers ($F(1, 118) = 79.674$, $p < .0001$), but after taking into account the number of correct answers, there is no evidence for an effect of interpolated activity on the total number of chosen intrusors ($F(2, 118) = 0.844$, $p = .433$). For now, we may claim that we do not have any evidence to support our second hypothesis that the type of interpolated activity will have an effect on the number of intrusors.

In order to test our first hypothesis, we have contrasted (i) the rereading group with the two test groups, and (ii) the two test groups with each other, taking only the total number of correct answers as the DV. The first contrast finds no evidence of a difference between

[1] All bootstrap estimates taken from 10000 replications.

the rereading group and the two test groups ($t(119) = 1.355$, $p = .178$, $g_s = 0.19$, 95% CI = [-0.19, 0.57], Cohen's $U_{3,g_s} = 57.6\%$, probability of superiority = 55.39%). However, there is a difference between the two test groups ($t(119) = 3.62$, $p = .0004$, $g_s = 0.66$, 95% CI = [0.21, 1.1], Cohen's $U_{3,g_s} = 74.43\%$, probability of superiority = 67.88%). Participants in the content related test group scored higher on the final test than participants in the general knowledge test condition. These two findings are not in line with our predictions.

The interaction between feedback and interpolated activity type

The remaining hypotheses deal with the effect of feedback on the total number of correct answers and the total number of intrusors. Therefore, these analyses are carried out only on the data from participants in the general and content related test conditions ($n = 163$). To test these hypotheses, we first conducted a two-way MANOVA with interpolated activity and feedback as independent variables, and total number of correct answers and total number of intrusors as the dependent variables.

Pillai's V for the interpolated activity effect (calculated with type III sums of squares) is .071, $p = .003$ (Wilks' $\Lambda = .929$, $p = .003$) confirming the main effect of interpolated activity type. The effect size $\omega^2_{mult} = .065$ (bootstrap median = .072, BC_α 95% CI = [.007, .139]).

On the other hand, we find no evidence for an effect of giving feedback on the linear combination of our two dependent variables — Pillai's V = .003, $p = .800$ (Wilks' $\Lambda = .997$, $p = .800$). The effect size is ω^2_{mult} = -.003 (bootstrap median = .003[2]).

Furthermore, we find no evidence for an interaction effect between activity type and feedback — Pillai's V = .001, $p = .941$ (Wilks' $\Lambda = .999$, $p = .941$). The effect size ω^2_{mult} = -.005 (bootstrap median = .003[3]). Both the feedback and the interaction estimates of ω^2_{mult} are to be considered to be zero, given their negative values.

Again, we have conducted a follow-up Roy-Bargmann stepdown analysis. In the ANOVA model with the total number of correct answers as the dependent variable and the type of

[2]The BC_α 95% CI for this estimate is $[-.006, .004]$.

[3]The BC_α 95% CI = $[-.006, -.005]$. Our guess is that this odd result is due to the fact that most of the density is concentrated around 0, causing an unreliable estimate. The same could be said for the CI in footnote 2.

Table 2

ANOVA and ANCOVA models for the second Roy-Bargmann procedure.

Term	*SS*	*df*	*F*	*p*
ANOVA				
Activity	109.393	1	11.200	.001
Feedback	3.904	1	0.400	.528
Activity x Feedback	0.045	1	0.005	.946
Residuals	1553.046	159		
ANCOVA				
Activity	0.301	1	0.175	.676
Feedback	0.173	1	0.100	.752
Total correct	63.216	1	36.760	$< .0001$
Activity x Feedback	0.813	1	0.473	.493
Activity x Total correct	0.862	1	0.501	.480
Feedback x Total correct	0.130	1	0.075	.784
Activity x Feedback x Total correct	1.229	1	0.715	.399
Residuals	266.551	155		

interpolated activity, feedback and their interaction as predictors, only the type of activity seems to be relevant ($F(1, 159) = 11.2, p = .001$). This result also shows that participants in the content related test condition scored higher on the final test than the participants in the general knowledge test condition, which should be no surprise given the results of the first stepdown analysis. In the second step, we fit an ANCOVA model with the total number of correct answers as the covariate. In this model, the type of interpolated activity ceases to be a relevant predictor ($F(1, 155) = 0.175, p = .676$). The full models are shown in Table 2.

Contrary to our expectations, we find no evidence of an effect of feedback on the total number of correctly answered questions (hypothesis 3). Also, we found no evidence for an interaction effect of feedback and type of interpolated activity on the total number of correct answers (hypothesis 4). The same findings apply to the predictions regarding the total number of intrusors chosen (hypothesis 5 and hypothesis 6).

Additional analyses

Because it is theoretically interesting to see whether there is evidence for absence of a difference between certain conditions, or no effect of certain manipulations, we have conducted a Bayesian reanalysis of the two Roy-Bargmann stepdown procedures. Since these analyses were not planned, we have decided to use the default priors provided in the *BayesFactor* (Morey & Rouder, 2018) package.[4]

Bayesian reanalysis of the first Roy-Bargmann procedure

As was earlier done in a frequentist setting, we first fit an ANOVA model with the total number of correct answers as the dependent variable, and the type of interpolated activity as the predictor. All effects are expressed as deviations from the estimated posterior subsample mean of 11.381. The estimated mean of the effect of content related testing is 1.254 (95% HDI = [0.553, 2.005]). The 95% highest density interval of the posterior indicates that there is a fair amount of uncertainty around the exact magnitude of the effect of content-related testing. However, most of the probability density is quite far above zero, implying that there really is a positive effect. The means of the posterior distributions for the general-knowledge-test and rereading conditions bs are -0.805 (95% HDI = [-1.549, -0.116]) and -0.449, (95% HDI = [-1.125, 0.257]) respectively. Most of the posterior distribution for the effect of general knowledge testing lies below zero, pointing to a negative effect on the total number of correct answers, although the distance is not as marked as in the content-related condition. On the other hand, there is a lot of uncertainty about the effect of rereading, compared to the other two estimates. Still, 89.8% of the posterior lies below zero, leading us to believe that the effect is most likely negative.

Furthermore, we wanted to explore the difference between the rereading and general-knowledge-test conditions, given their somewhat similar coefficient and HDI estimates, as well as sample means. To do this, we conducted a Bayesian t-test, again with the *BayesFactor* package's default priors. The estimated posterior mean of the difference in the total number of correct answers between the two groups is -0.362 (95% HDI = [-1.49, 0.856]). As can be

[4] All posteriors obtained from 6000 simulations.

seen from the HDI, there is a lot of uncertainty around the estimate of the difference, which points to a lack of evidence for any claim regarding the effect.

In the second step of the Roy-Bargmann procedure, we fit an ANCOVA model with the total number of correct answers as the covariate and the total number of intrusive options chosen as the dependent variable. Effects are again expressed relative to the estimated posterior subsample mean of 4.193. There is uncertainty around the estimates of the effects of the different experimental conditions — content related testing b = -0.214 (95% HDI = [-0.583, 0.146]), general-knowledge testing b = 0.072 (95% HDI = [-0.288, 0.424]), rereading b = 0.142 (95% HDI = [-0.216, 0.494]). The HDIs show that there could be either a slight increase or a slight decrease in the number of intrusors, preventing us from making a conclusion about the nature of the effects. However, given the current data and priors, we find the following — 87.43% of the posterior for the effect of content related testing falls below zero; 65.57% of the posterior for the effect of general knowledge testing falls above zero; 77.68% of the posterior for the effect of rereading falls above zero. Given the stated, there is some evidence implying that content related testing decreases the number of intrusors chosen, after controlling for the effect of the total number of correct answers. Further, there is some, albeit weaker evidence that rereading leads to an increase in the number of chosen intrusive distractors. Lastly, the posterior of the general knowledge testing effect points to no particular direction. A stronger test of these claims is desired.

Bayesian reanalysis of the second Roy-Bargmann procedure

In the second Roy-Bargmann analysis, we wanted to test whether there is an effect of the type of interpolated activity, receiving feedback, and their interaction on the total number of correct answers and chosen intrusors. Again, we first fit an ANOVA model with the two predictors and the total number of correct answers as the dependent variable.

Effects are expressed relative to the estimated posterior subsample mean of 11.868. We find that content related testing leads to an increase in the total number of correct answers, b = 1.086 (95% HDI = [0.589, 1.559]), compared to the general knowledge testing. This is aligned with the finding obtained in the frequentist setting. The mean of the posterior

for the effect of receiving feedback is 0.218 (95% HDI = [-0.251, 0.679]). The HDI around the estimate prevents us from making any firm conclusions regarding the effect of receiving feedback. However, we will mention that 82.25% of the posterior lies above zero, implying a possible positive effect on learning. Finally, the estimate for the interaction effect (being in the content condition and receiving feedback) is -0.013 (95% HDI = [-0.46, 0.432]). This could point to there not being a relevant interaction effect. According to the collected data and the priors, we could claim that the effect is practically equivalent to zero if we were not interested in a half-point increase or decrease in the average scores (i.e. defining a region of practical equivalence (ROPE) between [-0.5, 0.5]). Still, greater precision, which would require further data collection, is desired.

We continue with the ANCOVA model, taking the total number of correct answers as the covariate. The estimate of the intercept is 3.821 (95% HDI = [3.6, 4.03]). The estimate for the effect of content related testing on the total number of intrusive distractors chosen is b = -0.118 (95% HDI = [-0.325, 0.092]), compared to general knowledge testing. There is some evidence for a slight decrease in the number of intrusive distractors chosen in the content related testing condition. However, an increase is also possible, but less likely and negligibly small. The estimate for the effect of receiving feedback is -0.091 (95% HDI = [-0.302, 0.121]). Although the mean of the posterior is close to zero, the lower bound of the HDI shows that values which may be considered non-negligible are still somewhat probable. Therefore, we shall refrain from making a judgement regarding the effect of feedback on choosing intrusive distractors. Finally, the estimate of the interaction effect is $b = 0.047$ (95% HDI = [-0.153, 0.244]). The mean of the posterior is close to zero, and we could declare the effect to be practically equivalent to zero with a ROPE of approximately [-0.25, 0.25].

As previously stated, all these analyses were not planned a priori. This warrants certain caveats. The *BayesFactor* package's default priors were used. The appropriateness of these priors should certainly be questioned. However, we have decided to use them because we did not want to choose priors after already seeing the data, which would have been more problematic. Further, the statements about effects made in this section are noncommittal. Whether a 0.5 increase or decrease in the total number of correct answers is practically

equivalent to zero or not is left to the reader. We conclude by reminding the reader that the data is available online, at `REF`.

Deviations from the preregistered analysis plan

Initially, we have planned to do a robustness check of our findings using data with an additional exclusion criterion, based on the number of times each participant has read each of the three parts of the main text. This analysis was never conducted because (i) applying this criterion would have lead to unacceptably low power and (ii) the participants' estimates of the number of times they have read each part were similarly distributed across all conditions. Further, we have planned to conduct a TOST procedure to test whether there is no difference between the content-related and general-knowledge testing groups. This analysis was not conducted because we have found a difference. A Bayesian t-test was also considered for the same comparison, but was dropped early on due to some conceptual concerns.

Discussion

The aim of this study was to explore the effects of different interpolated activities and feedback reception on learning complex materials. Participants read a text about weeds divided into three parts, and engaged in interpolated activities between reading episodes. Two testing activities were chosen so as to tap into episodic (content-related testing) or semantic (general-knowledge testing) memory, while a rereading condition served as a control. Participants in the content-related and general-knowledge conditions were also randomly assigned to receive or not to receive feedback. Learning was measured through the total number of correct answers on a final test, and through the number of intrusive distractors chosen.

We found evidence for an effect of interpolated activity type on the total number of correct answers — participants engaging in episodic retrieval scored higher than both the participants engaging in semantic retrieval, and the participants in the control condition.

Notes for discussion

Chan et al. (2018). across a retention interval In contrast to unrelated word lists, text passages and videos are typically written/produced in a coherent manner, which should naturally invite relational processing, so any relational processing advantage induced by prior testing is likely to be modest relative to of the strategy change account that is not tied strictly to relational processing, however, may provide a reasonable explanation for the TPNL effect with text passages and videos. In a broader sense, the strategy change account specifies that performing retrieval practice allows participants to discover the type of learning needed to ensure satisfactory performance (or conversely, to realize the type of learning that is inadequate to produce satisfactory performance, if participants are performing poorly during retrieval practice), and participants can then adjust their subsequent encoding strategy accordingly. If we take this broader approach to strategy change, then this account can explain the TPNL effect with prose/video materials. However, we realize that the idea that "retrieval practice can improve later encoding strategies" is perhaps vaguely defined. In fact, such a broad definition of strategy change may render the account difficult to falsify. With this in mind, we believe that the strategy change account, as we currently conceive, should only be applied to explain the TPNL effect with word list type materials, for which advantageous encoding strategies can be more precisely defined (but see Jing et al., 2016 in which interspersed testing improved conceptual integration of materials across sections of a video lecture). In our opinion, application of this account to prose/video material should only be done when one clearly outlines what is considered an advantageous encoding strategy so that the hypothesis can be adequately tested.

Možda ZV intruzori nije pokazala razlike između skupina jer smo koristili recognition, a ne free recall. Context change account?

Methodological concerns. The expectation of a final test ensured the continued processing of materials across the study sequence. Chan et al. (2018): For example, in a multilist learning environment, having taken a recent memory test increases learners' expectation that they will again be tested in the immediate future, even when they are told that whether a test will follow each study list is determined randomly (Weinstein et al., 2014). Such test

expectancies have been shown to significantly influence how participants approach Weinstein et al. (2014): The experiments reported here are based on the assumption that participants in the tested group may be more likely to expect a test after the fifth (last) list, having consistently received tests after previous lists. Those in the untested group, having never received a test during the experiment until the fifth list test, may therefore pay less attention or engage in lower quality encoding strategies during encoding of the fifth list. To test for this alternative explanation, we compared the two standard conditions (tested and untested) with two novel conditions that were identical to the standard conditions but included a warning before presentation of the final list to alert participants that they would be tested on the upcoming list. If attentional processes are mediating the observed release from proactive interference, warning participants in the untested group should produce the same benefit as the participants taking a test after every list

Matej [11:05 PM] E, sjetio sam se opet da bi možda bilo dobro da negdje navedemo razlike u učinku na testovima prije zadnjega...

Denis [11:09 PM] Mda, neke te stvari su mi pale na pamet, i činilo mi se kao da bi bilo zgodno spomenuti ih u raspravi. Kao, ako se radi o nekim stvarima koje bi mogle ugroziti efekte ili objasniti neznačajne

Pastötter et al. (2011): Whereas, relative to the two no-retrieval conditions, both episodic and semantic memory retrieval effectively eliminated List 1–4 intrusions during immediate List 5 recall, short-term memory retrieval led to intrusion rates that were equivalent in amount to the no-retrieval conditions. This difference in intrusion errors may suggest that the effects of short-term and long-term memory retrieval are not perfectly identical.

Yang et al. (2018): za neznačajan efekt na intruzore! the activation facilitation and enhanced encoding effort mechanisms may play important roles for complex materials whereas the release from PI mechanism is likely to play little role.29

Divis i Benjamin (2014) However, their protocol didn't allow for assessing the contribution of proactive interference to TPNL. Furthermore, the authors argue for the irrelevance of the level of difficulty of alternative activities (i.e. perhaps the semantic retrieval and the distractor tasks were not equal with regards to difficulty) whilst referring to the variety of

tasks used by Pastötter et al. (2011), who found effects of similar magnitude for the retrieval tasks and a lower but approximately equal magnitude for the distractor task and restudy. But it does not follow that these patterns in the data refute an explanation based on task difficulty, i.e. the distractor task and restudy may have been easier than the retrieval tasks.

Notes

Analyses conducted using the *R* language (R Core Team, 2019). Plots created using *ggplot2* (Wickham, 2016). Bootstrap conducted using the *boot* package (Canty & Ripley, 2017). Methods and analyses written using *rmarkdown* (Allaire et al., 2019) and *knitr* (Xie, 2019). The package *car* (Fox & Weisberg, 2011) was used to obtain type III sums of squares. *compute.es* (Re, 2013) was used to obtain effect sizes for contrasts. *kableExtra* was used to help generate tables (Zhu, 2019). Other utilities used are *tidyverse* (Wickham, 2017), *magrittr* (Bache & Wickham, 2014), *here* (Müller, 2017), *conflicted* (Wickham, 2018), *psych* (Revelle, 2018). Highest density intervals obtained using *HDInterval* (Meredith & Kruschke, 2018).

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