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Divided Attention During Encoding Constrains the Benefits of Interim Testing for Subsequent Learning

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Abstract

Retrieval practice can enhance learning of subsequently studied target information, a phenomenon known as the forward testing effect or test-potentiated new learning. The present study examined whether this effect depends on attentional engagement during encoding. In two experiments, participants studied three lists of unrelated words (Experiment 1) or three educationally relevant prose passages (Experiment 2). After the first two learning blocks, they either restudied the material or were tested on it. Attention during encoding of the final target material was manipulated by a concurrent secondary task. Under full attention, interim testing enhanced recall of the final target material in both experiments and improved performance on a final knowledge transfer test in Experiment 2. Under divided attention, these effects were reduced in Experiment 1 and eliminated in Experiment 2. The findings indicate that the beneficial effect of interim testing depends critically on attention during encoding of the latter studied information.

Keywords

Learning; Long-term memory; Attention; Testing effects; Forward testing effect; Test-potentiated new learning

General Audience Summary

Testing is widely known to strengthen memory for previously learned information. Less widely appreciated is that testing can also improve learning of new material studied afterward. This phenomenon, known as the forward testing effect or test-potentiated new learning, suggests that inserting quizzes during learning may help students better learn information that follows. However, students often study in distracting environments, for example, while checking their phones or listening to background media, which can reduce attention during learning. In addition, attentional conditions can change unexpectedly during a study session—for example, after receiving an emotionally important message or when a previously quiet environment suddenly becomes noisy. The present research examined whether the benefits of interim testing depend on the attentional conditions under which new material is studied. Across two experiments, participants studied several sets of learning materials. Between study phases, they either restudied the material or took brief memory tests. Attention during study of the final material was manipulated: some participants studied under full attention, whereas others completed a concurrent task designed to divide their attention. In the first experiment, the materials consisted of unrelated word lists; in the second, they consisted of short explanatory texts about memory processes, similar to materials students may encounter in educational settings. The results showed that interim tests improved learning of subsequently studied material when participants studied under full attention. When attention was divided during learning, however, this benefit was reduced for word lists and disappeared for text materials. These findings suggest that quizzes can support later learning, but they are likely to be most effective when subsequent material is studied with minimal distraction. More generally, the results highlight that the success of interim testing depends not only on whether learners are tested, but also on the attentional levels under which the new material is studied.

Introduction

Learning new information becomes increasingly difficult as more and more information is accumulated over time. Consistent with this subjective experience, research on proactive interference demonstrates that memory performance for later studied information is impaired because the memory load grows and interference from earlier material increases, leading to both encoding and retrieval problems for newly studied material (Kliegl et al., 2015; Wixted & Rohrer, 1993; for a review, see Kliegl & Bäuml, 2021). A simple and effective way to counteract these problems is interim testing, that is, inserting brief memory tests during learning. Interim testing reduces or even eliminates the typical impairment for later studied information, such that encoding and retrieval efficiency for later material become comparable to those for earlier studied material – a benefit of testing often referred to as the forward testing effect or test-potentiated new learning (e.g., Pastötter et al., 2011; Szpunar et al., 2008; Yang et al., 2019; for reviews, see Pastötter & Bäuml, 2014; Yang et al., 2018).

Not only memory performance but also attentional engagement tends to decline across study episodes and can be much reduced for later compared to earlier studied information. Indeed, EEG studies show that neural markers associated with reduced attentional engagement, most notably increases in alpha power during encoding, rise both within and across study lists (Hanslmayr et al., 2012; Pastötter et al., 2008; Sederberg et al., 2006; Serruya et al., 2014). Critically, this increase in alpha power is attenuated or even absent when interim testing is inserted between study phases (Pastötter et al., 2011), indicating that testing helps sustain attentional engagement during later encoding. Maintaining a high level of attention during encoding may be critical for the cognitive mechanisms induced by interim testing to operate successfully and keep learning and memory fairly stable across study.

A number of cognitive mechanisms have been proposed to operate in response to interim testing. For relatively simple materials, accounts emphasize processes such as changes in encoding or retrieval strategy, whereby testing promotes more effective organization and elaboration during subsequent learning and remembering (Chan et al., 2018; Cho et al., 2017); a reset of encoding, whereby testing restores encoding efficiency for subsequently studied information (Pastötter et al., 2011, 2018); or induced contextual change and interference reduction, whereby testing separates successive study episodes and reduces competition from previously learned material at test (Bäuml & Kliegl, 2013; Szpunar et al., 2008). For more complex materials, facilitated

comprehension has been suggested as a key mechanism, whereby prior testing improves understanding and integration of subsequently studied information (Kriechbaum & Bäuml, in press; Wissman et al., 2011). Importantly, although these mechanisms differ in detail, each of them likely benefits from high levels of attention during encoding of the later studied information.

Despite strong evidence that interim testing can enhance learning of later material, it remains unclear whether interim testing per se is sufficient to produce this beneficial effect. Although interim testing may help sustain attention and thus pave the way for the cognitive mechanisms typically mediating the effect, the beneficial effect may critically depend on attention not being otherwise reduced during subsequent learning. In real-world learning environments, attentional resources are often limited by external factors (Calderwood et al., 2014; Jacobsen & Forste, 2011). For instance, learners may begin studying under optimal conditions but then receive a highly emotional or personally important text message or email that continues to occupy their thoughts while studying the remaining material. Likewise, a previously quiet learning environment may suddenly become noisy because of nearby construction work or other unexpected disturbances, substantially reducing attentional resources during the remainder of the learning episode. Such reductions in attention could make learning after interim testing resemble learning without testing, thereby diminishing or eliminating the potential advantage for later studied information that testing would otherwise provide.

To date, the role of attention for interim testing has received little direct examination. Two recent studies have begun to address this issue. Mulligan and Buchin (2025) manipulated attention during the interim phase of a four-list paradigm using categorized word lists. During restudy or interim testing of Lists 1 to 3, half of the participants performed a secondary task that required categorizing aurally presented digits as even or odd, whereas the other half practiced under full attention. List 4 served as the critical target list. The results showed that the benefits of interim testing were of similar magnitude under full and divided attention, suggesting that interim testing does not critically depend on controlled, attention-demanding processes. Chan et al. (2025) manipulated attention during study of a 20-min video lecture divided into four segments. After each of the first three segments, participants either completed interim quizzes or viewed review slides for restudy. Attention during study was manipulated by presenting onscreen distractions (e.g., continuously changing silent TikTok videos). The results showed that quizzing relative to

reviewing enhanced recall of the final target material in the no-distraction condition, but not in the TikTok-video distraction condition. Surprisingly, this null effect in the distraction condition was not driven by reduced recall in the quizzing condition, but by increased recall in the reviewing condition, which contrasts with most research on the effects of divided attention in the literature (Craik et al., 1996; Naveh-Benjamin et al., 2006). Individuals' attentional engagement in online learning environments may thus differ fundamentally from that in other learning environments, and the results may not easily generalize to these conditions (see Chan et al., 2025, p. 9).

The present study addresses the issue of whether interim testing per se is sufficient to produce the beneficial effect for the final material by using a typical in-lab learning environment and by manipulating attention during study of the final target material only. Participants thus either studied all materials under full attention or studied the previous materials under full attention and the final target material under divided attention. Because learning in everyday contexts involves both relatively simple materials (e.g., memorizing a list of items) and more complex materials (e.g., understanding explanatory texts), we conducted two experiments in which participants studied either unrelated word lists (Experiment 1) or educationally relevant prose passages (Experiment 2). The prose materials consisted of short explanatory texts about human memory processes similar to those students may encounter in introductory psychology courses. Interim testing or restudy was administered between study phases, and attention during encoding of the final target material was manipulated using a concurrent secondary task. This design allows us to test whether interim testing alone is sufficient to enhance subsequent learning or whether its benefits are critically tied to maintaining a high level of attention during encoding of the final target material.

Experiment 1

Experiment 1 used unrelated word lists as study material to examine whether attentional engagement during encoding of the final list modulates the benefits of interim testing. Participants studied three lists of unrelated words with interim testing or restudy phases between lists. Critically, attention during encoding of the final list (List 3) was manipulated using a concurrent secondary task that required categorizing aurally presented digits as even or odd (Buchin & Mulligan, 2017; Mulligan & Buchin, 2025). This design provides a first direct test of

whether interim testing alone is sufficient to enhance subsequent learning or whether its benefits depend on maintaining a high level of attention during encoding of later studied information.

Method

We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in Experiment 1. Data were collected between May 2024 and November 2024.

Participants

Ninety-six students from Trier University (mean age = 24.03 years, SD = 4.01, range = 18 – 35 years; 66 females, 30 males) participated in Experiment 1. The required sample size was determined a priori using G*Power (Version 3.1.9.7; Faul et al., 2007). Assuming $\alpha = .05$ and a desired power of $1 - \beta = .95$ to detect a forward testing effect with an effect size of $d = .75$ for a two-tailed independent-samples *t* test (equivalent to $f = .375$ for a between-subjects ANOVA; see the meta-analysis by Boustani & Shanks, 2022), the analysis indicated a minimum sample size of 95 participants. All participants provided written informed consent prior to participation and received course credit. The study was conducted in accordance with the ethical standards of the ethics committee of Trier University. Information on race/ethnicity was not collected and therefore cannot be reported.

Material

The item material for the memory task was taken from Pastötter et al. (2012, Exp. 2). It consists of 144 unrelated German nouns of medium frequency and word length (4 – 8 letters; see <https://doi.org/10.17605/OSF.IO/WDFHK>), drawn from the CELEX database (Duyck, Desmet, Verbeke, & Brysbaert, 2004). For each participant, 45 of these 144 words were randomly selected and assigned to three 15-item lists.

Experimental Design

Experiment 1 employed a 2×2 between-subjects design with the factors *interim activity* (restudy vs. testing) and *attention* (full vs. divided). In the restudy condition, Lists 1 and 2 were presented a second time for additional study, whereas in the testing condition, Lists 1 and 2 were each followed by a free-recall test. In the full-attention condition, List 3 was studied without any concurrent task, whereas in the divided-attention condition, List 3 was studied while participants simultaneously performed a secondary task requiring them to categorize aurally presented digits as even or odd (e.g., Buchin & Mulligan, 2017; Mulligan & Buchin, 2025).

Procedure

The experiment was conducted in individual or small-group sessions with up to four participants tested simultaneously in the laboratory. After providing informed consent and entering demographic information, participants received oral instructions about the procedure of the study and were asked to put on headphones, which would be used during parts of the experiment. Participants were informed that they would study three word lists and that they should try to remember both the words and the list to which each word belonged. They were also told that all lists would be tested at the end of the experiment, regardless of whether a list had already been tested earlier during the experiment. Participants were further instructed that the order in which words had been presented was irrelevant for later recall.

Before the experiment began, participants received instructions about the possible task formats: restudy, retrieval practice, the symmetry decision task, and the even-odd digit categorization task. Participants were told that after each list they would either restudy the material or complete a recall test. In fact, this manipulation followed the assigned experimental condition: in the restudy condition, Lists 1 and 2 were restudied, whereas in the testing condition, Lists 1 and 2 were tested. In both conditions, List 3 was tested after the symmetry decision task that followed its study phase. Prior to the experiment, all participants (in both the full-attention and the divided-attention condition) completed a short practice phase of the digit categorization task with feedback. In this task, they were instructed to classify aurally presented digits as even or odd by pressing a left (blue) key for even digits and a right (red) key for odd digits. After completing the practice phase, participants had the opportunity to ask questions before the experiment started.

Words were presented visually for 3.5 s each with an interstimulus interval of 0.5 s, resulting in a study time of one minute per list. After each study phase, participants performed a 30-s symmetry decision task in which they judged whether mosaic patterns arranged in a 4×4 grid were symmetrical along the vertical axis (Foster et al., 2015). Following this distractor task, participants either restudied the list or completed a free-recall test, depending on condition. During recall tests, participants typed the remembered words on a QWERTZ computer keyboard. No feedback was provided. In the restudy condition, the words of the list were presented again in a new random order for 1 min. During study of List 3, attention was manipulated. In the divided-attention condition, participants performed the digit categorization task concurrently while studying the list. Thirty digits were presented aurally via headphones

with a presentation rate of 2 s. In the full-attention condition, no digits were presented and participants studied the list without any concurrent task. Assignment of participants to the four experimental conditions (restudy vs. testing $\times$ full vs. divided attention) was fully balanced.

After the short symmetry decision task that followed study of List 3, participants completed a free-recall test for List 3. At the end of the experiment, final recall tests for Lists 2 and 1 were administered, each lasting 1 min. List 2 was tested first, followed by List 1. Thus, as announced at the beginning of the experiment, all lists were tested regardless of earlier testing phases. The experiment was programmed and run using E-Prime software (Version 3.0; Psychology Software Tools, Pittsburgh, PA).

Data Analysis

Both frequentist and Bayesian statistics were computed using JASP (Version 0.95.4; JASP Team, 2025). The forward testing effect was operationalized as superior recall of List 3 in the testing condition relative to the restudy condition. In addition, prior-list intrusions – that is, words from Lists 1 and 2 that were erroneously recalled during the immediate recall test of List 3 – as well as immediate and final recall performance for Lists 1 and 2 were examined. Percentage of correctly recalled list items and the number of prior-list intrusions were examined as dependent variables in frequentist and Bayesian analyses of variance (ANOVAs) and post-hoc t tests. For the Bayesian analyses, BF_{01} is reported when the data provide relatively stronger evidence for the null hypothesis than for the alternative hypothesis; otherwise BF_{10} is reported (see Wagenmakers et al., 2018). Default priors were used for the calculation of Bayes factors (r -scale fixed effects = 0.5; r -scale random effects = 1). To determine the strength of evidence, we followed Jeffreys's (1998) benchmarks, with Bayes factors corresponding to anecdotal (0–3), substantial (3–10), strong (10–30), very strong (30–100), or decisive (>100) evidence in favor of either the null (BF_{01}) or the alternative hypothesis (BF_{10}). The data and analysis script are available as a JASP file on OSF (<https://doi.org/10.17605/OSF.IO/WDFHK>).

Results

Secondary Task

Participants made on average 24.60 correct responses out of 30 ($SD = 5.83$) in the digit categorization task. Accuracy was clearly above chance level, as indicated by a one-sample t test against the test value of 15, $t(47) = 11.420$, $p < .001$, $d = 1.648$ ($BF_{10} > 100$).

Immediate Recall of Lists 1 and 2

The results of all recall tests are presented in Table 1. Immediate recall of Lists 1 and 2 was assessed only in the testing condition. A 2×2 repeated-measures ANOVA with the within-subjects factor *list* (List 1 vs. List 2) and the between-subjects factor *attention* (full vs. divided) revealed no significant main effect of *list*, $F(1, 46) = 0.019$, $p = .890$, $\omega_p^2 < .001$ ($BF_{01} = 4.655$, relative to the null model), no significant main effect of *attention*, $F(1, 46) = 1.248$, $p = .270$, $\omega_p^2 = .005$ ($BF_{01} = 1.992$, relative to the null model), and no significant interaction between the two factors, $F(1, 46) = 1.794$, $p = .187$, $\omega_p^2 = .005$ ($BF_{01} = 1.548$, relative to the two-main-effects model).

--- Table 1 about here ---

Immediate Recall of List 3

For correct List 3 recall, a 2×2 ANOVA with the between-subjects factors *interim activity* (restudy vs. testing) and *attention* (full vs. divided) revealed a significant main effect of *interim activity*, $F(1, 92) = 33.996$, $p < .001$, $\omega_p^2 = .250$ ($BF_{10} > 100$, relative to the null model), and a significant main effect of *attention*, $F(1, 92) = 72.873$, $p < .001$, $\omega_p^2 = .428$ ($BF_{10} > 100$, relative to the null model). Importantly, the interaction between the two factors was also significant, $F(1, 92) = 3.978$, $p = .049$, $\omega_p^2 = .030$ ($BF_{10} = 1.454$, relative to the two-main-effects model). Post-hoc comparisons indicated a reliable forward testing effect under full attention, $t(46) = 4.596$, $p < .001$, $d = 1.327$ ($BF_{10} > 100$), and a reduced but still significant forward testing effect under divided attention, $t(46) = 3.475$, $p = .001$, $d = 1.003$ ($BF_{10} = 28.268$; see Fig. 1).

--- Figure 1 about here ---

Regarding prior-list intrusions in the List 3 recall test, a 2×2 ANOVA revealed a significant main effect of *interim activity*, $F(1, 92) = 5.876$, $p = .017$, $\omega_p^2 = .048$ ($BF_{10} = 2.891$, relative to the null model), but neither a significant main effect *attention*, $F(1, 92) = 0.092$, $p = .763$, $\omega_p^2 < .001$ ($BF_{01} = 4.481$, relative to the null model), nor a significant interaction between the two factors, $F(1, 92) = 0.367$, $p = .546$, $\omega_p^2 < .001$ ($BF_{01} = 3.208$, relative to the two-main-effects model). These results indicate a reliable forward testing effect on prior-list intrusions that was unaffected by the attention manipulation.

Final Recall of Lists 2 and 1

Two 2×2 ANOVAs with the between-subjects factors *interim activity* (restudy vs. testing) and *attention* (full vs. divided) were conducted for List 2 and List 1 recall. For List 2, the ANOVA revealed no significant main effect of *interim activity*, $F(1, 92) = 0.823, p = .367, \omega_p^2 < .001$ ($BF_{01} = 3.224$, relative to the null model), no main effect of *attention*, $F(1, 92) = 0.490, p = .486, \omega_p^2 < .001$ ($BF_{01} = 3.744$, relative to the null model), and no interaction between the two factors, $F(1, 92) = 0.490, p = .486, \omega_p^2 < .001$ ($BF_{01} = 2.647$, relative to the two-main-effects model). Similarly, for List 1, no significant main effects of *interim activity*, $F(1, 92) = 0.090, p = .765, \omega_p^2 < .001$ ($BF_{01} = 4.476$, relative to the null model), or *attention*, $F(1, 92) = 0.023, p = .881, \omega_p^2 < .001$ ($BF_{01} = 4.613$, relative to the null model), and no significant interaction were observed, $F(1, 92) = 1.564, p = .214, \omega_p^2 = .006$ ($BF_{01} = 1.861$, relative to the two-main-effects model).

Discussion

Experiment 1 examined whether dividing attention during encoding of the target material modulates the benefits of interim testing for new learning when using unrelated word lists for study. Replicating prior work, interim testing enhanced recall of subsequently studied material and reduced prior-list intrusions. Dividing attention during study of the target list substantially impaired recall overall and attenuated the benefit of interim testing on recall of the target list, although the effect remained reliable under divided attention. These findings suggest that attentional engagement during encoding of the target material contributes to the benefits of interim testing for new learning. They are consistent with the view that dividing attention during target-list encoding reduces the extent to which interim testing can facilitate subsequent encoding. Interim testing also reduced prior-list intrusions, but this effect was not modulated by the attention manipulation, suggesting that interference reduction may contribute to the benefits of interim testing in a manner that is less dependent on attentional resources during target encoding. Finally, no backward testing effect emerged for the previously studied lists. This finding is consistent with evidence that the mnemonic benefits of retrieval practice over restudy for previously studied information typically emerge only after longer retention intervals (Roediger & Karpicke, 2006; Toppino & Cohen, 2009).

Experiment 2

Experiment 2 extended the investigation to more educationally relevant learning materials by using related prose passages instead of unrelated word lists. The texts were adopted from recently developed materials by Kriechbaum and Bäuml (in press) and consisted of three short expository passages on fundamental mechanisms of human memory and forgetting. These materials were selected because they have been validated in previous forward-testing research with prose materials (Kriechbaum & Bäuml, in press), allowing direct comparison with prior findings. In contrast to the unrelated word lists used in Experiment 1, the passages contained conceptually related information and thus more closely resembled the kinds of materials encountered in educational settings. In addition to the change in materials, two further modifications were implemented to increase ecological validity. First, the participant sample included both university students and non-students to increase the generalizability of the findings across the adult population and therefore covered a broader adult age range than in Experiment 1; importantly, prior work indicates that the benefits of interim testing for subsequent learning are largely independent of age within adulthood (Pastötter & Bäuml, 2019). Second, the attention manipulation employed a more complex and naturalistic secondary task than in Experiment 1. Participants listened to a fictional news report about the Summer Olympic Games that contained numerous single-digit numbers referring, for instance, to scores or statistics. While studying the text material, participants were required to monitor the auditory stream and raise one arm whenever they detected an odd digit, while withholding a response for even digits, thereby inducing sustained divided attention during encoding.

Method

We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in Experiment 2. Data were collected between May 2025 and November 2025.

Participants

Participants in Experiment 2 were 96 adults, including 74 students from Trier University and 22 non-students, resulting in a broader adult age range than in Experiment 1 (mean age = 27.58 years, SD = 11.70, range = 19 – 74 years; 57 females, 39 males). The sample size was identical to that of Experiment 1. All participants provided written informed consent prior to participation, and the students received course credit. The study was conducted in accordance with the ethical

standards of the ethics committee of Trier University. Information on race/ethnicity was not collected and therefore cannot be reported.

Material

The learning material consisted of three conceptually related German prose passages identical to those used in Experiment 2 of Kriechbaum and Bäuml (in press). Each passage contained approximately 180 words and addressed fundamental mechanisms of human memory and forgetting (see <https://doi.org/10.17605/OSF.IO/WDFHK>). Specifically, the passages described (a) how forgetting can arise from competition between memory representations during retrieval, (b) how blocking mechanisms can resolve such retrieval competition, and (c) how inhibitory processes can suppress competing memories. The three passages were presented in a fixed order for all participants. Passages 1 and 2 served as practice materials during the interim manipulation phase, whereas Passage 3 served as the target material. To assess transfer of the learned material, a final knowledge test consisting of 10 open-ended questions identical to the test used in Experiment 2 of Kriechbaum and Bäuml (in press) was administered after the immediate recall test of Passage 3. The questions required short written responses and assessed both integration of information across the three passages and transfer of the learned concepts to new situations. The experiment was conducted using paper-and-pencil materials. Printed copies of the passages and answer sheets were provided to participants.

For the divided-attention condition, a six-minute audio recording was used that consisted of a fictional news report about the results of the Summer Olympic Games. The report contained 60 single-digit numbers (30 even and 30 odd) referring to scores or statistics (see <https://doi.org/10.17605/OSF.IO/WDFHK>). The script was generated with the assistance of ChatGPT (OpenAI), and the audio was spoken and recorded by the first author. The recording was subsequently adjusted in playback speed to achieve a total duration of exactly 6 min and was played at medium volume via a smartphone placed next to the participant.

Experimental Design

Experiment 2 employed a 2×2 between-subjects design with the factors interim activity (restudy vs. testing) and attention (full vs. divided). The design was conceptually identical to that of Experiment 1 but used prose passages instead of unrelated word lists as learning material. In the testing condition, participants completed two free-recall tests for each of the first two passages, whereas in the restudy condition, participants reread each passage for an equivalent

amount of time. By including two recall/restudy cycles, we closely followed the procedure established by Kriechbaum and Bäuml (in press), ensuring comparability with that work. In the full-attention condition, Passage 3 was studied without any concurrent task. In the divided-attention condition, participants studied Passage 3 while simultaneously monitoring an auditory stream containing single-digit numbers and were instructed to raise one arm whenever an odd digit occurred.

Procedure

Participants were tested individually in a quiet laboratory environment. After providing informed consent, participants received standardized instructions explaining that they would study three passages and that their memory for the material would be tested later. The experiment began with the study of Passage 1, which participants read for 6 min. After the study phase, participants completed a 30-s distractor task in which they counted backward in steps of three from a three-digit number. Next followed two 5-min phases separated by a 2-min arithmetic distractor task. In the testing condition, participants were instructed to write down everything they could remember from the passage during each of the two phases. In the restudy condition, participants reread the passage during the two phases. The identical procedure was then applied to Passage 2.

The attention manipulation was introduced during study of Passage 3, which participants studied for 6 min. In the full-attention condition, participants studied the passage without any concurrent task. In the divided-attention condition, participants simultaneously listened to the Olympic news recording and were instructed to monitor the auditory stream for single-digit numbers. Whenever an odd digit occurred, they raised either their left or right arm, while no response was required for even digits. This task created sustained divided attention during encoding of the critical passage. After study of Passage 3, participants again completed the 30-s backward-counting distractor task, followed by a 5-min free-recall test for Passage 3. Subsequently, participants performed a brief visual distractor task in which they searched for differences between pairs of pictures for 3 min. Finally, participants completed the final knowledge transfer test on the contents of the passages, for which they were given up to 15 min. The entire experiment lasted approximately 70 min.

Data Analysis

Data were analyzed using the same statistical procedures as in Experiment 1. Percentage of correctly recalled idea units from Passage 3 (maximum = 14 idea units) and performance on the

final knowledge transfer test (maximum = 10 points) were examined as dependent variables in frequentist and Bayesian ANOVAs and post-hoc t tests. All responses were scored by one rater. In addition, as a reliability check, the responses of 40 participants were independently scored by a second rater. Inter-rater reliability was very high for both recall performance for Passage 3, $r = .950, p < .001$, and performance on the final knowledge transfer test, $r = .950, p < .001$. The data and analysis script are available as a JASP file on OSF (<https://doi.org/10.17605/OSF.IO/WDFHK>).

Results

Secondary Task

Participants made on average 27.19 correct responses to odd digits (hits) out of 30 ($SD = 2.56$). They produced 0.85 false alarms on average, that is, arm raises in response to even digits (out of 30; $SD = 1.34$). Accuracy, calculated as hits minus false alarms, was on average 26.33 ($SD = 3.06$) and was clearly above chance level, as indicated by a one-sample t test against the test value of 0, $t(47) = 59.583, p < .001, d = 8.600 (BF_{10} > 100)$.

Immediate Recall of Passages 1 and 2

The results of all recall tests are presented in Table 2. Immediate recall of Passages 1 and 2 was assessed only in the testing condition. Note that each passage was tested twice after study. A $2 \times 2 \times 2$ repeated-measures ANOVA with the within-subjects factor *passage* (Passage 1 vs. Passage 2), the within-subjects factor *recall test* (first vs. second), and the between-subjects factor *attention* (full vs. divided) revealed a significant main effect of *passage*, $F(1, 46) = 4.861, p = .033, \omega_p^2 = .013 (BF_{10} = 2.108, \text{relative to the null model})$, and a significant main effect of *recall test*, $F(1, 46) = 4.563, p = .038, \omega_p^2 = .004 (BF_{10} = 1.065, \text{relative to the null model})$. The main effect of attention was not significant, $F(1, 46) = 1.194, p = .280, \omega_p^2 = .004 (BF_{01} = 1.378, \text{relative to the null model})$, and no significant interactions were observed, all $F_s(1, 46) \leq 2.011$, all $p_s \geq .162$. Overall, recall was higher in the first than in the second test, and Passage 2 was recalled better than Passage 1.

--- Table 2 about here ---

Immediate Recall of Passage 3

For correct recall of Passage 3, a 2×2 ANOVA with the between-subjects factors *interim activity* (restudy vs. testing) and *attention* (full vs. divided) revealed a significant main effect of *interim activity*, $F(1, 92) = 14.128, p < .001, \omega_p^2 = .120$ ($BF_{10} = 30.252$, relative to the null model), and a significant main effect of *attention*, $F(1, 92) = 16.400, p < .001, \omega_p^2 = .138$ ($BF_{10} = 72.154$, relative to the null model). Importantly, the interaction between the two factors was also significant, $F(1, 92) = 6.239, p = .014, \omega_p^2 = .052$ ($BF_{10} = 3.590$, relative to the two-main-effects model). Post-hoc comparisons indicated a reliable forward testing effect under full attention (5.71 vs. 3.02 recalled idea units), $t(46) = 4.255, p < .001, d = 1.228$ ($BF_{10} > 100$), but not under divided attention (2.90 vs. 2.35 recalled idea units), $t(46) = 0.930, p = .357, d = 0.291$ ($BF_{01} = 2.446$; see Fig. 2).

--- Figure 2 about here ---

Regarding intrusions from prior passages in the Passage 3 recall test, a 2×2 ANOVA showed no significant main effect of *interim activity*, $F(1, 92) = 0.441, p = .508, \omega_p^2 < .001$ ($BF_{01} = 3.844$, relative to the null model), no significant main effect *attention*, $F(1, 92) = 2.403, p = .125, \omega_p^2 = .014$ ($BF_{01} = 1.611$, relative to the null model), and also no significant interaction between the two factors, $F(1, 92) = 1.226, p = .271, \omega_p^2 = .002$ ($BF_{01} = 2.075$, relative to the two-main-effects model). Thus, no reliable forward testing effect in intrusions was observed.

Final Knowledge Transfer Test

A 2×2 ANOVA with the between-subjects factors *interim activity* (restudy vs. testing) and *attention* (full vs. divided) revealed a significant main effect of *interim activity*, $F(1, 92) = 4.554, p = .035, \omega_p^2 = .036$ ($BF_{10} = 1.371$, relative to the null model), and a significant main effect of *attention*, $F(1, 92) = 5.764, p = .018, \omega_p^2 = .047$ ($BF_{10} = 2.288$, relative to the null model). The interaction between the two factors was only marginally significant, $F(1, 92) = 3.290, p = .073, \omega_p^2 = .023$ ($BF_{01} = 0.882$, relative to the two-main-effects model). Although the interaction did not reach significance, exploratory post-hoc comparisons were conducted to examine whether the pattern of results was consistent with the predicted forward testing effect under full attention. These comparisons showed that the forward testing effect in the final transfer test was significant under full attention (restudy: mean = 46.87%, SE = 4.96%; testing:

mean = 62.29%, SE = 3.32%; 6.23 vs. 4.69 points), $t(46) = 2.581$, $p = .013$, $d = 0.745$ ($BF_{10} = 3.945$), but not under divided attention (restudy: mean = 44.58%, SE = 2.95%; testing: mean = 45.83%, SE = 4.08%; 4.58 vs. 4.46 points), $t(46) = 0.248$, $p = .805$, $d = 0.289$ ($BF_{01} = 3.393$).

Discussion

Experiment 2 extended the investigation of the benefits of interim testing under divided attention to more educationally relevant learning materials by employing related prose passages instead of unrelated word lists. Replicating prior work with text materials, interim testing enhanced recall of the subsequently studied passage and improved performance on the final knowledge transfer test under full attention (e.g., Kriechbaum & Bäuml, in press; Szpunar et al., 2013; Wissman et al., 2011). Dividing attention during study of the target passage substantially impaired recall overall and eliminated the benefit of interim testing for immediate recall of Passage 3. A similar descriptive pattern emerged for the final knowledge transfer test, for which interim testing was beneficial under full attention but not under divided attention, although the interaction was only marginally significant. This pattern is unlikely to reflect a mere floor effect in the divided-attention condition, because recall remained clearly above zero and variances in Passage 3 recall did not differ significantly across conditions (Levene's test, $p = .594$). No reliable effect of interim testing on prior-passage intrusions was observed. Together, these findings suggest that high attentional engagement during encoding of the target material is an important precondition for interim testing to benefit subsequent learning. Notably, divided attention had only a relatively small effect on recall performance in the restudy condition. This pattern may reflect differences between prose learning and list learning. In contrast to unrelated word lists, prose provides semantic structure and contextual support, which may render encoding more resilient to reductions in attentional resources. Importantly, however, although divided attention had only a limited effect on baseline prose learning, it eliminated the benefits of interim testing for subsequent learning. This pattern suggests that the mechanisms underlying the benefits of interim testing for subsequent learning may be more sensitive to reductions in attentional resources than baseline prose learning.

General Discussion

In two experiments, the present study examined whether the benefits of interim testing for subsequent learning depend on attentional engagement during encoding of the final target

material. In both experiments, interim testing enhanced recall of the target material when attention during final encoding was left unaffected, thus replicating prior work with both word lists (e.g., Pastötter et al., 2011; Szpunar et al., 2008; Yang et al., 2019) and prose passages (e.g., Kriechbaum & Bäuml, 2024; Szpunar et al., 2013; Wissman et al., 2011). In contrast, when attention during encoding of the target material was experimentally reduced, the benefit of interim testing was attenuated in Experiment 1 and even eliminated in Experiment 2. Together, these results indicate that interim testing per se may not be sufficient to produce its full beneficial effect on subsequent learning. Rather, a high level of attentional engagement during encoding of the final material appears critical for interim testing to maximize learning of the material.

Several mechanisms have been proposed to explain how interim testing benefits subsequently studied material. For relatively simple materials such as word lists, the effect has been linked to changes in encoding or retrieval strategy (Chan et al., 2018; Cho et al., 2017), a reset of encoding (Pastötter et al., 2011, 2018), and reduced proactive interference (Bäuml & Kliegl, 2013; Szpunar et al., 2008). For more complex prose materials, facilitated comprehension has been proposed as an additional mechanism, whereby prior testing promotes understanding and integration of subsequently studied information (Kriechbaum & Bäuml, in press; Szpunar et al., 2013; Wissman et al., 2011). Although all of these processes likely benefit from high attentional engagement during encoding of the final target material, they may do so to different degrees. The intrusion findings from Experiment 1 suggest that proactive-interference reduction is comparatively less affected by attentional distraction, because interim testing reduced prior-list intrusions regardless of attentional condition. By contrast, facilitated comprehension and integration may depend more strongly on attentional engagement. This interpretation is consistent with the stronger reduction of the benefits of interim testing under divided attention for related prose passages in Experiment 2 than for unrelated word lists in Experiment 1.

The present findings also extend those of Mulligan and Buchin (2025) by showing that, whereas divided attention during interim testing did not modulate the forward testing effect in their study, divided attention during encoding of the final target material did so in the present study. Although the present study was not designed to directly compare attentional demands during encoding and retrieval, the observed pattern is broadly consistent with the divided-attention literature, which has repeatedly shown that attentional distraction during encoding typically

impairs later memory more strongly than distraction during retrieval (Craig et al., 1996; Naveh-Benjamin et al., 2006; Yeung & Fernandes, 2021). In addition, the results of Experiment 2 further suggest that the benefits of interim testing may extend beyond immediate retention to performance on a final knowledge transfer test, replicating earlier work with related prose materials (Kriechbaum & Bäuml, in press; Szpunar et al., 2013). Under full attention, interim testing improved both recall of the target passage and transfer performance. Under divided attention, the numerical effect on transfer performance was markedly smaller and not statistically reliable. However, because the interaction in the transfer analysis did not reach conventional significance, the reduction of the transfer benefit under divided attention should be interpreted with caution. Nevertheless, the overall pattern is consistent with the possibility that attentional engagement during encoding constrains not only the retention-related but also the transfer-related benefits of interim testing.

From a practical perspective, the present findings suggest that interim testing can be a highly effective tool for promoting subsequent learning, but that its benefits depend on the attentional conditions under which new material is encoded. This issue is particularly relevant for application because, in everyday learning environments, learners may complete quizzes or self-tests and then continue studying under less favorable attentional conditions. Importantly, attentional conditions during an ongoing learning episode are not necessarily stable but may change unexpectedly because of external or internal events. Such abrupt changes can substantially reduce the attentional resources available for continued learning and thereby impair learning and academic performance (May & Elder, 2018; van der Schuur et al., 2015). Although learners may not intentionally divide their attention only during the final phase of a study episode, the present manipulation should therefore be viewed as a controlled experimental analogue of such sudden changes in attentional conditions rather than as a literal simulation of a specific real-world learning scenario.

The present findings also help place the findings of Chan et al. (2025) into a broader context. Chan et al. proposed that attentional engagement during online learning may already be comparatively low, such that stimuli that are distracting in a conventional sense, like entertaining onscreen videos, can under some conditions paradoxically re-engage learners instead of further reducing attention. Moreover, in their study, the elimination of the benefits of interim testing under distraction was driven by improved performance in the review condition rather than by

impaired performance in the quiz condition. By contrast, in the present study, divided attention reduced the benefits of interim testing by impairing learning of the target material. Together, these findings suggest that the effects of attentional distraction depend on the timing, duration, and type of distraction, as well as the broader learning context. Future work should examine these factors more directly.

In conclusion, the present findings show that divided attention during encoding constrains the benefits of interim testing for subsequent learning. Interim testing enhanced learning of later studied material when attention during target encoding was left unaffected, but this benefit was reduced or even eliminated when attention was divided. These results identify a high level of attentional engagement during encoding of later studied information as an important precondition for interim testing to support later learning.

Authors' Contributions

BP developed the study concept and experimental design, coordinated data collection, analyzed the data, and drafted the manuscript. KHB provided critical revisions. Both authors approved the final version of the manuscript for submission.

Data Accessibility Statement

Material, data, and analysis scripts are available on the Open Science Framework:

<https://doi.org/10.17605/OSF.IO/WDFHK>.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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Tables

Table 1. Results of Experiment 1: Recall rates (percent) and number of intrusions as a function of *interim activity* (restudy vs. testing) and *attention* (full vs. divided). Means and standard errors of the mean (in parentheses).

Attention	Recall Test	Interim Activity	Recall Rates		Intrusions	
			List 1	List 2	List 3	List 3
<i>Full</i>	Immediate	Restudy			37.50 (4.63)	0.50 (0.20)
		Testing	62.22 (3.63)	57.78 (3.76)	64.44 (3.60)	0.08 (0.06)
	Final	Restudy	39.72 (5.65)	49.72 (5.31)		
		Testing	48.33 (5.45)	48.61 (5.41)		
<i>Divided</i>	Immediate	Restudy			14.72 (2.16)	0.46 (0.15)
		Testing	52.78 (4.66)	56.39 (4.01)	27.78 (3.07)	0.21 (0.10)
	Final	Restudy	47.50 (5.30)	57.22 (5.69)		
		Testing	42.22 (5.80)	48.61 (5.00)		

Table 2. Results of Experiment 2: Recall rates (percent) and number of intrusions as a function of *interim activity* (restudy vs. testing) and *attention* (full vs. divided). Means and standard errors of the mean (in parentheses).

Attention	Recall Test	Interim Activity	Recall Rates		Intrusions	
			Passage 1	Passage 2	Passage 3	Passage 3
<i>Full</i>	First	Restudy			21.58 (2.84)	0.37 (0.12)
		Testing	48.81 (2.67)	53.87 (4.23)	40.77 (3.51)	0.21 (0.10)
	Second	Testing	48.06 (3.32)	49.70 (3.86)		
<i>Divided</i>	First	Restudy			16.81 (2.70)	0.12 (0.07)
		Testing	43.45 (3.20)	49.11 (3.40)	20.68 (3.17)	0.17 (0.08)
	Second	Testing	42.56 (3.19)	46.58 (3.40)		

Figures

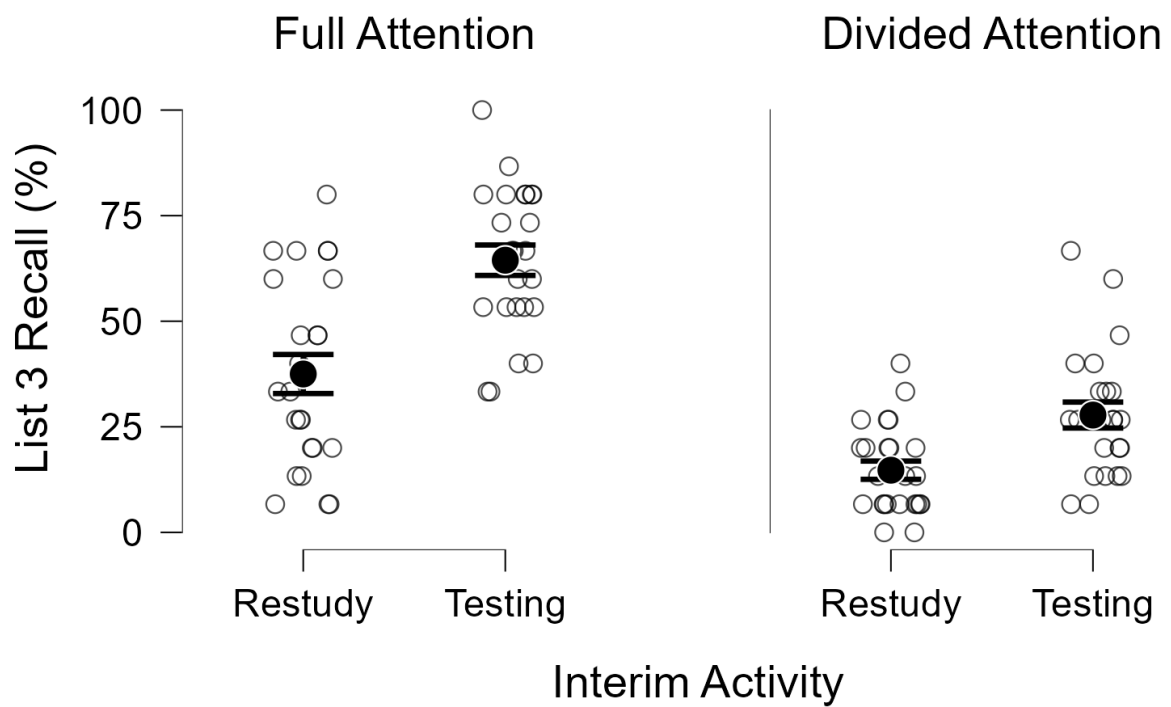


Figure 1. Results of Experiment 1: List 3 recall (percent) as a function of *interim activity* (restudy vs. testing) and *attention* (full vs. divided). Error bars show standard errors of the mean.

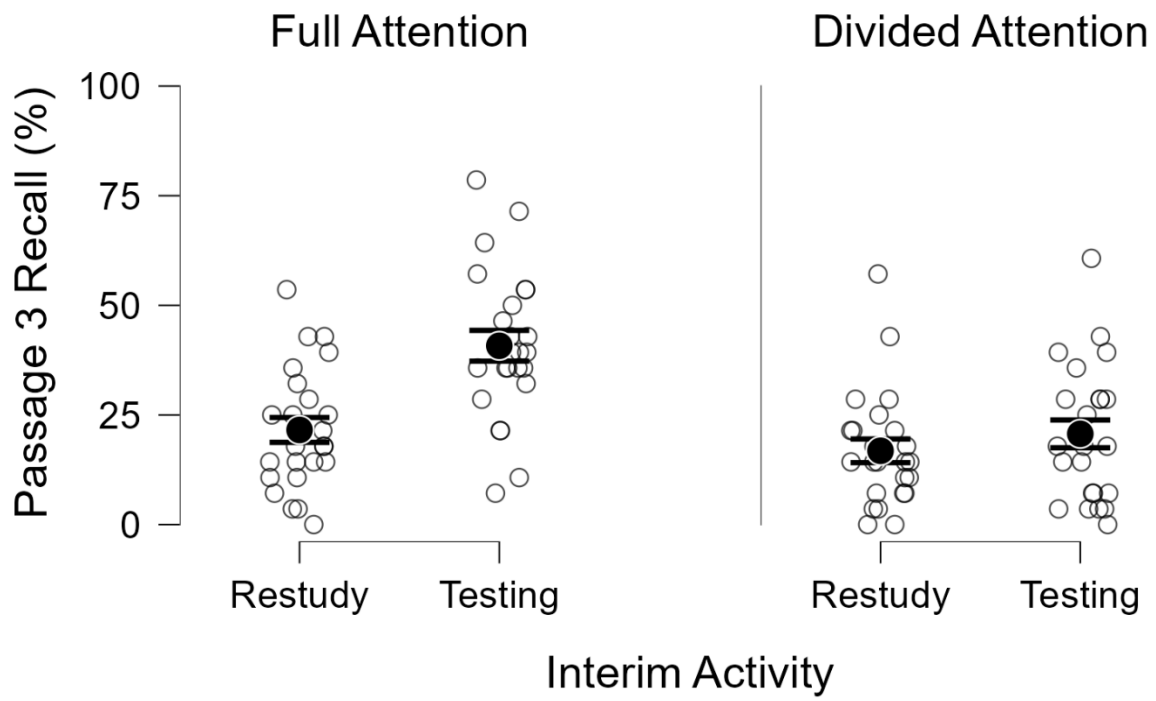


Figure 2. Results of Experiment 2: Passage 3 recall (percent) as a function of *interim activity* (restudy vs. testing) and *attention* (full vs. divided). Error bars show standard errors of the mean.