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Elaboration by Superposition: From Interference in Working Memory to Encoding in Long-term Memory

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Abstract

Distraction embedded in working memory tasks leads to impaired performance. This impairment is mitigated when targets and distractors that follow them share common features – a signature effect of interference by superposition. Here we propose that target-distractor similarity modulates not only forgetting from working memory but also encoding into long-term memory. In five experiments, we test this elaboration-by-superposition hypothesis, demonstrating that semantic relatedness between targets and distractors benefits delayed category-cued recall performance (Experiments 1a and 1b), which is not due to carry-over effects from working-memory testing (Experiment 2). Just as in the case of working memory, this long-term memory effect is reduced when distractors precede targets (Experiment 3). Finally, we show that while high target-distractor similarity reduces forgetting from working memory, it produces net benefits for long-term memory performance (Experiment 4). Together, the results suggest that common mechanisms underlie encoding into working and long-term memory, and that bindings between features of spatiotemporal context and features of to-be-remembered items play a crucial role.

Keywords: Working memory, Long-term memory, Distraction, Cued recall

Elaboration by Superposition: From Interference in Working Memory to Encoding in Long-term Memory

Working memory (WM) is a system that serves to keep a limited amount of information in an active state so that it can be manipulated and used in ongoing activities. For instance, retaining prices of several items to calculate their total value, or holding someone's phone number in memory while engaged in a conversation are typical functions of the WM system. The defining feature of WM is its limited capacity, by which WM performance drops rapidly when a relatively small number of to-be-maintained items is exceeded. By contrast, long-term memory (LTM) is characterized by in principle unlimited capacity for storing new information, which can be accessed after prolonged delays. This capacity distinction between WM and LTM determines the research agenda for researchers investigating these two theoretical constructs. WM researchers are often interested in the reasons for which information is lost from WM, postulating mechanisms like decay or interference to account for rapid forgetting. LTM researchers typically assume that information is not lost, although it may become inaccessible (Tulving & Pearlstone, 1966), and often concentrate their efforts on establishing how information is encoded into LTM in the first place (e.g., Craik & Tulving, 1975; Hunt & Einstein, 1981; Naveh-Benjamin & Brubaker, 2019). In the present study, we present an attempt to link these two perspectives, showing how a mechanism postulated to account for forgetting from WM is responsible for determining the type of information encoded into LTM. The mechanism of forgetting from WM which we put under scrutiny here is one of interference by superposition (Oberauer, 2009; Oberauer et al., 2016; Oberauer, Farrell, et al., 2012). The mechanism by which changes are introduced into LTM representations is often termed elaboration (Craik &

Watkins, 1973; Greene, 1987). Thus, the current study constitutes a proof of concept for a mechanism of *elaboration by superposition*.

The tool of choice for investigating WM is a complex-span task, which requires both maintaining items for a subsequent serial-recall test and processing distraction inserted in between study items (Daneman & Carpenter, 1980). Much discussion has been devoted to the issue of why exactly distraction causes forgetting from WM, with studies assigning this phenomenon to decay – fading of memory representations due to passage of time when attention is devoted to processing distraction (e.g., Barrouillet et al., 2004, 2007; Lilienthal et al., 2014; Page & Norris, 1998; Ricker et al., 2020; Soemer, 2019; Towse et al., 2000; Vergauwe et al., 2009) – or interference resulting from storing new information when distractors enter WM (e.g., Lewandowsky et al., 2010; Lewandowsky & Oberauer, 2008, 2009; Nairne, 1990; Oberauer et al., 2004; Oberauer & Kliegl, 2006; Saito & Miyake, 2004). Independent of whether one accepts a role of decay in forgetting from WM, the role of interference remains uncontested. Indeed, proponents of WM models incorporating a decay mechanism have argued that decay may actually make memory representations more vulnerable to interference (e.g., Barrouillet et al., 2007; Portrat et al., 2008). The current state of research on WM thus assigns the limits of maintaining items in WM in the face of ongoing distraction at least partially to the fact that processing distractors means that distractors are themselves encoded into WM, interfering with representations already maintained in this system.

When interference is considered as a mechanism by which distraction causes forgetting from WM, one key point concerns the similarity between the to-be-remembered targets and to-be-ignored distractors. Arguably, for distractors to interfere with target memory there has to be some similarity between the two. And, indeed, studies have repeatedly found that distractors from the same domain (e.g., words or digits) as targets cause more forgetting from WM than distractors from a different domain (e.g., Bayliss et al., 2003; Conlin et al., 2005; Turner & Engle, 1989). However, there is also an exception to this general pattern of the effect of item-distractor similarity. Oberauer (2009) showed that when targets and distractors come from the same domain, WM performance can actually benefit from distractors that are similar to the to-be-remembered target. This counterintuitive pattern, to which we will turn in more detail now, is predicted by one of the leading models of WM, the Serial Order in a Box – Complex Span model (SOB-CS; Oberauer, Lewandowsky, et al., 2012). It also provides support for a particular mechanism of interference implemented in this model – interference by superposition.[1]

In the study by Oberauer (2009), participants performed a series of trials of the complex-span task. In this task, four to-be-remembered target words were consecutively displayed, each followed by four words that participants were asked to read aloud but otherwise ignore for the purpose of performing the WM task. Each target on a given trial was taken from a different semantic category. In the related-distraction condition, the to-be-read distractors that followed the targets were taken from the same semantic category as the target word, whereas they were from a different semantic category than any of the targets on a given trial in the unrelated-distraction condition. Each trial of this complex-span task concluded with participants attempting to serially recall the presented targets. The

[1] Interference by superposition should not be confused with another mechanism, one of interference by confusion: an observation that retrieval becomes less effective when a cue is associated with more competing memory representations (Watkins & Watkins, 1975). In our studies, we took care to eliminate any influence of interference by confusion – as described in the Method section of Experiment 1a – and thus we do not consider this mechanism here. Whenever we refer to interference throughout this paper, it should be taken to denote interference by superposition as implemented in the SOB-CS model (Oberauer, Lewandowsky et al., 2012).

results revealed better serial-recall performance in the related- than in the unrelated-distraction condition, confirming that the similarity of distractors to their respective targets can mitigate the interference these distractors generally cause in WM. A similar pattern of results was also documented by Oberauer, Farrell, et al. (2012) in a study that manipulated phonetic rather than semantic target-distractor similarity in a task requiring memorizing non-words.

The patterns observed by Oberauer (2009) and Oberauer, Farrell, et al. (2012) were predicted by the SOB-CS model, which specifies how distractors encoded into WM interfere with maintenance of target items (see Oberauer, Lewandowsky, et al., 2012, for a full specification). Briefly, in this model it is assumed that items have distributed representations consisting of a number of features. These features are bound during study with position cues, also represented as bundles of features. Interference occurs because targets and distractors immediately following them are bound to the same position cues. In this model, new position-distractor bindings are superimposed on position-target bindings, distorting them and, thereby, causing interference. However, when the target and the following distractors share common features (e.g., their semantic category), the overall distortion of position-target bindings is less severe because superposition strengthens the bindings between shared features and the common position cue. This net result of less severe distortion for related distractors can be observed in a serial-recall task, where using position cues to serially retrieve targets results in accessing the original position-target bindings (see Figure 1 in Oberauer, Farrell, et al., 2012, for a visualization of the superposition mechanism).

So far, the studies on target-distractor similarity have been concerned with testing predictions of the SOB-CS model and thus they were limited to assessing performance in variants of serial-recall tasks tapping WM. The novel question asked here is how superposition affects LTM performance. Going back to SOB-CS, this model assumes that serial-recall performance is determined by bindings between items and their positions within a study list. The idea of position cues that encode the place of a particular item within a study list is common in conceptual work on WM (Burgess & Hitch, 1999; Kowialiewski et al., 2021; Oberauer, Lewandowsky et al., 2012). However, modelling of LTM often substitutes position cues for context cues – the overall contents of the mind that accompany the presentation of an item and which include details about the environment and also thoughts elicited by processing the item itself (Howard & Kahana, 2002). Importantly, recent work by Logan (2021; see also Logan & Cox, 2021) underscores that position cues in models of WM may in fact be an example of a broader class of context cues as defined in conceptual frameworks of LTM (see Howard & Kahana, 2002). This stance follows from previous work on WM in which the role of context cues has been implicated, accounting in particular for the patterns of errors in the immediate serial recall task (Unsworth & Engle, 2006). The postulated identity of position and context cues has important consequences for mechanisms operating across WM and LTM. If position cues used to describe the operations of the WM system are the same as context cues used to describe the operations of the LTM system, then mechanisms that build on position cues in WM should affect LTM performance, also in tests that are context-dependent but that do not require strict serial reproduction of study items.

Returning to interference by superposition, reduced interference caused by distractors that follow related targets is assumed in SOB-CS to reflect a superposition of bindings between overlapping features of related targets and their distractors on the one hand and a common position cue on the other (Oberauer, Lewandowsky et al., 2012). Thus, in the complex-span task used by Oberauer (2009), if the word EMERALD is followed by four other instances of gemstone, as opposed to instances of a different category (e.g., fish), participants' ability to remember EMERALD in its actual position within the study list is enhanced. However, if this position cue is taken to constitute context as understood in the models of LTM, then it follows that presenting related distractors should strengthen bindings between overlapping item-distractor features and context that is then used to access items at the time of contextually-cued retrieval from LTM. Thus, the word EMERALD, when followed by related distractors, should be easier to recall within the context of a given study list, not only at its particular position within this list. In other words, related distractors would serve to elaborate episodic, contextually-bound representation of a target by rendering the particular features that are shared by these distractors and immediately preceding targets more prominent. Testing this prediction of the parallel effects in WM and LTM of using related distractors is the main empirical aim of the present work.

The chances to detect the putative after-effects of superposition of feature and context bindings should be increased in a test of LTM in which performance is dependent on accessing these particular bindings. Such a test requires cueing with both context and specific features shared across targets and distractors. All explicit tests of episodic LTM, that is tests that require accessing a particular contextual representation, are necessarily dependent on contextual bindings (e.g., Davis et al., 2008; Schwartz et al., 2005). However, not all tests can be assumed to benefit from stronger episodic representations of particular features common to targets and related distractors. For example, when EMERALD is followed by distractors such as *diamond* or *ruby*, the bindings between context and features describing EMERALD as a gemstone should be strengthened. If a subsequent test used the word *green* as a cue, this would fail to match the particular features strongly bound to the context by virtue of using related distraction, reducing our chances of observing the effect that we pursue here. Generally, the chances of observing our effect of interest should be greatest with cues that specifically embed the information that superposition helps encode into episodic memory, which in this case is common categorical membership of targets and their distractors – the gemstone label in our example. In other words, what is most auspicious for detecting after-effects of superposition in this case is a category-cued recall test (see Hanczakowski et al., 2017; Zawadzka et al., 2021, for similar logic). In the present work, we thus adopt the paradigm developed by Oberauer (2009) and test for effects of target-distractor similarity, implemented in the WM task, for LTM performance. We use category membership as a feature linking targets and their respective distractors in the complex-span task and a test of category-cued recall to reveal the effects of elaboration by superposition of targets and distractors.

We present five experiments designed to reveal the common dynamics across WM and LTM systems. All experiments utilized a variant of the complex-span task and manipulated target-distractor similarity, by which targets were accompanied by distractors that were either taken from the same category as the target itself, or from a different semantic category. For WM performance, we expected to replicate the results of Oberauer (2009) and thus demonstrate the signature effect of interference by superposition: reduced interference when related (rather than unrelated) distractors follow their respective targets. The novel feature in our design was an LTM test of category-cued recall that was tailored to determine whether related distractors strengthen contextual encoding of features shared across targets and their respective distractors. If superposition of the to-be-remembered targets and distractors determines contextual encoding, then related distractors should strengthen episodic representations of features shared across targets and their respective distractors, leading to better category-cued recall performance as compared to a situation in which targets are followed by unrelated distractors. Experiments 1a, 1b and 2 tested this basic prediction of the mechanism we term elaboration by superposition. Experiment 3 tested an additional specific prediction of the superposition account, by which the discussed effects of superposition on both WM and LTM performance should be observed primarily when related distractors follow rather than precede their respective targets. Experiment 4 included an additional no-distraction condition to demonstrate that target-distractor similarity reduces interference in WM but produces a net benefit to LTM performance.

Experiments 1a and 1b

In Experiments 1a and 1b, we adapted the procedure used previously by Oberauer (2009) for assessing the role of target-distractor similarity for WM performance to examine whether the type of distraction within the WM task also determines LTM performance. Participants performed a series of complex span trials in which four target words, each from a different semantic category, were interspersed with distractors that had to be read aloud by participants. Across trials, distractors were either from the same or a different semantic category as the directly preceding target. Immediate serial recall was used to assess WM performance, in a direct replication of the design used by Oberauer. A category-cued recall test followed a series of four complex span trials – two from the related- and two from the unrelated-distraction condition – to assess LTM performance. We used a category-cued recall task, as previous work indicated that to detect whether elaborative encoding of semantic features of to-be-remembered words a test is necessary that taps those particular features (Hanczakowski et al., 2017; Zawadzka et al., 2021).

Experiments 1a and 1b differed in that in Experiment 1a all trials were followed by the immediate serial-recall test, whereas in Experiment 1b immediate serial-recall tests were administered only for half of the trials of the complex span task, with an arithmetic distractor task administered for the other half. In this way, Experiment 1b assessed whether any effect observed in LTM measure of cued recall could be due to carry-over effects from differences observed in immediate serial recall. If the same effects are observed for trials for which immediate serial recall tests were administered, this would serve to eliminate the explanation based on carry-over effects.

Method

Participants

The sample size was based on Oberauer's (2009, Experiment 2) results for the benefits of semantic relatedness with in-position scoring – an effect size of $d = 0.66$. A power analysis suggested that to obtain power of .95, 27 participants were required. Thus, 30 undergraduates from the SWPS University participated in Experiment 1a and 32 undergraduates participated in Experiment 1b. All participants received partial course credit. Due to technical problems, two participants in Experiment 1a did not complete the procedure, and so two more participants were tested to replace their data. We attempted to retain the same sample size for all experiments presented here. Demographic data (age, gender) were not collected in this series of experiments. The study was approved by the Research Ethics Committee at the SWPS University.

Materials and Design

A set of 192 Polish nouns, with 12 instances of 16 categories, was chosen based on an online survey conducted with an independent sample of participants (*N* = 173). In this survey, participants were given unique category labels (e.g., “fish” or “family member”) and were asked to generate exemplars for these categories. From each category, the most often mentioned one-word exemplars were picked to serve as stimuli. Any words that were deemed not appropriate for their category labels (e.g., *dolphin* for “fish”) were excluded. In the experiments reported here, words from each category were used both as targets and distractors in the complex span task, with each word serving once as a target in the entire experimental task but three times as a distractor across various blocks. Category labels were then used as cues for the delayed recall test.

A trial in the complex span task consisted of four targets, each from a different semantic category, followed by four distractors. A block consisted of four trials and ended with a cued-recall test for all 16 targets (four from each trial). Each target within one block came from a different semantic category, which allowed for using unique category cues on the cued-recall test. The same 16 categories were used across all 12 blocks of the procedure.

There were two types of trials of the complex span task (see Figure 1). On related-distraction trials, each target was followed by four distractors from the same category (e.g., EMERALD, *topaz, amber, diamond, opal*; the target is capitalized here for illustration purposes as in the actual experiment all items were presented in lowercase). On unrelated-distraction trials, targets were followed by a set of four distractors from a single category that was different from the category of that target (e.g., EMERALD, *larch, fir, spruce, yew*). Within a block, two trials were assigned to the related-distraction condition, and the other two to the unrelated-distraction condition. The order of trials in a given block was random.

The assignment of targets to conditions was counterbalanced across participants. Importantly, for the unrelated-distraction condition, unrelated distractors were re-paired across trials within the same block. Thus, if EMERALD, followed by *larch*, *fir*, *spruce*, *yew*, was one of the targets in one of the unrelated trials, then the distractors *topaz*, *amber*, *diamond*, *opal* would follow one of the other targets within the same block, chosen randomly. With this design, the number of items associated with each category cue in the test of LTM was equated across related- and unrelated-distraction conditions: one cue was associated with a single target from the WM task and four different distractors that either immediately followed this target in the related-distraction condition, or were used in a different unrelated-distraction trial within the same block. This served to equate the set size of cues across experimental conditions, eliminating any potential effects of interference by confusion.

In Experiment 1a, each trial of the complex-span task ended with a serial-recall test in which participants were asked to reproduce the most recent targets in the same order in which they were presented. In Experiment 1b, for half of the trials within a given block – one trial from the related-distraction condition and one trial from the unrelated-distraction condition, counterbalanced across participants – the immediate serial-recall test was substituted with an arithmetic task. Thus, Experiment 1a had a single independent variable of type of distraction (related vs. unrelated), whereas Experiment 1b used a 2 (distraction: related vs. unrelated) x 2 (immediate serial-recall test: present vs. absent) design. All variables were manipulated within participants.

Procedure

The experiment was conducted online. Throughout the experiment, an experimenter supervised one participant at a time via a video and audio link to ensure that experimental instructions were followed. The experiment began with a training session wherein participants were accustomed with the complex-span task in a single trial of study and serial recall. Participants then performed 12 blocks of four trials each.

On each trial, four target words were presented individually on the screen for 1400 ms in a red font. Each target was followed by four distractors, displayed individually on the screen for 1500 ms in a black font, with a 100 ms interstimulus interval. Participants were instructed to read silently and memorize the words displayed in red, and to read aloud but otherwise ignore those displayed in black. All trials in Experiment 1a and half of the trials in Experiment 1b concluded with a serial-recall test in which participants were asked to recall and type in all the targets (red words) from the present trial in the order of their presentation. If participants could not recall a word in a certain position, they were asked to type in "x" in its place. The remaining half of the trials in Experiment 1b concluded with an arithmetic task, where participants were presented with four simple algebraic tasks of addition and subtraction. The average time needed for completing the math task was 17.30 s (*SD* = 8.10).

After completing four trials of the complex-span task, participants were given a cued-recall test. In the cued-recall test, a single category label (e.g., *Gemstone*) was displayed on the screen at a time and participants were asked to recall and type in the word from this category that served as the target in the current block (EMERALD). If a participant failed to type in and accept the answer within 10 s, the procedure automatically advanced to the next cue. The order of presentation of 16 category cues from each block was randomized anew for each participant.

Transparency and Openness

The study was not preregistered. All data are publicly available at https://osf.io/jemzs. All experiments, variables, as well as data exclusions are reported.

Results

Descriptive statistics for all serial- and cued-recall measures are presented in Table 1. Figure 2 depicts aggregate as well as participant-level data.

Experiment 1a

Immediate Serial Recall

Two scoring methods were used to assess performance in the serial-recall task. For correct-in-position scoring, words were counted as correctly recalled only if they were provided in the same output position in which they were presented at study. For item scoring, correctly recalled words were counted as such regardless of their output position. The analysis of performance with correct-in-position scoring revealed a significant difference, $t(29) = 5.53$, $p < .001$, $d = 0.83$, with higher performance in the related-distraction than in the unrelated-distraction condition. Likewise, the analysis of performance with item scoring revealed higher performance in the related-distraction than in the unrelated-distraction condition, $t(29) = 4.56$, $p < .001$, $d = 0.84$.

Delayed Cued Recall

An analysis of category-cued recall performance revealed a significant difference between the experimental conditions, $t(29) = 5.02$, $p < .001$, $d = 0.92$, with higher performance in the related-distraction than in the unrelated-distraction condition, mirroring the results found in the serial-recall measures.[2]

To ensure that this pattern is not due to carry-over effects from the immediate serial-recall test, we also examined the results of the delayed cued-recall test conditionalized on whether items were recalled correctly in the immediate recall test. The conditionalized results replicated the difference between related- and unrelated-distraction conditions, $t(29) = 4.04$, $p < .001$, $d = 0.74$. The specific results for the conditionalized analyses for this and the remaining experiments in this study can be found in the Appendix.

Experiment 1b

Descriptive statistics for all serial-recall and cued-recall measures are presented in Table 1, and aggregated and participant-level data are presented in Figure 2.

Immediate Serial Recall

Here the results were analyzed for half of the trials that concluded with an immediate serial recall test. The analysis of performance with correct-in-position scoring revealed a significant difference, $t(31) = 2.59$, $p = .015$, $d = 0.46$, with higher performance in the related-distraction than in the unrelated-distraction condition. Likewise, when item scoring was

[2] In the present design, the cued-recall test followed immediately the last trial of the complex-span task. It is thus possible that some of the targets in the cued-recall task were actually retrieved from WM, whenever cues for particular words from the last trial of the complex-span task happened to be presented at the beginning of the cued-recall task. To address this issue, we re-analyzed cued-recall data excluding targets that were recalled in the last complex span trial of each block and that could thus contaminate our measure of LTM performance. The difference between related- and unrelated-distraction conditions remained significant, $t(29) = 4.34$, $p < .001$, $d = 0.79$.

used, performance was significantly higher in the related- than in the unrelated-distraction condition, $t(31) = 2.72$, $p = .011$, $d = 0.48$.

Delayed Cued Recall

A 2 (distraction: related vs. unrelated) x 2 (serial recall: present vs. absent) within-participants analysis of variance (ANOVA) was conducted on category-cued recall performance. This analysis revealed a significant main effect of distraction, $F(1, 31) = 33.59$, $MSE = .26$, $p < .001$, $\eta^2 = .22$, which reflected overall higher performance in the related-distraction ($M = .48$, $SD = .15$) than in the unrelated-distraction condition ($M = .39$, $SD = .19$). The main effect of serial recall was also significant, $F(1, 31) = 8.70$, $MSE = .08$, $p = .006$, $\eta^2 = .07$. This reflected higher performance when immediate serial recall was present ($M = .46$, $SD = .16$) than when it was absent ($M = .41$, $SD = .18$). Critically, however, the interaction was not significant, $F < 1$. Because non-significant interactions are not straightforwardly interpretable, we also computed a Bayes factor for this analysis, using the default settings in JASP (Wagenmakers et al., 2018), which provided moderate evidence against the interaction, $BF_{10} = 0.26$. We also confirmed that the effects of related distraction were reliable both in the condition with an initial serial recall test, $t(31) = 3.93$, $p < .001$, $d = 0.70$, and – with an almost identical magnitude of the effect – without it, $t(31) = 3.96$, $p < .001$, $d = 0.70$.

Discussion

In the first two experiments, we found similar benefits of semantically related distractors embedded in the complex-span task for immediate WM performance and delayed LTM performance. The results for immediate serial recall replicate those reported by Oberauer (2009) and document reduced forgetting from WM when targets and distractors share common features. The WM results confirm that the interference-by-superposition mechanism described by the SOB-CS model (Oberauer, Lewandowsky, et al., 2012) operated in our study. The novel contribution of the present experiments concerns LTM performance, which also revealed benefits of related distraction at study. This effect on cued-recall performance was not due to carry-over effects from immediate testing, as evidenced by both the analysis of conditionalized results in Experiment 1a and the results from the condition omitting immediate testing in Experiment 1b. These LTM results are consistent with the notion that not only does superposition underlie forgetting from WM, but at the same time it determines the type of information encoded into LTM. This confirms that the operation of the superposition mechanism is not limited to position cues determining performance in tests dependent on serial information, such as serial recall used to assess WM performance, but generalizes to other tests tapping episodic memory representations, such as in this case category-cued recall. By implication, our results suggest that position cues determining serial recall within WM are in fact identical with context cues that determine performance across a variety of tests of episodic memory (see Logan, 2021).

We argue that to observe the benefits of related distraction, semantic and temporal-contextual characteristics of distraction need to be confounded: only when distractors are presented in the same contexts as their respective targets, can contextual bindings of their common semantic features be augmented. However, in Experiments 1a and 1b the baseline condition of unrelated distraction de-confounded semantic and context features in a particularly dramatic way, as distractors related to their targets were presented in different trials of the complex-span task. In this way, in the related-distraction condition targets and distractors shared exactly the same context, while in the unrelated-distraction condition targets and distractors were presented in the contexts of different study lists. This raises the question of how exact the confounding needs to be for our effect of interest to emerge. Would benefits of related distractors following their respective targets still emerge if they were compared to an unrelated-distraction condition in which targets and their distractors were presented within the same list context? Experiment 2 addressed this issue by modifying the unrelated-distraction condition so that distractors were presented within the same list context but not immediately after their respective target.

Experiment 2

In the present experiment, we aimed at establishing the extent to which temporal proximity of targets and related distractors determines the benefits of related distraction for both WM and LTM performance. Here, in the related-distraction condition distractors from the same category immediately followed their respective targets, while in the modified unrelated-distraction condition distractors from the same category were presented within the same trial of the complex span task, but after the next target. Thus, if EMERALD was the first word in the modified unrelated-distraction condition and PIKE was the second word, then distractors *topaz*, *amber*, *diamond*, and *opal* were presented after PIKE. In this way, in both related- and unrelated-distraction conditions, targets and their related distractors shared the same list context but only in the related-distraction condition did they share exactly the same context due to their close temporal proximity. Because we assume that the benefits of related distraction are due to augmented bindings between semantic features common to targets and distractors and contextual features present when both targets and distractors are processed, we expected the greater contextual overlap in the related-distraction condition to result in benefits of related distraction also in the present design, both for WM and LTM performance.

Method

Participants

Thirty participants who reported Polish as their first language were recruited via Prolific. In the honesty-check question displayed after the completion of the study, five participants reported not committing to the experimental instructions and thus their results were excluded from the analyses and replaced with data from five new participants. Each participant was remunerated with £6 for their participation.

Materials, Design and Procedure

The same materials as in Experiments 1a and 1b were used. As this study was not supervised by an experimenter, a prerecorded demonstration of the experimental task was added at the beginning of the procedure and a question asking whether the participant followed experimental instructions by reading the targets silently and the distractors out loud was included at the end of the experiment. The experimental procedure was the same as in Experiment 1a, with serial recall on all trials of the complex-span task, except for the design of the unrelated-distraction trials. In the modified unrelated-distraction trials, each target was followed by distractors related to the previous target, with the first target followed by the distractors related to the fourth target. To illustrate, if the targets in an unrelated-distraction trial were to be APPLE, CAR, UNCLE and EMERALD, the first target would be followed by four distractors taken from the "gemstones" category, the second target would be followed by four fruits, the third would be followed by four vehicles, and the last target would be followed by four family members.

Results

Descriptive statistics for all serial-recall and cued-recall measures are presented in Table 1. Aggregated and participant-level data are presented in Figure 3.

Immediate Serial Recall

As in this experiment targets presented on positions 1-3 in the unrelated-distraction trials differed from targets presented on position 4, with only targets in positions 1-3 adhering to our design of having related distractors following the next target in the list, we excluded targets from position 4 from all analyses, regardless of the distraction condition. The analysis using correct-in-position scoring revealed that performance in the related-distraction condition was significantly higher than in unrelated-distraction condition, $t(29) = 2.48$, $p = .019$, $d = 0.45$, and similar results were obtained when item scoring was employed, $t(29) = 2.11$, $p = .044$, $d = 0.38$.

Delayed Cued Recall

For the analyses of cued recall, we again excluded targets presented in position 4. We obtained a significant difference between related- and modified unrelated-distraction conditions, $t(29) = 3.54$, $p = .001$, $d = 0.65$, demonstrating that related distraction immediately following targets benefits LTM performance compared to a situation when such distraction is delayed to after the presentation of the next target.

Discussion

Experiment 2 extended the results of Experiments 1a and 1b by again showing that related distractors that immediately follow their respective targets augment memory performance for these targets both when assessed immediately in the WM task and after a delay in the LTM task. This time these benefits emerged relative to a situation in which related distractors shared the same context lists with their targets but not close temporal proximity in the modified unrelated-distraction condition. Again, this remains consistent with the assumptions of the interference-by-superposition mechanism operating in WM, and by extension the elaboration-by-superposition mechanism we postulate for LTM. When a novel target is presented, it creates either a new position cue (Oberauer, Lewandowsky et al., 2012), or – as we argue in the present study – a new context representation, to which distractors following it become bound. Due to this change in cues with the presentation of a new target, distractors no longer augment cue-feature bindings that determine performance for the previous target to which these distractors were semantically related. The parallel effects observed here for WM and LTM performance again suggest that the process initially described as updating position cues that determine WM performance can be reformulated as updating context cues that also determine LTM performance. Ultimately, it seems that close temporal proximity between targets and distractors is necessary for the benefits of related distraction to emerge as it ensures that these are processed within highly overlapping context cues.

But is temporal proximity sufficient to produce the benefits of related distraction in both WM and LTM? Somewhat counterintuitively, the interference-by-superposition hypothesis predicts that a mere co-occurrence of targets and related distractors in close temporal proximity may not always be sufficient to affect WM performance. According to the SOB-CS model, the benefits of related distraction – in the form of reduced interference – are most apparent when related distractors *follow* their respective items. This is because distractors in this model are bound to the position cues of their preceding targets and these position cues are updated only with the presentation of the next study item. Thus, if distractors precede their related targets, they are bound to position cues of a different target than the one they are related to. There is some room for moderating interference also under these conditions because there is partial overlap in features of position cues across neighboring targets in a study list, but such moderation is markedly reduced compared to a situation in which distractors are bound to the same position cues as their respective targets.

Oberauer, Farrell, et al. (2012) confirmed this specific prediction of the interference-by-superposition hypothesis in a study examining WM, using non-words as study materials and phonetically related distractors. In this study, related distractors did not affect serial-reconstruction performance when they preceded rather than followed their respective targets. Throughout the present study, we have proposed that position-to-target bindings determining WM performance are identical to context-to-target bindings determining performance in tests of episodic memory, exemplified by a category-cued recall test of LTM. If so, then LTM performance in the category-cued recall test should evidence exactly the same regularities as these previously assigned to changes to position-to-target bindings assumed to determine WM performance. Thus, the effects of elaboration by superposition should likewise be reduced when related distractors precede rather than follow their respective targets. This prediction was tested in Experiment 3.

Experiment 3

The present experiment assessed whether the benefits of related distraction for LTM performance are merely due to occurrence of related distraction in temporal proximity to their respective targets. If the elaboration-by-superposition hypothesis is to encompass also the interference-by-superposition hypothesis formulated for WM, it necessitates a prediction that such temporal co-occurrence is not sufficient, and that related distractors elicit changes in episodic memory representations primarily when they follow their respective targets, and not when they precede them. This asymmetry is predicted explicitly in the SOB-CS model (Oberauer, Lewandowsky et al., 2012), where new position cues are created when a target in a particular list position is presented for study but not when distractors are processed. Consequently, related distractors are bound to position cues of targets that precede them and thus WM performance is improved only by related distractors following, not preceding, their respective targets, despite equated temporal proximity across these two situations (see Oberauer, Farrell et al., 2012). If our argument about identity of position and context cues is to be upheld, context cues also need to be updated by processing targets and not by processing distractors. This should lead to an asymmetry in benefits of related distraction for LTM performance, with benefits observed when related distractors follow but not precede their respective targets.

Method

Participants

Thirty undergraduate students, recruited in the same way as in Experiments 1a and 1b, participated in exchange for partial course credit.

Materials, Design, and Procedure

Materials and design were the same as in Experiment 1a. The procedure was the same as in Experiment 1a, with the sole exception that the order of presentation of targets and distractors was flipped. Thus, trials started with four to-be-read distractors, after which the first target was presented (e.g., *topaz, amber, diamond, opal*, EMERALD). A serial-recall test immediately followed the presentation of the last target and was administered on all trials.

Results

Descriptive statistics for all serial-recall and cued-recall measures are presented in Table 1, and aggregated and participant-level data are presented in Figure 3.

Immediate Serial Recall

When correct-in-position scoring was applied to the data, there was no significant difference between the related- and unrelated-distraction conditions, $t(29) = 1.71$, $p = .097$, $d = 0.31$. By contrast, using item scoring revealed a significant difference between the two conditions, $t(29) = 2.55$, $p = .016$, $d = 0.47$, with higher performance in the related-distraction than in the unrelated-distraction condition.

Delayed Cued Recall

The analysis of category-cued recall performance failed to reveal a significant difference between the two experimental conditions, $t(29) = 1.58$, $p = .125$, $d = 0.29$.

Combined Analyses of Experiments 1a and 3

We compared the effects of relatedness found in the present experiment against the baseline established in Experiment 1a, which had the same method bar the ordering of targets and their distractors. An analysis of serial recall with in-position scoring with a 2 (distraction: related, unrelated) x 2 (Experiment: 1a, 3) mixed ANOVA yielded a significant main effect of distraction, $F(1,29) = 20.45$, $MSE = .03$, $p < .001$, $\eta^2 = .005$, a significant main effect of Experiment, $F(1,29) = 7.24$, $MSE = .67$, $p = .009$, $\eta^2 = .11$, and also a significant interaction between the two, $F(1,29) = 5.01$, $MSE = .01$, $p = .029$, $\eta^2 = .001$. The same analysis for item scoring also yielded a significant main effect of distraction, $F(1,29) = 26.18$, $MSE = .04$, $p < .001$, $\eta^2 = .01$, a significant main effect of Experiment, $F(1,29) = 16.95$, $MSE = .98$, $p < .001$, $\eta^2 = .22$, and a non-significant interaction, $F(1, 29) = 2.80$, $MSE = .004$, $p = .10$, $\eta^2 < .001$. Finally, the same analysis for cued-recall performance yielded a significant main effect of distraction, $F(1,29) = 22.55$, $MSE = .09$, $p < .001$, $\eta^2 = .02$, a significant main effect of Experiment, $F(1,29) = 4.17$, $MSE = .26$, $p = .046$, $\eta^2 = .06$, and a significant interaction, $F(1, 29) = 6.75$, $MSE = .03$, $p = .012$, $\eta^2 = .01$. Significant interactions for immediate serial and delayed cued-recall tests reflected the fact that the effects of distraction relatedness for these measures were reduced in Experiment 3 compared to Experiment 1a.[3] A similar interaction for item scoring in immediate recall was not significant, which reflects the fact that this measure was the only one sensitive to distraction relatedness in Experiment 3.

Discussion

The present experiment tested the specific prediction of the superposition account by which the benefits of related distraction, observed in Experiments 1a, 1b and 2, should be reduced when distractors precede rather than follow their respective study items. Indeed, this reduction was observed here for WM performance (albeit only with correct-in-position scoring) and, more importantly for the present purpose, for LTM performance. This pattern once again underscores the commonality of mechanisms that operate across WM and LTM. Whether performance is assumed to depend on position cues delineating a place of an item within a study list, as theorized for serial recall tests used to assess WM performance (Oberauer, Lewandowsky et al., 2012), or on broadly defined context defining entire study blocks and supporting LTM performance, the processes of binding these cues with features of targets and distractors appear to be the same. In both cases, it needs to be assumed that distractors are bound to the same cues to which preceding targets were bound, resulting in

[3] The main effects of Experiment observed for serial-recall performance measures and which reflected reduced performance in Experiment 1a compared to Experiment 3 were most likely caused by differences in the lag to the serial-recall test in these experiments. In Experiment 1, each trial started with a target and the last target was followed by distractors. In Experiment 3, each trial started with distractors and the last target was followed immediately by a test. Thus, the lag to test was shorter in Experiment 3, accounting for improved performance. Note that this did not affect performance in cued recall.

stronger bindings for features shared across targets and their distractors. When the same distractors precede their related targets, they are not bound to exactly the same cues and thus no superposition for their featural bindings occurs. Ultimately, the similarity of empirical patterns once again suggests that position cues in WM and contextual cues in LTM are in fact one and the same.

The asymmetry in the effects of related distraction, depending on the timing of its presentation related to its corresponding target, stems – according to the SOB-CS model (Oberauer, Lewandowsky et al., 2012) – from the assumption that targets update position cues, while distractors do not, and thus distractors are bound to position cues established by the preceding targets. Since our results for LTM performance parallel the results obtained for WM performance, our hypothesis of elaboration by superposition seems to require an analogous assumption that targets update context representations while distractors do not, or at least update them to a much lesser extent. Older models of context in LTM (Estes, 1955; Mensink & Raaijmakers, 1988) assumed that context evolved randomly with time, in a way independent of the presentation of targets. Clearly, such models would be inconsistent with the conclusions derived from the present experiment. However, a newer class of context models, referred to as retrieved-context models (Howard & Kahana, 2002; Polyn et al., 2009), assume that context and target processing are not independent and indeed context representations depend on thoughts elicited by processing targets within a memory task. In these models, experimental context to which items become bound at encoding evolves, as it becomes updated by pre-experimental contexts associated with the processed items. Adapting this perspective to our results would thus require an assumption that while processing targets updates the experimental context with pre-experimental contexts associated with those targets, such updating is markedly reduced when distractors are processed.

It is important to note that while context evolving randomly cannot accommodate our results, the assumption of differential context updating by targets and distractors is fully compatible with the retrieved-context models, even if not directly necessitated by them. Indeed, there are already suggestions in the literature that items processed intentionally (such as targets in our procedure) and items processed incidentally (such as distractors used here) lead to different manifestations of the context effects. Healey (2018, see also Mundorf et al., 2021) first showed that the contiguity effect in free recall – a hallmark context effect by which recalling an item reinstates its context, which in turn cues the next item that was bound at encoding to an overlapping context representation, resulting in serial-like pattern of free recall – is markedly reduced for incidentally processed items. This observation is consistent with the conclusions of the present experiment: distractors, or incidentally processed items more generally, do not update the experimental context in the same way as intentionally studied items. This differential updating of context by targets and distractors led in the case of our study to a temporal asymmetry in the benefits of related distraction.

One remaining feature of the present results that is worth discussing is that while they provide evidence for the *reduction* of the relatedness effects with flipping the order of items and distractors, they cannot be taken to argue that these effects are eliminated under these conditions. Although these effects were not significant for correct-in-position scoring in serial recall and in category-cued recall, such an effect was still obtained when item memory was scored in the serial-recall task and indeed the item-scoring method did not yield a statistically significant reduction in the magnitude of the relatedness effect. We also note that numerical trends in all measures pointed to somewhat better performance in the related-distraction conditions. However, the residual effects of relatedness do not pose serious problems for the superposition account advocated here. The SOB-CS model assumes some overlap in features of different position cues – a mechanism necessary for accounting for order errors in serial recall. Similarly, models evoking a mechanism of contextual drift to account for LTM performance (Howard & Kahana, 2002) postulate that although the presentation and retrieval of targets update features of context, such updating is incomplete and thus neighboring targets are associated with partially overlapping contexts. This overlap in position and context cues means that even distractors preceding their targets are bound to at least some position/context features associated with the following target, that is features carried over from previous targets. Consequently, the superposition account does not predict the elimination of the effects stemming from relatedness but rather their reduction when distractors precede rather than follow their respective targets.

Experiment 4

The results presented so far chime with the predictions of both the interference-by-superposition hypothesis for WM performance, as well as its LTM analog in the form of elaboration by superposition. Both hypotheses predict that being exposed to related distraction augments memory performance compared to unrelated distraction, and both use the same mechanism of superposition of bindings between item and position/context features to account for these patterns. However, there is one conceptual difference between these two hypotheses. The interference-by-superposition hypothesis accounts for forgetting in WM, showing how target-distraction relatedness minimizes interference accruing from processing distraction. However, even related distraction differs from targets and thus should be able to distort position-feature bindings for the preceding targets, resulting in some degree of interference. So far, we have not tested this prediction as our study lacked a baseline condition of no distraction.

Regarding LTM, the elaboration-by-superposition hypothesis accounts for processing information in LTM that creates episodic memory representations skewed towards features shared across targets and their related distractors. This leads to a different type of episodic memory representations, ones that are enriched in specific features that are only weakly encoded in the absence of related distraction following the study of targets. In other words, elaboration by superposition predicts that related distraction is more beneficial for LTM performance than both the condition that employs unrelated distraction (as in Experiments 1a, 1b and 2) and a condition that eliminates distraction altogether, in which case no augmented episodic encoding occurs. Here we tested both the predictions of reduced interference in case of WM and benefits for LTM of including related distractors by comparing performance across related- and unrelated-distraction conditions to a novel condition of no distraction.

It is worth noting the similarity of the present design to studies investigating the McCabe effect (Loaiza & McCabe, 2012; McCabe, 2008) – a phenomenon by which inclusion of distraction in the complex-span task reduces WM performance while augmenting LTM performance. Although the McCabe effect has not been tested specifically with the procedures used here, with distraction in the form of to-be-read words and a test of category-cued recall, we nevertheless predict that this pattern would generalize to the current conditions. In this case, target-distractor similarity should modulate the magnitude of the McCabe effect, reducing the overall costs of distraction for WM performance, while augmenting the overall benefit of distraction for LTM performance.

Method

Participants

Thirty undergraduate students participated in exchange for partial course credit.

Materials, Design, and Procedure

The same materials were used as in Experiments 1a-3. There were now three experimental conditions: the related-distraction and unrelated-distraction conditions were the same as in Experiments 1a and 2 (with distractors following their respective targets and unrelated distractors re-paired across separate trials within a single block), and a novel simple-span condition was added in which there were no distractors. Given that now we had three experimental conditions which had to be split across blocks consisting of four trials (in accord with previous experiments), we mixed the conditions between blocks so that only two were used within a single block. There were thus three types of blocks: mixing related- and unrelated-distraction conditions, related-distraction and simple-span conditions, and unrelated-distraction and simple-span conditions. There were four blocks of each type, with a total of 12 blocks. The procedure for distraction trials was the same as in Experiments 1a and 2, and for the simple-span condition only target words in red were displayed at the rate of 1400 ms with a 100 ms interstimulus interval. Before the experiment proper, participants performed two practice trials, one for the unrelated-distraction condition and another one for the simple-span condition.

Results

Descriptive statistics for all serial-recall and cued-recall measures are presented in Table 1. Aggregate and participant-level data are additionally depicted in Figure 3.

Immediate Serial Recall

A one-way within-participants ANOVA on performance calculated using correct-in-position scoring revealed significant differences across experimental conditions, $F(2,58) = 69,52$, $MSE = 1.20$, $p < .001$, $\eta^2 = .71$. Post-hoc comparisons showed that performance in the simple-span condition exceeded performance in the unrelated-distraction condition, $t(29) = 9.12$, $p < .001$, $d = 1.67$, as well as that in the related-distraction condition, $t(29) = 8.15$, $p < .001$, $d = 1.50$. Performance in the related-distraction condition also was higher than in the unrelated-distraction condition, $t(29) = 3.07$, $p = .005$, $d = 0.56$. The same analysis of performance with item scoring also revealed significant differences across conditions, $F(2,58) = 75.31$, $MSE = 1.01$, $p < .001$, $\eta^2 = .72$. Performance in the simple-span condition was higher than in the unrelated-distraction condition, $t(29) = 9.50$, $p < .001$, $d = 1.73$, and in the related-distraction condition, $t(29) = 8.57$, $p < .001$, $d = 1.56$. Performance in the related-distraction condition also exceeded performance in the unrelated-distraction condition, $t(29) = 3.20$, $p = .003$, $d = 0.58$.

Delayed Cued Recall

The analysis of category-cued recall performance with a one-way within-participants ANOVA revealed significant differences across experimental conditions, $F(2,58) = 69.45$, $MSE = .49$, $p < .001$, $\eta^2 = .70$. Post-hoc comparisons revealed that performance in the simple-span condition was *worse* than both performance in the unrelated-distraction condition, $t(29) = 8.04$, $p < .001$, $d = 1.47$, and in the related-distraction condition, $t(29) = 11.49$, $p < .001$, $d =$

2.10. At the same time, performance in the related-distraction condition exceeded performance in the unrelated-distraction condition, $t(29) = 3.18$, $p = .003$, $d = 0.58$.

Discussion

The present experiment compared the effects of related distraction on WM and LTM performance relative to the baseline of not only unrelated distraction but also no distraction. Consistent with the interference-by-superposition hypothesis, processing distractors generally impaired WM performance but less so when they were related to the preceding item. Consistent with the elaboration-by-superposition hypothesis, processing related distractors after a study item led to benefits to LTM performance compared to processing unrelated distractors, as well as compared to a case in which distraction was eliminated altogether. Related distractors thus mitigate the interference leading to forgetting from WM, while simultaneously producing LTM representations yielding better memory performance in a delayed cued-recall test.

The results reported here also revealed the McCabe effect (McCabe, 2008), showing that inclusion of distraction in a complex-span procedure simultaneously disrupts WM performance and benefits LTM performance. The current results extend the conditions under which this effect emerges from free-recall testing of LTM to category-cued recall. Even though the mechanisms of the McCabe effect are not the topic of the current work, it is worth outlining some potential consequences of the present results for this line of research. On the empirical side, it is interesting to note that the main facet of the McCabe effect, the improved LTM performance due to inclusion of distractors in the complex span task, was particularly – and somewhat surprisingly, given that the McCabe effect is sometimes absent when results are not conditionalized on correct immediate recall (see Souza & Oberauer,

2017) – pronounced with the methods used here, with a difference between the unrelated and no-distraction conditions of 19 percentage points (*d* = 1.47). This could result from either of the two methodological choices we took: using a cued-recall task instead of free recall usually employed in the studies on the McCabe effect (but see Loaiza & McCabe, 2012), or the distraction that we used, which involved multiple word repetitions. Regarding the retrieval task, the cued-recall test of the type used here taps item information at the exclusion of relational information linking study items to each other. Future studies could assess whether distraction in the complex-span task differentially promotes encoding of item-specific and relational information across study times, possibly meaning that the magnitude of the McCabe effect should be modulated by the type of a final LTM test.

Regarding the distraction task employed here, it is worth noting that the time to pronounce four words in the current procedure was longer than the duration of distraction – usually in the form of an arithmetic task – commonly employed in research on the McCabe effect (McCabe, 2008). Current theories of the McCabe effect seem to suggest that the duration of distraction may be important for the benefits that distraction implemented in the complex span task confers on LTM performance. The original account of the McCabe effect argues that the benefits emerge there because targets are strengthened by covert retrieval in-between presentation of distractors (McCabe, 2008). More distractors should lead to more covert retrieval, augmenting the effect, and equally distractors that take longer to process should increase spacing across covert retrieval attempts, also potentially augmenting the effect. Thus, although duration of distraction *per se* should not determine the magnitude of the McCabe effect if the covert retrieval process is adopted, it may still remain correlated with this magnitude via indirect influence of the number and spacing of covert retrieval events.

Two other accounts of the McCabe effect give an even more direct role to time it takes to process distraction. First, Loaiza and Lavilla (2021) have recently proposed that the McCabe effect at least partially stems from additional elaboration that the targets are subjected to when distraction follows target presentation in the complex-span task. The effectiveness of elaboration could be dependent on the time available before the presentation of the next target or the immediate recall test. While such elaboration is not directly observed and remains outside experimental control, it remains possible that a unified account of all LTM effects documented in the present experiment could be proposed, where the presence of distraction determines the overall strength of encoding of study items and the particular type of distraction determines the likelihood of encoding specific features of these items into episodic memory. Second, Souza and Oberauer (2017) have proposed that distraction is not necessary for observing the McCabe effect and instead the effect simply reflects the longer time for which targets remain in WM in the complex-span task compared to the simple-span task. The argument here is that encoding into LTM is directly a function of time for which targets are maintained in WM, and from this perspective the particularly pronounced benefit found in our data could stem directly from our use of long distraction-filled intervals. Thus, overall, the particular choice of distraction for our study could have contributed in a number of ways to the highly robust McCabe effect observed here, and future studies should thus focus not only on the type of distraction – such as related or unrelated to targets – but also its duration.

General Discussion

In the present study, we assessed the role of target-distraction similarity within the complex-span procedure for both WM and LTM performance. Building on the interference-by-superposition hypothesis (Oberauer, 2009; Oberauer et al., 2016; Oberauer, Farrell, et al., 2012), by which the extent to which distractors interfere with maintenance of targets in WM depends on the overlap in features across those targets and the distractors that follow their presentation in a study list, we predicted that a similar mechanism determines encoding into LTM. We tested this elaboration-by-superposition hypothesis by using the complex-span task with distractors that were either semantically related or unrelated to study items, and testing LTM via a category-cued recall task that was attuned to the features shared across distractors and study items in the related-distraction condition. Experiment 1a demonstrated that relative to unrelated distraction, related distraction improved both immediate serial-recall and delayed cued-recall performance. Experiment 1b ruled out the possibility that those benefits for cued-recall performance were due to carry-over effects from immediate serial-recall tests. Experiment 2 revealed that the benefits of related distraction that directly follows its target are still observed relative to a condition in which the same distraction shares the list context with its target but not temporal proximity. Experiment 3, however, showed that temporal proximity may not be sufficient for the benefits of related distraction to emerge as these benefits were reduced when related distractors preceded rather than followed their respective targets. This observation constitutes strong evidence that both effects in immediate and delayed performance are due to operation of the superposition mechanism, which specifically predicts this pattern of results. Finally, Experiment 4 showed that while related distraction mitigates the costs of interference in WM, it also produces net benefits for LTM performance compared to a condition in which distraction is absent from the encoding task. Overall, the results support the elaboration-by-superposition hypothesis, by which the very same mechanism that operates within the working WM system also determines the type of information that is encoded into LTM.

The mechanism of elaboration by superposition is an extension of the interference-by-superposition mechanism embedded in the SOB-CS model (Oberauer, Lewandowsky, et al., 2012). This model was proposed to account for performance in the complex-span task. It did so by making several theoretical assumptions, of which of particular interest for the present work are those of distributed representations of items and position cues that determine serial-recall performance. In this model, interference occurs because distributed representations of both targets and distractors are bound to distributed representations of position cues and these bindings are superimposed on each other. This superposition leads to a distortion of bindings whenever features of targets and distractors following them differ from each other, but also to strengthening of these bindings when features are shared. This strengthening is what mitigates the interference that superposition generally causes, which is reflected in the relative benefits of related distraction – compared to unrelated distraction – for WM performance.

The fact that similar benefits are observed in LTM indicates that the logic of superposition can be extended beyond bindings of item features and position cues. The present study indicates that benefits of related distraction can be observed in category-cued recall, in which the role of position cues should be minimal given the random order in which category cues are presented at test. Instead, performance in this task is determined by category information provided in a cue and the context of the study list preceding the particular test that needs to be reinstated to limit the search set (Unsworth, 2008). For the superposition mechanism to determine performance in such a test, the bindings established during encoding thus need to be between target/distractor features and features of the context, not position cues. Therefore, we propose that the mechanism of superposition described in the SOB-CS model is a specific case in which position cues serve as context to which item features are bound, and that allows participants to retrieve targets in the order in which they were presented at study. The same bindings are then responsible for performance across tests of episodic memory, including tests in which context is necessary to retrieve studied items independently of the order of their presentation.

The assumption by which target features are bound to context features is central to a prominent family of models of LTM – the retrieved-context models, such as the temporal-context model (Howard & Kahana, 2002; see also Lohnas, Polyn, & Kahana, 2015; Polyn, Norman, & Kahana, 2009). These models are concerned mostly with describing free-recall performance, with a specific focus on contiguity effects at retrieval, by which transitions in recall are often local with respect to the position of items in the study list. These transitions are characterized by an asymmetry favoring for retrieval items which followed the last retrieved item at encoding, thus giving rise to commonly observed serially-ordered free recall. This asymmetry in recall transitions reflects the fact that context is updated by features of the study items and thus each study item is encoded in the context of the features of the preceding item(s). At a subsequent free-recall test, successful retrieval of an item also updates the context with its features, which then match the context to which the subsequent study item was bound, resulting in an increased probability of retrieving this subsequent study item. The way retrieved-context models account for forward transitions in free recall can be considered in light of the results obtained in our Experiment 3, where it was shown that while related distractors following targets augment both WM and LTM performance, these effects are markedly reduced when these distractors precede their respective targets (see also Oberauer, Farrell et al., 2012). If we assume that distractors are also bound to contextual cues but do not update them substantially, then the retrieved-context models provide a straightforward account of why they are bound more strongly to the context of the preceding rather than the following target. This is so because when distractors are presented, the experimental context has already been updated with the features of the preceding target, but it does not yet contain features that will later update it with the presentation of the subsequent target. The assumption that context features and item features are not independent of each other – absent from most models of WM but recently adopted in Logan's (2021) model of serial order effects in memory, perception, and action – thus provides an overarching account of asymmetries observed both in recall from LTM and in interference effects in WM.

In describing the LTM consequences of the postulated superposition of item and context features, we used the term elaboration, which we understand as any qualitative change in memory representations due to processing at study. This definition follows also from our previous work on the encoding variability effect (Zawadzka et al., 2021), where we showed that varying orienting questions (e.g., "Would this fit into a shoebox?") – rather than keeping them constant – across study presentations of to-be-remembered items leads to better memory performance if a memory test is used that taps the specific features that item representations accrue due to variable processing. We argued that in this study, variable processing served to skew memory representations towards semantic features highlighted by varying orienting questions and this process of stronger encoding of particular semantic features was termed 'elaboration'. However, this understanding of elaboration differs to some extent from how this concept is commonly understood. In the LTM literature, the concept of elaboration has been criticized for its vagueness (Lehman & Karpicke, 2016), bordering on circularity, where any manipulation introduced at encoding that leads to better subsequent memory is assigned to elaboration, which is in turn measured by better performance in a memory test. In the WM literature, elaboration is sometimes used as an explanatory term, but is usually understood narrowly as semantic processing and defined as strategic behavior participants may engage in lieu of various ineffective encoding strategies (Bailey et al., 2008, 2009; Dunlosky & Kane, 2007). As such, recent studies have suggested a limited role of elaboration in WM performance (Bartsch et al., 2018, 2019; Bartsch & Oberauer, 2021).

Here we argue that elaboration is a useful term for an umbrella of processes that lead to qualitative changes in memory representations that do not need to be strategic but can also be imposed by the local context in which study items are presented — be it an orienting question (e.g., Zawadzka et al., 2021) or distractors accompanying the to-be-remembered items. We also argue that elaboration need not be semantic in nature. Although our study used a semantic manipulation of target-distractor similarity, our WM results closely followed the results obtained by Oberauer, Farrell, et al. (2012), who manipulated phonological similarity. Because we argue that the same mechanisms are in operation in both of these studies, it is plausible that elaboration can also concern non-semantic features. Indeed, work on the transfer-appropriate processing framework (Morris et al., 1977) has long established that memory representations can be elaborated both in terms of semantic and non-semantic features, leading to variable results depending on whether a particular memory test is sensitive to features that had been encoded (Blaxton, 1989). This understanding of elaboration means that the use of the concept allows for specific predictions of how encoding can be changed by strategic and non-strategic factors and how any such changes would be detectable in appropriately tailored memory tests, avoiding the criticism of circularity (Lehman & Karpicke, 2016).

The point of departure for the present work was a consideration of the extent to which WM and LTM share common processes, determining whether the mechanisms underlying WM can be adopted to understand the dynamics of LTM. This situates our work within a recently renewed discussion about the extent to which two separate systems are necessary to describe memory functioning at short and long delays (Abadie & Camos, 2019; Humphreys et al., 2020; Loaiza & Camos, 2018; Oberauer & Greve, 2021). A twofold interpretation of our results in this context is possible. There are models that assume separate constructs to explain memory performance across short and long timescales, often referred to as primary and secondary memory (Unsworth & Engle, 2007). Interestingly, in this formulation, it has already been argued that the contribution of secondary memory to WM performance can be described in terms of context-dependent processes (Unsworth & Engle, 2006). If such an account is adopted, then the present results provide additional evidence for the contribution of LTM (or secondary memory) to performance in the WM task, despite the latter measuring memory performance in a short term. This can be gleaned not only from the fact that target-distractor similarity affected LTM and WM performance in the same way, but also from the results of Experiment 2, in which the presence of WM testing affected LTM performance. As argued by Rose et al. (2014), such testing effects are a signature effect of retrieval from LTM and, thus, they confirm that performance in the WM task depends on secondary memory.

A simpler interpretation of our results, however, is that the same mechanisms operate in memory processing across short and long terms, or even – deriving an ultimate conclusion from the assumption of shared mechanisms – that there is only one episodic memory system, governed by the dynamics of continuous storage of superimposed item-context bindings. Indeed, as already argued, the reinterpretation of positional cues in terms of context links the present work with the retrieved-context models, which explicitly assume that a large number of memory phenomena can be described by a unitary model of memory, with contextual representations serving the role usually played by a short-term memory store (see Howard & Kahana, 2002, for a discussion) – explaining how access to memory information is lost due to context drift between encoding and retrieval and how items neighboring one another in a study list appear to become associated by the virtue of shared associated contextual representations.

The assumption of a unitary memory system requires an auxiliary assumption, by which memory processes can operate across different sets of codes, or – in other words – in different representational domains. The discussion of the previous studies on target-distraction similarity can serve as an example here. Oberauer (2009) introduced the paradigm we used in the present study – with words as study materials – and manipulated both semantic and phonological target-distractor similarity. In Oberauer's study, only the effects of the semantic manipulation were revealed, and we built on these results here. Phonological target-distractor similarity failed to affect WM performance, but its effects were revealed in a subsequent study by Oberauer, Farrell, et al. (2012) who used non-words as study materials. According to Oberauer, Farrell et al., this discrepancy can be explained by participants using semantic coding for words and phonological coding for non-words. Arguably, strengthening contextual bindings for phonological features through the target-distractor similarity effects of the sort described here would not affect performance when participants rely on semantic cues to reconstruct the study list. Importantly, however, the underlying mechanism of superposition should be the same independent of how items are coded in the WM task. If participants encode targets in terms of their semantic features, then bindings of such semantic features to context can be strengthened by using semantically similar distractors, but if participants encode targets in terms of phonological features, then only bindings of such phonological features can be strengthened. The assumption of a unitary memory system does not imply that dissociations across WM and LTM systems are impossible. Instead, dissociations can be understood in terms of various features that are encoded and subsequently accessed during retrieval, and then subjected to the operations of a unitary set of mechanisms. Our findings show that superposition is one such mechanism, shaping both WM and LTM performance, serving as a demonstration of the power of this unitary approach.

Conclusion

The present study demonstrated how a mechanism recognized as one reason for which information is lost from WM – interference by superposition of context-to-item bindings across targets and distractors that follow them – can also explain patterns of performance in a test of LTM. When similar distractors follow targets in the complex-span task, shared features of these distractors and targets become strongly bound to context, augmenting subsequent LTM performance in a test tapping these shared features. We termed this change in memory representations induced by processing distraction elaboration by superposition, arguing that elaboration can be understood as the process of change in the encoded features that need not be a result of a strategic approach to the encoding task. The fact that a common mechanism can be traced back as underlying both

WM and LTM performance suggests that a unitary approach to memory processes can serve as the basis of new insights into how memory operates across various delays.

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Table 1.

Mean proportions of correctly recalled items in the WM serial recall task - according to strict correct-in-position scoring and more lax item scoring - and in the LTM category-cued recall task in Experiments 1a-4. The results for Experiment 1b are presented also as a function of whether serial recall was administered or not after list presentation. Standard deviations are given in parentheses.

	Serial recall – in-position scoring			Serial recall – item scoring			Category-cued recall		
	Related distraction	Unrelated distraction	No distraction	Related distraction	Unrelated distraction	No distraction	Related distraction	Unrelated distraction	No distraction
Experiment 1a	.53 (.20)	.48 (.20)	-	.57 (.19)	.52 (.19)	-	.44 (.16)	.35 (.15)	-
Experiment 1b									
Immediate test present	.51 (.26)	.45 (.26)	-	.58 (.23)	.52 (.25)	-	.51 (.15)	.42 (.19)	-
Immediate test absent	-	-	-	-	-	-	.46 (.18)	.36 (.20)	-
Experiment 2	.75 (.19)	.71 (.20)	-	.78 (.18)	.75 (.18)	-	.59 (.18)	.54 (.18)	-
Experiment 3	.66 (.23)	.65 (.23)	-	.74 (.15)	.72 (.15)	-	.50 (.20)	.48 (.20)	-
Experiment 4	.55 (.21)	.50 (.22)	.87 (.12)	.61 (.19)	.56 (.21)	.90 (.08)	.53 (.17)	.46 (.17)	.28 (.15)

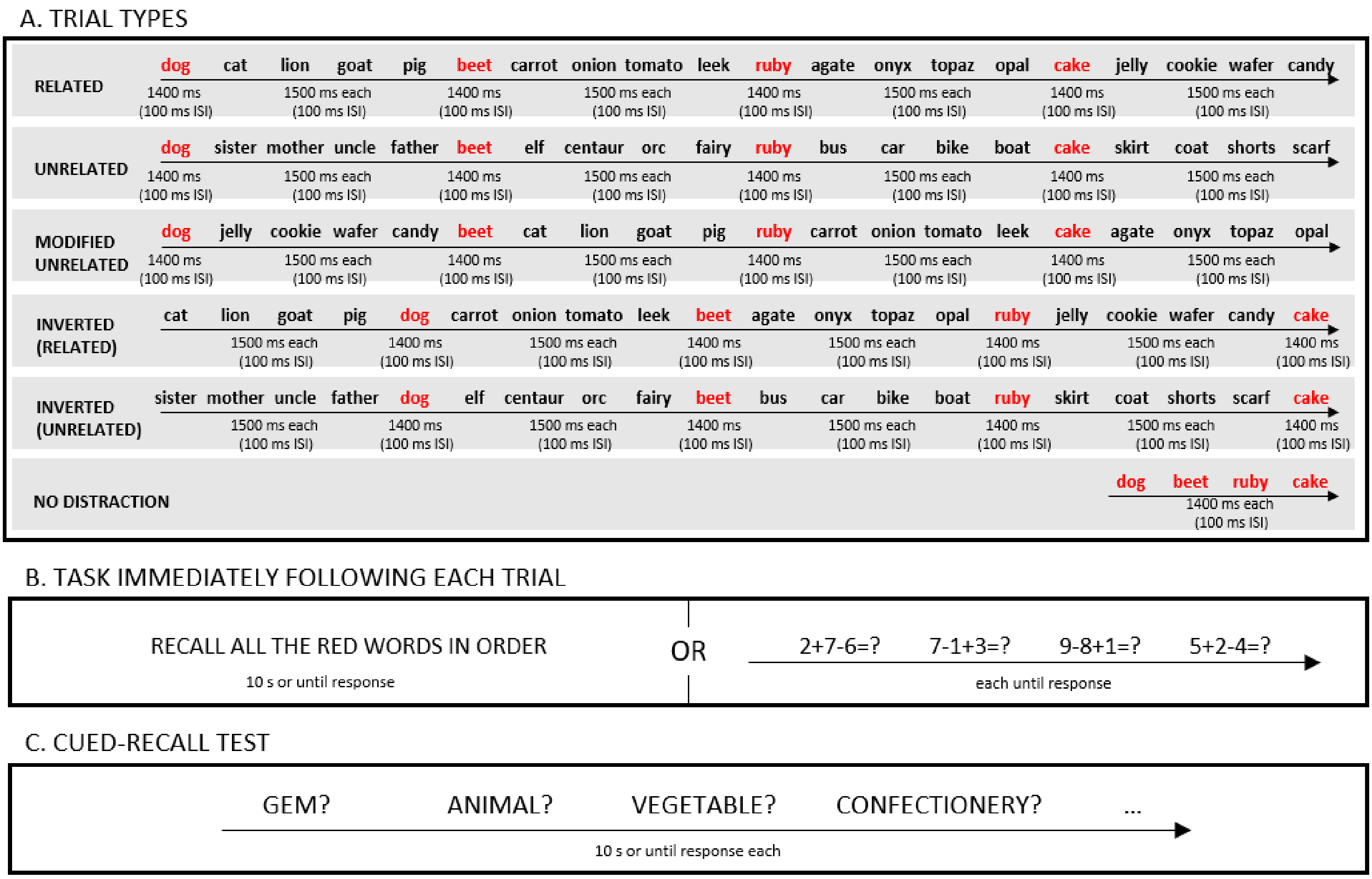

Figure 1. Experimental design of Experiments 1a-4. Panel A shows six types of study trials, with targets marked with red and distractors with black color: Related trials used in Experiments 1a, 1b, 2, and 4; Unrelated trials from Experiments 1a, 1b and 4; Modified Unrelated trials from Experiment 2; Inverted trials, with related and unrelated distractors, from Experiment 3; and No-distraction trials used in Experiment 4. Panel B presents tasks to be performed immediately after each trial: the immediate serial recall test used in Experiment 1a, 2, 3, 4, and for half of Experiment 1b trials (left) and the filler task used for the other half of Experiment 1b trials (right). Panel C depicts the delayed category-cued recall test to be completed after each block of four trials in each experiment. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

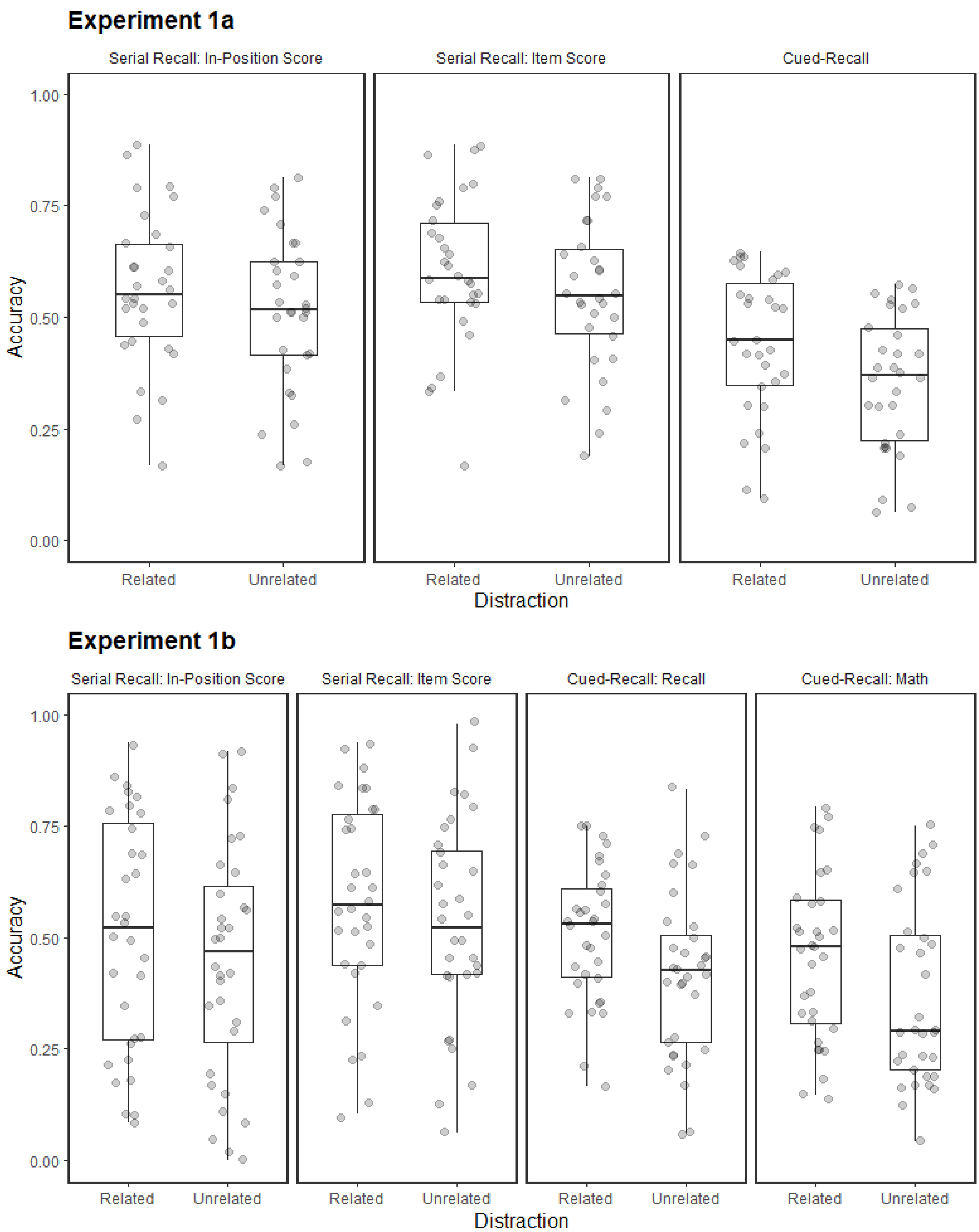

Figure 2. Immediate serial recall and delayed category-cued recall performance in Experiments 1a (top) and 1b (bottom). Boxplots represent group-level data and dots depict accuracy scores of individual participants. For both experiments in-position-, as well as item-scores of serial recall performance are presented and for Experiment 1b cued-recall results for items from trials concluded with serial recall ("Cued-Recall: Recall") and from trials concluded with a math filler task ("Cued-Recall: Math") are presented separately.

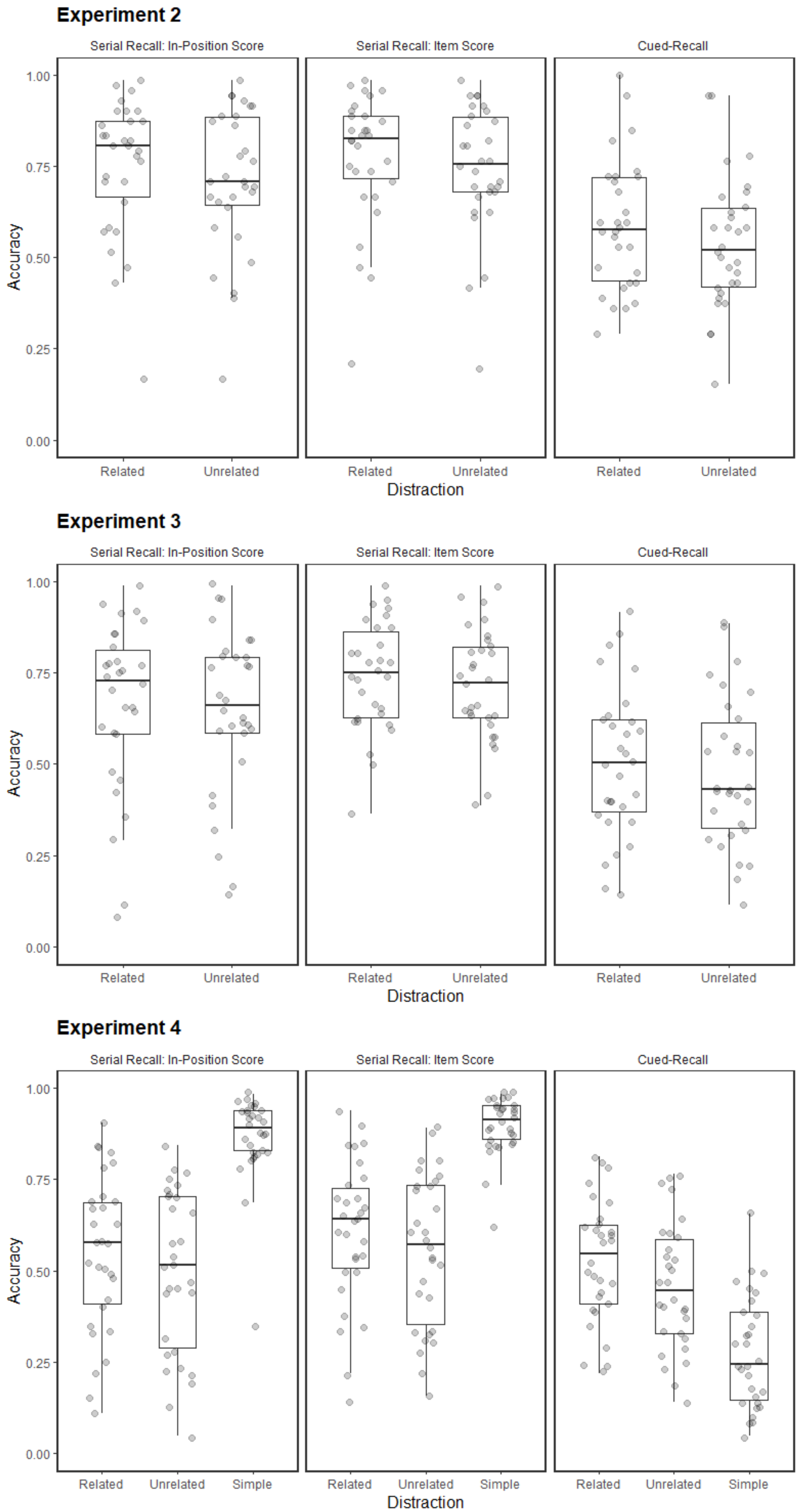
Experiment 2
Serial Recall: In-Position Score
Serial Recall: Item Score
Cued-Recall
Accuracy
1.00
0.75
0.50
0.25
0.00
Related
Unrelated
Distraction
Experiment 3
Serial Recall: In-Position Score
Serial Recall: Item Score
Cued-Recall
Accuracy
1.00
0.75
0.50
0.25
0.00
Related
Unrelated
Distraction
Experiment 4
Serial Recall: In-Position Score
Serial Recall: Item Score
Cued-Recall
Accuracy
1.00
0.75
0.50
0.25
0.00
Related
Unrelated
Simple
Distraction

Figure 3. Immediate serial recall and delayed category-cued recall performance in Experiments 2 (top), 3 (middle) and 4 (bottom). Boxplots represent group-level data and dots depict accuracy scores of individual participants. For all experiments in-position, as well as item scores of serial recall performance are presented.

Appendix 1

Conditional analyses of cued-recall results

To confirm that the relatedness effects in cued-recall were not due to carry-over effects from serial recall, following Loaiza and Lavilla (2021) we ran additional analyses on cued-recall data conditionalized on recall success in the immediate serial-recall test. Here we present analyses of cued-recall results narrowed down to items that were correctly recalled prior to the cued-recall test (as indicated by the item-scoring method). Descriptive statistics for the resulting data are presented in Table 2.

Paired samples t-tests for items that were successfully recalled in the serial-recall test revealed that performance was higher when distraction was related than unrelated in Experiment 1a, $t(29) = 4.04$, $p < .001$, $d = 0.74$, and Experiment 1b, $t(30) = 2.96$, $p = .006$, $d = 0.53$, but no significant differences were detected in Experiment 2, $t(29) = 1.82$, $p = .079$, $d = 0.33$, and Experiment 3, $t(29) = 1.91$, $p = .07$, $d = 0.35$. Also, a one-way within-participants ANOVA revealed significant differences between conditions in Experiment 4, $F(2,58) = 139.69$, $MSE = 1.532$, $p < .001$, $\eta^2 = .82$, with post-hoc comparisons showing significant advantage of related distraction over unrelated distraction, $t(29) = 3.28$, $p = .003$, $d = 0.60$, and over no distraction, $t(29) = 17.25$, $p < .001$, $d = 3.15$, as well as an advantage of unrelated distraction over no distraction, $t(29) = 12.47$, $p < .001$, $d = 2.77$.

References

Loaiza, V. M., & Lavilla, E. T. (2021). Elaborative strategies contribute to the long-term benefits of time in working memory. *Journal of Memory and Language*, *117*, 104205. https://doi.org/10.1016/j.jml.2020.104205

Table 2.

Mean proportions of correctly recalled items in the LTM category-cued recall task in Experiments 1a-4 conditionalized on whether items were initially correctly recalled in the WM serial recall task. Standard deviations are given in parentheses.

	Previously recalled			Previously not recalled		
	Related distraction	Unrelated distraction	No distraction	Related distraction	Unrelated distraction	No distraction
Experiment 1a	.62 (.17)	.52 (.16)	-	.22 (.14)	.16 (.12)	-
Experiment 1b	.71 (.16)	.59 (.18)	-	.40 (.16)	.33 (.19)	-
Experiment 2	.69 (.15)	.66 (.15)	-	.26 (.20)	.20 (.16)	-
Experiment 3	.59 (.20)	.55 (.19)	-	.23 (.19)	.22 (.18)	-
Experiment 4	.72 (.14)	.63 (.17)	.29 (.16)	.21 (.12)	.24 (.14)	.19 (.29)