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The negative reminding effect: Reminding impairs memory for contextual information

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ABSTRACT

Encountering events that are meaningfully related to prior episodes can prompt retrieval of those prior events. Reminders are events that prompt retrieval of prior learned information, while reminded materials are the events that are retrieved in response. Reminders are an important component of efficient and effective cognition because they partially automate the process of bringing relevant prior knowledge to bear on novel situations. Across four experiments, we investigated whether reminders boosts memory for the entire prior reminded *episode* or for only specific *aspects* of prior experiences that are relevant to the reminder. To do so, we combined a reminding procedure with a paradigm for measuring memory for the incidental context of encoding. Participants studied lists of words in which semantically related pairs (e.g., "volcano" and "erupt") were presented across brief lags and in different color contexts. Memory for the content and color of the first-presented word in pairs (the reminded information) was measured. Recall of related word pairs was consistently greater than recall of unrelated pairs, in agreement with prior work on the reminding effect. However, when the color of related words differed across the pair, memory for the color of the reminded words was impaired compared to unrelated words. The results support a view of reminding as a leveling and sharpening process in which memory for the focal content of reminded episodes is enhanced, but differences in peripheral details are smoothed over. Such a process can lead to the acquisition and application of prototypical knowledge over experience.

Introduction

Stimulus-driven retrievals of specific past events, or *remindings*, are a fundamental component of cognition. Reminders are events that spur retrieval; reminded materials are the events that are retrieved in response. Reminders direct us to relevant prior knowledge and link past experiences to current problems, which helps us navigate novel situations. In doing so, they reduce the separation of events in time and guide our current behavior and understanding. For example, when math students approach a novel problem, the superficial features of the problem can remind them of an earlier problem and prompt them to use the previously successful methods to solve the novel problem (Ross, 1984). Reminders also improve memory for the content of the retrieved episode because they bring to mind earlier studied episodes (Benjamin & Ross, 2010; Tullis, Benjamin, & Ross, 2014). Here, we specifically examined how reminding impacts our memories for the context of the reminded episodes in order to test theories about what processes underlie remindings.

Remindings have been implicated across a wide variety of cognitive activities, including the interpretation of ambiguous events (Ross & Bradshaw, 1994; Tullis, Braverman, Ross, & Benjamin, 2014), categorization (Medin & Schaffer, 1978; Ross, Perkins, & Tenpenny, 1990), generalization across events (Gick & Holyoak, 1983; Ross & Kennedy, 1990), transfer of knowledge to superficially different situations (Tullis & Goldstone, 2016), and solving novel problems (Reeves & Weisberg, 1994). Remindings may even contribute to how learners represent number (Hintzman, 2008). Remindings benefit memory in many direct ways, including enhancement of recall for the first member of a related pair (Tullis et al., 2014), increased accuracy of recency judgments (Hintzman, 2010; Tzeng & Cotton, 1980; Wahlheim & Jacoby, 2013; Winograd & Soloway, 1985), more accurate judgments about the spacing between individual episodes (Friedman & Janssen, 2010; Hintzman, Block, & Summers, 1973), improved list discrimination (Jacoby, Wahlheim, & Yonelinas, 2013), and more accurate judgments of frequency (Hintzman, 2004). Further, remindings are theorized to contribute to the benefits of distributed learning (Benjamin & Tullis,

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2010; Maddox, Pyc, Kauffman, Gatewood, & Schonhoff, 2018; Wahlheim, Maddox, & Jacoby, 2014), may prompt the generation of critical lures in false memory paradigms (Roediger & McDermott, 1995), and influence the output order of items in free recall (Howard & Kahana, 2002; Howard, Kahana, & Wingfield, 2006). Yet, no prior research has examined the impact of remindings on memory for the contextual details of the related episodes. This is a surprising omission, because results about the impact of remindings on memory for contextual details can bear on important questions about the processes that underlie remindings. For example, retrieval theories of reminding (e.g. Hintzman, 2010; Tullis et al., 2014) suggest that studying new episodes can provoke the retrieval of prior related episodes. Retrieval of content improves memory for the associated contextual information (Akan, Stanley, & Benjamin, 2018); if remindings involve retrieval, memory for contextual information should be impacted similarly.

We tested whether remindings impact memory for the contextual details of studied episodes across four experiments. Learners studied lists of singly presented words that included semantically related pairs and unrelated items, in different colors. Words in pairs were separated in the study list by short lags so that the second word (the reminder) could bring the first word (the reminded item) back to mind. We assessed memory for content (i.e., the identity of the studied words) on some study lists and context (i.e. the color of the studied words) on other study lists. We expected that studying the second item in related word pairs (i.e., P2s or the *reminders*) would improve memory for the earlier, related member of that pair (i.e. P1s, or the *reminded* item), as in previous research (Tullis et al., 2014). If remindings enhance memory for the entire prior episode, we expect to see improvements in memory for both the content and context of words in semantically related pairs compared to unrelated items. Across the four experiments reported here, different relationships between the color of the two members of a pair were implemented. We start with the simplest case, in which both members of each pair were presented in the same color.

Experiment 1

In Experiment 1, participants viewed a list of related (e.g., “king” and “queen”) and unrelated (e.g., “chess” and “salad”) pairs of words presented in one of four different colors at short lags. In this experiment, words from related and unrelated word pairs were always presented in the same color to maximize the probability of remindings across pairs (Tullis et al., 2014). We compared the effects of a later presentation of a related word on memory for the content and context of the earlier, related word. The novel question in Experiment 1 was whether remindings would enhance memory for the perceptual aspects of the previously studied, semantically related episodes, in addition to its semantic content. To test this question, we assessed participants’ memory for the content using free recall tests on some study lists (to replicate prior research: Tullis et al., 2014) and memory for the context using font color tests on other study lists.

Method

Participants

Ninety introductory psychology students at Indiana University participated in exchange for partial course credit. A sample size of 90 was required to detect an effect size of 0.3 (which was found in similar tasks in Tullis et al., 2014) with alpha = 0.05 and power of 0.80 (GPower).

Materials

One-hundred-and-fifty-two primary associate pairs were collected from the University of South Florida Free Association Norms (Nelson, McElvoy, & Schreiber, 2004). Associated pairs were bi-directionally strongly related (mean associative strength = 0.49: S.D. = 0.15) and included noun/action pairs (volcano, erupt), thematically related words (salt, pepper), synonyms (dinner, supper), antonyms (good, bad), and male/female counterparts (king, queen). During study, the order of the words within pairs was randomized, such that each item in a pair had an equal chance of being studied first or second.

One list structure was created that differentiated between 40 paired slots at a lag of 4 items and 8 single, unpaired slots. Single items were dispersed throughout the study list to ensure a lag of 4 items between all word pairs. At the time of the presentation, words were randomly selected from the word pair list and inserted into the list structure so that each list had 10 related word pairs, 10 unrelated word pairs, and 8 single items, for a total of 48 study items per list. For unrelated pairs, two words were drawn from two different primary associate pairs an pairted together in an unassociated pair. For single items, one word from a primary associate pair was randomly selected and presented. All studied items came from the 152 primary associate pairs described above; for each of the 4 study lists, 10 pairs were used as the studied related word pairs, 20 pairs were recombined to create 10 unrelated word pairs, and 8 words from pairs were selected to be presented as single items. Paired slots were randomly assigned to the related and unrelated conditions, such that the first and second half of the study list contained an equal number of related and unrelated pairs. Across all word pairs, the order of presentation within that pair (e.g., which item was first or second) was randomized.

Procedure

In this and the following experiments, participants first read and signed a consent form. The experiment was presented in MATLAB using the Psychophysics Toolbox (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007) and CogToolbox (Fraundorf et al., 2014) across 10 different personal computers in individual testing booths. Participants were instructed: “In a moment, you will see a list of words presented one at a time. Please try to remember these words for a later memory test. During the test, you may be asked about the word or the color of the word.” Participants then viewed each word, presented in one of four colors (green, blue, orange, and gray) for 3 sec per word in lowercase 65 point Arial font. Word pairs were randomly assigned to a color, such that the first presentation (P1) and the second presentation (P2) in each related and unrelated pair were shown in the same color. Pairs were assigned to colors so that each color was used equally often within each study list. Colors were randomly assigned to the 8 single items throughout each list under the constraint that each color was represented equally often. After studying the first list with 48 presented words, participants took a free recall test for all of the studied words from that list.

When they were done recalling as many words as they could from that list, participants entered a question mark and started studying the second study list. The second list followed the same procedure as the first, but new words were used. Participants took a context memory test after the second study list. During the context memory test, a studied word was presented in black in the middle of the screen. At the bottom of the screen, the same studied word was presented in each of the four possible colors. Participants selected which of the four colors they believed it was studied in and indicated their confidence in their choice on a scale from 1 (not confident) to 3 (confident). The order of the words during the context memory test was controlled such that all P1s were tested before P2s, but the order of all P1s (and of all P2s) tested was randomized within their respective sub-lists. We were primarily interested in comparing memory performance between related and unrelated P1s because remindings are theorized to primarily affect memory for P1 (Tullis et al., 2014). Testing P2s before P1s may cause remindings to occur *during* testing, which can contaminate participants’ memory for P1; it is for this reason that we tested memory for the color of all P1s before P2s.

Participants completed two more study/test cycles (for a total of 4 study/test cycles), where the third cycle was a free recall test of content and the fourth was the context memory test. We tested memory for content and context in different lists in order to analyze whether

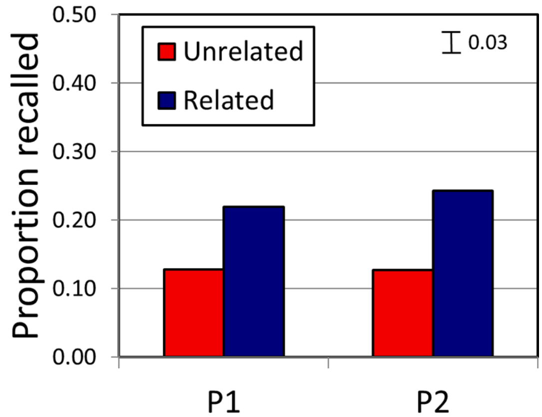

Fig. 1. The proportion of studied words recalled in Experiment 1 as a function of type of pair (unrelated vs. related) and position in the pair (P1 or P2). The width of the error bars here and on all subsequent graphs indicate the within-subjects 95% confidence interval across conditions (Loftus & Palmer, 1974).

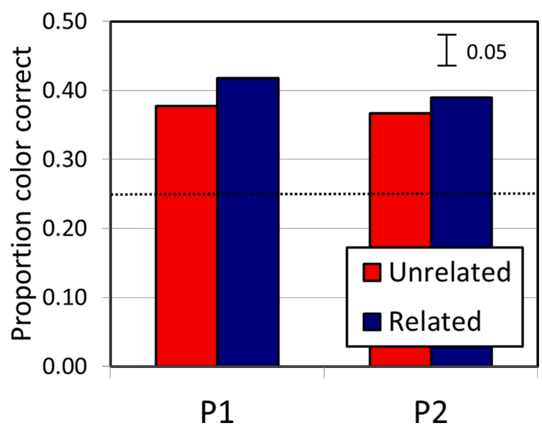

Fig. 2. The proportion of correct color selections in Experiment 1 as a function of type of pair (unrelated vs. related) and position in the pair (P1 or P2). The dashed line represents chance performance assuming all choices are equally probable.

reminding boosts memory for both content (i.e. the traditional reminding effect) and for the context while minimizing the risk of contamination via carry-over effects.

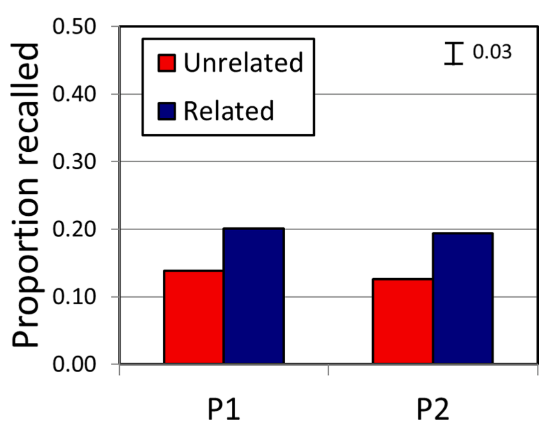

Fig. 3. Proportion of studied words recalled in Experiment 2 as a function of type of pair (unrelated vs. related) and position in the pair (P1 or P2).

Results

The data from this experiment and those that follow can be found here: https://osf.io/4gbf6/?view_only=9fff6bca16b14b12a9d0faa16cfd378d.

Content memory

We grouped the free recall results from tests 1 and 3 together and the memory context results from tests 2 and 4 together. For the free recall tests, answers were only counted as recalled if they matched the studied words exactly. Free recall performance is displayed in Fig. 1. A 2 (related or unrelated) × 2 (P1 or P2) ANOVA on free recall showed a significant effect of relatedness, $F(1, 89) = 72.39$, $p < .001$, $\eta_p^2 = .45$. Neither position, $F(1, 89) = 2.72$, $p = .10$, $\eta_p^2 = .03$, nor the interaction between relatedness and position, $F(1, 89) = 3.66$, $p = .06$, $\eta_p^2 = .04$, reached significance. We also specifically examined recall of P1s as a more stringent test of the reminding effect: related P1s were recalled more frequently than unrelated P1s, $t(89) = 6.84$, $p < .001$, $d = 0.72$, which replicates prior research (Tullis et al., 2014). Participants recalled 16.3% ($SD = 10.1\%$) of the 8 singly presented items.

Context memory

Fig. 2 shows performance on the context memory test. First, we compared the proportion of related and unrelated items whose colors were correctly identified. A 2 (related or unrelated) × 2 (P1 or P2) ANOVA on context memory showed a significant effect of relatedness, $F(1, 89) = 6.66$, $p = .01$, $\eta_p^2 = .07$. Neither position, $F(1, 89) = 2.95$, $p = .09$, $\eta_p^2 = .03$, nor the interaction between relatedness and position, $F(1, 89) = 0.74$, $p = .39$, $\eta_p^2 = .01$, reached significance. Because we tested all P1s before testing P2s on the context memory test, we again conducted a planned comparison between context memory specifically for related and unrelated P1s. Context memory for related P1s was higher than for unrelated P1s, $t(89) = 2.75$, $p = .007$, $d = 0.29$.

Discussion

Relatedness enhanced memory for both the content (i.e., the words) and the context (i.e., the color of the words) of associated words. These results support the idea that remindings can influence memory for the context in addition to memory for the content. However, Experiment 1 cannot rule out the idea that the reminding benefits seen for the context could result from confusion (or strategic guessing) between the colors of related items within a pair. If learners remember that P2 was presented in red, for example, they may (strategically or not) guess that the related P1 was also presented in red. The color of P2 perfectly correlated with the color of P1, so knowing the color of one item in a pair provided correct information about the color of the other item. Further, because P1 and P2 were always studied in the same colors, it is impossible to assess whether remindings always boost memory for context via retrieval or if remindings have the potential to interfere with that memory (c.f., Wahlheim & Jacoby, 2013). We address these potential limitations in the next three experiments by presenting items within related pairs in different colors.

Experiment 2

Experiment 1 revealed that remindings can bolster memory for the contextual details of related episodes. However, P1s and P2s were always presented in the same color in Experiment 1, which limits the strength of the conclusions we can draw about how later episodes influence memory for the context of prior related ones. Here, we test whether P2 can modify or interfere with memory for the contextual details of P1 by presenting P1s and P2s with different color contexts.

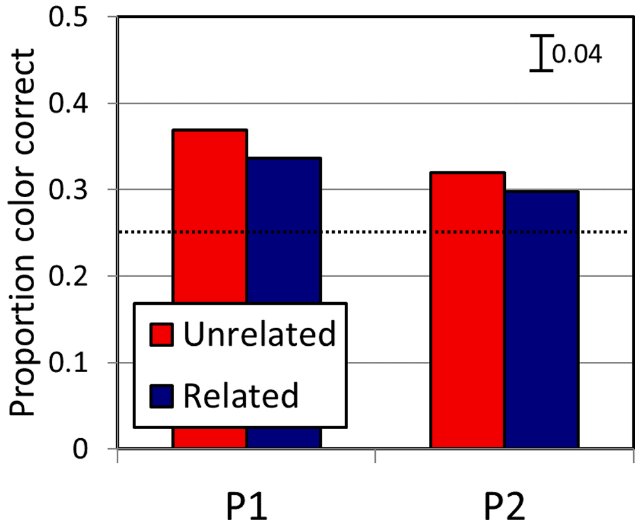

Fig. 4. The proportion of color correct in Experiment 2 as a function of type of pair (unrelated vs. related) and position in the pair (P1 or P2). The dashed line represents chance performance.

Methods

Participants

Ninety introductory psychology students at Indiana University participated in exchange for partial course credit.

Materials

The same materials were used as in Experiment 1.

Procedure

Experiment 2 differed from Experiment 1 in one way: paired words were never presented in the same color as each other. Each P1 was randomly assigned to a color, and corresponding P2s were subsequently randomly assigned to one of the three remaining colors for both related and unrelated pairs. Within each study list, however, presentation colors were used equally often.

Results

Content memory

Free recall performance is displayed in Fig. 3. A 2 (relatedness) × 2 (position) repeated measures ANOVA on free recall revealed a significant effect of relatedness, $F(1, 89) = 40.40$, $p < .001$, $\eta_p^2 = .31$. Neither the effect of position, $F(1, 89) = 2.27$, $p = .14$, $\eta_p^2 = .03$, nor the interaction between position and relatedness, $F(1, 89) = 0.14$, $p = .71$, $\eta_p^2 = .002$, reached significance. We specifically tested the difference between related and unrelated P1s; related P1s were recalled more frequently than unrelated P1s, $t(89) = 5.07$, $p < .001$, $d = 0.54$, replicating the free recall results of Experiment 1. Participants recalled 17.1% (SD = 10.3%) of the 8 singly presented items.

Context memory

Next, we examined participants' performance on the context memory test, displayed in Fig. 4. A 2 (relatedness) × 2 (position) repeated measures ANOVA on context memory showed a significant effect of relatedness, $F(1, 89) = 6.52$, $p = .01$, $\eta_p^2 = .07$, and a significant effect of position, $F(1, 89) = 14.16$, $p < .001$, $\eta_p^2 = .14$. The interaction between relatedness and position did not reach significance, $F(1, 89) = .32$, $p = .57$, $\eta_p^2 = .004$. As in Experiment 1, we conducted a planned comparison between context memory for related and unrelated P1s. Context memory was worse for related P1s than for unrelated P1s, $t(89) = 2.41$, $p = .02$, $d = 0.26$, a result that contrasts with the results from Experiment 1.

Context error analysis

Finally, we examined whether errors on the color test arose because participants picked the color of P2 for the color of P1. To compare color confusions across conditions, we first tallied the number of errors each participant made for the color of P1. We then computed the proportion of those errors for which participants selected the color of P2 for P1. Participants made a similar proportion of color confusions for P1 in the related condition (M = .34, SD = 0.13) as the unrelated condition (M = .33, SD = .12), $t(89) = 0.88$, $p = .38$, $d = 0.09$. We repeated the analysis by examining the proportion of errors for the color of P2 in which participants selected the color of P1. Participants made the similar proportion of color confusions for P2 in the related condition (M = .34, SD = 0.11) as the unrelated condition (M = .34, SD = .13), $t(89) = 0.28$, $p = .78$, $d = 0.03$.

Discussion

Experiment 2 showed mnemonic benefits of remindings for the content of related episodes (as in Experiment 1) but revealed *impairments* to memory for the context of related episodes. Studying related words presented in different colors impaired memory for the color of both the earlier and later related words. In other words, we found interference between the contexts of related episodes, even though memory for the related *content* of the episodes was enhanced.

In Experiment 2, color did carry some information value, since subjects could learn that colors were never repeated across items within a pair. Experiment 3 resolves this issue by decorrelating color across pairs. It includes paired items whose colors were sometimes the same and sometimes different. In this way, Experiment 3 combines the procedures of Experiments 1 and 2 into a single experiment to prevent the use of strategies for guessing colors of studied words.

Experiment 3

Experiment 3 seeks to replicate the patterns found in Experiment 1 and 2 within the same experiment. In Experiment 3, learners studied a list of pairs of related and unrelated words, as in the first two experiments, but the color of the second word in a pair was uncorrelated with the color of the first word. Disentangling the colors of P1 and P2 allows us to more cleanly test the impact of studying related episodes on memory for the context of earlier ones, while eliminating the ability to accurately guess the color of P1 based upon memory for the color of P2 (or vice versa).

Methods

Participants

Ninety introductory psychology students at Indiana University participated in exchange for partial course credit, as in the prior two experiments.

Materials

The same materials were used as in Experiment 1.

Procedure

Experiment 3 differed from Experiment 1 in three ways. First, the colors of P1 and P2 were not dependent on each other. Colors were randomly assigned to each word, regardless of position in pair and relation to other words. Learners, then, could not strategically guess the color of related words based upon their knowledge of the colors of related words. Randomly assigning colors to each word affected the experimental design, such that an additional within-subjects factor was inherently included: color consistency within a pair. Because colors were randomly assigned to each presented item, approximately ¼ of related pairs were shown in the same color, while approximately ¾ of related pairs were shown in different colors. Second, we tested learners'

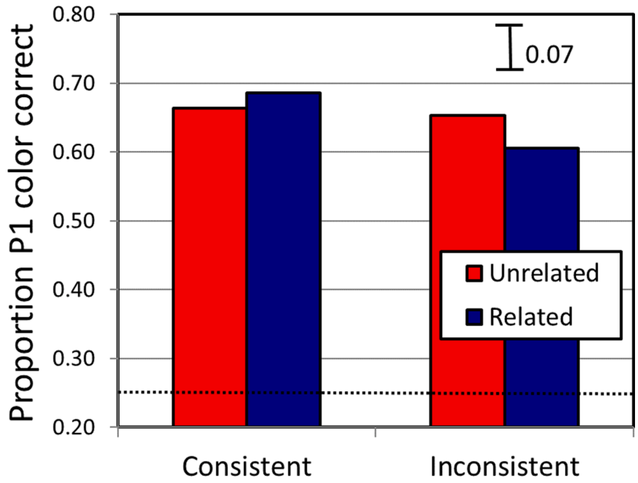

Fig. 5. Proportion of correct color selections for P1s in Experiment 3 as a function of type of pair (unrelated vs. related) and color consistency (same color across P1 & P2 or different colors for P1 & P2). The dashed line represents chance performance.

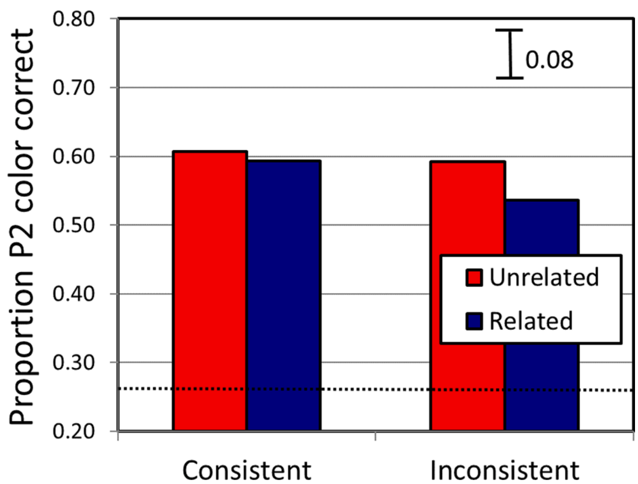

Fig. 6. The proportion of correct color selections for P2s in Experiment 3 as a function of type of pair (unrelated vs. related) and color consistency (same color across P1 & P2 or different colors for P1 & P2). The dashed line represents chance performance.

memory for the color of the words across all 4 study/test cycles; we did not include any free recall tests of the content. We tested context memory on each of the study/test cycles to maximize the amount of context data collected, particularly since only ¼ of pairs are expected to be assigned to the color-consistent condition. Finally, we increased the presentation time to 8 s per word so that memory for the context would be superior to that evident in the near-floor performance in the prior experiment.

Results

Context memory

As in the prior experiments, P1s were tested before P2s. Therefore, we first examined participants' context memory for P1s, displayed in Fig. 5. Performance was far above chance in all conditions, and also above the levels of performance in Experiments 1 and 2. This result suggests that longer presentation durations in Experiment 3 enabled participants to better remember the font colors. A 2 (consistent color vs. inconsistent color) × 2 (related vs. unrelated) ANOVA on context memory for P1s revealed a significant interaction, $F(1,89) = 4.39$, $p = .04$, $\eta_p^2 = .047$, a main effect of color consistency, $F(1,89) = 6.37$, $p = .01$, $\eta_p^2 = .067$, but no main effect of relatedness, $F(1,89) = 0.70$, $p = .41$, $\eta_p^2 = .008$. Follow-up t-tests showed that presenting pairs in different colors impaired contextual memory for related P1s compared to unrelated P1s, $t(89) = 3.48$, $p = .001$, $d = 0.37$, which replicates the results from Experiment 2. However, presenting pairs in the same color showed no differences for contextual memory of related P1s over unrelated P1s, $t(89) = 0.77$, $p = .44$, $d = 0.08$, BF01 = 6.67, which contrasts with the benefits to context memory in the related condition that we found in Experiment 1. The Bayes Factor suggests moderate evidence that memory for the colors of related and unrelated P1s in consistent colors are equivalent.

We repeated these analyses for memory for the context of P2, as displayed in Fig. 6. A 2 (same color vs. different color) × 2 (related vs. unrelated) ANOVA on context memory for P2s did not show a significant interaction, $F(1,89) = 1.34$, $p = .25$, $\eta_p^2 = .015$, but both the main effect of color consistency, $F(1,89) = 4.71$, $p = .03$, $\eta_p^2 = .05$, and relatedness, $F(1,89) = 4.18$, $p = .04$, $\eta_p^2 = .045$, reached significance. Planned comparisons showed that memory for the color of P2 was worse when a related P1 was presented in a different color than when an unrelated P1 was presented in the different color, $t(89) = 3.06$, $p = .003$, $d = 0.32$. Memory performance for the color of P2 did not differ between related and unrelated pairs when both were presented in the same color, $t(89) = 0.44$, $p = .66$, $d = 0.05$, BF01 = 7.69. Again, the Bayes Factor indicated moderate support in favor of the null hypothesis that memory for the contexts of related and unrelated P2s were equivalent.

Context error analysis

As in Experiment 2, we examined the color confusions in Experiment 3. Participants made a similar proportion of color confusions for P1 in the related condition ($M = .45$, $SD = 0.22$) as the unrelated condition ($M = .40$, $SD = .25$), $t(89) = 1.45$, $p = .15$, $d = 0.15$. We also examined the proportion of errors for the color of P2 in which participants selected the color of P1. Participants selected the color of P1 for P2 in the related condition ($M = .41$, $SD = 0.23$) more frequently than in the unrelated condition ($M = .31$, $SD = .23$), $t(88) = 2.68$, $p = .009$, $d = 0.29$. We are cautious to strongly interpret the results for color confusions for P2 because the color of P2 was always tested after all P1s were tested.

Discussion

Experiment 3 replicated the results of Experiment 2 in a situation in which the opportunity to use effective guessing strategies during testing was minimized. Memory for the color of P1 (and P2) in related pairs showed interference when they were presented in different colors. Remindings did not enhance memory for the context of earlier, semantically related words, as in Experiment 1; yet, the more novel and counterintuitive portion of the effect did replicate. Further, the significant interaction reveals a meaningful difference across the conditions of color consistency. We return to this discussion after replicating this procedure in Experiment 4.

Experiment 4

The principal aim of Experiment 4 was to replicate the critical result from Experiments 2 and 3 that color inconsistency harmed memory for the context of P1. We increased the number of trials that learners' memory for the color of P1 was tested so that we could more powerfully examine errors in memory for the color of P1. As we describe below, this result can help distinguish competing theories of the cognitive processes happening during a reminding.

One possible cognitive process that could yield interference between colors of related items is reactivation and context integration. Earlier episodes may be retrieved and reactivated by the later presentation of related events; later episodic details then may become incorporated into the memory for the context of earlier events (and impair true memories

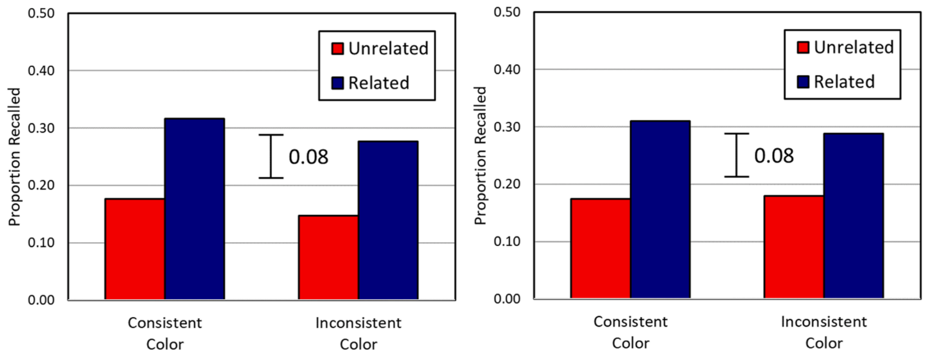

Fig. 7. Proportion of P1s (left graph) and P2s (right graph) freely recalled in Experiment 4 as a function of type of pair (unrelated vs. related) and color consistency (same color across P1 & P2 or inconsistent colors across P1 & P2).

of the earlier event). More specifically, the temporal context model of memory suggests that later related episodes can reinstate context of earlier episodes and ultimately cause later items to intrude into memory for earlier lists (Sederberg, Gershman, Polyn, & Norman, 2011). This result is consistent with findings indicating the pernicious effect of misinformation on memory (Gordon & Spear, 1973; Loftus & Palmer, 1974; Misanin, Miller, & Lewis, 1968). This perspective suggests that learners should be more likely to confuse the colors of individual presentations; specifically, learners should select the color of P2 when tested about the color of P1.

Alternatively, remindings may prompt generalizations across related instances which may affect memory for contexts of the individual episodes. Remindings are theorized to bring two distinct episodes into mind simultaneously and prompt generalization or abstraction across episodes, according to the reminder generalization account (Benjamin & Ross, 2010). If remindings prompt generalizations, memory for elements common to both instances may be enhanced, and features that differ between episodes may be discarded (Watkins & Kerkar, 1985). Memories for superficial details that vary across presentations (like color of presentations) may be disregarded. In this case, learners would not confuse the color of P2 for P1 at levels greater than chance. In Experiment 4, we increased the number of trials we assessed context memory so that we would have more power to detect differences in the kinds of errors participants make during the context test.

Methods

Participants

Ninety introductory psychology students at University of Arizona participated in exchange for partial course credit.

Materials

One hundred and ninety-two associate pairs were collected from the University of South Florida Free Association Norms (Nelson et al., 2004). Associated pairs were unidirectionally strongly related (Mean backward associative strength = .62, SD = 0.17; Mean forward associative strength = .20, SD = .20). Items were selected to maximize the associative strength from the reminder back to the target while ensuring that associated pairs were not related to any other items. A list structure that only differentiated between P1s, P2s, and single items was created and comprised 16 P1s, 16 P2s, and 2 single items. P1s were separated from P2s by a lag of 3 other items. Eight study lists were created using the same list structure. For each subject and each list, words were randomly inserted into the list and randomly assigned a color. Half of the pairs were assigned to the related condition; the other half of the pairs were assigned to the unrelated condition and were paired with a word from a different associated pair. Half of the associated pairs appeared in the first half of the study list and half appeared in the second half to ensure that position within the list was comparable across conditions.

Procedure

The procedure largely mimicked that from Experiment 3, with four notable changes. The first change was that learners studied 8 different lists of items (rather than 4 lists), which allowed us to assess memory for both content and color. We tested free recall of the content of study lists 2 and 5 by asking learners to type any studied items they remembered from that study list. We tested memory for the color of studied items in lists 1, 3, 4, 6, 7, and 8. Learners' memory for the colors was only tested for P1s: We exclusively focused the memory tests on the color of P1s in order to maximize the power to detect differences in memory for the color of P1s. Learners were instructed to remember both the content and the color of the studied items for later memory tests, but were never told what type of memory test they would face for each list until they were done studying that list. Second, we reduced the study presentation time to 6 s per word to ensure that the experiment fit within time limits. Finally, we limited color presentations to 3 different colors: blue, green, or orange. Reducing the color possibilities increases the percent of trials on which colors are consistent between P1 and P2. In Experiment 3, random chance allocates about ¼ of trials to be consistent; in Experiment 4, about 1/3 of word pairs were presented in consistent colors across P1 and P2.

Results

Content memory

We first examined the proportion of items recalled during the free recall content tests on lists 2 and 5. The free recall of P1s is displayed on the left side of Fig. 7. A 2 (consistent color vs. inconsistent color) × 2 (related vs. unrelated) ANOVA on the proportion of P1s recalled showed a significant main effect of relatedness, $F(1,89) = 44.91$, $p < .001$, $\eta_p^2 = .335$. Neither the interaction, $F(1, 89) = 0.09$, $p = .77$, $\eta_p^2 = .001$, nor the main effect of color consistency, $F(1, 89) = 3.83$, $p = .054$, $\eta_p^2 = .041$, reached significance[1]. The mnemonic advantages found for related P1s over unrelated P1s replicates prior research (Tullis et al., 2014) and Experiments 1 and 2. As shown in the right panel of Fig. 7, a 2 (consistent color vs. inconsistent color) × 2 (related vs. unrelated) ANOVA on proportion of P2s recalled showed a significant main effect of relatedness, $F(1,89) = 43.41$, $p < .001$, $\eta_p^2 = 0.328$. Neither the interaction, $F(1, 89) = 0.66$, $p = .42$, $\eta_p^2 = .007$, nor the main effect of color consistency, $F(1, 89) = 0.29$, $p = .59$, $\eta_p^2 = .003$, reached significance. These effects provide a convincing replication of the traditional reminding effect in memory for content (Tullis et al., 2014). Participants recalled 27.5% (SD = 26%) of the 4 singly presented items.

[1] For a Bayesian analysis of this ANOVA and for the ANOVA testing memory of P2, see Appendix A.

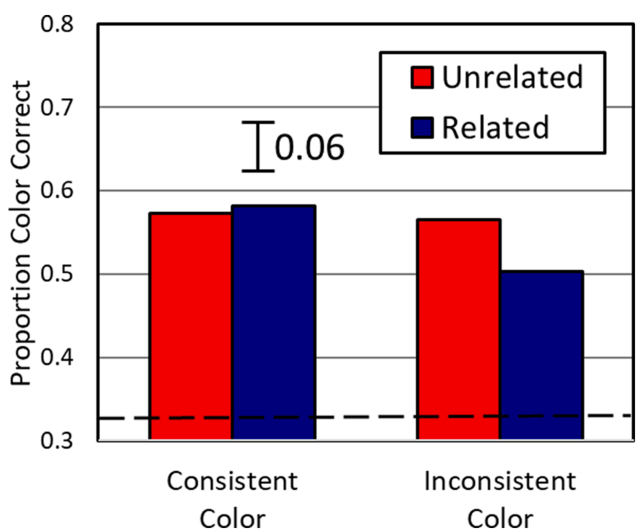

Fig. 8. Proportion of correct color selections for P1s in Experiment 4 as a function of type of pair (unrelated vs. related) and color consistency (same color across P1 & P2 or different colors for P1 & P2). The dashed line represents chance performance, assuming random selection of color contexts.

Context memory

Next, we examined participants' memory for the color of P1s, shown in Fig. 8. A 2 (consistent color vs. inconsistent color) × 2 (related vs. unrelated) ANOVA on context memory for P1s revealed a significant interaction, $F(1,89) = 7.31$, $p = .008$, $\eta_p^2 = .076$, a main effect of color consistency, $F(1,89) = 21.10$, $p < .001$, $\eta_p^2 = .192$, and a main effect of relatedness, $F(1,89) = 5.99$, $p = .02$, $\eta_p^2 = .063$. Follow-up t-tests showed that presenting pairs in different colors impaired contextual memory for related P1s compared to unrelated P1s, $t(89) = 4.16$, $p < .001$, $d = 0.44$, replicating the results from Experiments 2 and 3. However, presenting pairs in same colors did not affect contextual memory differentially for related or unrelated P1s, $t(89) = 0.49$, $p = .63$, $d = 0.05$, BF01 = 7.69, which replicates the results from Experiment 3 but fails to replicate the results from Experiment 1. The Bayes Factor indicated moderate evidence that memory for the contexts of related and unrelated pairs do not differ.

Context error analysis

Finally, we examined whether errors on the color test arose because participants picked the color of P2 for the color of P1. As in the prior experiments, we tallied the number of errors each participant made for the color of P1 and computed the proportion of those errors for which participants selected the color of P2 for P1. Participants wrongly attributed the color of P2 to P1 more frequently in the related ($M = .58$, $SD = 0.14$) than the unrelated condition ($M = .50$, $SD = .17$), $t(89) = 3.50$, $p < .001$, $d = 0.37$. In the related condition, out of the instances when participants made errors (and P1 and P2 were not in the same color), participants selected the color of P2 for P1 more frequently than random selections from among the remaining colors (i.e. 50%), $t(89) = 5.42$, $p < .001$, $d = 0.57$. In the unrelated condition, out of the instances when participants made errors (and P1 and P2 were not in the same color), participants did not select the color of P2 for P1 more frequently than expected by chance (i.e. 50%), $t(89) = 0.02$, $p = .98$, $d = 0.002$.

Discussion

Experiment 4 showed that reminding can impair the memory for color while benefiting memory for the content of related episodes. Consistent with the prior two experiments, when the context changed across related episodes, memory for the context of P1 was impaired. Memory for the color of P1 was not randomly impaired; rather, learners reliably more often selected the color of related P2s. This error suggests a blending of the two episodes involved in reminding.

Combined analysis

We combined our data across the experiments to precisely estimate effect sizes for the positive impact of reminding on memory for content and the negative impact of reminding on memory for color, to increase our power to detect small effects, and to draw conclusions about null effects.

Content memory

We first examined free recall of the content across Experiments 1, 2, and 4 using a 2 (related or unrelated word pairs) × 2 (P1 or P2) repeated measures ANOVA. The results showed a significant main effect of relatedness, $F(1, 269) = 182.32$, $p < .001$, $\eta_p^2 = .40$. Neither the main effect of position, $F(1, 269) = 1.16$, $p = .28$, $\eta_p^2 = .004$, nor the interaction, $F(1, 269) = 0.06$, $p = .81$, $\eta_p^2 < .001$, reached significance. Follow-up paired t-tests showed a significant mnemonic benefit of related P1s over unrelated P1s, $t(269) = 11.33$, $p < .001$, $d = 0.69$, BF10 $= 2.64\text{x}10^{21}$, and a significant mnemonic benefit of related P2s over unrelated P2s, $t(269) = 11.59$, $p < .001$, $d = 0.71$, BF10 $= 1.90\text{x}10^{22}$.

Context memory

Next, we examined memory for the color of P1 using a 2 (related or unrelated word pairs) × 2 (consistent or inconsistent color) repeated measures ANOVA on the data from Experiments 3 and 4. The results showed a significant interaction, $F(1, 179) = 11.07$, $p = .001$, $\eta_p^2 = .058$, a main effect of color consistency, $F(1, 179) = 19.18$, $p < .001$, $\eta_p^2 = .097$, and a main effect of relatedness, $F(1, 179) = 4.32$, $p = .04$, $\eta_p^2 = .024$. Examining the data from Experiments 2–4, which are the experiments that include inconsistent color conditions, paired t-tests showed that inconsistent colors impaired memory for the colors of related P1s compared to unrelated P1s, $t(269) = 5.83$, $p < .001$, $d = 0.36$, BF10 = 527,282. In contrast, aggregated data across Experiments 1, 3, and 4 (which are the experiments that include consistent color conditions) show that consistent colors did not significantly affect memory for related P1s compared to unrelated P1s, $t(269) = 1.92$, $p = .06$, $d = 0.12$, BF01 = 2.33. The Bayes Factor for the consistent color comparison indicates anecdotal evidence in favor of the null hypothesis. The marginal benefit for related P1s over unrelated P1s is driven by the mnemonic benefits found in Experiment 1, in which related word pairs were always shown in the same color and participants may have used strategic guessing to boost performance.

We completed the same repeated measures t-tests on memory for the color of P2. The t-tests showed that inconsistent colors impaired memory for the color of related P2s, $t(179) = 3.29$, $p = .001$, $d = 0.25$, BF10 = 14.72, but consistent colors did not affect memory for P2s, $t(179) = .27$, $p = .79$, $d = 0.02$, BF01 = 11.11. The Bayes Factor for the consistent color comparison indicates strong evidence in favor of the null hypothesis. However, we are hesitant to interpret these results strongly because the color of P2s were always tested following the tests for the color of P1s. These data could, therefore, be affected by remindings that occurred during testing, as well as greater output interference among related word pairs than unrelated word pairs (Malmberg, Criss, Gangwani, & Shiffrin, 2012; Mueller & Watkins, 1977).

Context errors

We also examined the proportion of color confusions (participants reporting the color of P2 for the color of P1 when they incorrectly judged the color of P1) combined across Experiments 2 to 4. Participants made significantly more color confusions when pairs were related ($M = .46$, $SD = .19$) than when they were unrelated ($M = .41$, $SD = .20$), $t(268) =$

3.22, p = .001, d = 0.20.

General discussion

Remindings consistently improved the free recall of words in related pairs over words in unrelated pairs across the experiments presented here, as in prior research (Tullis et al., 2014). However, remindings affected memory for more than just the semantic content across events; they also affected memory for the context of the specific episodes. Remindings impacted memory for the contextual details of the episodes, but those effects varied with the consistency of the contextual details. When context was consistent across related presentations, memory for the font color of related episodes was largely unaffected, though the results were inconsistent across experiments, and more work is needed to determine precisely what happens under such conditions. When context differed across related presentations, however, the effects were clear: memory for the font color was clearly and substantially impaired. The results of these experiments reveal interference between the contextual details of related episodes. This interference between contexts of related episodes causes learners to confuse the context of P2 for P1.

These results have significant implications for understanding the cognitive processes involved in remindings. The impairment in memory for context following reminding provides evidence against an account of reminding that depends solely on spreading semantic activation. In such accounts, memory for the content of semantically related episodes improves due to repeated activation. When learners encode semantically related pairs across time, the mental encoding of each item activates semantic features of the other and the residual activation of semantic features of related words facilitates memory for items in related pairs. Such a view can explain, for example, why study times are shorter for the second member of a related than an unrelated pair (McKinley, Ross, & Benjamin, 2019). If the benefits of remindings were due to activation spreading across semantic features shared between related episodes, memory for context would be unaffected. It is unclear how spreading semantic activation would affect memory for episodic details (but see evidence for episodic priming: Durgunglu & Neely, 1987; Neely, Schmidt & Roediger, 1983), let alone exhibit different effects when contexts are similar versus when they are different. Further, additional theoretical machinery would be needed to explicate why spreading activation due to remindings would enhance long-term memory.

Other accounts of reminding suggest that later related episodes activate earlier episodes and cause learners to consciously rehearse related pairs more frequently (Rundus, 1971, Experiment 4). In this view, remindings cause extra conscious rehearsal of related items, and this rehearsal boosts memory for related episodes. Indeed, recent research suggest that these extra rehearsals contribute to the mnemonic benefits of remindings (McKinley & Benjamin, 2020). However, the results of this experiment challenge the view that conscious rehearsal plays an exclusive role in producing the effects of reminding, as extra conscious rehearsal would presumably improve, and not impair, memory for context. Reminding accounts that involve spreading semantic activation and extra conscious rehearsal thus have trouble explaining the complex and often negative consequences of remindings on memory for context.

Alternative retrieval-based views, including the recursive reminding theory (Hintzman, 2010, 2011) and the retrieval account of remindings (Benjamin & Tullis, 2010), suggest that stimuli prompt learners to retrieve earlier related stimuli during encoding. Benefits of reminding are ultimately driven by the retrieval of the earlier stimulus alone (Benjamin & Tullis, 2010; Tullis et al., 2014) or by retrieval and re-encoding of the earlier stimulus (Jacoby et al., 2013; Hintzman, 2010, 2011; Wahlheim & Jacoby, 2013). Within retrieval-based accounts, remindings could affect memory for context in two different ways. Retrieval of the earlier episode could always boost memory for its context, just as retrieval reliably produces big benefits for memory of content (Roediger & Karpicke, 2006). Because prior research has shown that retrieval of content also benefits memory for unrelated contextual information (Akan et al., 2018; but see Hong, Polyn, & Fazio, 2019), the retrieval-based account suggests that reminding for P1s produced by their related P2s should enhance memory for the font color of P1, even when font colors differ between P1 and P2. The finding that P1 font memory was impaired disconfirms this prediction. Alternatively, retrieval of the earlier episode could reactivate the memory for that earlier episode, making it labile and subject it to modification (Debiec, LeDoux, & Nader, 2002). Memories for later episodes could be incorporated into the traces of the earlier episodes, which can result in confusion between the colors of the related presentations (Sederberg et al., 2011). When the colors are consistent across related events, that confusion is not evident and may even reveal itself as an apparent advantage. But when those colors are different, it becomes clear that the contextual aspects of the two experiences have become intermingled. From an adaptive perspective, confusions among contexts may arise as a byproduct of memory-updating processes, which typically fortify existing memory representations and assimilate relevant new information (Lee, 2009; Bjork 1978) but can cause memory distortions when novel information is confused with old information (Hardt, Einarsson, & Nader, 2010; Schacter, Guerin, & St. Jacques, 2011).

Yet another perspective is that reminding informs learners to generalize across experiences along dimensions of commonality. This act of generalization extracts features of the experiences that are prototypical and discards aspects that vary (Watkins & Kerkar, 1985). Such a view can make sense out of the decrement to memory for the context of features that differ between related episodes, but cannot fully explicate the increased confusions of the context of P2 for the context of an earlier P1.

Historical views of interference may also provide some insight into the pattern of disrupted context memory we see here. Interference can be caused by blocking, in which a stronger memory prevents access to a weaker memory (Anderson & Neely, 1996). Blocking seems like an inadequate explanation for reminding-based interference in context because prior research (Tullis et al., 2014) and the current results show that memory for the content of P1s is enhanced when later related items are studied. Given the enhanced memory for the content of P1, there is no clear candidate for what would block access specifically to the context of P1. Interference can also be caused by cue overload (e.g., Watkins & Watkins, 1975), in which one cue is associated with many targets. Associating one cue with many targets reduces the recallability of those targets. Like blocking, cue overload seems to be a poor candidate for explaining interference due to remindings in the present research because each P1 can cue its own context (i.e. the associated color). Cues (P1s) are not shared between multiple targets, so cue overload should not be able to explain the interference among contexts of related items. However, remindings could cause P1 to become associated with both its original context and the context of P2. Associating multiple contexts with P1 could reduce mnemonic access to both contexts via cue overload. In contrast to cue overload explanations, however, our results suggest that there is not reduced access to both contexts; instead, impairments in context memory arise because participants confuse contexts between related episodes.

While we find no consistent evidence of mnemonic benefits of reminding on context in these experiments, there may be other circumstances in which remindings do benefit memory for contexts. For example, if context is better integrated with content, retrieving the content may also affect memory for the context. Similar debates exist about whether testing content improves memory for the associated contexts, with some research suggesting there are benefits (Akan et al., 2018) and some suggesting no benefits (Hong et al., 2019). Further, the degree to which remindings involve a full episodic retrieval versus partial retrieval may differ depending on the specific study circumstances (see Hintzman, 2011 for examples of detailed personal episodes of reminding). Finally, the mnemonic consequences of studying related episodes when changes occur between episodes may depend upon learners' conscious awareness of the reminding. In A-B, A-D learning paradigms, learners study a list of word pairs in which a cue (A) is sometimes repeated with the same target (B) or is sometimes repeated with a new target (D). Learners who notice and remember the change in content between related presentations remember the B and D items that are associated to the same cue A better than B and D items that are associated to different cues, whereas learners who do not notice or remember the change between presentations suffer from interference across related items (Jacoby, Wahlheim, & Kelley, 2015; Wahlheim & Jacoby, 2013). In our experiments, if the color of the words in related pairs changes across presentations, learners who notice this change may experience benefits of reminding and learners who fail to notice this change may suffer interference across presentations. However, we did not measure conscious noticing of color changes because we wanted the remindings in our paradigm to be wholly stimulus-driven, rather than provoked by explicit memory queries.

Broadly, remindings reveal that learners actively encode new information by retrieving related information and integrating information across episodes. Prior reminding research shows that studying related information alters learners' ongoing encoding. For example, prior related episodes increase learners' judgments of learning while studying later information (even though it only benefits memory for the earlier episode; Tullis et al., 2014). Prior related episodes additionally alter the amount of study time that learners allocate to later episodes (McKinley et al., 2019). The detrimental effects of reminding when contexts change across related episodes add an intriguing layer to mnemonic research about reminding. Prior results have shown widespread advantages of reminding for memory of the content, order, schedule, and frequency of presentations (Hintzman, 2010; Jacoby et al., 2013; Wahlheim & Jacoby, 2013). Remindings bring to mind earlier related episodes during study of later episodes; interestingly, bridging the temporal gap between related episodes has differential effects on memory for order and context. Bringing the two different episodes together in mind improves memory for their study order and list discrimination but causes interference among studied contexts. Bringing temporally separated episodes together in mind has been thought to be an adaptive feature of remindings (Benjamin & Ross, 2010; Ross et al., 1990; Tullis et al., 2014). Connecting events distant in time allows learners to utilize prior knowledge in novel situations, to compare segregated events, generalize across episodes to form schemas, and make predictions about new situations. Yet, enabling distant events to influence each other may come at a cost of impairing memories for the specific contextual details of individual episodes. These results indicate that reminding can play a role in transitioning knowledge from a catalogue of episodic memories, each highly bound to context, to semantic memory that is well-learned and flexibly accessible, but with less accurate memory for context.

Open practices statement

The datasets generated during the current study are available in the Open Science Framework repository, https://osf.io/4gbf6/?view_only=9fff6bca16b14b12a9d0faa16cfd378d.

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CRediT authorship contribution statement

Jonathan G. Tullis: Conceptualization, Funding acquisition, Methodology, Data curation, Writing - original draft, Writing - review & editing. **Aaron S. Benjamin:** Conceptualization, Writing - review & editing.

Table A1
Bayes Factors for all possible models in a 2 (relatedness) × 2 (color consistency) ANOVA on free recall of P1 in Experiment 4.

Model	Bayes Factor
Color consistency	.49 ± 1.56%
Relatedness	3.74×10^9 ± 1.08%
Color consistency + Relatedness	2.51×10^9 ± 3.60%
Color consistency × Relatedness	3.98×10^8 ± 2.73%

Table A2
Bayes Factors for all possible models in a 2 (relatedness) × 2 (color consistency) ANOVA on free recall of P2 in Experiment 4.

Model	Bayes Factor
Color consistency	.12 ± 0.87%
Relatedness	6.64×10^8 ± 1.55%
Color consistency + Relatedness	8.55×10^7 ± 1.46%
Color consistency × Relatedness	1.79×10^7 ± 1.83%

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

We computed the Bayes Factors for the 2 (related vs. unrelated) × 2 (consistent color vs inconsistent color) repeated measures ANOVAs on the free recall of P1 and P2 in Experiment 4 using the BayesFactor package in R. The Bayes Factor analysis on the free recall of P1, as shown in Table A.1 below, suggests that a model with only a main effect of relatedness is most likely and replicates the traditional ANOVA analysis presented in the manuscript. The comparison model (i.e. the model in the denominator of the Bayes Factors) includes just the participant.

A similar Bayes Factor analysis on the free recall of P2 suggests that a model with only a main effect of relatedness is most likely, as shown in the Table A.2 below. These results replicate the results of the traditional ANOVA presented in the main text.

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