# Context differentiation and remindings in episodic memory updating

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## Abstract

Navigating an ever-changing environment requires memory updating to distinguish past events from more recent experiences. Memory updating is important for adapting to everyday changes such as a collaborators' new work routine or for correcting misinformation. An enduring puzzle in the study of episodic memory is that two apparently conflicting updating mechanisms can support memory for changes. One mechanism involves differentiating the contexts associated with representations of the past and the present to keep them separate and prevent them from interfering with each other. Another mechanism involves integrating representations of the past and present to encode the relationship between events and facilitate recent memories. In the present chapter, we selectively review key studies showing how these apparently conflicting updating mechanisms can both support memory for new information. Studies

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from the classic interference literature suggest that updating is supported by context differentiation occurring when more time passes between study episodes, learning occurs in separate locations, and thoughts between events shift to new contexts. In contrast, studies from the temporal memory literature suggest that new events can trigger remindings of previous events, allowing them both to be encoded as part of an integrated representation. To reconcile these conflicting findings, we advance the perspective that reinstating past contexts during study can impair or improve memory for changed information, depending on whether remindings enabled integrative encoding and later retrieval was recollection-based. Our work shows that this view accounts for remembering in several updating paradigms varying in their likeness to everyday situations.

## 1. Introduction

Every day, people contend with changes that require them to learn new information that conflicts with existing memories. This fundamental cognitive ability is necessary to successfully navigate dynamic environments because future behaviors are often best informed by recent information. For example, suppose that a new professor parks her car in a parking deck on her first visit to campus. To find her car later, she would need to remember details of the parking event, such as the location of the deck and the floor on which she parked. Suppose that on her next visit to campus, she attempted to park in the same location as before but needed to use another deck because the original deck was full. To return to her car on the second occasion, she would need to update her memory of the earlier parking location with the more recent location. In situations like these, people can often keep their memories current, but for various reasons, people sometimes mistakenly remember that earlier events happened more recently.

The consequences of such memory errors illustrate the importance of remembering the details of new conflicting events. In the parking example, failure to remember the recent location could lead the professor to walk to the original location before realizing her error. Although the resulting frustration may seem trivial, the consequences of such errors in higher-stakes situations can be dire. For example, early in the coronavirus pandemic of 2020, health officials changed behavioral recommendations about mask wearing. They indicated that masks were unnecessary in order to preserve supply for healthcare workers, but reversed this recommendation when it became clear that masks were needed to protect others. If someone remembered reading the recommendation to not wear a mask but failed to

remember hearing the updated information from a friend, that person might continue to avoid wearing a mask in public.

The examples above describe instances when existing memories conflict with memory for more recent events and illustrate how episodic memories can be *updated*. In this chapter, we use the term *episodic memory updating* to describe the ability to distinguish between earlier and more recently acquired memories. Episodic memory updating is shown by successful retrieval of recent memories that conflict with earlier memories. Theories of updating assume that context processing plays a role in memory quality. The term *context* here refers to internal or external states and locations that accompany experiences (Anderson & Bower, 1972; Estes, 1955; McGeoch, 1932; Pan, 1926). For example, context could refer to one's mood and the time of day. It has been proposed that memory is best when current contexts cue retrieval of earlier contexts from when the information was encoded (Hintzman, 1988; Raaijmakers & Shiffrin, 1981; Tulving & Thomson, 1973).

Classic perspectives propose that updating is supported when the contexts of recent and earlier memories are kept apart (e.g., Smith, Glenberg, & Bjork, 1978). Such *differentiation* is assumed to involve encoding experiences with their contexts and later retrieving desired contexts and memories. This view assumes that separate contexts keep memories from interfering with each other. However, a more contemporary perspective holds that episodic memory updating can also be supported when existing memories are bound with current experiences. This may occur when those experiences remind people of existing memories (Hintzman, 2010; Tzeng, Lee, & Wetzel, 1979; Wahlheim & Jacoby, 2013). Such remindings-based *integration* is assumed to create new memories that store information about relationships between memories and their contexts.

Bjork (1978) and Finn (2017) in this series have discussed studies of mechanisms that differentiate or integrate contexts associated with episodic memories. Here, we extend on those reviews by synthesizing classic and contemporary studies that characterize the operation of both updating mechanisms (for a related approach, see Kliegl & Bäuml, 2021). Studies examining how relationships among memories affect subsequent retrieval accuracy have spanned broadly across domains in human memory research (for reviews, see Murayama, Miyatsu, Buchli, & Storm, 2014; Pastötter, Tempel, & Bäuml, 2017). Instead of attempting to bridge all potentially relevant literatures, we evaluate the evidence for context differentiation and integration from a narrow range of updating paradigms. Specifically,

we consider updating mostly within A-B, A-D paired-associate learning paradigms and sometimes within related paradigms assessing memory for events from designated times. These studies provide the foundation for our theoretical perspective positing critical roles for context reinstatement during current events (i.e., remindings) and recollection of such remindings. We advance that perspective here and describe our own tests of that account.

To concretize how we operationally define episodic memory updating, we provide examples of response patterns from the A-B, A-D paradigm indicating varying levels of updating success. In this paradigm (Fig. 1A), people learn consecutive associations (such as word pairs, e.g., lawn-grass), including a shared cue (lawn; A) with responses that change across occasions (grass → green; B → D).

Original associations (A-B) are learned first, and updated associations (A-D) are learned next, either in separate phases or during the same phase (i.e., the A-B, A-D condition). To assess how memory for original associations affects subsequent memory for updated associations, some paradigms include a control condition in which original associations (e.g., wine-glass [A-B]) and new associations (e.g., pure-gold [C-D]) do not have any common stimuli (i.e., the A-B, C-D condition). This condition serves as a basis for comparing memory for recent associations that did not change from original associations, and therefore did not require updating. In the A-B, A-D condition, when people attempt to recall what was more recently paired with the cue (A), updating is operationalized as correct recall of the recent response (D).

These paradigms often include lists of many associations, thus providing many updating opportunities (for reviews, see Anderson & Neely, 1996; Postman & Underwood, 1973). The frequency of successful updating is indicated by the size and direction of differences in overall recall of A-D and C-D associations, referred to as *proactive effects* of memory (see Fig. 1B). When earlier associations impair memory for most of the updated associations, *proactive interference* effects are shown as lower overall recall of A-D than C-D associations (light gray bar vs white bar). When earlier associations impair and promote memory for updated associations equally (or do not affect memory), *equivalence* is observed in overall recall of A-D and C-D associations (medium gray bar vs white bar). When earlier associations promote memory for most of the updated associations, *proactive facilitation* effects are shown as higher overall recall of A-D than C-D associations (black bar vs white bar). The challenge of episodic memory updating is therefore to overcome proactive interference to achieve equivalence or facilitation.

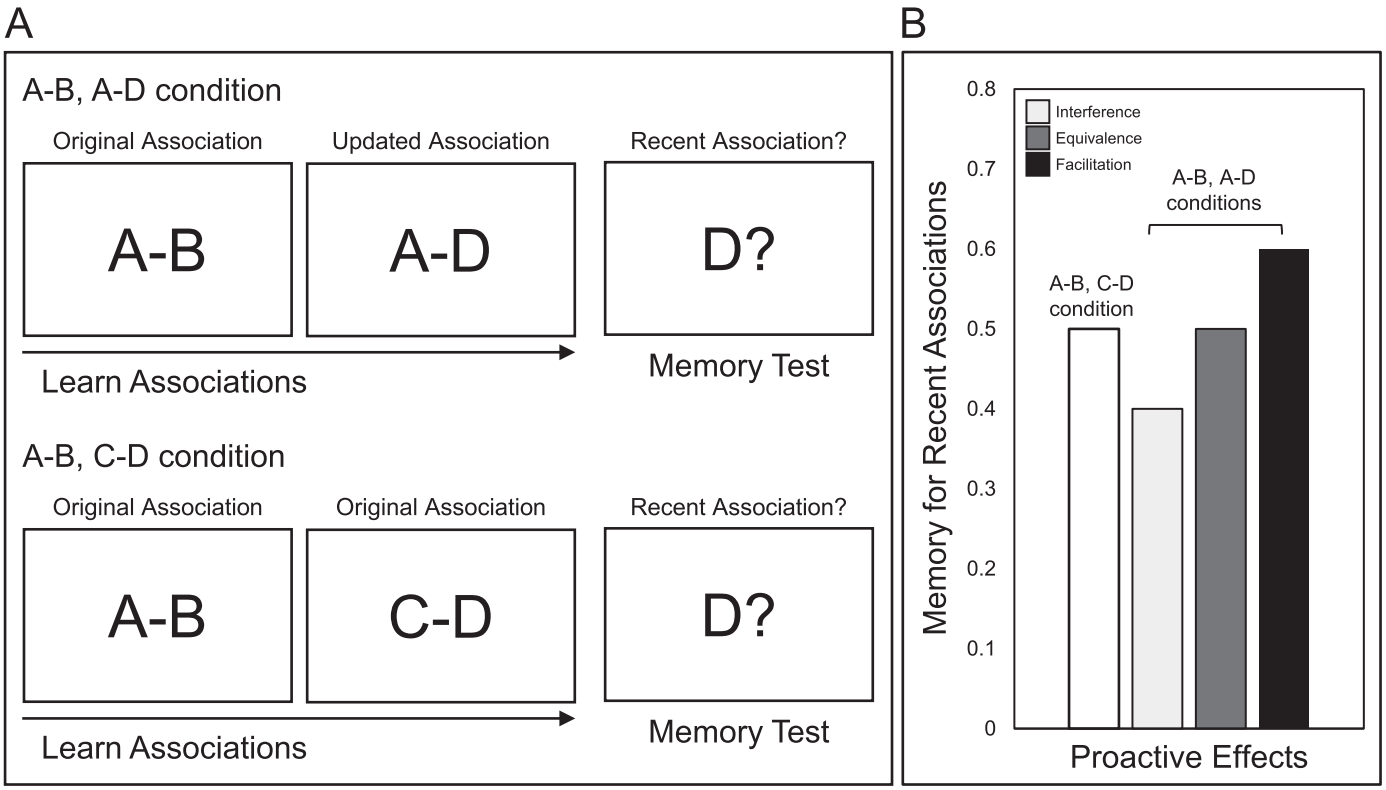


**Fig. 1** Paired-associate learning paradigm and proactive effects of memory. (A) Schematics of the A-B, A-D condition (top) and the A-B, C-D condition (bottom). People learn associations that are sometimes updated and are later tested on their memory for recent associations. (B) Example pattern of results showing proactive effects of memory assessed by comparing overall recall for A-D and C-D associations. An example proactive interference effect, operationalized as lower A-D than C-D recall, is shown in the comparison of the white (first) and light gray (second) bars. An example of equivalence in A-D and C-D recall indicating the absence of an overall proactive effect of memory is shown in the comparison of the white (first) and medium gray (third) bars. An example proactive facilitation effect, operationalized as higher A-D than C-D recall, is shown in the comparison of the white (first) and black (fourth) bars.

Context differentiation and remindings-based integration accounts of performance in the A-B, A-D paradigm predict different possible outcomes. According to differentiation accounts, recall of A-D associations can range from proactive interference to equivalence. By this view, associations that share a cue (A) can lead to interference. However, completely separating the contexts of those associations can lead A-D associations to be functionally equivalent to C-D associations, as if the A-B associations had never appeared. In contrast, according to integration accounts, overlapping associations can lead to overall recall that ranges from proactive interference to facilitation, depending on how often A-D associations remind people of A-B associations. Such accounts assume that effective integration can promote the retrieval of memory representations that include the relationship between the associations along with information that indicates when each association was learned. Therefore, these accounts predict proactive interference when integration is most often unsuccessful, equivalence when integration is somewhat successful, and proactive facilitation when integration is most often successful.

In sum, the goal of the present chapter is to contrast classic views on context differentiation with recent perspectives on remindings-based integration to provide a more comprehensive understanding of episodic memory updating mechanisms. To do this, we first summarize key studies from the interference literature showing how various manipulations of contextual overlap between study episodes affect updating. We then summarize key studies showing how integrative encoding processes can lead to varying proactive effects of memory. In that section, we overview foundational studies from the temporal memory and classic interference literatures before emphasizing our own growing collection of theoretical and empirical work examining remindings-based integration (Jacoby, Wahlheim, & Kelley, 2015; Wahlheim & Jacoby, 2013; Wahlheim & Zacks, 2019). We conclude by synthesizing these findings and mentioning future research directions.

## 2. Context differentiation: Separating experiences

Context differentiation can be accomplished in several ways. In this section, we review studies showing how changes in the time, environment, and mental states associated with study and test episodes can promote updating through differentiation that reduces interference between competing memories and improves memory for recent information.

## 2.1 Temporal changes

One manipulation used to differentiate the contexts of original and updated associations to promote updating is to increase the time between phases in A-B, A-D paradigms. This is assumed to induce changes in the temporal context associated with competing responses. Evidence for this idea was shown in an early study examining how the schedule of learning A-B associations in a first phase affected memory for A-D associations learned in a second phase (Underwood & Ekstrand, 1966). Updating was assessed as the difference in memory for A-D associations when A-B associations were either spread across 4 days or presented four times in 1 day. Recall of A-D associations was better when A-B associations were distributed across 4 days. This suggested that the increased temporal distance between contexts differentiated original from updated associations, thus reducing proactive interference. Related to this, reducing the difference in temporal contexts by repeating A-B associations from the first phase during study of A-D associations in the second phase was shown to produce more proactive interference (Underwood & Ekstrand, 1967). However, the impairing effects of bridging contexts in this way were reduced by increasing the time between A-B and A-D study phases from 0–3 days (Underwood & Freund, 1968). These findings suggest that proactive interference is reduced and updating is promoted when temporal contexts are better differentiated.

The proposal that context differentiation promotes updating also leads to the prediction that the distance between A-D learning and the final recall test should influence the degree of proactive interference effects. The idea here is that the temporal contexts of A-D associations should be more similar to those cued during the test phase when the A-D learning and test phase occur closer than farther apart in time. Consequently, increasing the delay between A-D learning and test should make the contexts from the A-B and A-D phases relatively more similar. Support for this proposal comes from studies that systematically varied test delays and found that shorter delays led to better recall of A-D than A-B associations. In contrast, longer test delays led to comparable recall of A-B and A-D associations, as well as more intrusion errors where D responses were mistaken for B responses and vice versa, presumably because the contexts of those associations were too similar (Underwood, 1948a, 1948b). Relatedly, increasing the number of A-B presentations led to more intrusions when there was a longer delay between A-D and test phases (Underwood, 1949), and extending that delay created more impairment in recall of A-D associations (Houston, 1967; Koppenaal,

1963). These findings suggested that presenting A-B associations in more contexts made them especially difficult to distinguish from A-D associations when the test context was quite different from both associations. Together, the studies in this section provide converging evidence that temporal context changes between learning episodes lead to differentiation that promotes episodic memory updating.

## 2.2 Environmental changes

The benefits of context differentiation for episodic memory updating are also observed when the physical location of learning environments change. This occurs, for example, when A-B and A-D associations are studied in different rooms, thus creating distinct contextual associations for each learning phase. Early work on these effects assessed how well people relearned A-B associations after studying A-B associations in a first phase and A-D associations in a second phase (Bilodeau & Schlosberg, 1951). Memory for relearned A-B associations was better when earlier phases occurred in different rooms, suggesting that interference was reduced by context differentiation. Subsequent work showed that these effects additionally depend on the similarity between the contexts of study and test locations. For example, after A-B and A-D learning phases occurred in different rooms, recall of A-D associations was best when the testing room was the same as the A-D study room and worst when it was the same as the A-B study room (Smith et al., 1978). These and related findings (for a review, Smith & Vela, 2001) suggest that context differentiation across environments can improve memory updating, especially when the final recall context reinstates features of the study context with updated associations.

## 2.3 Internal and strategic changes

The studies in Sections 2.1 and 2.2 suggest that updating supported by context differentiation can result from changes in external attributes (e.g., time and place). However, simultaneous changes in internal states (e.g., thoughts, feelings, and mental states) may also play a role in such updating. This has been examined in free recall tasks that resemble A-B, A-D paradigms by including two learning phases that must be distinguished. To assess the role of internal context change on memory for the second list, people studied word lists in separate rooms and later recalled the second list from either the same or different room (Smith, 1979; Experiment 2). To induce internal context change, some people were told to think about the second room

before recall, whereas others were told to think about a different room. Recall was better when people imagined the second room, regardless of the testing location. These results suggest that the benefits of differentiation involve internal reinstatement of the study context at test. Internal context changes between study lists may also help people forget interfering events. In a similar free recall paradigm, inducing internal context change between study lists increased first-list forgetting and improved second-list recall (e.g., Sahakyan & Kelley, 2002). These and related findings suggest that context differentiation involves people controlling their thought content.

This idea also suggests that internal context change contributes to the improved updating observed when intentional forgetting is encouraged in the A-B, A-D paradigm. For example, earlier work showed that instructions to forget A-B associations impaired memory for them and improved memory for A-D associations, relative to a control condition (Allen & Arbak, 1976). Similarly, instructions to not think about A-B associations before learning A-D associations was shown to speed A-D learning, thus reducing interference from A-B associations (Postman & Gray, cited as personal communication in Bjork, 1978). Further evidence that internal context change promotes differentiation-based updating has been inferred from testing effects in A-B, A-D paradigms. For example, interpolated testing of A-B associations before learning A-D associations was shown to improve recall of A-D associations (Tulving & Watkins, 1974). Subsequent theorizing proposed that interpolated testing promoted differentiation by inducing internal context change (Jang & Huber, 2008; Pastötter, Schicker, Niedernhuber, & Bäuml, 2011). However, this view is controversial because testing can increase the accessibility of retrieved associations (for a review, see Roediger & Karpicke, 2006), which would increase the similarity of contexts associated with A-B and A-D associations. We return to this below when discussing the role of remindings in episodic memory updating.

Effects of internal context change may also be observed when semantic associations as well as encoding and retrieval strategies are updated in A-B, A-D paradigms. One example of semantic changes can be seen when the distinctiveness between pairs with shared cues is varied by including associations with convergent (e.g., organ-music, organ-piano) or divergent (e.g., organ-music, organ-heart) meanings (Hay & Jacoby, 1999, Experiment 3). Divergent meanings reduced interference in recall of A-D associations relative to convergent meanings for older adults, presumably because semantic differences naturally produce separate internal contexts. In addition, one example of strategy changes can be seen when context

differentiation is induced by giving people two rounds of experience with an A-B, A-D paradigm. Doing so was shown to reduce interference from A-B associations on A-D recall from the first to second round (Jacoby, Wahlheim, Rhodes, Daniels, & Rogers, 2010). Such strategic context differentiation has been attributed to more elaborative encoding of A-D associations and more effective reinstatement of the context associated with A-D associations at test (Wahlheim & Jacoby, 2011). Collectively, the studies in this section converge in suggesting that internal context changes can promote updating, especially when the conditions promote reinstatement of the updated contexts during final recall.

### 2.4 Summary of context differentiation: Separating experiences

This section summarized foundational studies that provide empirical evidence for three types of context change that can promote episodic memory updating through differentiation. First, studies examining how the time among study and test phases affects updating show that longer temporal gaps can reduce interference when they are between study phases and increase interference when they are between the recent study phase and test. Second, changing the environmental context associated with study phases can reduce interference, especially when people mentally reinstate the recent study context during final recall. Third, the benefits of context differentiation are enhanced when people mentally reinstate the study phase context or think about different contexts between study phases. Changes in internal context that separate study phases and reinstate contexts during test may also occur following interpolated retrieval events, changes in semantic context, and strategic adaptation of elaborating on and reinstatement of context after experience in an updating task. Together, these studies support the perspective that episodic memory updating can be accomplished through context differentiation.

## 3. Context reinstatement at study: Remindings of past experiences

The findings above showing improved updating with context differentiation could be interpreted as suggesting that similar study contexts will consistently impair updating. However, other work has shown that reinstating earlier contexts during new learning can either impair or improve updating. In this section, we review research showing that the balance of such effects primarily depends on the extent to which current study events

remind people of earlier study events. We first summarize classic research showing the balance of interference and facilitation from remindings through dependencies in recall between original and updated responses, and how remindings have consequences for memory of temporal order. Through these sections, we foreshadow our perspective on the updating mechanisms involved. We then present that perspective and corresponding empirical evidence accounting for this mixture of effects across situations by proposing a critical role for remindings-based integration during study. We end the section by discussing a theory that builds on this framework to account for updating of everyday events along with recent empirical evidence addressing the assumptions of this theory.

## 3.1 Context reinstatement and recall dependencies

As described in Section 1, variants of the A-B, A-D paradigms can lead to a variety of response patterns in overall recall of updated associations. One variable that moderates these patterns is the relationship among experimental stimuli. This moderating effect was shown in early work using an A-B, A-B′ paradigm (Barnes & Underwood, 1959) that was described as such because the responses (B and B′) were strongly related (e.g., *afraid* and *scared*). This relationship led to facilitation in overall recall of original A-B associations that was not observed when A-D associations appeared in the second learning phase. This effect was originally accounted for by a mediation mechanism in which semantic activation between responses improved their accessibility. Importantly, such findings would not be predicted by a context differentiation account. Although mediation may have played a role in these benefits, another possibility is that the relationship allowed the second response to *remind* people of the first response (for a similar suggestion, see Sahakyan & Goodmon, 2007), thereby reinstating the original study context, linking the responses, and facilitating recall. Note that this idea that task conditions that encourage the noticing of relationships can lead to integrative encoding and reduce interference has been shown in other paradigms requiring recall of responses associated with the same cue (e.g., Anderson & McCulloch, 1999; Goodmon & Anderson, 2011).

Other studies using the A-B, A-B′ paradigm have also supported this view. For example, Dallett and D'Andrea (1965) examined how providing instructions that encouraged mediation or forgetting of earlier responses influenced later memory. The results showed that instructions to not think about A-B associations during A-B′ learning reduced interference. Although this is consistent with a context differentiation view, subjective reports of

mnemonics linking B and B′ responses also played a role. These mnemonics could have been used when people experienced spontaneous remindings when B′ responses triggered retrievals of B responses. Further evidence for remindings was illustrated in a modified A-B, A-D paradigm where people were instructed to either recall B and D (accretion condition) or only D (substitution condition) responses during an A-D learning phase in which they repeatedly studied and were tested on A-D associations (Postman & Gray, 1977). Recalling both responses during A-D learning led to better subsequent recall of A-D associations and memory for the phases in which both responses originally appeared. Important for our remindings view, this improved A-D recall was associated with dependence in recall of both responses. Correct recall was higher when B and D responses were both recalled, and this occurred more often when both responses had been retrieved during A-D learning (see Fig. 2).

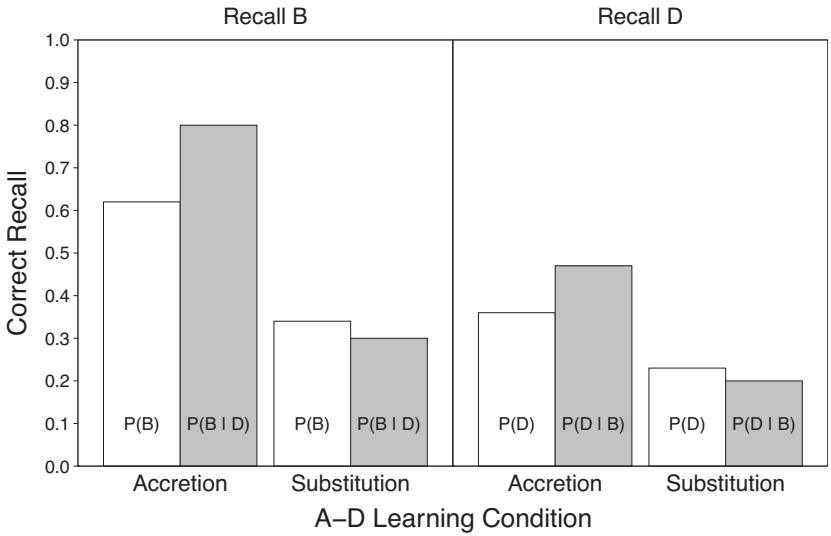


**Fig. 2** Recall dependencies as a function of A-D learning conditions: Postman and Gray (1977). Proportion of correct recall of B (left panel) and D (right panel) responses on the final test as a function of A-D learning condition and recall dependencies. In the Accretion condition, people recalled B and D responses in the transfer phase. In contrast, in the Substitution condition, people only recalled the D responses during the transfer phase. Importantly, correct recall on the final test was greater when both responses were recalled (gray bars) than when only one response was recalled (white bars), but only in the Accretion condition. Data were extracted from the original table and plotted here for ease of interpretation.

From a remindings view, such recall dependence can reflect instances when both responses were earlier integrated into an efficient representation. This was originally proposed to account for the greater dependence observed when elements of A-B-D trigrams had been studied together instead of in separate phases (Bellezza & Schirmann, 1975). However, this interpretation has been cautioned because recall dependence shown by conditional probabilities can obscure subject and item selection artifacts as well as individual variation in mediation strategies (Hintzman, 1972; but see, Martin & Greeno, 1972). In our view, these concerns are better framed as indicating that such variability reflects differences in the frequency of remindings that is driven by encoding strategies and features of experimental stimuli and paradigms. Thus, we propose that the causes and consequences of remindings-based integration can be better understood using manipulations and analytic techniques that determine when and how frequently context reinstatement of earlier learning during new learning leads to recall dependencies.

## 3.2 Temporal coding and recursive remindings

The mechanisms of remindings-based integration that comprise the foundation of our view were originally proposed in theories of temporal order coding (for a review, see Friedman, 1993). Specifically, these mechanisms were proposed to partly explain how people remember temporal information about stimuli studied at various distances apart. The tasks in these studies are similar to the A-B, A-D paradigm, as the typical objective is to remember relative temporal information about the stimuli. For example, remembering that one word appeared more recently than another is similar to remembering the most recently presented response in an A-B, A-D paradigm. Here, we summarize foundational work from this literature that supports key aspects of the role of remindings in facilitating memory for temporal order.

The original reminding-based model of order coding was proposed to account for the observation that judgments about the spacing between pairs of individually studied words were more accurate for related (e.g., queen → king) than unrelated (e.g., spider → table) pairs (Hintzman, Summers, & Block, 1975). Similar to our suggestion about the A-B, A-B′ paradigm above, this study-phase retrieval model proposed that semantic associations between related words allowed the more recent word to cue retrieval of the earlier word, allowing them to become encoded together. Consistent with this, a related context-based theory proposed that

study-phase remindings depended on the first item within a pair of words being available in a rehearsal set when the second item later appeared. Evidence for this theory was shown when intentional forgetting of the first items of pairs reduced order memory relative to when the first items were not intentionally forgotten (Tzeng et al., 1979). More support for remindings-based integration was shown by recency judgments for word pairs being more accurate when the pairs belonged to the same rather than different categories, regardless of how far apart they were studied (Tzeng & Cotton, 1980). Indeed, indirect remindings measured during study have shown that the recency advantage for related pairs in such paradigms are associated with first items coming to mind more often when second items are studied (Winograd & Soloway, 1985). Collectively, these and related findings show that remindings promoted contact between study items that bridged the temporal gaps and facilitated order memory (also see, e.g., Nairne & Neumann, 1993).

The role of remindings in recency judgments was further accounted for by a more comprehensive proposal referred to as the recursive remindings hypothesis (Hintzman, 2004, 2010). This hypothesis was partly inspired by dual-process models positing that recognition can be based on contextual recollection or acontextual familiarity (for a review, see Yonelinas, 2002). Based on the finding that judgments of the distance between repetitions of studied items are more accurate when recognition of those items was accompanied by recollected context (Hintzman, 2001), the recursive reminding hypothesis posited that automatic recollection (i.e., spontaneous reminding) enabled earlier representations to be integrated in later representations (Hintzman, 2010). Critically, this hypothesis proposes that subsequent recollection of remindings on the final test is used to infer the relative recency of items comprising those representations. We propose that these compound mental states are akin to integrated representations formed when remindings occur in A-B, A-D paradigms, as described in Section 3.1.

Although the recursive reminding hypothesis conceptualizes of remindings as spontaneous recollections, remindings can be controlled by task instructions and strategies. For example, instructing people to think back in a study list to identify relationships between earlier and current category exemplars improves subsequent memory for earlier exemplars (Jacoby, 1974). This looking back method can also enhance recency judgments and cued recall of recent category exemplars and has been shown to increase the frequency of recall dependencies indicating that later exemplars are better remembered when earlier related exemplars are also recalled

(Jacoby & Wahlheim, 2013). These findings suggest that controlled remindings can also enhance memory for relative order by promoting integrative encoding (also see, Jacoby, Wahlheim, & Yonelinas, 2013). Contrary to the context differentiation literature reviewed above, these studies examining memory for order suggest that sometimes bridging the contexts of separate phases can improve rather than impair episodic memory updating.

### 3.3 The memory-for-change framework

The studies above identifying a role for remindings in memory for temporal order inspire our account of how final recall in A-B, A-D paradigms can range from interference to facilitation effects. The *Memory-for-Change* (MFC) framework (Wahlheim & Jacoby, 2013) is a verbal theory of episodic memory updating that includes assumptions from the recursive remindings hypothesis (Hintzman, 2004) and a dual-process model of interference effects (Hay & Jacoby, 1996). The MFC framework proposes that the accessibility of original associations (A-B) determines both the strength of interference from those associations and likelihood that updated associations (A-D) will trigger remindings (for a schematic, see Fig. 3). When remindings occur, a comparison process is activated that allows changes (B → D) to be detected. The co-activation of original and updated associations in working memory supports integrative encoding that stores both associations with information about the relationship between their temporal contexts (for neural findings suggesting integrative encoding, see e.g., Chanales, Dudukovic, Richter, & Kuhl, 2019; Kuhl, Shah, DuBrow, & Wagner, 2010). These representations can facilitate memory for updated associations when detected changes are accessed by recollection-based retrieval processes (Fig. 3A). When detected changes are not recollected, automatic influences of original associations interfere with updated associations because original associations were strengthened by retrieval during remindings (Fig. 3B).

The predictions of the MFC framework were first tested using a variant of the A-B, A-D paradigm (Wahlheim & Jacoby, 2013, Experiment 1). After learning A-B associations in the first phase, people attempted to detect updated associations (A-D) among repeated associations (A-B) and new associations (C-D) in the second phase. People then attempted to recall responses from the second phase and reported if other responses had come to mind during the retrieval attempts. Change recollection was assumed to occur when original responses (B) also came to mind. The association between change processing and the balance of interference and facilitation

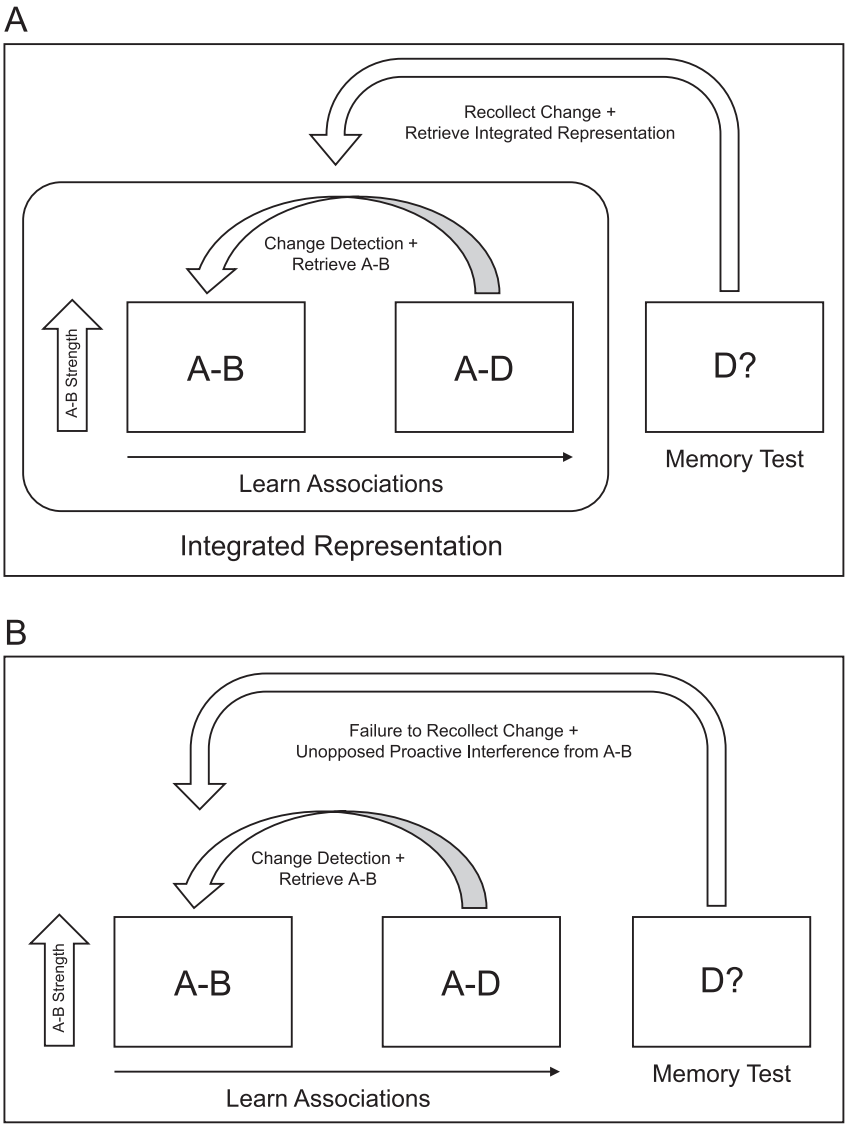


**Fig. 3** Schematic of the Memory-for-Change Framework. (A) Process model showing proposed mechanisms that lead to proactive facilitation effects in A-B, A-D conditions. Remindings of A-B associations during A-D study increase the strength of A-B representations and enable change detection that leads to integrative encoding of A-B and A-D associations. Representations including both associations and their relative order is accessed via recollection-based retrieval on a subsequent memory test of A-D associations. (B) Process model showing proposed mechanisms that lead to proactive interference effects in A-B, A-D conditions. Remindings of A-B associations during A-D study increase the strength of A-B representations leading to them to interfere with recall of A-D associations on a subsequent memory when recollection is not engaged to oppose the accessibility of A-B representations.

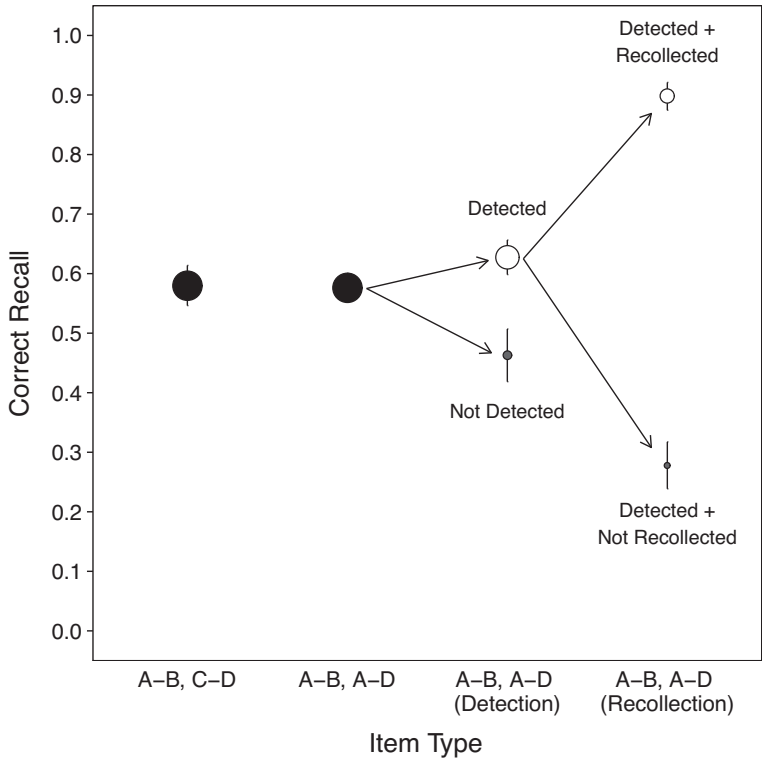


**Fig. 4** Proactive effects of memory in recall performance in the A-B, A-D paradigm. Correct recall of C-D and A-D associations from the second phase in Wahlheim and Jacoby (2013; Experiment 1). Recall in the A-B, A-D condition is collapsed across a manipulation of first-phase repetitions because that manipulation did not produce overall performance differences. The black points indicate correct recall probabilities for all observations in those conditions. The white points indicate conditional recall probabilities when changes were detected as well as detected and recollected. The gray points indicate conditional probabilities when changes were not detected as well as when they were detected but not recollected. Error bars are 95% confidence intervals. The far-right column (A-B, A-D [Recollection]) shows a proactive facilitation effect when changes were detected and recollected, and a proactive interference effect when changes were detected and not recollected. These effects illustrate how overall recall reflected a mixture of facilitation and interference.

effects was assessed via recall dependencies akin to those described in Section 3.2. Correct recall was comparable for A-D and C-D associations (Fig. 4), which reflected offsetting interference and facilitation effects for A-D associations that depended on change detection and recollection. Conditional analyses showed that recall was higher for A-D than C-D items

(proactive facilitation) when detected changes were recollected. In contrast, recall was lower for A-D than C-D items (proactive interference) when detected changes were not recollected. Concerns about subject and item selection artifacts were mitigated by results showing that more A-B presentations led to more instances of recall dependence and that change recollection explained unique variance in recall above people's memory ability and item memorability.

The primary tests of the MFC framework provided by Wahlheim and Jacoby relied on conditional analyses that are inherently correlational. To improve on this approach, subsequent experiments used manipulations to examine a causal role of remindings in episodic memory updating. One approach modified an A-B, A-D paradigm to include A-D associations that updated A-B associations that originally appeared in either the first or second phase (Jacoby et al., 2015, Experiment 3). Including changes both within and between phases allowed for a between-subjects manipulation of instructions in the second phase about how far back to look for original associations. One group was told to only look back within the second phase, whereas the other group was told to look back both within the second phase and to the first phase. Both groups indicated when they saw associations that changed from locations within their range of looking back. They then completed a cued recall task that measured memory for updated associations and recall dependencies that indicated change recollection. When attempting to recall changed responses from the second phase that updated associations from the first phase, recall and change recollection were better in the group that looked back across both study phases. This group also showed proactive facilitation in overall recall, whereas the other group showed no difference in recall of A-D and C-D associations. These findings implicate a clear causal role for task-controlled awareness of remindings in episodic memory updating.

The role of awareness of remindings-based change detection in updating is an important assumption of the MFC framework that sets it apart from accounts of facilitation effects in A-B, A-B′ paradigms. For example, an account of such effects that we mentioned above posits that associations among stimuli allowed them to become unconsciously linked in memory (e.g., Barnes & Underwood, 1959; Bugelski & Scharlock, 1952). However, other work has shown that such facilitation effects only occur when people retrospectively report that they were aware of changes (Martin & Dean, 1964). Converging evidence for the role of awareness

of change was recently shown in an experiment using an A-B, A-D paradigm to examine the relationship between attention during study and memory for changes on a subsequent test (Garlitch & Wahlheim, 2020a). That study showed that self-reported attention to updated A-D associations during study was positively associated with both recall of those associations and change recollection indicating memory for the original A-B associations, which were associated with each other. Together, these findings are consistent with the MFC framework assumption that integrative encoding that supports later memory for updated associations requires awareness of changes.

The utility of the MFC framework for understanding how learning updated associations can lead to a mixture of interference and facilitation effects has inspired new interpretations of long-standing questions about episodic memory updating phenomena. For example, age-related episodic memory deficits in interference-based tasks, such as the A-B, A-D paradigm, have often been attributed to older adults being more susceptible to interference. However, such age-related deficits are not always found, and these inconsistencies across studies have been accounted for by differences in stimulus selection and procedural details (for a review, Kausler, 1994). More recent research adopting the MFC framework has suggested that such inconsistencies reflect interactions between the extent to which experimental circumstances promote remindings and older adults experience recollection deficits. For example, semantic associations between A-B and A-D associations and additional presentations of A-B associations in the first phase have both been shown to increase remindings and change recollection (Wahlheim, 2014). However, the memory benefits associated with these processes may be offset when older adults detect and recollect fewer changes. Thus, the effects of these variables on remindings indicate that the resulting balance of interference and facilitation may determine when older adults experience poorer episodic memory updating than younger adults (also see, Garlitch & Wahlheim, 2020b).

As another example, we earlier described findings showing that interpolated testing of original A-B associations before updated A-D associations are studied enhances subsequent memory for A-D associations (Tulving & Watkins, 1974). The reduction in proactive interference resulting from interpolated testing had been attributed to enhanced context differentiation between learning phases (Jang & Huber, 2008; Pastötter et al., 2011). However, interpolated testing has more recently been shown to improve updating and recall dependencies between B and D responses taken as

evidence for recollection-based retrieval of changes (Wahlheim, 2015). This suggested that testing increased the accessibility of A-B associations, leading more updated associations to be detected and recollected. This finding has since been replicated and extended to older adults, whose episodic memory updating deficit can be partly improved by successful retrieval during interpolated testing (Kemp & Wahlheim, 2021).

Related to testing effects, studies have examined how reactivating memories using various reminder cues affect episodic memory updating. Providing reminders of earlier-learned information before new learning produces a range of memory performance for updated information ranging from impairment to enhancement. This has led to debate about whether such effects emerge from contextual or reconsolidation processes (for a review, Elsey, Van Ast, & Kindt, 2018). We do not discuss that literature here because it is outside the scope of this paper. However, we propose the MFC framework as another way to understand such mixtures of effects. Consistent with this view, recent experiments testing reminder effects on recall dependencies including recollection of changes in A-B, A-D paradigms have shown a key role for retrieval success of original associations for subsequent updating (Wahlheim, Smith, & Delaney, 2019, Experiment 4). Reminders of A-B associations from a first phase appeared immediately before A-D associations in a second phase. Complete reminders (A-B) served as recognition memory probes, whereas partial reminders (A-?) served as cued recall prompts. The main finding was that successful A-B retrieval before A-D learning was associated with enhanced recall of A-D associations when change was recollected and impaired recall when change was not recollected. Importantly, retrieval strength moderated this effect as higher A-B recognition confidence predicted higher change recollection. These findings suggest that the direction and magnitude of reminder effects in related paradigms partly reflect the extent that experimental conditions promote reactivation and integrative encoding.

Thus far, we have discussed studies testing the MFC framework using well-controlled stimuli that are ideal for examining the theoretical updating mechanisms proposed by this account. Despite the virtues of this approach, the generalizability of the foregoing investigations to everyday situations is limited. To address this limitation, other studies have drawn inspiration from the features of A-B, A-D paradigms to examine whether the MFC framework can account for updating effects observed with more naturalistic

stimuli. One such study examined memory for positions held by politicians after they flip-flopped on their views (Putnam, Wahlheim, & Jacoby, 2014, Experiment 3). People learned associations between two fictional politicians and their partisan-congruent (liberal vs conservative) positions on controversial issues during two debates. The politicians changed their positions on some issues from the first to second debate. For example, when arguing for whom the government should subsidize healthcare, the democratic candidate sometimes first argued for only children and the elderly and then argued for all Americans. Detection of changed positions was measured during the second debate, and memory for the updated position from that debate was subsequently assessed on a cued recall test. Memory updating for recent positions was facilitated when detected changes were later recollected and impaired when detected changes were not recollected, suggesting that these processes proposed by the MFC framework generalize beyond standard paired-associate learning.

Related to these findings, subsequent research has shown that the MFC framework can account for the continued influence of everyday misinformation on memory for corrections of fake-news headlines (Wahlheim, Alexander, & Peske, 2020). The primary purpose of this study was to examine if presenting misinformation reminders before corrections would enhance or impair subsequent memory and belief accuracy (cf. Ecker, Hogan, & Lewandowsky, 2017). One longstanding perspective predicts that presenting misinformation in the context of corrections should impair updating (Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012), similar to the context differentiation view. In contrast, the MFC framework and related perspectives (also see, Kendeou, Walsh, Smith, & O'Brien, 2014; Stadtler, Scharrer, Brummernhenrich, & Bromme, 2013) predict that reminders should enhance detection of contradictions and integrative encoding. To compare these accounts, fake-news stories and their corrections were taken from various internet websites and converted into statements resembling news headlines. People studied true and false statements in an initial phase, then studied all true statements in a second phase that affirmed facts and corrected misinformation from the first phase. Importantly, misinformation statements were presented as reminders before some corrections, akin to the complete reminders described above. Consistent with the MFC framework predictions, reminders increased the accuracy of memory and beliefs for corrections of fake news as well as recollection that misinformation had earlier been corrected. Recollecting misinformation was

associated with facilitated memory and belief updating, suggesting that by reinstating the study context of the first phase, reminders promoted integrative encoding and recollection of those representations. Together with the studies above, these findings support the MFC framework assumptions and provide examples of situations in which the proposed mechanisms can account for everyday episodic memory updating.

### 3.4 Event memory retrieval and comparison theory

To increase the comprehensiveness and extend the generalizability of this remindings-based integration perspective, we developed the MFC framework further by including mechanisms assumed to support perception of and memory for dynamic everyday events. Although the flip-flopping and fake news correction studies above used naturalistic stimuli, those stimuli lack the dynamic qualities of perceived events that unfold in real time, such as action sequences performed by an actor. In everyday life, observers often perceive changes in such events. For example, one might notice when their partner prepares a regular meal but includes a substituted ingredient that lowers the sodium content.

Event Memory Retrieval and Comparison Theory (EMRC) attempts to account for the mechanisms of registering event changes and preserving memory for recent actions (Wahlheim & Zacks, 2019). EMRC extends on the MFC framework by incorporating mechanisms of naturalistic event comprehension (Radvansky, 2012; Zacks, Speer, Swallow, Braver, & Reynolds, 2007). EMRC assumes that observers form working memory representations of what is happening, called event models. Event models are established when perceptual inputs cue retrieval of event schemata that support comprehension of observed actions and lead to predictions of future actions. When observed actions deviate substantially from expectations, a prediction error signal triggers event model updating, leading observers to perceive an event boundary. Event memories are assumed to be represented with higher fidelity when boundaries are perceived at normative locations. EMRC assumes that the quality of event memories plays a critical role in episodic memory updating. According to the theory, new events that share features with event representations cue retrieval of those memories, leading to mnemonic predictions about upcoming actions. Perceived changes lead to mnemonic prediction errors (Chen, Olsen, Preston, Glover, & Wagner, 2011; Lisman & Grace, 2005) that trigger comparisons between perceptual

inputs and expected actions that upregulate attention to changed features (cf. Rescorla & Wagner, 1972). This should lead to the processing chain proposed by the MFC framework that supports integrative encoding and leads to a mixture of facilitation and interference in memory for recent actions depending on whether retrieval is recollection-based.

In an *everyday changes* paradigm developed to test this account (Wahlheim & Zacks, 2019, Experiment 2), people watched separate movies of an actor performing everyday activities on two fictional days in her life. The activities were constructed to be similar to paired-associates in which the beginnings (A) and endings (B or D) could be manipulated between movies (Fig. 5A). The original paradigm included three activity types: repeated activities were identical in both movies, control activities were only in the second movie, and changed activities had identical beginnings and different endings in each movie. Younger and older adults watched the Day 1 movie passively, identified changed activities in the Day 2 movie, and subsequently recalled activity features from the Day 2 movie. The role of change recollection was assessed by requiring people to indicate if activities had changed, and if so, to recall the features from the Day 1 movie. The results replicated studies showing proactive facilitation when changes were detected and recollected, and proactive interference when changes were detected but not recollected (Fig. 5B). There was an age-related deficit in memory updating shown by proactive facilitation in overall recall of changed activities for younger adults but not older adults. This age difference reflected older adults' deficit in detecting and recollecting changes.

Taken with the findings from the studies testing the MFC framework, the results from the initial study testing EMRC suggested that remindings-based integration and recollection-based retrieval played a role in event memory updating. Subsequent studies of age-related differences in event memory updating were conducted to further test the mechanisms proposed by EMRC. Neural activation was recorded using functional magnetic resonance imaging to examine the role of prior-event reinstatement in memory for changed actions (Stawarczyk, Wahlheim, Etzel, Snyder, & Zacks, 2020). Younger and older adults watched both movies while lying in the scanner and watched the first movie passively. During the second movie, each activity paused after the first segment before the actor initiated the critical action. When this happened, people imagined the completing actions from the first movie. Neural

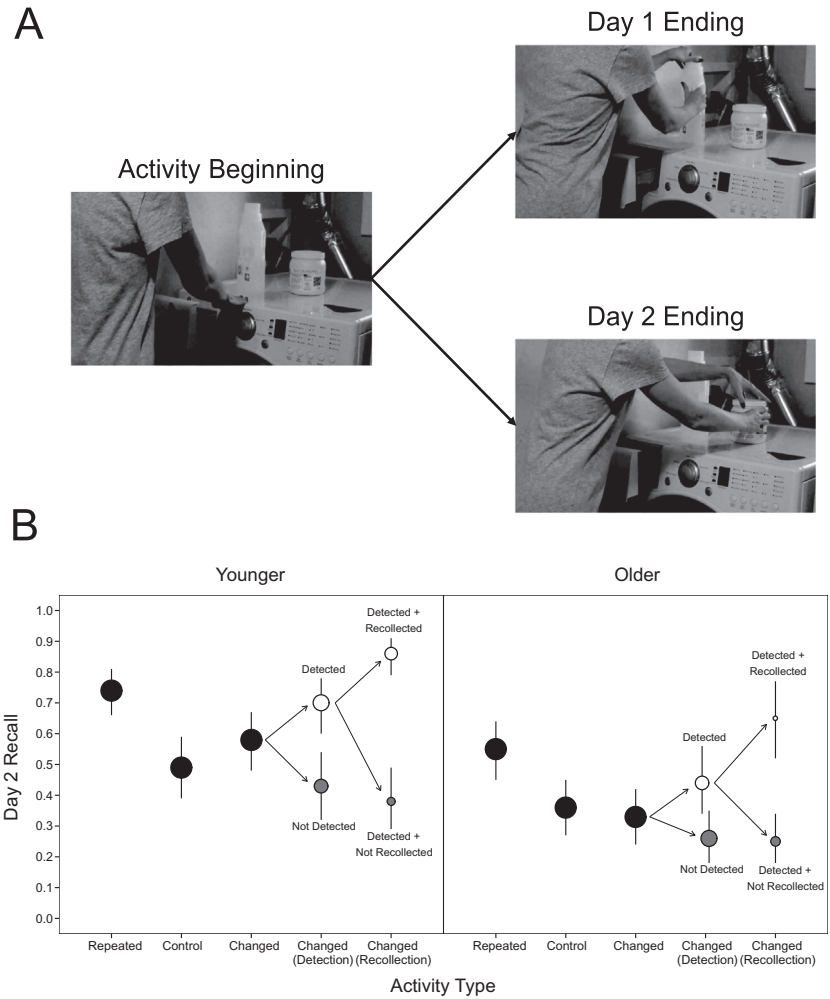


**Fig. 5** Example stimulus materials and recall performance in the everyday changes paradigm. (A) Pictures taken from two versions of an activity shown in the *everyday changes* paradigm from Wahlheim and Zacks (2019). The picture of the repeated activity beginning (left) shows a moment before the actor performs one of two possible actions. The pictures of the two possible actions (right) show moments from activity endings from the Day 1 and Day 2 movies for changed activities. The change shown here indicates that after approaching the washer, the actor filled the washer with liquid detergent in the Day 1 movie and powdered detergent in the Day 2 movie. (B) Correct recall of action features from Day 2 movies. The black points indicate correct recall probabilities for all observations in those conditions. The white points indicate conditional recall probabilities when changes were detected as well as detected and recollected. The gray points indicate conditional recall probabilities when changes were not detected as well as detected but not recollected. Error bars are 95% confidence intervals. Overall recall in the Changed condition showed a proactive facilitation effect for younger adults (left panel), and no proactive effect of memory for older adults (right panel). The far-right column [Changed (Recollection)] in each panel shows a proactive facilitation effect when changes were detected and recollected, and a proactive interference effect when changes were detected and not recollected. The age-related difference in overall recall of changed activities was partly accounted for by older adults detecting and recollecting fewer changes than younger adults.

reactivation in posterior medial cortex and regions of the medial temporal lobe presumed to support event memory predicted better memory for changed endings for younger but not older adults. These results suggested that reactivation enabled integrative encoding and that older adults integrated existing and new event representations less effectively. The results also suggested that mnemonic prediction error, assayed by neural reinstatement strength for actions from the first movie before changed action endings, also facilitated updating. Following this, a behavioral study showed that older adults' memory for changed actions was improved using cues to indicate the presence of action changes, implicating a role for attention deficits in older adults' impaired memory for recent actions (Garlitch & Wahlheim, 2021).

Further studies have examined the role of mnemonic prediction error in episodic memory updating of everyday actions using converging measures. In one approach, activities in the second movie were stopped before changed actions could appear, and people overtly predicted that the action would end in the same way as in the first movie (Hermann, Alexander, Wahlheim, & Zacks, 2021, Experiment 2). People predicted which action would be performed when the movie resumed from two pictures of possible action endings. Updating was better when predictions were based on memory for prior actions, but the role of prediction error was inconclusive, possibly reflecting task insensitivity. To improve on this approach, another study used eye tracking to examine how memory for prior events affected predictive looking to contacted objects (Wahlheim, Eisenberg, Stawarczyk, & Zacks, 2021; see Fig. 6, for task details and results). As it became clear which object the actor would contact, observers looked more to those objects. Subsequent memory for change actions was facilitated when actions from the first day were recollected. Critically, this benefit was associated with more looking to objects the actor contacted in the first movie *before* the actor contacted an object in the second movie. These findings suggest that mnemonic prediction errors, shown in anticipatory looking, were associated with enhanced updating that may partly reflect benefits of integrative encoding. Taken together, these studies support the assumptions of EMRC, thus extending the MFC framework to account for episodic memory updating of naturalistic actions.

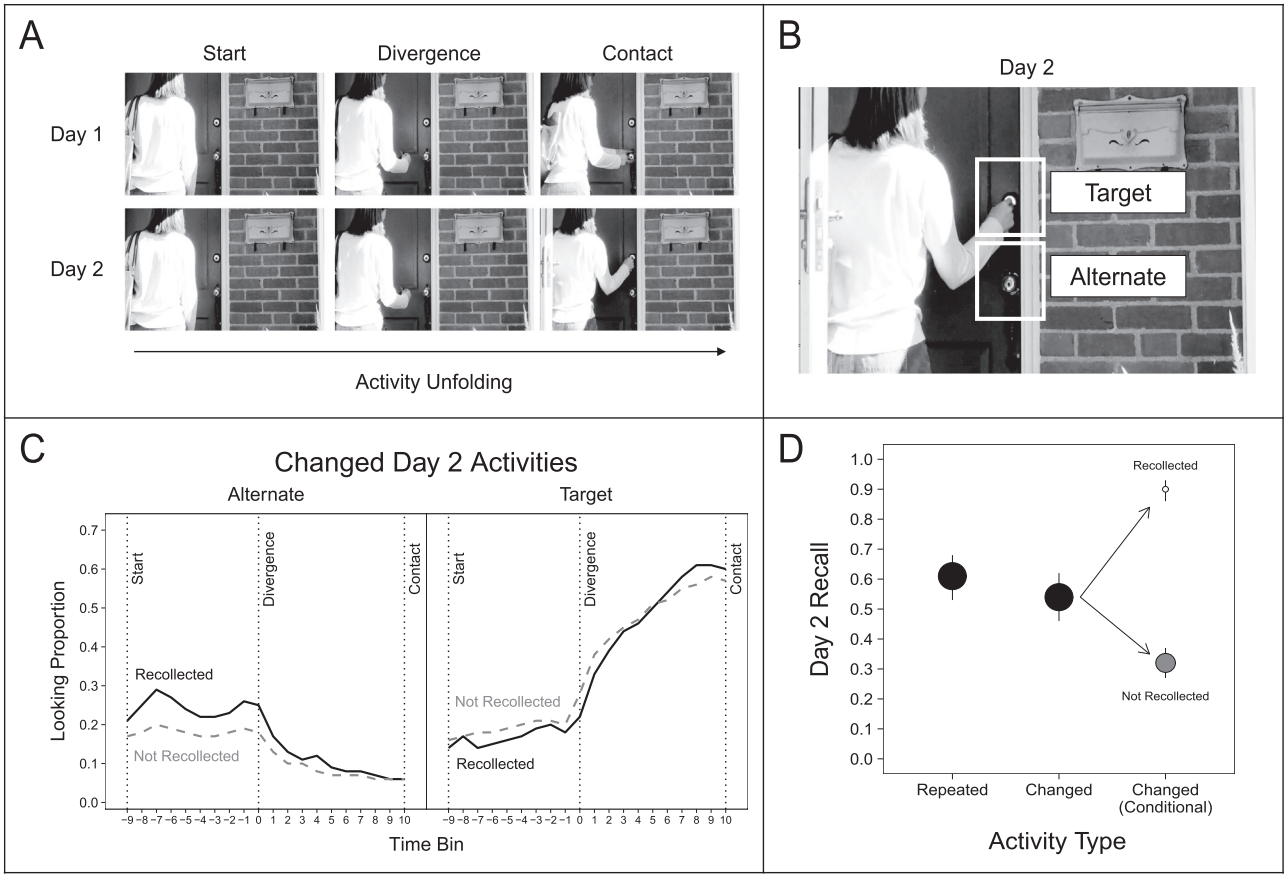


**Fig. 6** See figure legend on opposite page.

## 3.5 Summary of context reinstatement at study: Remindings of past experiences

This section summarized key studies examining how remindings occurring when updated associations are studied can lead to integration that promotes episodic memory updating. This work showed that by bridging study contexts, remindings improved memory for original and updated associations. This finding contrasts with the context differentiation view that encoding information from competing sources within the same temporal context should increase interference and impair updating. We highlighted our perspective on the roles of remindings-based integrative encoding and recollection-based retrieval. We showed that this perspective accurately predicts the balance of interference and facilitation comprising overall memory for changed information. In variants of the A-B, A-D paradigm, recollection of detected changes was associated with facilitation, whereas failure to recollect detected changes was associated with interference. This pattern has been observed across stimuli varying in their naturalism. Together, these findings imply that when current events cue prior-event retrievals, integrative encoding can promote episodic memory updating when recollection-based retrieval is engaged.

**Fig. 6** Stimulus materials and results from an eye tracking study of episodic memory updating. (A) Pictures showing moments from two versions of a changed activity that appeared in Day 1 and Day 2 movies from Wahlheim et al. (2021, Experiment 1). Each version showed the same general action sequence from the "Start" of the activity until the "Divergence" point. The two actions then diverged as the actor reached for different objects in each version. The activity ended when the actor touched the object at the "Contact" point. (B) The changed activities in the Day 2 movie included interest areas (white boxes) for "Target" objects that the actor contacted in that movie and "Alternate" objects that the actor had contacted in the Day 1 movie. (C) The proportion of looks to interest areas including Alternate objects (left panel) during the repeated actions at the beginning of Day 2 activities was greater for changed activities that were subsequently recollected as such (black line). After divergence, people looked increasingly more often at Target than Alternate objects. (D) Recall of changed action features from Day 2 was better when changes were recollected. The black points indicate correct recall probabilities for all observations. The white points indicate conditional recall probabilities when changes were recollected. The gray points indicate conditional recall probabilities when changes were not recollected. Error bars are 95% confidence intervals. The conditional recall results showed that overall recall performance comprised a mixture of proactive facilitation and interference effects that depended on whether changes were recollected.

## 4. Concluding remarks

This chapter summarized key evidence for two apparently conflicting mechanisms of episodic memory updating: context differentiation and remindings-based integration. Context differentiation can be induced by changes in temporal, environmental, and internal contexts to reduce interference and promote memory for recent information. In contrast, remindings-based integration enabled by context reinstatement while studying updated associations can also enhance memory for recent information, but this requires detecting changes and subsequently recollecting them. Our work provides mounting evidence for the reminding-based perspective advanced by the MFC framework and EMRC theory that updating is supported when representations of distinct experiences are simultaneously divided and united. The extent that these competing mechanisms contribute to final recall of updated information appears to depend on task demands, strategic approaches, and the potential for event features to cue reinstatement of related event contexts. These competing views can potentially be reconciled by assuming that both updating mechanisms can support recall performance within the same task, depending on whether reminding occurred. A more comprehensive understanding of the interplay of context differentiation and remindings-based integration mechanisms will benefit from examining the neural activity and predictive looking associated with memory for changes.

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