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Episodic memory updating is required in everyday life when we must learn something new that differs from existing memories. A recent framework proposes that updating can be promoted when such changes are detected, allowing for an integrated representation to be formed that can be recollected later. This framework makes predictions about situations when, and for whom, updating will be more effective. Older adults are predicted to show deficits in memory updating to the extent that they detect and recollect changes less often than younger adults. Furthermore, attention during encoding of changes is presumed to play a critical role in memory updating. In this integrated dissertation, three empirical papers are presented to assess age differences and the role of attention in episodic memory updating. The results generally supported the predictions from this framework about how aging and attention influence the mechanisms that promote successful memory updating. The theoretical and applied implications of this work are discussed along with future directions aimed at building a more comprehensive understanding of episodic memory updating.

EXAMINING THE ASSOCIATIONS BETWEEN ADULT AGE DIFFERENCES, ATTENTION, AND EPISODIC MEMORY UPDATING

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DEDICATION

I would like to dedicate my dissertation to my husband, AJ Garlitch. Your endless and unconditional support through graduate school has been incredible. You have always been right there next to me in the best and worst of times. I am forever thankful that you are my person. As I finish the graduate chapter of my life, I am looking forward to starting a new chapter of our lives together.

APPROVAL PAGE

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CHAPTER I: INTEGRATIVE INTRODUCTION

We live in a dynamic environment characterized by constant changes that can pose problems for our memories of specific experiences. For example, imagine being prescribed a new medication. After several weeks, your doctor runs a test to assess your renal function and finds that the dosage is too high and could eventually cause kidney damage. Consequently, your doctor lowers the dosage. Because there can be negative side effects to your health if the incorrect dosage is taken, you must remember to take the most recent dosage. This is an example of a situation where episodic memory updating is required. Memory errors that occur in these and related situations can have serious consequences. It is therefore critical to understand the factors that contribute to differences in the ability to update episodic memories.

Here, I define episodic memory updating as the ability to overcome interference, as evidenced by successful retrieval of target information in the face of competing information. In the medication dosage example above, memory updating would occur when you remember to take the most recent dosage. There are multiple ideas about the mechanisms that contribute to episodic memory updating. Classic perspectives on memory updating would propose that updating is successful when the original and new information are differentiated, as this reduces competition between the conflicting memories. This could occur when original memories are intentionally forgotten, suppressed, or learned in separate environments from the new information to facilitate the distinction between them (Bjork, 1970; S. M. Smith et al., 1978). More recent views suggest that successful updating can also be supported by integration of the original and new information. Here, integrating the competing memories can enable the formation of a representation that contains both pieces of information along with their temporal relationship (for a review, see Wahlheim et al., 2021). In some instances, this can result in facilitation in memory for the information that has changed, resulting in a benefit to memory updating.

One example of an integration-based account that is the focus of this paper is the Memory-for-Change (MFC) framework (Jacoby et al., 2015; Wahlheim & Jacoby, 2013). The MFC framework proposes that episodic memories can be updated when new information triggers retrieval of existing memories that share feature overlap, like when learning the new dosage of medication reminds you of the original dosage. The reminding enables change to be detected because the original and new information can be compared in working memory. This process also enables the formation of an integrated representation containing both pieces of information and their relative temporal order. When recollection is used to gain access to integrated representations later, then memory updating is enhanced, as evidenced by enhanced memory for the new information. However, if recollection is not engaged at retrieval, then memory updating is impaired, as evidenced by worse memory for the new information (Garlitch & Wahlheim, 2020b, 2021; Jacoby et al., 2015; Wahlheim, 2014; Wahlheim & Jacoby, 2013; Wahlheim & J. M. Zacks, 2019).

The MFC framework has implications for identifying the people for whom, or situations in which, episodic memory updating will be most successful. Prior work has shown that older adults update memories less effectively than younger adults partly because older adults detect and recollect fewer changes (Wahlheim, 2014; Wahlheim & J. M. Zacks, 2019). Furthermore, there is some evidence that guiding participants on where to look for changes can influence their awareness of those changes and enhance memory for them later (Jacoby et al., 2015). In this integrated dissertation, I will present empirical evidence that further assesses predictions from this framework about age-related differences and the role of attention in episodic memory updating processes. The first empirical paper tests age-related differences in change detection and recollection and the association with updating memory for originally learned information (Garlitch & Wahlheim, 2020a). The second empirical paper tests the assumption from the MFC framework about the role of attention by examining self-reported task engagement during intentional learning of changed information and the association with updating memory for new information (Garlitch & Wahlheim, 2020b). The final empirical paper assesses how adult age differences in controlled attention abilities contribute to deficits that older adults experience in updating memory for naturalistic events (Garlitch & Wahlheim, 2021). Collectively, this research line extends our understanding of how aging and attention influence episodic memory updating mechanism, which can in turn help inform strategies for improving updating to prevent memory errors that can pose serious problems in everyday life, like taking the wrong medication dosage.

In sum, the goal of this integrated dissertation is to present work testing predictions from the framework on age differences and the associations between attention and episodic memory updating. To do this, I first present a brief overview of the classic studies on interference effects to demonstrate the situations and typical outcomes of failures in memory updating. I then describe the MFC framework as a perspective for understanding whether episodic memory updating will be enhanced or impaired. Following this, I describe classic studies on age-related differences in memory updating failures and the implications that the MFC framework has in explaining such differences. Then, I describe the assumptions from the MFC framework about the role of attention and how this can be tested, and the relationship between controlled attention and age-related differences in updating memory for naturalistic events, including a brief description of a related theoretical account on event memory updating. After presenting the empirical work, I end with an integrated discussion on the implications for our understanding of these variables, their relationships to episodic memory updating, and what future research should aim to accomplish to continue developing a scientific understanding of memory updating.

Proactive and Retroactive Interference

Episodic memory updating is required to overcome memory interference. As in the medication example above, interference can occur when two responses (i.e., the dosages) are associated with the same cue (i.e., the medication). Once you are prescribed the new medication dosage, you may find yourself thinking of only the original dosage. This is an example of proactive interference, where memory for earlier learned information interferes with memory for new information. In contrast, if you had been prescribed this medication dosage for several months, you may find it difficult to remember whether your original dosage was higher or lower than your current dosage. This would be an example of retroactive interference, where new information impairs memory for earlier learned information. Experiencing proactive and retroactive interference are examples of unsuccessful or failures in memory updating. In contrast, successful memory updating is observed when the most recent response is retrieved (when examining proactive memory effects) and the original response is remembered as well as what it changed to (when examining retroactive memory effects).

Proactive and retroactive interference effects have often been measured in the laboratory using paired associate learning paradigms where participants study two lists of word pairs and then take a memory test for the responses when presented with the cue (for reviews, see Anderson & Neely, 1996; Postman & Underwood, 1973). Across the study lists, some of the word pairs repeat (A-B, A-B), some are control pairs only presented in one list (C-D), and some are changed pairs with the same cue and different responses across lists (A-B, A-D). Interference effects are assessed by comparing memory for the changed pairs to memory for control pairs because the control pairs are not vulnerable to item-level interference effects. Typical results show proactive and retroactive interference, where memory for the changed pairs (presented in List 2 for proactive effects and List 1 for retroactive effects) is lower than memory for the control pairs.

Traditional interference-based theories have proposed that proactive interference effects are due to response competition at retrieval (Postman & Underwood, 1973) while retroactive interference effects are due to both unlearning of the earlier response and response competition at retrieval (McGeoch, 1932; Melton & Irwin, 1940). Although interference effects were often obtained in these paradigms, some results show facilitation effects, such that memory for changed pairs was better than memory for control pairs (Barnes & Underwood, 1959; Bruce & Weaver, 1973; Martin & Dean, 1964). For example, Bruce and Weaver (1973) examined retroactive effects in short- and long-term memory by presenting original A-B pairs followed by multiple presentations of interpolated pairs that either shared the same cue with a changed response (A-D) or were unrelated pairs (C-D). Then, participants were given a cued recall test for the A-B pairs. In Experiment 3, the results showed that memory for A-B was better when it was followed by A-D than C-D pairs. To explain this facilitation effect, the authors suggested that the presentation of the A-D pair sometimes resulted in retrieval of the A-B pair from long-term memory, which then enhanced its memorability due to increased rehearsal.

In studies of proactive effects of memory, proactive facilitation for the A-D pairs has been shown when participants could use A-B as an explicit mediator for learning A-D (Martin & Dean, 1964) and when the degree of learning for the A-B pairs was high, as shown by correct recall of those pairs over many learning trials (Underwood, 1949). In a variant of the paired associate learning paradigm, Postman and Gray (1977) showed higher recall of A-D when participants were asked to recall the B and D responses during learning of A-D (Postman & Gray, 1977). In addition, recall for A-D was better when A-B could also be recalled at test, meaning that there was dependence between the responses (also see Bellezza & Schirmann, 1975). The response dependency between the original and changed pairs suggests that, under some circumstances, there can be benefits to memory for both the original and changed responses when information changes across episodes.

One interpretation of the facilitation effects described above is that learning the changed pair reminded participants of the earlier pair, which was then associated with a memory benefit later (e.g., Jacoby et al., 2015). A reminding is defined as a study-phase retrieval that enables the earlier response to be recalled in the context of the new response. Remindings have been proposed to explain enhanced recency, frequency, and spacing judgments (Hintzman, 2004, 2010; Hintzman et al., 1975; Tzeng & Cotton, 1980; Winograd & Soloway, 1985) as well as memory benefits associated with repetition (Benjamin & Tullis, 2010). In addition, Hintzman (2004, 2010, 2011) developed a recursive reminding hypothesis, which suggests that remindings allow earlier representations to be integrated with current representations. Recollecting this reminding later can allow one to infer which response was more recent because the item that triggered the reminding must have occurred more recently than the item that was the object of the reminding. Consistent with this idea, it was shown that recursive remindings led to more accurate judgments of recency and that such benefits extended to cued recall of recent responses (Jacoby & Wahlheim, 2013). Together, these results indicate that recursive remindings are associated with benefits to memory for both responses as well as their temporal relationship. In addition, the formation of an integrated representation could help explain why dependence was shown between responses in earlier studies (e.g., Postman & Gray, 1977).

A Framework for Understanding Episodic Memory Updating

Beyond the role of remindings in memory for recency and temporal order, the MFC framework proposes that remindings are critical to understanding when memory updating will be successful or not. The MFC framework combines assumptions from the recursive remindings hypothesis (Hintzman, 2004, 2010) with a dual-process account of memory interference effects (e.g., Hay & Jacoby, 1999) to posit that learning new information that shares overlap with earlier learned information can cue a reminding of the earlier information. The account further proposes that this reminding allows one to detect the changes in the responses and enables integrative encoding. The integrated representation formed during change detection contains both responses and their relative temporal order. The account further proposes that to the extent that this integrated representation is formed and can be recollected then, then there will be memorial benefits.

The MFC framework proposes critical differences in the association between memory updating and change detection and recollection under conditions of retroactive versus proactive effects of memory. Retrieval of the original information is a key component of the change detection process. For retroactive effects of memory, change detection should then be associated with benefits to target information in the form of retroactive facilitation and impairments when changes are not detected, in the form of retroactive interference. Although not required to show memory updating under conditions of retroactive effects of memory, there may be additional benefits to the original memory associated with change recollection, presumably due to the changed response acting as an additional cue for retrieval of the original response (Jacoby et al., 2015; Negley et al., 2018). Under conditions of proactive effects of memory, the increase in accessibility to the original information can result in greater interference since the original information is the competitor rather than the target. Therefore, the MFC framework posits that change recollection at test is required to experience benefits when updating memory for new information, shown as proactive facilitation. If changes are detected but not later recollected, then the increased accessibility of the original response is unopposed by recollection. Failing to recollect change under conditions of proactive effects of memory will be associated with memory updating failures, shown by severe proactive interference.

To test whether predictions from MFC framework could explain proactive interference and facilitation, Wahlheim and Jacoby (2013) conducted several experiments using variants of the A-B, A-D paired associate learning paradigm. In the first experiment, participants studied a list of word pairs (A-B). In a second list, some word pairs repeated (A-B, A-B), some were new to the list (C-D), and some had the same cue with a different response (A-B, A-D; e.g., wine-*glass*, wine-*grape*). While studying List 2, participants indicated when they noticed a changed pair and then attempted to recall the corresponding List 1 response as a measure of change detection. On a final cued recall test, participants saw the cue and were asked to recall the List 2 response. Then, they were asked whether another response came to mind prior to or with the List 2 response. This was used as a measure of change recollection, with the idea that bringing the List 1 response to mind with the List 2 response was evidence that participants had engaged in integrative encoding earlier. The results showed no difference in List 2 recall between the changed and control pairs, which likely reflected the combination of facilitation and interference effects that depended on how often changes were detected and recollected. When changes were detected and recollected, this was associated with higher recall for changed than control pairs, indicating proactive facilitation. In contrast, when changes were detected and not recollected, this was associated with lower recall for changed than control pairs, indicating proactive interference. Together, the results from all three experiments provided correlational evidence for the roles of detection and recollection of change when updating for proactive effects of memory.

To test predictions from the MFC framework for retroactive effects of memory, and to compare this to the associations between change detection and recollection for the proactive conditions, Jacoby et al. (2015) conducted a series of experiments. Here, the researchers used a variant of the paired associate learning paradigm where changes occurred both across and within the study lists. To test whether change detection caused better memory for List 1 recall, the researchers used a between-subjects manipulation where half of the participants were told to look for changed across List 1 and List 2 while the other half were told to look for changes only within List 2 (Experiment 1). To measure change detection, both groups were told to indicate when they noticed changes during List 2. The results showed that, on the final cued recall test, participants told to notice changes across lists showed retroactive facilitation in memory for List 1 pairs that changed across lists. In contrast, participants who were told to look for changes only within List 2 showed no difference in memory between the control and between-list changed pairs. Although remindings-based change detection resulted in retroactive facilitation for between-list changes, there was no measure of change recollection at test. Therefore, it remained unclear whether the prediction from the MFC framework about an additional benefit to recollection of change under conditions of retroactive interference would be supported.

To further examine predictions from the MFC framework in retroactive effects of memory, Negley et al. (2018) conducted two experiments that included a change recollection measure at test. These experiments also examined whether more time to experience remindings would result in higher change detection and recollection rates. Although traditional interference theories would predict that more encoding time for the competitor (i.e., List 2 response) would result in greater response competition at retrieval, the MFC framework would predict that more time to encode List 2 changed pairs would allow more opportunities to detect change and engage in integrative encoding of the two responses than when less time is given to encode List 2 pairs. To test this, participants studied two lists of word pairs. For the changed pairs in List 2, half were shown for a shorter duration (1 s) and half were shown for a longer duration (7 s). The results showed retroactive facilitation in overall memory for List 1 responses when the corresponding changed pair was presented for a longer, but not shorter duration. When changes were detected in List 2, there was retroactive facilitation in List 1 recall, and there was an additional benefit to List 1 recall when changes were also recollected at test. Together, these results demonstrate support for the predictions from the MFC framework about the roles of change detection and recollection in retroactive effects of memory.

Age Differences in Episodic Memory Updating

One factor that may influence the success of episodic memory updating is age. Older adults sometimes experience deficits in episodic memory updating, as evidenced by greater susceptibility to interference than younger adults (for reviews, see Kane & Hasher, 1995; Kausler, 1994). For example, Traxler (1973) tested age-related differences in forgetting rates by using a variant of the paired associate learning paradigm with younger and older adult participants. One group of participants studied pairs that were unrelated across lists (A-B, C-D), one group studied pairs that had different cues but shared responses across lists (A-B, C-B), and the last group studied pairs that had the same cue but different responses across lists (A-B, A-D). The final cued recall test presented participants with the cue and asked them to recall the associated response(s), and to indicate list membership for each response. Retroactive effects of memory were tested by examining recall of List 1 responses and proactive effects of memory were tested by examining recall of List 2 responses. Older adults showed more susceptibility to both retroactive and proactive interference than younger adults, as indicated by lower recall of the original and changed responses for A-B, A-D pairs. This effect has been replicated in some studies (Hulicka, 1967; Query & Megran, 1983; Traxler & Britton, 1970), but other studies suggest that once degree of learning is equated across age groups, there are no differences in interference effects (Gladis & Braun, 1958; for a review, see Kausler, 1994).

Several theories have been proposed to explain age differences in interference effects when they are obtained. One prominent explanation is proposed by the inhibitory deficit theory (IDT; Hasher & R. T. Zacks, 1988). IDT proposes that interference is eliminated by an inhibition function that prevents, removes, and suppresses irrelevant information from working memory. Memory impairments arise when this function is inefficient, allowing irrelevant information to enter working memory, which can then lead to greater response competition between the irrelevant and target information at retrieval. IDT assumes that older adults experience an inhibition deficit. Studies testing this account have found that older adults are less likely to ignore the irrelevant information and are more likely to encode and later retrieve it than younger adults (for a review, see Lustig et al., 2007). In the context of paired associate learning paradigms like those described above, IDT would predict that the nontarget response should be inhibited to successfully remember the target response for changed pairs.

Alternatively, the MFC framework predicts that older adults may show increased susceptibility to interference partly because they experience episodic memory deficits that lead to fewer retrievals of the competitor during encoding and later retrieval, which will be associated with lower rates of change detection and recollection. To test age differences in change detection and recollection as well as its relationship with memory updating in proactive effects of memory, Wahlheim (2014) conducted three experiments. Similar to the studies described above, participants studied two lists of word pairs, with the second list comprised of repeated (A-B, A-B), control (A-B, C-D), and changed pairs (A-B, A-D). Participants then completed a cued recall test for response from List 2. To measure change recollection at test, participants were asked to report whether another word came to mind prior to the List 2 response. Change recollection was operationalized as the B response coming to mind prior to the D response for A-B, A-D pairs. Younger adults showed higher List 2 recall than older adults, and both age groups showed comparable memory for the A-B, C-D and A-B, A-D pairs. Older adults also had lower rates of change recollection than younger adults at test. To examine how change recollection was associated with memory for the A-B, A-D pairs, recall was conditionalized on whether changes were recollected. Consistent with predictions from the MFC framework, proactive facilitation was observed when changes were recollected, and proactive interference was observed when changes were not recollected. Together, the results suggested that both age groups had overall performance for the changed pairs that was comprised of a balance of facilitation and interference effects based on how often changes were initially detected and later recollected.

Older adults' deficit in change recollection could have been driven by age differences in the availability of List 1 responses. To test whether older adults would continue to show a change recollection deficit when List 1 was equally available to both age groups, Wahlheim (2014) varied the number of List 1 presentations for the A-B, A-D pairs. The results showed that List 1 availability was equated for older adults when they were given six presentations and younger adults were given two presentations. Older adults still showed a change recollection deficit compared to younger adults. In the third experiment, participants engaged in self-paced study of List 2 to examine whether older adults' change recollection deficit was driven by differences in change detection during List 2, which would presumably result in fewer integrated representations that older adults could access later. Self-paced study was assumed to allow older adults time to detect changes as often as younger adults. Indeed, the results showed no age differences in change detection during List 2, but older adults were less likely to recall the corresponding List 1 response after detecting change. In addition, older adults recollected fewer changes at test than younger adults. Together, these results support the proposal from the MFC framework that older adults experience a change recollection deficit, which was associated with their impaired ability to update episodic memories in some situations.

The results from Wahlheim (2014) demonstrated the association between change detection and recollection and age differences in updating for proactive effects of memory. The MFC framework suggests that similar processes underlie age differences in situations that could lead to retroactive interference, except that change recollection may not be critical to experiencing benefits to memory updating for the original information. As outlined above, the MFC framework predicts that change detection results in retrieval of the original information, which is the target when examining retroactive effects of memory. While recollecting change at test can be associated with additional benefits to memory for the original information above change detection, it is not required to show facilitation effects (Negley et al., 2018).

Prior studies have shown mixed evidence for whether older adults show greater susceptibility to retroactive interference compared to younger adults (for a review, see Kausler, 1994). According to the MFC framework, overall performance under conditions that can lead to retroactive interference depends on how often change can be detected (Jacoby et al., 2015;

Negley et al., 2018). Therefore, the mixture of results in the literature on age differences may reflect how often experimental conditions promoted change detection and allowed opportunities for integrative encoding. If the experimental conditions support fewer retrievals of the original response during encoding of the changed response, then older adults will detect changes less often. In contrast, if the experimental conditions promote retrieval of the original response for older adults, they may detect changes as often as younger adults. The goal of the first empirical paper presented in this integrated dissertation was to test the roles of change detection and recollection in age-related differences under conditions of retroactive effects of memory (Garlitch & Wahlheim, 2020a). In addition to further testing predictions from the MFC framework, the results from this work can extend our understanding on the processes that contribute to age differences in interference susceptibility, which can then inform intervention-based studies on which processes should be targeted.

Role of Attention in Episodic Memory Updating

In addition to predictions about adult age differences in change detection and recollection, the MFC framework also assumes that differences in attention and awareness to changes will be associated with differences in change detection and recollection. As described previously, the MFC framework proposes that encoding changed pairs can cue retrieval of original pairs (e.g., retrieving A-B when encoding A-D), and this enables the change to be detected. This also allows one to form an integrated representation containing both responses and their relative temporal relationship, which can be accessed using recollection-based retrieval later. It follows, then, that attention must be given during encoding of both the original and the changed pair so that encoding of the changed pair can trigger such retrieval and enable change detection. If attention is not focused on the original or changed pair, then changed pairs should trigger fewer retrievals of the original pairs, leading to fewer opportunities to detect change and form integrated representations that can be recollected later.

Described above in the section on retroactive effects of memory, prior work has tested the assumption from the MFC framework about attending to changes indirectly by examining how participants' awareness of change was associated with differences in memory updating (Jacoby et al., 2015). As a reminder, the researchers conducted three experiments to examine how instructions to notice changes that occurred either between or within lists would influence memory for changed pairs. Half of the participants were instructed to look for between-list changes while the other half were told to look for within-list changes. In Experiments 2 and 3, participants who looked for between-list changes showed proactive facilitation in recall of the between-list changes while those who looked for within-list changes showed recall for between-list changes that was comparable to that of control pairs. This suggested that participants could direct their attention to look for changes across lists, and this resulted in better memory than for participants who were not told to look for these changes.

The results from Jacoby et al. (2015) are consistent with the assumption from the MFC framework that being encouraged to detect change can influence how well those changes are later remembered. However, this study was primarily focused on how variation in change detection and recollection can be brought under experimenter control using an instructional manipulation. We know that people naturally differ on how often they detect and recollect change, which contributes to variability in episodic memory updating (e.g., Putnam et al., 2014; Wahlheim & Jacoby, 2013). Therefore, a more direct test of the assumption from the MFC framework on the role of attention in episodic memory updating should examine how natural variation in attention during encoding of changed information is related to ongoing detection of change and later recollection of such.

One way to measure natural variation in attention during a task is to capture mind wandering episodes. Mind wandering is a specific lapse in attention that occurs when thoughts drift from an external focus, like performing a task, to an internal focus, like thoughts and feelings about the task (for a review, see Smallwood & Schooler, 2015). To measure mind wandering episodes as they occur, researchers have often used a thought-probe procedure where they insert probes that prompt participants to report on their current thoughts in the moment (e.g., Smallwood & Schooler, 2006).

By using the thought-probe method and related techniques, researchers have found that mind wandering is negatively associated with episodic memory. For example, Thomson, Smilek, and Besner (2014) had participants study a list of words and make deep or shallow encoding judgments. They inserted thought probes throughout the encoding phase that asked participants to indicate if they were on- or off-task. The results showed a negative association between mind wandering rates and recognition performance, but only when participants were in the deep encoding condition. Furthermore, this effect was mediated by the accuracy of the deep encoding judgments. Together, these results suggest that mind wandering was associated with worse episodic memory performance because when mind wandering occurs, one is unable to make the deep encoding judgment, leading to poorer encoding and retrieval later. In addition to impaired recognition memory, mind wandering also disrupts the ability to retrieve and later integrate information in memory when reading narrative texts (Smallwood et al., 2008). Therefore, when required to update episodic memories, mind wandering episodes should be negatively associated with the ability to detect and recollect changes.

The MFC framework assumes that attention is required during encoding of the original and changed information to detect and recollection changes (Jacoby et al., 2015; Jacoby & Wahlheim, 2013). It then follows that if attention is not focused during encoding of the changed information, then this will be associated with fewer instances of processing the features of that information and triggering retrieval of the original information with shared features (e.g., the same cue with a different response). Some evidence in support of the role of attention was shown indirectly by Jacoby et al. (2015). However, this study did not assess how natural variation in attention is correlated with differences in change detection and recollection. Therefore, the goal of the second empirical article presented in the integrated dissertation was to use the thought-probe method from the mind wandering literature to test the assumption from the MFC framework about the role of attention in episodic memory updating (Garlitch & Wahlheim, 2020b). Here, the measure of attention was operationalized as self-reported task engagement reports. It was expected that being on-task during encoding of the changed pair should increase rates of change detection and recollection relative to being off-task, and this should be associated with differences in memory updating. In addition to testing a theoretical prediction from the MFC framework, this work can further inform situations under which change detection and recollection would be more likely to occur, which allows for more precise predictions about whether episodic memory updating will be successful.

Role of Attention in Age-Related Differences in Event Memory Updating

In addition to natural fluctuations in attention, there may also be individual and age-related differences in controlled attention when trying to select what information to attend to. In the more basic, well-controlled stimuli used in the studies described above on episodic memory updating, participants are only presented with static stimuli. Unless participants turn their focus inwardly, as in the case of mind wandering, they only have one individual item to attend to on each trial. In real life, however, people are often required to update memories for dynamic events. In these situations, it can require controlled attention to focus on specific features of events that may be changing. Older adults are impaired in some aspects of attention, including executive or controlled attention (McCabe et al., 2010). Therefore, older adults may show deficits in the ability to update episodic memories partly because of their diminished ability to direct attention to critical features of more naturalistic activities.

Consistent with this idea, prior work has shown that tasks of sustained and controlled attention, older adults show slower response times and more errors than younger adults (Armstrong, 1997; Lufi & Haimov, 2019; Mani et al., 2005; Parasuraman et al., 1989; Vasquez et al., 2016, but see Carriere et al., 2010). Similarly, older adults perform worse than younger adults on tasks that require them to inhibit irrelevant or distracting information (Bedard et al., 2002; for a review, see Hasher & R. T. Zacks, 1988). In work on change blindness, which is a phenomenon where people fail to detect instantaneous visual changes (for reviews, see Simons, 2000; Simons & Ambinder, 2005), older adults show more change blindness than younger adults (Costello et al., 2010; James & Kooy, 2011; Rizzo et al., 2009; Veiel et al., 2006). Further, older adults' increased change blindness is associated with impairments in attention, working memory, and executive function (Rizzo et al., 2009). Together, this work supports the idea that age differences in controlled attention are related to the ability to detect changed features from one situation to the next.

Detection of ongoing changes is also posited to underlie the ability to comprehend and later remember actions that are observed in everyday events. Event cognition theories propose that attention to incoming perceptual information is required for people to form event models of ongoing activity (Radvansky, 2012; J. M. Zacks et al., 2007). The incoming perceptions can trigger retrieval of event schemata about events and are then used to make predictions about the upcoming features of events. When current perceptions mismatch predictions, then people update their event models. Event model updating is supported by an upregulation of attention to new actions that cue retrieval of event schemata related to these new actions. Researchers have tested this theory of event cognition by having participants watch movies of everyday activities, indicate when one event ends and another begins, and then have their memory for those events tested (e.g., Newtson, 1973; J. M. Zacks et al., 2001). Individual differences in demarking event boundaries predicts memory for constituent actions of events (Sargent et al., 2013; J. M. Zacks et al., 2006). Older adults sometimes show less consistent formation of event models, as evidence by poorer event segmentation ability, and when they do, this is associated with their poorer memory for event details (Bailey et al., 2013; Kurby & J. M. Zacks, 2011; J. M. Zacks et al., 2006; but see Kurby & J. M. Zacks, 2019; Sargent et al., 2013). Together this literature suggests that older adults may attend to actions of everyday events less effectively than younger adults, and this is associated with deficits in memory for those events.

Although studies from event cognition have shown that older adults are less consistent in comprehending and remembering distinct events, these theories do not address age-related differences in updating of event memories, which is required when event features change between temporally disconnected episodes. Recently, Wahlheim and J. M. Zacks (2019) proposed the Event Memory Retrieval and Comparison (EMRC) theory to address the mechanisms that support updating event memories that change across episodes. EMRC combines assumptions from the MFC framework with assumptions from theories of event segmentation (e.g., Radvansky, 2012; J. M. Zacks et al., 2007). EMRC theory assumes that attending to ongoing features of actions allows events to be perceived, which cues retrieval of relevant event schemata. This enables the observer to comprehend the event and make predictions about upcoming features. When observers later attend to another event with features that overlap with existing representations, this can trigger a reminding of the existing representation. This allows the observer to recognize repeated actions and make memory-based predictions about how the event will end. When events end differently than expected, attention is directed to the changed features, which are compared with the existing representation, thus allowing the formation of an integrated representation. Similar to the processes described above by the MFC framework, recollecting this change later can benefit memory for the changed events while failing to recollect change can impair memory.

Regarding age differences, EMRC theory predicts that the deficit in controlled attention sometimes shown by older adults would be associated with impaired event comprehension (e.g., Kurby & J. M. Zacks, 2011; J. M. Zacks et al., 2006). When observing repeated events later, older adults would be less likely to notice the similarity between current and existing event representations. Therefore, older adults should make fewer memory-based predictions, leading to poorer detection of change between events. This would then limit the number of opportunities they have to form integrated representations between the changed events, and thus would experience fewer of the memory updating benefits associated with recollecting the integrated representations later.

Wahlheim and J. M. Zacks (2019) tested predictions from EMRC theory about age-related differences in event memory updating in two experiments using an *everyday changes* paradigm. Participants watched two movies of an actor performing everyday activities (e.g., putting clothes in the washing machine) across two fictive “days” in her life (hereafter referred to as Day 1 and Day 2). Critically, there are some activities across the movie that the actor starts the same way across both days (e.g., putting clothes in the washer), but then ends the activity differently in the second movie (changed activities; e.g., using liquid on Day 1 and then powder detergent on Day 2). In the first experiment, participants watched both movies passively. In the second experiment, the Day 2 movie was paused, and participants were asked to indicate whether the activity feature was repeated, changed, or new across Day 1 and Day 2. One week after watching the Day 2 movie, participants completed a cued recall test where they attempted recall of the features from the Day 2 movie. Memory updating was assessed as recall of the changed features relative to control (i.e., new) features from Day 2. Then, as a measure of change recollection, participants indicated whether an activity feature changed, and when they indicated it had, they attempted recall of the Day 1 feature.

Younger adults showed proactive facilitation in memory for the Day 2 features, as evidenced by higher recall of the changed than control activities from the second movie. In contrast, older adults showed no difference between these two conditions. This suggests that older adults experienced a deficit in event memory updating. This deficit was partly accounted for by older adults detecting and recollecting fewer changes, which was associated with proactive facilitation. Together, these results are consistent with the predictions from EMRC about the relationship between change detection and recollection and age-related deficits in event memory updating.

The behavioral results from Wahlheim and J. M. Zacks (2019) were recently replicated and extended to examine how neural reinstatement of existing memories during encoding of changed events related to event memory updating using functional magnetic resonance imaging (fMRI; Stawarczyk et al., 2020). In this experiment, participants completed a variant of the *everyday changes* paradigm where both movies were viewed in an fMRI scanner. The Day 2 movie was stopped prior to the point at which an activity feature could change, and participants were asked to reimagine the ending of the activity from the Day 1 movie. The Day 2 movie then continued to play the ending of the activity, and participants were asked to indicate if this repeated or changed from the Day 1 movie as a measure of change detection. Three days later, participants completed a cued recall test outside of the scanner where they attempted recall of the Day 2 movie features, indicated whether the features changed from Day 1 to Day 2, and then attempted recall of the Day 1 feature when they indicated change. Older adults recollected change less often than younger adults, which contributed to their deficit in event memory updating. The neural results showed that higher reinstatement of the Day 1 activity during the Day 2 activity was associated with greater change recollection and better event memory updating. This relationship was weaker for older than younger adults. Together, these results suggest that older adults had poorer encoding of original events features, which was associated with lower rates of change detection and recollection for changed events, and this contributed to older adults' poorer event memory updating.

EMRC theory assumes that attention is critical for perceiving, comprehending, and later remembering of events. Furthermore, attention is necessary during encoding of events on separate occasions that are related to existing event representations, as this can trigger retrieval of the existing event memory, allowing for integrated representations to be formed that can be recollected later (Wahlheim & J. M. Zacks, 2019). Prior work has shown behavioral and neural evidence that older adults are impaired in the processes that contribute to event memory updating (Stawarczyk et al., 2020; Wahlheim & J. M. Zacks, 2019), and this may be related to their deficit in controlled attention to event features during encoding. The goal of the third empirical paper presented here was to assess whether a deficit in controlled attention was related to older adults' event memory updating deficit (Garlitch & Wahlheim, 2021). Controlled attention was measured indirectly by using exogenous cues to guide attention to event features during encoding of original and changed events. Both the original and changed events were cued to enhance comprehension of the original events and detection of changes during encoding of changed events, which should allow more opportunities for integrated representations to be formed that can be recollected later. It was expected that if controlled attention deficits contribute to older adults' event memory updating deficit, then older adults should benefit more from the attentional cues than younger adults. This work has implications for understanding how directing attention to changes that occur in more naturalistic situations is associated with event memory updating. In addition, the results can contribute to our understanding of how best to support older adults as they navigate everyday situations that require them to update their event memories.

Aims

The goal of my research program is to understand how adult age differences and attention contribute to differences in the processes that promote successful episodic memory updating. More specifically, this line of research takes the perspective from the MFC framework that episodic memory updating can be enhanced when change detection and recollection occur while updating is impaired when change is not detected (retroactive effects of memory) or when change is detected and not recollected (proactive effects of memory). This work aimed to further test the predictions from the MFC framework in explaining how age and attention contribute to differences in change detection and recollection, and how this is associated with differences in episodic memory updating. By using both well-controlled and naturalistic stimuli, this work can contribute to more precise understanding of the mechanisms that contribute to memory updating and how this occurs in more everyday situations. In addition, this work has implications for theories on the deficits in episodic memory updating that older adults experience and provides empirical evidence for ways that such deficits can be eliminated.

Empirical paper 1 (Garlitch & Wahlheim, 2020a) tests predictions from MFC framework using a variant of the A-B, A-D paired associate learning paradigm to examine whether change detection and recollection can partly explain age-related differences under conditions of retroactive effects of memory. Across two experiments, it was shown that detection and recollection of changes was associated with retroactive facilitation, and that failing to detect changes was associated with retroactive interference for both age groups. Furthermore, younger adults recollected changes more often than older adults, and showed greater facilitation when changes were recollected relative to remembered. Older adults did not show this difference, which suggests that they experienced fewer benefits associated with recollecting change than younger adults.

Empirical paper 2 (Garlitch & Wahlheim, 2020b) tested a primary assumption from the MFC framework that attention is necessary to detect and later recollect changes by using a variant of the A-B, A-D paradigm where participants studied one long list of word pairs. Thought probes from the mind wandering literature (for a review, see Smallwood & Schooler, 2015) were inserted during the study phase to assess self-reported task engagement during encoding. Then, the relationship between these reports and later memory updating performance on the test was assessed. The results showed that being on-task during encoding of the changed pairs was associated with better episodic memory updating both within- and between-participants. Furthermore, being on-task was associated with increased change recollection, suggesting that when participants were attending to changed pairs, they were more likely to detect changes and engage in integrative encoding, which could be recollected later. Together, these results demonstrate that fluctuations in attention, as indicated by these self-reports, are associated with differences in change recollection and episodic memory updating.

Empirical paper 3 (Garlitch & Wahlheim, 2021) tested whether controlled attention contributed to the deficit that older adults experience in updating memories for everyday events by using a variant of the *everyday changes* paradigm (Wahlheim & J. M. Zacks, 2019). To test the role of controlled attention, attentional cues were included during encoding of both original and changed event features. The results showed greater event memory updating for cued changes in both older and younger adults. Furthermore, changes were recollected more often when event features were cued than when they were not. Together, the results suggest that both older and younger adults benefitted from the attentional cues. Critically, this was the first study to show that older adults experienced overall proactive facilitation in memory for changed events, which suggests that cuing attention was an effective tool for improving event memory updating for older adults.

CHAPTER II: ROLE OF REMINDING IN RETROACTIVE EFFECTS OF MEMORY IN OLDER AND YOUNGER ADULTS

Abstract

Retroactive interference refers to the impairing effects of new learning on earlier memories. The Memory-for-Change framework posits that being reminded of earlier information when learning new information can alleviate such retroactive interference and lead to facilitation. Such effects have been shown in younger adults, but the extent to which remindings play a role in retroactive effects of memory for older adults has not been examined. We address this issue here in two experiments using variants of an A-B, A-C paired associate paradigm. Participants studied two lists containing associated word pairs that: repeated across lists (A-B, A-B), included the same cue with a changed response in List 2 (A-B, A-C), or only appeared in List 1 (A-B), and then completed a cued recall test of List 1. Participants reported List 1 reminding during List 2 study and recollection of reminding at test. Neither age group showed retroactive interference in overall List 1 recall, but younger adults showed poorer source monitoring by producing more List 2 intrusions onto List 1 recall than older adults. For both age groups, reminding was associated with retroactive facilitation for List 1 recall, whereas the absence of reminding was associated with retroactive interference. The benefits associated with reminding and recollection of reminding were greater for younger than older adults, partly because younger adults were able to recollect remindings more often than older adults. Together these results implicate a role for reminding in retroactive effects of memory that is more facilitative for younger than older adults.

Introduction

Suppose that a patient sees a new physician after an increased dosage of medication caused negative side effects. To determine what dosage is appropriate, the physician asks about the original dosage, but the patient can only remember the current dosage. This memory failure is an example of *retroactive interference*, whereby memory for the current dosage impaired memory for the original dosage. Memory errors resulting from retroactive interference such as these may be more likely to occur in older adulthood (for reviews, see Kane & Hasher, 1995; Kausler, 1994). In this example, the diminished ability to remember the original dosage could prolong the process of finding the appropriate dosage, resulting in longer periods of adverse side effects. Thus, an important goal of cognitive aging research is to identify the mechanisms underlying age differences in retroactive interference. This can lead to more effective strategies for avoiding the negative effects of interference in memory. In the present study, we used variants of the A-B, A-C paradigm to examine the extent to which remindings that occur when studying new information may counteract retroactive interference for older and younger adults.

We examined this issue using variants of the A-B, A-C paradigm because older adults have often shown greater susceptibility to retroactive interference under such conditions (Arenberg, 1967; Traxler, 1973). In this paradigm, participants are sometimes instructed to study two lists of word pairs that contain some pairs that repeat across lists (A-B, A-B), control pairs that have no relationship across lists (A-B, C-D), and some that have the same cue with a different response in List 2 (A-B, A-C). Then, participants are asked to recall responses from List 1. Retroactive interference is observed when recall of the first list response (B) is poorer for A-B, A-C pairs than recall for control pairs. In the prior studies showing that older adults are more susceptible to retroactive interference than younger adults, the predominant explanation for such age differences is that older adults' have an impaired ability to inhibit non-target information (for a review, see Kane & Hasher, 1995).

The idea that older adults experience an inhibitory deficit has been forwarded primarily by Hasher and colleagues (e.g., Hasher & R. T. Zacks, 1988; Lustig et al., 2007). The theory proposes that inhibitory functions are used to prevent distracting information from entering working memory, remove irrelevant information that does enter working memory, and suppress prepotent or habitual responses. The theory assumes that efficient processing takes place when one can successfully engage inhibition to suppress information from the past or the present that is attracting attention away from the current goal or stimuli to be processed (for a review, see Lustig et al., 2001). Older adults are presumed to process new information less efficiently because they experience an inhibition deficit, which allows more irrelevant or distracting information to enter working memory. This leads to increased response competition at retrieval, and subsequently, impairs memory performance. In studies testing this account, Hasher and colleagues (e.g., Connelly, et al., 1991; Hamm & Hasher, 1992; Hartman & Hasher, 1991; Hasher et al., 1997) have shown that older adults are less likely than younger adults to ignore distracting information and more likely to retrieve it. When applied to interference-based memory paradigms, the inhibitory deficit theory posits that one must inhibit the non-target list both during encoding and retrieval in order to successfully remember the target list responses (for a discussion of this issue, see Lustig et al., 2001).

In contrast to this perspective, we argue that inhibition of competing information during encoding and retrieval is not always necessary to successfully recall earlier-studied information. Specifically, we argue that one need not invoke inhibition deficit theory to understand age differences in A-B, A-C paired associate paradigms when the task allows for and encourages integrative encoding of competing information. This argument is partly based on evidence from other paradigms showing that integrative encoding can counteract interference effects in both older and younger adults. For example, consider studies on the fan effect. Those studies often show that response time to retrieve facts associated with a common cue increases as the number of encoded facts increases, which indicates interference effects in memory (e.g., Anderson, 1974). However, if one can integrate the facts into one, more complex representation, such interference is eliminated (Myers et al., 1977; Radvansky et al., 1993; Radvansky & R. T. Zacks, 1991). Both older and younger adults can engage in such integrative processing, which results in comparable avoidance of this sort of interference (e.g., Radvansky et al., 1996, 2005).

Despite evidence suggesting that both age groups can leverage integrative encoding to reduce interference, no studies to our knowledge have examined the role of integrative encoding in retroactive effects of memory in older and younger adults using the A-B, A-C paradigm. This is surprising given that the prominent theoretical perspective of age differences in A-B, A-C recall, inhibition deficit theory (e.g., Hasher & R. T. Zacks, 1988), is somewhat controversial (for a review see, Lustig et al., 2007). We addressed this gap here by examining whether participants could improve memory for original information in an A-B, A-C paradigm in part by retrieving earlier-learned pairs while studying new pairs with shared cues and changed responses. To explain how such mechanisms may improve memory, we adopted the perspective of the Memory-for-Change (MFC) framework (Jacoby et al., 2015; Wahlheim & Jacoby, 2013).

The MFC framework combines the recursive remindings hypothesis (Hintzman, 2011) with dual-process theory (Jacoby, 1991) to argue that study phase retrievals (i.e., remindings) can eliminate interference and sometimes lead to facilitation by promoting integrative encoding. The framework was originally developed to account for proactive effects of earlier-learned information on memory for more recent information. Under such conditions, the framework proposes that a currently perceived stimulus can trigger a reminding of an earlier memory that includes overlapping features. Bringing the earlier memory into working memory along with the current one enables them to be integrated, along with the reminding that links them, into a configural representation. The reminding process allows earlier memories to receive retrieval practice benefits, making them more accessible in memory. The increased accessibility of information from non-target sources can be opposed if the configural representation formed during List 2 is recollected later at test. This recollection allows access to both responses and the temporal order in which they occurred, leading to a recall benefit for more recent information. However, if this configural representation is not recollected at test, the accessibility of the earlier memory enhanced by retrieval practice leads to proactive interference. The framework posits that overall recall of changed information is comprised of both facilitation and interference effects that depend on the frequencies of remindings and later recollection of remindings.

Important for the present study, this mixture of effects has been shown in experiments examining the role of reminding in proactive effects of memory for older and younger adults (e.g., Wahlheim, 2014; Wahlheim & J. M. Zacks, 2019). Those studies showed that older adults were more susceptible to memory impairment from response competition primarily because they detected and recollected fewer changes than younger adults. We extend on that work in the present study by examining whether similar age differences exist under retroactive experimental conditions. Under such conditions, the MFC framework predicts that remindings will improve memory for earlier-learned information through retrieve practice. In contrast to proactive experimental conditions, recollection of reminding is not required to oppose the accessibility of List 1 responses because those responses are targets under such conditions. Nevertheless, retrieval of existing memories may still be further enhanced when configural representations can be recollected at test. Recollecting those representations could improve retrieval of existing memories beyond reminding alone when retrieval of more recent information serves as an additional retrieval cue for earlier information (Negley et al., 2018), or when the representation preserves temporal order in a manner shown to support list discrimination (Jacoby et al., 2013). When remindings do not occur in List 2, recall of earlier memories should be poorest because they do not receive retrieval practice benefits.

Support for these predictions was shown in two recent studies of retroactive effects of memory for younger adults. In the first study, Jacoby et al. (2015, Experiment 1) examined the effects of controlled remindings on List 1 recall in an A-B, A-C paradigm, where participants studied two lists that included word pairs for which cues remained the same and responses changed between or within lists (between-list and within-list A-B, A-C, respectively), and control pairs that only appeared in List 1. During List 2 study, one group looked for changes originating in either List 1 or List 2 (N-Back), whereas another group only looked for changes from within List 2 (Within-list back). List 1 recall for between-list A-B, A-C pairs showed retroactive facilitation for the N-Back group, but did not differ from control pairs for the Within-list back group. These results suggested that directed remindings of List 1 pairs during List 2 study enhanced List 1 recall through retrieval practice. However, the effects of recollecting remindings could not be assessed because the final test did not include a measure of that sort.

To address this limitation, Negley et al. (2018) examined the effects of List 1 remindings during List 2 in a paradigm that included a measure of reminding recollection at test. Reminding recollection was assumed to occur when participants could both successfully indicate that a pair had changed and correctly recall the List 2 response. By also including a manipulation of List 2 study time, the authors tested the idea that more time spent with competing information can lead to better memory. Although classic interference theories predict that more exposure to competing information should further impair retrieval of earlier memories (e.g., McGeoch, 1932), the MFC framework predicts that more exposure to competing information with shared features could allow for more remindings and therefore improve retrieval of earlier memories. Consistent with this prediction, longer List 2 study time was associated with more remindings and enhanced List 1 recall compared to shorter List 2 study time. In addition, retroactive facilitation was observed when remindings occurred during List 2, regardless of whether remindings were later recollected at test. Important for the MFC framework, reminding recollection was associated with higher List 1 recall than when List 1 recall was conditionalized on remindings alone. These results suggest that retrieval practice during List 2 benefitted later memory, and that recollection-based retrieval of configural representations conferred an additional benefit to List 1 recall.

The two studies of retroactive effects of memory above suggest that manipulations that increase opportunities for integrative encoding in A-B, A-C paradigms can alleviate retroactive interference. Those studies also suggest that when people are reminded less often, they are more susceptible to retroactive interference. Accordingly, the MFC framework predicts that older adults should experience greater retroactive interference than younger adults to the extent that older adults’ recollection deficit (for reviews, see Balota et al., 2000; R. T. Zacks et al., 2000) reduces the frequency of remindings and later recollection of remindings. In the present study, we tested the hypothesis that older adults would experience greater retroactive interference than younger adults because older adults would be reminded of List 1 responses less often during List 2 and recollect fewer remindings at test.

Experiment 1

In Experiment 1, we characterized retroactive effects of memory in older and younger adults in a variant of an A-B, A-C paradigm with instructions that encouraged integrative encoding during List 2. This allowed us to test predictions from the MFC framework about the role of remindings in such effects. To examine these effects, we attempted to manipulate the frequency of remindings during List 2 by varying List 2 study times within subjects, which replicated the approach from Negley et al. (2018). This manipulation also allowed us to determine whether longer List 2 study times would confer differential benefits for older and younger adults. We tested the hypothesis that longer List 2 study durations would provide more opportunities for remindings, particularly for older adults because they are generally assumed to process information more slowly (e.g., Salthouse, 1996). We assessed potential variations in the frequencies of remindings indirectly using a reminding recollection measure at test.

Method

In both experiments, we report how we determined sample sizes, all data exclusions, all manipulations, and all measures (Simmons et al., 2012). The stimuli, data, and analysis scripts can be found here: https://osf.io/z78fc/. The research reported here was approved by the Institutional Review Board at The University of North Carolina at Greensboro (UNCG).

Participants

We tested 48 younger adults (34 women, 14 men), ages 18-23 (M = 19.25, SD = 1.42), from UNCG, and 36 older adults (25 women, 11 men), ages 60-75 (M = 68.75, SD = 3.95), from Greensboro and the surrounding areas. For compensation, younger adults received course credit and older adults received $10 per hour. We screened for cognitively healthy older adults by administering the Short Blessed Test (SBT; Katzman et al., 1983) over the phone and the Mini

Mental State Exam (MMSE; Folstein et al., 1975) in person. The inclusion criteria were: an SBT weighted error score $\leq$ 4, an MMSE score $\geq$ 25, and no reported recent neurological event (e.g., a stroke)[1]. All older adults had a visual acuity score $\geq$ 20/50 on the Snellen Eye Test (Hetherington, 1954). Table 1 displays all cognitive ability scores.

We chose the sample sizes here based on prior work and available resources (i.e., time and money). We oversampled younger adults to increase power; we doubled the sample size of younger adults and chose a 50% larger sample of older adults relative to Wahlheim (2014; Experiment 3), from which the current materials were taken. According to G*Power Version 3.1.9.2. (Faul et al., 2009), with N = 84, we had 80% power (α = .05, two-tailed) to detect a medium effect size (η_p^2 = .089).

Design

We used a 2 (Age: Younger vs. Older) × 3 (Item Type: A-B, A-B vs. A-B vs. A-B, A-C) × 2 (Study Time: 2 s vs. 10 s) mixed design. Age was treated as a between subjects factor, while Item Type and Study Time were manipulated within subjects.

Materials

The materials, taken from Wahlheim (2014), consisted of 96 three-word sets comprised of one cue (e.g., ball) and two responses (e.g., bounce; park). According to the Nelson et al. (1998) free association norms, the forward and backward association strengths between cues and responses were comparably low ([forward: *M* = .04, *SD* = .02, *range* = .01-.10] vs. backward: [*M*

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[1] We replaced 3 older adults for the following reasons: after the experimental session, one person reported having recently experienced a stroke; we discovered that one person who scored above the cutoff on the SBT error measure was invited to participate due to a response coding error; and one person scored below the MMSE cutoff.

= .021, *SD* = .031, *range* = .00-.10]). The responses in each set were not associated, which minimized the possibility that reminding effects could be completely explained by spreading activation between responses.

Table 1. Performance and Demographic Measures for Younger and Older Adults: Experiments 1 and 2

		Age			
		Younger		Older	
Experiment	Task	Mean (SD)	Range	Mean (SD)	Range
Experiment 1	Vocabulary (out of 40)	27.18 (4.27)	19 – 37	35.50 (2.90)	30 – 40
	Education (years)	13.13 (1.26)	12 – 16	16.02 (1.99)	12 – 19
	SBT (error score)			0.61 (1.02)	0 – 4
	MMSE			28.14 (1.46)	25 – 30
Experiment 2	Vocabulary (out of 40)	27.23 (4.70)	11 – 37	35.06 (3.13)	27 – 39
	Education (years)	12.96 (1.07)	12 – 16	16.44 (2.24)	12 – 19
	SBT (error score)			0.58 (1.02)	0 – 4
	MMSE			28.25 (1.13)	26 – 30
	DSST (in 90 s)			51.61 (9.84)	27 – 71
	DSST (out of 9)			6.00 (2.31)	1 – 9

Note. Vocabulary = Shipley vocabulary (Shipley, 1975); MMSE = Mini Mental State Exam (Folstein et al., 1975); Education = self-reported years of education; DSST = Digit Symbol Substitution Task (WAIS-R, Wechsler, 1981).

Of the 96 sets, 90 served as critical items, and six served as buffers against primacy and recency effects. We divided the critical items into six group of 15 items that were each matched on word frequency according to Hyperspace Analog to Language (HAL) log frequency counts

(Lund & Burgess, 1996) taken from the English Lexicon Project database (Balota et al., 2007). The values for each group ranged from 5.73 to 12.67 (*M* = 9.60, *SD* = 1.48). Groups were also matched on word length (*M* = 5.30, *SD* = 1.22, *range* = 4-8).

The experiment included the following phases: List 1, List 2, practice test, and actual test. List 1 contained 90 critical and six buffer items. Thirty critical items appeared in each of the Item Type conditions, and one buffer item appeared in each combination of Item Type and list position (i.e., primacy and recency) conditions. List 2 contained 60 critical pairs and four buffer items. Thirty pairs appeared in each of the A-B, A-B, and A-B, A-C conditions (control pairs were not included in List 2), and one buffer item appeared in each combination of Item Type and list position conditions. In both lists, the 30 critical pairs in each Item Type condition were divided into two groups of 15 pairs corresponding to each of the Study Time conditions. Note that this distinction was arbitrary for A-B control items in List 1 because those items were not subjected to the study time manipulation. For counterbalancing, we rotated critical item sets across within-subject conditions, producing six experimental formats. The assignment of buffer items to conditions remained constant across formats. The practice test phase contained cues from the six buffer pairs that appeared in List 1. The actual test phase contained cues from the 90 critical pairs that appeared in List 1.

Procedure

All participants were tested individually. The stimuli were presented on computers using E-Prime 2 software (Psychology Software Tools, Pittsburgh, PA, USA). In all phases of the experiment, stimuli appeared in a white font against a black background.

In List 1, pairs appeared for 8 s each followed by a 500 ms interstimulus interval (ISI). Primacy and recency buffers appeared in the first and last three positions of the list, respectively.

Participants were asked to read the pairs aloud and study them for an upcoming test. In List 2, pairs appeared for either 2 s or 10 s each followed by a 500 ms ISI. Participants were told that some pairs would appear for longer than others. They were further told that some pairs would be the same as in List 1, whereas others would include the same cue paired with a changed response. Finally, they were told that noticing the changed pairs could help them on the memory test. In both lists, pairs appeared in a fixed random order, with the constraint that items from the same condition did not appear consecutively more than three times. The average list position was equated across conditions to control for serial position effects.

On both the practice and actual tests, cues appeared one at a time next to a question mark (e.g., ball- ?). Participants were instructed to first attempt to recall the response that was paired with the cue in List 1. After typing their response, participants indicated whether that response changed between lists by clicking on boxes labeled “Yes” or “No” that were shown below the cue. When participants selected “Yes,” they were prompted to type in the changed response that appeared in List 2. When participants selected “No,” the next test cue appeared. Cues remained on the screen until participants responded. Cues appeared in a fixed random order, with the constraint that items from the same condition did not appear more than three times consecutively. The average serial position was equated across conditions to control for serial position effects and to equate lags between study and test items in each condition.

Finally, all participants completed a computerized Shipley Vocabulary test (Shipley, 1986). Older adults then completed the MMSE (Folstein et al., 1975).

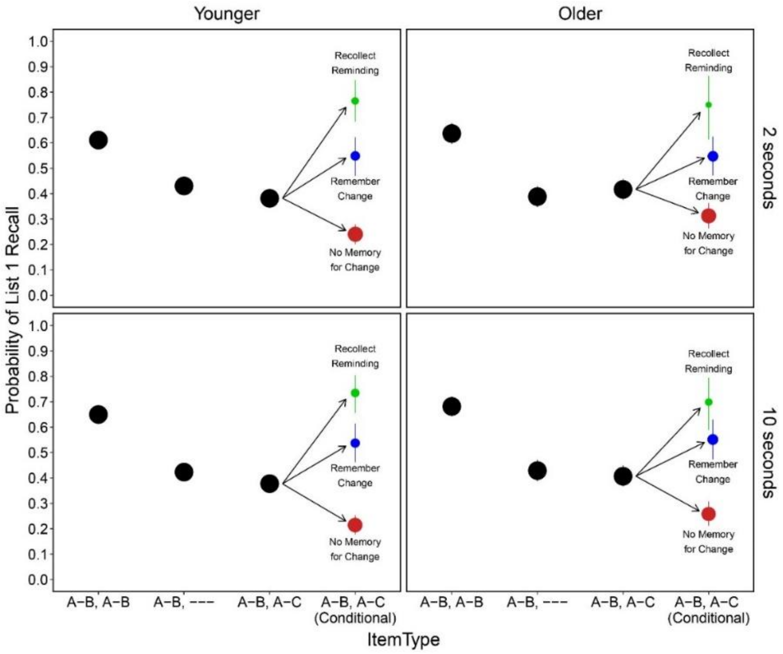
Results

We performed all statistical tests using R software (R Development Core Team, 2008). We modeled the effects of experimental manipulations using linear and logistic mixed effects models, fit with the lme4 package (Bates et al., 2015). We performed hypothesis tests using the Anova function of the car package (Fox & Weisberg, 2011), and posthoc comparisons using the Tukey method in the emmeans package (Lenth, 2018). In both experiments, we treated experimental factors as fixed effects, and Subjects and Items as random effects. Importantly, this allowed us to examine whether performance differences revealed by conditional analyses remained while controlling for variability due to subjects and items. The level for significance was $\alpha = .05$.

List 1 Recall

To examine whether Age and Study Time interacted with retroactive effects of memory, we first analyzed overall List 1 recall (Figure 1; black points). Note that in the following analyses we treated A-B control item subgroups as separate cells based on the arbitrary study time labels from the counterbalance scheme. List 1 recall did not differ across the arbitrary cells for either age group, *largest* $z = 1.44$, $p = .15$, indicating that these cells could be included in pairwise comparisons to evaluate retroactive effects of memory in our subsequent models. We examined List 1 recall using an Age × Item Type × Study Time model. The model indicated a significant effect of Item Type, $\chi^2(2) = 431.46$, $p < .001$, showing that List 1 recall was significantly higher for A-B, A-B items than the other two item types, *smallest* $z = 17.26$, $p < .001$, and did not differ between A-B and A-B, A-C items, $z = 1.75$, $p = .19$. No other effects were significant, *largest* $\chi^2(2) = 4.48$, $p = .11$. These results showed that retroactive effects of memory were comparable across Age and Study Time conditions.

Figure 1. Probability of List 1 Recall for Experiment 1



Note. Probabilities of correct List 1 recall as a function of Age, Item Type, and Study Time: Experiment 1. The areas of the conditional points (in green, blue, and red) for A-B, A-C items correspond to the proportions of responses on the cued recall test that were included in each of the three conditions. The green points indicate when remindings were recollected, while the blue points indicate when participants said a pair had changed but did not report the List 2 response at test (Remember Change). The red points indicate when change was not classified at test (No Memory for Change). The heights of the conditional points indicate the probability of correct List 1 recall for those subsets of items. Error bars are bootstrap 95% confidence intervals.

List 2 Intrusions onto List 1 Recall

We further examined whether Age and Study Time interacted with retroactive effects of memory by analyzing the rates of List 2 intrusions onto List 1 recall (Table 2; top rows). Note that intrusions for A-B, A-B and A-B control items are baseline estimates of guessing the alternative response during List 1 recall that would have appeared in List 2 had those items been assigned to the A-B, A-C condition. The baseline rates were comparably low in all cells ($M \leq .02$), so we do not include them in the following analysis. An Age × Study Time model fitted to A-B, A-C items indicated a significant effect of Age, $\chi^2(1) = 5.18$, $p = .02$, showing higher List 2 intrusions onto List 1 recall for younger than older adults. No other effects were significant, *largest* $\chi^2(1) = 1.93$, $p = .17$. These findings showed that younger adults made more source monitoring errors than older adults.

Table 2. List 2 Intrusions onto List 1 Recall for A-B, A-C Items as a Function of Age and Study Time: Experiments 1 and 2

		Study Time	
Experiment	Age	2 s	10 s
Experiment 1	Younger	.15 [.12, .18]	.18 [.15, .21]
	Older	.13 [.10, .16]	.12 [.10, .15]
Experiment 2	Younger		.19 [.17, .22]
	Older		.13 [.11, .16]

Note. Bootstrap 95% confidence intervals are displayed in brackets. Baselines intrusion estimates for A-B, A-B, and A-B conditions were $\leq .02$ in all cells.

Change Classifications

To examine the role of remindings in retroactive effects of memory described above (inferred here from rates of reminding recollection at test), we first computed probabilities for three categories of change classification for A-B, A-C items (Table 3). *Recollect Reminding* refers to instances when items were classified as changed and List 2 responses were correctly recalled. *Remember Change* refers to instances when items were classified as changed and List 2 responses were not correctly recalled. These two response categories were computed as joint probabilities. *No Memory for Change* refers to instances when items were not classified as changed. Note that MFC makes clear predictions about how recall performance should be associated with reminding recollection and the absence of memory for change. However, theoretical and empirical work is currently underway to establish the processes involved when changes are remembered but not recollected, and the associated effects on recall performance. Consequently, we treat all analyses including those cells as exploratory.

Table 3. Change Classification Probabilities for A-B, A-C Items as a Function of Age, Classification Type, and List 2 Study Time: Experiment 1

	Classification Type					
	Recollect Reminding		Remember Change		No Memory for Change	
Age	2 s	10 s	2 s	10 s	2 s	10 s
Younger	.14 [.11, .16]	.18 [.15, .21]	.23 [.20, .26]	.22 [.19, .25]	.63 [.60, .67]	.60 [.57, .64]
Older	.08 [.06, .11]	.14 [.11, .16]	.29 [.25, .33]	.30 [.27, .34]	.63 [.59, .67]	.56 [.52, .60]

Note. Bootstrap 95% confidence intervals are displayed in brackets.

To simplify comparisons of age differences across response categories, we fitted separate Age × Study Time models to each category. The model for Recollect Reminding responses indicated a significant effect of Study Time, χ^2 (1) = 14.68, *p* < .001, showing that more remindings were recollected in the longer compared to shorter study time condition. No other effects were significant, *largest* χ^2 (1) = 2.20, *p* = .14. The model for Remember Change responses indicated a significant effect of Age, χ^2 (1) = 4.53, *p* = .03, showing that more changes were remembered without remindings being recollected by older than younger adults. No other effects were significant, *largest* χ^2 (1) = 0.45, *p* = .50. The model for No Memory for Change responses indicated a significant effect of Study Time, χ^2 (1) = 7.79, *p* = .005, showing that changes were remembered less often when study time was shorter compared to when it was longer. No other effects were significant, *largest* χ^2 (1) = 0.97, *p* = .32. Together these results showed that longer study time benefitted reminding recollection, and that older adults were more likely to indicate change at test without being able to recall the List 2 response.

List 1 Recall Conditionalized on Change Classification

To examine the associations between reminding recollection and List 1 recall, we examined probabilities of List 1 recall conditionalized on change classifications made for A-B, A-C items (Figure 1, green, red, and blue points). We performed conditional analyses of List 1 recall using an Age × Item Type × Study Time model. The Item Type factor included four levels: the three levels of change classification for A-B, A-C items described above, and A-B control items. A-B control items were included to assess variations in retroactive effects of memory across A-B, A-C conditions. We do not report main effects redundant with previous analyses.

The model indicated a significant effect of Item Type, χ^2 (3) = 178.36, *p* < .001, and a significant Age × Item Type interaction, χ^2 (3) = 9.00, *p* = .03. Regarding retroactive effects of memory, List 1 recall was significantly higher for Recollect Reminding and Remember Change than for A-B control items for both age groups, *smallest* $z = 4.50$, $p < .001$, indicating retroactive facilitation for items in which remindings were recollected or were identified as changed at test. Conversely, List 1 recall was significantly lower for No Memory for Change compared to A-B control items for both age groups, $z = 8.23$, $p < .001$, indicating retroactive interference for items that were not identified as changed at test. These results showed that both age groups experienced retroactive facilitation when changes were remembered or remindings were recollected, and retroactive interference when changes were not remembered. The interaction showed that, for younger adults, List 1 recall was significantly higher for Recollect Reminding than for Remember Change, $z = 2.87$, $p = .02$. In contrast, for older adults, List 1 recall did not differ between Recollect Reminding and Remember Change, $z = 2.07$, $p = .16$. These results show a qualitative age difference in recall patterns: Older adult showed comparable List 1 recall benefits when remindings were recollected and changes were remembered at test while younger adults showed significantly higher recall when remindings were recollected than when changes were remembered at test. No other effects were significant, *largest* $\chi^2 = 3.16$, $p = .37$.

Discussion

The results from Experiment 1 showed comparable List 1 recall for both age groups, and more List 2 intrusions onto List 1 recall for younger than older adults. Contrary to most of the prior cognitive aging research, these results suggest that source monitoring errors were greater for younger than older adults. In addition, both age groups recollected remindings more often when List 2 pairs appeared for a longer rather than a shorter length of study time. However, this did not lead to age differences in overall List 1 recall for A-B, A-C items due to the balance of recall probabilities across conditional cells. Importantly, the analyses of change classifications showed that older adults were more likely than younger adults to remember changes without recollecting remindings. This age difference suggests that older adults had less precise memory for changes, which is consistent with the idea that older adults experience a recollection deficit. Consistent with the MFC framework, both age groups showed retroactive facilitation in List 1 recall for A-B A-C items when they recollected remindings and retroactive interference when they did not remember change. However, younger adults showed greater retroactive facilitation when they recollected remindings than when they remembered changes, whereas older adults showed comparable performance in both instances. To further investigate remindings and their association with List 1 recall, we included a direct measure of remindings in Experiment 2.

Experiment 2

In Experiment 2, we attempted to replicate the patterns of overall memory performance from Experiment 1 and included a direct measure of remindings as they occurred in List 2. This allowed us to more completely characterize the association between remindings and later recall performance. The MFC framework predicts that remindings in List 2 will enhance List 1 recall for both age groups, but older adults' recollection deficit should lead to fewer remindings and recollection of remindings. Consequently, older adults should receive fewer of the List 1 recall benefits that are associated with remindings and their recollection. We chose not to manipulate study time here to provide more observations for analyses of List 1 recall conditionalized on remindings during List 2 and later memory for remindings at test.

Method

Participants

We tested 48 younger adults (32 female, 16 male), ages 18-26 (*M* = 19.17, *SD* = 1.37), from UNCG, and 36 older adults (24 female, 12 male), ages 60-75 (*M* = 68, *SD* = 4.17), from

Greensboro and the surrounding areas. The compensation, eligibility requirements, and sample size justification were the same as in Experiment 1. Table 1 displays demographic information and cognitive ability scores.

Design

We used a 2 (Age: Younger vs. Older) × 3 (Item Type: A-B, A-B vs. A-B, vs. A-B, A-C) mixed design. Age was treated as a between subjects variable, and Item Type was manipulated within subjects.

Materials

We reduced the overall number of items from Experiment 1 by selecting the 60 critical sets that produced the highest List 1 recall performance. Doing so allowed the experiment to be completed in one hour. The average association strengths between responses, word lengths, and word frequencies were comparable to the larger set. List 1 contained 60 critical items, and List 2 contained 40 critical items (20 per condition). The counterbalancing scheme and buffer items were the same as in Experiment 1.

Procedure

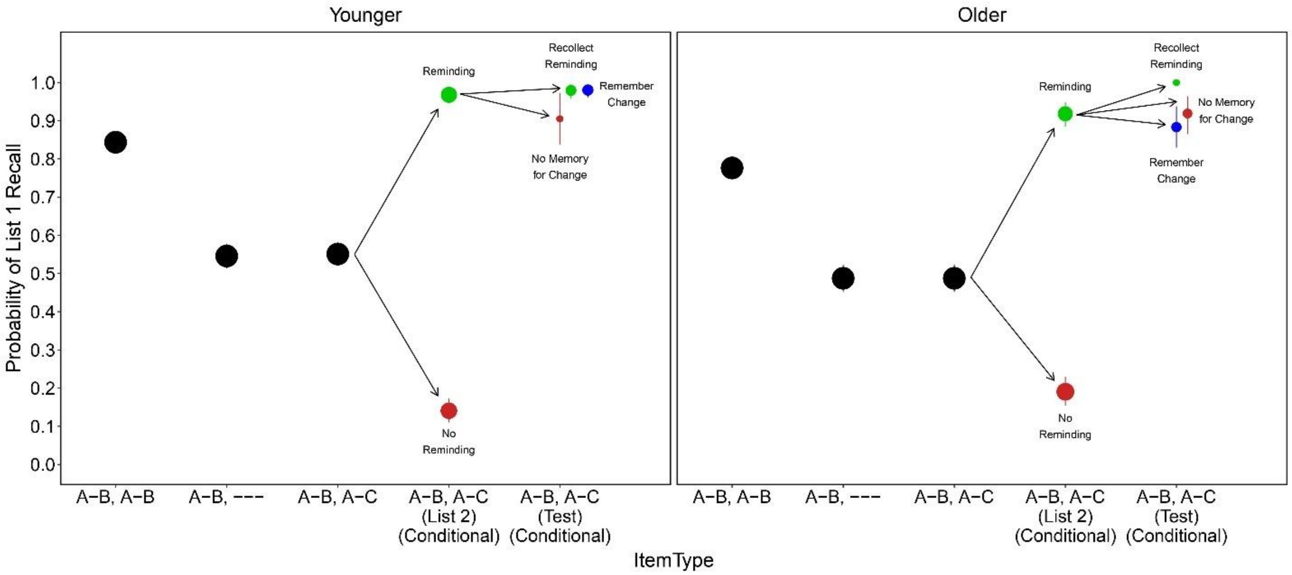
The procedure for Experiment 2 followed that of Experiment 1, with the following modifications. List 2 pairs appeared for 10 s each. Participants were instructed to press the “1” key when they detected changed pairs, and to study the pair until it disappeared after detecting the change. To measure remindings, a screen appeared after the 10 s study time had elapsed that asked participants to report the List 1 response. An experimenter recorded those responses, and participants pressed the spacebar to move onto the next study pair. If participants did not detect a change, they were told to study the pair until it disappeared from the screen. We modified the response mapping for change classifications on the cued recall test because some older adults from Experiment 1 had difficulty alternating between the mouse and keyboard. Participants indicated that pairs had changed by pressing the “1” key and that pairs had not changed by pressing the “0” key. After the experiment, older adults completed the MMSE (Folstein et al., 1975) and then the Digit Symbol Substitution Task (DSST), which was taken from the WAIS-R (Wechsler, 1981).

Results

List 1 Recall

We first assessed overall List 1 recall performance (Figure 2, black points) using an Age × Item Type model. The model indicated a significant effect of Item Type, χ^2 (2) = 446.32, $p < .001$, showing that recall was higher for A-B, A-B than both A-B and A-B, A-C items, *smallest z* = 19.02, $p < .001$, and did not differ between A-B and A-B, A-C items, $z = .12$, $p = .99$. Neither the effect of Age, χ^2 (1) = 3.67, $p = .055$, nor the Age × Item Type interaction was significant, χ^2 (2) = 2.03, $p = .36$. These results showed that correct recall for List 1 did not differ significantly for older and younger adults.

Figure 2. Probabilities of Correct Recall for Experiment 2



Note. Probabilities of correct List 1 recall as a function of Age and Item Type: Experiment 2. The areas of the conditional points (in green, blue, and red) for A-B, A-C items correspond to the proportion of responses on the cued recall test that were included in each condition. For the points above A-B, A-C (Cond), green represents when participants experienced a reminding while the red indicates when participants were not reminded. The green and blue points above A-B, A-C (Cond) indicate when remindings were recollected, and when participants indicated change but did not recall the List 2 response (Remember Change), respectively. The corresponding red dot indicates when change was not classified at test (No Memory for Change). The heights of the conditional points indicate the probability of correct List 1 recall for those subsets of items. Error bars are bootstrap 95% confidence intervals

List 2 Intrusions onto List 1 Recall

We compared the rates of List 2 intrusions onto List 1 recall between age groups (Table 2, bottom rows). Baseline intrusion rates for A-B, A-B, and A-B control items were comparably low for both age groups ($M \leq .02$). The model including only intrusions for A-B, A-C items indicated a significant effect of Age, $\chi^2(1) = 4.35$, $p = .04$, showing more intrusions for younger than older adults. Replicating Experiment 1, these results showed more source monitoring errors for younger than older adults in the form of List 2 intrusions onto List 1 recall.

Change Classifications

We examined age differences in memory for change both during List 2 and at test. We first examined each measure separately to characterize potential age differences in List 2 responses and to provide a direct comparison of change classification responses at test with those reported in Experiment 1. We then combined these measures to establish how change classifications made during List 2 translated in change classifications made at test. The analyses combining measures from List 2 and test were important for understanding how overall recall patterns were achieved when interpreting later conditional analyses of recall performance.

List 2. We computed probabilities for three categories of change classification for A-B, A-C items during List 2 (Table 4, top rows). *Reminding* refers to instances when items were classified as changed and List 1 responses were correctly recalled. *Notice Change* refers to instances when items were classified as changed and List 1 responses were not recalled. These response categories were computed as joint probabilities. *No Change* refers to instances when items were not classified as changed.

To simplify comparisons of age differences across response categories, we fitted separate models with Age as the factor to each classification type. The model for Reminding responses indicated no significant effect, χ^2 (1) = 3.59, *p* = .058. The model for Notice Change responses indicated a significant effect, χ^2 (1) = 29.26, *p* < .001, showing that older adults detected changes without recalling List 1 responses more often than younger adults. The model for No Change indicated no significant effect, χ^2 (1) = 3.29, *p* = .069. Finally, we also examined false alarm rates for A-B, A-B items classified as changed. The rates were comparably low for both younger (*M* = .02, *CI* = [.01, .03]) and older (*M* = .05, *CI* = [.03, .06]) adults, χ^2 (1) = 0.00, *p* = .99. These results show that older adults made change classifications on the basis of memory for List 1 responses less often than younger adults. This age difference in List 1 recall presumably reflects older adults' deficit in recollection.

Test. We analyzed the same three categories of change classification at test as in Experiment 1 (Table 4, bottom rows). The model for Recollect Reminding responses indicated a significant effect, χ^2 (1) = 13.30, *p* < .001, showing that younger adults recollected more remindings than older adults. The model for Remember Change responses indicated no significant effect, χ^2 (1) = 0.54, *p* = .46. The model for No Memory for Change responses also indicated no significant effect, χ^2 (1) = 3.31, *p* = .07. Finally, there was no difference in false alarm rates between older and younger adults for the A-B, A-B items (Older: *M* = .04, *CI* = [.02, .06]; Younger: *M* = .02, *CI* = [.01, .03], χ^2 (1) = 3.74, *p* = .053), but there was a significant difference for A-B control items (Older: *M* = .05, *CI* = [.03, .09]; Younger: *M* = .02, *CI* = [.01, .03], χ^2 (1) = 9.55, *p* = .002). These results suggest that younger adults were better able to recollect List 2 changes and show that older adults were more biased to classify control items as changed.

Table 4. Change Classification Probabilities for A-B, A-C Items as a Function of Age and Classification Type during the List 2 and Test Phases: Experiment 2

		Classification Type		
			No Reminding	
Phase	Age	Reminding	Notice Change	No Change
List 2	Younger	.49 [.45, .52]	.13 [.11, .16]	.38 [.35, .41]
	Older	.41 [.37, .44]	.30 [.27, .33]	.29 [.26, .32]
			Reminding Not Recollected	
Phase	Age	Recollect Reminding	Remember Change	No Memory for Change
Test	Younger	.26 [.23, .29]	.27 [.25, .30]	.47 [.44, .50]
	Older	.12 [.10, .15]	.30 [.27, .34]	.58 [.54, .61]

Note. Bootstrap 95% confidence intervals are displayed in brackets.

List 2 and Test. The combined measures of change classification from List 2 and test are displayed in Table 5. As in the analyses above, we fitted separate models with Age as the factor to each classification type. The model for Reminding + Recollect Reminding responses indicated a significant effect, χ^2 (1) = 16.71, p < .001, showing a higher rate of being reminded in List 2 and recollecting reminding at test for younger than older adults. The model for Reminding + Remember Change responses indicated no significant effect, χ^2 (1) = 1.96, p = .16. The model for Reminding + No Memory for Change responses indicated a significant effect, χ^2 (1) = 9.02, p

= .003, showing a higher rate of being reminded in List 2 and not indicating change at test for older than younger adults. These combinations of List 2 and test measures confirmed that older adults were less likely to recollect remindings that occurred in List 2.

List 1 Recall Conditionalized on Change Classifications

In the final set of analyses, we examined List 1 recall conditionalized on whether participants were reminded during List 2 and on the three categories of change classification at test (Figure 2, green, red, and blue points) in order to investigate the associations of remindings and later reminding recollection with List 1 recall. For the absence of remindings during List 2, we created a "No Reminding" response category that collapsed across the Notice Change and No Change categories.

Table 5. Change Classification Probabilities for A-B, A-C Items as a Function of Age and Classification Type for Combinations of List 2 and Test Phases: Experiment 2

	Classification Type			
Age	Reminding + Recollect Reminding	Reminding + Remember Change	Reminding + No Memory for Change	No Reminding
Younger	.20 [.18, .23]	.21 [.19, .24]	.08 [.06, .09]	.51 [.48, .54]
Older	.08 [.06, .09]	.18 [.15, .21]	.15 [.13, .18]	.59 [.56, .63]

Note. Bootstrap 95% confidence intervals are displayed in brackets.

Reminding in List 2. We fitted a model to conditional List 1 recall with Age and Item Type (A-B, A-C [Reminding] vs. A-B, A-C [No Reminding] vs. A-B) as factors. The model indicated a significant effect of Item Type, $\chi^2(2) = 544.04$, $p < .001$, showing that List 1 recall for A-B, A-C items was higher when remindings occurred in List 2 than when they did not.

There was no significant effect of Age, $\chi^2(1) = 1.69$, $p = .19$, but there was a significant Age × Item Type interaction, $\chi^2(2) = 12.93$, $p = .002$. When remindings occurred, List 1 recall was significantly greater for younger than older adults, $z = 2.84$, $p = .005$. However, when remindings did not occur, List 1 recall did not differ between age groups, $z = 1.13$, $p = .26$. Regarding retroactive effects of memory, retroactive facilitation was observed when remindings occurred, as reminded items were recalled more often than control items, $z = 15.52$, $p < .001$, and retroactive interference was observed when remindings did not occur, as non-reminded items were recalled less often than control items, $z = 15.68$, $p < .001$. These results show that retrieval of List 1 responses during List 2 was associated with retroactive facilitation, and that older adults showed an episodic memory deficit for List 1 responses at test even when they were successfully reminded of those responses during List 2.

Reminding in List 2 and Reminding Recollection at Test. In the final set of analyses, we conditionalized List 1 recall of A-B, A-C items for which remindings occurred during List 2 on change classifications at test. We fitted an Age × Classification model to A-B, A-C items for the three levels of change classification at test (i.e., Recollect Reminding, Remember Change, and No Memory for Change).

The model indicated no significant effect of Age, $\chi^2(1) = 3.53$, $p = .06$, no significant effect of Classification, $\chi^2(2) = 2.60$, $p = .27$, and a significant Age × Classification interaction, $\chi^2(2) = 6.98$, $p = .03$. The interaction showed that for younger adults, List 1 recall was significantly higher for both Recollect Reminding and Remember Change than for No Memory for Change, *smallest* $z = 2.39$, $p = .045$, and List 1 recall did not differ between Recollect Reminding and Remember Change, $z = 0.10$, $p = .99$. For older adults, there were no significant differences among conditional cells, *largest* $z = 1.02$, $p = .56$. This lack of an effect for older adults could partly reflect the low number of observations in the reminding recollection cell for older adults. Despite this lack of differences, it is noteworthy that List 1 recall was perfect for all of the items for which remindings were recollected. Taken together, these results are consistent with the MFC framework in showing that reminding recollection was associated with benefits above reminding without memory for change. These results also suggest that older adults can benefit from reminding recollection, but they do so less often than younger adults.

Discussion

Consistent with Experiment 1**,** there was no age-related difference in retroactive effects of memory in overall List 1 recall, but younger adults made more source monitoring errors, as they produced more List 2 intrusions onto List 1 recall than older adults. During List 2, older adults were more likely to notice change without recall of List 1. At test, older adults were less likely to recollect remindings and were more likely to indicate changes for control items than younger adults. These results suggest that older adults relied on recollection as a basis for change classifications in both List 2 and at test less than younger adults. The benefits of reminding for List 1 recall were greater for younger than older adults, which suggests that retrieval practice led to more durable List 1 representations for younger adults. Consistent with the MFC framework, conditional List 1 recall showed that remindings led to retroactive facilitation and the absence of remindings led to retroactive interference. There was also an additional benefit from recollecting such remindings that appeared for younger but not older adults. However, the low number of observations in the reminding recollection cell for older adults likely precluded our ability to detect such benefits in the statistical analyses. Overall, these results are generally consistent with predictions from the MFC framework, as remindings that allowed for integrative encoding were associated with enhanced memory performance for List 1 to varying degrees for older and younger adults.

General Discussion

The primary goal of the present study was to examine the role of reminding in retroactive effects of memory for older and younger adults using variants of an A-B, A-C paradigm. We found that older and younger adults showed comparable overall List 1 recall in both experiments. Younger adults showed higher List 2 recall after indicating change at test and more List 2 intrusions onto List 1 recall than older adults in both experiments. Older adults were more likely to notice changes without recalling List 1 responses during List 2 and recollected fewer remindings at test than younger adults. Critically, remindings were associated with higher List 1 recall at test for younger than older adults. Recollection of remindings at test were also more clearly associated with an additional benefit to List 1 recall for younger than older adults. These results are generally in line with predictions from MFC in showing critical roles for reminding and reminding recollection in age differences in retroactive effects of memory. In what follows, we consider the theoretical implications of the present findings.

Theoretical Implications for Age Differences in Episodic Memory

It has previously been shown that in A-B, A-C paired associate paradigms, older adults experience greater susceptibility to retroactive interference than younger adults (e.g., Arenberg, 1967; Traxler, 1973). As discussed in the Introduction, it has long been assumed that using A-B, A-C paradigms to examine memory under conditions of retroactive interference adequately measures age differences in inhibition abilities (e.g., Kane & Hasher, 1995). However, the present results clearly show that one need not propose a role for inhibitory processing to explain the age differences in retroactive effects of memory found in prior work. Instead, the MFC framework proposes that older adults experience age-related recollection deficits that reduce the ability to recall List 1 responses during List 2 (a reminding) and to later recollect such experiences. The framework further assumes that remindings increase the accessibility of List 1 responses through retrieval practice and enable the encoding of responses from both lists and the associated temporal order in which they occurred. Consequently, the framework predicts that older adults should experience fewer memorial benefits of reminding and reminding recollection than younger adults in retroactive experimental conditions. Consistent with this, we found that older adults were more likely to indicate change without recall of the List 1 response during List 2 than younger adults (i.e., older adults experienced fewer remindings). At test, older adults were less likely to recollect remindings, and were more likely to remember changes without correct recall of the List 2 response. Furthermore, older adults showed lower conditionalized List 1 recall than younger adults even when they experienced remindings.

Although the present findings fit with predictions from MFC, it is noteworthy that older adults were not more susceptible to retroactive interference in overall performance. This lack of effect may seem surprising given that several extant theories predict that older adults should be less able to differentiate between competing sources of information. As mentioned in the Introduction, inhibition deficit theory posits that older adults are less effective at suppressing distracting or irrelevant information in memory, which causes them to experience greater response competition when attempting to recall target information (e.g., Hasher & R. T. Zacks, 1988; Lustig et al., 2007). In addition, dual process theories of age differences in episodic memory assume that older adults experience a selective deficit in controlled retrieval processes, which explains why older adults have poorer memory for temporal contextual features that are associated with a response (for a review, see Koen & Yonelinas, 2014). Similarly, source memory accounts of age-related episodic memory deficits also claim that older adults experience impairments in memory for contextual information, as shown by poorer memory for the features associated with items than for the items themselves (for a review, see Dodson, 2017).

This incompatibility between the present results and these prominent theories further highlights the utility of the MFC framework for explaining age-related memory differences under retroactive experimental conditions. The feature of this framework that allows it to accommodate the present results is that it assumes that overall recall performance is comprised of a balance of facilitation and interference effects that is determined by the extent to which remindings occur and are later recollected. This framework could explain the lack of age differences in the susceptibility of retroactive interference by assuming age differences in encoding efficacy in List 2. Older adults may have encoded List 2 study items less effectively than younger adults, either because older adults experienced greater proactive interference (cf. Wahlheim, 2014) and/or because they strategically prioritized attention to List 1. In either case, List 2 pairs would be less competitive at retrieval for older than younger adults, which would reduce the need for recollection to retrieve List 1 responses. This may also explain why younger adults experienced greater List 2 intrusions onto List 1 recall. If younger adults processed List 2 more effectively than older adults, then it would be a stronger competitor when asked to recall List 1. Further empirical work is needed to test the viability of this proposal.

There are also methodological differences between the present and earlier experiments that could help explain why older adults were not more susceptible to retroactive interference in overall performance here. First, the materials used in the current study are different from previous experiments examining age differences in retroactive interference. In the current study, cues and responses within word pairs were semantically associated, while Traxler (1973), whose results showed greater retroactive interference for older adults, used unrelated word pairs. Given that older adults show greater episodic memory deficits in cued recall when word pairs are unrelated (e.g., Naveh-Benjamin, 2000, Experiment 4), the inclusion of semantically associated word pairs in the current study could have made those pairs memorable enough for older adults to eliminate retroactive interference through reminding or some other mechanism. Second, Traxler (1973) intermixed study and test trials, which could have encouraged participants to encode each list in isolation. Further, between-list retrievals occurred at short lags, and this could have limited the potential benefits of remindings on later recall. In contrast, in the present experiments, we encouraged participants to retrieve from List 1 during List 2, and such retrievals occurred at much longer lags. Based on the findings from Jacoby et al. (2015) showing that List 1 recall for A-B, A-C items was greater when remindings occurred at longer compared to shorter lags, we believe that the experimental conditions of including changes at longer lags between lists optimized the benefits of remindings on later List 1 recall for both age groups.

Although we found clear evidence for the role of reminding in age differences in retroactive effects of memory, one limitation to the study is that younger and older adults showed comparable List 1 recall. The lack of age differences in recall is inconsistent with most aging studies included in the literature, as cued recall performance is typically lower for older than younger adults (e.g., Craik & McDowd, 1987). Although this creates a minor complication for interpretation, it was more important that we found age differences in conditional analyses of List 1 recall when original learning was equated between age groups. Therefore, we argue that these experiments provide important information for theories of age-related memory differences. To improve the precision of interpretation in future experiments, it could be worthwhile to characterize our samples using a broader battery of standardized cognitive ability measures. This would allow us to examine the extent to which younger and older adults in our samples are representative of a larger group of people who were also tested on those measures.

Implications for the Memory-For-Change Framework

The MFC framework was originally proposed to explain proactive effects of memory (Jacoby et al., 2015; Wahlheim & Jacoby, 2013). Along with two recent studies (Jacoby et al., 2015; Negley et al., 2018), the present study extends MFC to explain how remindings and recollection of remindings can influence earlier memories under conditions of retroactive interference. In addition, one goal of Experiment 1 was to replicate the List 2 study time effects on remindings, and later List 1 recall shown by Negley et al. (2018). Classic interference theories predict that more exposure to List 2 items should increase retroactive interference, thus further impairing List 1 recall. However, MFC predicts that more exposure to List 2 items should increase the opportunity for remindings. Consistent with this, Negley et al. (2018) showed that longer List 2 study times (7 s vs. 1 s) were associated with higher List 1 recall, which was driven by higher rates of reminding and recollection of remindings.

We replicated the study time effect on reminding recollection in Experiment 1, as remindings were recollected more often when List 2 items appeared for a longer compared to a shorter length of time. However, in contrast to earlier findings, this effect was not associated with an increase in overall List 1 recall. Our failure to replicate the complete pattern of results could reflect the difference in presentation rates between studies. Rather than using 1 s for the shorter study time condition as in Negley et al. (2018), we chose 2 s to accommodate older adults because they are generally believed to be slower at encoding (e.g., Salthouse, 1996). However, the difference in study time from 2 s to 10 s resulted in negligible benefits for overall List 1 recall in the current study. The lack of benefit to overall List 1 recall from additional study time may have occurred because 2 s was sufficient to cue spontaneous remindings (cf. Benjamin & Tullis, 2010; Hintzman, 2011). It is possible that effect of study time observed by Negley et al. (2018) was the result of the shorter 1 s study time undermining the efficacy of List 2 items as retrieval cues for List 1 at test. To resolve this issue, one could examine how parametric manipulations of study time influence study phase retrievals and their consequences for memory in an A-B, A-C paradigm.

More generally, the recent studies examining the roles of remindings and recollection of remindings in retroactive effects of memory point out an important contrast with earlier studies examining the roles of remindings and their recollection in proactive effects of memory. For retroactive effects of memory, remindings are associated with facilitation in List 1 recall regardless of whether those remindings are later recollected (Negley et al., 2018). In contrast, for proactive effects of memory, remindings are only associated with facilitation of List 2 recall when those remindings are later recollected (e.g., Wahlheim & Jacoby, 2013). Consistent with Negley et al. (2018), the present study showed that remindings were necessary and sufficient to obtain retroactive facilitation. This finding is consistent with the notion that retrieval practice improves memory for original information. However, there was some ambiguity regarding whether recollecting reminding was associated with additional List 1 recall benefits. One possibility is that the facilitation from the reminding in List 2 elevated younger adults' performance near ceiling, leaving little room for reminding recollection to further increase performance. In addition, the number of observations for older adults in the reminding recollection cell could have limited our ability to detect additional benefits. More research is required to identify when reminding recollection benefits memory beyond remindings alone.

Concluding Remarks

The present findings implicate a critical role for reminding in retroactive effects of memory for older and younger adults. When remindings were recollected, both age groups avoided retroactive interference and showed retroactive facilitation. However, younger adults recollected more remindings than older adults, providing further evidence that older adults experience a recollection deficit. Further research on the factors that moderate the associations among remindings, their recollection, and retroactive effects of memory could fundamentally influence longstanding perspectives regarding age effects on episodic memory. Further research examining the role of remindings and recollection of remindings could also lead to integration-based interventions for the negative effects of retroactive interference that occur when separate events have both shared and distinctive features.

CHAPTER III: THE ROLE OF ATTENTION FLUCTUATING IN RECOLLECTING CHANGES

Abstract

Changes in stimulus features across episodes can lead to proactive interference. One potential way to avoid such interference is to detect and later recollect changes. The Memory-for-Change framework assumes that attention during encoding is necessary for detecting and later recollecting change. We tested this assumption in the current experiment by assessing the covariation of attention and change recollection in a large undergraduate sample (N=132). Participants studied a list of word pairs comprised of four seamless blocks. Some word pairs repeated across all four blocks (A-B^4), some were unique to each block (C-D), and some pairs repeated across the first three blocks with a changed response in the fourth block (A-B^3, A-D). To measure attention during study, participants periodically responded to probes asking whether they were on- or off-task. Participants then completed a cued recall test of responses from the fourth study block. To measure change recollection, participants were asked to identify which pairs changed during study and to report the earlier responses for pairs they identified as changed. Replicating prior findings, recollecting change was associated with proactive facilitation in recall of the most recent responses. Extending these findings, the frequency of on-task reports was positively associated with cued recall accuracy and change recollection in both within- and between-subjects comparisons. Together, these findings implicate a critical role for self-reported attention during study in change recollection, which is associated with proactive facilitation in recall of changed responses.

Introduction

In daily life, people experience moments of inattention, where their focus drifts from a current task to something irrelevant to the task. For routine activities, there are minor consequences associated with such attentional lapses because those activities can be performed automatically. However, attentional lapses may have greater consequences for novel activities that require new learning. To illustrate, suppose that someone was repeatedly told about the positive effects of a drug. Later, they were told that the drug also has negative side effects, but they were distracted by other thoughts when told this. Their divided attention may have impaired their encoding of the negative side effects, resulting in memory for only the positive effects. This impairment in memory updating could have negative consequences if this person decides to either take or recommend the drug. Such updating failures can be avoided by detecting and later recollecting information changes (e.g., Wahlheim & Jacoby, 2013; Jacoby et al., 2015), but little is known about the role of attention to changes in these effects. We addressed this here by examining how memory updating is associated with attention to changes during study and recollection of changes at test.

Episodic Memory Updating and Memory for Change

As illustrated by the example above, proactive interference effects are likely to occur when two stimuli have both shared and distinctive features. Proactive interference for individual items has often been examined using the A-B, A-D paradigm. In this paradigm, participants study two lists of paired associates and are later given a cued recall test for responses from the second list (for a review, see Anderson & Neely, 1996). The study lists sometimes contain a mixture of pairs that either repeat across lists (A-B, A-B), appear only in the second list (C-D), or have the same cue paired with different responses in each list (A-B, A-D). Proactive interference occurs for A-B, A-D items when the two responses compete at retrieval (e.g., Postman & Underwood, 1973). Proactive interference is observed as lower recall for recent responses (D) relative to control (C-D) items and higher intrusions of earlier responses (B) relative to baseline.

A recent theory of episodic memory updating proposes that recollecting integrated memory representations that include both responses can counteract proactive interference. According to the Memory-for-Change (MFC) framework (e.g., Jacoby et al., 2015; Wahlheim & Jacoby, 2013), recall performance for A-B, A-D items reflects a combination of both interference and facilitation effects that depend on how often changes are initially detected and later recollected. The MFC framework builds on Hintzman's (2004, 2010, 2011) recursive reminding hypothesis by proposing that when two stimuli have overlapping features, the current stimulus can trigger a reminding of the prior stimulus. This reminding enables change detection and encoding of configural representations that include both stimuli together with the cognitive operation (i.e., the reminding) that co-activated them in working memory. Configural representations are assumed to preserve the temporal order of the stimuli, since it can be inferred at retrieval that the reminder stimulus occurred more recently than the reminded stimulus. Critically, access to those representations is assumed to require recollection-based retrieval, which has recently been operationalized in paired associate paradigms as correct classification of changed test items as such and recall of the List 1 response (e.g., Garlitch & Wahlheim, 2020a; Wahlheim et al., 2019). Support for these predictions has been shown by proactive facilitation when changes are recollected, and proactive interference when changes are not remembered as such (Jacoby & Wahlheim, 2013; Jacoby et al., 2013; Jacoby et al., 2015; Putnam et al., 2014; Wahlheim, 2014, 2015; Wahlheim & Jacoby, 2013; Wahlheim & J. M. Zacks, 2019).

The MFC framework assumes that attention influences detection and recollection of change, but only a few studies have investigated this. These studies have focused on the role of controlled attention in detecting change and its consequences for later recall. For example, Jacoby et al. (2015) examined how varying instructions about the breadth of retrieval during encoding influenced change detection rates and associated differences in change recollection and recall of recent responses (also see Jacoby, 1974; Jacoby & Wahlheim, 2013). The main assumption was that the instructions given to participants guided their use of controlled attention to look back across various temporal distances to determine whether a currently perceived stimulus had changed from one presented earlier. Their variants of the A-B, A-D paradigm (Experiments 2 and 3) included pairs that changed at long lags (between List 1 and List 2) and pairs that changed at short lags (only within List 2), followed by cued recall of recent List 2 responses. One group of participants, who were instructed to only identify changes that originated from List 2, were assumed to direct their attention narrowly to items presented earlier in that list. In contrast, the other group of participants, who were instructed to identify changes originating from either List 2 or List 1, were assumed to direct their attention broadly back across both lists. Participants who looked back across both lists recollected more changes originating from List 1 than participants who looked back within List 2 only. Importantly, the group that looked back over both lists showed proactive facilitation in recall of List 2 responses for pairs that changed from List 1 to List 2, whereas the group that looked back within List 2 did not. These recall differences suggested that participants were able to differentially guide their attention to past events in order to detect changes in the present.

Results of this sort provide clear evidence that attention influences how often changes are detected from the past. Although compelling based on the causal inferences that can be drawn, the characterization of the role of attention in change detection from Jacoby et al. (2015) is limited. For example, the between-subjects manipulation reduces both intra- and inter-individual variability in participant-selected attention strategies for detecting change, and the procedure does not allow for direct assessment of memory differences associated with these sources of variability. Also, the conclusion about group differences in attention allocation was based on a combination of indirect measures during study and test, and data that were collapsed across participants within conditions. It is unclear from these experiments how momentary differences in attention during encoding is associated with change detection and performance on downstream memory measures, including change recollection.

The most novel contribution of the present study is that we addressed these limitations by directly measuring momentary fluctuations of attention in a variant of the A-B, A-D memory updating paradigm using self-reports. This allowed us to characterize intra- and inter-individual variation in attention to changed stimuli and associations with change recollection and other memory measures at test. Based on Jacoby et al. (2015), we assumed that when participants in the present experiment report attending to changed pairs during study, they should be more likely to retrieve related stimuli, thereby enabling change detection, and overtly recollect those detected changes at test.

Self-Reported Attention, Mind Wandering, and Episodic Memory

As stated above, previous work has examined how task-controlled attention influences episodic memory updating, but no studies to our knowledge have examined the association between momentary fluctuations in attention during encoding and change recollection at test. To develop a more comprehensive understanding of the role of attention in episodic memory updating, we sought inspiration from studies of self-reported lapses in attention, referred to as mind wandering. Mind wandering occurs when one’s thoughts drift from the current task to one’s internal state (for a review, see Smallwood & Schooler, 2015). Mind wandering episodes can be captured by inserting thought probes throughout a task that ask participants to report on their current thoughts (e.g., Smallwood & Schooler, 2006). Mind wandering typically increases during less demanding tasks (e.g., Smallwood et al., 2009) and as time on task increases (e.g., Metcalfe & Xu, 2016; McVay & Kane, 2012a; Teasdale et al., 1995, Experiment 3; Thomson, Seli et al., 2014). Mind wandering can also vary across people, as shown by consistency in mind wandering rates within people across tasks (e.g., McVay & Kane, 2012b) and by associations between mind wandering and executive control abilities (e.g., Kane et al., 2007, 2016; Kane & McVay, 2012; McVay & Kane, 2009).

The literature on the association between mind wandering and episodic memory has shown that mind wandering is associated with impaired memory when deep or elaborate processing is required during encoding (e.g., Maillet & Rajah, 2013; Thomson, Smilek, & Besner, 2014). For example, Thomson, Smilek, and Besner (2014) examined mind wandering in deep and shallow encoding conditions and associated differences in recognition memory between those conditions. Mind wandering reports were associated with poorer recognition memory only in the deep encoding condition (also see, Maillet & Rajah, 2013). However, this correlation was not present when controlling for the accuracy of the deep encoding judgements. This suggested that mind wandering interfered with participants’ ability to make correct encoding judgments, which reduced the effectiveness of deep encoding and impaired recognition memory.

Mind wandering has also been shown to disrupt the encoding that facilitates inductive reasoning and inferences. For example, mind wandering during encoding of artwork exemplars is negatively associated with classification of unstudied artwork from studied artists (Metcalfe & Xu, 2016). Mind wandering is also negatively associated with situation model updating in narrative comprehension (Smallwood et al., 2008). Smallwood et al. reasoned that mind wandering while reading critical passages prevented participants from retrieving and integrating information necessary to later make inferences. Finally, mind wandering is associated with poorer learning in both the classroom (Risko et al., 2012; Wammes et al., 2016) and the laboratory (Farley et al., 2013; Kane et al., 2017; Loh et al., 2016; Risko et al., 2013). Greater mind wandering during lectures was associated with poorer learning, presumably because the ability to retrieve knowledge and integrate it with new information was reduced when attention was not focused on the lecture.

Collectively, these findings suggest that when attention is off-task, particularly during a mind wandering episode, memory performance suffers. This relationship is most robust when encoding requires elaborative processing, such as during deep encoding (e.g., Thomson, Smilek, & Besner, 2014) or when information must be integrated (e.g., Smallwood et al., 2008). These findings inform predictions in the present study as change recollection is assumed to reflect retrieval of integrated representations formed using elaborative encoding processes. Based on these findings, we predict that when participants are off-task, they should be less likely to detect change and form the integrative representations that support change recollection at test.

The Present Study

The primary aim of the present study was to extend prior work examining the relationship between attention during encoding and associated memory performance, particularly the ability to update memory for changed information. The MFC framework assumes that attention is required to encode original and changed pairs during study. When attention is not engaged during either presentation, due to mind wandering or external distractions, changed pairs should trigger fewer retrievals of original pairs, thus precluding integrative encoding and diminishing recall of changed pairs. To our knowledge, this is the first study to directly test this idea by measuring the covariation among attention during study, change recollection at test, and recall performance. Here, we used a single-list variant of the A-B, A-D paradigm that included thought probes periodically during the study phase. The study phase consisted of word pairs that *repeated* four times, appeared once as *control* items, or repeated three times and included a *changed* response on the fourth appearance. The cued recall test assessed memory for the most recent responses paired with cues and recollection of changes between responses.

To foreshadow, we established that the single-list variant of the task replicated earlier findings showing proactive facilitation when change was recollected and proactive interference when change was not recollected (e.g., Jacoby et al., 2015; Wahlheim & Jacoby, 2013). Based on earlier studies showing a relationship between self-reported attention and memory (e.g., Thomson, Smilek, & Besner, 2014), we expected recall of recent responses and change recollection to be greater for participants who indicate being on-task more often and for items that are followed by on-task reports. We also expected these associations to be greater for items that required new learning than for repeated items because repetitions allowed for more encoding opportunities. Related to fluctuations of attention, we expected to replicate earlier findings showing that on-task reports decrease as time on task increases (e.g., McVay & Kane, 2012a). We also explored the possibility that new features of changed responses that did not appear in earlier repetitions may capture attention towards the end of the study phase, thus leading to more on-task reports.

Method

In what follows, we report how we determined sample size, all data exclusions, all manipulations, and all measures in this study (Simmons et al., 2012). The data and analysis scripts are available on the Open Science Framework: https://osf.io/56t9k/.

Participants

The final sample[2] consisted of 132 undergraduates (95 female), ages 18-29 (*M* = 19.02, *SD* = 1.70) from the University of North Carolina at Greensboro (UNCG). Participants were recruited from the Psychology Department participant pool. The sample size was based on the number of participants needed to examine the within-subjects interaction between task reports and item type on recall performance. Prior experiments manipulating external variables to influence change recollection and recall performance have found small to medium effect sizes effects ranging from $\eta_p^2 = .06 - .09$ (Negley et al., 2018; Wahlheim, 2015). According to G*Power Version 3.1.9.2 (Faul et al., 2009), with power = .80 and $\alpha = .05$ (two-tailed), a sample size of 128 is sufficient to detect a small to medium interaction effect ($\eta_p^2 = .06$) and a small to medium between-subjects correlation of $r = .25$. We included 132 participants to ensure that an equal number completed each of the 12 experimental formats (described in the next section). Participants received partial course credit as compensation.

Design and Materials

The current experiment used a within-subjects design, with Item Type (A-B^4 [*repeated*] vs. C-D [*control*] vs. A-B^3, A-D [*changed*]) as the independent variable. The materials consisted of 156 word sets (144 critical and 12 buffers) taken from Jacoby (1996) and Nelson et al. (1998).

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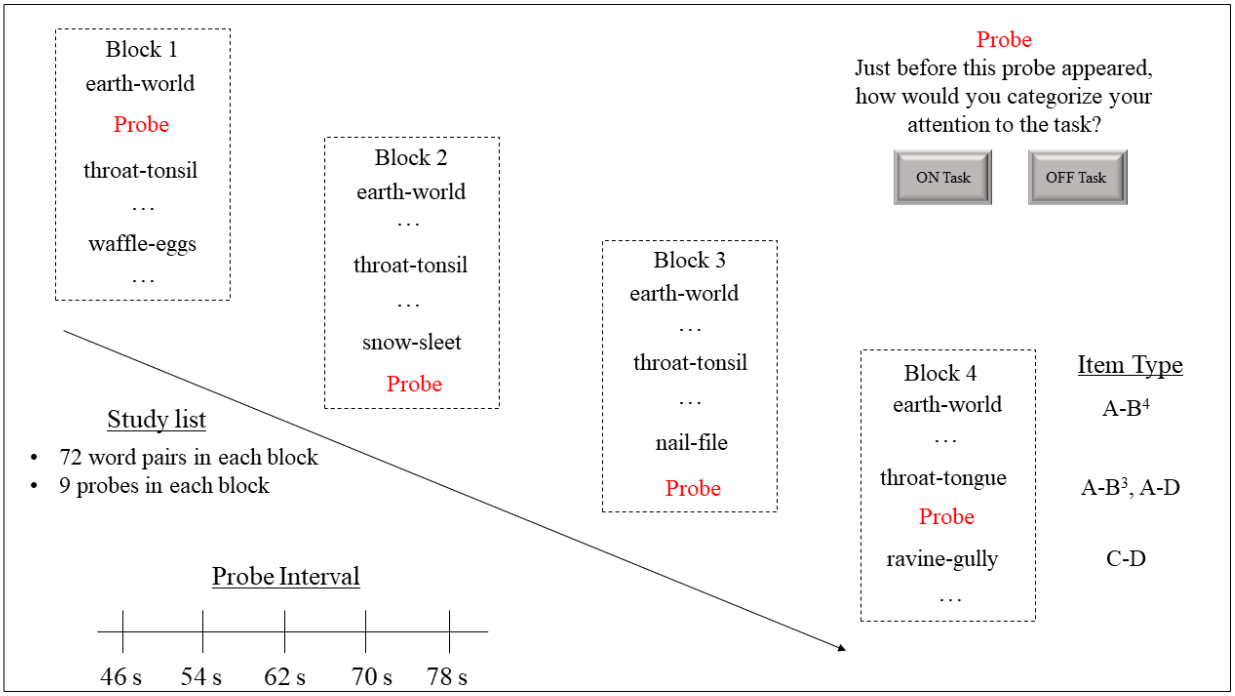
[2] Two participants were replaced, one due to an interruption from a fire drill, and one for falling asleep during the session (total of 134 participants tested).

Each set contained a cue (e.g., throat) and two responses (e.g., tonsil, tongue). The two responses had overlapping orthographic features because they were originally created so that each response could complete the same word fragment (e.g., ton_ _ _). We did not use the fragments. For counterbalancing, the critical word sets were divided into six groups of 24. Each group appeared as each item type equally often across participants. For the first six formats, the response arbitrarily labeled as Response 1 was the target word (e.g., *tonsil* appeared as the second or only response) while the response labeled as Response 2 was the target word for the other 6 formats (e.g., *tongue* appeared as the second or only response). The non-target response from each set appeared as the response in the first three blocks for A-B^3, A-D items.

The average lengths of cues (*M* = 5.26, *SD* = 1.60, range = 2-9) and responses (*M* = 4.76, *SD* = 1.08, range = 3-8) were matched across groups. The average word frequency, assessed using the Hyperspace Analog to Language method (HAL; Lund & Burgess, 1996), and catalogued by the English Lexicon Project (Balota et al., 2007), was matched across groups for the cues (*M* = 9.44, *SD* = 1.45, range = 6-14) and the responses (*M* = 9.34, *SD* = 1.60, range = 5-14). The associative strength between words in each set was indexed by the Nelson et al. (1998) free association norms. The average associative strength between cues and responses was low (forward: *M* = .06, *SD* = .08, range = .03-.10; backward: *M* = .08, *SD* = .14, range = .03-.15). The average forward and backward associative strengths between responses within sets was comparably low (*M* = .02, *SD* = .06, range = .001-.07).

A schematic for the study phase is shown in Figure 3. The study list comprised four seamless blocks with 72 word pairs in each block. One set of word pairs (24 in each block) *repeated* in all four blocks (A-B^4). Another set of word pairs (24 in each block; 96 total) that served as *control* items were new in each block and had no overlapping terms with pairs from previous blocks (C-D). The last set of word pairs (24 in each block) repeated across the first three blocks and then had the same cue word paired with a *changed* response in the fourth block (A-B^3, A-D). For example, the pair throat-*tonsil* could appear in the first, second, and third blocks and then the pair throat-*tongue* could appear in the fourth block. Buffer items appeared at the beginning and end of the study phase, with four buffer items from each of the three item types (12 total). Word pairs appeared in a fixed random order in each block of the study phase, with the stipulation that no item type appeared more than three times consecutively. The average serial position for each item type was equated within blocks to control for serial position effects.

Figure 3. Study Phase Schematic



Note. Schematic of study procedure. Participants studied a list that contained four seamless blocks. Each block contained word pairs that repeated across each block (A-B^4), repeated in the first three blocks and then had the same cue with a changed response in the fourth block (A-B^3, A-D), or were unique to each block (C-D). Thought probes were inserted pseudo-randomly such that three probes came after each Item Type in each block, and the probes appeared 6-10 word pairs apart. The probe appeared immediately after the previous word pair, and asked participants to indicate if they were on-task or off-task.

Nine thought probes appeared between word pairs in each of the four study blocks (36 total). We inserted the probes pseudo-randomly with the stipulation that an equal number appeared following each item type (i.e., three probes after each item type in each block). Probes were assigned to the same item type condition as the pair they followed. Probes appeared after 6-10 word pairs to minimize the systematicity of their presentation with intervals of 46, 54, 62, 70, or 78 s. The average duration between probes was 62 s (*SD* = 12.09 s). Each probe consisted of a discrete on-task or off-task judgment.

The test phase was self-paced and included cues from all 72 pairs that appeared in the fourth study block. The cues for the cued recall test appeared in a fixed random order for each of the 12 formats, with the stipulations that cues from the same item type condition did not appear more than three times consecutively and that the serial position was equated across item types.

Procedure

All participants were tested individually. All experimental stimuli were administered using E-prime software (Version 3, Psychology Software Tools, Inc). Word pairs and test cues appeared in white Arial size 24 font on a black background. Participants were told that their first task would be to study a list of word pairs for an upcoming memory test. Word pairs appeared for 6 s each with a 2 s interstimulus interval (ISI) between each presentation. Participants were told that they would periodically be asked about their attention to the task and were given an explanation about the meaning of “On-task” and “Off-task” reports (see Supplemental Materials for instructions). Each probe screen appeared immediately following the 6 s study duration for the previous word pair (before the ISI). We did this to ensure that participants made their probe judgments based on their attentional state while studying the prior word pair. Participants were told to indicate that they were "On task" or "Off task" by clicking on the corresponding button on the left or right, respectively. These responses were self-paced. The experimenter left the room after monitoring performance on the primacy buffers to allow for natural fluctuations in attention.

After the study phase, the experimenter returned and remained in the room for the test phase. Participants were told that their tasks would be to recall the most recent responses from the study phase and indicate when they remember that responses had changed (see Supplemental Materials for instructions). To begin, six of the buffer items appeared as practice items for the test phase. In both the practice and actual test phases, a cue appeared with a question mark (e.g., throat-?), and participants were asked to type the most recent response paired with each cue (e.g., tongue). After entering their response, a question appeared asking if the right word paired with the cue changed during the study phase. Participants indicated that responses had changed by pressing the "1" key and that responses had not changed by pressing the "0" key. When participants indicated that a pair had changed, they were asked to type the response that was paired with that cue earlier in the study phase (e.g., tonsil). When participants indicated that a pair had not changed, they moved on to the next trial. After completing the test phase, participants completed a final exploratory task[3]. Each session lasted approximately 1.5 hours.

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[3] As an exploratory measure, we examined the relationship between task reports in the current study and everyday attention errors by administering a computerized version of the Revised Attention Related Cognitive Errors Scale at the end of the experimental session (ARCES; Carriere, Cheyne & Smilek, 2008). For each participant, we calculated an item mean, with higher scores indicating more everyday attention errors (Cheyne, Carriere, & Smilek, 2006). The average score on the measure across all participants was *M* = 3.33 (95 % *CI* = [3.28, 3.38]).

Results

All analyses were conducted using R software (R Core Team, 2019). All models in the analyses below include subjects and items as random intercept effects and experimental manipulations as fixed effects unless otherwise noted. We fitted logistic mixed effects models using the glmer function from the lme4 package (Bates et al., 2015). We conducted hypotheses tests using the Anova function from the car package (Fox & Weisburg, 2011) and pairwise comparisons using the emmeans package (Lenth, 2018) with the Tukey method to control for the family wise error rate. For the interested reader, we also report results from ANOVAs and t-tests along with their corresponding standardized effect size estimates in the Supplemental Materials. The level for significance was set at α = .05. In what follows, we report analyses for each measure in approximately the order that they appeared during the experiment.

Study

On- and Off-Task Reports

In our first set of analyses, we tested the hypothesis that self-reported attention would decrease across the task and examined whether attention was captured by the characteristics of changed pairs. To assess self-reported attention across the study phase, we calculated the proportion of on-task reports as a function of Block (1-4) and Item Type (see Figure 4). A model

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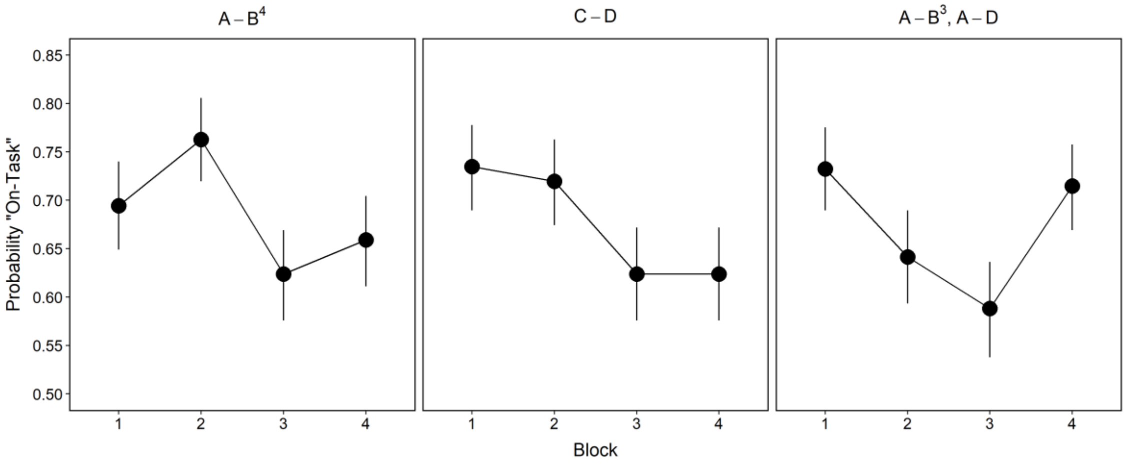
The correlation between the mean score on the ARCES and the proportion on task during the study phase was weak, *r*(130) = -.02, *p* = .79. This suggests that there was no relationship between the propensity to experience everyday attention errors, as indexed by the ARCES measure, and attention fluctuation during study. This lack of association could be because the ARCES was designed to tap into errors that occur as a result of lapses in attention and correlates most strongly with errors made on sustained attention tasks like the SART (Cheyne et al., 2006). Consequently, the measure may be best suited to assess self-reported attention lapses that follow errors, which was not a feature of the present experiment.

including Block and Item Type as fixed effects indicated a significant effect of Block, $\chi^2(3) = 40.94$, $p < .001$, no significant effect of Item Type, $\chi^2(2) = .83$, $p = .66$, and a significant Block × Item Type interaction, $\chi^2(6) = 26.00$, $p < .001$.

To investigate the Block × Item Type interaction, pairwise comparisons were conducted to examine the on-task reports across block for each item type. For A-B^4 items, the on-task proportion did not differ between Block 1 and the other three blocks, *largest z* ratio = 2.50, $p = .06$. The on-task proportion was higher in Block 2 than Blocks 3 and 4, *smallest z* ratio = 3.48, $p = .003$, and did not differ between Block 3 and 4, *z* ratio = 1.17, $p =.64$. For C-D items, the on-task proportion in Block 1 did not differ from Block 2, *z* ratio = .62, $p = .93$, but was significantly higher in Blocks 1 and 2 than in Blocks 3 and 4, *smallest z* ratio = 2.80, $p = .03$. The on-task proportion did not differ in Block 3 and Block 4, *z* ratio = .18, $p = 1.00$. For A-B^3, A-D items, the on-task proportion was significantly higher in Block 1 than in Blocks 2 and 3, *smallest z* ratio = 2.79, $p = .03$, but did not differ from the on-task proportion in Block 4, *z* ratio = .53, $p = .95$. The on-task proportion in Block 2 did not differ from Blocks 3 and 4, *largest z* ratio = 2.27, $p = .11$. Notably, the on-task proportion was significantly higher in Block 4 than in Block 3, *z* ratio = 3.53, $p = .002$.

To examine how this increase in on-task reports for A-B^3, A-D items compared to on-task reports for the other item types, we examined the pairwise comparisons for Block 4 across item types. There was a significant difference for on-task reports in Block 4 between A-B^3, A-D and C-D items, *z* ratio = 2.81, $p = .01$. There was not a significant difference for on-task reports in Block 4 between A-B^3, A-D and A-B^4, *z* ratio = 1.81, p = .17, but it was in the direction that would be expected (A-B^3, A-D: $M = .71$, 95% CI [.66, .76], A-B^4: $M = .66$, 95% CI [.61, .71]). Collectively, these results suggest that attention decreased across the study phase, which is consistent with earlier findings. However, attention to changed items also appeared to increase in Block 4. Importantly, this was not a novelty effect because on-task reports did not follow this pattern for C-D items and were significantly lower in Block 4 for C-D compared to A-B^3, A-D items.

Figure 4. Study Phase On-Task Probability



Note. Probability of on-task reports as a function of Item Type and Block. Error bars are bootstrap 95% confidence intervals.

Test

Recall Performance

Here, we examined the effect of Item Type on correct recall and intrusions. We expected to replicate earlier findings showing better recall for repetitions (A-B^4) than single presentations (C-D). It was unclear whether changed pairs (A-B^3, A-D) would lead to overall proactive facilitation or interference, and the extent to which intrusions would be output, because that cell should comprise a mixture of facilitation and interference effects that depend on the extent to which change is recollected (Wahlheim & Jacoby, 2013).

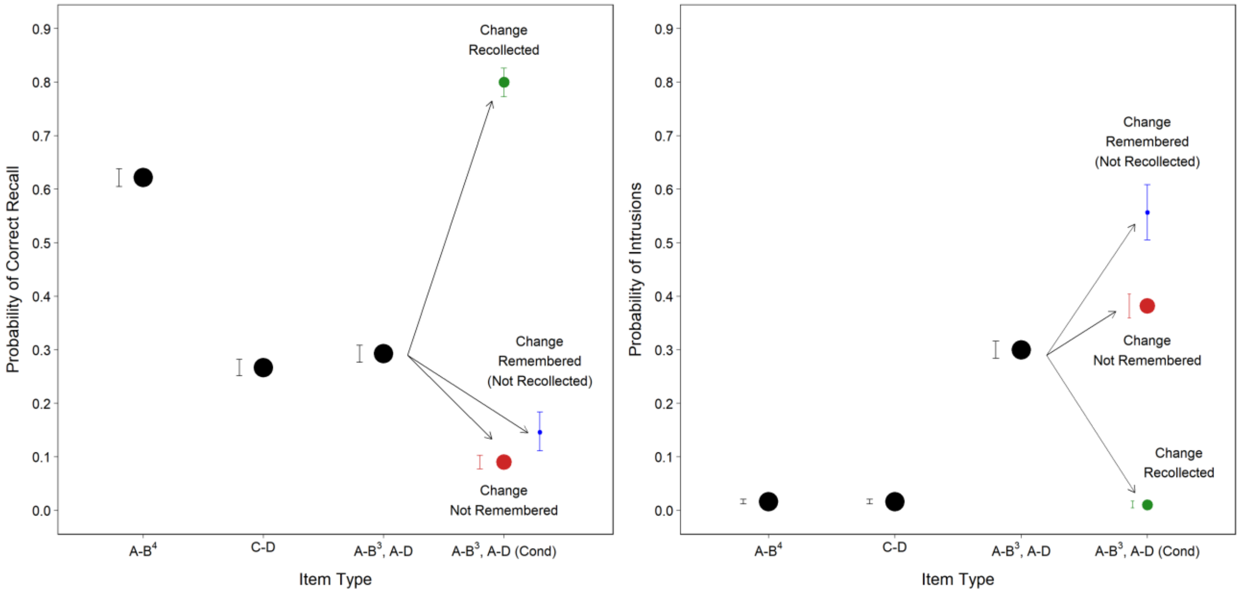
Figure 5 (left panel, black points) displays correct recall of Block 4 responses. A model with Item Type as a fixed effect indicated a significant effect, χ^2 (2) = 1167.60, *p* < .001, showing that recall for A-B^4 items was higher than for the other two item types, *smallest z* ratio = 28.81, *p* < .001. Recall for A-B^3, A-D items was also higher than for C-D items, *z* ratio = 2.67, *p* = .02. These results show that spaced repetitions of A-B pairs improved memory for those items above once-presented items. In addition, spaced repetitions of A-B pairs prior to changed A-D pairs led to proactive facilitation in overall recall. Later, we verify that this facilitation effect was associated with the extent to which change was recollected.

Figure 5 (right panel, black points) displays intrusions of responses from Blocks 1-3 (for A-B^3, A-D items) and baseline intrusion rates (for A-B^4 and C-D items). The baseline intrusion rates are estimates of how often participants produced what would have been the earlier response for items in the A-B^3, A-D condition. A model with Item Type as a fixed effect indicated a significant effect, χ^2 (2) = 982.26, *p* < .001, showing that intrusions were higher for A-B^3, A-D items than both baseline estimates for the other item types, *smallest z* ratio = 23.18, which were not significantly different, *z* ratio = .11, *p* = .99. These results show that participants experienced proactive interference on A-B^3, A-D items that led to intrusion errors.

Change Classifications

Next, we assessed change classification rates to contextualize later analyses of cued recall conditionalized on those classifications. The probability of correct classifications for A-B^3, A-D items was .39 (95% CI = [.37, .41]). False alarms to A-B^4 and C-D items were rare, but did occur slightly more often for A-B^4 (*M* = .06, 95% CI = [.05, .07]) than for C-D items (*M* = .05, 95% CI = [.04, .06]), *z* ratio = 2.73, *p* = .02. As described in the Introduction, the MFC framework proposes that change recollection allows one access to the configural representation that contains both responses and their relative order. Most recently, change recollection has been operationally defined as instances when changed items are classified as such and participants can recall the earlier response (e.g., Wahlheim et al., 2019; Wahlheim & J. M. Zacks, 2019). We followed that definition here. When participants classified changed items correctly but could not recall the earlier response, we categorized those instances as Change Remembered (Not Recollected). Theoretical work is still needed to explain the processes leading to different patterns for those instances, so we interpret them cautiously. Finally, when participants did not classify changed items as such, we categorized those instances as Change Not Remembered. The probabilities for each change classification category were the following: Change Recollected (*M* = .28, 95% CI = [.26, .30]); Change Remembered (Not Recollected) (*M* = .11, 95% CI = [.10, .13]); and Change Not Remembered (*M* = .61, 95% CI = [.59, .63]).

Figure 5. Probabilities of Correct Recall and Intrusions



Note. Probabilities of correct recall (left panel) and prior-block intrusions (right panel) as a function of Item Type. Black points represent overall performance on each measure for each Item Type. The green point represents conditionalized performance for A-B^3, A-D items given that participants indicated change and were able to recall the earlier response (Change Recollected). The blue point represents conditionalized performance for A-B^3, A-D items given that participants indicated change and did not correctly recall the earlier response (Change Remembered). The red point indicates conditionalized performance for A-B^3, A-D items given that participants did not indicate change (Change Not Remembered). The size of the colored points indicates the relative frequencies of responses in each cell. Error bars are bootstrap 95% confidence intervals. Confidence intervals that could not be seen around their respective points are displayed to the left of those points.

Recall Performance Conditionalized on Change Classifications

In our next set of analyses, we conditionalized recall performance on the change classifications described above to verify that the associations between these measures shown in earlier studies replicated here in our single-list variant of the A-B, A-D paradigm. We conditionalized correct recall and intrusions for A-B^3, A-D items on the three instances of change classification outlined above (Figure 5, green, blue, and red points). We fit separate models with a fixed effect of Change Classification to the conditionalized recall and intrusion data. The model for correct recall also included C-D items to assess proactive effects of memory of earlier responses on recall of the most recent response for A-B^3, A-D items.

Based on earlier studies, we expected change recollection to be associated with higher correct recall. The model for correct recall indicated a significant effect of Change Classification, $\chi^2(3) = 669.37$, $p < .001$. Recall performance was significantly higher for Change Recollected responses compared to the other two classification types, *smallest z* ratio = 15.62, $p < .001$, and did not differ between those other classifications, *z* ratio = 2.01, $p = .18$. Proactive facilitation was observed when change was recollected, as recall for A-B^3, A-D items was significantly higher than recall for C-D items, *z* ratio = 20.42, *p* < .001, whereas proactive interference was observed in the other cells in which participants did not recollect change, as recall for A-B[3], A-D items was significantly lower than recall for C-D items, *smallest z* ratio = 4.65, *p* < .001. These results replicate prior results showing a strong association between change recollection and correct recall of recent responses (e.g., Jacoby et al., 2015; Wahlheim & Jacoby, 2013).

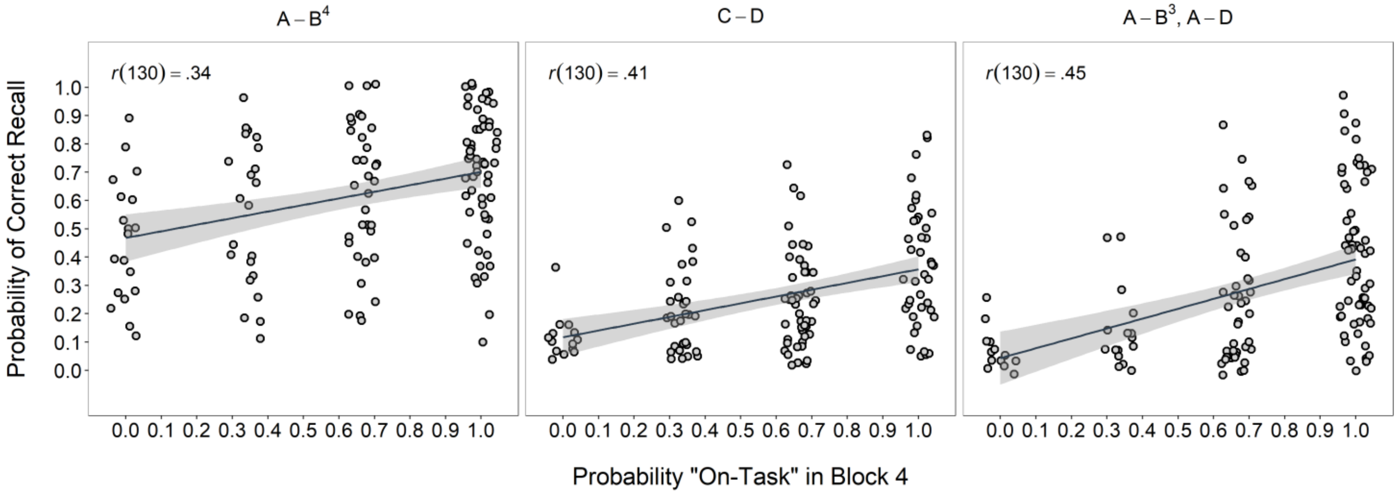
For intrusions, we expected that when participants recollected change, which we defined here as correct recall of the earlier response following a change classification, they would rarely, if ever produce an intrusion. We expected this because responses of that kind would only occur when participants output the earlier response twice; once as the most recent response and once as the earlier response. We considered these instances to reflect guessing, but we plotted those data to visualize the proportion of observations for change recollection relative to the other cells and to distinguish between intrusion rates associated with the two classifications that included correct change classifications. The model indicated a significant effect of Change Classification, χ^2 (2) = 205.20, *p* < .001, showing significantly fewer intrusions in the Change Recollected cell than the two other two cells, *smallest z* ratio = 12.96, *p* < .001. Unexpectedly, intrusions were also significantly lower for Change Not Remembered responses compared to Change Remembered (Not Recollected) responses, *z* ratio = 5.22, *p* < .001. From the perspective of the MFC framework, these instances may have reflected memory for change without recollection, which could render participants unable to oppose the high accessibility of A-B responses established through repeated presentations. However, we interpret these differences cautiously and document them primarily for comparison with other studies and to inspire future theorizing.

Relationships between Attention during Study and Memory at Test

The analyses above established that self-reported attention generally decreased across the study phase, but attention increased when changed items appeared in Block 4. The analyses above also established that change recollection was associated with proactive facilitation and that the absence of change recollection was associated with proactive interference. Having established these patterns, we next examined associations between self-reported attention during the study phase and both recall of recent responses and change recollection at test.

We first tested the prediction that correct recall of recent responses should be greater for participants who indicate being on-task more often than those who indicate being on-task less often. Since participants were only tested on items from Block 4, we correlated recall performance to on-task reports in Block 4 only. To do this, separate between-subjects Pearson product-moment correlations were computed for each Item Type between on-task report proportions in Block 4 and correct recall of Block 4 responses. Figure 6 shows that there were positive correlations between on-task reports and correct recall with medium to large effect sizes for each item type (A-B^4: $r(130) = .34$, $p < .001$; C-D: $r(130) = .41$, $p < .001$; A-B^3, A-D: $r(130) = .45$, $p < .001$). Next, we computed correlations between Block 4 on-task reports and intrusions for A-B^3, A-D items to examine how attention during encoding of changed items, which only appeared in Block 4, would influence intrusions. We treated this analysis as exploratory because we reasoned that being on-task more often during Block 4 could indicate that more attention was also allocated during encoding of responses from Blocks 1 – 3. Indeed, there was a strong positive correlation between on-task reports collapsed across Blocks 1 – 3 and on-task reports in Block 4, $r(130) = .67$, $p < .001$. This increased attention in Blocks 1 – 3 could facilitate rejection of intrusions post retrieval, make intrusions more accessible and likely to be misattributed as accurate, or some combination of both. Figure 7 (left panel) shows that on-task reports and intrusions were negatively correlated with a small effect size, $r(130) = -.12$, $p = .16$. Finally, to test the hypothesis that change recollection would be higher for participants who were on-task more often, we computed correlations between Block 4 on-task reports and change recollection for A-B[3], A-D items. Figure 7 (right panel) shows that on-task reports and change recollection were positively correlated with a medium effect size, $r(130) = .39$, $p < .001$. Together, these results show that participants who reported being on-task more in Block 4 had higher correct recall, fewer prior-block intrusions, and higher rates of change recollection than participants who reported being on-task less often. We interpret the negative correlation between on-task reports and intrusion cautiously due to the exploratory nature of the analyses and the small effect size.

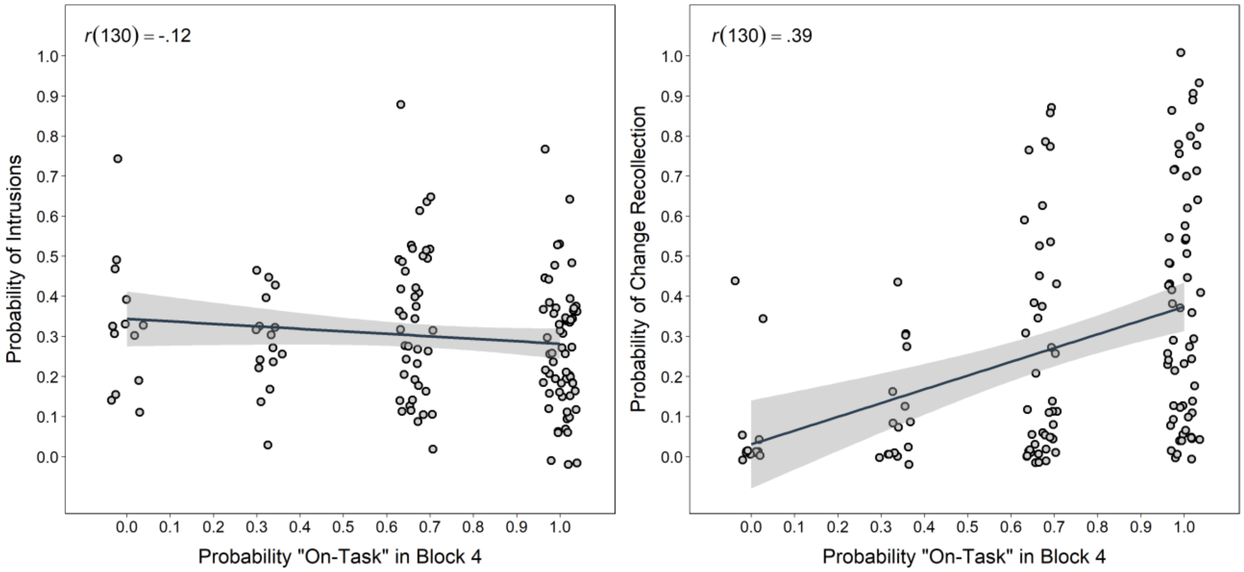
Figure 6. Between-Subject Correlations of On-Task Probability and Correct Recall



Note. Between-subjects correlations between Block 4 probability on-task and correct recall for each Item Type. Given that this analysis was only for Block 4, the on-task probabilities were calculated based on three probes per participant for each Item Type. The shaded regions show bootstrap 95% confidence intervals. The effect size and degrees of freedom for each correlation are displayed in the upper left corner of each panel.

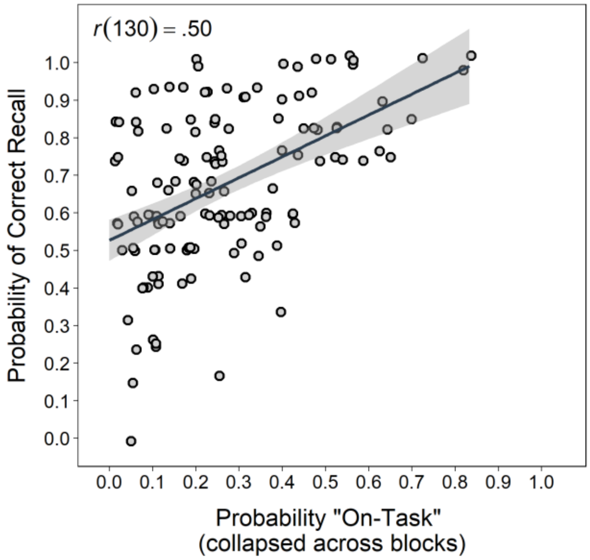
We conducted another exploratory analysis to more generally characterize the association between individual variation in attention during study and episodic memory at test in our sample. We computed the between-subject correlation between on-task reports collapsed across all study blocks and recall performance for C-D items. Figure 8 shows that these variables were positively correlated with a large effect size, $r(130) = .50$, $p < .001$, showing that participants who paid more attention during encoding also retrieved episodic memories more accurately.

Figure 7. Between-Subjects Correlations for On-Task Probability and Intrusions and Change Recollection



Note. Between-subject correlations between Block 4 probability on-task and intrusions (left panel) and change recollection (right panel) for A-B[3], A-D items. Given that this analysis was only for Block 4, the proportion on-task was calculated based on three probes per participant. The shaded regions show bootstrap 95% confidence intervals. The effect size and degrees of freedom for each correlation are displayed in the upper left corner of each panel.

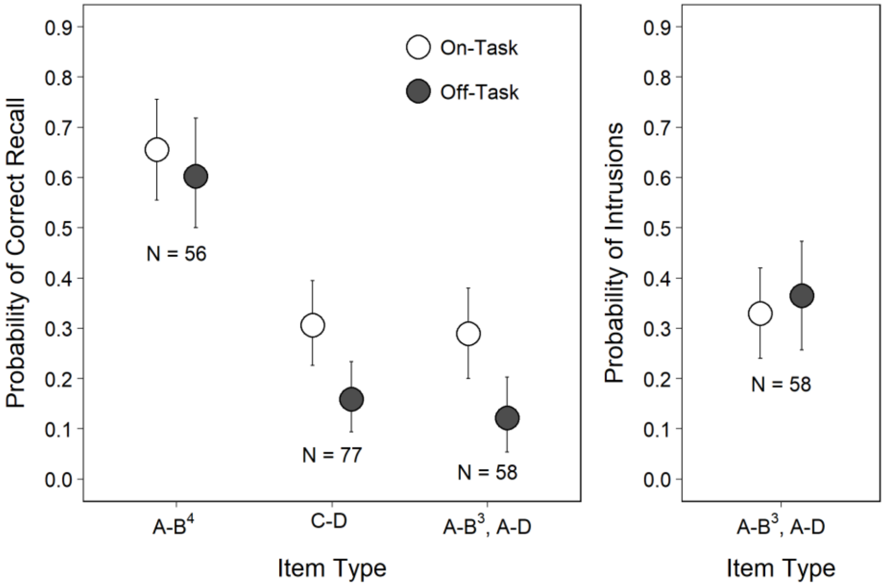
Figure 8. Between-Subjects Correlation for On-Task Probability and Recall of Control Items



Note. Between-subjects correlation between the probability on-task during study and correct recall for C-D items. The proportion on-task was calculated based on all 36 probes. The shaded region shows the bootstrap 95% confidence interval. The effect size and degrees of freedom are displayed in the upper left corner of the figure.

Next, we tested the prediction that the associations between on-task reports and memory measures should be stronger for items that require new learning than for repeated items by examining recall performance conditionalized on thought probe responses during study. We assumed that if self-reported attention during study improves the ability to correctly recall recent responses, then participants should recall more responses for study items that were followed by on- than off-task reports. Further, we expected this difference to be greater for pairs that appeared for the first time in Block 4 (i.e., in the C-D and A-B^3, A-D conditions) than items that repeated throughout the study phase (i.e., A-B, A-B items) because repeated items would have more opportunities to be encoded with full attention. We first conditionalized correct recall for each Item Type on whether participants gave an on- or off-task report during Block 4 (Figure 9, left panel). This analysis only included participants with at least one of each task report in Block 4. This resulted in different combinations of participants being included in each Item Type condition (for the sample sizes, see Figure 9), and in comparisons of recall differences between Task Reports being made within participants.

Figure 9. Probability of Correct Recall and Intrusions Conditionalized on On-Task Reports



Note. Probability of correct recall (left panel) and intrusions (right panel) as a function of probe reports in Block 4. The number of participants that contributed to each on- and off-task comparison is displayed below the recall probabilities for each Item Type. Error bars are bootstrap 95% confidence intervals.

We fitted a model to the conditionalized correct recall data that included fixed effects of Item Type and Task Report. The model indicated a significant effect of Task Report, χ^2 (1) = 10.26, p = .001, showing that correct recall was higher when participants reported being on- than off-task. The interaction between Item Type and Task Report was not significant, χ^2 (2) = 2.77, p = .25, but visual inspection suggested that, consistent with our hypothesis, the recall advantage for on-task reports was greater for novel Block 4 items. Pairwise comparisons confirmed this observation as there was no significant recall difference between task reports for A-B^4 items, *z* ratio = .69, $p = .49$, but recall was significantly higher for on- than off-task reports for both C-D items, *z* ratio = 2.58, $p = .001$, and A-B^3, A-D items, *z* ratio = 2.44, $p = .01$. These preliminary results suggest that the relationship between attention during Block 4 study and correct recall was stronger for new and changed items than for repeated items. We also conducted an exploratory analysis of intrusions with a model fitted to only A-B^3, A-D items (Figure 9, right panel). Consistent with the comparable between-subject correlation above, the model indicated no significant effect of Task Report, $\chi^2(1) = .23$, $p = .63$, showing little, if any, association between task reports and intrusions.

In our final set of analyses, we tested the prediction that change recollection would occur more often when participants reported being on- than off-task during Block 4 study. We also performed an exploratory analysis of the association between task reports and remembering but not recollecting change for which we had no a priori prediction. We assessed differences in the rates of each change classification type conditionalized on task reports (see Figure 10) by fitting separate models with a fixed effect of Task Report to each classification. The model for Change Recollected indicated a significant effect, $\chi^2(1) = 5.98$, $p = .01$. The model for Change Remembered indicated no significant effect, $\chi^2(1) = 2.76$, $p = .10$. Finally, the model for Change Not Remembered indicated a significant effect, $\chi^2(1) = 29.75$, $p < .001$. Together, these results show that when participants reported being on-task while studying changed pairs during Block 4, they recollected changes more often at test.

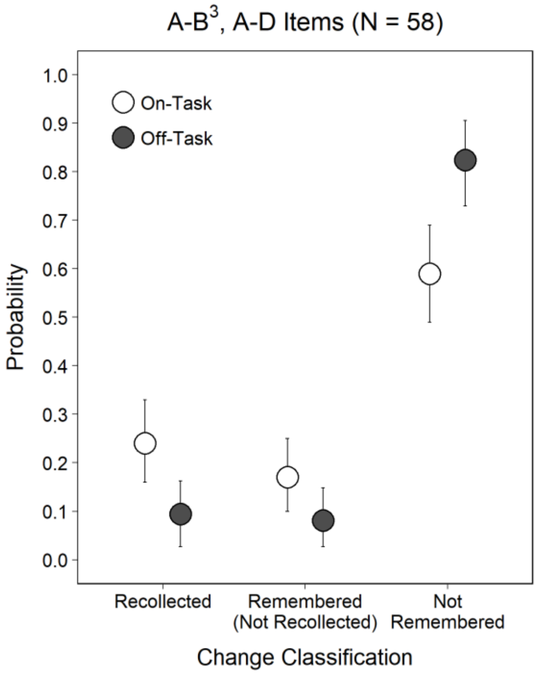
Discussion

The present experiment examined how natural fluctuations in self-reported attention were associated with change recollection and memory performance under conditions that could lead to proactive interference effects. The results showed that attention generally decreased across the study phase, except when changed items appeared in the last block. In addition, cued recall for changed items replicated prior findings showing that overall performance comprised a mixture of proactive facilitation and proactive interference effects, depending on whether change was recollected or not. Analyses examining the relationship between self-reported attention during study and memory measures at test showed positive associations between on-task reports and correct recall of recent responses in both between- and within-subject comparisons. For the latter, there was suggestive evidence that this association was greater for items that were novel during the last study block than for items that repeated across study blocks. Critically, both between- and within-subjects comparisons also showed that on-task reports were positively associated with change recollection. In what follows, we discuss the implications of these findings for the MFC framework perspective on memory updating and the literature reporting associations between on-task reports and episodic memory performance.

Attentional Fluctuation and Memory for Changes

As described in the Introduction, the MFC framework proposes that overall recall performance for changed items in an A-B, A-D paired associate learning paradigm comprises both proactive facilitation and interference effects. When change is recollected, proactive facilitation is observed and when change is not recollected, proactive interference is observed (Jacoby et al., 2015; Wahlheim & Jacoby, 2013). We replicated these effects which are typically observed in dual-list paradigms using a single-list variant with changes occurring towards the end of the list. We also observed overall proactive facilitation for changed items, suggesting that the current design and materials lead to frequencies of change detection and recollection that were suitable to produce proactive facilitation in overall recall.

Figure 10. Probability of Change Classifications Conditionalized on On-Task Reports



Note. Probability of change classifications as a function of Task Reports in Block 4 for A-B^3, A-D items. The number of participants that contributed to the on- and off-task comparison is displayed in parentheses in the figure title next to the Item Type. Error bars are bootstrap 95% confidence intervals.

The most novel contribution of the present study to the episodic memory updating literature was the examination of the association between self-reported attention during encoding and change recollection at test. This allowed us to evaluate an untested assumption of the MFC framework about the role of attention in change processing and the associated benefits for memory updating. Based on previous work showing that elaborative encoding is more effective for later memory performance when mind wandering does not occur (e.g., Thomson, Smilek, & Besner, 2014), we predicted that on-task reports would be positively associated with change recollection, which would be associated with higher memory accuracy on the cued recall test. Consistent with this hypothesis, we found that people who were on-task more often were more likely to show higher recall for all item types and higher change recollection than people who were on-task less often. Furthermore, when participants indicated being on-task in the last block, change recollection rates and correct recall for A-B^3, A-D items were both higher than when participants were off-task. Taken with the finding that change recollection is associated with proactive facilitation in recall of recent responses, the positive association between on-task reports and change recollection provides correlational evidence supporting the casual assumption of the MFC framework that attention to changed stimuli during encoding can trigger retrieval of related stimuli that appeared earlier and enable encoding of configural representations that preserve memory for temporal order.

As described above, we also expected that recall differences based on task reports would be greatest for novel items that appeared in Block 4 because that was the only opportunity to encode such items. Consistent with this prediction, on-task reports during the final study block were associated with higher recall performance for both C-D and A-B^3, A-D items, but not A-B^4 items. However, we interpret these findings with caution because they emerged from pairwise comparisons that followed up a non-significant interaction. Note that we were underpowered to detect this interaction after excluding participants from the analysis if they did not make at least one on-task and one off-task report in Block 4.

The associations between attention during study and change processing reported here suggest that more theoretical work is needed for the MFC framework to account for the role of variations in attention in the memory benefits observed when changes are detected and recollected. The present results suggest that conscious attention to the changed response may be required to stimulate retrievals, either spontaneously or with controlled processes, that enable integration of both the original and changed response into configural memory representations. One fruitful direction for development of the MFC framework would be to conduct empirical studies aimed at characterizing how self-reported attention to both original and changed information are associated with later memory performance. This would provide a more complete view of how attentional process give rise to the formation of configural representations. Another direction would be to manipulate how participants allocate attention to changed items, perhaps using incentives (cf. Friedman & Castel, 2013), to establish a causal link between controlled attention during encoding and the memorial benefits associated with detecting and recollecting change.

Mind Wandering and Episodic Memory

In the current experiment, we used thought probes as a tool to measure attentional fluctuation during study. By doing so, the present findings can further contribute to the limited literature reporting associations between mind wandering and episodic memory in standard memory paradigms. Research has shown that the type of processing used during encoding can influence how likely participants are to pay attention. When participants are asked to engage self-referential encoding (Maillet & Rajah, 2013), or if the word is too easy or too difficult for them to study (Xu & Metcalfe, 2016), they are more likely to mind wander. The present results add to these findings by showing that participants are less likely to mind wander when changed items appear after several repetitions. We interpret our findings as showing that changed pairs captured participants’ attention more than did repetitions or even completely novel items. This could reflect a type of memory based-prediction error that occurs when repeated cues lead participants to expect responses that they remembered from prior repetitions (for a similar suggestion in the context of event comprehension, see Wahlheim & J. M. Zacks, 2019). It is also possible that the increase in attention to changed items could represent an increase in task difficulty, as this has also been shown to reduce mind wandering (e.g., Ju & Lien, 2018; Rummel & Boywitt, 2014).

This finding of increased attention to changes is somewhat consistent with other work showing that different kinds of stimulus changes are associated with less mind wandering. For example, Faber et al. (2018) examined the number of self-caught mind wandering episodes while participants watched a narrative film that included a range of situational changes. They found that more situational changes in the narrative and a higher likelihood of an event boundary (which is another type of change) were associated with less mind wandering. Related to this, Metcalfe and Xu (2016) found that interleaving artwork from different artists during study led to less mind wandering than did presenting the artwork from the same artist in a massed fashion (for additional evidence of differential allocation of attention during blocked and intermixed study, see, Wahlheim et al., 2011). Together these findings suggest that changes either at the situation model or item level may help one sustain their attention during a task. This may have also occurred in the present experiment when changed responses appeared in the last block of the study phase.

Another possibility is that retrieving the earlier response when changed responses appeared (which was assumed to occur during change detection) acted as a type of test. Prior work has shown that inserting tests during study can reduce the rates of mind wandering (Szpunar et al., 2013). According to the MFC framework, the presentation of a changed A-D pair may have stimulated retrieval of earlier A-B pairs, suggesting that A-D pairs sometimes acted as test cues. It could be argued that the presentation of a repeated A-B pairs may also stimulate the retrieval of earlier A-B pairs (Wahlheim et al., 2014), but the experience associated with such retrievals may differ. The retrievals triggered by A-D pairs will likely stimulate a qualitatively different subjective experiences and subsequent representations because of the additional response (i.e., the D term) compared to retrievals triggered by the re-presentation of A-B pairs.

Limitations and Future Directions

Although the results of the current study support the proposed relationship between attention and the ability to recollect changes, there are several limitations that should be acknowledged. First, the current study included thought probes that were inserted pseudo-randomly throughout the blocks in order to capture attention lapses more naturally, but this meant that there was not a direct match for probes to appear after the same items in each block. Consequently, the data reported here do not allow us to draw conclusions about attention allocation for the original and changed presentation of specific items during the study phase. In order to more accurately capture the associations of attention on change detection and recollection for items, we plan to compare attention for the presentations of both the A-B item and associated A-D items in the study phase and then examine the associations between task reports and later memory measures. In addition, we plan to increase the number of changes in the study list to increase observations. One concern with the current experiment is that the primary analyses involved conditionalization and, as noted earlier in the Discussion, many participants had to be removed from the analyses because they did not have both an on- and off-task report in Block 4, thereby reducing power. Consequently, one limitation that should be improved on in future work is increasing the power to detect the experimental effects of interest.

As with earlier studies relying on self-reported mind wandering episodes, the accuracy of self-reported attention to the task is difficult to verify. Furthermore, it is possible that variations in the experimental design could influence the results. For example, asking participants to make a discrete on- and off-task judgement in the current study deviates from other mind wandering work that uses several categorized thought options (e.g., Kane et al., 2007; Kane et al., 2017) or explicitly gives participants the option to indicate that they are “mind wandering” (e.g., Metcalfe & Xu, 2016; Xu & Metcalfe, 2016). Prior work has found that mind wandering rates can vary as a function of probe framing (e.g., Weinstein et al., 2018), and this could influence the rates at which participants reported being on-task in the present experiment. Furthermore, due to the constraints of the present design, probes appeared 62 seconds apart on average. Choices about the distance between probes could also impact on-task reports because mind wandering rates increase with the time between probes (Seli et al., 2013). Given these considerations, future work should examine how thought probe framing and timing moderate the relationship between self-reported attention and change processing.

Conclusions

The current experiment was the first to characterize the associations between attention fluctuation, change processing, and episodic retrieval in order to test the assumption from the MFC framework about the role of attention in episodic memory updating. Results showed that recall performance and change recollection were higher when participants reported being on- than off-task in both between- and within-participant comparisons. These correlational results are consistent with the MFC framework, positing that attention to changed stimuli during encoding is necessary to later recollect changes, which in turn is associated with higher memory performance for more recent responses. Future work should examine the causal role of attention during encoding on memory for changes, examine how combinations of attention on both original and changed information can influence the processes posited by the MFC framework, and test the boundary conditions of the present findings using various thought-probe methods from the mind wandering literature.

CHAPTER IV: DIRECTING ATTENTION TO EVENT CHANGES IMPROVES MEMORY UPDATING

Abstract

People use memory for observed actions to guide current perceptions. When actions change from one situation to the next, one must register the change to update memory. Research suggests that older adults may sometimes update memory for naturalistic action changes less effectively than younger adults. We examined whether this deficit reflects age differences in attention allocation by cuing attention to changed action features and testing memory for those features. Older (*N* = 47) and younger (*N* = 73) adults watched movies of an actor performing everyday activities on two fictive "days" in her life. Some activities began identically on both days (e.g., reaching for dessert) and ended with features that changed across days (e.g., cookie vs. brownie). Half of the changed activities included audio-visual cues on both days that signaled changed features, whereas the other half did not include cues. Memory updating was assessed through cued recall and two-alternative forced choice recognition of recent action features. Cuing attention improved cued recall but not recognition of recent action features for both older and younger adults. These recall benefits were associated with improved recollection that changes had earlier occurred. The present findings suggest that although older adults sometimes experience deficits in aspects of attention, using cues to guide their attention to features of everyday activities can enhance their event memory updating when the later memory test emphasizes recollection-based retrieval.

Introduction

People often repeat everyday actions. But when circumstances change, people must modify their behavior. For example, suppose a physical therapist demonstrates an exercise technique to relieve a patient's neck pain. Then, on a later visit, the therapist demonstrates a modified technique to further the patient's rehabilitation. The patient must comprehend the change to later remember the updated action. Otherwise, the patient may continue to perform the earlier exercise, thus slowing their recovery. The ability to update memory for prior actions is critical for navigating such everyday changes. Older adults have been shown to experience deficits in memory updating for naturalistic action changes (Stawarczyk et al., 2020; Wahlheim & J. M. Zacks, 2019) and memory for the source of event details (for a review, see Dodson, 2017). To improve these abilities in older adults, we must first identify their underlying mechanisms. Here, we examined the role of controlled attention in event memory updating.

We assessed this mechanism based on views proposing that attention is necessary to detect changes during ongoing perception (e.g., Andermane et al., 2019; Rizzo et al., 2009) and across episodes (Garlitch & Wahlheim, 2020b; Wahlheim & J. M. Zacks, 2019), and that older age is associated with some deficits in attention when executive control is required (McCabe et al., 2010). When these age-related impairments in controlled attention are observed, they have also been linked to deficits in self-initiated elaboration during encoding that impairs retrieval of episodic memories (e.g., for a review, see Craik, 2020). Therefore, age differences in attention allocation may partly account for findings showing less effective event memory updating for older than younger adults. We tested this in the current study by using cues to direct older and younger adults' attention to action changes occurring across episodes. Our approach was inspired by findings showing that older adults can prioritize attention to subsets of information (for a review, see Castel, 2008). We reasoned that if age-related updating deficits occur when attention to changes in ongoing actions is inefficiently allocated, then directing attention to features that change across episodes could remedy it.

Evidence suggesting that older adults detect fewer ongoing changes comes from work on change blindness, which occurs when observers fail to notice visual changes across moments (for reviews, see Simons, 2000; Simons & Ambinder, 2005). Detecting such changes requires attending to changing features to compare them in working memory (Rensink et al., 1997; Simons, 1996). Older adults sometimes show poorer visual attention and control over visual short-term memory, suggesting that they may be more susceptible to change blindness than younger adults (Rizzo et al., 2009). Indeed, studies using various paradigms have consistently reported such age differences (e.g., Costello et al., 2010; James & Kooy, 2011; Rizzo et al., 2009; Veiel et al., 2006). These findings suggests that older adults may allocate attention to the features needed to detect moment-to-moment visual changes less efficiently than younger adults.

Detecting ongoing visual changes is also required for comprehending observed actions in everyday events. Theories of event cognition propose that attention to incoming perceptual information is required to form event models of “what is happening now” (Radvansky, 2012; J. M. Zacks et al., 2007). Event models include current perceptions and retrieved schemata for events cued when observers attend to action features. These schemata are used to predict upcoming actions. When current perceptions substantially mismatch predictions, observers update their models. Error-driven updating is supported by upregulated attention to new actions that cue retrieval of new event schemata. Researchers have tested this view using paradigms where participants watch movies of an actor performing everyday activities (e.g., making a bed). Participants demark the boundaries of actions comprising events (e.g., placing sheets on the mattress) and their memory for those actions is later tested (e.g., Boltz, 1992; Newtson, 1973; J. M. Zacks et al., 2001). Older adults identify event boundaries less normatively than younger adults, which is often associated with poorer memory for action features (e.g., Bailey et al., 2013; Kurby & J. M. Zacks, 2011, J. M. Zacks et al., 2006, but see Sargent et al., 2013; Kurby & J. M. Zacks, 2018). Together with the work above, these findings suggest that older adults allocate attention to ongoing events less efficiently than younger adults.

Beyond detection of moment-to-moment changes, attention is also needed to detect changes between current perceptions and event representations in long term-memory. This can occur when attention to current stimuli that share features with existing memories trigger retrieval of those memories. This cue-dependent retrieval process, referred to as reminding, is proposed to both strengthen existing memory representations and enable integrative encoding of separate events and their temporal relationship (e.g., Hintzman, 2010; Jacoby & Wahlheim, 2013). Evidence for these reminding functions have been shown by enhanced memory for order (e.g., Hintzman, 2010; Jacoby & Wahlheim, 2013; Tzeng & Cotton, 1980; Winograd & Soloway, 1985) and frequency (Hintzman, 2004). These reminding functions also play roles in spacing effects (Benjamin & Tullis, 2010; Hintzman & Block, 1973; Hintzman et al., 1975), memory for semantic associates (Tullis et al., 2014; McKinley & Benjamin, 2020), and reading comprehension when current reading resonates with earlier reading (e.g., Cook et al., 1998; Cook & O’Brien, 2014; Myers & O’Brien, 1998; O’Brien et al., 1998).

Most relevant here, research has shown adult age differences in reminding processes that enable change detection and memory updating in paired-associate learning tasks. For example, in a study by Wahlheim (2014), older and younger adults studied two lists of word pairs and later attempted to recall words from the second list. Some pairs had the same cues in each list with changed responses (e.g., wine-grape; wine-glass) while control pairs appeared only in the second list. To account for updating mechanisms, the author invoked the Memory-for-Change (MFC) framework (Jacoby et al., 2015; Wahlheim & Jacoby, 2013). The framework assumes that when studying a second pair that shares features with an earlier pair, the overlap can trigger reminding of the first pair and enable change detection. Critically, it also assumes that change detection requires effective encoding, which is more likely when attention is self-directed to changed pairs (Garlitch & Wahlheim, 2020b). The MFC framework further assumes that comparing memories with current events enables integrative encoding that includes the temporal relationship of the responses (for neural evidence, see, e.g., Chanales et al., 2019; Zeithamova et al., 2012). Accordingly, memory for changed responses should be better when integrated representations are recollected. These elaborative representations should enable proactive facilitation shown by better recall of changed than control pairs. In contrast, failures to recollect detected changes should lead to proactive interference shown by poorer recall for changed than control pairs. This would result from an increased accessibility of retrieved pairs that is unopposed by recollection.

Wahlheim (2014) tested these predictions using measures of change detection and remindings that required participants to indicate when they noticed changed pairs in the second list (e.g., wine-glass), and to recall the response from the first list (e.g., grape). Recollection of integrated representations was inferred from a cued recall test that required participants to recall responses from the second list and indicate whether another word also came to mind. Converging measures across prior experiments indicated that changes were recollected most often when first-list responses also came to mind. Memory updating was better for younger than older adults as younger adults did not show proactive interference in overall performance, whereas older adults did. Both groups showed proactive facilitation when changes were detected and recollected, and proactive interference when changes were detected but not recollected. Although the magnitudes of such proactive effects of memory were comparable for both age groups, older adults' greater interference proneness was accounted for by their impaired detection and recollection of changes. Similar roles for these processes were also shown in comparisons of retroactive effects of memory for changes in older and younger adults (Garlitch & Wahlheim, 2020a).

The perspectives on episodic memory updating and event cognition described above have been invoked together to explain memory updating for changes in observed actions. Event Memory Retrieval Comparison theory (EMRC; Wahlheim & J. M. Zacks, 2019) subsumes those accounts and includes assumptions about the role of attention during event encoding and the formation of integrated representations when actions change across episodes. EMRC assumes that attending to central features of ongoing activities allows action features to be perceived, which cues retrieval of relevant schemata that allow observers to comprehend observed actions and predict upcoming features. Action comprehension promotes effective encoding partly because observers can detect moment-to-moment changes (i.e., event boundaries) that enable encoding of discrete representations of actions and their constituent features. When observers later attend to the start of an action with features that overlap with an existing representation, perception of the observed actions can cue reminding of that related representation. This allows observers to recognize repeated actions as such and then make memory-based predictions about how actions will end. When actions end differently than expected, attention is directed to changed features, which are compared with event memory representations, thus enabling integrative encoding. The memorial consequences of this processing chain for memory updating and change recollection should be comparable to the retrieval dependencies described above.

Regarding age differences in controlled attention, EMRC predicts that the inefficient attention allocation sometimes shown by older adults can impair comprehension, leading to less coherent event memory representations (e.g., Kurby & J. M. Zacks, 2011; J. M. Zacks et al., 2006). When later observing repeated actions, this deficit should lead to poorer perception of action features, and fewer remindings due to less perceived similarity between perceptions and memory representations. Older adults should then predict fewer upcoming actions based on event memories, leading to poorer change detection. This would limit the opportunities they have for integrative encoding and the memory updating benefits associated with later recollection-based retrieval.

Wahlheim and J. M. Zacks (2019) tested EMRC predictions by developing an *everyday changes* paradigm that includes procedural elements from studies of paired-associate learning (e.g., Wahlheim & Jacoby, 2013) and event cognition (e.g., J. M. Zacks et al., 2006). The paradigm also resembles change blindness paradigms including movies of everyday actions (e.g., Levin & Simons, 1997; Simons & Levin, 1998). However, these paradigms differ in the timescale of changes, as changes occur on shorter time scales in change blindness paradigms (e.g., continuity errors across cuts) than in the *everyday changes* paradigm (e.g., 30 mins – 1 week between events). The *everyday changes* paradigm includes movies of an actor performing continuous activity sequences in which she accomplishes many goals (e.g., styles hair, packs lunch) on two fictive "days" in her life (hereafter referred to as Day 1 and Day 2). The actor starts some activities in the same way on both days (e.g., approaching mirror to style hair), but sometimes ends the actions differently on the second day (e.g., styling with a *comb* [Day 1] then a *brush* [Day 2]).

In the first two experiments to use this paradigm, observers passively watched both movies or passively watched the Day 1 movie and overtly detected changes in the Day 2 movie (Wahlheim & J. M. Zacks, 2019). Along with changed activities, some activities repeated all actions across days whereas others appeared only in the second movie. The latter were control activities used for evaluating subsequent memory effects of changed actions. Memory updating was assessed by comparing cued recall of Day 2 action features (e.g., What did the actor use to style her hair? Answer: *brush*) for changed and control activities. Recollection of change was assessed by asking participants to indicate if the actions changed, and if so, to recall Day 1 features (e.g., *comb*). Younger adults showed proactive facilitation, with better Day 2 recall for changed than control activities, but older adults showed comparable memory for both activity types. This interaction indicated an age-related deficit in event memory updating, consistent with the earlier finding of greater interference proneness in older adults (Wahlheim, 2014). This deficit was partly accounted for by older adults' impaired detection and recollection of changes, which were associated with proactive facilitation. These results suggested that older adults formed and retrieved fewer integrated representations, thus experiencing the associated benefits less often. Converging evidence for this interpretation was shown using fMRI, as neural reinstatement of Day 1 activities in regions associated with event memories (i.e., posterior medial cortex and hippocampus) predicted recall of changed features and change recollection for younger but not older adults (Stawarczyk et al., 2020).

The studies above converge in suggesting that impairments in change detection, integrative encoding, and recollection-based retrieval contribute to age-related event memory updating deficits. These findings are compatible with an account positing a role for controlled attention in such age differences, but no studies have tested this. Support for this idea also comes from studies of aging and attention. Older adults experience deficits in some aspects of attention (for a review, see Kramer & Madden, 2008) that are associated with episodic memory deficits (for a review, see Craik, 2020). These attention deficits are observed in tasks requiring controlled processing to sustain attention and avoid distraction (e.g., Hasher & R. T. Zacks, 1988; Lufi & Haimov, 2019; Mani et al., 2005; Parasuraman et al., 1989). Research has also shown that associations between age-related decreases in executive attention and episodic memory deficits become more pronounced across the adult lifespan (McCabe et al., 2010). Collectively, these findings suggest that older adults may be less effective in self-directing attention to task-relevant features.

Despite sometimes experiencing deficits in controlled attention, older adults can benefit from environmental support to prioritize attention to specific information. For example, in visual search tasks, valid cuing of upcoming stimuli benefits reaction times comparably for older and younger adults (e.g., Hartley et al., 1990; Nissen & Corkin, 1985; Robin & Rizzo, 1992). Similarly, in a visual flanker task, multisensory orienting cues that guide attention to future target locations benefits reaction times for both age groups (e.g., Mahoney et al., 2012). Important for the present study, older adults can strategically direct attention to information deemed valuable to subsequently repair episodic memory deficits (for a review, see Castel, 2008). Perhaps most encouraging, Gold et al. (2017) found that using audio-visual cues to signal normative event boundary locations in movies of actors performing everyday activities improved memory for actions for older and younger adults. These findings suggest that directing older adults' attention to features that support activity comprehension can improve subsequent event memory. However, no studies have examined whether such external cuing benefits extend to the updating of event memories. If guiding attention to central action features with external cues improves older adults' event memory updating, then this would suggest that environmental support can mitigate their inefficient control over allocating attention to relevant action features.

The Present Experiment

The primary goal of the present experiment was to examine the role of controlled attention in age-related event memory updating deficits. We examined this in an *everyday* *changes* paradigm that included audio-visual cues that signaled the central action features that changed across days. Based on the EMRC assumptions detailed above, we expected that cuing Day 1 features would improve event comprehension by directing attention to action features that would trigger retrieval of relevant event schemata. This would increase the quality of event memory representations, thus increasing their accessibility when observers later view actions with overlapping features. We also expected that cuing changed Day 2 features would improve comparisons with Day 1 features by motivating observers to search memory for related features and consider how they changed. This would provide more opportunities for integrative encoding that should improve memory for the temporal order of action features and support recollection-based retrieval of Day 2 features. This is consistent with recent work showing that retrieving Day 1 features before encoding changed Day 2 features was associated with better subsequent memory for Day 2 features (Hermann et al., 2021). We expected that older adults would especially benefit from cues signaling when to allocate attention to action features. Importantly, this prediction contrasts sharply with established interference theories of age-related memory deficits. For example, Inhibition Deficit Theory (IDT; e.g., Hasher & R. T. Zacks, 1988) generally posits that older adults experience more response competition than younger adults. Therefore, IDT predicts that by promoting the co-activation of competing action features in working memory, cuing changes should lead to *more* interference and source confusion for older adults.

As in earlier studies, we assessed event memory updating, change recollection, and their association using a cued recall test. Participants attempted to recall Day 2 features, indicated if the features had changed between days, and attempted to recall Day 1 features for activities identified as changed. We operationalized change recollection as instances when participants identified changed actions as such and correctly recalled Day 1 features. We treated this measure as an indirect assay of age and cuing effects on the processing of Day 2 changes that enabled integrative encoding (e.g., Wahlheim & J. M. Zacks, 2019). We did not measure change detection during the Day 2 movie to avoid interfering with the cuing manipulation. We also assessed instances when changes were remembered but not recollected, which were operationalized as when participants identified actions as changed but could not recall the Day 1 features. We assumed this occurred when observers had a vague memory that actions differed across days, but could not recollect precise details about which features had changed. We did not expect these presumably fuzzier memory representations to be associated with improved memory updating based on the theoretical assumption that recollection-based retrieval of integrated representations is necessary to obtain such benefits. This prediction is supported by findings from related event memory updating studies showing that correct change classifications were only associated with better memory for Day 2 features when Day 1 features were also correctly recalled at test (e.g., Hermann et al., 2021; Stawarczyk et al., 2020; Wahlheim & J. M. Zacks, 2019).

A final aim of the present experiment was to test whether the predicted cuing benefits depend on subsequent retrieval requirements. Following cued recall, participants completed a two-alternative forced choice recognition task (2AFC recognition) that presumably depended less on recollection than the cued recall test (for a review and meta-analysis, see Rhodes et al., 2019). If cuing promotes integrative encoding and supports recollection, then its benefits should be more likely for cued recall than 2AFC recognition.

Method

Participants

The final sample included 73 younger adults (51 female; $M_{age} = 19.60$, $SD_{age} = 2.22$, range = 18-30) from the University of North Carolina at Greensboro (UNCG) and 47 older adults (32 female; $M_{age} = 70.75$, $SD_{age} = 5.43$, range = 65-82) from the Greensboro community.[4]The rationale for sample size selection and the results from sensitivity analyses indicating the power to detect key effects given the sample size are provided in the Supplemental Material. Younger adults received partial course credit, and older adults received $10 per hour.

Cognitive health status for older adults was initially assessed over the phone with the Short Blessed Test (SBT; Katzman et al., 1983), and then in person with the Mini Mental State Exam (MMSE; Folstein et al., 1975). All older adults in the final sample had a weighted SBT error score ≤ 4, an MMSE score ≥ 24, and a score of 20/50 or better with one or both eyes on the Snellen Eye Test (Hetherington, 1954). Table 6 displays demographic information and performance on various cognitive tasks for all participants. Relative to younger adults, older adults had higher scores on the Shipley Institute of Living vocabulary subtest (Shipley, 1986)[5], $t(113.14) = 11.86$, $p < .001$, and more years of education, $t(92.38) = 7.61$, $p < .001$.[6] Younger adults had higher working memory capacity (WMC) than older adults as measured by partial

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[4] We excluded four younger and four older adults who failed to complete all three sessions. We excluded an additional older adult who later disclosed a neurological disorder and another older adult who had experienced a head injury.

[5] The Shipley vocabulary score was not collected for one younger adult.

[6] We fitted models to the cued recall and recognition data that included self-reported years of education as an additional fixed effect and compared them to reduced models that did not include that variable. All comparisons showed that including education did not improve model fit. The interested reader can download these analysis scripts from OSF: https://osf.io/ekvh6/.

scores on both the Rotation Span (ROSPAN; Kane et al., 2004), $t(107.86) = 7.88$, $p < .001$, and Reading Span (RSPAN; Redick et al., 2012)[7] tasks, $t(94.54) = 2.36$, $p = .02$.

We chose the sample size for the present study based on prior experiments examining age differences in event memory updating using variants of the *everyday changes* paradigm. We planned to test more people than in earlier experiments because the present design included fewer observations per cell. We accomplished this by increasing the sample size of the older adults from a previous study by ~25% (Wahlheim & J. M. Zacks, 2019) and oversampling the younger adults. The sample sizes were as large as our resources permitted. We then conducted sensitivity analyses in G*Power Version 3.1.9.2 (Faul et al., 2007). For models including four repeated measures, we had 80% power to detect the interactions of interest with a small effect size of $\eta_p^2 = .02$ (Cohen's $f = .13$). We ran a comparable analysis for the main effects of interest which showed that we could detect a comparable effect size as reported above. For models with two repeated measures, we had 80% power to detect the interactions of interest with a small effect size of $\eta_p^2 = .02$ (Cohen's $f = .14$). Finally, the sensitivity analyses for t-tests indicated that we had 80% power to detect dependent (matched) pairwise differences with a small effect size of $d_z = 0.26$ and independent (two group) pairwise differences with a medium effect size of $d_z = 0.53$. For specific details about the statistical test and input parameters for each analysis, see the Supplemental Material.

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[7] Two younger and three older adults did not complete the RSPAN task.

Design

The experiment used a 2 (Age: Younger vs. Older) × 4 (Activity Type: Repeated, Control, Changed, Changed Cued) mixed design. Age was treated as a between-subjects variable and Activity Type was a within-subjects variable.

Table 6. Descriptive Statistics for Demographics and Performance on Cognitive Tasks

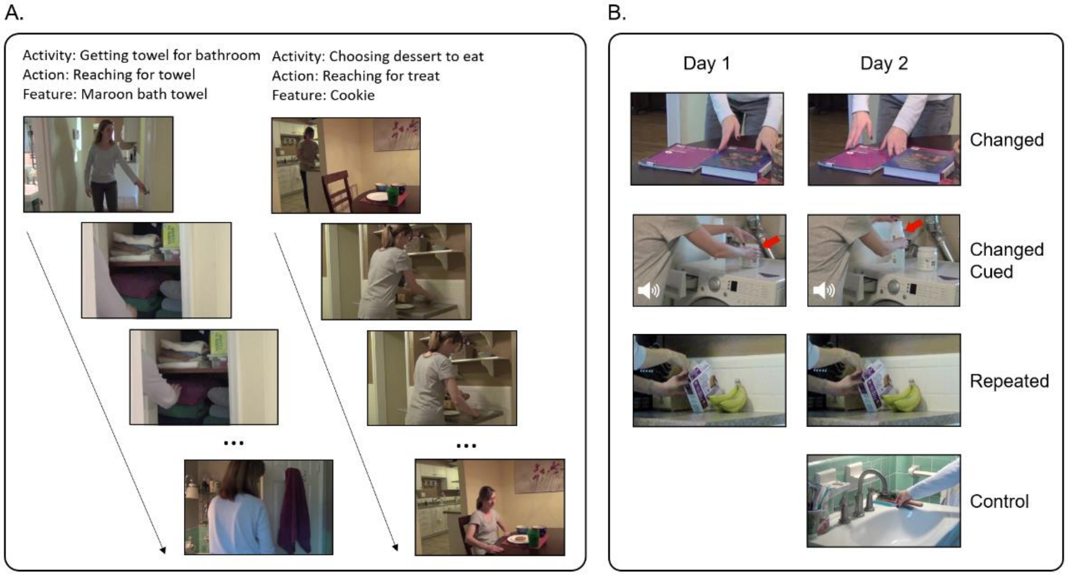
Age	Task	Mean	SD	Range
Younger	Vocabulary (out of 40)	27.28	3.85	18-38
	Education (years)	13.66	1.73	12-19
	ROSPAN	24.53	7.98	2-41
	RSPAN	31.86	16.17	3-68
Older	Vocabulary (out of 40)	34.77	3.01	29-39
	Education (years)	16.26	1.88	12-19
	ROSPAN	13.68	6.93	0-29
	RSPAN	24.75	15.43	0-61
	SBT (error score)	0.47	0.95	0-4
	MMSE	28.23	1.49	24-30
	DSST (in 90 s)	48.83	9.51	24-66
	DSST (out of 9)	6.19	2.04	1-9

Note. SD = standard deviation, Vocabulary = Shipley Institute of Living vocabulary subtest (Shipley, 1986), Education = self-report years of education, ROSPAN = Rotation span (Kane et al., 2004), RSPAN = Reading span (Redick et al., 2012), SBT = Short Blessed Test (Katzman et al., 1983), MMSE = Mini Mental State Exam (Folstein et al., 1975), and DSST = Digit Symbol Substitution Task (WAIS-R, Wechsler, 1981).

Materials

Two movies (Day 1 and Day 2) showed a female actor performing everyday activities during two fictive "days" in her life (movies are available on OSF: https://osf.io/ekvh6/). Each activity was a goal-oriented event (e.g., getting a towel for the bathroom) comprising a sequence of actions (e.g., opening the closet, reaching for a towel, hanging the towel in the bathroom; Figure 11A). The action of interest in each activity (e.g., reaching for a towel) included a central feature (e.g., a maroon bath towel). There were two versions of each activity (A and B) with the same initial action sequence (e.g., approaching the kitchen table to pick up a book) but with a different central feature in the subsequent actions (e.g., picking up a *textbook* or *notebook*; Figure 11B, first row). To incorporate the audio-visual cues, we created another set of clips that had superimposed red arrows indicating central features and a bell tone audio effect that played simultaneously with the appearance of the arrows (Figure 11B, second row). The cues started moments before the action feature was clearly visible and stopped shortly after feature onset and before any cuts. Each arrow appeared for an average of 154 ms (*SD* = 56 ms, range = 19-302 ms). A list of the cue durations is available on OSF: https://osf.io/ekvh6/.

Figure 11. Example Activities, Actions, and Features



Note. (A) Example activities showing action sequences and central features. The left activity shows the actor getting a towel for the bathroom. This included the action of reaching for the towel with the central feature being a maroon bath towel. The right activity shows the actor choosing a dessert to eat. This included the action of reaching for a treat with the central feature being a cookie. For both activities, the first image shows the action that occurred just before the central feature appeared, the second image shows the point in the action when features could change, the third image shows the actor engaging with the central feature, and the fourth shows the end of the activity. The ellipses indicate that more time passed between the actions in the third and fourth images than between the earlier images. (B) Example images showing the relationship between action features on Day 1 and Day 2 for each Activity Type. Note that the white speaker icons indicate that a tone played along with the red arrow cues, but the speaker icons did not appear in the movies.

There were 59 total activities (48 critical and 11 filler). Filler activities were inserted throughout the movies to improve continuity and always repeated across movies. Day 1 movies contained 47 activities (36 critical and 11 filler). Of the 36 critical activities, there were 12 in each of the Repeated, Changed, and Changed Cued conditions. Day 2 movies contained 59 activities (48 critical and 11 filler). Of the 48 critical activities, there were 12 in each of the Repeated, Control, Changed, and Changed Cued conditions. Because the focus of the experiment was on memory updating, we were primarily interested in differences between the conditions including changed action features (i.e., Changed and Changed Cued). Control activities that only appeared on Day 2 were included as a contrast condition against which to assess effects of Day 1 actions on memory for Day 2 actions (i.e., proactive effects of memory). Repeated activities were included to encourage participants to use a recollective basis when attempting to classify "changed" activities at test. This is because without repeated activities, participants could use the greater familiarity of beginning actions in Changed and Changed Cued than Control activities as a basis for their classifications. Example stills from Repeated and Control activities appear in Figure 11B (third and fourth rows, respectively). To counterbalance the assignment of activities to conditions, the 48 critical activities were divided into four groups of 12 and rotated across Activity Type conditions. The version of the changed action feature (A or B) that was shown on Day 2 was also counterbalanced. This counterbalancing arrangement produced eight experimental formats.

The Day 1 movie durations ranged from 26 min and 14 s to 28 min and 46 s, and the Day 2 movie durations ranged from 34 min and 19 s to 35 min and 55 s. The activities appeared in a fixed random order such that no more than three critical activities from the same Activity Type condition appeared consecutively. The activity sequences for the Day 2 movies were created by arranging the activities so that the movies for each format played with high continuity. The sequences for the Day 1 movies were then created by removing the Control activities from the Day 2 movies and keeping activities from the remaining conditions in the same order.

The cued recall test included 59 questions about the central action features that appeared on Day 2 (e.g., What form of laundry detergent did the actor use in the washing machine?). Questions appeared in the same order as the activities in the Day 2 movie to minimize confusion about the activity to which each question referred (the list of cued recall questions is available on OSF: https://osf.io/ekvh6/). The 2AFC recognition test included 59 trials that appeared in the same order as the cued recall questions. Each trial displayed two still frames side-by-side depicting both versions of the same action without cues. The position of stills (left or right) was randomized with the stipulation that the still including the central feature from the Day 2 movie did not appear in the same position more than three times consecutively. Only responses for the 48 critical activities are included in the analyses reported below.

Procedure

Participants completed the experiment in three sessions, each separated by approximately one week depending on availability (M_{days} = 7.08, SD_{days} = 0.68, range = 5-12). Interval lengths between age groups and sessions were compared by fitting a linear model and then conducting an analysis of variance (ANOVA) with Type III sums of squares to accommodate the unbalanced design. There were no significant effects, largest $F(1, 236) = 0.57$, $p = .45$. This inter-session interval was selected to parallel earlier experiments showing age-related event memory updating differences (Wahlheim & J. M. Zacks, 2019), prevent ceiling effects in change detection shown at shorter intervals during pilot testing, and because it best aligned with the instructions that participants should imagine the actions in each movie being performed one week apart.

Table 7 displays the order of tasks in each session. In Session 1, participants watched the Day 1 movie and then completed the ROSPAN task. In Session 2, participants watched the Day 2 movie and then completed the Shipley Institute of Living vocabulary subtest. In Session 3, all participants completed the cued recall test, the 2AFC recognition test, and then the RSPAN task. Older adults then completed the MMSE and Digit Symbol Substitution Task (DSST) taken from the WAIS-R (Wechsler, 1981). The full descriptions of the ROSPAN and RSPAN tasks are on OSF: https://osf.io/ekvh6/. All computerized tasks were presented using E-Prime 3.0 software (Psychology Software Tools, Pittsburgh, PA). The Institutional Review Board at UNCG approved the following procedures.

In Session 1, before the Day 1 movie, participants were told that their task was to attend to the actions performed by the actor and prioritize attention to features cued by an arrow and bell sound because they would change in the next movie. Participants could use any strategy to remember the actions. They first watched an example movie (lasting 1 min and 9 s) in which the actor performed an activity that later repeated, an activity that later changed (without a cue), and a cued activity that changed in the Day 2 practice movie. They then watched the Day 1 movie.

Table 7. Task Order for Experimental Sessions

	Task Order				
Session	1	2	3	4	5
1	Day 1 Movie	ROSPAN			
2	Day 2 Movie	Vocabulary			
3	Cued Recall	2AFC Recognition	RSPAN	MMSE*	DSST*

Note. ROSPAN = Rotation span task (Kane et al., 2004), RSPAN = Reading span task (Redick et al., 2012), MMSE = Mini Mental State Exam (Folstein et al., 1975), and DSST = Digit Symbol Substitution Task (WAIS-R, Wechsler, 1981). *These tasks were completed by older adults only.

In Session 2, participants were told to watch another movie with the same actor and to imagine it occurring one week later. They were also told to look for features that changed from the Day 1 movie and that activities cued in the Day 1 movie would also be cued in the upcoming movie. Participants were further told that when they noticed a changed feature, they should compare it with their memory for the feature from the Day 1 movie. To standardize the incidental encoding strategy of comparing features of cued activities from both movies, there were no intentional learning instructions before the Day 2 movie. Participants first watched the example Day 1 movie again as a reminder of the example activities they viewed earlier. Then participants watched a second example movie (lasting 1 min and 22 s) that included one activity from each condition. A summary slide appeared next, showing still shots from the example movies illustrating the activity types. Participants then watched the Day 2 movie.

In Session 3, participants were told that their memory for Day 2 action features would be tested. Before the actual test, they completed a practice cued recall test that included questions about features from the Day 2 example movie. For both the practice and actual cued recall tests, participants typed each response.[8] Next, they indicated whether the activity had changed from Day 1 to Day 2 by clicking either a “Yes” or “No” button. When they responded “Yes,” they were asked to type the Day 1 feature. When they responded “No,” they clicked a button to indicate whether the activity “Repeated exactly across days” or “Only appeared on Day 2” to indicate Repeated and Control activities, respectively. Participants were told that they could guess or pass when they could not recall an action feature.

Day 2 cued recall responses were coded into four types. *Day 2 Recall* refers to responses that included the central Day 2 feature. *Day 1 Intrusion* refers to responses that included the central Day 1 feature. Note that Day 1 intrusions were actual episodic intrusions for only the activities that included changes. When reporting the results below, we also give estimates of semantic intrusions for Repeated and Control activities as baseline rates for how often participants reported the feature that would have appeared on Day 1 had those activities included changes. *Ambiguous* refers to descriptions of the correct activity that did not include a central feature from either of the movies. *Other Errors* were any other error responses or omissions. Responses for Day 1 recall following “changed” classifications were coded similarly, except that *Day 1 Recall* refers to *correct* recall of the Day 1 feature. Two raters coded the responses independently. Cohen’s kappa for the initial ratings ($\kappa = .84$, $p < .001$) showed high agreement (Landis & Koch, 1977). Discrepancies were resolved through discussion. Given that Ambiguous

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[8] The experimenter typed cued recall responses for two older adults who were uncomfortable using a computer keyboard.

and Other Error responses were not of theoretical interest, only correct Day 2 recalls, Day 1 intrusions, and correct Day 1 recalls were included in the analyses.

Immediately following the cued recall test, participants completed the 2AFC recognition test.[9] They were first given a practice test using stills of actions from the Day 1 and Day 2 example movies. On the practice and actual 2AFC recognition tests, two stills appeared showing the actor performing each version of the action. Below the pictures appeared the statement, “Click on the Day 2 activity.” Participants clicked on the picture to indicate the action they recognized from the Day 2 movie. Next, a question appeared asking if the non-selected activity had appeared on Day 1. When participants clicked “Yes,” they could move on to the next trial by then clicking the “Next” button. We assumed that “Yes” responses indicated when participants remembered that action features had changed between movies. When participants clicked “No,” they were asked to indicate how the activity shown in the still related to the Day 1 movie. They responded by clicking either “Repeated exactly across days” or “Only appeared on Day 2” to indicate Repeated and Control activities, respectively. Participants then clicked “Next” to move on. The complete instructions for all phases and a schematic of the procedures for the cued recall and 2AFC recognition test phases are available on OSF: https://osf.io/ekvh6/.

Statistical Approach

All analyses were conducted using R software (R Core Team, 2020). Unless noted, all models included age and activity type as fixed effects with subjects and activities as random intercept effects. We fitted logistic mixed-effects models using the *glmer* function from the *lme4* package (Bates et al., 2015). We chose this approach because mixed-effects modeling can

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[9] One younger adult did not complete the 2AFC recognition test.

simultaneously account for variability within and across subjects and items, thus improving the precision of effect estimation (e.g., Baayen et al., 2008; Brown, 2021). We then conducted hypothesis tests using the *Anova* function from the *car* package (Fox & Weisburg, 2011), and pairwise comparisons using the *emmeans* function from the *emmeans* package (Lenth, 2020) with the Tukey method controlling for the family-wise error rate. The level for significance was set at $\alpha = .05$. Below we report model comparison statistics and p-values from each analysis. When applicable, we report estimated probabilities derived from these models.

To provide standardized effect size estimates, we fitted simple linear regression models with the *lm* function in R treating subjects as random effects. We then computed partial eta squared (η_p^2), d_r, and corresponding 95% confidence intervals from those models. We report these effect size estimates with the results of the mixed-effects models below. The specific details about the computation of effect sizes and the results from the simple linear regression models are available in the Supplemental Material.

Results

Cued Recall Performance

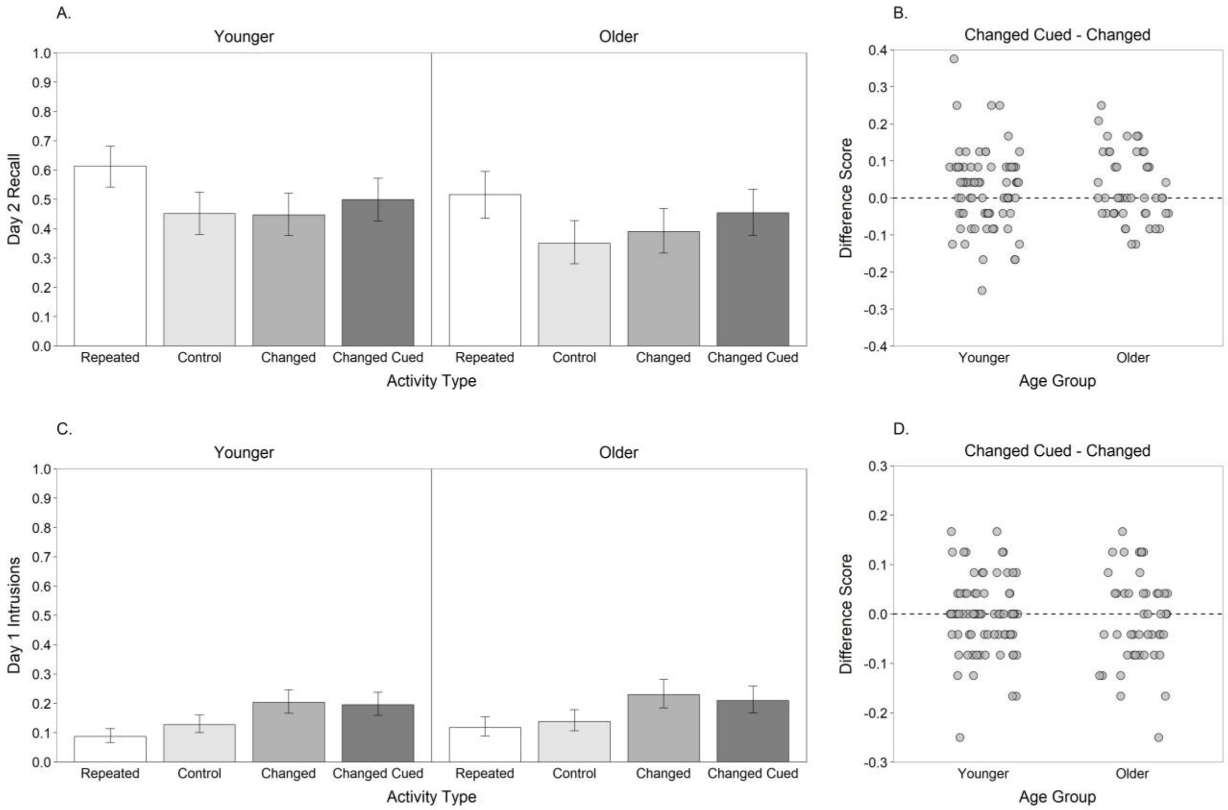
Day 2 Recalls

Day 2 recalls were examined to assess the effect of cuing on event memory updating. An Age × Activity Type model was fitted to overall recall performance (Figure 12A). A significant effect of Age, $\chi^2(1) = 7.71$, $p < .01$, $\eta_p^2 = .03$ [$CI = .01, .07$], indicated that recall was higher for younger than older adults. In addition, a significant effect of Activity Type, $\chi^2(3) = 80.77$, $p < .001$, $\eta_p^2 = .09$ [$CI = .04, .14$], indicated that recall was higher for Changed Cued than Changed activities, z ratio = 2.83, $p = .02$, $d_r = 0.28$ [$CI = -0.08, 0.64$], showing that cuing benefitted memory updating. The extent to which each participant benefitted from cuing is plotted as difference scores subtracting recall probabilities in the Changed from Changed Cued condition (Figure 12B). Other pairwise comparisons indicated that recall was higher for Repeated than all other activities, smallest *z* ratio = 4.29, $p < .001$, $d_r = 0.42$ [*CI* = 0.05, 0.78], higher for Changed Cued than Control activities, *z* ratio = 3.75, $p < .01$, $d_r = 0.37$ [*CI* = 0.01, 0.73], and did not differ between Changed and Control activities, *z* ratio = 0.93, $p = .79$, $d_r = 0.10$ [*CI* = -0.26, 0.45]. There was no significant Age × Activity Type interaction, $\chi^2(3) = 3.12$, $p = .37$, $\eta_p^2 < .01$ [*CI* = .00, .02]. Together, these results showed that cuing changed features benefitted memory updating comparably for both age groups. Although both groups enjoyed cuing benefits, this is the first time that older adults have shown proactive facilitation in overall Day 2 recall of changed features. Taken with previous findings showing disproportionate age-related deficits in recall of changed features (Wahlheim & J. M. Zacks, 2019), these results suggest that directing older adults' allocation of attention to central action features improved their event memory updating deficit.

Day 1 Intrusions

Day 1 intrusions were examined to assess potential age differences in proactive interference susceptibility and to determine whether cuing offset those effects. An Age × Activity Type model was fitted to overall intrusions (Figure 12C). A significant effect of Activity Type, $\chi^2(3) = 99.34$, $p < .001$, $\eta_p^2 = .17$ [*CI* = .11, .22], indicated higher estimates for Changed and Changed Cued activities (episodic memory intrusions) than Repeated and Control activities (semantic memory intrusions), smallest *z* ratio = 4.98, $p < .001$, $d_r = 0.64$ [*CI* = 0.27, 1.01]. However, there was no difference between Changed and Changed Cued activities, *z* ratio = 0.91, $p = .80$, $d_r = 0.12$ [*CI* = -0.24, 0.48], indicating that cuing did not offset proactive interference effects on intrusion production. The extent to which each participant benefitted from cuing is plotted as difference scores subtracting intrusion probabilities in the Changed from Changed Cued condition (Figure 12D). Finally, intrusion estimates were significantly higher for Control than Repeated activities, z ratio = 2.70, $p = .04$, $d_r = 0.30$ [$CI = -0.06, 0.66$], suggesting that better memory for repeated features also reduced intrusions from semantic memory. No other effects were significant, largest, $\chi^2(1) = 3.39$, $p = .07$, $\eta_p^2 < .01$ [$CI = .00, .03$]. Together, these results replicate Stawarczyk et al. (2020) in showing comparable Day 1 intrusions for both age groups. They also indicated that cuing benefits did not extend to preventing intrusion errors for either group.

Figure 12. Day 2 Recalls and Day 1 Intrusions



Note. Model-estimated probabilities of (A) Day 2 recall and (C) Day 1 intrusions as a function of Age and Activity Type. Error bars are 95% confidence intervals. Participant-level cuing effects are displayed as difference scores (gray dots) subtracting probabilities for Changed from Changed Cued activities for (B) Day 2 recall and (D) Day 1 intrusions. Cuing effects reflecting better memory accuracy for cued than uncued changes were shown by difference scores above 0 for Day 2 recall and scores below 0 for Day 1 intrusions. For Day 2 recalls, 52% of younger adults and 40% of older adults showed a cuing effect. For Day 1 intrusions, 32% of younger adults and 40% of older adults showed a cuing effect.

“Changed” Classifications

To further understand how cuing affected memory updating, classifications of activities as having earlier changed were examined. Based on prior studies, “changed” classifications were used to indirectly assay differences in change detection and attendant integrated representations formed while viewing the Day 2 movie (Hermann et al., 2021; Stawarczyk et al., 2020; Wahlheim & J. M. Zacks, 2019). Overall “changed” classifications were assumed to comprise instances when changes were recollected (operationalized as correctly classified changes and *correct* recall of Day 1 features) and when changes were remembered but not recollected (operationalized as correctly classified changes and *incorrect* recall of Day 1 features). Recollected changes were assumed to primarily reflect instances when participants could access integrated representations. In contrast, remembered but not recollected changes were assumed to primarily reflect instances when less precise representations of changes were retrieved. Specifically, these representations were assumed to be characterized as remembering *that* features had changed but not recollecting *what* earlier features had changed. Such instances were not expected to be associated with memory updating benefits because they would not elicit the necessary contents of integrated representations. Age differences in the bases for “changed” classifications were examined by comparing the frequencies of these two kinds of classifications.

Based on EMRC, we assumed that classifications based more on recollection of changes would result in better discrimination between activities that included changes (Changed and Changed Cued) and activities that did not (Repeated and Control). We expected younger adults to show better discrimination because older adults sometimes experience episodic memory deficits characterized by less accurate recollections (e.g., Dodson et al., 2007).

The overall probabilities of "changed" classifications collapsed across the two kinds are displayed in Table 8 (top rows). An Age × Activity Type model indicated no significant effect of Age, $\chi^2(1) = 2.26$, $p = .13$, $\eta_p^2 = .01$ [$CI = .00, .04$], a significant effect of Activity Type, $\chi^2(3) = 428.64$, $p < .001$, $\eta_p^2 = .30$ [$CI = .23, .36$], and a significant Age × Activity Type interaction, $\chi^2(3) = 58.11$, $p < .001$, $\eta_p^2 = .04$ [$CI = .01, .08$]. There were fewer incorrect classifications of Repeated and Control activities for younger than older adults, smallest z ratio = 3.18, $p < .01$, $d_r = 0.57$ [$CI = 0.21, 0.94$], but there was no age difference in correct classifications of Changed and Changed Cued activities, largest z ratio = 1.89, $p = .06$, $d_r = 0.36$ [$CI = 0.00, 0.72$]. This showed better mnemonic discrimination between changed and unchanged action features for younger than older adults. Further comparisons showed that both age groups were more likely to correctly classify Changed and Changed Cued activities than to incorrectly classify Repeated and Control activities, smallest z ratio = 2.62, $p = .04$, $d_r = 0.35$ [$CI = -0.01, 0.71$], and were more likely to incorrectly classify Control than Repeated activities, smallest z ratio = 3.15, $p < .01$, $d_r = 0.40$ [$CI = 0.04, 0.76$]. Finally, younger adults were more likely to correctly classify Changed Cued than Changed activities, z ratio = 6.68, $p < .001$, $d_r = 0.74$ [$CI = 0.37, 1.11$], while older adults did not show this difference, z ratio = 2.42, $p = .07$, $d_r = 0.32$ [$CI = -0.04, 0.68$]. These results could suggest that cuing was less effective at directing attention to changes for older than younger adults. However, taken with the finding that older adults showed poorer discrimination between changed and unchanged activities than younger adults, these results likely indicate that overall “changed” classifications were generally less sensitive to cuing effects for older than younger adults.

Table 8. Model-Estimated "Changed" Classification Probabilities for Each Test as a Function of Age and Activity Type

		Activity Type			
Test	Age	Repeated	Control	Changed	Changed
Cued Recall	Younger	.12 [.09, .15]	.22 [.18, .27]	.41 [.35, .48]	.59 [.52, .65]
	Older	.25 [.20, .32]	.34 [.28, .41]	.42 [.35, .50]	.50 [.42, .58]
2AFC	Younger	.26 [.22, .30]	.30 [.26, .35]	.70 [.65, .75]	.80 [.76, .84]
	Older	.37 [.31, .43]	.34 [.28, .40]	.57 [.50, .63]	.65 [.58, .70]

Note. 95% confidence intervals are displayed in brackets.

To further understand the basis of cuing effects on “changed” classifications, we decomposed overall classifications for Changed and Changed Cued activities into the two kinds described above: change recollected and change remembered but not recollected (Table 9). If cuing improved recall of Day 1 features during Day 2 viewing, change recollection characterized by accurate recall of Day 1 features at test should be greater for Changed Cued than Changed activities. This hypothesis was tested by comparing change recollection rates for both age groups (Table 9, top rows) with an Age × Activity Type model. The model indicated a significant effect of Age, χ^2 (1) = 29.90, $p < .001$, $\eta_p^2 = .15$ [*CI* = .07, .23], showing higher change recollection for younger than older adults. The model also indicated a significant effect of Activity Type, χ^2 (1) = 34.74, $p < .001$, $\eta_p^2 = .06$ [*CI* = .01, .12], showing that change recollection was greater for

Changed Cued than Changed activities. There was no significant Age × Activity Type interaction, χ^2 (1) = 0.03, $p = .86$, $\eta_p^2 < .01$ [*CI* = .00, .03]. These results supported the hypothesis that cuing attention to changes should improve recollection of the features that had changed.

For completeness, changes that were remembered but not recollected (Table 9, bottom rows) were also examined with an Age × Activity Type model. The model indicated significant effects of Age, χ^2 (1) = 24.73, $p < .001$, $\eta_p^2 = .13$ [*CI* = .06, .21], and Activity Type, χ^2 (1) = 4.18, $p = .04$, $\eta_p^2 < .01$ [*CI* = .00, .05], and no significant Age × Activity Type interaction, χ^2 (1) = 3.71, $p = .05$, $\eta_p^2 < .01$ [*CI* = .00, .04]. This showed that older adults classified more activities as changed without recalling Day 1 features, which might have reflected an age-related deficit in encoding and recollecting integrated representations.

Table 9. Model-Estimated "Changed" Classification Probabilities as a Function of Classification, Age, and Activity Type

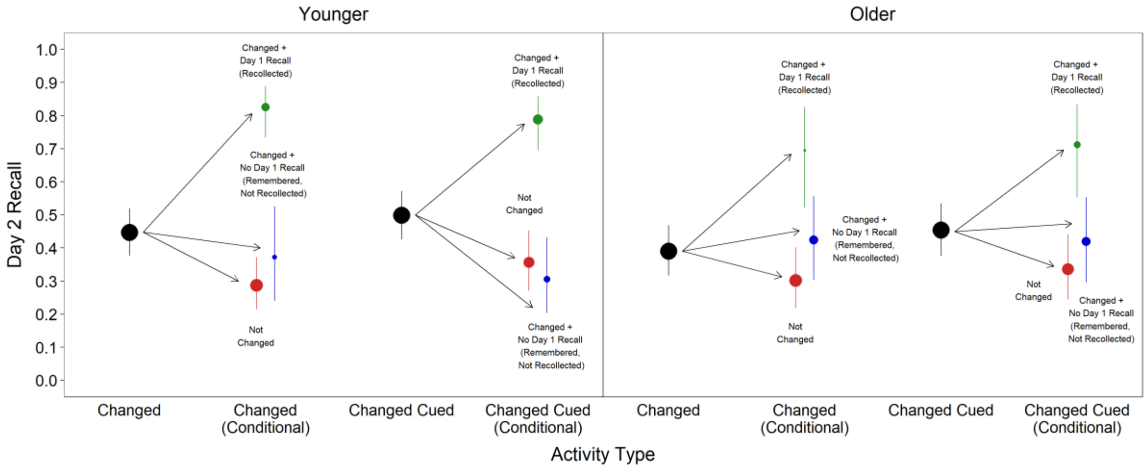
		Activity Type	
Classification	Age	Changed	Changed Cued
Changed + Day 1 Recall (Recollected)	Younger	.22 [.17, .29]	.34 [.27, .42]
	Older	.10 [.07, .14]	.16 [.11, .22]
Changed + No Day 1 Recall (Remembered, Not Recollected)	Younger	.14 [.11, .17]	.18 [.15, .22]
	Older	.28 [.23, .34]	.28 [.23, .34]

Note. 95% confidence intervals are displayed in brackets.

Day 2 Recalls Conditionalized on “Changed” Classifications

The results showing that cuing attention to action features increased Day 2 recall and change recollection suggested that these two measures were positively associated. This was verified by conditionalizing Day 2 recall for both changed activity types on three “changed” classifications: change recollected, change remembered but not recollected, and change not remembered (Figure 13, green, blue, and red points, respectively). The first two classifications were the same as defined above, and the last included instances when changed activities were *not* classified as such. An Age × Activity Type × Classification model indicated a significant effect of Classification, $\chi^2(2) = 157.54$, $p < .001$, $\eta_p^2 = .33$ [$CI = .27, .38$], showing higher recall when change was recollected (green points) than when it was not (blue and red points), smallest z ratio $= 8.47$, $p < .001$, $d_r = 1.39$ [$CI = 0.99, 1.78$], and no difference between the latter classifications for which change was not recollected, z ratio $= 1.68$, $p = .21$, $d_r = 0.05$ [$CI = -0.31, 0.41$]. No other effects were significant, largest $\chi^2(2) = 5.82$, $p = .06$, $\eta_p^2 = .02$ [$CI = .00, .04$]. Taken with the observed differences in classification probabilities, these results suggest that the cuing benefit on memory updating was partly due to its improvement of detection and recollection of changes.

Figure 13. Day 2 Recalls Conditionalized on "Changed" Classifications



Note. Model-estimated probabilities of Day 2 recall for Changed and Changed Cued activities as a function of Age. The black points are the overall probabilities, and the colored points are the conditional probabilities. The green points are when changed activities were correctly classified and Day 1 features were recalled (Change Recollected); the blue points are when changed activities were correctly classified and Day 1 features were not recalled (Change Remembered, Not Recollected); and the red points are when changed activities were incorrectly classified as not changed (Change Not Remembered). The conditional point sizes indicate the proportions of responses that went into each cell. Error bars are 95% confidence intervals.

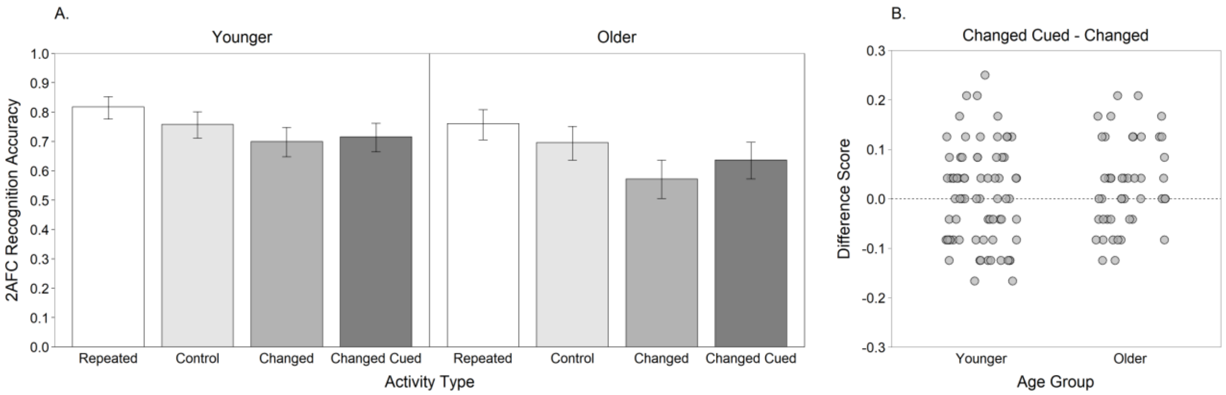
2AFC Recognition Memory

Day 2 Recognition Accuracy

Cuing effects on 2AFC recognition accuracy were also examined to determine whether the cuing benefits shown in cued recall above depended on recollection-based retrieval. If so, then such benefits should be unlikely to occur in a 2AFC recognition task that is less dependent on recollection. An Age × Activity Type model was fitted to 2AFC recognition accuracy (Figure 14A). There was a significant effect of Age, $\chi^2(1) = 13.18$, $p < .001$, $\eta_p^2 = .05$ [$CI = .02, .09$], showing higher accuracy for younger than older adults. There was also a significant effect of Activity Type, $\chi^2(3) = 79.61$, $p < .001$, $\eta_p^2 = .09$ [$CI = .04, .14$], showing higher accuracy for Repeated than all other activity types, and for Control than Changed and Changed Cued activity types, smallest z ratio = 2.85, $p = .02$, $d_r = 0.29$ [$CI = -0.07, 0.65$]. Critically, accuracy for Changed and Changed Cued activities was not significantly different, z ratio = 2.06, $p = .17$, $d_r = 0.21$ [$CI = -0.15, 0.57$]. The extent to which each participant benefitted from cuing is plotted as difference scores subtracting recognition accuracy probabilities in the Changed from Changed Cued condition (Figure 14B). There was no significant Age × Activity Type interaction, $\chi^2(3) =$

2.53, $p = .47$, $\eta_p^2 < .01$ [$CI = .00, .02$]. Thus, contrary to the cued recall results, cuing did not improve 2AFC recognition accuracy for Day 2 action features. Taken together, these results suggest that cuing enhanced integrative encoding that improved updating to a greater extent when subsequent retrieval conditions were recollection-based.

Figure 14. 2AFC Recognition Accuracy



Note. (A) Model-estimated probabilities of 2AFC recognition accuracy. Error bars are 95% confidence intervals. (B) Participant-level cuing effects displayed as difference scores (gray dots) calculated by subtracting probabilities for Changed from Changed Cued activities. Cuing effects reflecting better recognition accuracy for cued than uncued changes were shown by difference scores above 0. A cuing effect was shown by 47% of younger adults and 51% of older adults.

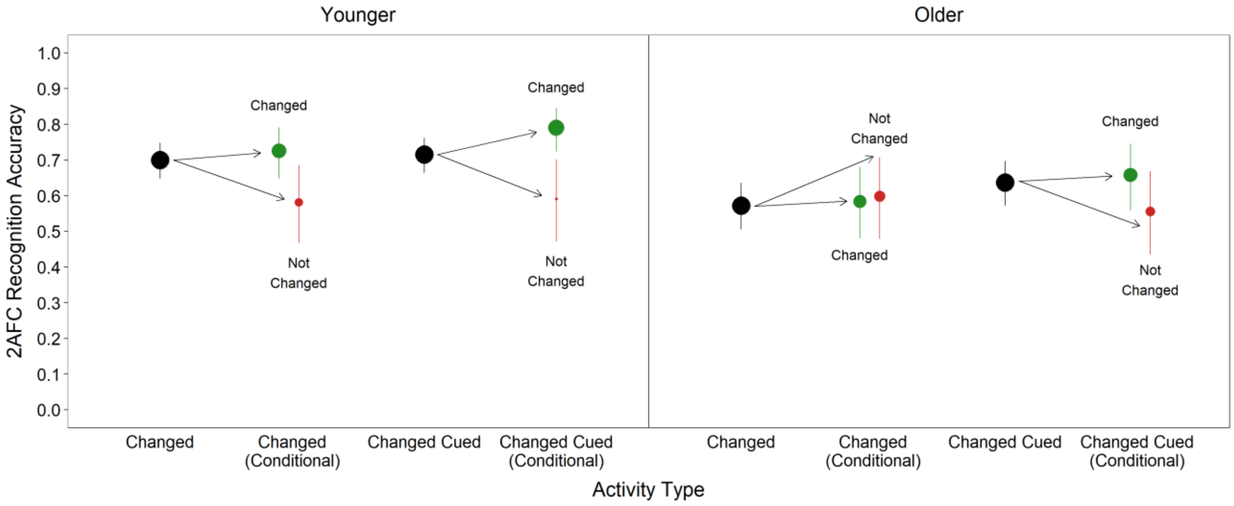
“Changed” Classifications

Following the approach for cued recall, “changed” classifications on the recognition test were examined to determine the basis for such judgments in older and younger adults. An Age × Activity Type model was fitted to overall “changed” classifications (Table 8, bottom rows). The model indicated no significant effect of Age, $\chi^2(1) = 1.79$, $p = .18$, $\eta_p^2 < .01$ [$CI = .00, .03$], a significant effect of Activity Type, $\chi^2(3) = 694.77$, $p < .001$, $\eta_p^2 = .47$ [$CI = .41, .52$], and a significant Age × Activity Type interaction, χ^2 (3) = 75.33, $p < .001$, $\eta_p^2 = .07$ [*CI* = .03, .11]. Relative to younger adults, older adults correctly classified fewer Repeated activities, *z* ratio = 3.14, $p < .01$, $d_r = 0.54$ [*CI* = 0.17, 0.91], and comparable Control activities, *z* ratio = 0.97, $p = .33$, $d_r = 0.17$ [*CI* = -0.19, 0.53]. In contrast, relative to older adults, younger adults correctly classified more Changed and Changed Cued activities, smallest *z* ratio = 3.60, $p < .001$, $d_r = 0.64$ [*CI* = 0.27, 1.00]. Both age groups correctly classified more Changed Cued than Changed activities, smallest *z* ratio = 2.63, $p = .04$, $d_r = 0.38$ [*CI* = 0.01, 0.74], and were more likely to correctly classify Changed and Changed Cued activities than to incorrectly classify Repeated and Control activities as changed, smallest *z* ratio = 6.29, $p < .001$, $d_r = 0.93$ [*CI* = 0.55, 1.31]. Finally, both age groups showed no significant difference between incorrect classifications of Repeated and Control activities, largest *z* ratio = 2.04, $p = .17$, $d_r = 0.22$ [*CI* = -0.14, 0.58]. These findings converge with the results from the cued recall test in showing that “changed” classifications better discriminated changed from unchanged activities for younger than older adults, suggesting that younger adults based those classifications more on recollection. However, in contrast to the cued recall results, there was no strong evidence that cuing increased accuracy for both “changed” classifications and memory for Day 2 features. This suggested that the accessibility differences for integrated representations resulting from cuing may have been offset by including recognition probes that provided more environmental support.

2AFC Recognition Accuracy Conditionalized on “Changed” Classifications

The association between 2AFC recognition accuracy for the two changed activity types and the ability to accurately classify them as such was examined by conditionalizing the former on the latter (Figure 15). These analyses could potentially illuminate the inconsistencies in cuing effects on recognition and classification accuracy. An Age × Activity Type × Classification model indicated significant effects of Age, $\chi^2(1) = 8.18$, $p < .01$, $\eta_p^2 = .02$ [*CI* = .00, .05], and Classification, $\chi^2(1) = 15.43$, $p < .001$, $\eta_p^2 = .03$ [*CI* = .01, .07], and a significant Age × Classification interaction, $\chi^2(1) = 5.50$, $p = .02$, $\eta_p^2 < .01$ [*CI* = .00, .03]. No other effects were significant, largest $\chi^2(1) = 2.30$, $p = .13$, $\eta_p^2 < .01$ [*CI* = .00, .03]. Accuracy was higher for correct than incorrect classifications for younger, *z* ratio = 4.51, $p < .001$, $d_r = 0.47$ [*CI* = 0.10, 0.83], but not older adults, *z* ratio = 0.95, $p = .34$, $d_r = 0.18$ [*CI* = -0.18, 0.54]. These results replicate the positive associations between correct change classifications and cued recall for changed action features in younger adults. The absence of such associations for older adults suggest that they based their judgments less on diagnostic information such as recollection of changes. Although these results again point to age differences in the basis for classifications, they do not clearly illuminate the disconnect in cuing effects on recognition and “changed” classifications above.

Figure 15. 2 AFC Recognition Accuracy Conditionalized on "Changed" Classifications



Note. Model-estimated probabilities of 2AFC recognition accuracy for Changed and Changed Cued activities as a function of Age. The black points are the overall probabilities, and the colored points are the conditional probabilities. Green points are correctly classified changes, and red points are incorrectly classified changes. The conditional point sizes indicate the proportions of responses that went into each cell. Error bars are 95% confidence intervals.

Discussion

The present experiment examined the role of controlled attention in age-related event memory updating deficits. Specifically, it examined whether older adults' updating could be improved by cuing their attention to changed action features. Cuing improved subsequent cued recall of recent action features for older and younger adults. Importantly, cuing changed features led to the first reported observation of proactive facilitation in overall recall of those features for older adults. These results suggest that cuing benefits partly reflected improved integrative encoding and recollection of changes. This was shown as cuing increased change recollection, which was associated with better memory updating for both age groups. Cuing also increased how often changes were classified in 2AFC recognition, but the associated benefits did not translate into significantly better overall recognition for cued changes. Taken with the cued recall results, these findings suggest that cuing led to encoding improvements that were realized to the greatest extent when the subsequent memory task required recollection-based retrieval.

Age Differences in Event Memory Updating

Prior research indicates that older adults experience deficits in detecting and recollecting changed actions features, which contributes to their impaired ability to update event memories (Wahlheim & J. M. Zacks, 2019; Stawarczyk et al., 2020). Older adults also experience some normative declines in controlling and sustaining attention (for a review, see Kramer & Madden, 2008), which contributes to poorer detection of moment-to-moment visual changes (e.g., Rizzo et al., 2009). Therefore, deficits in attention allocation to changed features may also play a role in the event memory updating deficit older adults showed previously. However, under certain conditions, older adults can marshal attentional resources to prioritize encoding important information and rescue their memory deficits (for a review, see Castel, 2008; Gold et al., 2017). These findings lead to the hypothesis that directing attention to changed features should improve age-related memory updating deficits by promoting integrative encoding and later recollection of change.

The present results support this hypothesis as cuing original and changed action features improved memory updating, shown by proactive facilitation in memory for changed actions for both older and younger adults. The role of controlled attention in age-related event memory updating deficits assumed here led to the prediction that cuing would improve memory updating more for older than younger adults. Taken with the results from Wahlheim and J. M. Zacks (2019) showing that older adults were impaired in recall of changed features relative to younger adults who showed overall proactive facilitation, the comparable cuing benefits for both groups observed here suggests that older adults benefitted more from attentional cuing. However, stronger evidence for this conclusion would have been shown if younger adults had demonstrated overall proactive facilitation in memory for uncued changes, as in previous studies. The implication from these results of a role for attention in memory updating converges with findings from paired-associate learning paradigms with younger adults. In those studies, change recollection and associated updating benefits were greater when participants were instructed to look for changes (Jacoby et al., 2015), and when they reported attending to stimuli when changes appeared (Garlitch & Wahlheim, 2020b). Importantly, the present results contradict the IDT prediction that older adults should experience more interference when competing responses are co-activated (e.g., Hasher & R. T. Zacks, 1988).

How did external cues enhance overall memory for changed features? One possibility, according to EMRC, is that the cues promoted recall of Day 1 features during Day 2 encoding. This then enabled change detection and subsequent integrative encoding to occur more often during Day 2, which provided more opportunities for integrated representations to be recollected later. Such recollection is accompanied by benefits for remembering the temporal order of features, consistent with work on remindings-based accounts of temporal memory (Hintzman, 2004; 2010). The present results support this view by showing that change recollection rates, which presumably assay the extent to which integrated representations were retrieved, were higher when changed features were cued relative to uncued. Furthermore, change recollection was associated with proactive facilitation in Day 2 recall, and therefore suggests that the cuing benefit to memory for recent features reflected enhanced memory integration. However, one caveat is that these correlational results do not definitively support this causal interpretation.

Another possibility, consistent with independent trace accounts of temporal memory (e.g., Flexser & Bower, 1974), is that cuing improved encoding of separate event representations and their associations with temporal context. These theories would assume that cuing the features would result in stronger associations between the features and the time of their occurrence, leading to better independent recall of both actions from which change recollection can be inferred. This is consistent with findings showing that information learned across overlapping experiences can be flexibly recombined at retrieval (e.g., Zeithamova & Preston, 2010). Based on prior work showing that increasing the accessibility of original information improves both detection of changes during study and recollection of changes at test (e.g., Wahlheim & Jacoby, 2013), and that participants in this study were told to think back to Day 1 features when cued on Day 2, we invoke an EMRC interpretation that cuing enhanced integrative encoding on Day 2.

However, we acknowledge that more systematic experimentation is required to determine whether cuing also improved flexible recombination at test for some actions.

Age Differences in Recognition of Changed Events

The present experiment also examined whether attentional cuing would lead to improved memory updating in 2AFC recognition. This was intended to provide insight into whether the benefits of cuing reflected improved encoding that supported subsequent memory when the task required recollection-based retrieval. Since the 2AFC recognition task presumably relied less on recollection than cued recall, an absence of cuing effects in recognition would suggest that cuing enhanced recollection of changed features. Contrary to the broader literature showing little age differences in recognition (for a review and meta-analysis, see Rhodes et al., 2019), older adults showed worse 2AFC recognition than younger adults, replicating recent findings (Stawarczyk et al., 2020). Importantly, cuing did not improve 2AFC recognition for changed actions, but it did lead to more accurate classification of changes, which was associated with improved memory updating for younger but not older adults. Although these complex patterns created some ambiguity for interpretation, the selective presence of cuing effects in cued recall led us to the provisional conclusion that cuing had its effects partly by supporting recollection-based retrieval.

Limitations

The present study is limited by the cross-sectional extreme-groups design. Dichotomizing continuous variables, such as age, can minimize individual differences within groups, reduce the reliability of effect size estimates or statistical testing, and complicate cross-study comparisons (e.g., MacCallum et al., 2002). Future studies may benefit from including a continuous age range to determine the linearity of the relationship between age and cuing effects. A further limitation is that artificial audio-visual cues do not appear in everyday life. A naturalistic analog to examine in future work would be gestures or directives in which an experimenter points to the actions of the observed actor. A final limitation worth noting is the type of action changes depicted in the current paradigm. Although naturalistic, the changed features (e.g., brush and comb) were associated with the same function of an action (e.g., styling hair). This aspect of the procedure may contribute to age-related updating differences because older adults are more likely to show gist-based memory errors (for a review, see Devitt & Schacter, 2016). This could be tested directly by using movies with more obvious feature changes that alter the functions of actions.

Conclusion

In summary, cuing attention to changed action features improved event memory updating for older and younger adults. Although there were no age differences in the cuing benefits, the present study was the first to show proactive facilitation in overall memory for changed features in older adults, and this required external cuing. This suggests that older adults were able to strategically allocate attention to central action features when those features were signaled. Taken with previous findings showing no proactive facilitation in memory for changed features in older adults in the absence of cues (Wahlheim & J. M. Zacks, 2019), the present results suggest that an impairment in controlled attention contributed to older adults' earlier-observed updating deficit. However, stronger support for this claim would have required the present results to replicate the finding of proactive facilitation in memory for changed activities without cuing for younger adults. The present results also implied an association between the cuing benefit and increased detection and recollection of changes, which only emerged when subsequent retrieval was more recollection-based. Future research should examine cuing effects with more naturalistic cues and more variability in action changes in a continuous adult lifespan sample.

CHAPTER V: INTEGRATIVE DISCUSSION

The goal of this integrated dissertation was to present a program of research aimed at further assessing the mechanisms that are proposed by the MFC framework to support episodic memory updating (Jacoby et al., 2015; Jacoby & Wahlheim, 2013). The MFC framework proposes that whether episodic memory updating is enhanced or impaired depends on how often changes can be detected, allowing for integrative encoding to occur of the changes, and how often these experiences can be later recollected. Here, I presented work that examined adult age differences and the role of attention to test predictions from the framework about how these variables influence change detection and recollection and are associated with differences in memory updating. Below, I discuss the implications that this work has for the theoretical framework, for our understanding of age differences in episodic memory, and the relationship between attention and episodic memory. Finally, I conclude with a brief section on the applied implications of this work. Through each section of the integrative discussion, I highlight the limitations of the work reported here and discuss approaches that could be used in future research to address outstanding questions that remain.

Theoretical Implications for the Memory-for-Change Framework

The MFC framework generally proposes that detecting changes can promote memory updating when new information and existing memories with shared features can be integrated during encoding, thus supporting later recollection-based retrieval. The results across the empirical papers included here were consistent with this proposal. In the first empirical paper, the roles for change detection and recollection were tested for retroactive effects of memory across two experiments (Garlitch & Wahlheim, 2020a). The MFC framework predicts that the retrieval practice of the original information that occurs when changes are detected should be sufficient to produce memory updating benefits because the original information is the target under these conditions (e.g., Jacoby et al., 2015). Indeed, Garlitch and Wahlheim (2020a, Experiment 2) showed that when changes were detected, this was associated with retroactive facilitation effects and when changes were not detected, this was associated with retroactive interference effects. Furthermore, when change detection was indirectly inferred from the measure of change recollection at test (Experiment 1), change recollection was associated with retroactive facilitation effects and when changes were not identified as such at test, this was associated with retroactive interference.

In the second and third empirical papers, the roles for change detection and recollection were examined for proactive effects of memory (Garlitch & Wahlheim, 2020b; Garlitch & Wahlheim, 2021). Under these conditions, the MFC framework proposes that when changes are detected initially, this experience must also be recollected for the associated benefits to memory updating to be observed. The integrated representation formed during change detection is associated with an increase in the accessibility of the original information. Therefore, recollection-based retrieval must be engaged at test to oppose the increase in accessibility of the original information and retrieve information about the relative temporal order for the changes. When recollection-based retrieval is not engaged at test, this is expected to be associated greater proactive interference effects. Consistent with this proposal, the results from these experiments showed that change recollection was associated with proactive facilitation effects and failing to recollect change was associated with proactive interference effects (Garlitch & Wahlheim, 2020b) or lower performance (Garlitch & Wahlheim, 2021).

The MFC framework and a related account proposing the mechanisms of event memory updating (Wahlheim & J. M. Zacks, 2019) assume that attention plays an integral role in episodic memory updating. For change detection and subsequent integration to occur during encoding, attention must first be given to the original information so that it can be remembered later. Then, attention must be given during new learning to cue retrieval of the original information that shares overlapping features. The work presented here tested how attention was associated with differences in these mechanisms of memory updating in two ways. First, Garlitch and Wahlheim (2020b) measured the association between self-reported task engagement (i.e., focusing on learning the changed pairs) and later change recollection and memory updating. The results showed that being on-task was associated with higher rates of change recollection rates both within- and between-participants. Put differently, when participants reported being on-task to the changed pair, they were more likely to recall the earlier pair that it had changed from. This suggests that when participants were focused on learning the changed pairs, or for participants who focused on learning the changed pairs more often, there were increased opportunities to engage in integrative encoding that could be recollected later. Given that change recollection was associated with proactive facilitation, this suggests that being on-task when encoding the changed pairs enhanced memory updating, partly through increased recollection of change.

The second way that the relationship between attention and episodic memory updating was assessed was through a manipulation that guided participants on where to look for changes to enhance intentional encoding of event features would be or were changed (Garlitch & Wahlheim, 2021). Here, the MFC framework predicts that pointing out the competing features when first presented prior to the changed features should enhance change detection, allowing more opportunities for changes to be recollected later. Consistent with this, change recollection rates and recall were higher for cued than uncued changes. Although change detection was not measured directly here, it can be assumed that increased rates of change recollection partly reflect increases in detecting change during the presentation of the changed features. Since change recollection was associated with proactive facilitation, it suggests that the overall benefit in memory for the cued changes shown by both age groups was partly due to the cues enhancing the ability for participants to form integrated representations that could be recollected later.

There were some unexpected results that can be accommodated by the MFC framework. For example, Garlitch and Wahlheim (2020a) found that older adults were not more susceptible to retroactive interference than younger adults, and younger adults reported more intrusions during the test than older adults. From the perspective of the MFC framework, the finding that older adults were not more susceptible to interference than younger adults can be accommodated by assuming that older adults encoded List 2 less effectively. If older adults had impaired memory for List 2 responses, this should lead those responses to create less interference in memory for the List 1 responses of changed pairs. Instead, older adults could rely on the memory strength of the List 1 responses to enhance memory on the test. Furthermore, this could explain why older adults did not show benefits to the same extent when they were able to recollect changes. Gaining access to the List 2 responses would be less likely to act as an additional retrieval route to List 1 responses for older adults. Finally, if younger adults encoded List 2 more effectively than younger adults, this would also suggest that these responses were more likely to create interference for younger adults when attempting retrieval of List 1 responses at test. This could partly explain why younger adults showed more List 2 intrusions at test than older adults.

Another unexpected finding was shown by Garlitch and Wahlheim (2020b). When using a single-list variant of the paired associate learning paradigm that featured three spaced repetitions of a word pair (e.g., wine-*grape*) prior to the presentation of the same cue with a changed response (e.g., wine-*glass*), there was proactive facilitation in overall recall for the changed pairs. Here, the MFC framework assumes that this likely occurred because the task design and materials, which were comprised of pairs containing weak associations and orthographic relationships, allowed participants to detect changes and engage in integrative encoding that could be recollected later often enough to benefit performance. Therefore, the facilitation effects observed in overall recall reflect a balance of facilitation associated with change recollection that outweighed interference effects that were associated with not recollecting changes.

Finally, it was surprising that there were no age differences in proactive effects of memory for the changed events (Garlitch & Wahlheim, 2021). Prior work using the same materials found proactive facilitation in overall recall of changed event for younger adults and no proactive effects for older adults, suggesting that older adults were differentially impaired in recalling the changed activities (Wahlheim & J. M. Zacks, 2019). Based on the difference in younger adults' performance across the experiments, the MFC framework can accommodate these differences by proposing that there was a more comparable balance of facilitation and interference effects for older and younger adults in our study than in prior work. This balance is presumed to be driven by the extent to which changes can be detected and later recollected. This suggests that younger and older adults detected and recollected changes more similarity here than in prior work. Although speculative, another possibility is that this difference across experiments reflects an unintended consequence of the attentional cues. Perhaps the attentional cues in our experiment (Garlitch & Wahlheim, 2021) also influenced older adults' approach to encoding of the uncued changes. The attentional cues were a form of environmental support (e.g., Craik, 1986) that could have led older adults to prioritize encoding both types of changes, thus improving their ability to detect and recollect the uncued changes more often than has been previously shown.

In addition to supporting predictions from the MFC framework about the roles of change detection and recollection in episodic memory updating, the work presented here highlights areas for further theoretical refinement. One such area is understanding instances when changes are remembered but not recollected, including how these experiences are formed and clarifying their relationship to memory performance. As a reminder, this category reflects instances in which participants indicate that a change occurred but do not correctly recall the other non-target response on the test phase. For example, in the experiment examining attentional cuing effects on event memory updating (Garlitch & Wahlheim, 2021), these instances entailed remembering that an event feature changed from Day 1 to Day 2 but not recalling the Day 1 feature during the cued recall test. When conditionalizing recall of the target event features from Day 2 on these instances, performance is typically intermediate to instances when changes are recollected and when changes are not remembered at test or comparable to the latter. The change remembered but not recollected instances could reflect when less durable or elaborative memory representations were formed during initial change detection, thus resulting in a lower likelihood of recollecting the full details of that experience later, a point that I return to when discussing age differences in episodic memory updating (see section on the Implications for Understanding Age Differences in Episodic Memory, p. 92). It is also possible that these instances include partial recollections of non-target information that serve as a basis for indicating when information has changed across episodes. For example, while watching the *everyday changes* paradigm (Wahlheim & J. M. Zacks, 2019), a participant may remember that the actor poured two different drinks across days but be unable to remember the original drink.

There are several ways that future studies could better understand the experience of remembering but not recollecting changes. First, to test whether differences in the quality of integrated representations distinguishes change remembered but not recollected responses from change recollected responses, an elaborative encoding strategy could be given to some participants during encoding. If the change remembered but not recollected responses represent instances where less durable integrated representations were formed during change detection, these instances should occur less often for the group that received the elaborative encoding instructions. Instead, to the extent that elaborative encoding enhances the quality of integrated representations during change detection, this group should show higher rates of change recollection than change remembered but not recollected instances. To test whether change remembered but not recollected instances reflect partial recollections, future studies could incorporate a variant of a think-aloud protocol during measures of change detection and recollection (for a review, see Austin & Delaney, 1998). Participants could be asked to describe their thoughts during encoding when they detect changes and at retrieval when completing the change recollection measure. The verbal reports at both measures could then be coded for whether participants could recollect specific details of the changed features (e.g., what type of drink the actor had first) or whether they experienced changes in a more general way (e.g., that the type of drink changed in some way). This would allow for a more complete characterization of whether change remembered but not recollected instances reflect poorer quality integrative encoding experiences or partial-recollections, or some combination of both.

Finally, future work should continue refining the MFC framework to demonstrate the causal role of change detection and understand whether there is a causal role for change recollection in memory updating. Since change detection enables integrative encoding of the original and new information together with information about their relative temporal order, it follows that the change detection process is the primary causal mechanism in whether interference or facilitation in memory updating will be observed. This is consistent with the causal evidence presented by Jacoby et al. (2015) showing that participants told to detect changes between the lists showed facilitation in recall for those between-list changed pairs while participants told to look within lists did not show this facilitation. The results showed that the manipulation of where to look for changes caused the differences observed in overall performance across the groups.

Apart from the work described above, the evidence supporting the role of change detection in episodic memory updating has been correlational, including the work presented here. To further demonstrate causal evidence, future studies could use manipulations that influence change detection rates and examine if this causes enhanced or impaired memory updating. For example, a variant of the selectivity paradigm (for a review, see Castel, 2008) could be used where some original and corresponding changed pairs are assigned high point values and others are assigned low point values. Assigning higher point values should increase change detection and integrative encoding because participants should prioritize encoding the items with high value, thus increasing their memorability. Therefore, there should be facilitation in memory for the high value changes and no facilitation in memory for the low value changes. Another method could be to manipulate whether participants are in divided or full attention during encoding. Divided attention impairs the efficacy of memory representations formed during encoding, thus impairing cued recall performance (e.g., Craik et al., 1996). Divided attention at encoding should reduce how often change detection occurs, thus reducing the opportunities to form integrated representations. Divided attention may also influence the quality of the integrated representation given that full attentional resources are not available and thus may result in partial or incomplete retrieval of the original information. Memory updating should be impaired when participants are under divided attention while participants under full attention may show no interference or facilitation effects depending on how often changes were detected.

Reducing the rate and quality of change detection during encoding should also reduce opportunities for those changes to be recollected later. It follows then that the integrated representation formed when changes are detected likely determines whether that experience will be recollected later. Rather than being a causal agent in the memory updating process, change recollection may merely be a consequence of earlier detected changes. Developing empirical tests to determine whether change recollection plays a causal role in episodic memory updating is complex and requires additional theorizing. One way to try and separate the contributions of change detection and recollection could be to use manipulations that only influence recollection-based retrieval at test, not study-phase retrievals that enable change detection and integrative encoding. One example could be increasing the retention interval, as previous work has shown that recollection estimates decrease from immediate to delayed tests (e.g., Gardiner & Java, 1991). Here, it would be expected that change recollection rates would be decreased at longer than shorter retention intervals. However, the rates of change detection should not differ across retention intervals. Whether there is facilitation or interference in overall recall in the longer retention interval will depend on whether earlier-detected changes could be recollected despite lower recollective processing due to the longer delay.

Implications for Understanding Age Differences in Episodic Memory

Older adults sometimes experience episodic memory deficits partly because they are impaired at recollecting specific details of prior experiences (for reviews, see Balota et al., 2000;

Park & Festini, 2017; Zacks et al., 2000). Related to the present work, older adults have also shown impaired updating of episodic memories when information changes across temporally distant episodes like across lists or movies (e.g., Wahlheim, 2014; Wahlheim & J. M. Zacks, 2019). The results from the studies reported in this integrated dissertation show mixed evidence for age-related impairment in episodic memory updating. In our study of retroactive effects of memory, there were no age differences in recall of existing memories nor did older adults show a differential memory updating deficit (Garlitch & Wahlheim, 2020a). Decomposition of overall performance showed that how older and younger adults reached similar performance was different based on the balance of interference and facilitation effects associated with change detection and recollection. Older adults detected changes as often as younger adults but showed impairments in recollecting changes and this was associated with less clear benefits to memory updating for them. The results from our study on the effects of attentional cuing in event memory updating were more consistent with prior work, with one exception (Garlitch & Wahlheim, 2021). Consistent with prior work, the results showed lower overall recall and change recollection rates for older than younger adults. However, older adults did not show a differential event memory updating deficit.

There are several variables that may help explain why older adults do not consistently show an episodic memory updating deficit. First, age differences in memory updating may differ based on the type of materials used in the study, particularly the extent to which the materials allow older adults to leverage their intact semantic memory to benefit episodic memory performance (for a review, see Umanath & Marsh, 2012). In our study of retroactive effects of memory (Garlitch & Wahlheim, 2020a), the word pairs contained weak associations between the cues and responses (e.g., pencil-wood). Although older adults typically show a deficit in binding and forming associations between multiple components during an episode (e.g., Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000), this deficit is reduced or eliminated when the word pairs are related (e.g., Badham et al., 2012; Naveh-Benjamin, 2000, Experiment 4; Naveh-Benjamin et al., 2003, Experiment 2; Naveh-Benjamin et al., 2005; Patterson et al., 2009). One explanation for this effect is that having semantic associations present across the word pairs decreases the burden for older adults to form new associations because they can rely on existing associations that are already present in their semantic network (e.g., Patterson et al., 2009).

Not only can semantic associations enhance the binding of studied information for older adults, but this may also benefit their ability to detect when these associated pairs change. Older adults detect changes more often where the original and changed pairs are semantically associated than when they are unrelated (Wahlheim, 2014). However, this increase in change detection does not necessarily rescue a deficit in episodic memory updating, as older adults were still less likely to recollect those experiences later and sometimes showed greater susceptibility to proactive interference. Compared to the results from our study showing that older adults were not more susceptible to retroactive interference when there were semantic associations present between the original and changed pairs (Garlitch & Wahlheim, 2020a), this suggests that the benefit of semantic associations on episodic memory updating also depends on whether the conditions are proactive or retroactive effects of memory.

Future studies could test this proposal by combining the approaches from our study and the work by Wahlheim (2014) to systematically examine the role of semantic associations in age differences in memory updating for both retroactive and proactive effects of memory. When word pairs are associated, this should enhance older adults’ ability to engage in change detection and integrative encoding but may not translate to enhanced recollection of change later, which would lead to poorer performance when examining proactive but not retroactive effects of memory. When word pairs are not associated, this should reduce older adults' ability to detect changes and engage in integrative encoding. This could lead to poorer memory updating because the inability to integrate the responses could lead to older adults experiencing more competition at retrieval due to their inhibition deficit (e.g., Hasher & R. T. Zacks, 1988; for a review, see Lustig et al., 2007).

Age differences in event memory updating may also be influenced by how well older adults can apply their semantic knowledge to their episodic memory performance. Older adults sometimes show deficits in event comprehension partly due to impairments in their sensitivity to the hierarchical and causal structure of events (e.g., Zacks et al., 2006). However, prior work has also shown that older adults are not impaired in perceiving and remembering familiar everyday events that are consistent with established schemata, like balancing a checkbook (e.g., Pitts et al., 2021; M. E. Smith et al., 2020, 2021). The role of prior knowledge cannot be assessed from the study reported here because there is no existing data on how familiar older adults are with the events depicted in the movies (Garlitch & Wahlheim, 2021). The material set likely included a range with some activities being more familiar to older adults, like ironing, and some activities being less familiar to older adults, like plugging an iPod into the stereo of a car. To address this limitation future work could get ratings of familiarity from older and younger adults for these materials and examine whether there were age differences in event memory updating as a function of familiarity. Additional studies could be conducted by developing a new material set comprising of some changed events that are familiar and some changed events that are less familiar to older adults. Older adults should detect changes more often for familiar events, which should increase opportunities to form integrated representations that could be recollected later.

Therefore, older adults should show better memory updating for familiar than unfamiliar changed events.

Another variable that may influence older adults' ability to update episodic memories is attention. As previously mentioned, theories on age-related deficits in inhibition (Hasher & R. T. Zacks, 1988) and executive attention (McCabe et al., 2010) suggest that older adults have less attentional control which impairs encoding and later retrieval of target information. However, older adults can marshal attentional resources to strategically allocate attentional resources to information that is important or relevant to them (for a review, see Castel, 2008; Hess, 2006, 2014). Consistent with this, our study on the attentional cuing effects in event memory updating showed that older adults benefitted from these cues, presumably because they strategically allocated attention to prioritize encoding the event features, thus benefitting event memory updating (Garlitch & Wahlheim, 2021). This suggests that providing attentional guidance can allow older adults to overcome deficits in inhibition and controlled attention processing by encouraging them to integrate information together in memory. The ability to overcome interference through integration show in our work is somewhat consistent with other findings showing that the interference typically shown when learning multiple facts associated with the same cue is eliminated when older adults can integrate the facts together into a more complex representation (e.g., Radvansky et al., 1996, 2005).

Although our work can be taken as indirect evidence for a role of controlled attention in older adults' event memory updating deficit, there are several reasons why a lack of attention to the event features, at least as it is measured here, cannot fully explain why older adults have previously shown event memory updating deficits. One reason for this is because we found that younger adults benefitted comparably from the attentional cues as older adults and the cues did not eliminate age differences in memory. The latter finding suggests that age differences in recall of changed events cannot be entirely due to age differences in attention to event features. Other work using naturalistic stimuli has found no differences in where older and younger adults look during a movie, as evidenced by comparable eye-movement synchrony (Davis et al., 2021), suggesting that both age groups are looking at similar event features during encoding. In addition, other work using more direct measures of attention during encoding indicate that older adults are as engaged in the task as younger adults but still show lower performance (for a review, see Jordão et al., 2019). Together, this suggests that differences in what information or how consistently older adults are paying attention while encoding events does not explain why they are sometimes less able to update events following changes.

It is worth considering whether other measures of attention may give a more precise understanding of how aging is associated with differences in episodic memory updating. Two aspects of attention that future studies could measure include the intensity and the quality of attention. The intensity of attention reflects how much attention allocation is given to the task while the quality of attention reflects what qualitative aspects are being focused on during the task or what one is doing with their attention. An existing theory of age differences suggests that older adults have fewer attentional resources available, which affects the quality of their encoding and subsequent retrieval (Rabinowitz et al., 1982). Future studies could evaluate age differences in the intensity and quality of attention and examine whether this is related to age differences in episodic memory updating. Divided attention is a manipulation that may impact both intensity and quality of attention by reducing the amount of attention available and impairing the quality of encoding. If younger adults under divided attention at encoding show similar memory updating performance to older adults under full attention, this would provide initial evidence that attention intensity and quality are related to older adults' deficit in episodic memory updating. Furthermore, it would be expected that older adults under divided attention at encoding would show greater decreases in performance than younger adults under divided attention given the complexity of the integrated encoding required to promote memory updating. I return to this point below and provide additional ideas about attentional intensity, quality, and the interaction between the two (see section on the Relationship Between Attention and Episodic Memory, p. 96).

More generally, older adults may sometimes show less successful memory updating in more basic or more naturalistic paradigms because they experience a selective deficit in controlled retrieval processes (e.g., Hay & Jacoby, 1999; Jacoby, 1999; Koen & Yonelinas, 2016). Dual-process theories posit that older adults experience deficits in conscious recollection but show intact familiarity-based retrieval processes. A general recollection deficit has implications for several processes supporting episodic memory updating. First, the general recollection deficit should render older adults less likely to retrieve the original information, which would lead to fewer instances of change detection when encoding new information that shares overlapping features. If changes are detected less often, this creates fewer opportunities to form integrated representations that can be recollected later. Furthermore, even if older adults detect changes as often as younger adults, they are expected to recollect these experiences less often than younger adults (e.g., Wahlheim, 2014).

Age-related differences in the rates of change detection and integrative encoding may be further compounded by differences in the quality of how these representations are formed. Making a judgment that a change has occurred should partly rely on how well the original information can be retrieved during new learning, so age differences in the quality of that retrieval could negatively impact the basis for which this change judgment is made. Prior work has suggested that older adults encode and retrieve information in a more general or global way (e.g., Castel et al., 2007; Greene & Naveh-Benjamin, 2020; Rabinowitz et al., 1982). Both behavior and neural evidence has also shown that older adults reinstate and report fewer specific perceptual, spatial, and temporal details from past experiences (e.g., Hashtroudi et al., 1990; McDonough et al., 2014; St-Laurent et al., 2014) and use these details to a lesser extent to assess the quality of their memory experiences than younger adults (Folville et al., 2020; Wong et al., 2012). For example, Folville et al. (2020) found that older adults recalled fewer perceptual details but subjectively reported higher ratings of vividness for those memories than younger adults, and the number of perceptual details recalled better predicted vividness ratings for younger than older adults. This suggests that older adults recall fewer recollective details and then adjust their judgments of memory quality to account for this.

It follows from these findings that when being asked to detect changes, older adults may be less likely to use detailed and specific features of the original information as a basis for change detection. Somewhat consistent with this idea, the results reported here showed that older adults were more likely to indicate change during List 2 (Garlitch & Wahlheim, 2020a) and at test without being able to recall the other non-target information that led to or was changed (Garlitch & Wahlheim, 2020a; Garlitch & Wahlheim, 2021). Together, this indicates that the integrative encoding experiences that occur for older adults may not contain the details necessary to promote later recollection and successful memory updating.

With deficits in recollection potentially impairing both the frequency and quality of integrated representations that older adults form when encoding changes, this is a clear area for potential remediation. One recent study showed that improving recall of the originally learned information by testing participants on this information prior to new learning partly improved older adults' memory updating performance (Kemp & Wahlheim, 2021). Future studies could employ additional manipulations aimed at supporting recollective abilities for older adults to enhance their ability to create durable integrated memory representations. One way could include providing instructions to older adults during encoding that emphasizes elaborative or distinctive processing (e.g., Coane, 2013; Hay & Jacoby, 1999). To further improve the quality of integrated representations that are formed during change detection, an instruction manipulation could encourage participants to think about the relationship between the changed information or to create a mental image that links them together. This should then lead to more instances in which older adults could later recollect this experience later and thus would be associated with more successful memory updating.

Relationship Between Attention and Episodic Memory

As described earlier, a key assumption of the MFC framework is that attention during encoding is necessary to form initial memory representations and to cue retrievals of existing memories when encoding new information that shares overlapping features. As described above, the results from our study on the association between self-reported task engagement and memory updating provided initial evidence for this previously untested assumption (Garlitch & Wahlheim, 2020b). As a reminder, participants were instructed to pay attention and intentionally encode word pairs for a later memory test and were intermittently asked to report whether they were engaged with the task of learning those pairs. The results showed that being on-task while encoding the changed pairs was associated with higher change recollection and recall than being-off task. These relationships were also shown between-participants. Together, these findings suggest that when participants reported being on-task to changed pairs during study, they were more likely to subsequently recall not only the changed response but also the original response paired with the same cue and this process was associated with better recall for the changed pair.

There are some limitations to the prior work that should be addressed in future studies to improve our understanding of natural fluctuations in attention during encoding and how this relates to subsequent memory updating. First, as mentioned above, this study did not directly measure change detection because doing so would have undermined our ability to measure natural variations in task engagement across study items and participants. Therefore, conclusions about whether being on-task is associated with enhanced change detection rates during encoding had to be inferred from retrieval dependencies during the cued recall test. Secondly, the probes measuring self-reported task engagement were placed after changed pairs, but they were not systematically placed following original pairs in a way that would provide suitable experimental control. This limits the characterization of when task engagement is most critical during the updating process and how disengagement during encoding of the original or new information is associated with differences in episodic memory updating. For example, being on-task during encoding of the original information may lead to better change detection because the conflicting features would be more salient. In contrast, being on-task during encoding of the changed information may be necessary to cue retrieval of the original information and detect changes. It is likely that both possibilities play a role in updating. Future work is ongoing to address this limitation by systematically varying whether probes measuring self-reported attention are given following the presentation of original events, events with changed features, or both. This will allow for a more comprehensive understanding of the role of attention during encoding and the subsequent errors that occur in event memory updating when there are lapses in attention.

Similar to the discussion above on the role of attention in age differences in event memory updating, there may generally be a role for more strategic, top-down attentional control processes in the ability to update episodic memories. Prior work suggests that participants can be encouraged to look for changes, and that this leads to differences in memorial benefits for that information (Jacoby et al., 2015). Furthermore, the results reported here support this idea by showing that providing attentional cues to critical event features that would be or were changed was associated with greater rates of change recollection and higher recall (Garlitch & Wahlheim, 2021). Since participants were told to prioritize encoding to these features, this suggests that they were able to employ more strategic control of attention to encode original features and to detect when such features had changed, thus allowing for more integrated representations to form that could be recollected later. One limitation of this study is that including the attention cues also likely increased bottom-up attention processes, like an attention capture effect, especially when event features changed (cf. Garlitch & Wahlheim, 2020b). To better distinguish the contributions of top-down attentional processes to episodic memory updating, future studies could employ manipulations that primarily influence strategic attention processes like value-directed encoding manipulations (for a review of studies using this method, see Castel, 2008) or motivated forgetting of specific items (for a review, see Sahakyan et al., 2013) to examine how this influences both detection and recollection of changes and their associations with memory updating.

Strategic control of attention may also influence the intensity or quality of attention that is given during encoding, and this may also be related to differences in memory updating. As a reminder, intensity of attention reflects the amount of attention allocated to the task while the quality of attention reflects what qualitative aspects are being focused on during the task. At present, there have not yet been any studies to examine how the intensity or quality of attention plays a role in episodic memory updating. Understanding how these two factors interact may help predict situations that will result in more effective episodic memory updating. For example, if someone is intensely allocating effort to encoding an event feature but is doing so by thinking of their own personal thoughts, feelings, or evaluations of the event feature, then this would result in lower quality of attention than if their attention had been allocated to encoding the contextual details, including perceptual, spatial, and temporal information about it. Since they were not attending to the features of the event that could help them detect changes later, this would be associated with poorer episodic memory updating. Testing these ideas may require a combination of methodological approaches to assess intensity and quality. To measure intensity of attention during encoding, future studies could use methods that examine oculomotor characteristics, such as pupillometry, as pupil dilation may indicate attentional effort (for a review, see Unsworth & Miller, 2021). To measure attentional quality, future studies could ask participants to recall what they remember thinking about during that encoding experience to get a measure of the types of thoughts they had and whether this included contextual details of the information (e.g., Folville et al., 2020).

A final way that attention may influence episodic memory updating is through predictive looking. Predictive looking occurs when viewers attend to information in anticipation of future actions based on past experiences (for a review, see Gredebäck & Falck-Ytter, 2015). Predictive looking can be a way to measure attention in the moment and can be indicative of memory for previous actions, as it requires memory for the past to anticipate the future. When a change is experienced that differs from the past, this can result in a predictive looking error, which can facilitate new learning and updating of event memories. For example, in an event memory paradigm including movies of an actor performing everyday actions, Wahlheim et al. (2022) found that predictive looking errors during the second movie were associated with better recollection of actions from the first movie, which was associated with facilitation in memory for changed actions. This suggests that predictive looking errors occurred when participants were thinking back to the original event, and thus it may facilitate integrative encoding of the original and changed event features.

One future direction that could further inform the role of predictive looking in event memory updating is to examine age differences in predictive looking. Older adults may show fewer predictive looking errors due to reductions in the intensity or quality of attention during encoding of the originally learned information. This may also interact with the extent to which older adults can rely on semantic memory. A recent study showed that semantic knowledge contributed to older adults' ability to attend to goal-relevant event features, as indicated by eye fixations (M. E. Smith et al., 2021). Therefore, more familiar events may be associated with greater predictive looking errors for older adults when those events change, which would be associated with better event memory updating.

Applied Implications

In addition to the consequences for our theoretical understanding on the roles of aging and attention in episodic memory updating, the findings reported here have implications for everyday situations of memory interference that require updating. In particular, the results suggest that recommendations or strategies to support memory updating in everyday life should focus on bringing together the competing information when changes are experienced, especially when the information shares semantic overlap. Encouraging individuals to consciously initiate retrieval of previously learned information when changes are experienced can enable change detection and the formation of an integrated representation that they can rely on later at retrieval.

Recommending an integrative encoding strategy when faced with changes may be particularly important for older adults who are less likely to deploy this type of strategy without prompting. A recent qualitative study found that it was common for older adults to assume that they would remember to complete activities in everyday life because those activities were familiar and habitual for them, but they reported somewhat ineffective uses of external devices, mnemonic strategies, and self-regulatory approaches to support remembering these activities (Hertzog et al., 2019). The results from our study on the attentional cuing effects on event memory updating suggest that making the changed features more salient and encouraging older adults to prioritize encoding of the information that is cued can be beneficial for integrative encoding and memory updating (Garlitch & Wahlheim, 2021). Although it would be quite difficult to insert visual cues in uncontrolled everyday environments, emphasizing which details in the environment may change could help older adults adopt a more strategic approach to directing their attention in the service of remembering when experiencing conflicting information. This strategy could be applied to situations in which older adults experience changes in activities of daily living or when they are required to learn new procedures. As described in the Introduction, one example of this could occur when a medication dosage gets updated. In these cases, older adults could learn to prioritize attention to encode the new dosage while comparing it to the old dosage. Medical professionals could also prompt older adults to adopt this strategy by reminding patients of their previous dosage.

These results may also have implications for educational contexts when students are required to integrate new learning with information they may have learned in a previous class. In many cases, the new information is congruent with prior learning, but in other cases, the new learning may be inconsistent with previously learned information. The work reported here suggests that instructors should encourage students to retrieve previously learned information prior to introducing the new learning it is related to. By encouraging retrieval of the previously learned information, this can help students to integrate this information together and support retention for it later. Consistent with this idea, prior work using materials comprised of psychological concepts and images that correspond to their definitions showed that reactivation of prior learning was associated with a benefit to new learning (van Kesteren et al., 2018). Although this benefit was greatest when the new learning was congruent with pre-existing knowledge that students had about the concepts, there was also a benefit for reactivation when the new learning was inconsistent with prior knowledge. In situations where students are learning new information in the absence of existing knowledge, integration could be further enhanced by administering interpolated tests after initial learning. Prior work has shown memorial benefits associated with interpolated testing that include reduced mind wandering rates during online lectures (Szpunar et al., 2013) and improved memory updating and recollection of changes (e.g., Kemp & Wahlheim, 2021; Wahlheim, 2015). Therefore, this strategy could be effective for increasing attention to and integration of the previously learned and new information.

Conclusions

The three empirical papers reported here had the overarching goal of understanding how age and attention interact with the processes underlying episodic memory updating. Across the studies, there was evidence that older adults recollected changes less often than younger adults, and this was associated with deficits in episodic memory updating under certain conditions. Age differences in episodic memory updating can be reduced or even eliminated when older adults detect changes as often as younger adults, particularly when associations among the stimulus materials allow older adults to leverage their intact semantic knowledge. Furthermore, older adults experience a deficit in some aspects of attention that may partly contribute to their ability to update event memories, but other factors should be considered to fully understand how aging affects episodic memory updating. More generally, attention appears to play a necessary role in episodic memory updating, as updating is more likely to occur when participants report being engaged with learning the changed information and when attentional cues point out event features that will be or are changed. Future studies should consider more precise and converging measures of the type of attention that contributes to episodic memory updating. By continuing to understand the roles of aging, attention, and the interaction of the two, we can more comprehensively predict situations when, and for who, memory updating will be successful. This can inform intervention strategies that aim to support memory updating across the life span.

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APPENDIX A: SUPPPLEMENTAL MATERIAL FOR CHAPTER III

Study Phase Instructions

In this part of the experiment, you will be asked to study word pairs for an upcoming test. Some of the word pairs will repeat, some will appear once, and some will change at a later point in the study phase. For changed word pairs, the left-hand member of a pair will be presented later with a different right-hand member (e.g., silly-clown; silly-giggle). Each pair will appear on the screen for 6 seconds. Please learn each pair as best as you can for a test that you will be given at the end of the experiment.

Do you have any questions?

Press the SPACE BAR for more instructions.

While you are studying the word pairs, you may notice that your ability to focus your attention on the task waxes and wanes throughout this period. It is normal for people to experience various levels of attentional engagement. We are interested in the extent to which you experience these variations in task engagement. Every now and then, we will ask you to indicate your current level of engagement during the upcoming study phase.

To measure this, we will randomly present a screen that asks you to indicate whether you are on-task or off-task. If your attention just before the probe was firmly directed at learning the word pairs, then indicate that you are On-task. In contrast, if your attention was on something else other than studying the word pairs, then indicate that you are Off-task. You will indicate this by clicking the appropriately labeled button on the screen.

Do you have any questions?

Press the SPACE BAR when you are ready to begin studying.

Test Phase Instructions

Test Phase

In this part of the experiment, you will be tested on your memory for the word pairs that you studied. You will be presented with the left member of a word pair (e.g., silly - ?), and your task will be to type the word that it was most recently paired with during the study phase.

Do you have any questions?

Press the SPACE BAR for more instructions.

After you have made your response, you will be asked whether the right word changed during the study phase. The question, “Did the right word change during the study phase?” will appear in the middle of the screen with boxes labeled “Yes (1)” and “No (0)” displayed below.

If you think that the right word that was presented with the left-hand member of a pair changed in the study phase (e.g., silly-clown; silly-giggle), then press the "1" on the keyboard. When you indicate that a pair has changed (silly-giggle), you will next be asked to recall what the cue was paired with earlier in the study phase (clown). If you cannot remember the earlier pairing, then it is fine to either guess or pass. Please type your response into the box below and check your spelling carefully. In contrast, if you do not think that the right word of a pair changed during the study phase, then you should press the “0” on the keyboard.

Do you have any questions?

Press the SPACE BAR to start with some practice trials.

ANOVAs and Effect Sizes

All analyses were conducted using R software (R Core Team, 2019). For ANOVAs, we first fit a simple linear regression using the base lm function. Then we conducted hypotheses tests using the Anova function from the car package (Type III). The base t-test function was used for two-group comparisons. The level for significance was set at $\alpha = .05$.

Task Reports

A two-way ANOVA was performed to compare the effects of Item Type and Block on the proportion of on-task reports. There was a significant effect of Block, $F(3, 4740) = 6.43$, $p < .001$, $\eta_p^2 = .004$, no significant effect of Item Type, $F(2, 4740) = .94$, $p = .39$, $\eta_p^2 < .001$, and a significant Block × Item Type interaction, $F(6,4740) = 4.00$, $p < .001$, $\eta_p^2 = .005$. As shown in Figure 4, the proportion of on-task thoughts increased from Block 3 to Block 4 for A-B^3, A-D items but was not significantly different for A-B^4 or C-D items.

Recall performance

A one-way ANOVA was performed to compare the effects of Item Type on recall performance. The effect of Item Type was significant, $F(2, 9501) = 582.79$, $p < .001$, $\eta_p^2 = .11$. As can be seen in Figure 5 (right panel), recall for A-B^4 items was significantly higher than the other two item types, but recall did not differ between A-B^3, A-D and C-D items. A separate one-way ANOVA was performed to compare the effects of Item Type on intrusion rates. The effect of Item Type was significant, $F(2, 9501) = 1051.18$, $p < .001$, $\eta_p^2 = .18$. As shown in Figure 5 (right panel), intrusions were highest for A-B^3, A-D items, but did not differ between A-B^4 and C-D items.

Recall performance Conditionalized on Change Classifications

A one-way ANOVA was performed to compare the effects of the three levels of change classification outcomes at test on conditionalized correct recall (Change Recollected, Change Remembered (Not Recollected) and Change Not Remembered). Recall performance on the C-D items was also included as a level in the ANOVA so that proactive effects of memory could be examined. There was a significant effect of Change Classification, $F(2, 9501) = 582.79$, $p < .001$, $\eta_p^2 = .25$. As shown in Figure 5 (left panel), recall performance was higher when participants recollected change compared to when they did not recollect change. A comparable model was fit to the conditionalized intrusion data, showing a significant effect of Change Classification, $F(2, 3165) = 316.09$, $p < .001$, $\eta_p^2 = .17$. As shown in Figure 5 (right panel), intrusions were higher when change was not recollected than when it was.

Relationships between Attention during Study and Memory at Test

Since there were an unequal number of participants that contributed to recall performance for each Item Type based on the task reports made in Block 4, we fit separate one-way ANOVAs to each Item Type to examine the effects of Task Report on correct recall (see Figure 9, left panel). The ANOVA for A-B[4] items showed no significant effect of Task Report, $F(1, 110) = .01$, $p = .92$, $\eta_p^2 < .001$. The ANOVA for C-D items showed a significant effect of Task Report, $F(1, 152) = 5.47$, $p = .02$, $\eta_p^2 = .03$. The ANOVA for A-B, A-D items also showed a significant effect of Task Report, $F(1, 114) = 5.52$, $p = .02$, $\eta_p^2 = .05$.

Finally, we conducted pairwise comparisons for intrusions and change classification responses conditionalized on the task reports made in Block 4. Differences in the degrees of freedom in the following analyses reflect that there were different numbers of responses that contributed to the conditionalized comparisons. As seen in Figure 9 (right panel), there was no significant difference in intrusion rates when participants indicated being on- than off-task, *t*(155) = .47, *p* = .64, *d* = .07. Figure 10 displays the differences in change classifications conditionalized on task reports. The pairwise comparison for Change Recollected responses showed that change was recollected more often when participants reported being on- compared to off-task, *t*(171) = 2.64, *p* < .001, *d* = .39. The pairwise comparison for Change Remembered responses showed no significant difference in remembering change when participants reported being on- than off-task, *t*(171) = 1.80, *p* = .07, *d* = .27. Finally, the pairwise comparison for Change Not Remembered showed that participants were less likely to indicate a change when they were off- than on-task, *t*(278) = 7.74, *p* < .001, *d* = .80.

APPENDIX B: SUPPLEMENTAL MATERIALS FOR CHAPTER IV

In this section, we provide more detailed information about the sensitivity analyses that we ran based on the sample size of the present study. Following this, we report results from ANOVAs based on simple linear regression models that included only subjects as random effects with corresponding standardized effect size estimates. The order of analyses parallels the organization of the main text.

Sensitivity Analyses

The sensitivity analyses were conducted in G*Power Version 3.1.9.2 (Faul et al., 2007) using statistical tests for within-between interactions in repeated measures ANOVA and for t-tests. For the sensitivity analyses with repeated measures, age was the between-subjects factor with two groups (younger vs. older), the sphericity assumption was met, power was set to 80% and α was set to .05. We took the conservative approach of including the weakest correlations among repeated measures as input parameters in these analyses. For regression models assessing cued recall and recognition performance that included four repeated measures (all four levels of the Activity Type factor), the weakest correlation was Pearson's $r = .24$. We ran a comparable analysis for the main effect of Activity Type using the within factors repeated measures ANOVA test in G*Power. For models examining overall change classifications, change recollected responses, and change remembered but not recollected responses that included two repeated measures (two levels of the Activity Type factor), the weakest correlation was Pearson's $r = .43$. Note that we did not include repeated and control activities as factor levels in the sensitivity analysis for models examining overall change classifications since these reflect incorrect classifications of change. Sensitivity analyses with sample sizes of 120 (cued recall) or 119 (recognition) showed nearly identical effect size estimates could be detected. Therefore, the results reported in the main text are from the analyses specifying a sample size of 120 as our primary hypotheses pertained to outcomes from the cued recall test. We were unable to determine sensitivity for models including more than one within-subject factor (i.e., models with Activity Type and Classification as factors) because such models are not supported in G*Power. Finally, the sensitivity analyses regarding pairwise comparisons were two-tailed with power set to 80%.

Statistical Approach

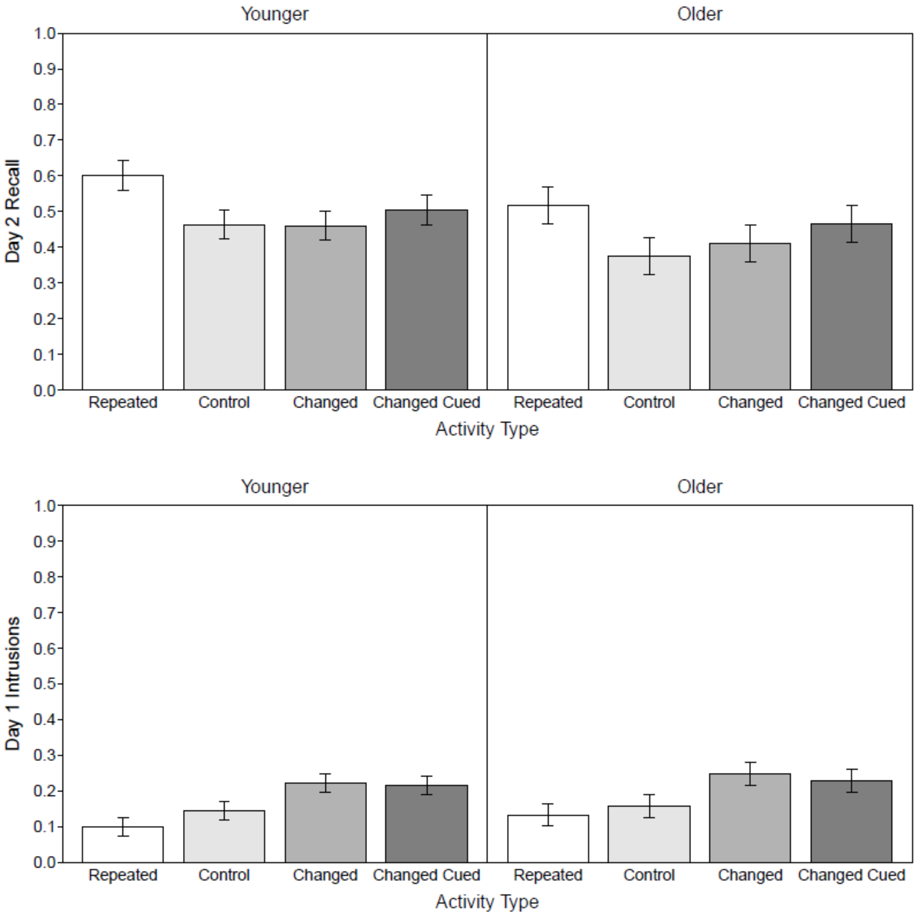
We fitted simple linear regression models with subjects as random effect using the *lm* function in R software (R Core Team, 2020). We then performed hypothesis tests using the *Anova* function (Type III sums of squares) from the *car* package (Fox & Weisburg, 2011). We computed partial eta squared and corresponding 95% confidence intervals (CI) from these models using the *eta_squared* function from the *effectsize* package (Ben-Shachar et al., 2020). Pairwise comparisons for mean differences were conducted using the *emmeans* function from the *emmeans* package (Lenth, 2020). We also computed d_r as an effect size estimate for differences in pairwise comparisons by dividing estimates of the difference across conditions by the residual standard deviations from the simple linear regression models (Westfall, 2016). We computed 95% CIs around these estimates using the *d.ci* function from the *psych* package (Revelle, 2020).

Cued Recall Performance

Day 2 Recalls

Day 2 recalls were examined to assess the effects of age and the cuing manipulation on event memory updating (Figure S1, top panel). An Age × Activity Type model indicated a significant effect of Activity Type, $F(3, 472) = 5.84$, $p < .001$, $\eta_p^2 = .09$ [$CI = .04, .14$], showing that Repeated activities were better remembered than all other activity types, smallest *t*(472) = 3.15, *p* = .01, d_r = 0.42 [*CI* = 0.05, 0.78], and Changed Cued activities were better remembered than Control activities, *t*(472) = 2.82, *p* = .03, d_r = 0.37 [*CI* = 0.01, 0.73]. Recall did not differ between Changed and Changed Cued activities, nor between Changed and Control activities, largest *t*(472) = 2.11, *p* = .15, d_r = 0.28 [*CI* = -0.08, 0.64]. No other effects were significant, largest *F*(1, 472) = 1.31, *p* = .25, η_p^2 = .03 [*CI* = .01, .07].

Figure S1. Day 2 Recalls and Day 1 Intrusions as a Function of Age and Activity Type



Note. Model-estimated probabilities of Day 2 recall (top panel) and Day 1 intrusions (bottom panel) for younger (left panels) and older (right panels) adults. Error bars are 95% confidence intervals.

Day 1 Intrusions

Day 1 intrusions were examined to assess whether cuing benefits would extend to intrusion production (Figure S1, bottom panel). An Age × Activity Type model indicated a significant effect of Activity Type, $F(3, 472) = 11.57$, $p < .001$, $\eta_p^2 = .17$ [CI = .11, .22], showing that intrusion rates for Changed and Changed Cued activities were higher than baseline estimates for Repeated and Control activities, smallest $t(472) = 4.84$, $p < .001$, $d_r = 0.64$ [CI = 0.27, 1.01]. There were no other significant pairwise differences, largest $t(472) = 2.24$, $p = .11$, $d_r = 0.30$ [CI = -0.06, 0.66]. No other effects were significant, largest $F(1, 472) = 0.45$, $p = .50$, $\eta_p^2 < .01$ [CI = .00, .03].

"Changed" Classifications

We examined overall "changed" classification probabilities made during the cued recall test (Table S1). An Age × Activity Type model indicated no significant effect of Age, $F(1, 472) = 3.65$, $p = .06$, $\eta_p^2 = .01$ [CI = .00, .04], and a significant effect of Activity Type, $F(3, 472) = 10.05$, $p < .001$, $\eta_p^2 = .30$ [CI = .23, .36], that was qualified by a significant Age × Activity Type interaction, $F(3, 472) = 6.71$, $p < .001$, $\eta_p^2 = .04$ [CI = .01, .08]. Pairwise comparisons revealed that older adults incorrectly classified Repeated and Control activities as changed more often than younger adults, smallest $t(472) = 3.07$, $p < .05$, $d_r = 0.57$ [CI = 0.21, 0.94], but there was no age difference in correctly classifying Changed and Changed Cued activities as such, largest $t(472) = 1.91$, $p = .54$, $d_r = 0.36$ [CI = 0.00, 0.72]. Both age groups were more likely to correctly classify Changed and Changed Cued activities than to incorrectly classify Repeated and Control activities as changed, smallest $t(472) = 3.27$, $p = .03$, $d_r = 0.67$ [CI = 0.30, 1.04], except for the comparison of Changed and Control activities for older adults, $t(472) = 1.70$, $p = .69$, $d_r = 0.35$ [CI = -0.01, 0.71]. Younger adults correctly classified Changed Cued better than Changed activities, $t(472) = 4.46$, $p < .001$, $d_r = 0.74$ [$CI = 0.37, 1.11$], while older adults did not show this difference, $t(472) = 1.57$, $p = .77$, $d_r = 0.32$ [$CI = -0.04, 0.68$]. In addition, younger adults incorrectly classified Control activities as changed more often than Repeated activities, $t(472) = 3.13$, $p = .04$, $d_r = 0.52$ [$CI = 0.15, 0.88$], while older adults did not show this difference, $t(472) = 1.95$, $p = .52$, $d_r = 0.40$ [$CI = 0.04, 0.76$].

Table S1. Model-Estimated Probabilities of "Changed" Classifications on the Cued Recall Test as Function of Age and Activity Type

	Activity Type			
Age	Repeated	Control	Changed	Changed Cued
Younger	.14 [.10, .19]	.25 [.20, .30]	.43 [.38, .47]	.57 [.53, .62]
Older	.28 [.23, .34]	.37 [.31, .42]	.44 [.38, .49]	.50 [.44, .56]

Note. 95% confidence intervals are shown in brackets.

We further decomposed overall "changed" classifications into change recollected and change remembered but not recollected responses for Changed and Changed Cued activities (Table S2). To reiterate from the main text, change recollected responses were operationalized as "changed" classifications accompanied by *correct* recall of the Day 1 feature while change remembered but not recollected responses were operationalized as "changed" classifications accompanied by *incorrect* recall of the Day 1 feature. An Age × Activity Type model fitted to change recollection responses (Table S2, top rows) indicated a significant effect of Age, $F(1, 236) = 25.36$, $p < .001$, $\eta_p^2 = .15$ [$CI = .07, .23$], showing that younger adults recollected changes more often than older adults. No other effects were significant, largest $F(1, 236) = 3.17$, $p = .08$, $\eta_p^2 = .06$ [$CI = .01, .12$].

An Age × Activity Type model fitted to responses of remembering but not recollecting change (Table S2, bottom rows) indicated a significant effect of Age, $F(1, 236) = 11.00$, $p < .01$, $\eta_p^2 = .13$ [$CI = .06, .21$], showing that, relative to younger adults, older adults classified more changed activities as such without recalling Day 1 features. No other effects were significant, largest $F(1, 236) = 1.44$, $p = .23$, $\eta_p^2 < .01$ [$CI = .00, .04$].

Table S2. Model-Estimated Probabilities of "Changed" Classifications as a Function of Classification, Age, and Activity Type

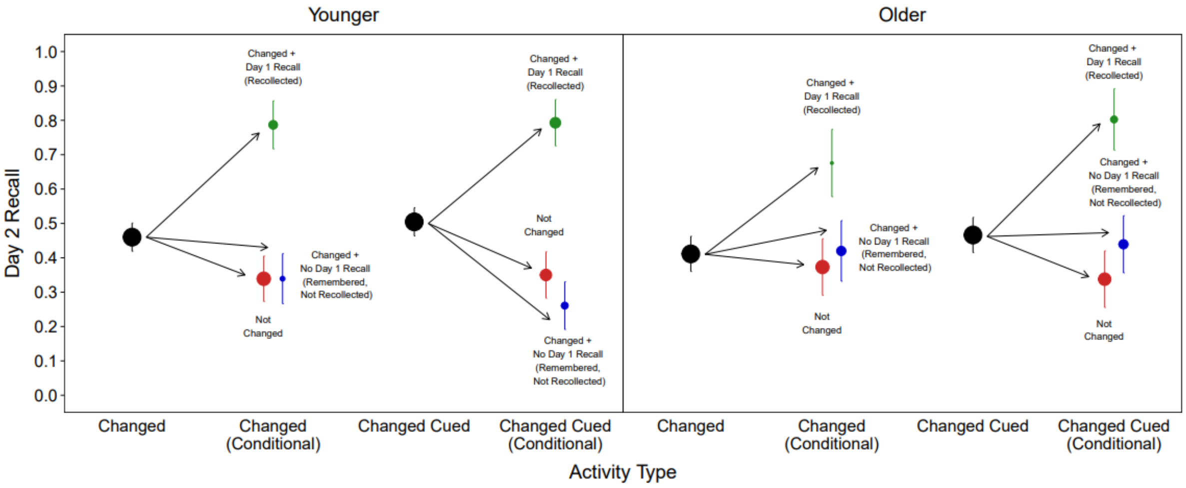
		Activity Type	
Classification	Age	Changed	Changed Cued
Changed + Day 1 Recall (Recollected)	Younger	.27 [.23, .31]	.37 [.33, .41]
	Older	.14 [.09, .19]	.20 [.15, .26]
Changed + No Day 1 Recall (Remembered, Not Recollected)	Younger	.15 [.12, .19]	.20 [.17, .24]
	Older	.30 [.25, .34]	.30 [.25, .34]

Note. 95% confidence intervals are displayed in brackets.

Day 2 Recalls Conditionalized on "Changed" Classifications

To examine the association between "changed" classifications and Day 2 recall, Figure S2 displays Day 2 recall for the two types of changed activities conditionalized on the three types of "changed" classifications (change recollection, change remembered but not recollected, and change not remembered). An Age × Activity Type × Classification model indicated a significant effect of Classification, $F(2, 646) = 30.53$, $p < .001$, $\eta_p^2 = .33$ [$CI = .27, .38$], and a significant Age × Classification interaction, $F(2, 646) = 3.58$, $p = .03$, $\eta_p^2 = .02$ [$CI = .00, .04$]. This interaction indicated that both age groups showed higher Day 2 recall when change was recollected (green points) than when it was remembered but not recollected (blue points) or not remembered (red points), smallest $t(646) = 6.76$, $p < .001$, $d_r = 1.08$ [$CI = 0.70, 1.46$], and no difference in Day 2 recall between the two classifications for which change was not recollected (blue and red points), largest $t(646) = 1.73$, $p = .51$, $d_r = 0.26$ [$CI = -0.10, 0.62$]. There were no age differences in conditionalized Day 2 recall when changes were recollected (green points) or when changes were not remembered (red points), largest $t(646) = 1.21$, $p = .83$, $d_r = 0.18$ [$CI = -0.18, 0.54$], but recall was higher for older than younger adults when changes were remembered but not recollected (blue points), $t(646) = 3.23$, $p = .02$, $d_r = 0.45$ [$CI = 0.09, 0.81$]. No other effects were significant, largest $F(2, 646) = 1.65$, $p = .19$, $\eta_p^2 < .01$ [$CI = .00, .02$].

Figure S2. Day 2 Recalls Conditionalized on "Changed" Classifications



Note. Model-estimated probabilities of Day 2 recall for Changed and Changed Cued activities for younger (left panel) and older (right panel) adults. The black points are overall probabilities, and the colored points are conditional probabilities. The green points are when changed activities were correctly classified and Day 1 features were recalled (Change Recollected); the blue points are when changed activities were correctly classified and Day 1 features were not recalled (Change Remembered, Not Recollected); and the red points are when changed activities were not classified as changed (Change Not Remembered). The conditional point sizes indicate the proportions of responses that went into each cell. Error bars are 95% confidence intervals.

2AFC Recognition Memory

Day 2 Recognition Accuracy

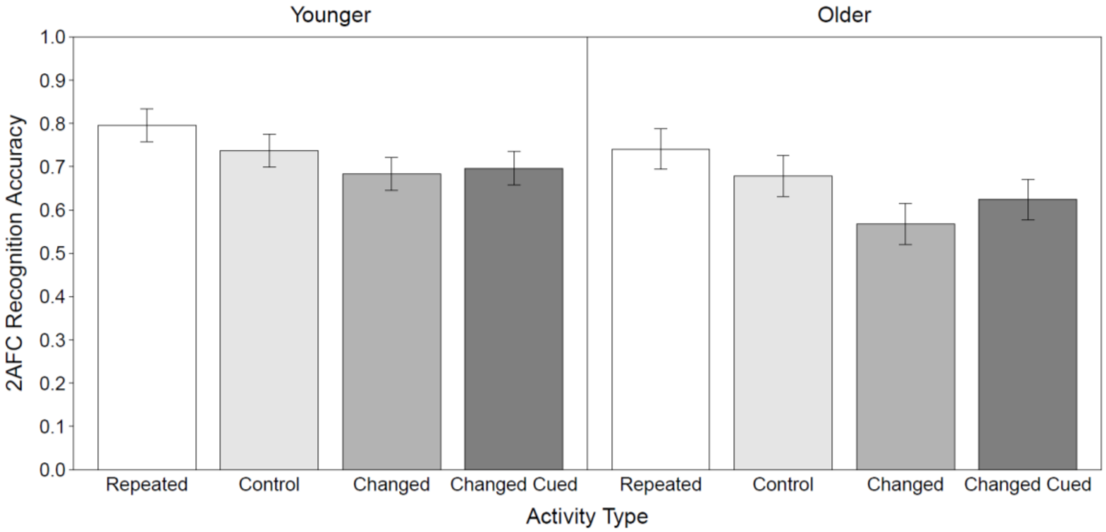
We also examined whether there was a cuing effect for older and younger adults in recognition accuracy (Figure S3). An Age × Activity Type model indicated significant effects of Age, $F(1, 468) = 5.51$, $p = .02$, $\eta_p^2 = .05$ [$CI = .02, .09$], and Activity Type, $F(3, 468) = 9.55$, $p < .001$, $\eta_p^2 = .09$ [$CI = .04, .14$], and no significant Age × Activity Type interaction, $F(3, 468) = 0.81$, $p = .49$, $\eta_p^2 < .01$ [$CI = .00, .02$]. Recognition accuracy was higher for younger than older adults. Repeated activities were better recognized than all other activity types, smallest $t(468) = 2.77$, $p = .03$, $d_r = 0.37$ [$CI = 0.00, 0.73$], and Control activities were better recognized than Changed activities, $t(468) = 3.79$, $p < .01$, $d_r = 0.50$ [$CI = 0.14, 0.87$]. There was no difference in accuracy between Control and Changed Cued activities, nor between Changed and Changed Cued activities, largest $t(468) = 2.18$, $p = .13$, $d_r = 0.29$ [$CI = -0.07, 0.65$].

“Changed” Classifications

Next, we examined the “changed” classification probabilities made during the 2AFC recognition test (Table S3). An Age × Activity Type model indicated significant effects of Age, $F(1, 468) = 17.26$, $p < .001$, $\eta_p^2 < .01$ [$CI = .00, .03$], and Activity Type, $F(3, 468) = 23.55$, $p < .001$, $\eta_p^2 = .47$ [$CI = .41, .52$], that were qualified by a significant Age × Activity Type interaction, $F(3, 468) = 11.48$, $p < .001$, $\eta_p^2 = .07$ [$CI = .03, .11$]. Younger adults correctly classified more Changed and Changed Cued activities than older adults, smallest $t(468) = 3.41$, p

= .02, d_r = 0.64 [*CI* = 0.27, 1.00], but there was no age difference for incorrect classifications of Repeated and Control activities as changed, largest *t*(468) = 2.88, *p* = .08, d_r = 0.54 [*CI* = 0.17, 0.91]. Younger adults were more likely to correctly classify Changed Cued relative to Changed activities, *t*(468) = 3.10, *p* = .04, d_r = 0.52 [*CI* = 0.15, 0.88], while older adults did not show this difference, *t*(468) = 1.83, *p* = .60, d_r = 0.38 [*CI* = 0.01, 0.74]. Both age groups were more likely to correctly classify Changed and Changed Cued activities than to incorrectly classify Repeated and Control activities, smallest *t*(468) = 4.51, *p* < .001, d_r = 0.93 [*CI* = 0.55, 1.31], and showed no significant difference between incorrect classifications of Repeated and Control activities, largest *t*(468) = 1.33, *p* = .89, d_r = 0.22 [*CI* = -0.14, 0.58].

Figure S3. 2AFC Recognition Accuracy as a Function of Age and Activity Type



Note. Model-estimated probabilities of 2AFC recognition accuracy as a function of Age and Activity Type. Error bars are 95% confidence intervals.

2AFC Recognition Accuracy Conditionalized on "Changed" Classifications

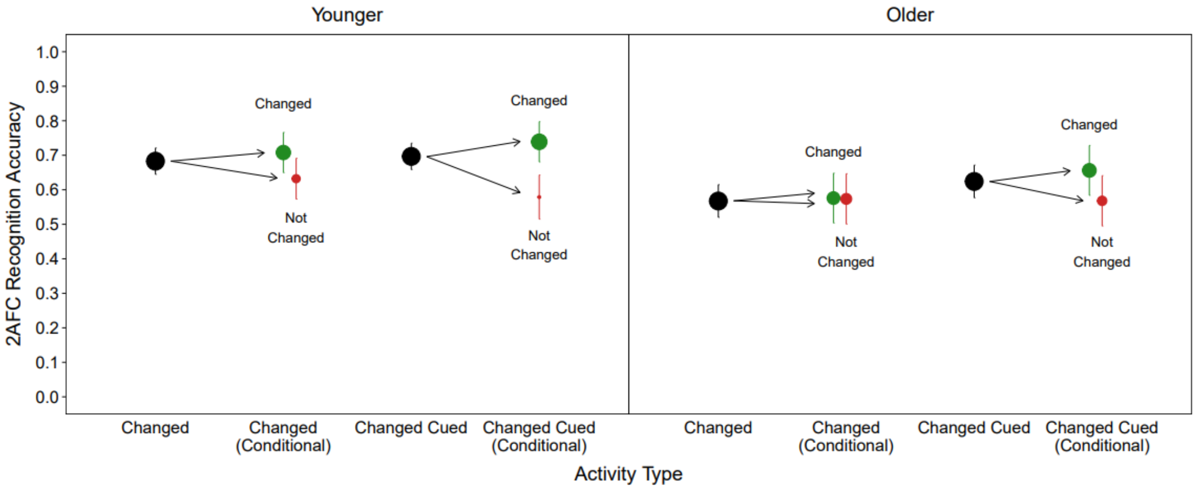
Lastly, we examined the association between recognition accuracy for the two changed activity types and memory for changes by conditionalizing recognition on "changed" classifications (Figure S4). An Age × Activity Type × Classification model revealed no significant effects, largest $F(1, 452) = 3.09$, $p = .08$, $\eta_p^2 = .02$ [*CI* = .00, .05].

Table S3. Model-Estimated Probabilities of "Changed" Classifications on 2AFC Recognition Test as a Function of Age and Activity Type

	Activity Type			
Age	Repeated	Control	Changed	Changed Cued
Younger	.28 [.23, .32]	.32 [.27, .36]	.68 [.64, .73]	.78 [.74, .83]
Older	.38 [.32, .44]	.35 [.30, .41]	.56 [.50, .61]	.63 [.58, .69]

Note. 95% confidence intervals are shown in brackets.

Figure S4. 2AFC Recognition Accuracy Conditionalized on "Changed" Classifications



Note. Model-estimated probabilities of 2AFC recognition accuracy for changed and changed cued activities for younger (left panel) and older (right panel) adults. The black points are overall probabilities, and the colored points are conditional probabilities. Green points show recognition conditionalized on correctly classified changes, and red points show recognition conditionalized on incorrectly classified changes. The size of the conditional points indicates the proportion of responses that went