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Directing Attention to Event Changes Improves Memory Updating for Older Adults

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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 (2AFC recognition) of recent action features. Cuing attention improved cued recall but not 2AFC 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.

Keywords: attention, change detection, event cognition, interference, memory updating

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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 & 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 & 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 present 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).

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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 suggest 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; 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; 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 & Zacks, 2011; Zacks et al., 2006, but see Kurby & Zacks, 2018; Sargent et al., 2013). 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 (McKinley & Benjamin, 2020; Tullis et al., 2014), and reading comprehension when current reading resonates with earlier reading (e.g., Cook & O'Brien, 2014; Cook et al., 1998; 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 & 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 & Zacks, 2011; 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 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., 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 min–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 & 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 & 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 benefit 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 & 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 & 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 & 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; $M_{\text{age}} = 19.60$, $SD_{\text{age}} = 2.22$, range = 18–30) from the University of North Carolina at Greensboro (UNCG) and 47 older adults (32 female; $M_{\text{age}} = 70.75$, $SD_{\text{age}} = 5.43$, range = 65–82) from the Greensboro community.[1] 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 1 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),[2] $t(113.14) = 11.86$, $p < .001$, and more years of education, $t(92.38) = 7.61$, $p < .001$.[3] Younger adults had higher working memory capacity (WMC) than older adults as measured by partial 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)[4] 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 & 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.

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.

[1] 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.

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

[3] 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 the OSF: https://osf.io/ekvh6/.

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

Table 1
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

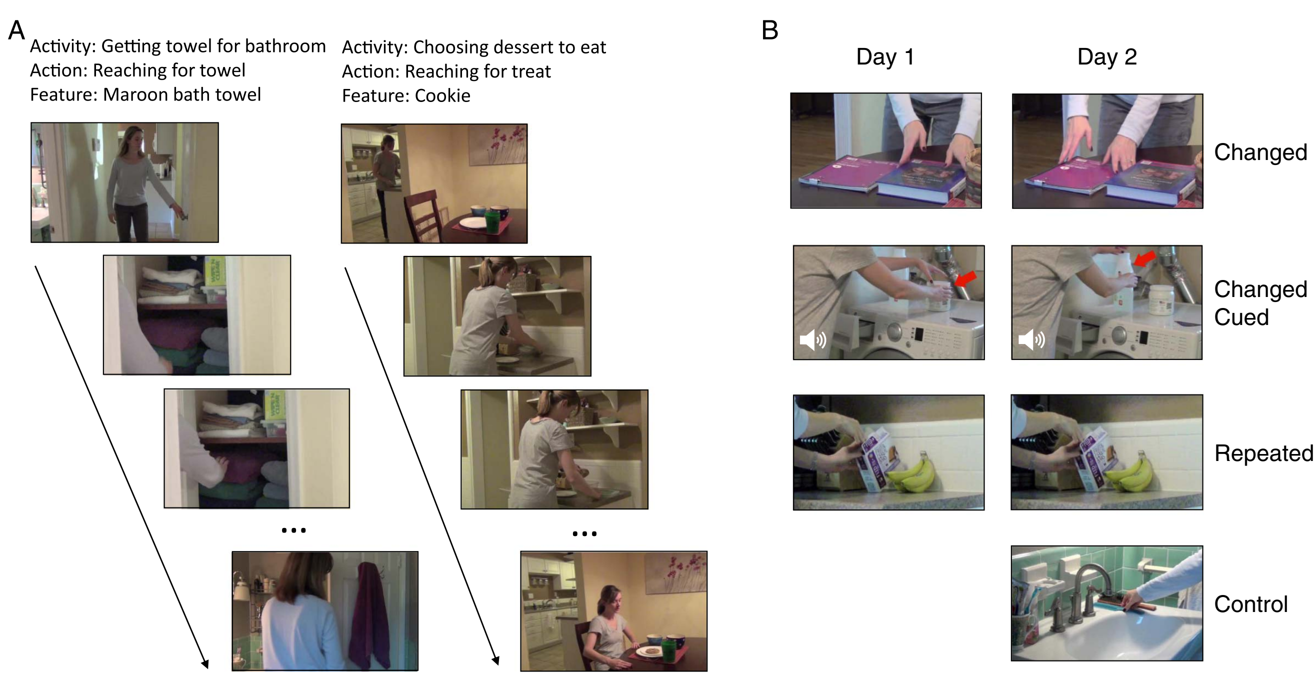
Note. *SD* = standard deviation, Vocabulary = Shipley Institute of Living vocabulary subtest (Shipley, 1986), Education = self-report years of education, ROSPAN = Rotation span (Kane et al., 2004), RSPAN = Reading span (Redick et al., 2012), SBT = Short Blessed Test (Katzman et al., 1983), MMSE = Mini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

Materials

Two movies (Day 1 and Day 2) showed an actor performing everyday activities during two fictive "days" in her life (movies are available on the 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 1A). 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 1B, 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 1B, 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 the OSF: https://osf.io/ekvh6/.

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

Figure 1
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. See the online article for the color version of this figure.

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 1B (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 the 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 1 week, depending on availability ($M_{\text{days}} = 7.08$, $SD_{\text{days}} = 0.68$, 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 & Zacks, 2019), to 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 1 week apart.

Table 2 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 the OSF: https://osf.io/ekvh6/. All computerized tasks were presented using E-Prime 3.0 software (Psychology Software Tools, 2016). 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.

In Session 2, participants were told to watch another movie with the same actor and to imagine it occurring 1 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

Table 2
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 (Wechsler, 1981).
* These tasks were completed by older adults only.

and actual cued recall tests, participants typed each response.[5] 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 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.[6] 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 the 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 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

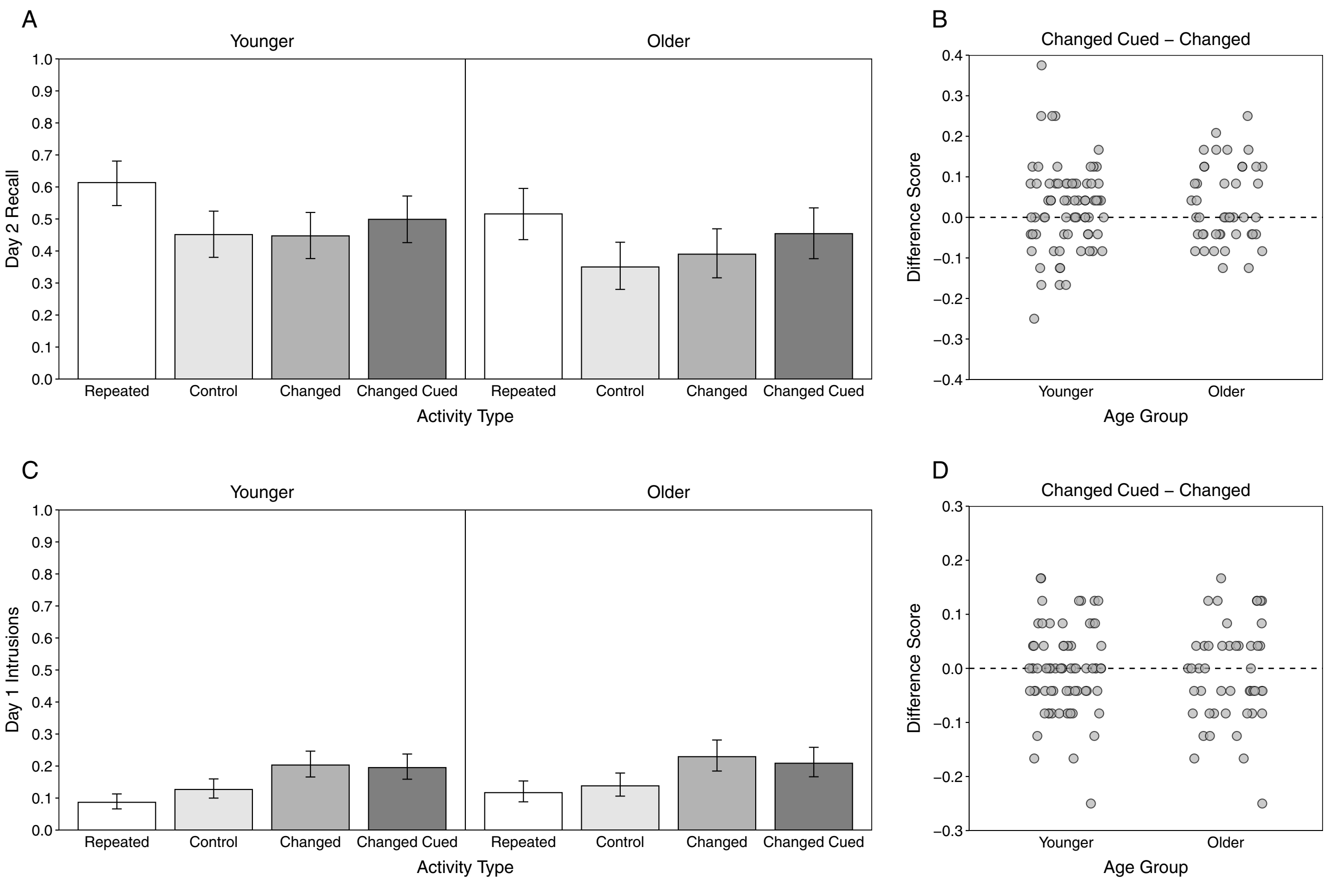
Cued Recall Performance

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 2A). 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 2B). 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 & Zacks, 2019), these results suggest that directing older adults' allocation of attention to central action features improved their event memory updating deficit.

[5] The experimenter typed cued recall responses for two older adults who were uncomfortable using a computer keyboard.
[6] One younger adult did not complete the 2AFC recognition test.

Figure 2
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.

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 2C). 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 2D). 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.

"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 & 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 3 (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.

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 4). 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 4, top rows) with an Age × Activity Type model. The model indicated a significant effect of Age, $\chi^2(1) = 29.90$, $p < .001$, $\eta_p^2 = .15$ [CI .07, .23], showing higher change recollection for younger than older adults. The model also indicated a significant effect of Activity Type, $\chi^2(1) = 34.74$, $p < .001$, $\eta_p^2 = .06$ [CI .01, .12], showing that change recollection was greater for Changed Cued than Changed activities. There was no significant Age × Activity Type interaction, $\chi^2(1) = 0.03$, $p = .86$, $\eta_p^2 < .01$ [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 4, bottom rows) were also examined with an Age × Activity Type model. The model indicated significant effects of Age, $\chi^2(1) = 24.73$, $p < .001$, $\eta_p^2 = .13$ [CI .06, .21], and Activity Type, $\chi^2(1) = 4.18$, $p = .04$, $\eta_p^2 < .01$ [CI .00, .05], and no significant Age × Activity Type interaction, $\chi^2(1) = 3.71$, $p = .05$, $\eta_p^2 < .01$ [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.

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 3, 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)

Table 3
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
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 recognition	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.

Table 4
Model-Estimated "Changed" Classification Probabilities as a Function of Classification, Age, and Activity Type

Classification	Age	Activity type: Changed	Activity type: 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.

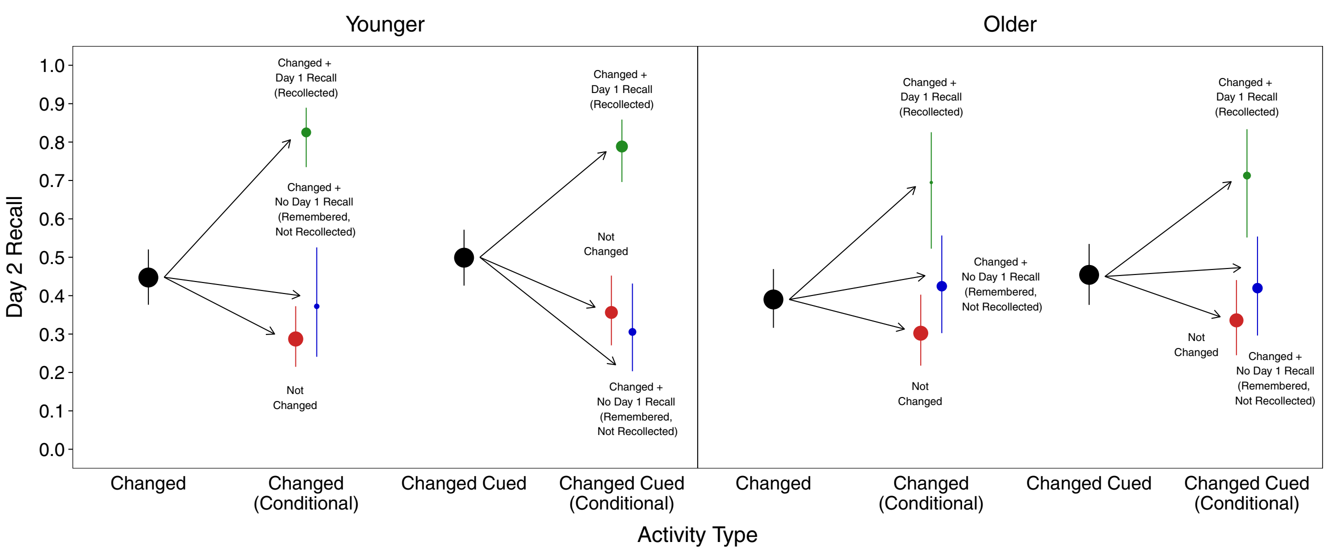
than when it was not (blue and red points), smallest z ratio = 8.47, $p < .001$, $d_r = 1.39$ [CI 0.99, 1.78], and no difference between the latter classifications for which change was not recollected, z ratio = 1.68, $p = .21$, $d_r = 0.05$ [CI −0.31, 0.41]. No other effects were significant, largest $\chi^2(2) = 5.82$, $p = .06$, $\eta_p^2 = .02$ [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.

2AFC Recognition Memory

Day 2 Recognition Accuracy

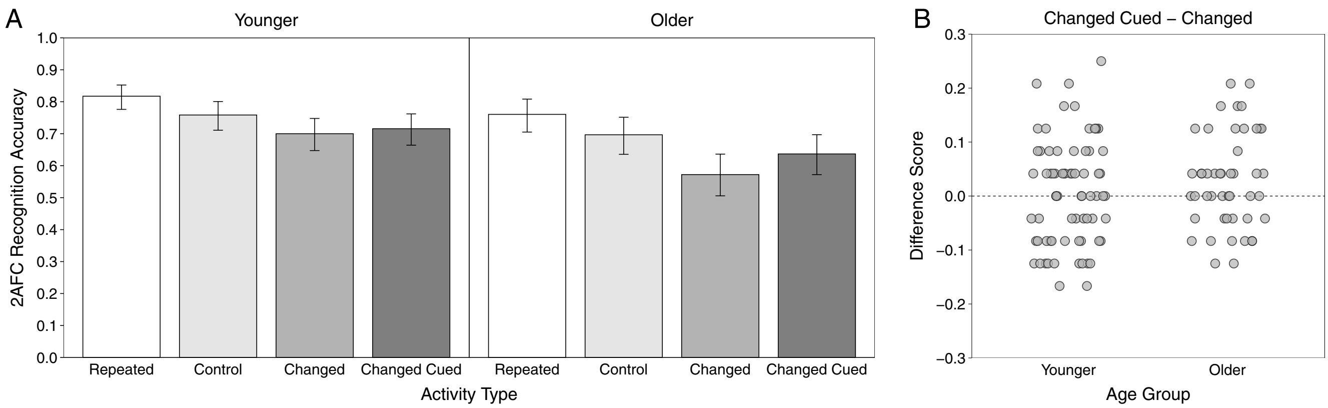
Cuing effects on 2AFC recognition accuracy were also examined to determine whether the cuing benefits shown in cued recall above depended on recollection-based retrieval. If so, then such benefits should be unlikely to occur in a 2AFC recognition task that is less dependent on recollection. An Age × Activity Type model was fitted to 2AFC recognition accuracy (Figure 4A). 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 4B). 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

Figure 3
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. See the online article for the color version of this figure.

Figure 4
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.

improved updating to a greater extent when subsequent retrieval conditions were recollection-based.

"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 3, 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, $\chi^2(3) = 75.33$, $p < .001$, $\eta_p^2 = .07$ [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

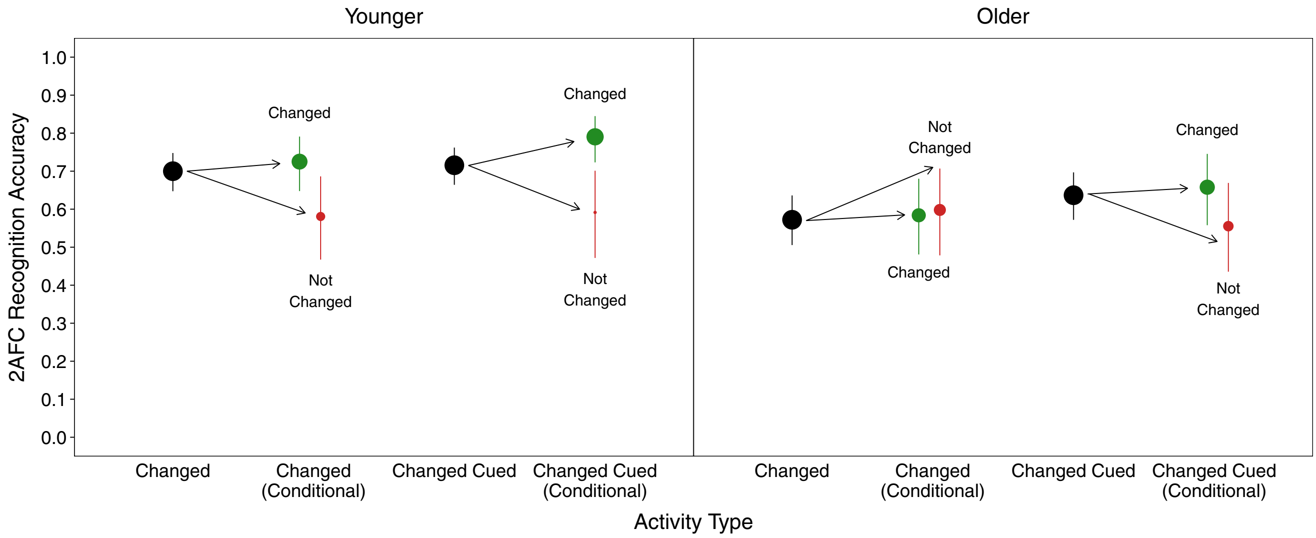
The association between 2AFC recognition accuracy for the two changed activity types and the ability to accurately classify them as such was examined by conditionalizing the former on the latter (Figure 5). These analyses could potentially illuminate the inconsistencies in cuing effects on recognition 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 suggests 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.

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

Figure 5

2AFC 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. See the online article for the color version of this figure.

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 action features, which contributes to their impaired ability to update event memories (Stawarczyk et al., 2020; Wahlheim & Zacks, 2019). 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 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 suggest 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 & 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 & 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.

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