# Proactive effects of memory in young and older adults: The role of change recollection

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## Abstract:

Age-related deficits in episodic memory are sometimes attributed to older adults being more susceptible to proactive interference. These deficits have been explained by impaired abilities to inhibit competing information and to recollect target information. In the present article, I propose that a change recollection deficit also contributes to age differences in proactive interference. Change recollection occurs when individuals can remember how information changed across episodes, and this counteracts proactive interference by preserving the temporal order of information. Three experiments were conducted to determine whether older adults are less likely to counteract proactive interference by recollecting change. Paired-associate learning paradigms with two lists of word pairs included pairs that repeated across lists, pairs that only appeared in List 2 (control items), and pairs with cues that repeated and responses that changed across lists. Young and older adults' abilities to detect changed pairs in List 2 and to later recollect those changes at test were measured, along with cued recall of the List 2 responses and confidence in recall performance. Change recollection produced proactive facilitation in the recall of changed pairs, whereas the failure to recollect change resulted in proactive interference. Confidence judgments were sensitive to these effects. The critical finding was that older adults recollected change less than did young adults, and this partially explained older adults' greater susceptibility to proactive interference. These findings have theoretical implications, showing that a change recollection deficit contributes to age-related deficits in episodic memory.

**Keywords:** Aging | Change detection | Change recollection | Proactive interference | Reminding | Metacognition

## Article:

Older adults' performance in episodic memory tasks is often impaired as compared to that of young adults (Balota, Dolan, & Duchek, 2000; Craik & Jennings, 1992; Grady & Craik, 2000; Hasher & Zacks, 2006; Kausler, 1994; Light, 1991; Lindenberger & Ghisletta, 2009). One explanation for this impairment is that older adults are sometimes more susceptible to interference that is created by competing memories (Campbell, Hasher, & Thomas, 2010; Hasher

& Zacks, 1988; Hay & Jacoby, 1999; Healey, Hasher, & Campbell, 2013; Jacoby, Debner, & Hay, 2001; Kane, 2002; Logan & Balota, 2003; Radvansky, Zacks, & Hasher, 2005; Winocur & Moscovitch, 1983). This can be observed in proactive interference situations in which memory for new information (targets) is impaired by earlier learning of related information (competitors). Age differences in proactive interference have been explained by an inhibition deficit that renders older adults less able to suppress competitors after they come to mind (Hasher & Zacks, 1988), and by a recollection deficit that renders older adults less able to constrain their retrieval to targets and prevent competitors from coming to mind (Hay & Jacoby, 1999). The primary aim of the present article is to show that the greater susceptibility to proactive interference sometimes experienced by older adults can also be partially explained by a deficit in change recollection.

Change recollection is a specific type of recollection that occurs when individuals can remember that the details of competing information changed from earlier to later learning. For example, this could happen when an individual remembers that a politician had earlier changed his position on a controversial issue (flip-flopping). Change recollection counteracts proactive interference by allowing individuals to remember the relative temporal order of targets and competitors. This was recently demonstrated by Wahlheim and Jacoby (2013) using variations of classic A–B, A–D paradigms. In their Experiment 1, two lists of word pairs appeared with some pairs repeating across lists (A–B, A–B), others appearing as control items only in List 2 (A–B, C–D), and critical items appearing with the same cue in both lists with changed responses (A–B, A–D). Incidental learning instructions were given for List 1. During List 2, participants self-paced their study of pairs for an upcoming test and indicated when they detected changed pairs (A–B, A–D). On a final test, a remindings-report procedure was used to assess change recollection and its effects on recall of the List 2 responses. Participants were told to recall List 2 responses and to report whether another word came to mind prior to the responses they output. Instances in which List 1 responses were reported as coming to mind prior to the output responses were shown to be valid indices of change recollection, in that they occurred nearly exclusively for A–B, A–D pairs that had earlier been detected as changed (for converging evidence, see Jacoby & Wahlheim, 2013). The critical finding was that List 2 recall for A–B, A–D items depended on the detection and recollection of change. When change was detected in List 2 and later recollected at test, performance on A–B, A–D items was greater than performance on control items, showing proactive facilitation. In contrast, when change was detected but not recollected, performance on A–B, A–D items was lower than performance on A–B, C–D items, showing proactive interference.

The mechanisms underlying these effects were explained by a *memory-for-change* account forwarded by Wahlheim and Jacoby (2013). Their account holds that when change is detected, a reminding episode (study-phase retrieval) is encoded into an integrated trace along with the responses from each list. At test, when change is recollected, the integrated trace is retrieved and the relative temporal order of responses is preserved by memory for the reminding episode that had fostered the integration of responses (for similar accounts, see Hintzman, 2010; Tzeng & Cotton, 1980; Winograd & Soloway, 1985). In contrast, when change is detected but not recollected, competitors in List 1 are made more accessible by retrieval practice during List 2, but the accessibility of the competitors remains unopposed at the time of test, resulting in the competitors being stronger responses. The important proposal here is that change recollection is paramount in determining whether competing information produces proactive interference or proactive facilitation.

An age-related deficit in change recollection would render older adults less likely to remember the temporal order of competing information, and this might contribute to the greater susceptibility to proactive interference that they sometimes exhibit. In the present experiments, variations of A–B, A–D paradigms similar to that of Wahlheim and Jacoby (2013) were used to determine whether older adults have a deficit in change recollection. It is important to note here that *change recollection* refers to episodic memory for competing responses and the reminding episode that occurred when change was detected. This is different from general *recollection*, which refers to episodic memory for the responses presented in a specific list. A change recollection deficit could arise for older adults in at least three ways. First, if the availability of List 1 responses is lower for older adults due to a recollection deficit, then they would be less likely to detect change in List 2 and to later recollect change at test. Second, even when the availability of List 1 responses does not differ for young and older adults, a recollection deficit for older adults would still make them less likely to remember List 1 responses while studying List 2, thus impairing their detection and later recollection of change. Third, even when change detection does not differ between young and older adults, older adults might still remember fewer details of the change, thus impairing their ability to recollect the change later. These negative cascading effects were explored here across three experiments.

In each of the present experiments, word pairs appeared in two lists prior to a cued-recall test of List 2 responses. Pairs were repeated between lists (A–B, A–B), were only presented in List 2 (controls; A–B, C–D), or were changed between lists (A–B, A–D). The remindings-report procedure was employed to explain how age differences in proactive interference occur by examining the retrieval dynamics for A–B, A–D items. Consistent with Wahlheim and Jacoby (2013), change recollection was indexed here as instances when List 1 responses were reported as coming to mind prior to the output responses. Recalling a List 1 response and then withholding it in favor of reporting another response was taken as evidence of remembering that a different response had appeared in List 2. However, note that recollecting change in this manner does not guarantee that the List 2 response will always be recalled. In addition to indexing change recollection, the remindings-report procedure also provided information about general recollection ability, in the form of retrieval constraints. Recollection serves to restrict access to a set of potential responses by constraining retrieval, and this can be applied to specific lists or to the experimental context more generally. Thus, general recollection ability can be indexed by comparing the extent to which extralist responses are reported as coming to mind prior to the output responses, relative to the extent to which List 1 responses are reported. General recollection ability is preserved to the extent that the responses coming to mind prior to the responses output at test are more often from List 1 than from outside the experimental context (extralist responses).

The remindings-report procedure was used in all of the present experiments to examine age differences in change recollection and its effects on cued recall. It also allowed for an assessment of general recollection ability. In Experiment 3, a change detection measure was included in List 2 to examine the combined effects of detection and recollection of change on cued recall. Change recollection and its effects were compared for young and older adults when List 1 availability was presumably lower for older adults (Exp. 1), when List 1 availability was equated for both age groups, but change detection was presumably lower for older adults (Exp. 2), and when change detection was equated for both age groups (Exp. 3). Consistent with the earlier studies, proactive facilitation was expected in recall of A–B, A–D items when change was recollected, whereas proactive interference was expected when change was not recollected. These effects were expected to be enhanced in Experiment 3 when change had been detected earlier. Older adults were expected to recollect change less often than young adults, and this would partially explain age differences in proactive interference when they were observed. Older adults were also expected to show a general recollection deficit as compared to young adults, in the form of a greater probability of extralist relative to List 1 responses coming to mind prior to the responses output at test.

Along with the remindings-report procedure, confidence judgments were collected at test in Experiments 1 and 2, to evaluate participants' sensitivity to the effects of change recollection on the recall of List 2 responses. One possibility is that when List 1 responses come to mind first, they create confusion about list membership for the subsequently output responses and decrease confidence judgments. Alternatively, when participants withhold List 1 responses that come to mind first, this could indicate their awareness of the temporal order of targets and competitors, resulting in increased confidence judgments. Preliminary evidence for the latter possibility was shown by Wahlheim (2011), by predictions of memory performance for A–B, A–D items being higher when participants could remember that two responses were paired with the same cue. Given that young and older adults show similar metacognitive accuracy in a variety of memory tasks (see Dunlosky & Metcalfe, 2009), it is likely that both groups will be sensitive to the beneficial effects of change recollection on cued recall.

## Experiment 1

The primary purpose of Experiment 1 was to compare change recollection and its effects on cued recall for young and older adults. Experiment 1 was also designed to test the memory-for-change account against an often-cited mediation account that can also explain why competing information does not always produce interference effects. The mediation account holds that when competing responses are associated, interference is diminished because the presentation of later responses increases the accessibility of prior responses. This account can handle the finding that retroactive interference is eliminated when responses are strong associates (e.g., Barnes & Underwood, 1959), because increased activation of the first response makes it more likely to be recalled. However, increasing the accessibility of the first response would also increase proactive interference, so a mediation account cannot explain why proactive interference is not always obtained. A memory-for-change account can explain a lack of proactive interference in overall performance being due to the offsetting effects of proactive facilitation and proactive interference, depending on whether change was recollected. Here, the relationships between competing responses were varied to show that change recollection can counteract proactive interference in the absence of associations between responses, which could not be accommodated by a mediation account.

## Method

### Participants

Groups of 36 young adults (26 women, 10 men; $M_{\text{age}}$ = 19.31 years, *SD* = 1.12, age range 18–22 years) and 36 older adults (27 women, nine men; $M_{\text{age}}$ = 75.81, *SD* = 6.46, age range 63–86 years) were recruited from the participant pools at Washington University. The compensation for young adults was partial course credit or $10/h, and the compensation for older adults was $10/h. The mean score on the Vocabulary subtest of the Shipley Institute of Living Scale (Shipley, 1986) was lower for young adults (*M* = 34.00, *SD* = 2.96) than for older adults (*M* = 36.11, *SD* = 2.08), $t(70) = -3.50$, $p < .001$.

### Design and materials

A 3 (Item Type: A–B, A–B vs. A–B, C–D vs. A–B, A–D) × 3 (Associations: all-associated vs. cue–response-only vs. unrelated) × 2 (Age: young vs. older) mixed design was used. Item type and associations were manipulated within subjects, and age was a between-subjects variable.

The materials consisted of 99 three-word sets. Each set contained a cue (e.g., debate) and two responses (e.g., talk, speech). Three groups of 33 sets were created, with each group representing one of the associations conditions. In each condition, associative strengths were indexed according to the Nelson, McEvoy, and Schreiber (1998) norms. The all-associated sets (e.g., debate–talk, debate–speech) contained cues with forward associations to responses (*M* = .03, *SD* = .02, range .01–.09) and responses with forward and backward associations between each other (*M* = .14, *SD* = .15, range .01–.55). The cue–response-only sets (e.g., pearl–jewelry, pearl–harbor) contained forward associations from the cues to the responses (*M* = .03, *SD* = .02, range .01–.09) and no associations between responses. The unrelated sets (e.g., glow–plan, glow–seed) contained no associations.

The lengths of the cues and responses were matched across groups (*M* = 4.94, *SD* = 0.26, range 3–8 letters). Word frequency was indexed according to the English Lexicon Project database (Balota et al., 2007). Log Hyperspace Analog to Language frequencies (Lund & Burgess, 1996) were matched for the cues and responses across groups (*M* = 9.63, *SD* = 0.42, range 4.73–14.73). Each 33-set group was then divided into three 11-set subgroups matched on the above dimensions. In each subgroup, ten sets served as critical items and one set served as primacy and recency buffers. Subgroups were rotated through item type conditions and served equally often across experimental formats.

Item types were created by varying the relationship between pairs in Lists 1 and 2. A–B, A–B items consisted of the same cues and responses in each list; A–B, C–D items were only presented in List 2; and A–B, A–D items had the same cues in each list, with responses being changed between lists. The assignments of responses to lists for A–B, A–D items were counterbalanced such that responses were presented equally often in each list across the six experimental formats.

## Procedure

There were three phases: List 1, List 2, and test. For List 1, 66 word pairs appeared three times each (198 presentations). Of the 66 pairs, 33 came from each of the A–B, A–B and A–B, A–D conditions; and of the 33 in each of those conditions, 11 came from each of the associations conditions. Pairs appeared repeatedly to increase their accessibility, so that they could be remembered in List 2. Pairs appeared for 2 s each, followed by a 500-ms interstimulus interval (ISI) in a pseudorandom order, with the restriction that no pairs from the same condition appeared more than three times consecutively. Participants read the pairs aloud.

In List 2, 99 word pairs (33 per item type) appeared for 3 s each, followed by a 500-ms ISI. The first three pairs were primacy buffers, the last six pairs were recency buffers, and the 90 pairs in between were critical items. Participants read the pairs aloud and studied them for an upcoming test. They were told that List 2 pairs would be repetitions of List 1 pairs, would be new to List 2, or would have cues from List 1 with changed responses. They were also told that noticing changes would help them remember those pairs, so they should look out for changes.

At test, a practice phase with nine buffer items appeared first, followed by the actual test of 90 critical items. Cues appeared with a question mark (e.g., debate–?), and participants attempted to recall the List 2 responses, guessing if necessary. Following recall of each item, they reported whether another word had come to mind prior to the response they gave (i.e., the remindings-report procedure). The prompt “Did another word come to mind?” appeared, and participants clicked either “Yes” or “No” in boxes displayed below. When they responded “Yes,” they were asked to report the other word that came to mind. In earlier studies, participants sometimes experienced two words coming to mind simultaneously, but these instances were reported rarely. Participants were told that if this happened, they should first give the response that they thought was from List 2 and then report the other response as coming to mind first. Finally, participants gave confidence ratings for List 2 recall of each item on a scale from 0 (*wild guess*) to 100 (*certain correct*). All responses were made aloud and recorded by an experimenter.

## Results and discussion

The significance level in the following experiments was $\alpha = .05$. Variations in degrees of freedom reflect differences in the numbers of participants included in conditional analyses.

### Cued recall

Table 1 (top rows) shows that overall, memory performance was higher for young than for older adults (.40 vs. .26), $F(1, 70) = 17.18$, $p < .001$, $\eta_p^2 = .20$. An effect of associations, $F(2, 140) = 246.79$, $p < .001$, $\eta_p^2 = .78$, showed greater performance in the cue–response-only than in the all-associated condition (.43 vs. .38), and in the all-associated than in the unrelated condition (.38 vs. .17), smallest $t(71) = 4.82$, $p < .001$. The advantage in the cue–response-only condition was likely due to those words being more concrete than those in the other conditions according to the MRC database (Wilson, 1988), and the disadvantage for unrelated pairs occurred because there were no associations. Performance did not differ for A–B, A–D and A–B, C–D items (.22 vs. .23), $t(71) = 1.67$, $p = .10$, and the advantage for A–B, A–B over A–B, C–D items was largest for cue–response-only items and smallest for unrelated items, $F(4, 280) = 4.94$, $p = .001$, $\eta_p^2 = .07$, consistent with the differences in overall recall performance.

**Table 1**. Probabilities of correct recall of List 2 responses as a function of age, associations, List 1 presentations, and item type: Experiments 1–3

| **Experiment** | **Age** | **Associations / List 1 Presentations** | **Item Type** | | |
|---|---|---|---|---|---|
| | | | **A–B, A–B** | **A–B, C–D** | **A–B, A–D** |
| Experiment 1 | Young | All-associated | .65 (.04) | .34 (.03) | .36 (.03) |
| | | Cue–response-only | .74 (.04) | .40 (.04) | .35 (.06) |
| | | Unrelated | .47 (.05) | .15 (.02) | .12 (.02) |
| | Older | All-associated | .48 (.04) | .21 (.03) | .22 (.03) |
| | | Cue–response-only | .63 (.04) | .25 (.04) | .22 (.03) |
| | | Unrelated | .23 (.05) | .03 (.02) | .03 (.02) |
| Experiment 2 | Young | Six List 1 presentations | .86 (.03) | .38 (.02) | .40 (.03) |
| | | Two List 1 presentations | .81 (.03) | .38 (.02) | .46 (.03) |
| | Older | Six List 1 presentations | .64 (.04) | .21 (.02) | .18 (.02) |
| | | Two List 1 presentations | .55 (.04) | .21 (.02) | .25 (.02) |
| Experiment 3 | Young | — | .83 (.04) | .52 (.04) | .48 (.04) |
| | Older | — | .67 (.04) | .38 (.04) | .25 (.04) |

In Experiment 2, A–B, C–D items were not subjected to the List 1 presentation manipulation. Consequently, performance on those items is displayed twice for each age group (once for each List 1 presentation condition) for comparisons between A–B, A–B and A–B, A–D items. Standard errors of the means are presented in parentheses.

Remindings-report responses

Table 2 displays the probabilities of responses being reported as coming to mind prior to the responses output at test. These probabilities represent the numbers of A–B, A–D items for which each type of response was reported as coming to mind first, divided by the total number of A–B, A–D items. The top rows show a deficit in change recollection for older adults. List 1 responses were reported as coming to mind prior to the output responses more often for young than for older adults (.16 vs. .08), $F(1, 70) = 7.39$, $p < .01$, $\eta_p^2 = .10$. In addition, change recollection also occurred more often when relationships were present among the cues and responses, as indicated by an effect of associations, $F(2, 140) = 30.15$, $p < .001$, $\eta_p^2 = .30$. List 1 responses came to mind first more often for the all-associated and cue–response-only conditions than for the unrelated condition for both young and older adults, smallest $t(71) = 6.80$, $p < .001$. No Age × Associations interaction was apparent, $F(2, 140) = 1.61$, $p = .20$, $\eta_p^2 = .02$.

**Table 2**. Probabilities of responses reported as coming to mind prior to the responses output at test on A–B, A–D items, as a function of age, associations, List 1 presentations, and response type: Experiments 1–3

| **Experiment** | **Age** | | **Response Type** |
|---|---|---|---|

| | | **Associations / List 1 Presentations** | **List 1 (Change Recollection)** | **Extralist** | **List 2** | **No Other First** |
|---|---|---|---|---|---|---|
| Experiment 1 | Young | All-associated | .21 (.03) | .08 (.02) | .02 (.01) | .69 (.03) |
| | | Cue–response-only | .20 (.03) | .08 (.02) | .02 (.01) | .70 (.03) |
| | | Unrelated | .06 (.02) | .11 (.03) | .01 (.01) | .82 (.03) |
| | Older | All-associated | .10 (.03) | .09 (.02) | .01 (.01) | .80 (.03) |
| | | Cue–response-only | .13 (.03) | .13 (.03) | .01 (.01) | .73 (.04) |
| | | Unrelated | .02 (.01) | .10 (.03) | .00 (.00) | .88 (.03) |
| Experiment 2 | Young | Six List 1 presentations | .35 (.03) | .10 (.02) | .01 (.01) | .54 (.03) |
| | | Two List 1 presentations | .29 (.03) | .11 (.02) | .01 (.01) | .59 (.04) |
| | Older | Six List 1 presentations | .14 (.03) | .16 (.02) | .02 (.01) | .68 (.04) |
| | | Two List 1 presentations | .10 (.02) | .21 (.03) | .01 (.01) | .68 (.04) |
| Experiment 3 | Young | — | .32 (.05) | .06 (.02) | .03 (.01) | .59 (.04) |
| | Older | — | .16 (.04) | .09 (.03) | .03 (.01) | .72 (.05) |

The probabilities displayed above represent the average numbers of responses of each type that were reported as coming to mind prior to responses output at test for A–B, A–D items, divided by the total number of A–B, A–D items. Standard errors of the means are presented in parentheses.

An alternative interpretation of the finding that older adults reported List 1 responses as coming to mind prior to the output responses less often than did young adults is that this reflected older adults' poorer overall memory for responses from both lists. If this is correct, then older adults should also have mistakenly recalled fewer List 1 intrusions on A–B, A–D items. Against this possibility, an Age × Associations interaction, $F(2, 140) = 4.55$, $p = .01$, $\eta_p^2 = .06$, showed that young and older adults did not differ in their probabilities of List 1 intrusions in the all-associated (.28 vs. .26) and cue–response-only conditions (.32 vs. .34), largest $t(70) = 0.66$, $p = .51$, but young adults did show more intrusions in the unrelated condition (.20 vs. .08), $t(70) = 3.41$, $p = .001$. The difference in the unrelated condition can be largely dismissed due to low levels of performance. These results show that older adults reported List 1 responses as coming to mind prior to output responses less often than young adults because they were less likely to withhold them in favor of reporting List 2 responses.

Older adults also showed diminished general recollection ability, as compared to young adults. An Age × Response Type interaction, $F(1, 70) = 4.51$, $p = .04$, $\eta_p^2 = .06$, revealed that older adults reported List 1 responses as coming to mind first as often as extralist responses (.08 vs. .10), $F(1, 35) = 0.69$, $p = .41$, $\eta_p^2 = .02$, whereas young adults reported List 1 responses as coming to mind first more often than extralist responses (.16 vs. .09), $F(1, 35) = 4.81$, $p = .04$, $\eta_p^2 = .12$. However, a Response Type × Associations interaction, $F(2, 140) = 20.11$, $p < .001$, $\eta_p^2 = .22$, showed that this effect was restricted to items with associations among the cues and responses, in that extralist responses came to mind first more often than List 1 responses for unrelated items (.10 vs. .04), $F(1, 70) = 7.50$, $p = .008$, $\eta_p^2 = .10$. This effect did not interact with age, $F(1, 70) = 0.63$, $p = .43$, $\eta_p^2 < .01$. Finally, List 2 responses were seldom reported as coming to mind prior to output responses.

Cued recall conditionalized on change recollection

The finding above that cued recall did not differ for A–B, C–D and A–B, A–D items leaves open the possibility that performance on A–B, A–D items reflected a mixture of proactive facilitation and proactive interference that depended on change recollection. The following conditional analyses compared young and older adults within each associations condition separately, to maximize observations. A–B, A–D items for which change was recollected are instances in which a List 1 response was reported as coming to mind before the response output, and those items are denoted as *A–B, A–D* $_{CR}$. A–B, A–D items for which change was not recollected are instances in which no other response was reported as coming to mind first, and those instances are denoted as *A–B, A–D* $_{CNR}$. Cued recall of both types of A–B, A–D items was compared with that for A–B, C–D items to assess the effects of change recollection.

Table 3 (top rows) shows that performance was significantly better for A–B, A–D$_{CR}$ than for A–B, C–D items in the all-associated (.78 vs. .30) and cue–response-only (.67 vs. .34) conditions, smallest $F(1, 42) = 35.89$, $p < .001$, $\eta_p^2 = .46$, and numerically better in the unrelated condition (.30 vs. .12), $F(1, 18) = 2.46$, $p = .14$, $\eta_p^2 = .12$. None of these effects interacted with age, largest $F(1, 46) = 0.87$, $p = .36$, $\eta_p^2 = .02$. In contrast, performance was significantly lower for A–B, A–D$_{CNR}$ than for A–B, C–D items in the all-associated (.20 vs. .30) and cue–response-only (.22 vs. .34) conditions, smallest $F(1, 46) = 9.19$, $p = .004$, $\eta_p^2 = .17$, and marginally lower in the unrelated condition (.04 vs. .12), $F(1, 18) = 3.47$, $p = .08$, $\eta_p^2 = .16$. None of these effects interacted with age, largest $F(1, 42) = 2.40$, $p = .13$, $\eta_p^2 = .05$. Consistent with the memory-for-change account, proactive facilitation occurred when change was recollected, whereas proactive interference occurred when change was not recollected for both young and older adults. Critically, these effects were obtained in the cue–response-only condition, wherein responses were not associated with each other, which cannot be accommodated by a mediation account.

**Table 3**. Probabilities of correct recall of List 2 responses as a function of age, associations, List 1 presentations, and item type: Experiments 1–3

| Experiment | Age | Associations / List 1 Presentations | *N* | Item Type | | |
|---|---|---|---|---|---|---|
| | | | | **A–B, A–D$_{CR}$** | **A–B, C–D** | **A–B, A–D$_{CNR}$** |
| Experiment 1 | Young | All-associated | 32 | .79 (.06) | .37 (.03) | .24 (.03) |
| | | Cue–response-only | 26 | .73 (.08) | .44 (.04) | .27 (.04) |
| | | Unrelated | 15 | .30 (.11) | .17 (.05) | .08 (.05) |
| | Older | All-associated | 16 | .77 (.09) | .24 (.05) | .15 (.04) |
| | | Cue–response-only | 18 | .60 (.09) | .23 (.05) | .16 (.05) |
| | | Unrelated | 5 | .30 (.19) | .08 (.08) | .01 (.08) |
| Experiment 2 | Young | Six List 1 presentations | 34 | .82 (.05) | .38 (.02) | .18 (.02) |
| | | Two List 1 presentations | 34 | .80 (.05) | .38 (.02) | .32 (.03) |
| | Older | Six List 1 presentations | 19 | .48 (.07) | .24 (.03) | .16 (.03) |
| | | Two List 1 presentations | 19 | .47 (.07) | .24 (.03) | .25 (.04) |
| Experiment 3 | Young | — | 21 | .86 (.05) | .53 (.03) | .34 (.03) |
| | Older | — | 17 | .82 (.06) | .43 (.04) | .15 (.04) |

A–B, A–D$_{CR}$ = A–B, A–D items for which change was recollected; A–B, A–D$_{CNR}$ = A–B, A–D items for which change was not recollected. The numbers of participants with observations in all cells are displayed in the column labeled *N*. Standard errors of the means are presented in parentheses.

Confidence conditionalized on change recollection

Table 4 (top rows) displays confidence judgments for A–B, A–D items conditionalized on change recollection. Confidence was not compared for A–B, A–D and A–B, C–D items as with cued recall, because repeating cues across lists increases their familiarity and artificially inflates the magnitude of judgments (e.g., Metcalfe, Schwartz, & Joaquim, 1993). Confidence was greater for A–B, A–$D_{CR}$ than for A–B, A–$D_{CNR}$ items in the all-associated (.75 vs. .45) and cue–response-only (.66 vs. .54) conditions, smallest $F(1, 42) = 6.79$, $p = .01$, $\eta_p^2 = .14$, and a numeric difference in this direction emerged for the unrelated condition (.40 vs. .34), $F(1, 18) = 0.43$, $p = .52$, $\eta_p^2 = .02$. None of these effects interacted with age, largest $F(1, 18) = 1.00$, $p = .33$, $\eta_p^2 = .05$. These results show that young and older adults were both sensitive to the benefits of change recollection on cued recall.

**Table 4**. Confidence judgments for List 2 recall as a function of age, associations, List 1 presentations, and item type: Experiments 1 and 2

| **Experiment** | **Age** | **Associations / List 1 Presentations** | ***N*** | **Item Type** | |
|---|---|---|---|---|---|
| | | | | **A–B, A–$D_{CR}$** | **A–B, A–$D_{CNR}$** |
| Experiment 1 | Young | All-associated | 32 | .76 (.05) | .50 (.03) |
| | | Cue–response-only | 26 | .72 (.06) | .58 (.04) |
| | | Unrelated | 15 | .34 (.09) | .38 (.05) |
| | Older | All-associated | 16 | .74 (.06) | .40 (.05) |
| | | Cue–response-only | 18 | .60 (.07) | .50 (.04) |
| | | Unrelated | 5 | .46 (.16) | .30 (.09) |
| Experiment 2 | Young | Six List 1 presentations | 34 | .82 (.03) | .57 (.02) |
| | | Two List 1 presentations | 34 | .79 (.03) | .54 (.02) |
| | Older | Six List 1 presentations | 19 | .61 (.07) | .56 (.04) |
| | | Two List 1 presentations | 19 | .60 (.06) | .48 (.03) |

A–B, A–$D_{CR}$ = A–B, A–D items for which change was recollected; A–B, A–$D_{CNR}$ = A–B, A–D items for which change was not recollected. The numbers of participants with observations in all cells are displayed in the column labeled *N*. Standard errors of the means are presented in parentheses.

Item effects

One concern with conditionalized data is that the results could simply be explained by item selection effects. Here, the effects of change recollection on cued recall could have been due to the sorting of items on the basis of retrievability. To eliminate this item selection artifact, a hierarchical regression with items as the units of analysis was conducted to examine whether unique variance in A–B, A–D recall could be explained by change recollection when controlling for differences in item memorability. The predictors in the model included age group in the first step, item differences (A–B, C–D recall performance) in the second step, change recollection in the third step, two-way interactions in the fourth step, and the three-way interaction in the fifth step. The outcome variable was cued recall on A–B, A–D items. Table 5 (left data column) shows that age and item differences explained unique variance in A–B, A–D recall, but that change recollection explained variance in A–B, A–D recall above and beyond age and item differences. No unique variance in A–B, A–D recall was explained by the interactions. These results show that the benefits of change recollection on cued recall could not be fully explained by item differences.

**Table 5**. Proportions of variance in cued recall of A–B, A–D items explained by age, item differences, and change recollection: Experiments 1–3

| | | **Experiment** | | |
|---|---|---|---|---|
| **Step** | **Predictor** | **1** | **2** | **3** |
| 1 | Age | .11$^*$ | .28$^*$ | .20$^*$ |
| 2 | Item differences | .26$^*$ | .06$^*$ | .02$^†$ |
| 3 | Change recollection | .27$^*$ | .25$^*$ | .25$^*$ |
| 4 | Two-way interactions | .01 | .01 | .01 |
| 5 | Three-way interaction | .00 | .00 | .01 |

$\Delta R^2$ values computed at the item level, collapsed across participants, are displayed above. The data from Experiment 1 were collapsed across associations, and the data from Experiment 2 were collapsed across List 1 presentations. “Age” refers to the age group, “Item Differences” to cued-recall performance for A–B, C–D items, “Change Recollection” to List 1 responses coming to mind before responses output at test, “Two-Way Interactions” to three possible two-way interactions among the predictor variables, and “Three-Way Interaction” to the three-way interaction among the predictor variables. $^*$ $p < .001$, $^†$ $p < .10$

Experiment 2

Experiment 1 showed that older adults were less able to recollect that responses changed between List 1 and List 2 at the time of test. This was likely due to older adults being less able to remember List 1 responses while they were studying List 2 because of decreased availability of List 1 responses. Experiment 2 examined whether older adults would show this same deficit when the availability of List 1 responses was equated for both age groups, by varying the numbers of List 1 presentations. Despite equivalent List 1 availability, older adults might still show a deficit in change recollection at test resulting from impairment in change detection during List 2 study. In addition, greater List 1 availability should increase change recollection overall by increasing the probability of remembering List 1 responses during List 2 study. However, the increase in List 1 availability should also increase proactive interference when List 1 responses are unopposed in the absence of change recollection at test. Finally, additional evidence against a mediation account was sought by including only items that have associations from cues to responses, as in the cue–response-only condition in Experiment 1. Finding that change recollection again produces proactive facilitation when responses are not associated would provide more evidence in favor of a memory-for-change account.

Method

Participants

Groups of 36 young adults (25 women, 11 men; $M_{age}$ = 19.33 years, *SD* = 1.24, age range 18–23 years) and 36 older adults (25 women, 11 men; $M_{age}$ = 78.47, *SD* = 6.80, age range 65–89 years) were recruited from the participant pools at Washington University. The compensation for young adults was partial course credit or $10/h, and the compensation for older adults was $10/h. The mean score on the Shipley vocabulary test was lower for young adults (*M* = 34.17, *SD* = 2.38) than for older adults (*M* = 35.83, *SD* = 2.68), $t(70) = –2.79$, $p = .01$.

Design and materials

A 3 (Item Type: A–B, A–B vs. A–B, C–D vs. A–B, A–D) × 2 (List 1 presentations: six vs. two) × 2 (Age: young vs. older) mixed design was used. Item type and List 1 presentations were manipulated within subjects, and age was a between-subjects variable. Item type and List 1 pairs were crossed for A–B, A–B and A–B, A–D items, but could not be crossed for A–B, C–D items because no List 1 items were presented.

The materials consisted of three-word sets with forward associations from cues to responses. Ninety-six sets were divided into six groups of 16 sets. Each group contained 15 critical sets (90 total), and the remaining sets served as primacy and recency buffers. Forward associations from cues to responses were matched for each group (*M* = .04, *SD* = .02, range .01–.10), and there were no associations between responses. Cues and responses in each group were matched on length (*M* = 4.94, *SD* = 0.26, range 3–8 letters) and word frequency (*M* = 9.60, *SD* = 1.56, range 1.11–14.35). Across participants, groups served equally often in each within-subjects condition. Responses for A–B, A–D items were counterbalanced such that they appeared equally often in each list across the 12 experimental formats.

Procedure

The procedure was identical to that of Experiment 1, with a few exceptions. In List 1, 64 word pairs appeared: Half appeared twice, and half appeared six times (256 total). In List 2, 160 items were presented in total: 64 items tested List 1 responses (60 critical, four buffers), and 96 items were studied (90 critical, six buffers).

List 1 test items (e.g., pearl–?) appeared in white lowercase form and were intermixed among the List 2 study items. List 1 items that repeated (A–B, A–B) or changed (A–B, A–D) in List 2 were tested 16–22 items (*M* = 19.13, *SD* = 1.40) before their corresponding List 2 study items appeared. In a pilot study, the lags between List 1 test items and List 2 study items were manipulated so that some study items appeared immediately following test items, whereas others occurred after lags similar to those used here. Change recollection did not differ between the lag conditions, so delayed lags were used to provide a more natural flow to the procedure. List 2 study items were capitalized (e.g., PEARL–HARBOR) and printed in yellow to distinguish them from the List 1 test items. Following List 2, six practice items (critical buffers) were included on a practice test of List 2 responses, and 90 items were included on the actual test. Test items were printed in yellow to match the format of the List 2 study items (e.g., PEARL–?). All responses were made aloud and recorded by an experimenter.

Results and discussion

Cued recall (List 2)

Table 1 (middle rows) displays cued recall of List 2 items. The subscripts “2” and “6” are used here to denote the numbers of List 1 presentations (e.g., A–$B_6$, A–D = six List 1 presentations). As in Experiment 1, overall performance was better for young than for older adults (.58 vs. .37), $F(1, 70) = 52.99$, $p < .001$, $\eta_p^2 = .43$. An Item Type (A–B, A–B vs. A–B, A–D) × List 1 Presentations interaction, $F(1, 70) = 25.98$, $p < .001$, $\eta_p^2 = .27$, showed that increasing List 1 presentations increased performance on A–B, A–B items (A–$B_6$, A–B = .75 vs. A–$B_2$, A–B = .68), and decreased performance on A–B, A–D items (A–$B_6$, A–D = .29 vs. A–$B_2$, A–D = .36), smallest $t(71) = –3.73$, $p < .001$. This effect did not interact with age, $F(1, 70) = 0.71$, $p = .40$, $\eta_p^2 = .01$. Performance was better for both types of A–B, A–B items than for A–B, C–D items for both age groups, smallest $t(35) = 13.45$, $p < .001$, whereas performance was greater for A–$B_2$, A–D than for A–B, C–D items for young adults, $t(35) = 2.79$, $p = .008$, and did not differ between A–B, C–D items and the remaining A–B, A–D items, largest $t(35) = 1.68$, $p = .10$.

Cued recall (List 1)

List 1 availability for A–B, A–D items was matched for young and older adults by varying the numbers of presentations of List 1 pairs. List 1 recall did not differ between A–$B_2$, A–D items for young adults and A–$B_6$, A–D items for older adults (.59 vs. .59), $t(70) = 0.04$, $p = .97$. Overall, List 1 recall was greater for young than for older adults (.69 vs. .51), and for six than for two presentations (.70 vs. .50), and an unexpected Item Type × List 1 Presentations interaction also emerged, showing that the advantage for List 1 pairs presented six times was larger for A–B, A–B items (.73 vs. .49) than for A–B, A–D items (.67 vs. .51), smallest $F(1, 70) = 6.29$, $p = .01$, $\eta_p^2 = .08$. This was likely due to the average serial position of the List 1 test items being closer to the beginning of List 2 for A–$B_6$, A–B than for A–$B_6$, A–D items (63.31 vs. 78.31, both out of 160), $t(15) = –3.27$, $p = .005$.

Remindings-report responses

Table 2 (middle rows) shows that change recollection was greater for young than for older adults (.32 vs. .12), and after six than two List 1 presentations (.25 vs. .20), smallest $F(1, 70) = 9.64$, $p = .003$, $\eta_p^2 = .12$. No Age × List 1 Presentations interaction was apparent, $F(1, 70) = 0.30$, $p = .59$, $\eta_p^2 < .01$. Critically, the manipulation of List 1 presentations allowed for the comparison of change recollection for young and older adults when the availability of List 1 responses was equated. Change recollection for young adults on A–$B_2$, A–D items was greater than change recollection for older adults on A–$B_6$, A–D items (.29 vs. .14), $t(70) = 3.78$, $p < .001$, showing an age-related deficit in change recollection when the availability of List 1 responses was equated. As in Experiment 1, an analysis of List 1 intrusions confirmed the age-related deficit in change recollection, in that young and older adults did not differ in their List 1 intrusions for A–B, A–D items following six List 1 presentations (.37 vs. .38) or two List 1 presentations (.23 vs. .29), $F(1, 70) = 1.19$, $p = .28$, $\eta_p^2 = .02$. No Age × List 1 Presentations interaction emerged, $F(1, 70) = 1.53$, $p = .22$, $\eta_p^2 = .02$. These results again show that older adults were less likely to withhold List 1 responses in favor of reporting List 2 responses.

Additional evidence for the validity of the remindings-report procedure as an index of change recollection was obtained from analyses of change recollection conditionalized on List 1 recall. List 1 responses that came to mind prior to the output responses presumably reflect instances when List 1 responses were retrieved during List 2. If so, then List 1 responses should only be reported as coming to mind prior to output responses when they were earlier recalled during List 2. Consistent with this, when List 1 responses were recalled in List 2, young adults reported List 1 responses as coming to mind first at test more often than did older adults (.43 vs. .20), but both groups almost never did so when List 1 responses were not recalled in List 2 (.02 vs. .03), $F(1, 63) = 31.96$, $p < .001$, $\eta_p^2 = .34$.

As in Experiment 1, evidence for an age-related deficit in general recollection ability was shown by comparisons of the probabilities of extralist and List 1 responses that were reported as coming to mind prior to the responses output at test. An Age × Response Type interaction, $F(1, 70) = 31.79$, $p < .001$, $\eta_p^2 = .31$, revealed that List 1 responses came to mind first more often than extralist responses for young adults (.32 vs. .11), $F(1, 35) = 34.29$, $p < .001$, $\eta_p^2 = .50$, whereas extralist responses came to mind first marginally more often than List 1 responses for older adults (.18 vs. .12), $F(1, 35) = 3.78$, $p = .06$, $\eta_p^2 = .10$. No Age × Response Type × List 1 presentations interaction emerged, $F(1, 70) = 0.17$, $p = .68$, $\eta_p^2 < .01$. Finally, consistent with Experiment 1, List 2 responses were seldom reported as coming to mind prior to output responses.

## Cued recall (List 2) conditionalized on change recollection

The results above showed no proactive interference in overall List 2 recall of A–B, A–D items, again leaving open the possibility that performance reflected a mixture of proactive facilitation and proactive interference that depended on change recollection. Table 3 (middle rows) shows cued recall for A-B, C-D items and for A–B, A–D items conditionalized on change recollection. Given that the A–B, C–D items were not subjected to the List 1 presentations manipulation, those items were compared with A–B, A–D items, collapsed across List 1 presentation conditions when there were no differences, and separately for List 1 presentation conditions when there were differences.

Performance on A–B, A–$D_{CR}$ items did not differ between List 1 presentation conditions within each age group, nor was there an interaction, largest $F(1, 51) = 0.94$, $p < .001$. Consequently, performance was collapsed across List 1 presentations for each age group for comparison with A–B, C–D items. Performance was better for A–B, A–$D_{CR}$ than for A–B, C–D items for both age groups, and an interaction showed that the difference was greater for young (.81 vs. .38) than for older (.48 vs. .24) adults, smallest $F(1, 51) = 8.58$, $p = .005$, $\eta_p^2 = .14$. Although the benefits of change recollection did not differ on the basis of the number of List 1 presentations, the interaction indicated that older adults benefited less from change recollection overall. It is possible that the lack of associations rendered older adults less able to form unique associations between competing responses (Naveh-Benjamin, 2000) and that this somehow diminished the quality of integrated traces.

In contrast, failure to recollect change resulted either in no difference between A–B, A–D and A–B, C–D items or proactive interference for A–B, A–D items, depending on the number of List 1 presentations. Performance did not differ between A–$B_2$, A–$D_{CNR}$ and A–B, C–D items for either age group, and there was no interaction, largest $F(1, 51) = 0.55$, $p = .46$, $\eta_p^2 = .01$. This likely occurred because two List 1 presentations were insufficient to produce proactive interference. However, performance was worse for A–$B_6$, A–$D_{CNR}$ than for A–B, C–D items, and a significant interaction indicated that this difference was greater for young than for older adults, smallest $F(1, 51) = 5.54$, $p = .02$, $\eta_p^2 = .10$. However, the interaction likely occured because of floor effects for older adults. Thus, proactive interference was obtained when change was not recollected and there were sufficient List 1 presentations.

### Confidence conditionalized on change recollection

Young and older adults were again sensitive to the benefits of change recollection on cued recall. Table 4 (bottom rows) shows that confidence was higher for A–B, A–$D_{CR}$ than for A–B, A–$D_{CNR}$ items, and an interaction showed that this difference was greater for young (.81 vs. .56) than for older (.61 vs. .52) adults, smallest $F(1, 51) = 15.04$, $p < .001$, $\eta_p^2 = .23$. This is consistent with proactive facilitation in recall performance being greater for young than for older adults when change was recollected.

### Item effects

The extent to which change recollection explained variance in recall of A–B, A–D items was examined as in Experiment 1. Replicating Experiment 1, Table 5 (middle column) shows that age and item differences explained unique variance in A–B, A–D recall. However, change recollection explained variance in A–B, A–D recall above and beyond age and item differences. No unique variance was explained by any of the interactions. These results again show that the benefits of change recollection on cued recall of A–B, A–D items could not be fully explained by item differences.

## Experiment 3

Experiments 1 and 2 showed an age-related deficit in change recollection when the availability of List 1 responses was greater for young adults and when it was equated for both age groups. The age differences observed thus far provide preliminary evidence for a change recollection deficit in older adults, but this deficit might still simply reflect older adults detecting change less often during List 2. Experiment 3 was designed to examine whether older adults would show a selective deficit in change recollection when they were able to detect change in List 2 as often as young adults. To do this, a change detection measure was included in List 2, and participants were allowed to self-pace their study, as in Wahlheim and Jacoby (2013, Exp. 1). Given that older adults process information more slowly than young adults (Salthouse, 1996), they should take longer to detect change than young adults. However, the extra time should allow them to detect change as often as young adults, which would allow for a more direct comparison of change recollection in young and older adults.

### Method

## Participants

Groups of 24 young adults (17 women, seven men; $M_{age}$ = 20.17 years, *SD* = 1.20, range 18–22 years) and 24 older adults (16 women, eight men; $M_{age}$ = 78.33 years, *SD* = 8.06, range 65–91 years) were recruited from the participant pools at Washington University. The compensation for young adults was partial course credit or $10/h, and the compensation for older adults was $10/h. The mean score on the Shipley vocabulary test was higher for older adults (*M* = 36.79, *SD* = 2.34) than for young adults (*M* = 34.04, *SD* = 2.37), $t(46) = 4.05$, $p < .001$.

## Design and materials

A 3 (Item Type: A–B, A–B vs. A–B, C–D vs. A–B, A–D) × 2 (Age: young vs. older) mixed design was used. Item type was manipulated within subjects, and age was a between-subjects variable. A total of 75 three-word sets were taken from Wahlheim and Jacoby (2013) and divided into groups of 60 critical items and 15 buffer items. The 60 critical items were further divided into three subgroups of 20 items that were matched on cued-recall performance in the other experiments. The 15 buffer items were distributed throughout the experiment to serve as primacy and recency buffers as well as practice items for the change detection task in List 2 and the final test (details below). The responses in each set were orthographically related, because they were originally designed to complete the same fragments (e.g., *b_n_* could be completed by either *bone* or *bend*). Some cues were associated with responses, whereas others were not (forward associative strength: *M* = .05, *SD* = .09, range = .00–.64; backward associative strength: *M* = .07, *SD* = .14, range = .00–.73). The same was true for associations between responses (forward associative strength: *M* = .01, *SD* = .03, range = .00–.25; backward associative strength: *M* = .01, *SD* = .04, range = .00–.27). These groups served equally often in each condition across participants in three experimental formats.

List 1 consisted of 50 word pairs, including six buffers (two primacy and four recency; three of each were A–B, A–B and A–B, A–D) that were later used as practice pairs for the change detection procedure in List 2, four filler pairs (two of each were A–B, A–B and A–B, A–D) that were later used as buffers in List 2 and as practice pairs at test, and 40 critical pairs. Buffers appeared once each, and the remaining pairs appeared three times each (138 total presentations). The List 2 practice phase included nine pairs (three of each item type), and List 2 included 66 pairs that consisted of six buffers (three primacy and three recency; two of each item type) and 60 critical pairs. Twenty critical pairs were included in each item type condition. At test, the six buffer pairs from List 2 were used for practice, and the actual test included all 60 critical pairs.

## Procedure

The procedure was the same as in Experiment 1, with the following exceptions. A practice phase occurred before List 2. Participants self-paced their study in List 2 and indicated when responses had changed. Boxes labeled “next” and “right word changed” appeared below the pairs. Participants clicked “next” once they had learned unchanged pairs, and “right word changed” when they detected changed pairs. After detecting change, they attempted to recall the List 1 responses. After attempting recall, they continued studying the changed pairs until the pairs were learned, and they clicked “next” to move on. Confidence judgments were not taken at test.

## Results and discussion

### Cued recall (List 2)

Table 1 (bottom rows) shows that performance was greater for young than for older adults (.61 vs. .43), for A–B, A–B than for A–B, C–D items (.75 vs. .45), and for A–B, C–D than for A–B, A–D items (.45 vs. .37), smallest $F(1, 46) = 14.27$, $p < .001$, $\eta_p^2 = .24$. In contrast to Experiments 1 and 2, older adults showed a greater susceptibility to proactive interference in overall performance. A nearly significant Age × Item Type (A–B, C–D vs. A–B, A–D) interaction, $F(1, 46) = 3.91$, $p = .054$, $\eta_p^2 = .08$, showed that young adults' performance did not differ between A–B, C–D and A–B, A–D items, $t(23) = 1.32$, $p = .20$, but older adults' performance was greater for A–B, C–D than for A–B, A–D items, $t(23) = 3.78$, $p = .001$.

### Change detection and remindings-report responses

Older adults detected change as often as young adults (.58 vs. .61), $t(46) = 0.38$, $p = .71$, but when change was detected, young adults recalled the List 1 responses better than did older adults (.85 vs. .68), $t(46) = 2.59$, $p = .01$. Older adults' diminished ability to recall List 1 responses when detecting change contributed to their deficit in change recollection. The bottom rows of Table 2 show that older adults reported List 1 responses as coming to mind prior to the responses output at test less often than did young adults, $t(46) = 2.64$, $p = .01$. This change recollection deficit was verified by analyzing List 1 intrusions on A–B, A–D items as in Experiments 1 and 2. List 1 intrusions were actually greater for older than for young adults (.37 vs. .26), $t(46) = 2.38$, $p = .02$, which provided strong evidence that older adults were less likely than young adults to withhold List 1 responses in favor of reporting List 2 responses. In addition, older adults were again found to have a general recollection deficit. An Age × Response Type interaction, $F(1, 46) = 6.11$, $p = .02$, $\eta_p^2 = .12$, showed that young adults reported List 1 responses as coming to mind prior to the output responses more often than extralist responses, $t(23) = 4.40$, $p < .001$, whereas older adults showed no difference in reports of List 1 and extralist responses coming to mind first, $t(23) = 1.43$, $p = .17$. Again, as in the previous experiments, List 2 responses were seldom reported as coming to mind prior to the output responses.

The validity of the remindings-report procedure as a measure of change recollection was tested by examining the relationship between change detection during List 2 presentation and the probabilities of List 1 responses coming to mind prior to the responses output at test. List 1 responses came to mind first at test more often when change had earlier been detected for both young (.48 vs. .05) and older (.19 vs. .04) adults, $F(1, 45) = 52.14$, $p < .001$, $\eta_p^2 = .54$. Furthermore, List 1 responses came to mind first at test almost exclusively when they had earlier been recalled in List 2 after change detection, and almost never when they were not recalled in List 2 for both young (.55 vs. .01) and older (.31 vs. .03) adults, $F(1, 37) = 60.89$, $p < .001$, $\eta_p^2 = .62$. Age × Change Detection interactions showed that List 1 responses came to mind first at test more often for young adults in both of the above cases, smallest $F(1, 37) = 6.08$, $p = .02$, $\eta_p^2 = .14$. Critically, these results show that List 1 responses coming to mind prior to the responses output at test reflected memory for the earlier detection of change that was accompanied by retrieval of the List 1 response.

Cued recall (List 2) conditionalized on the detection and recollection of change

Comparison of recall performance on A–B, A–D items as a function of change detection and age revealed a significant interaction, $F(1, 45) = 4.69$, $p = .04$, $\eta_p^2 = .09$, showing that performance was better when change was detected than when it was not for young adults (.54 vs. .41), $t(23) = 2.26$, $p = .03$, but no difference was apparent between detected and undetected items for older adults (.23 vs. .27), $t(22) = –0.80$, $p = .43$. The same pattern was obtained when change detection was accompanied by correct recall of the List 1 response. As in Experiments 1and 2, Table 3 (bottom rows) shows that proactive facilitation was obtained for A–B, A–D items when change was recollected, and proactive interference was obtained when change was not recollected for both age groups. Performance was greater for A–B, A–$D_{CR}$ items than for A–B, C–D items, $F(1, 36) = 92.70$, $p < .001$, $\eta_p^2 = .72$, and this effect did not interact with age, $F(1, 36) = 0.80$, $p = .38$, $\eta_p^2 = .02$. In contrast, performance was lower for A–B, A–$D_{CNR}$ items than for A–B, C–D items, $F(1, 36) = 107.84$, $p < .001$, $\eta_p^2 = .75$, and a marginal interaction, $F(1, 36) = 3.56$, $p = .07$, $\eta_p^2 = .09$, showed a tendency for older adults to be more susceptible to proactive interference.

Finally, Fig. 1 displays the combined effects of the detection and recollection of change on cued recall. The analyses revealed an effect of item type, $F(2, 70) = 111.82$, $p < .001$, $\eta_p^2 = .76$, that did not interact with age, $F(2, 70) = 1.25$, $p = .29$, $\eta_p^2 = .04$, showing that when change was detected and recollected for A–B, A–D items, performance was better than for A–B, C–D items, but when change was detected but not recollected for A–B, A–D items, performance was worse than for A–B, C–D items, smallest $F(1, 34) = 60.61$, $p < .001$, $\eta_p^2 = .64$. Proactive interference was also obtained when change was neither detected nor recollected (A–B, C–D = .44 vs. A–B, A–D = .31), $F(1, 45) = 18.59$, $p < .001$, $\eta_p^2 = .30$, but performance was still worse for A–B, A–D items when change was detected but not recollected, $F(1, 44) = 9.71$, $p = .003$, $\eta_p^2 = .18$, showing that when change was not recollected, proactive interference was greater when change had initially been detected than when it had not. These results largely replicate the findings of Wahlheim and Jacoby (2013) and extend those findings to older adults. However, the finding of proactive interference for A–B, A–D items when change was neither detected nor recollected had not been shown earlier. The reason for this is unclear, but one possibility is that the self-paced study in this sample may have differentially increased cued-recall performance for A–B, C–D items. Regardless, the finding of similar effects of change recollection on cued recall for both age groups, taken with older adults' diminished ability to recollect change, shows that older adults' greater susceptibility to proactive interference is partially due to a change recollection deficit.

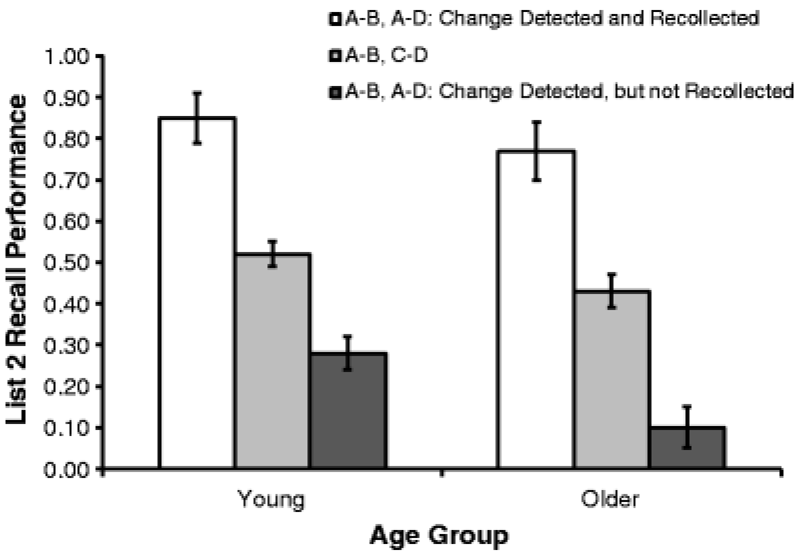


**Fig. 1**. List 2 recall on the final test is better for A–B, A–D items than for A–B, C–D items when change is detected and recollected, but worse than for A–B, C–D items when change is detected but not recollected, for both young and older adults. Error bars represent standard errors of the means

Study time

Table 6 (top panel) shows that older adults spent more time overall studying List 2 items than did young adults (8,065 vs. 5,201 ms), and both groups devoted more time to item types that produced lower recall performance, smallest $F(1, 46) = 6.80$, $p = .01$, $\eta_p^2 = .13$. More time was devoted to A–B, A–D than to A–B, C–D items (7,606 vs. 6,683 ms), and to A–B, C–D than to A–B, A–B items (6,683 vs. 5,612 ms), smallest $t(47) = 2.45$, $p = .018$. Table 6 (bottom panel) also shows that older adults took longer to detect change for A–B, A–D items than did young adults, $t(46) = 4.58$, $p < .001$, which presumably allowed them to detect change as often as young adults did. Older adults did not spend more time studying A–B, A–D items after detecting change, $t(46) = 0.89$, $p = .38$.

**Table 6**. Presentation times (in milliseconds) of List 2 items as a function of item type and age: Experiment 3

| | **Age** | |
|---|---|---|
| **Item Type** | **Young** | **Older** |
| Total Presentation Time | | |
| A–B, A–B | 4,542 (612) | 6,681 (991) |
| A–B, C–D | 5,008 (644) | 8,357 (1,219) |
| A–B, A–D | 6,052 (550) | 9,159 (818) |
| A–B, A–D Items | | |
| Time to detect change | 3,818 (197) | 7,214 (715) |
| Study post change detection | 2,988 (741) | 3,739 (398) |
| Change detected total | 6,806 (825) | 10,953 (846) |
| No change detected | 5,473 (560) | 8,363 (1,048) |

For the conditional analyses of A–B, A–D items in the lower panel, “Time to Detect Change” refers to the time that it took participants to identify that pairs had changed responses, “Study Post Change Detection” to the time that participants spent studying pairs after they had identified the pairs as changed, “Change Detected Total” to the total time spent viewing the changed items, including the time to detect change and the time spent studying after indicating that change had been detected, and “No Change Detected” to the study time spent on pairs that were not identified as changed. Standard errors of the means are presented in parentheses.

### Item effects

The extent to which change recollection explained variance in the cued recall of A–B, A–D items above and beyond item effects was examined, as in Experiments 1 and 2. Table 5 (right column) shows that age and item differences explained unique variance, but the variance accounted for by item differences was only marginally significant. Critically, change recollection again explained variance above and beyond age and item differences, and the interactions did not explain any unique variance. These results again show that the benefits of change recollection on cued recall of A–B, A–D items could not be fully explained by item differences.

## General discussion

Older adults showed a deficit in change recollection. This was found when (1) the availability of List 1 responses was lower for older adults, (2) the availability of List 1 responses was equated between young and older adults but change detection was presumably lower for older adults, and (3) change detection was equated between young and older adults but the retrieval of List 1 responses following change detection was poorer for older adults. Change recollection enhanced cued recall even when responses were not associated, providing evidence against a mediation account. Young and older adults were sensitive to the benefits of change recollection on cued recall, and those benefits could not be explained by item effects. Finally, older adults also showed a general recollection deficit in the form of poorer ability to constrain retrieval to experimental contexts.

Age differences in proactive interference were sometimes, but not always, observed in the present experiments. Neither young nor older adults exhibited proactive interference in overall recall performance in Experiments 1 and 2. One possibility is that in Experiment 1, older adults were more susceptible to proactive interference because of a deficit in change recollection, but List 1 responses were less available than for young adults, which counteracted proactive interference by decreasing the accessibility of competitors. Something similar may have also occurred in Experiment 2 if the availability of List 1 responses declined more rapidly for older adults between List 1 recall and study of the corresponding List 2 responses. The lack of proactive interference in overall performance for young adults is consistent with Wahlheim and Jacoby (2013), and more generally with results showing that interference effects are counteracted when targets and competitors have the potential to be integrated (e.g., Anderson & McCulloch, 1999; Radvansky & Zacks, 1991).

Despite the offsetting effects of List 1 availability, Experiments 1 and 2 still suggest that a change recollection deficit can explain older adults’ greater susceptibility to proactive interference when it is observed. Change recollection improved cued recall, but older adults were less likely to recollect change. Experiment 3 provided evidence for this notion in that proactive interference was obtained for older but not young adults. This resulted from the retrieval of List 1 responses following change detection being poorer for older adults, which produced a deficit in the recollection of change at test. Older adults took longer to detect change and recalled fewer List 1 responses, suggesting that both groups were sensitive to change when given enough time to notice it, but older adults were less able to identify which features changed, resulting in fewer integrated traces to be recollected. The lack of an age difference in change detection likely reflected a lack of age differences in automatic influences of memory. The subjective experience that accompanied A–D pairs in List 2 was likely influenced by presentations of corresponding A–B pairs in List 1, akin to how prior exposures to stimuli influence perceptual identification (Jacoby & Dallas, 1981). This may have allowed both groups to attribute their unique subjective experiences on A–D pairs to those pairs being changed from List 1 (Jacoby, Kelley, & Dywan, 1989). However, older adults recalled fewer List 1 responses when they detected change because of a general recollection deficit, and this resulted in their recollecting change less often at test.

In addition to showing similar awareness of change in List 2, young and older adults both showed similar awareness of the benefits of change recollection on cued recall. Confidence judgments in Experiments 1 and 2 were higher for A–B, A–D items when change was recollected than when it was not. Wahlheim (2011) had earlier showed that predictions of performance could be inflated by retrieval of competitors, resulting from the accessibility of those responses acting as a misleading basis for judgments. Although this occurs in some instances, it appears that individuals may also judge their memory to be better when competitors and targets have been retrieved with information about their temporal sequence. Finding that both young and older adults are aware of situations in which response competition can either facilitate or interfere with memory performance has implications for the regulation of memory accuracy (Koriat & Goldsmith, 1996).

Finding that an age-related deficit in the susceptibility to proactive interference can partially be explained by a deficit in change recollection also has implications for theory. As was mentioned earlier, a mediation account holds that interference effects in memory can be avoided when competing responses are associated, because the semantic associations between responses increase the activation of the former response when the latter is presented (e.g., Barnes & Underwood, 1959). However, this account cannot explain how changed responses that were unrelated produced proactive facilitation when change was recollected and proactive interference when change was not recollected. In contrast, a memory-for-change account can explain these findings, by holding that change detection produced integrated traces that included both responses and the reminding episode, and later recollection of the change provided access to the relative temporal order, which facilitated recall, whereas a lack of change recollection when change was detected resulted in responses being based on other information, such as overall memory strength.

Positing a role for change recollection in age differences in proactive interference also has theoretical implications for the forms that recollection can take. Recollection has been held to be a form of cognitive control that serves to constrain retrieval to target sources (Jacoby, 1999; Jacoby, Shimizu, Daniels, & Rhodes 2005b). In contrast, change recollection provides access to integrated traces that include targets and competitors, as well as reminding episodes that fostered their integration. Although the distinction between these types of recollection is clear, it is unclear how change recollection elicits retrieval of integrated traces. Retrieval of integrated traces may occur when individuals attempt to constrain their retrieval to a particular source and doing so brings competing and target information to mind along with the earlier reminding episode. However, such retrieval could also occur when cues are elaborated such that reminding episodes are first accessed, which brings to mind the constituent responses. The measure used to index change recollection may provide more information about how this type of retrieval occurs. The remindings-report procedure used here shows that attempts to constrain retrieval to List 2 sometimes elicits responses from List 1 prior to responses from List 2, and this may also bring the reminding episode to mind. In addition, self-reported change recollection occurring after List 2 retrieval attempts has shown that individuals can report when change had occurred earlier (Jacoby, Wahlheim, & Yonelinas, 2013; Putnam, Wahlheim, & Jacoby, 2014), which suggests that attributions of change may be made following the retrieval of multiple responses. Alternative procedures are needed to determine whether retrieval can be orientated to either reminding episodes or lists and whether both orientations would provide similar memorial benefits for target responses.

Understanding how change is recollected also has implications for the rehabilitation of memory. The distinction between an inhibition deficit (Hasher & Zacks, 1988) and a recollection deficit (Hay & Jacoby, 1999) is important for training procedures, in that training an inhibition mechanism would require teaching individuals to suppress competitors, whereas training a recollection mechanism would require teaching individuals to constrain retrieval to prevent competitors from coming to mind. Training a change recollection mechanism would require yet another set of procedures aimed at integrating responses during encoding and subsequent retrieval of integrated representations. It is likely that training either type of recollection mechanism could effectively remediate age-related deficits in proactive interference. Studies have shown that experience with proactive interference can diminish its effects either by tightening retrieval constraints, so that competitors are less likely to come to mind (Jacoby, Wahlheim, Rhodes, Daniels, & Rogers, 2010; Wahlheim & Jacoby, 2011), or by increasing the probability of targets and competitors being recalled together (Postman, 1964).

Rehabilitation efforts also stand to benefit from identifying the bases for older adults' metacognitive judgments in proactive interference situations. Older adults sometimes show dramatic false recollection in interference situations, such as when misleading primes immediately precede retrieval cues (Jacoby, Bishara, Hessels, & Toth 2005a). In contrast, older adults' confidence judgments in the present experiments were sensitive to memory impairments resulting from the absence of change recollection. This suggests that older adults might sometimes make metacognitive judgments on inappropriate bases such as the fluency of retrieval, but the bases used for those judgments might depend on how the retrieval task orients their attention. One possibility is that the remindings-report procedure directed participants' attention to information about change, and the presence or absence of change became the primary basis for metacognitive evaluations and decisions about withholding or reporting responses. It is possible that the remindings-report procedure might serve not only to assess retrieval dynamics in interference situations, but also to educate metacognitive assessments and improve the strategic reporting of responses at test.

In conclusion, age-related deficits in the susceptibility to proactive interference that older adults sometimes experience were partially explained by a deficit in change recollection. Integration of targets and competitors along with recollection of change eliminated proactive interference, and participants were aware of these effects. These findings provide a new perspective on the age-related memory deficits created by response competition, by showing the importance of memory for change. These findings also provide insight into the types of processes that should be targeted for the remediation of older adults' memory impairments in interference situations. Finding ways to enhance older adults' memory for change will be important for prolonging their ability to comprehend events in a rapidly changing environment.

Notes

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References

1. Anderson, M. C., & McCulloch, K. C. (1999). Integration as a general boundary condition on retrieval-induced forgetting. *Journal of Experimental Psychology Learning Memory and Cognition, 25,* 608–629. doi: 10.1037/0278-7393.25.3.608

2. Balota, D. A., Dolan, P. O., & Duchek, J. M. (2000). Memory changes in healthy older adults. In E. Tulving & F. I. M. Craik (Eds.), *The Oxford handbook of memory* (pp. 395–409). New York, NY: Oxford University Press.

3. Balota, D. A., Yap, M. J., Cortese, M. J., Hutchinson, K. A., Kessler, B., Loftis, B., . . . Treiman, R. (2007). The English Lexicon Project. *Behavior Research Methods, 39,* 445–459. doi: 10.3758/BF03193014

4. Barnes, J. M., & Underwood, B. J. (1959). "Fate" of first-list associations in transfer theory. *Journal of Experimental Psychology, 58,* 97–105. doi: 10.1037/h0047507

5. Campbell, K. L., Hasher, L., & Thomas, R. C. (2010). Hyper-binding: A unique age effect. *Psychological Science, 21,* 399–405. doi: 10.1177/0956797609359910

6. Craik, F. I. M., & Jennings, J. M. (1992). Human memory. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 51–110). Hillsdale, NJ: Erlbaum.

7. Dunlosky, J., & Metcalfe, J. (2009). *Metacognition*. Thousand Oaks, CA: Sage.

8. Grady, C. L., & Craik, F. I. M. (2000). Changes in memory processing with age. *Current Opinion in Neurobiology, 10,* 224–231.

9. Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 22, pp. 193–225). San Diego, CA: Academic Press. doi: 10.1016/S0079-7421(08)60041-9

10. Hasher, L., & Zacks, R. T. (2006). Aging and long term memory: Deficits are not inevitable. In E. Bialystok & F. I. M. Craik (Eds.), *Lifespan cognition: Mechanisms of change* (pp. 162–177). New York, NY: Oxford University Press.

11. Hay, J. F., & Jacoby, L. L. (1999). Separating habit and recollection in young and older adults: Effects of elaborative processing and distinctiveness. *Psychology and Aging, 14,*122–134. doi: 10.1037/0882-7974.14.1.122

12. Healey, M. K., Hasher, L., & Campbell, K. L. (2013). The role of suppression in resolving interference: Evidence for an age-related deficit. *Psychology and Aging, 28,* 721–728. doi: 10.1037/a0033003

13. Hintzman, D. L. (2010). How does repetition affect memory? Evidence from judgments of recency. *Memory & Cognition, 38,* 102–115. doi: 10.3758/MC.38.1.102

14. Jacoby, L. L. (1999). Ironic effects of repetition: Measuring age-related differences in memory. *Journal of Experimental Psychology Learning Memory and Cognition*, *25,* 3–22. doi: 10.1037/0278-7393.25.1.3

15. Jacoby, L. L., & Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General, 110,* 306–340. doi: 10.1037/0096-3445.110.3.306

16. Jacoby, L. L., & Wahlheim, C. N. (2013). On the importance of looking back: The role of recursive remindings in recency judgments and cued recall. *Memory & Cognition, 41,*625–637. doi: 10.3758/s13421-013-0298-5

17. Jacoby, L. L., Kelley, C. M., & Dywan, J. (1989). Memory attributions. In H. L. Roediger & F. I. M. Craik (Eds.), *Varieties of memory and consciousness: Essays in honor of Endel Tulving* (pp. 391–422). Hillsdale, NJ: Erlbaum.

18. Jacoby, L. L., Debner, J. A., & Hay, J. F. (2001). Proactive interference, accessibility bias, and process dissociations: Valid subject reports of memory. *Journal of Experimental Psychology Learning Memory and Cognition, 27,* 686–700. doi: 10.1037/0278-7393.27.3.686

19. Jacoby, L. L., Bishara, A. J., Hessels, S., & Toth, J. P. (2005a). Aging, subjective experience, and cognitive control: Dramatic false remembering by older adults. *Journal of Experimental Psychology: General, 137,* 131–148. doi: 10.1037/0096-3445.134.2.131

20. Jacoby, L. L., Shimizu, Y., Daniels, K. A., & Rhodes, M. G. (2005b). Modes of cognitive control in recognition and source memory: Depth of retrieval. *Psychonomic Bulletin & Review, 12,* 852–857. doi: 10.3758/BF03196776

21. Jacoby, L. L., Wahlheim, C. N., Rhodes, M. G., Daniels, K. A., & Rogers, C. S. (2010). Learning to diminish the effects of proactive interference: Reducing false memory for young and older adults. *Memory & Cognition, 38,* 820–829. doi: 10.3758/MC.38.6.820

22. Jacoby, L. L., Wahlheim, C. N., & Yonelinas, A. P. (2013). The role of detection and recollection of change in list discrimination. *Memory & Cognition, 41,* 638–649. doi: 10.3758/s13421-013-0313-x

23. Kane, M. J. (2002). Interference. In G. Maddox (Ed.), *Encyclopedia of aging* (pp. 514–516). New York, NY: Springer.

24. Kausler, D. H. (1994). *Learning and memory in normal aging*. New York, NY: Academic Press.

25. Koriat, A., & Goldsmith, M. (1996). Monitoring and control processes in the strategic regulation of memory accuracy. *Psychological Review, 103,* 490–517. doi: 10.1037/0033-295X.103.3.490

26. Light, L. L. (1991). Memory and aging: Four hypotheses in search of data. *Annual Review of Psychology, 42,* 333–376. doi: 10.1146/annurev.ps.42.020191.002001

27. Lindenberger, U., & Ghisletta, P. (2009). Cognitive and sensory declines in old age: Gauging the evidence for a common cause. *Psychology and Aging, 24,* 1–16. doi: 10.1037/a0014986

28. Logan, J. M., & Balota, D. A. (2003). Conscious and unconscious lexical retrieval blocking in younger and older adults. *Psychology and Aging, 18,* 537–550.

29. Lund, K., & Burgess, C. (1996). Producing high-dimensional semantic spaces from lexical co-occurrence. *Behavior Research Methods, Instruments, & Computers, 28,* 203–208. doi: 10.3758/BF03204766

30. Metcalfe, J., Schwartz, B. L., & Joaquim, S. G. (1993). The cue-familiarity heuristic in metacognition. *Journal of Experimental Psychology Learning Memory and Cognition, 19,* 851–861. doi: 10.1037/0278-7393.19.4.851

31. Naveh-Benjamin, M. (2000). Adult age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology Learning Memory and Cognition, 26,* 1170–1187. doi: 10.1037/0278-7393.26.5.1170

32. Nelson, D. L., McEvoy, C. L., & Schreiber, T. A. (1998). The University of South Florida word association, rhyme, and word fragment norms. Retrieved from http://w3.usf.edu/FreeAssociation/

33. Postman, L. (1964). Studies of learning to learn: II. Changes in transfer as a function of practice. *Journal of Verbal Learning and Verbal Behavior, 3,* 437–447.

34. Putnam, A. L., Wahlheim, C. N., & Jacoby, L. L. (2014). *Memory for flip-flopping: Detection and recollection of political contradictions*. Manuscripts under revision.

35. Radvansky, G. A., & Zacks, R. T. (1991). Mental models and the fan effect. *Journal of Experimental Psychology Learning Memory and Cognition, 17,* 940–953. doi: 10.1037/0278-7393.17.5.940

36. Radvansky, G. A., Zacks, R. T., & Hasher, L. (2005). Age and inhibition: The retrieval of situation models. *Journals of Gerontology, 60B,* P276–P278.

37. Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103,* 403–428. doi: 10.1037/0033-295X.103.3.403

38. Shipley, W. C. (1986). *Shipley Institute of Living Scale*. Los Angeles, CA: Western Psychological Services.

39. Tzeng, O. J., & Cotton, B. (1980). A study-phase retrieval model of temporal coding. *Journal of Experimental Psychology: Human Learning and Memory, 6,* 705–716. doi: 10.1037/0278-7393.6.6.705

40. Wahlheim, C. N. (2011). Predicting memory performance under conditions of proactive interference: Immediate and delayed judgments of learning. *Memory & Cognition, 39,*827–838. doi: 10.3758/s13421-010-0065-9

41. Wahlheim, C. N., & Jacoby, L. L. (2011). Experience with proactive interference diminishes its effects: Mechanisms of change. *Memory & Cognition, 39,* 185–195. doi: 10.3758/s13421-010-0017-4

42. Wahlheim, C. N., & Jacoby, L. L. (2013). Remembering change: The critical role of recursive remindings in proactive effects of memory. *Memory & Cognition, 41,* 1–15. doi: 10.3758/s13421-012-0246-9

43. Wilson, M. (1988). MRC Psycholinguistic Database: Machine-usable dictionary, version 2.00. *Behavior Research Methods, Instruments, & Computers, 20,* 6–10. doi: 10.3758/BF03202594

44. Winocur, G., & Moscovitch, M. (1983). Paired-associate learning in institutionalized and noninstitutionalized old people: An analysis of interference and context effects. *Journal of Gerontology, 38,* 455–464.

45. Winograd, E., & Soloway, R. M. (1985). Reminding as a basis for temporal judgments. *Journal of Experimental Psychology Learning Memory and Cognition, 11,* 262–271. doi: 10.1037/0278-7393.11.2.262