Memory Consequences of Looking Back to Notice Change: Retroactive and Proactive Facilitation

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Three experiments contrasted recollection of change with differentiation as means of avoiding retroactive interference and proactive interference. We manipulated the extent to which participants looked back to notice change between pairs of cues and targets (A-B, A-D) and measured the effects on later cued recall of either the first or second response. Two lists of word pairs were presented. Some right-hand members of pairs were changed within List 2, whereas others were changed between lists. Participants in a Within-List Back condition were instructed to detect changes that occurred only during List 2, in an effort to reduce noticing changes in pairs between lists while simultaneously differentiating the 2 lists. In contrast, participants in an N-Back condition were instructed to detect both within-list and between-list changes. Recall of first list responses that changed between lists produced retroactive facilitation for the N-Back condition but not for the Within-List Back condition. Similarly, recall of second list responses that changed between lists produced proactive facilitation for the N-Back condition but not for the Within-List Back condition. The greater extent of looking back increased detection of change and later recollection of change, which produced facilitation. When change was not recollected, detected change produced proactive interference. The recursive reminding produced when change is noticed contrasts with the simple associations of classic interference theory, and memory performance when change is recollected contrasts with the predictions of interference theory.

Keywords: change, interference, memory, recollection, reminding

A fundamental phenomenon of human memory is that experience of an event that is similar to an earlier event but substantially changed is a source of interference that impairs memory. As a commonplace example, suppose that an acquaintance changed her last name when she married. Memory for her changed name might interfere with your later ability to recall her original name, an example of *retroactive interference.* Memory for her original name might also interfere with your ability to recall her changed name, an example of *proactive interference.* Experimental analogs that test memory for word pairs have changed the response with which a cue is paired (A-B, A-D) and tested memory for the original pair (A-B) to show retroactive interference compared with a control condition for which only the target pair had been studied, or tested memory for the changed pair (A-D) to show proactive interference. The effects extend readily to more naturalistic materials such as

educational texts (Bower, 1974) and geometry proofs (Lovett & Anderson, 1994). Anderson and Neely (1996) review results from investigations of interference effects along with theories about the basis of such effects (also see Crowder, 1976), and interference is regarded as a main determinant of forgetting.

Theories about interference effects in the verbal learning tradition are associationistic in that learning is assumed to reflect simple associations between stimuli and responses. Melton and Irwin's two-factor theory (Melton & Irwin, 1940; also see Postman & Underwood, 1973) treated retroactive interference in the A-B, A-D paradigm as due to unlearning of original associations during the learning of changed associations and as also due to competition between changed and original responses at the time of test. In contrast, proactive interference was said to solely reflect response competition. Response competition readily accounts for intrusion errors such as retrieval of the response from the changed pair (A-D) being mistakenly produced during attempts to recall the original pair (A-B) in the case of retroactive interference or vice versa in the case of proactive interference. Response competition has been shown to be reduced if the contexts in which the original and changed pairs were differentiated (for a review of early research showing this, see Abra, 1972). Mensink and Raaijmakers (1988) model such effects by postulating that contextual cues are used in the search process in cued recall. In their model, the fluctuation of context cues over time is said to lead to a mismatch between context that is most current at the time of test and the learning context, and, consequently, lead to forgetting. The implication is that increasing the difference between the context in which the original and the changed responses are studied should

increase retroactive interference because the context cues at test are a better match to the context in which the changed responses were studied. In contrast, increasing the difference between the original and changed response contexts would reduce proactive interference, because the context cues at test are a worse match to the context in which the original responses were studied.

In accord with the context-change hypothesis, Sahakyan and Kelley (2002) presented two lists of unrelated nouns for study and manipulated mental context between them. Intervening between presentations of the two lists, half of the participants were required to imagine that they were invisible and write down what they would like to do knowing that they could not be held responsible for their actions. This was meant to shift their mental context from that of studying words to something very different. The other half of participants simply waited for an equivalent amount of time prior to presentation of the second list. Subsequent recall of words from the first list was much poorer following a change in mental context. That is, list differentiation created by change in mental context reduced proactive interference by causing forgetting of words in the first list. Sahakyan and Kelley used results produced by change in mental context to support their context-change account of directed forgetting, as they found evidence that participants in directed forgetting studies spontaneously try to "clear their heads" of the first list by thinking of something outside the context of the experiment. As will be described, we employed Sahakyan and Kelley's manipulation of mental context as a means of discouraging spontaneous noticing of between-list changes in responses.

Prior experiments have used a variety of manipulations, including those aimed at increasing list differentiation, in attempts to eliminate retroactive interference and proactive interference. Ultimate success in doing so would be to find that change produced no decrement in performance as compared with appropriate control conditions, fully eliminating proactive interference. In contrast, the goal of our current experiments is to show that noticing change can produce both retroactive facilitation (Experiment 1) and proactive facilitation (Experiments 2 and 3) as compared with the same control conditions used to measure interference effects. Our goal is to transform interference effects into facilitation effects. We defer additional consideration of proactive effects of memory to the introduction of Experiment 2. In what follows, we further consider retroactive effects of memory, and outline the procedure and prediction of results for Experiment 1.

Retroactive facilitation has sometimes been found in interference paradigms. Barnes and Underwood (1959) paired nonsense syllables with adjectives that were strongly associated (e.g., afraid–scared) to produce an A-B, A-B' paradigm. Learning the changed pairing was facilitated as was later recall of the original pairing, and the results were interpreted as due to learning the changed response by using the original association as a mediator (e.g., A-B-B'). As a consequence as its use as a mediator, the original response was said to be maintained during the learning of the changed response. However, retroactive facilitation is not restricted to situations in which there are strong associations between responses. Robbins and Bray (1974a, b) used a continuous paired-associate task with pairs repeated or changed (A-B, A-D) between presentations. Pairs were comprised of unrelated nouns that were presented at a 5-sec rate for study intermixed with tests. The lag between the presentations of repeated pairs or between

original and changed pairs varied from short (one intervening pair for 5 s) to long (five intervening pairs for 25 s). The retention interval between presentation of a pair and its test was also either short or relatively long (e.g., 5 or 25 s), with an even longer retention interval produced by testing memory for all pairs at the end of the experiment. Results sometimes revealed retroactive facilitation. Specifically, after a short lag between presentations and a relatively long or very long retention interval, presentation of A-D produced recall of B that was higher than that produced by the control condition of only having encountered A-B. Recall in the changed condition was sometimes as great as that produced by repetition of A-B. Similarly, Bruce and Weaver (1973) found retroactive facilitation in a short-term retention task using a paired-associate probe technique.

Retroactive facilitation produced by changing responses is a striking contrast to typical findings of retroactive interference. Robbins and Bray (1974b) noted that in their experiments and those of Bruce and Weaver (1973) participants were informed prior to study that some pairs would change during the list, whereas no such instructions are given in traditional investigations of retroactive interference. Indeed, participants' awareness of changes in responses is likely important. A possible interpretation of retroactive facilitation is that it simply reflects an implicit repetition effect produced when change is noticed. As in our earlier example of a friend's name change, to notice the change when being reintroduced requires that one be reminded of her original name. The reminding entails a repetition of the original name. Similarly, retroactive facilitation produced by a change in response could be due to noticing the change and thereby implicitly repeating the original response. In the experiments by Barnes and Underwood (1959), the strong association between responses in the original and changed pairs makes it likely that A-B' pairs reminded participants of the A-B pairs. Rather than requiring mediation of A-B' learning by the prior A-B association, noticing change might be sufficient to account for retroactive facilitation. Support for this noticing change interpretation is provided by the findings of retroactive facilitation even when original and changed responses are unrelated (Bruce & Weaver, 1973; Robbins & Bray, 1974a, 1974b). Noticing change would be increased by forewarning participants about the A-B, A-D condition and would be further increased by a short lag between the presentation of original and changed pairs.

In the current experiments, we use a "looking-back" procedure to manipulate the probability of noticing change. Looking-back procedures manipulate attention to the more recent versus more distant past to affect what is noticed and have been used to show the importance of noticing similarity among events for subsequent cued recall (Jacoby, 1974) and for memory of the temporal order of similar events (Jacoby & Wahlheim, 2013). As described later, a looking-back procedure similar to the one used in the current experiments has also been used to show the importance of noticing repetitions in creating an advantage of spaced over massed repetitions in later memory performance (Wahlheim, Maddox, & Jacoby, 2014). As described above, noticing change entails an implicit repetition of the original pair. The prior work establishing the effects of noticing repetitions on subsequent recall can be used to predict corresponding effects of noticing change in the current experiments, namely, retroactive facilitation.

The procedure employed in Experiment 1 in an attempt to show that noticing change can produce retroactive facilitation is illustrated in Table 1. Participants were presented with two lists of pairs with the right-hand member of some pairs being changed either between lists or within List 2, intermixed with control pairs. Presentation of the two lists was separated by an interval during which participants were asked to imagine what they would do if they were invisible, to aid differentiation of the two lists (cf. Sahakyan & Kelley, 2002). Participants in a "Within-List Back" condition indicated if the right-hand member of a pair was changed *within List 2*. This condition was meant to further differentiate the two lists, discouraging participants from being reminded of the original pairs from List 1 during the presentation of changed pairs in List 2. In an "N-Back" condition, participants indicated if the right-hand member of a pair was changed *either* between lists or within List 2. Thus, noticing of within-list change was encouraged for both conditions but noticing of between-list change was encouraged only for the N-Back condition. At test, participants were presented with the left-hand member of pairs as a cue for recall of the response from the original pair (A-B).

Our primary interest was in cued-recall for pairs that were changed between lists. We predicted that cued-recall of pairs that were changed between lists would reveal retroactive facilitation in the N-Back condition, producing a probability of recall that was higher than that for the control pairs. Retroactive facilitation for between-list changed pairs was not expected for the Within-List Back condition, because the instructions would discourage noticing of between-list changes in the Within-List Back condition. Further, in the N-Back condition we predicted that recall would be higher for between-list changed pairs than for within-list changed pairs. Noticing change requires that the original pair be brought to mind and the delay between the presentation of the original pair and its being brought to mind in the act of noticing change is much longer for between-list changes than for within-list changes. Thus, the longer between-list delay between the original pair and noticing the change should produce recall benefits that parallel the effects of delay on spaced repetitions, namely, a greater recall benefit for long than short spacing (for a review of spacing effects, see Delaney, Verkoeijen, & Spirgel, 2010).

Results reported by Wahlheim et al. (2014) are directly relevant to our prediction of an advantage in recall of between-list over within-list changed pairs. They used a similar looking-back procedure to examine effects of spacing. The important difference from the current studies is that pairs were repeated either within or between lists whereas in the present experiments, pairs were changed either within or between lists. Wahlheim et al. found an advantage in cued recall of between-list repetitions over within-list

repetitions in the N-Back condition but not in the Within-List Back condition. That result for repetitions supports our prediction that noticing change will be critical for spaced changes to produce a benefit in recall.

Experiments 2 and 3 sought evidence of proactive facilitation. The procedure employed in those experiments were the same as used in Experiment 1 to show retroactive facilitation except that tested control pairs were presented in List 2 rather than in List 1 and memory was tested for changed pairs (A-D) rather than for original pairs (A-B).

Experiment 1

Method

Participants. Forty-eight students from Washington University participated in exchange for $10/hr or partial course credit. Twenty-four participants were randomly assigned to each of the looking-back groups. Participants were tested individually.

Design and materials. A 3 (Item type: A-B, C-D vs. Within-List A-B, A-D vs. Between-List A-B, A-D) × 2 (Looking back: N-Back vs. Within-List Back) mixed design was used. Item type was manipulated within subjects and looking back instructions were manipulated between subjects.

The materials consisted of 88 three-word sets (80 critical items, eight buffer items), each including a cue word (e.g., *knee*) and two responses that were orthographically similar to each other (e.g., *bone, bend*) taken from Wahlheim and Jacoby (2013). The forward and backward associative strengths between cues and responses did not differ and were low on average ($M = .06$, $SD = .13$, $Range = 0–.92$; Nelson, McEvoy, & Schreiber, 1998). The forward and backward associative strengths between responses that shared a cue were extremely weak and did not differ ($M = .01$, $SD = .05$, $Range = 0–.36$).

As illustrated in Table 1, A-B, C-D pairs were presented in Lists 1 and 2 and did not overlap between lists. For A-B, A-D pairs, cues were the same, but responses changed either within List 2 or between Lists 1 and 2. Each of the three pair types were represented by 20 critical items and 2 buffers. Across formats, pairs were rotated through conditions such that pairs appeared equally often as each item type across participants.

List 1 consisted of 44 words pairs (40 critical, 4 fillers/buffers) divided evenly between A-B pairs from A-B, C-D items and A-B pairs from between-list A-B, A-D items. List 2 consisted of 88 word pairs (80 critical, 8 buffers) that were distributed equally across the 4 pair types: A-B pairs in List 1 from A-B, C-D items; C-D pairs in List 2 from A-B, C-D items; A-D pairs representing

Table 1
Schematic of Item Types and Correct Looking Back Responses: Experiment 1

Item type	Phase				Correct looking back responses	
	List 1	Invisibility	List 2	Test	N-Back	Within-List Back
A-B, C-D	A-B	5 min	C-D	A - ?	No	No
Within-List A-B, A-D	—		A-B, A-D	A - ?	Yes	Yes
Between-List A-B, A-D	A-B		A-D	A - ?	Yes	No

Note. At test, participants were instructed to recall the response from List 1.

within-list changed pairs; and A-D pairs representing between-list changed pairs. The average number of intervening items between presentations of Within-List A-B, A-D items ($M = 5.6$, $SD = 1.35$, $Range = 3–7$) was lower than for Between-List A-B, A-D items ($M = 66.82$, $SD = 1.95$, $Range = 5–121$).

A practice test included six buffers (two from each of the three conditions: C-D items; Within-List A-B, A-D items and Between-List A-B, A-D items). The practice test immediately preceded the main test and the procedure was identical to that of the main test. It was a practice test only in that performance on the buffer items comprising that test was not included in the analyses. The actual test consisted of 20 critical items from each of the conditions.

Procedure

In List 1, word pairs appeared in random order for 5 s each followed by a 500 ms interstimulus interval (ISI). Participants were told to read the words aloud and to study them for an upcoming memory test. In the interpolated task, participants were told to imagine what they would do if they were invisible and to write those things down for 5 minutes. In List 2, word pairs appeared for 5 s each followed by a 500 ms ISI in a random order, with the restriction that no pairs from the same condition appeared consecutively more than three times. Primacy and recency buffers, distributed evenly across item types, appeared at the beginning and end of the list.

During the presentation of List 2, participants in the N-Back group were told to detect pairs that changed from any point earlier in the experiment (Between- and Within-List A-B, A-D items), whereas those in the Within-List Back group were told to detect pairs that had changed only from earlier in List 2. Boxes labeled "Yes" and "No" appeared beneath the word pairs with a question about whether the pairs had changed that was specific to the set of looking back instructions. The boxes remained on the screen until one was clicked using the mouse cursor. After a box was clicked, pairs appeared on the screen for the remainder of the 5 s. When no response was made, pairs disappeared after 5 s. Participants failed to respond to fewer than 3% of the pairs, and this did not differ between looking back groups, $t(46) = .83$, $p = .41$. Feedback was given when incorrect responses about change were made to ensure that participants were following instructions. The message "incorrect" appeared in red ink when errors were made. Finally, on the practice and actual test, the left member of word pairs appeared and participants were told to recall the original response with

which it was paired, guessing if necessary. Further, they were told to produce a response for every test item. Test cues appeared until participants typed their responses onto the screen.

The significance level for all tests was set at $p < .05$.

Results

As shown in the top portion of Table 2, participants in the N-Back condition were more likely to incorrectly indicate change than were those in the Within-List Back group for control pairs (C-D pairs), $t(46) = 4.35$, $p < .001$. That difference likely reflects a bias effect that originates from the task in the N-Back group more often requiring participants to produce a "changed" response as compared with those in the Within-List Back group as well as poorer discrimination of change in the N-Back condition due to the greater number of intervening pairs across which change was to be detected. Change responding did not significantly differ across conditions for within-list changes. Most important, participants in the N-Back condition were much more likely to respond "changed" during the presentation of List 2 to between-list changed pairs than were participants in the Within-List Back condition, $t(46) = 12.64$, $p < .001$. The difference in "changed" responses for the two conditions provides evidence that the looking-back instructions brought noticing of between-list changes under task control.

The probability of correct recall (A-B) and of intrusion errors (A-D) is shown in Table 3 for each combination of conditions. The probability of correct recall for within-list changed pairs did not significantly differ from that for control pairs in either the N-Back or the Within-List Back condition. Most important, as compared with control pairs, correct recall of between-list changed pairs revealed retroactive facilitation in the N-Back condition, $t(23) = 3.96$, $p = .001$, but did not do so in the Within-List Back condition, $t(23) = .30$, $p = .77$. For the N-Back condition, correct recall was higher for between-list changed pairs than for within-list changed pairs, $t(23) = 3.54$, $p = .002$, which corresponds to an effect of spacing of repetitions. For pairs changed between lists, there was a nonsignificant trend showing that cued-recall was higher in the N-Back condition than in the Within-List Back condition $t(46) = 1.33$, $p = .19$, indicating the importance of noticing change.

The probability of producing the response from the changed pair (A-D) as an intrusion error was significantly higher for both between-list and within-list changed pairs than for control pairs as evidenced by a main effect of item type, $F(2, 92) = 41.03$, $p <$

Table 2

Probabilities of "Yes" Responses Indicating Change Detection in List 2 as a Function of Item Type and Looking Back Instructions: Experiments 1–3

| | | Item type | | |
	Looking back	A-B, C-D	A-B, A-D (Within)	A-B, A-D (Between)
Experiment 1	N-Back	.23 (.04)	.74 (.05)	.63 (.04)
	Within-List Back	.04 (.01)	.80 (.04)	.11 (.02)
Experiment 2	N-Back	.24 (.04)	.65 (.05)	.60 (.03)
	Within-List Back	.06 (.02)	.76 (.06)	.17 (.03)
Experiment 3	N-Back	.29 (.06)	.84 (.03)	.76 (.03)
	Within-List Back	.03 (.01)	.83 (.03)	.12 (.02)

Note. Standard errors of the means are presented in parentheses.

Table 3

Probabilities of Correct Recall and Intrusions as a Function of Item Type and Looking Back Instructions: Experiment 1

		Item type		
Response	Looking back	A-B, C-D	A-B, A-D (Within)	A-B, A-D (Between)
Correct	N-Back	.40 (.03)	.37 (.04)	.50 (.03)
	Within-List Back	.45 (.03)	.39 (.04)	.44 (.03)
P2 Intrusion	N-Back	.03 (.01)	.18 (.02)	.16 (.02)
	Within-List Back	.04 (.01)	.17 (.02)	.18 (.02)

Note. Standard errors of the means are displayed in parentheses.

.001, $\eta_p^2 = .47$. The probability of an A-D intrusion error did not differ significantly among looking-back conditions or type of change. Aside from correct response and intrusion errors from the changed pair, responses were extraexperimental intrusions that occurred with high probability, likely due to the requirement to produce a response to every test item.

The finding that A-D intrusion errors were higher for changed pairs than for control pairs suggests that responding reflected a mix of retroactive interference produced by response competition and retroactive facilitation produced by noticing change. Conditionalizing correct recall on whether change was noticed or not provides evidence that this was the case. For the N-Back condition, the probability of correct recall of original responses was higher when change was detected than when change was not detected for within-list changed pairs (.38 vs. .19) and for between-list changed pairs (.60 vs. .30), $F(1, 20) = 30.19$, $p < .001$, $\eta_p^2 = .60$. The effect of change detection did not interact with item type, $F(1, 20) = 1.28$, $p = .27$, $\eta_p^2 = .06$, but the larger recall advantage for original responses when between-list changes were detected accords with the overall recall advantage for between-list changed pairs over within-list changed pairs, and can be seen as akin to an effect of spacing repetitions. For the N-Back condition, it is notable that as compared with the probability of recall for control items, recall of original responses from between-list changed pairs for which change was detected shows retroactive facilitation (.60 vs. .38), $t(20) = 5.94$, $p < .001$, whereas recall of original responses from between-list changed pairs for which change was not detected shows a marginal trend toward retroactive interference (.30 vs. .38), $t(20) = -1.99$, $p = .06$.

Overall, the results provide support for the claim that noticing change requires that the original pair be brought to mind by presentation of a changed pair, and that doing so produces retroactive facilitation. Just as a longer lag between spaced repetitions increases the probability of recall, a longer lag between spacing of original and changed pairs increases the probability of recalling the response from an original pair. In contrast to arguments made by Barnes and Underwood (1959), the finding of retroactive facilitation does not require a strong association between the original and changed responses that is used to mediate the learning of the changed response. Rather, retroactive facilitation in the current experiment was found although there was little or no preexperimental association between the original and changed response (also see, Bruce & Weaver, 1973; Robbins & Bray, 1974a, 1974b). Rather, the repetition of the original response that is involved in noticing change by itself is sufficient to produce retroactive facilitation.

Noticing change could be useful in more applied contexts as well, and one candidate is the misinformation effect in eyewitness testimony. After viewing a staged crime, participants are exposed to changed details in the context of a narrative meant to recap the crime (Greene, Flynn, & Loftus, 1982), and then are tested for their memory of the original event. Misinformation produces worse memory for the original details, as in a retroactive interference paradigm. However, if participants notice the changed details in the misinformation narrative, they do not show impaired memory for the original event. Warning participants prior to presenting the misinformation narrative that some details may be incorrect reduces susceptibility to the misinformation (Greene et al., 1982), as does attributing the misinformation narrative to an untrustworthy source (the driver involved in a car accident, Dodd & Bradshaw, 1980.) Those effects likely stem from noticing the changes between the original event and changed narrative (Tousignant, Hall, & Loftus, 1986).

Requiring participants to detect change can be seen as akin to a testing effect. Many experiments have shown that testing participants on previously learned information produces memory benefits beyond rereading (for a review, see Roediger & Karpicke, 2006). Viewing instructed detection of change as a test raises the possibility that detection of change might produce an even higher probability of later recall than does rereading a repetition. That is, retrieving an original pairing to notice change might sometimes do more to enhance its later recall than does repeating the pairing to be read. Results reported by Mantyla and Cornoldi (2002) provide some support for this possibility. They presented photographs of faces with the second presentation being either identical or a mirror image of the first presentation. A test of recognition memory was given with participants being asked to report whether they recognized a face by consciously recollecting its prior presentation or on the basis of its familiarity. Changed faces were better recognized than were repeated faces and their recognition was more likely to be reported as relying on recollection than was that of repeated faces. Perhaps results of this sort will be obtained only when change is noticed.

In our experiment, the changed pair (A-D) was presented only once as in Robbins and Bray (1974a,1974b). Of course, in traditional experiments that have found retroactive interference, the A-D pair is repeatedly presented and tested until learned to a criterion. It is an empirical question whether people continue to be reminded of the original pair across repeated presentation of a changed pair, or whether mechanisms such as unlearning (e.g., Melton & Irwin, 1940), retrieval inhibition (e.g., Anderson, 2003),

or increased response competition eventually predominate to produce retroactive interference.

Experiment 2

As revealed by the results of Experiment 1, beneficial effects of retrieving the original response that are produced by reminding are sufficient to explain findings of retroactive facilitation. However, such facilitation of memory for the original response alone could not result in proactive facilitation. The original response is the target in experiments investigating retroactive effects but, instead, is the competitor for recall of the changed response, which is the target for experiments investigating proactive effects of memory. Proactive interference has been explained as solely due to response competition (Melton & Irwin, 1940; Postman & Underwood, 1973). A response competition account would predict that increased recall of the original response produced by noticing change would increase proactive interference. In contrast, we predict that noticing change can transform proactive interference into proactive facilitation as well as produce retroactive facilitation. The means by which proactive facilitation occurs can be illustrated by returning to the example of recalling an acquaintance's changed name. Upon later encountering the acquaintance, recollection that her name has changed, perhaps in combination with memory for the original name, provides additional cues for recall of the changed name compared with the case for recall of an equally learned, unchanged name (a control condition). Reliance on those additional cues can result in proactive facilitation. By this account, finding of proactive facilitation requires both detection of change at the time of presentation of a changed response and also requires that change be recollected at the time of test. As will be described, prior research (e.g., Wahlheim & Jacoby, 2013) has shown the importance of recollection of change for finding proactive facilitation.

Much research has been done to explore whether eliminating response competition can reduce proactive interference. However, none of the suggested techniques for doing so would predict finding proactive facilitation. Underwood (1945) suggested that list differentiation could reduce intrusion errors by allowing participants to identify the origin of potential responses and withhold those that originated from the wrong list. Later, Winograd (1968) measured list discrimination by asking people to identify the list from which their responses originated. Marcia Johnson and her colleagues have used similar measures of source memory, and have shown that source memory can be used to edit-out potential responses that originate from an undesired source (e.g., Johnson & Raye, 1981). By a source monitoring account, differentiation of sources can serve to reduce intrusion errors but would not increase correct responding over that of control items, as in Gruppuso, Lindsay, and Kelley (1997). Editing responses to avoid intrusions cannot be used to account for a finding of proactive facilitation.

Against the possibility that differentiation is the sole means of avoiding proactive interference, noticing change has been shown to turn proactive interference into proactive facilitation just as suggested by the example of remembering a changed name. Putnam, Wahlheim, and Jacoby (2014) provide a set of experiments that demonstrates the benefits of noticing and later recollecting change. In their experiments, fictitious politicians were paired with positions held in a first debate, and then with the same or changed positions in a second debate. The change in positions held by a politician across debates corresponds to an A-B, A-D condition for word pairs. During the second debate, participants were to press a key when they noticed that a candidate had changed his position on an issue. At test, the names of issues addressed during the second debate were provided as cues for recall of the position held by each candidate during that debate. Following recall, participants indicated whether the candidate changed his position on the issue across the two debates (a measure of recollection of change).

The probability of correct cued recall did not differ for positions that changed between debates as compared with a control condition for which the politician only expressed a position on an issue in the second debate (the control condition for measuring proactive interference). However, cued recall depended on the detection and recollection of change. When participants responded that they recollected that a politician's position changed across debates, proactive facilitation of memory for the changed position was found whereas absence of recollection of change at test resulted in proactive interference. That is, the lack of difference between the change and control conditions found in the unconditionalized data reflected a mix of proactive facilitation when change was recollected and proactive interference when change was not recollected. Further, noticing change alone was not sufficient for proactive facilitation to be found but, rather, it was necessary that change also be recollected at the time of test. Indeed, detection of change followed by a failure to recollect change produced poorer cued-recall performance than was found when change was not detected. Experiments that examined memory for word pairs have produced results showing similar benefits of change recollection (Jacoby, Wahlheim, & Yonelinas, 2013; Wahlheim, 2014; Wahlheim, 2015; Wahlheim & Jacoby, 2013).

To interpret the importance of noticing and recollecting change, these earlier studies (also see Jacoby & Wahlheim, 2013) extended the notion of "remindings" advanced by Hintzman (2011) and by Benjamin (e.g., Benjamin & Ross, 2010; Benjamin & Tullis, 2010). As outlined for the case of retroactive facilitation, noticing change requires that the presentation of A-D remind one of the prior presentation of A-B, and the reminding experience produces a recursive trace that embeds memory for the original event (A-B) into that of the changed event (A-D). Recollection of having noticed change provides access to the original and changed responses along with their order, producing proactive facilitation. The order of responses is preserved because recollection of having been reminded of A-B by the presentation of A-D allows one to be certain that A-D occurred more recently than did A-B. When change is not noticed or noticed but not recollected, proactive interference is produced due to competition between the original and changed responses. The retrieval of the original event (A-B) that is required to notice change acts as a repetition of the original response and, thereby, produces greater proactive interference when change is noticed but not recollected as compared with the case when change goes unnoticed.

From our prior results (e.g., Wahlheim & Jacoby, 2013) we inferred that proactive facilitation occurred when change was noticed and recollected, but we did not find an overall recall advantage for changed pairs as compared with control pairs. The overall recall of changed pairs was sometimes below that of control pairs, showing proactive interference, and was sometimes equal to that of control pairs. The conclusion that recollection of

change produces proactive facilitation has rested on conditionalized results showing that when change is recollected proactive facilitation as compared with control pairs is found whereas when change is not recollected proactive interference is found. In recognition that conditionalized results carries the danger of item differences being responsible for observed effects, we have used hierarchical regression analyses to show that recollection of change contributes to recall of responses from changed pairs (A-D) beyond item differences measured by performance on control items.

However, the hierarchical regression analyses do not allow the rejection of alternative accounts of our results. In particular, they leave open the possibility that the apparent advantage of change recollection actually reflects use of source information to edit potential responses (cf. Johnson & Raye, 1981; Winograd, 1968). What we have interpreted as evidence of an effect of recollection of change could actually reflect cases in which both the original and changed response are implicitly recalled with source editing used to choose between responses. Implicitly recalling both responses would result in participants judging that responses were changed. Recalling both responses would also make it obvious to participants that the source of the different responses should be assessed to choose the correct response. Recalling both responses would also provide an advantage for choosing between the two responses on the basis of source information. This is because identifying the source of either one of the two responses allows identification of the other by means of a process of elimination. Such source editing would create the possibility of an item-selection effect operating at the level of memory for the two pairs (A-B and A-D) rather than at the level of memory for an individual pair and, so, not be taken into account by prior hierarchical analyses. In sum, the argument is that judgments of "changed" occur when both responses come to mind but are less likely to occur when only a single response comes to mind. As well as resulting in a "changed" response, both responses coming to mind triggers source editing that leads to the correct response being given. Consequently, conditionalizing on the measure of recollection of change reflects pairs for which both responses come to mind holding a recall advantage over pairs for which only a single response comes to mind rather than an effect of recollection of change per se.

An argument of the above sort provides an alternative explanation for findings that we have interpreted as evidence of proactive facilitation when using conditionalized data as well as for results from the hierarchical regression analyses that we have done to take item differences into account. However, it would not be possible to use a source-editing explanation to account for a finding of proactive facilitation if conditions produce overall higher recall of changed responses as compared with control pairs. Again, perfect source editing would only eliminate proactive interference, but not produce proactive facilitation in unconditionalized results. Experiment 2 employed procedures that are the same as those employed in Experiment 1 to show retroactive facilitation but rather than asking participants to recall the original response (A-B), they were asked to recall the most recent response (A-D). Also, control pairs were in List 2 rather than in List 1.

We predicted that results for Experiment 2 would be very similar to those found for Experiment 1. That is, we predicted proactive facilitation in the N-Back condition for between-list, changed pairs but not for within-list changed pairs. We also predicted an effect of spacing such that recall of changed pairs in the N-Back condition would be higher for between-list, as compared with within-list, changed pairs. We did not expect to find corresponding differences in the Within-List Back condition. These predictions are based on the expectation that noticing change is important for later recollection of change, with recollection of change being more likely when noticing change occurs after a long delay between the original and the changed pair. The procedure of Experiment 2 parallels that of Experiment 1 in that recollection of change was not tested, although it will be measured in Experiment 3.

Our goal in Experiment 2 is to demonstrate proactive facilitation in overall recall to allow us to draw the conclusion that proactive facilitation results from detection and recollection of change. A second reason it is important to demonstrate proactive facilitation in overall recall relates to individual differences found in our prior investigations. In particular, hierarchical regression analyses done at the subject level in our prior experiments revealed that individual differences in the probability of recollecting change contributed greatly to the probability of recalling changed responses. For example, Wahlheim and Jacoby (2013, Experiment 3) found that individual differences in recollection of change accounted for 51% of the variance in cued recall of responses from changed pairs (A-D) after general memory ability, measured by performance on control pairs (C-D), had already been entered as a predictor. Jacoby (1974) provided evidence of individual differences in the extent to which participants looked back to notice similarity among presented items that contributed to their subsequent cued-recall performance. Similarly, individual differences in the extent to which participants look back to notice change might contribute to their subsequent cued recall of changed responses. A finding of greater cued-recall for between-list, changed responses in the N-Back condition than in the Within-Back condition would be consistent with this possibility, showing that looking back over a greater extent does improve subsequent cued recall performance in the form of proactive facilitation.

Method

Participants. Forty-eight students from Washington University participated in exchange for $10/hr or partial course credit. Twenty-four participants were randomly assigned to each of the looking-back groups. Participants were tested individually.

Design, materials, and procedure. The design, materials, and procedure were identical to Experiment 1 with the exception that recall of the changed response was tested rather than that of the original response, and control pairs were pairs presented in List 2 rather than in List 1.

Results

In general, results found for proactive effects in Experiment 2 replicated those found for retroactive effects in Experiment 1. As shown in Table 2, participants in the N-Back condition were more likely to incorrectly indicate change during the presentation of List 2 than were those in the Within-List Back group for control pairs (C-D pairs), $t(46) = 4.47$, $p < .001$. Change responding did not significantly differ across conditions for within-list changes. Most

important, participants in the N-Back condition were much more likely to respond "changed" during the presentation of List 2 to between-list changed pairs than were participants in the Within-List Back condition, $t(46) = 10.28$, $p < .001$. The difference in "changed" responses for the two conditions again provides evidence that the looking-back instructions brought the noticing of between-list changes under task control.

The probability of correct recall for within-list changed pairs did not significantly differ from that for control pairs in either the N-Back or the Within-List Back condition (top portion of Table 4). Most important, the probability of correct recall for control pairs versus between-list changed pairs significantly interacted with looking-back condition, $F(1, 46) = 7.38$, $p < .01$, $\eta_p^2 = .14$. As compared with control pairs, correct recall of between-list changed pairs revealed proactive facilitation in the N-Back condition, $t(23) = 2.71$, $p < .01$, but did not do so in the Within-List Back condition, $t(23) = -1.06$, $p = .30$. Correct recall of between-list changed pairs was higher in the N-Back condition than in the Within-List Back condition, $t(46) = 2.55$, $p = .01$. For the N-Back condition, correct recall for between-list changed pairs held a numerical advantage over that for within-list changed pairs, but the difference was not significant. As will be seen, the corresponding difference was significant in Experiment 3.

For intrusion errors, the main effect of item type was significant, $F(2, 92) = 99.60$, $p < .001$, $\eta_p^2 = .69$, qualified by an interaction between item type and looking-back condition, $F(2, 92) = 6.45$, $p < .002$, $\eta_p^2 = .12$. For both looking-back conditions, intrusion errors occurred more frequently for within-list and between-list changed pairs than for control pairs. For between-list changed pairs, the probability of an intrusion error was lower in the N-Back condition than in the Within-List Back condition, $t(46) = 2.17$, $p = .04$.

The pattern of results for correct responses in combination with the pattern of intrusion errors provides evidence that overall responding reflected a combination of proactive facilitation produced by recollection of change and proactive interference resulting from response competition when recollection of change failed. Such results are as expected if the N-Back condition held an advantage in recollection of change over the Within-List Back condition that both increased the probability of correct recall and decreased the probability of intrusion errors.

Comparing across the results of Experiments 1 and 2 (Tables 3 and 4), the N-Back condition produced overall retroactive facilitation (Experiment 1) and overall proactive facilitation (Experiment 2) for between-list changed pairs relative to control pairs. However, there are differences in results between the two experiments. For between-list changed pairs, the probability of an intrusion error is larger in Experiment 2 than in Experiment 1, particularly for the Within-List Back condition. That difference is understandable in terms of the repetition effect for responses from the original pair (A-B) produced by noticing change. For retroactive effects of memory (Experiment 1), that repetition effect favors the target response from the original pair (A-B), whereas, for proactive effects of memory, the repetition effect favors the competitor for the target response. In the N-Back condition, competition from the competitor is better countered by recollection of change as compared with the Within-List Back condition. Further evidence for this interpretation is provided by examining the probability of correct responding given the presence versus absence of detection of change. In Experiment 1, the probability of correct recall given detection of change for between-list changed pairs in the N-Back condition was much higher than was the probability of correct recall given the absence of detection of change (.62 vs. .29), $t(23) = 6.02$, $p < .001$. In contrast, in Experiment 2, the probability of correct recall given detection of change in the N-Back condition differed little from the probability of correct recall given the absence of detection of change for between-list changes (.45 vs. .47). The difference does not approach significance, $t(23) = -.34$, $p = .74$, and the direction of the differences is opposite to that observed in Experiment 1 for retroactive effects of memory. Again, the difference in results can be explained as arising because the repetition effect involved in noticing change favors the competitor for proactive effects of memory, whereas it favors the target response for retroactive effects of memory. Overall, proactive facilitation requires that the effect of recollection of change successfully counters the repetition effect produced for competitors by prior noticing of change.

Experiment 3

In Experiment 2, the proactive facilitation observed for between-list changed pairs in the N-Back condition but not in the

Table 4

Probabilities of Correct Recall and Intrusions as a Function of Item Type and Looking Back Instructions: Experiments 2 and 3

| | | | | Item type | |
Experiment	Response	Looking back	A-B, C-D	A-B, A-D (Within)	A-B, A-D (Between)
Experiment 2	Correct	N-Back	.36 (.03)	.40 (.03)	.46 (.04)
		Within-List Back	.36 (.04)	.36 (.04)	.33 (.03)
	P1 Intrusion	N-Back	.03 (.01)	.25 (.02)	.23 (.03)
		Within-List Back	.03 (.01)	.20 (.03)	.32 (.02)
Experiment 3	Correct	N-Back	.40 (.03)	.40 (.03)	.48 (.03)
		Within-List Back	.40 (.04)	.43 (.04)	.40 (.03)
	P1 Intrusion	N-Back	.02 (.01)	.19 (.02)	.20 (.02)
		Within-List Back	.02 (.01)	.18 (.02)	.39 (.02)

Note. Standard errors of the means are displayed in parentheses.

Within-List Back condition was predicted because of expected differences in recollection of change, but recollection of change was not directly measured. The procedure in Experiment 3 was generally the same as in Experiment 2, but following cued-recall for each pair, change recollection was measured by asking participants to indicate whether the pair was changed in the context of the experiment as a whole. If they indicated that the pair changed, they were asked to recall the response paired with the cue in the original pair. We predicted that the probability of recollection of change for between-list changed pairs would be greater in the N-Back condition than in the Within-List Back condition, and would produce overall proactive facilitation for between-list changed pairs. Given that cued recall depends on recollection of change, the difference in recollection of change would account for the difference between the N-Back and Within-List Back conditions in their cued-recall of responses from between-list changed pairs. Further, we predicted that recall of the original response in the N-Back condition would be high following a judgment that a pair was changed, and higher for between-list changes than for within-list changes. That result would show convergence between the retroactive facilitation found in Experiment 1 and a role of memory for responses in original pairs (A-B) in proactive facilitation. Other differences in the procedure were meant to generalize the results. Rather than instructing participants to learn pairs presented in List 1 as done in Experiments 1 and 2, participants were asked to judge the association between members of pairs. The change in tasks between Lists 1 and 2 was meant to further differentiate the lists, but results were expected to replicate those of Experiment 2.

Method

Participants. Seventy-two students from Washington University participated in exchange for $10/hr or partial course credit. Thirty-six participants were randomly assigned to each of the looking-back groups. Participants were tested individually.

Design, materials, and procedure. The design, materials, and procedure were identical to Experiment 2 with the following exceptions: During List 1, participants were told to rate the associations between cues and responses. Pairs appeared for 3 s, and then a scale ranging from (1 = *unrelated* to 7 = *related*) appeared below the pairs until participants entered a response. During List 2, no feedback was given following change detection responses. At test, a measure of change recollection was included. After participants attempted to recall the most recent response paired with a cue, they were asked to indicate whether the right-hand word paired with the cue had changed at any point earlier in the experiment. Boxes labeled "Yes" and "No" appeared below a question asking whether change had occurred until participants clicked one with the mouse cursor. When participants responded "Yes" they were then asked to recall the earlier response that had been paired with the cue and to type it onto the screen.

Results

Effects of condition on noticing change in Experiment 3 replicated those found in Experiments 1 and 2 (bottom portion of Table 2). Participants in the N-Back condition were much more likely to respond "changed" to between-list changes than were participants

in the Within-List Back condition, $t(70) = 20.03$, $p < .001$. During the presentation of List 2, participants in the N-Back condition were more likely to incorrectly respond "changed" to control pairs than were those in the Within-List Back condition, $t(70) = 4.51$, $p < .001$. Detection of within-list changed pairs did not differ between the looking-back conditions, $t(70) = .36$, $p = .72$.

The cued-recall results also replicated results found in Experiment 2 (bottom portion of Table 4). The probability of correct responding to within-list changed pairs did not significantly differ from that to control pairs in either the N-Back or the Within-List Back condition. As compared with control pairs, correct recall of between-list, changed pairs revealed proactive facilitation in the N-Back condition, $t(35) = 2.23$, $p = .03$, but not in the Within-List Back condition, $t(35) = .05$, $p = .96$. Cued-recall of between-list changed responses was higher in the N-Back condition than in the Within-List Back condition, $t(70) = 2.03$, $p < .05$. For the N-Back condition, correct recall for between-list changed pairs was greater than that for within-list changed pairs, $t(35) = 2.77$, $p = .009$. The corresponding difference in Experiment 2 only approached significance.

Replicating the results of Experiment 2, analyses of intrusion errors (bottom of Table 4) revealed a highly significant effect of item type, $F(2, 140) = 156.95$, $p < .001$, $\eta_p^2 = .69$, showing that intrusion errors were much lower for control pairs than for either within-list or between-list changed pairs, qualified by an interaction of item type and looking-back condition, $F(2, 140) = 26.30$, $p < .001$, $\eta_p^2 = .27$. The probability of an intrusion error for within-list changed pairs did not differ for the looking-back conditions. However, for between-list pairs, the probability of an intrusion error was much lower for the N-Back as compared with the Within-List Back condition, $t(70) = 5.79$, $p < .001$. Results for correct recall in combination with those for intrusions errors show that overall recall performance reflected a mix of proactive interference produced by response competition and proactive facilitation produced by recollection of change with the balance being one of overall proactive facilitation.

As shown in Table 5, the manipulation of looking-back instructions produced differences in recollection of change. As predicted, the probability of recollection of change for within-list versus between-list changes interacted with looking-back conditions, $F(1, 70) = 23.41$, $p < .001$, $\eta_p^2 = .25$. N-Back and Within-List Back conditions did not differ in the probability of erroneously recollecting change for control pairs, nor did they differ in correct recollection of change for within-list changes, *largest* $t(70) = .95$, $p = .35$. However, recollection of change for between-list changes was much higher in the N-Back than in the Within-List Back condition, $t(70) = 4.70$, $p < .001$, consistent with the suggestion

Table 5

Probabilities of Change Recollection as a Function of Item Type and Looking Back Instructions: Experiment 3

		Item type	
Looking back	A-B, C-D	A-B, A-D (Within)	A-B, A-D (Between)
N-Back	.10 (.01)	.56 (.03)	.70 (.03)
Within-List Back	.08 (.01)	.59 (.04)	.48 (.04)

Note. Standard errors of the means are displayed in parentheses.

that differences in correct cued-recall as well as differences in intrusion errors for changed pairs resulted from differences in recollection of change. Also, in the N-Back condition, recollection of change was higher for between-list changes than for within-list changes, $t(35) = 5.58$, $p < .001$. That difference is in accord with the corresponding advantage in cued recall for pairs that were changed between lists over those that were changed within List 2.

The advantage in recollection of between-list changes in the N-Back condition occurred even though the probability of noticing change was higher for within-list changes than for between-list changes, $F(1, 35) = 44.14$, $p < .001$, $\eta_p^2 = .56$. For the N-Back condition, between-list changes that were detected were almost always later recollected (.76 vs. .70), $t(35) = 2.58$, $p = .01$. By comparison, within-list changes that were detected were more prone to forgetting (.84 vs. .56), $t(35) = 7.80$, $p < .001$. Change detected after a long delay was more memorable than change detected after a short delay.

Surprisingly, for the Within-List Back condition, the probability of recollecting between-list changes was much higher than the probability of mistakenly accepting a between-list change as being a within-list change during the presentation of List 2 (.48 recollected vs. .12 mistakenly judged as changed), $t(35) = -7.88$, $p < .001$. That difference could arise from participants sometimes detecting between-list changes during the presentation of List 2 but correctly identifying them as between-list and, so, not false alarming to them as within-list changes. If so, the looking-back instructions reduced but did not fully eliminate noticing the between-list changes. Alternatively, when asked at test whether responses changed at any point in the experiment, participants in the Within-List Back condition might for the first time look back to memory for List 1 and detect between-list changes that were not detected during the presentation of List 2. Results from other experiments have provided evidence that asking a question about the relationship between events at the time of test can lead to noticing relationships that were previously unnoticed (Jacoby et al., 2013; Wahlheim et al., 2014).

At test, if change was recollected, participants attempted to recollect the original response. The results displayed in Table 6 reveal a significant interaction between type of change and looking-back condition in the probability of recollecting the original response $F(1, 70) = 14.16$, $p < .001$, $\eta_p^2 = .17$. The probability of recalling the original response given that change was recollected was greater for between-list changes than for within-list changes in both the N-Back condition, $t(35) = 10.78$, $p < .001$, and the Within-List Back condition, $t(35) = 2.19$, $p = .04$, but the effect was much larger in the N-Back condition. As described for

retroactive facilitation in Experiment 1, the advantage in recall of original responses for between-list changed pairs can be attributed to an effect of the increased spacing of their earlier retrieval. To notice change requires retrieval of the original response, and the experience of noticing produces a recursive trace that integrates the original response with the changed response. Consequently, recollection of change can cue recall of the original response with this being made more likely by the earlier spaced retrieval of the original response. In contrast, in the Within-List Back condition, there is more opportunity for a between-list change to be noticed for the first time at test, which would be more likely if an original response is particularly memorable.

Overall, the results from Experiments 2 and 3 show that recollection of change can produce proactive facilitation. These findings of overall proactive facilitation lend support for our interpretation of earlier findings using conditionalized data (e.g., Putnam et al., 2014; Wahlheim & Jacoby, 2013). In the following, we report conditionalized results to highlight points of convergence. We do so only for the N-back condition because that is the condition that showed overall proactive facilitation. Conditionalized results show that recollection of change relied on prior noticing of change. For the N-Back condition, recollection of change was greater when it was noticed in List 2 than when it was not for both within-list change (.58 vs. .33) and between-list change (.79 vs. .38), $F(1, 30) = 77.76$, $p < .001$, $\eta_p^2 = .72$. These results are in accord with unconditionalized results showing effects of within versus between-list changes on the probability of recollection of change and on correct recall of changed responses. However, note that the probability of recollection of change when change was not noticed during the presentation of List 2 is far from zero. In part, this likely reflects the influence of guessing on the recollection of change measure. Participants sometimes erroneously claimed that the response had been changed for control items, showing evidence of such guessing. Also, for changed pairs, there might be cases for which change was not noticed during the presentation of List 2 but was noticed for the first time when memory for change was tested.

Recollection of change as well as noticing change was important for subsequent recall in the N-Back condition (see Figure 1). When between-list change was noticed and recollected, recall of changed responses showed proactive facilitation as compared with control pairs, $t(29) = 4.38$, $p < .001$. In contrast, when between-list change was noticed but not later recollected, recall of changed responses showed striking proactive interference, $t(29) = -7.53$, $p < .001$. When between-list change was neither noticed nor recollected, recall of changed responses was lower than that for control pairs, but not significantly so, $t = -0.82$, $p = .42$. This pattern of results is the same as observed in prior experiments (Putnam et al., 2014; Wahlheim & Jacoby, 2013). The corresponding results for intrusion errors showed that the probability of the response from the original pair (A-B) being given as an intrusion error following noticing and recollection of change was quite low and not greatly different from that for control pairs (.08 vs. .02), $t(29) = 2.66$, $p = .01$. When change was noticed but not recollected, the probability of the original response being mistakenly given as an intrusion error was much higher than when change was not noticed and not recollected (.53 vs. .36), $t(29) = 2.14$, $p = .04$. As argued above, noticing change requires that memory of the original event is retrieved by presentation of the changed event.

Table 6

Probabilities of Recall of Original Responses (P1) for A-B, A-D Items Following Change Recollection as a Function of Item Type and Looking Back Instructions: Experiment 3
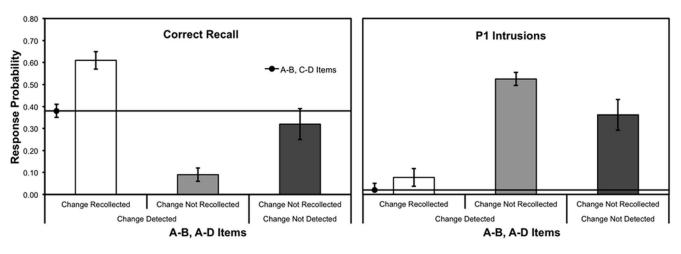
Looking back	Item type	
	A-B, A-D (Within)	A-B, A-D (Between)
N-Back	.44 (.04)	.79 (.04)
Within-List Back	.51 (.05)	.62 (.04)

Note. Standard errors of the means are displayed in parentheses.

Figure 1. Probabilities of correct recall of the most recent responses (left panel) and probabilities of P1 intrusions (right panel) for A-B, C-D items and Between-List A-B, A-D items in the N-Back group in Experiment 3 conditionalized on the detection and recollection of change are displayed above. These probabilities were computed from the 30 subjects who had at least one observation in each of the above cells. Error bars represent standard errors of the means.

Doing so serves as a repetition for the response from the original pair. Recollection of change increases recall of the changed response and reduces intrusion errors, producing proactive facilitation. When change is noticed but not recollected, the repetition effect for the original response produces increased proactive interference.

General Discussion

Results from the current experiments revealed both retroactive facilitation (Experiment 1) and proactive facilitation (Experiments 2 and 3) in overall cued recall performance. Retroactive facilitation can be understood as resulting from the repetition effect produced by bringing the original pair (A-B) to mind during the presentation of the changed pair (A-D), which is required for change to be noticed. To understand proactive facilitation, we argue that noticing change produces a recursive representation that embeds memory for the original pair into that for the changed pair. At test, the original response coming to mind sometimes assists in retrieval of the recursive representation and in combination with recollection of change, results in proactive facilitation. Proactive facilitation results from later recollection of change. This process was illustrated by the commonplace example of an acquaintance's original name coming to mind along with memory for it having changed, and its doing so aiding retrieval of the changed name. When change is not recollected, memory for the original response competes with that for the changed response, producing proactive interference. Evidence for the crucial role played by recollection of change was revealed by findings in Experiment 3 showing that looking back to List 1, which was instructed for the N-Back condition but discouraged for the Within-List Back condition, increased both the noticing and the later recollection of change with the result being that proactive facilitation was observed for between-list, changed pairs in the N-Back condition but not in the Within-List Back condition. The pattern of intrusion errors in combination with the pattern of correct responses across condi-

tions show that overall performance reflected a mix of proactive facilitation produced by recollection of change and proactive interference produced by response competition.

The repetition of the original response involved in noticing change favored the target item for retroactive effects, thereby producing retroactive facilitation in Experiment 1. Retroactive facilitation was found for pairs changed between lists but was not found for pairs changed within lists. The interval between the prior presentation of an original pair and its coming to mind to notice change was much longer for between-list, changed pairs, and, so, produced a beneficial effect of spacing repetitions (cf. Wahlheim et al., 2014). For proactive facilitation to be observed in Experiments 2 and 3, it was necessary for recollection of change to successfully overcome the stronger response competition produced by the retrieval of the original pair that occurred when change was noticed. Noticing a between-list change entails retrieval of the original pair after a long delay and so produced a spaced-repetition effect that favored the competitor, making recollection of change particularly important to overcome proactive interference. As expected, between-list change increased intrusion errors relative to within-list change in the Within-List Back condition, but did not do so in the N-Back condition. The increased probability of recollection of change in the N-Back condition was sufficient to counter the increased advantage for competitors produced by their spaced repetition, but recollection of change in the Within-List Back condition was not sufficient to do so.

By showing retroactive facilitation and the importance of recollection of change we depart from the associationistic view that motivated the two-factor theory of forgetting (Melton & Irwin, 1940; Postman & Underwood, 1973). Barnes and Underwood (1959) found that the presence of a strong association between original and changed responses (A-B, A-B') resulted in retroactive facilitation. They argued that retroactive facilitation occurred because participants learned the second list by creating mediators with the first responses (A-B-B'), and used that mediating rela-

tionship to retrieve the original response. Our results show that retroactive and proactive facilitation can be found with little or no association between responses (see also Wahlheim, 2015, which used completely unrelated pairs). Two-factor theory held that proactive interference reflects only response competition. In contrast, our results show the necessity of also taking into account noticing and recollection of change to predict when proactive interference in overall performance will be observed. The claim that noticing change produces a recursive representation contrasts with the description of retroactive and proactive interference effects as only involving simple associations between stimuli and responses.

The finding of retroactive and proactive facilitation in overall performance cannot be explained as a function of using source monitoring to edit out intrusion errors. At best, such source editing could produce performance that was equal to that for control pairs, but could not produce performance for changed pairs that was superior to that for control pairs. Differentiation of sources can be used to reduce retroactive and proactive interference produced by response competitions (for a review, see Abra, 1972). It is useful to compare the costs and benefits gained from differentiation of sources with those gained from noticing and recollection of change. If sources are sufficiently differentiated, responses from the inappropriate source will seldom come to mind, and if they do so, intrusion errors can be avoided by careful source monitoring. However, differentiation of sources is antagonistic to noticing change and later recollection of change. Noticing and recollection of change offers the benefit of allowing one to avoid proactive interference produced by response competition, and the additional benefit of allowing one to recall the earlier-presented, nontarget response. Ability to recall both the original and the changed response is sometimes useful, as in the case of educational materials, where one's aim is to learn both that King A used General B to fight War C, and King A used General E to fight War F (Bower, 1974).

Another benefit of noticing change and later recollection of change is that it supports memory for order and recency. Jacoby et al. (2013) showed that noticing and recollection of change produces memory for list membership that is superior to that produced when change is not noticed. Source memory, which is important for avoiding intrusion errors via an editing process, might itself be improved more when change is noticed than it would be had the situations been differentiated in a way that discouraged the noticing of change. However, noticing change also carries a potential cost if change is not recollected. The cost is due to the fact that noticing change strengthens the original response as it is retrieved during noticing, and so the original response is even more competitive with the target response if change is not recollected than if change had not been noticed in the first place. That pattern of results was illustrated in the conditionalized analyses of Experiment 3: Proactive interference was worse for change that was noticed but not later recollected.

One goal of the current experiments was to create situations where the probability of noticing and recollection of change could be increased and lead to overall retroactive and proactive facilitation. Our earlier articles demonstrating the role of noticing and recollection of change on proactive facilitation depended on conditionalized analyses, which were subject to item selection explanations. Nonetheless, results from the current experiments converge with results from our earlier experiments. Of particular interest, results of the current experiments show that the repetition involved in noticing change is responsible for retroactive facilitation. The increased memory for the original pair produced by such repetition in combination with recollection of change produces proactive facilitation, but serves as a source of heightened interference when change is not recollected.

Our theorizing about the importance of noticing and recollecting change builds on prior work done to show the importance of remindings (e.g., Benjamin & Ross, 2010; Hintzman, 2004). Hintzman (2004) proposed that remindings explain the lack of correspondence between effects of manipulations on frequency judgments versus recognition judgments. A general "memory strength" view holds that both recognition memory and frequency judgments rely on the same mechanism and, so, should be affected by various manipulations in the same way. In contrast, Hintzman showed that frequency judgments are more sensitive to effects of number of repetitions than is recognition confidence. He proposed that frequency judgments rely upon the recursive representation produced when a later presentation reminds one of an earlier presentation. Reminding was defined as "spontaneous recall of events related to the stimulus—particularly, earlier events in the experimental context." (p. 344) The memory record for a reminding embeds the earlier event in the later event. The construct of remindings was used to account for a variety of results in the memory literature, including the finding that participants can remember the temporal order of related words (e.g., *king* followed later in the list by *queen*) better than that of unrelated words (Tzeng & Cotton, 1980; Winograd & Soloway, 1985). Their ability to do is assumed to depend on recollection at the time of test that *queen* reminded them of *king* during study, a recollection based on the recursive trace formed during reminding. For a reminding to occur, a later presented item must provoke retrieval of memory for the earlier-presented item and its doing so is dependent upon well-known factors that are important for retrieval, including the delay since the encounter with the earlier-presented item and the similarity between the related items. In this vein, Hintzman and Stern (1978) found that judgments of frequency were higher when the test item had been repeated in the same context rather than in varying contexts. As noted by Hintzman (2004), the lack of correspondence between effects on different measures of memory is reason to reject theories holding that general strength underlies performance on all memory measures, including his own Minerva model. Similarly, current results are reason to reject traditional theories of interference that held that "associative strength" underlies performance (Postman & Underwood, 1973).

Recollection of remindings that reflect noticing relationships among events can enhance cued-recall of semantically related words (Jacoby, 1974), temporal judgments (Jacoby & Wahlheim, 2013, and list discrimination (Jacoby et al., 2013) as well as turn proactive interference into proactive facilitation and retroactive interference into retroactive facilitation. By emphasizing the importance of noticing, and by arguing for a consequent recursive representation, we depart from the associationistic tradition that marked investigations of retroactive and proactive effects from the perspective of the verbal learning tradition. Asch (1969) argued that "association" as used within the associationistic tradition referred to an "and" relationship between two events. He demonstrated that other forms of relationship were much more effective

as a basis for perception and for memory. Particularly relevant to results reported in the current article, Asch (1969) demonstrated that even repetition benefits in memory depend upon noticing the relationship between the prior event and the current event. Participants learned associations between pairs of items to criterion and after some intervening tasks, learned a second list that included a single critical pair from the first list. During study of the second list, many participants remained unaware that one item was a repetition, and took as many trials to learn the repeated item as to learn a completely new item. Only when people were aware of the relation between initial study and the repetition of an item in the second list did their learning of the item in the context of the second list inherit the learning that accrued to the item in the context of the first list. These results are often met with disbelief, but we recently replicated them (Komsky, Kelley, & Jacoby, in preparation), and found similar results when the critical pair changed between lists. Furthermore, in Wahlheim et al. (2014) repetitions of pairs that went unnoticed as such showed cued recall that was no better than control items presented once.

Similarity and Difference in Change Detection

Reed Hunt and his collaborators have done much research to make the important point that precision in memory (distinctiveness) derives from encoding differences in the context of similarity (for a review, see Hunt, 2012). We agree that good memory requires preserving information about differences against a background of similarity. This can be accomplished by a recursive representation of change. Similarity between events is necessary for a current event to trigger a reminding of an earlier event. For our experiments, an important basis of similarity was the left-hand member of pairs (A-B, A-D). Noticing change relies upon differences with both similarities and differences being represented in the recursive trace. One benefit of the interpretation of reminding and the recursive representation that embeds memory for the original event into the experience and memory of the second event is that such a representation can also account for improved memory for temporal order and list membership (Jacoby et al., 2013).

In line with Hunt's emphasis on the conditions that give rise to distinctiveness, whether greater attention is focused on differences or on similarities likely depends upon the task in which a person is engaged as well as the characteristics of the materials. Begg (1978) showed that for pairs of words that were similar (e.g., *whiskey, vodka*) subsequent memory performance was better if participants were asked to list differences rather than similarities between the two. In contrast, for pairs of words that had little in common, subsequent memory performance was better if participants were asked to list similarities. An interesting question is whether the recursive trace that results from attempting to detect change would differ from the recursive trace that results from attempting to detect similarity even with materials kept constant. Change is noticed against a background of similarity and the reminding required for noticing change likely reflects the task in which a person is engaged, along with the salience of similarities and differences as determined by one's goals and the materials.

Depth of Recursive Reminding

A key parameter in testing whether noticing change and recollection of change extends to other paradigms to produce proactive and retroactive facilitation may be the depth of recursion in remindings. People may be reminded of an earlier event by a changed event, but will a subsequent change lead them to be reminded of being reminded, and then later to being reminded of being reminded of being reminded, with a corresponding depth of recursion in the remembered representation? Hintzman (2004) proposed that recursive reminding could be quite deep, such that it could support frequency judgments in the range (one to three) used in his experiments, however, the depth of recursion may differ for repetitions versus changes.

Jacoby et al. (2001) investigated proactive interference using a training phase during which A-B and A-D pairs were intermixed and presented a large number of times so A-B sometimes followed A-D and vice versa. This training phase occurred prior to the presentation of study lists that were presented to assess effects of proactive interference. The frequent changes in responses paired with a cue during training makes it unlikely that recollection of change could be used to avoid response competition responsible for proactive interference under those conditions. If noticing change results in A-B being embedded in A-D, would representing A-B result in the earlier embedded trace being embedded in memory for the later presentation of A-B, and so forth? There must be some limit to the depth of such recursion. Beyond that limit, one might only recollect that change occurred frequently without being able to recollect the order or even which response was encountered most recently.

When changes in the response paired with a cue are frequent, people's best chance to reduce interference due to response competition may be to constrain retrieval to the targeted context or list, rather than relying on recollection of change as in the current experiments. Jacoby et al. showed that their results were fit well with the assumption that proactive interference is observed only when recollection fails. Jacoby et al. used "recollection" to refer to the process of constraining retrieval. In the current experiments, we use "recollection of change" to refer to remembering a particular content that can aid retrieval of the target. On a broader level, Jacoby et al. and the current results share a common explanation that interference stems from an automatic process of competition that prevails when controlled recollection fails to oppose it.

Given the pivotal role of noticing and recollection of change for transforming potential interference into facilitation, it is important to identify conditions that increase the likelihood of noticing and recollection of change. Repeated presentation of the original pair makes noticing and recollection of change more likely (Wahlheim, 2014; Wahlheim & Jacoby, 2013) as does a test on the responses from the original pairs as compared with representing the original pairs for restudy prior to study of List 2 (Wahlheim, 2015). Negley and Kelley (in preparation) manipulated the probability of noticing change by varying the background against which pairs were presented. Background nature scenes (an eagle in the mountains, a giant wave) were either repeated or changed between the A-B and A-D pairs. When scenes were repeated, change in the pair was more often noticed, change was more often recollected, and cued recall of the more recent pair was improved, compared with when scenes were changed. The finding that noticing of change is more

likely when background is held constant converges with Hintzman and Stern's (1978) finding that judgments of frequency were higher when the test item had been repeated in the same context rather than in varying contexts.

Spontaneous Reminding Versus Directed Noticing

Hintzman (2004, 2011) defines remindings as cases of spontaneous retrieval as does Benjamin and Ross (2010). Berntsen and colleagues (e.g., Berntsen, Staugaard, & Sorenson, 2013) also distinguish between spontaneous retrieval (remindings) and intentional retrieval. Berntsen et al. proposed that spontaneous remindings are particularly sensitive to reinstatement of rich context. Reinstatement of context is important for remindings (Hintzman & Stern, 1978; Negley & Kelley, in preparation), and does seem likely to sometimes give rise to spontaneous reminding. However, match in context is also likely to be important for directed reminding as revealed by the importance of the match between study and test context for intentional use of memory (e.g., Smith & Vela, 2001). It is an empirical question whether spontaneous noticing of repetitions, changes and other relationships differs qualitatively from intentional detection and whether they respond differently to various manipulations.

It is likely that results of the current experiments reflected both spontaneous and intentional reminding. The probability of recollecting between-list changes in the N-back condition was much higher than that in the Within-List Back condition, showing that looking-back instructions brought remindings partially under task control. However, the finding that recollection of between-list changes in the Within-List Back condition was far greater than zero suggests that spontaneous remindings of List 1 responses sometimes occurred during the presentation of List 2. Spontaneous remindings produced by between-list changes would serve as a source of change detection errors for the Within-List Back condition and might also slow correct rejection of between-list changes as having occurred in List 2. Such interference effects have been used as a measure of automaticity (e.g., Anderson, Jacoby, Thomas, & Balota, 2011). It opens the possibility that errors and slowing of correct rejections in looking-back tasks could be used to distinguish spontaneous remindings from those that are directed by instructions. For example, increasing the number of List 1 presentations of an A-B pair might increase the probability of mistakenly accepting between list changes as within list changes, and also slow the rejection of between-list changes in the Within-List looking back condition, showing an effect on spontaneous noticing of change. Even when one attempts to restrict oneself to examining the recent past, one might notice changes from particularly salient original events or find that frequently encountered original events spontaneously come to mind. Failures of looking-back instructions to fully bring reminding under task control are likely to be informative.

Individual Differences in Noticing and Recollection of Change

There are large individual differences in the probability of noticing and recollecting change, and individual differences in change recollection substantially contribute to differences in the probability of recalling changed responses (Jacoby et al., 2013;

Putnam et al., 2014; Wahlheim & Jacoby, 2013). The results produced by the use of the looking-back procedure in the current experiments suggest that individual differences in noticing and recollection of change partly reflect differences in the breadth of attention. That is, people may differ in the extent to which they look back over recent experiences as opposed to focus more narrowly on the current situation (cf. Jacoby, 1974). Similarly, in the misinformation effect, which is a case of retroactive interference that occurs when the misinformation (changed detail) is not detected as such, there are also individual differences. For example, participants who read the misinformation more slowly are more likely to notice the changes, and to then not show disruptive effects of the misinformation on memory for the original event (Tousignant et al., 1986). The slower reading may reflect more looking back to the original event.

Individual differences in looking back are potentially important in a variety of settings. Otero and Kintsch (1992) found that many students failed to detect contradictions between sentences in text but the few who did so showed facilitation of memory for both the original and contradicting sentences, whereas those who did not recalled one or the other of the contradictory sentences or neither. Their findings are similar to ours, and illustrate the general importance of individual differences in noticing and recollection of change. People also differ in the extent to which they compartmentalize prior knowledge and do not integrate it with current learning (e.g., Potts, Keller, & Rooley, 1981). A substantial proportion of people neglect to access general knowledge while doing a linear ordering task with a mix of real-world and novel elements (see also, Hannon & Daneman, 2001). Integration of prior knowledge in a current learning task may rely on noticing relationships and therefore point to the importance of individual differences in looking back in educational settings.

Even when participants are not required to explicitly detect change but, instead, are only instructed to learn List 2, we (Wahlheim & Jacoby, 2013) have found that recollection of change as well as recall of the changed response is high for some participants. Presumably, those participants detected change during the presentation of List 2 even though they were not instructed to do so, which might involve self testing as well as spontaneous noticing of change. Having spontaneously noticed change for one pair, participants might begin to self-test for other pairs, seeking further changes. Comparisons of effects of instructions to learn with those produced by instructions to explicitly detect change holds promise as a means of further examining individual differences in looking back (cf. Jacoby, 1974), as well as a means of further exploring the utility of the contrast between spontaneous and directed noticing of change.

To produce proactive facilitation, detection of change is not sufficient, but in addition, detected change must be recollected. As a consequence, overall proactive facilitation will occur only under conditions that promote recollection of change as well as detection of change. In this vein, detection of change was higher for within-list changes than for between-list changes (Experiments 2 and 3), but overall proactive facilitation was observed only for between-list changes. This outcome was a consequence of recollection of change being substantially higher for between-list changes than for within-list changes. The recollection advantage of between-list changes was interpreted as being an effect of the spacing of the original and changed response. Similarly, it was noted that the

effect of spacing repetitions depends on the detection of repetition, which can be manipulated by means of a looking-back procedure (Wahlheim et al., 2014).

Conclusions

A great deal of research and theorizing has been aimed at the effects of repetition. For example, a huge literature is devoted to recognition memory. Much less has been done to investigate conditions that are important for the noticing and recollection of change. In the current experiments, change was arbitrary in that there was little or no association between the original and changed responses. Even recollection of arbitrary change produced memory facilitation in a situation that could produce interference. In more natural settings, change is typically not arbitrary but causal (cf. Hintzman, 2011), which likely results in even larger effects of noticing and recollection of change.

Often, the first step toward adjustment to changed circumstances is to look back so as to notice and later recollect change. Recollection of change might serve as an important bridge to guide performance in changed circumstances until new automatic influences of memory develop to a level that makes recollection of change no longer needed. Further, it is likely that recollection of change is generally important for proactive facilitation in the form of learning. As an example, suppose one unintentionally changed one's golf swing and so produced a shot that was strikingly superior to that typically produced in similar situations. To incorporate this change into one's standard golf swing, it is seemingly necessary that the change be noticed and subsequently recollected prior to later swings in similar circumstances until the changed swing becomes habitual due to its repetition. Concerns of this sort highlight the importance of further investigating effects of noticing and recollection of change for applied purposes as well as for purposes of theory.

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