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The Role of Reminding in the Effects of Spaced Repetitions on Cued Recall: Sufficient but not Necessary

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Abstract

Three experiments examined the role of study-phase retrieval (reminding) in the effects of spaced repetitions on cued recall. Remindings were brought under task control to evaluate their effects. Participants studied two lists of word pairs containing three item types: single items that appeared once in List 2, within-list repetitions that appeared twice in List 2, and between-list repetitions that appeared once in List 1 and once in List 2. Our primary interest was in performance on between-list repetitions. Detection of between-list repetitions was encouraged in an *n*-back condition by instructing participants to indicate when a presented item was a repetition of any preceding item, including items presented in List 1. In contrast, detection of between-list repetitions was discouraged in a within-list back condition by instructing participants only to indicate repetitions occurring in List 2. Cued recall of between-list repetitions was enhanced when instructions encouraged detection of List 1 presentations. These results accord with those from prior experiments showing a role of study-phase retrieval in effects of spacing repetitions. Past experiments have relied on conditionalized data to draw conclusions, producing the possibility that performance benefits merely reflected effects of item selection. By bringing effects under task control, we avoided that problem. Our results provide evidence that reminding resulting from retrieval of earlier presentations plays a role in the effects of spaced repetitions on cued recall. However, our results also reveal that such retrievals are not necessary to produce an effect of spacing repetitions.

Keywords

cognitive control; reminding; repetition effects; spacing effects; study-phase retrieval

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In the absence of detecting repetitions as being such, repetition has been shown to have no effect on subsequent cued recall. A striking example of this can be seen in experiments conducted by Asch, Rescorla, and Linder, as reported by Asch (1969). In their experiments,

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a single well-learned pair from a first list was repeated in a second list that was presented after a delay. This form of presentation discouraged participants from detecting the repetition of the List 1 pair, and resulted in few participants doing so. At test, participants who did not report having earlier detected the repetition showed no difference in performance between the repeated pair and a pair that appeared only once in List 2. In contrast, participants who reported earlier detecting the repetition showed much higher performance on the repeated pair. When a subsequent group was encouraged to detect the repetition prior to studying List 2, nearly every participant reported having done so and showed a facilitative effect of repetition.

The results reported by Asch (1969) demonstrate that detection of an item as repeated is necessary for memory of later presentations to inherit the memory consequences of earlier presentations. In the present article, we examine whether the retrieval processes involved in detection of repetitions are sufficient and necessary for finding effects of spacing repetitions. Given that the detection of repetition relies on retrieval processes, its role in enhancing memory for repeated items should not be controversial. Indeed, many studies have shown that testing individuals on previously learned information produces memory benefits beyond providing additional study trials (for a review, see Roediger & Karpicke, 2006). Consequently, test trials initiated by participants in the form of retrieving earlier presentations during study should serve a similar function (e.g., Thios & D’Agostino, 1976). We begin with a brief review of the literature showing that detection of repetitions during study plays a role in spacing effects.

Detection of repetitions has been implicated in the effects of spaced repetitions in several studies (e.g., Appleton-Knapp, Bjork, & Wickens, 2005; Benjamin & Tullis, 2010; Braun & Rubin, 1998; Greene, 1989; Raaijmakers, 2003; Thios & D’Agostino, 1976; Verkoeijen, Rikers, & Schmidt, 2005). As an example, Appleton-Knapp et al. provided evidence for the role of detecting repetitions in memory for repeated advertisements. In one experiment, ads were presented in two booklets separated by an intervening task. Some ads were repeated within booklets at shorter spacings (i.e., 0, 2 and 4 intervening ads), whereas other ads were repeated between booklets at longer spacings (i.e., 10 minutes). The relationship between presentations of repetitions was manipulated such that the second presentation of an ad was either an exact repetition or a varied repetition that differed superficially from the first presentation. This was done to influence the extent to which repetitions could be detected, with varied-repetitions being more difficult to detect. Cued recall of exact-repetitions was greater at longer than shorter lags, whereas no benefits of longer lags were observed for varied-repetitions. These results suggest that varied-repetitions were detected less often than exact-repetitions, but detection of repetitions was not directly measured. In a follow-up experiment, participants were interrupted during their study of the second ad in the second booklet and asked whether they had seen an ad for the same product in the first booklet. When the ad was an exact-repetition, nearly all participants detected the repetition. In contrast, when the ad was a varied-repetition, only about half of the participants did so.

The relationship between detection of repetitions and subsequent recall performance was also noted earlier by Melton (1967). His results showed an inverse relationship between detection of repetitions and lag length, along with an increase in recall performance across lags. Importantly, the increase in recall performance was only observed for items that were detected as repetitions (also see Madigan, 1969). In a similar vein, Bjork (1988) pointed out that retrieval practice made more difficult by various means (e.g., delay) results in greater memory enhancement on a later test than when the initial retrieval is less difficult (also see, Whitten & Leonard, 1980). However, a problem for results interpreted as showing that the detection of repetitions contributes to the effects of spaced repetitions is that conclusions are often based on conditionalized data (e.g., Bellezza, Winkler, Andrasik, 1975; Bray & Robbins, 1976; Johnston & Uhl, 1976; Madigan; 1969; Melton, 1967). For example, conditionalizing recall on the detection of repetitions, as was done by Melton (1967), might simply serve to select items that were more easily remembered. This would only show that items for which repetitions were detected during study were easier to remember and, so, were also more likely to be later recalled. Reliance on conditional probabilities does not allow one to choose between the possibility of such item selection effects and the possibility that the difficulty of retrieving an earlier-presented instance is important for producing effects of spaced repetitions.

In contrast to reliance on conditional probabilities, bringing the detection of repetitions under task control allows for the examination of effects of detecting repetitions unconfounded with item differences. With few exceptions (e.g., Braun & Rubin, 1998; Thios & D'Agostino, 1976), prior research has not varied task demands as a means of manipulating study-phase retrieval. In the experiments reported in the current article, we did so by employing a variant of a looking back procedure that was used by Jacoby and Wahlheim (in press) to bring the detection of shared category membership under task control. They varied the distance that participants were told to look back through the study list for exemplars from the same category as currently presented exemplars, and showed the importance of the detection of category relationships for enhancing subsequent recency judgments and cued recall (also see Jacoby, 1974). In the experiments reported in the present article, we brought the detection of repetitions under task control to examine effects of spaced repetitions unconfounded with item differences.

In our experiments, word pairs appeared in two lists separated by an intervening task. Some pairs appeared only once in List 2 (single items), other pairs appeared twice in List 2 (within-list repetitions), and the remaining pairs appeared once in List 1 and once in List 2 (between-list repetitions). Detection of repetitions during List 2 study was brought under task control by varying the distance participants were told to look back through memory for earlier presentations. Participants in an *n*-back condition were told to identify items that had appeared anywhere earlier in the experiment (List 1 or List 2). In contrast, participants in a within-list back condition were told only to identify repetitions occurring earlier in List 2. The *n*-back instructions encouraged detection of all repetitions, whereas the within-list back instructions were meant to restrict detection to List 2 repetitions (see Table 1).

To examine the effects of detecting repetitions on cued recall, we presented within-list repetitions at lags that were shorter than those for between-list repetitions. We expected performance on between-list repetitions to be greater in the *n*-back than the within-list back condition, because the *n*-back instructions encouraged detection of repetitions whose first presentation occurred in List 1, whereas the within-list back instructions did not. Results of this sort would demonstrate that the detection of repetition plays a critical role in the effects of spaced repetitions without relying on conditionalized data. As a second means of showing effects of repetition detection, we made use of conditionalized data, but used multiple regression analyses to separate the contributions of item differences and repetition detection to later cued recall. In earlier work, we employed similar analyses to examine effects of detecting category relationships (Jacoby & Wahlheim, in press) and effects of detecting change between presentations of items (Jacoby, Wahlheim, & Yonelinas, in press; Wahlheim & Jacoby, 2013). Results of those earlier experiments revealed that detection of shared category membership and of change contributed to later memory performance even when item differences were taken into account. We expected the present experiments to reveal a similar contribution of detection of repetitions.

Stimulus sampling theory (Estes, 1955a, 1955b) has been extended to produce a prominent account of effects of spaced repetitions that appeals to advantages of encoding variability (e.g., Melton, 1970). By that account, repetition produces independent traces of a repeated item with each of the traces preserving information regarding the context for the particular occurrence of an item. Increasing the variability of encoding contexts is said to increase the probability of recalling at least one of the presentations of the repeated item. Given the probability of recalling a singly presented item (P1), the independence rule is used to compute the additive effect of the probability of recalling the second presentation (P2) of a repeated item: P(recall of a repeated item) = P1 + P2 – (P1*P2). Just as adding a second independent toss of a coin increases the probability of obtaining at least one head, adding a repetition is said to increase the probability of at least one of the presentations of a repeated item being recalled. For a stimulus sampling theory (SST) account of repetition effects, the additive effects dictated by the independence rule sets the hypothesized maximum effect of repetition that can be observed.

Against SST, performance that is greater than could be produced according to the independence rule (i.e., superadditive effects) have been observed (e.g., Begg & Green, 1988; Waugh, 1963). Benjamin and Tullis (2010) provided results from a meta-analysis to show that increasing the spacing of repetitions increases the probability of finding superadditive effects of repetition. In line with their results, we expected the finding of superadditive effects to depend on the detection of repetitions and being particularly pronounced for between-list repetitions in the *n*-back condition. In its simplest form, SST does not provide a means of accounting for the importance of detection of widely spaced repetitions for the finding of spacing effects. Indeed, detection of repetition, as compared to failure to do so, would be expected to decrease with the independence of traces and, thereby, decrease the probability of later recall.

Following Hintzman (2004, 2010), Benjamin and Tullis (2010) emphasized the importance of remindings (study-phase retrieval) for subsequent memory performance. Hintzman (2004) described reminding of repetitions as resulting from the retrieval of a first presentation at the time of its second presentation, and as producing a recursive trace that embedded memory for the first presentation in that of the second. He hypothesized a role for remindings in the effects of repetitions on judgments of frequency and recency. Benjamin and Tullis (2010) suggested that remindings play a critical role in effects of spaced repetitions on a variety of memory measures, most notably cued recall, and presented a model similar to the MINERVA 2 model (e.g., Hintzman, 1984) to show that such models can account for findings of superadditivity being dependent on the spacing of repetitions.

Hintzman's (1984) MINERVA 2 model postulates independent traces just as does SST, but the means by which the independent traces contribute to memory performance is very different for the two types of models. By the MINERVA 2 model, secondary memory is described as a vast collection of episodic memory traces, most of which were formed outside of the experimental context. Memory is addressed by means of a retrieval cue that includes contextual information that dictates the set of episodic memories that is activated. Traces within that set are activated in parallel with the contribution of each trace depending on its similarity to the probe. The result is a composite echo strength emanating back from secondary memory that is said to serve as a basis for responding. Correct responding is determined by the extent to which the echo strength emanating from the target exceeds that emanating from nontargets. In contrast to SST, the additive effects of repetition described by MINERVA 2 are not dictated by the independence rule. Rather, repetition serves to produce multiple traces of a target with echo strength being increased to the extent that the multiple traces are activated. Stated simply, the MINVERA 2 model does not subtract out the intersection (P1*P2) as dictated by the independence rule employed by SST but, instead, treats the joint activation of traces created by repetition as being important for repetition effects. Consequently, MINERVA 2 can accommodate superadditive effects of repetition although such effects are neither predicted nor given any special status.

Hintzman (2004) noted that the MINERVA 2 model as well as other global memory models (Murdock, Smith & Bai, 2001; Shiffrin, 2003) predict that judgments of frequency and recognition memory judgments have a common strength-like basis. Against that prediction, he showed that manipulations of presentation frequency and presentation duration had differential effects on judgments of frequency and recognition confidence. To account for those differences, Hintzman argued that later presentations of an item result in remindings of earlier presentations and serve to produce a recursive representation that can serve as a basis for frequency judgments. Further, he suggested that remindings also play a role in effects of spaced repetitions. Similarly, Benjamin and Tullis (2010) incorporated the notion of remindings into their model designed to account for spacing effects.

Do remindings contribute to repetitions effects? To anticipate, our results show that remindings that occur during the presentation of List 2 contribute to an advantage in subsequent cued recall for between-list as compared to within-list repetitions. However, across experiments, we show that remindings occurring during the presentation of List 2 are not *necessary* to produce that result. Rather, detecting between-list repetitions for the first time at test can also result in a cued recall advantage of between-list over within-list repetitions. Further, similar to results reported by Asch (1969) that were described to begin this article, we show that repetitions that were not detected as such hold no advantage over items that were singly presented.

Experiment 1

Method

Participants—Forty-eight Washington University students participated in exchange for course credit or $10 per hour. Twenty-four participants were randomly assigned to each looking back condition. They were tested in groups of one to three people.

Design and Materials—A 2(Looking Back: *n*-back vs. within-list back) X 3(Item Type: single vs. within-list repetitions vs. between-list repetitions) mixed design was used. List 2 instructions were manipulated between subjects and item type was manipulated within subjects.

Materials consisted of 121 weakly associated word pairs (60 critical, 40 fillers, and 21 buffers to prevent primacy and recency effects). The 60 critical pairs were divided into three sets of 20 pairs. Pairs in each set, including buffers and fillers, were equated on length and frequency (Balota et al., 2007). Pairs were considered weakly associated because many shared features (e.g., lady - queen) or could be combined to form a sentence or image (e.g., market - shelf). However, the normative forward and backward associative strengths were quite low ($M < .01$) according to Nelson, McEvoy, and Schreiber (1998).

List 1 contained 20 critical pairs and 6 buffers (3 primacy, 3 recency) that were the first presentations of between-list repetitions, along with 40 fillers and 6 buffers (3 primacy, 3 recency) that only appeared in List 1 (72 total presentations). List 2 consisted of buffers and critical pairs from each item type including: single items (4 buffers, 20 critical; 24 total presentations), the first and second presentations of within-list repetitions (5 buffers X 2 and 20 critical X 2; 50 total presentations), and the second presentations of between-list repetitions (6 buffers, 20 critical; 26 total presentations), for a total of 100 presentations. Buffers in List 2 were distributed such that there were 8 presentations in the primacy portion of the list, 6 in the recency portion, and 6 intermixed as fillers within the list.

Within-list repetitions occurred at an average lag of 12.70 intervening items (*Range* = 10–15, $SD = .86$), and between-list repetitions occurred at an average lag of 87.15 intervening items (*Range* = 62–104, $SD = 12.72$). The average serial positions of single items and the second presentation of within- and between-list repetitions were equated, as were the positions of the corresponding item types at test. Thus, there were no differences in retention intervals across item types. Item sets occurred equally often in each within-subject condition, resulting in three experimental formats. Buffers and fillers remained constant across formats.

Procedure—There were four phases in the experiment: List 1, an intervening task, List 2, and a cued recall test. In List 1, pairs appeared in a fixed random order with the restriction that none from the same condition appeared more than three times consecutively. The presentation duration was 5 s per pair, and each presentation was followed by a 500 ms interstimulus interval (ISI). Participants were told to study the pairs for an upcoming memory test.

Following List 1 and prior to List 2, participants were given a five minute intervening task. They were told to write down what they would do if they were invisible and were not responsible for their actions. We chose this task because it has been shown to create different contexts for individual lists (cf. Sahakyan & Kelley, 2002). It was important for adherence to the within-list back instructions that the list contexts be differentiated.

In List 2, the task differed depending on the looking back instructions (see Table 1). In the *n*-back condition, the task was to detect repetitions of pairs that appeared at any point earlier in the experiment, including List 1 (between-list repetitions) and List 2 (within-list repetitions). In contrast, in the within-list back condition, the task was to detect repetitions of pairs only from List 2 (within-list repetitions). Pairs appeared in a fixed random order with the same restrictions as in List 1. Pairs appeared for 5 s each above boxes labeled “yes” and “no” that corresponded to detection judgments. Participants were told to click on their response within 5 s, and to use the time remaining to study pairs for an upcoming test. When responses were not made before 5 s, the program advanced to the next pair. This happened on approximately 1% of the items. Pairs were followed by a 500 ms ISI.

On the cued recall test, the left-hand members of each critical pair appeared individually, and participants were told to type the earlier-presented right member onto the screen. Participants were encouraged to guess when they could not think of the response, but they were also allowed to pass. A practice phase with 6 buffers (3 of each item type) was given prior to the final test of 60 critical items. Test cues appeared in a fixed random order with the same restrictions as Lists 1 and 2.

Results and Discussion

In the following experiments, the level for significant effects was set at alpha < .05. Variations in degrees of freedom for conditional analyses are due to the exclusion of participants who did not have at least one observation in each cell.

Detection of Repetitions—Participants made their List 2 detection of repetition judgments for within- and between-list repetitions in accord with instructions (Table 2) as revealed by a significant Looking Back X Item Type interaction, $F(1, 46) = 134.97$, $p < .001$, $\eta_p^2 = .75$. Detection of within-list repetitions was near perfect and did not differ between conditions, $t(46) = .92$, $p = .36$. Between-list repetitions were more often correctly detected in the *n*-back condition than incorrectly detected in the within-list back condition, $t(46) = 11.77$, $p < .001$. These results provide evidence that the looking back instructions were effective in eliciting better detection of between-list repetitions in the *n*-back than within-list back condition. False alarms to single items were greater for the *n*-back than within-list back condition, $t(46) = 3.08$, $p = .004$. This result may have been produced by a bias to say “yes” more often in the *n*-back condition, as would be expected because of the greater number of “yes” responses required by that condition. Also, the *n*-back instructions created a functionally longer list which could result in an increase in false alarms.

Cued Recall—As suggested by earlier studies, repetition benefits in cued recall depended on the detection of repetitions (Table 3) as indicated by a significant Looking Back X Item Type interaction, $F(2, 92) = 6.10$, $\eta_p^2 = .12$. Performance in both looking back conditions was greater for within-list repetitions than for single items, and greater for between- than within-list repetitions, *t*s(23) ≥ 3.02, *p*s ≤ .01. Most important, performance on between-list repetitions was greater in the *n*-back condition than the within-list back condition (.46 vs. .33), $t(46) = 2.17$, $p = .04$. Consistent with the repetition detection results, these results show that differences in subsequent cued-recall performance for between-list repetitions were created by differences in the retrieval of List 1 items (remindings) during the presentation of List 2. Importantly, this conclusion is based on unconditional data and, so, eliminates the possibility of item selection effects. It is also important to note that the cued recall results showing greater performance for between-list repetitions in the *n*-back condition are incompatible with SST. SST does not provide a means of accounting for beneficial effects of detecting repetitions (remindings).

We further assessed the adequacy of SST by comparing performance on repeated items to the probability of recalling at least one of two single items (i.e., the independence rule). The adequacy of the independence rule was examined using the standard $2P\text{-}P^2$ equation (e.g., Ross & Landauer, 1978) with P referring to the probability of cued recall for single items in each respective looking back condition. Consistent with results reported by Benjamin and Tullis (2010), superadditivity was found for between-list repetitions in both looking back conditions and, showing the importance of detection of repetitions, was greater for the *n*-back than the within-list back condition. Superadditivity was significant in the *n*-back condition (.46 vs. .28), $t(23) = 4.74$, $p < .001$, and was marginally significant in the within-list back condition (.33 vs. .27), $t(23) = 1.96$, $p = .06$. Cued recall for within-list repetitions did not exceed the level of performance predicted by the independence rule in the *n*-back (.27 vs. .28) or within-list back (.27 vs. .27) condition, *t*s(23) < 1. Consistent with results from the meta-analysis reported by Benjamin and Tullis, superadditivity was found only at longer spacings.

Cued Recall Conditionalized on Detection of Repetitions—Converging evidence for the role of repetition detection in cued recall was found by examining cued-recall performance for between-list repetitions conditionalized on repetition detection in the *n*-back condition. Note that conditional analyses are not reported for within-list repetitions because detection of those repetitions was near perfect. Conditionalized analyses for between-list repetitions in the within-list back condition are not reported because following instructions should have led participants to respond “no” to between-list repetitions in that condition. Results from the *n*-back condition showed that performance was much higher when repetitions were detected than when they were not (.53 vs. .16), $t(20) = 5.83$, $p < .001$. Further, performance on undetected between-list repetitions did not differ from single items (.16 vs. .15), $t(20) = .32$, $p = .75$, similar to earlier findings reported by Asch (1969).

Item Effects—The unconditional cued recall results provide compelling evidence that repetition detection plays an important role in the production of repetition benefits. However, it is still possible that item selection effects made some contribution to conditionalized results. To investigate this possibility, we examined the extent to which detection of between-list repetitions in the *n*-back condition predicted recall performance on those items when controlling for item differences. We used hierarchical multiple regression with items as the unit of analysis. Item differences were indexed as performance on single items. Doing so was justified since items appeared equally often as both single items and as between-list repetitions across participants. Item differences were entered as a predictor on the first step of the model. Repetition detection was indexed as the probability of "yes" responses for between-list repetitions in List 2 and was entered on the second step. The interaction between item differences and repetition detection was entered on the third step. Cued recall of between-list repetitions was the criterion variable.

The top panel of Table 4 shows that item differences did explain a significant proportion of variance in cued recall. However, repetition detection significantly contributed to cued recall when item differences were controlled. The interaction did not improve prediction. In agreement with unconditionalized results gained by means of manipulating task control, results of the hierarchical multiple regression analysis show that effects of detecting repetitions on subsequent memory performance does not merely reflect item differences.

Summary—The results from Experiment 1 showed that the manipulation of looking-back instructions was successful in producing task control over the detection of repetitions, and also showed that the detection of between-list repetitions was important for subsequent cued-recall performance. Cued-recall performance was higher for between-list repetitions in the *n*-back condition than in the within-list back condition. However, surprisingly, even the within-list back condition showed an advantage in subsequent cued-recall performance for between-list repetitions over within-list repetitions. One possible interpretation of that result is that the within-list back task did not fully eliminate the detection of between-list repetitions during the presentation of List 2. Perhaps the false alarms in repetition detection in the within-list back condition reflected mistaken acceptance of between-list repetitions as being within-list repetitions. In addition, participants in the within-list back condition might have correctly detected some between-list repetitions and responded "no" to those items. A second possibility is that detection of repetitions during the presentation of List 2 was not necessary for finding an advantage of between-list over within-list repetitions. As will be seen, the results from Experiment 2 weigh on a choice between these two alternatives.

Experiment 2

Results from Experiment 1 showed the importance of detecting between-list repetitions for subsequent cued-recall performance. Presumably, remindings involved in the detection of repetitions resulted in a recursive representation that was subsequently employed to enhance cued-recall performance. However, for a recursive representation formed by reminding to enhance later performance, that representation must be recollected at the time of test. Experiment 2 was designed to examine the effect of looking back instructions on recollection of remindings. The procedure for Experiment 2 was the same as for Experiment 1 except that at the time of test, following cued recall for each pair, participants were instructed to judge whether or not the pair was repeated during study. This measure of recollection of remindings was expected to show that remindings occurred more often for between-list repetitions during the presentation of List 2 in the *n*-back condition as compared to the within-list back condition. Further, for reasons described next, we expected remindings for between-list repetitions to be more likely to be recollected than those for within-list repetitions.

Our measure of recollection of remindings, asking participants whether pairs were repeated, corresponds to a frequency judgment. Effects of spaced repetitions have been found for frequency judgments (e.g., Hintzman, 1969; Madigan, 1969). Madigan (1969, Experiment 1) examined the relationship between frequency judgments and free recall performance by manipulating the spacing of repetitions and requiring participants to judge whether each item that they recalled was presented twice or only once during study. Effects of spaced repetitions on frequency judgments paralleled effects on free recall. Similarly, we expected spacing effects on cued recall to parallel effects on our measure of recollection of remindings. That is, although within-list repetitions were expected to be more likely to be detected than between-list repetitions during study, as found in Experiment 1, between-list repetitions were expected to be more likely to be recollected at the time of test. This predicted pattern of results is the same as the inverse relationship between ease of recognition memory during study and subsequent recall performance that is generally found (e.g., Melton, 1967). A finding of parallel effects of spacing of repetitions would suggest that recollection of recursive remindings serves as a basis for responding that is common to frequency judgments and cued recall.

Method

Participants—Forty-eight Washington University students participated in exchange for course credit or $10 per hour. Twenty-four participants were randomly assigned to each looking back condition. They were tested individually.

Design, Materials, and Procedure—The design, materials, and procedure were identical to Experiment 1 with the exception that at test, participants judged whether pairs were repeated at any point earlier in the experiment. After participants typed their cued recall responses, boxes labeled “yes” and “no” appeared. They were told to click “yes” for pairs repeated during study and “no” for non-repeated pairs. Repeated pairs included within- and between-list repetitions.

Results and Discussion

Detection of Repetitions—Replicating Experiment 1, participants made their judgments in accord with instructions (Table 2) as indicated by a significant Looking Back X Item Type interaction, $F(1, 46) = 56.46$, $p < .001$, $\eta_p^2 = .55$. Between-list repetitions were more often correctly detected in the *n*-back condition than incorrectly given a “yes” response in the within-list back condition, $t(46) = 8.42$, $p < .001$. False alarms to single items were greater for the *n*-back than within-list back condition, $t(46) = 2.69$, $p = .01$, again resulting from a bias to say “yes” more often in the *n*-back condition and, perhaps, the functionally greater list length in the *n*-back condition.

Cued Recall—As shown in Table 3, the pattern of cued-recall performance was consistent with that shown in Experiment 1. Performance was greater for within-list repetitions than for single items, and greater for between- than within-list repetitions in both looking back conditions, *t*s(23) ≥ 3.23, *p*s ≤ .01. Performance tended to be higher for between-list repetitions in the *n*-back than within-list back condition, even though the Looking Back X Item Type interaction was not significant, $F(2, 92) = 1.56$, $p = .22$, $\eta_p^2 = .03$. Performance on between-list repetitions was numerically greater in the *n*-back than within-list back condition (.55 vs. .45), $t(46) = 1.35$, $p = .19$, and although the difference was not statistically significant, the effect was nearly as large as in Experiment 1. The lack of significance may have been simply due to insufficient power of the experiment.

It should be noted that the major difference in cued-recall performance between Experiments 1 and 2 is that for the within-list back condition, the cued-recall advantage of between-list repetitions over within-list repetitions was larger in Experiment 2 than in Experiment 1. A potential account of this difference is that requiring participants in Experiment 2 to judge whether items had been repeated in the experiment as a whole resulted in their being more likely to look back to List 2 and, so, detect repetitions for the first time at test. As described later, results from the measure of recollection of repetitions suggest that this was the case.

Cued recall of between-list repetitions exceeded the independence baseline in the *n*-back (.55 vs. .37) and within-list back (.45 vs. .30) conditions, $F(1, 46) = 29.10$, $p < .001$, $\eta_p^2 = .39$. Unlike Experiment 1, the level of superadditivity did not differ between looking back conditions, which might reflect the influence of participants in the within-list back condition being more likely to detect repetitions for the first time at test in Experiment 2 than in Experiment 1. Cued recall for within-list repetitions did not differ from the independence baseline in the *n*-back (.34 vs. .37) or within-list back condition (.33 vs. .30), $F < 1$, replicating the results of Experiment 1. Again, these results agree with results from the meta-analysis done by Benjamin and Tullis (2010) by showing that finding superadditivity depends on the spacing of repetitions.

Cued Recall Conditionalized on Detection of Repetitions—Replicating Experiment 1, cued recall of between-list repetitions was much higher in the *n*-back condition when repetitions were detected during the presentation of List 2 than when they were not (.58 vs. .22), $t(20) = 4.71$, $p < .001$, and there was not a significant difference between undetected between-list repetitions and single items (.22 vs. .19), $t(20) = .61$, $p = .55$. As noted in Experiment 1, these results suggest that undetected between-list repetitions acted as single items, but there is still the possibility of item selection effects. Nonetheless, it is striking that these results replicated so closely across experiments and parallel those reported by Asch (1969).

Repetition Recollection—Participants more often recollected between-list repetitions in the *n*-back condition that were earlier detected during List 2 than those that were not (.70 vs. .31), $t(20) = 5.66$, $p < .001$. Further, results from the repetition recollection measure (Table 5) show that between-list repetitions were recollected more often in the *n*-back than within-list back condition, $t(46) = 2.56$, $p = .01$, providing additional evidence that recollection of repetitions reflected their prior detection. For the *n*-back condition, the probability of recollecting between-list repetitions was higher than that of recollecting within-list repetitions, $t(23) = 2.82$, $p = .01$. This was true although as shown in Table 2, the probability of detecting repetitions was much higher for within-list than for between-list repetitions (.94 vs. .74), $t(23) = 6.48$, $p < .001$. This finding of opposite effects of spacing for detection and recollection of repetitions was expected due to prior findings of spacing effects on frequency judgments (e.g., Hintzman, 1969; Madigan, 1969). Further, comparisons of results in Table 2 with those in Table 5 for the *n*-back condition reveal a large drop between the probability of detection of repetitions and that of recollection of repetitions for within-list repetitions (.94 to.52) but a smaller drop (.74 vs. .62) for between-list repetitions, $F(1, 23) = 42.94$, $p < .001$, $\eta_p^2 = .65$.

Examining results for the within-list back condition in Table 5 suggests that the repetition recollection measure reflected repetitions that were detected for the first time at test as well as recollection of repetitions that were detected during study. The probability of "recollecting" between-list repetitions was much higher (.51) than would be expected if the repetition recollection measure reflected only recollection of repetitions that were detected during List 2. Indeed, the probability of "recollecting" between list repetitions in the within-list back condition was as high as that of recollecting within-list repetitions. To produce these results, it seems likely that between-list repetitions were sometimes detected for the first time at test in the within-list back condition. We explored this possibility further in Experiment 3.

As shown in Table 5, single items were more often mistakenly identified as repetitions for the *n*-back than the within-list back condition, $t(46) = 2.15$, $p = .04$. A concern raised by that result is that differences in recollection of between-list repetitions between conditions might have been due to bias effects, instead of because of true differences in the probability of correctly identifying items as having been repeated across the experiment as a whole at the time of test. However, the lack of difference in recollection of within-list repetitions for the looking back conditions eliminates that concern. Likely, the higher false recollection of repetitions for single items in the *n*-back condition reflected the higher probability of participants in that condition incorrectly identifying single items as being repetitions during the presentation of List 2.

Cued Recall Conditionalized on the Recollection of Repetitions—The results shown in Table 6 are collapsed across looking back conditions because the interaction between Looking Back condition and Item Type was not significant, $F(2, 82) = .84$, $p = .44$, $\eta_p^2 = .02$. Results revealed a significant Repetition Recollection X Item Type interaction, $F(2, 84) = 40.65$, $p < .001$, $\eta_p^2 = .49$, showing that the probability of cued recall was much higher for items that were identified at test as having been repeated during study than for those that were said to have occurred only once. That advantage was greater for between-list repetitions than for within-list repetitions. When repetitions were not identified as such, the probability of recall did not differ from or was less than that of singly presented items, *largest* $t(46) = 1.05$, $p = .30$, again producing results similar to those reported by Asch (1969).

Item Effects—As in Experiment 1, we examined the contribution of repetition detection to cued-recall performance on between-list repetitions in the *n*-back condition using hierarchical multiple regression analysis including as predictors: item differences on the first step, repetition detection on the second step, and their interaction on the third step. The results in Table 4 show that item differences explained a significant proportion of variance, but the detection of repetitions improved prediction when item differences were controlled. The interaction did not improve prediction.

Next, we examined the contribution of item differences, repetition recollection, and their interaction to cued recall of between-list repetitions (Table 7). This model differed from the previous model in that data were included from both the *n*-back and within-list back condition, because repetition recollection responses were unambiguous. The probability of recollecting repetitions at test was entered on the second step. The top panel of Table 7 shows that repetition recollection improved prediction beyond item differences, and the interaction term did not improve prediction.

As in Experiment 1, variance in cued recall of between-list repetitions in the *n*-back condition could not be fully explained by item selection effects. However, the results from Experiment 2 were more convincing because these results were shown both in a model that included data from the repetition detection measure (Table 4) and in a model that included data from the repetition recollection measure (Table 7). These results show that item selection effects could not completely explain the enhancement of cued-recall performance resulting from the detection and recollection of repetitions.

Experiment 3

The results from Experiment 2 revealed parallel effects of spaced repetitions on recollection of repetitions (i.e., frequency judgments) and cued-recall performance. Detection of repetition during List 2 resulted in a recursive trace that could be later accessed and serve as a basis for recollection of repetition at the time of test. In addition, the pattern of results suggests that repetitions were sometimes first detected at the time of test. Asking participants in the within-list back condition to judge whether or not an item was repeated apparently encouraged them to look back across both List 1 and List 2 to detect repetitions at test, and doing so enhanced cued-recall performance.

Experiment 3 was done to provide further evidence of the importance of the cognitive control of retrieval processes at the time of test for finding effects of spaced repetitions. The general procedure of Experiment 3 was the same as that in the earlier experiments. Two lists of pairs were presented for study with pairs being repeated either between lists or within List 2. However, looking back instructions were not manipulated. Rather, groups differed only with regard to their treatment at the time of test. For a “measure present” condition, participants were instructed to follow cued recall with a judgment of whether or not the tested pair was repeated across the experiment as a whole just as done in Experiment 2, whereas for a “measure absent” condition participants were not asked to judge whether the tested pair was repeated. We expected that the task of imagining what one would do if one were invisible that intervened between presentation of List 1 and List 2 would be sufficient to discourage the detection of between-list repetitions during the presentation of List 2. Consequently, we predicted that cued recall for pairs repeated between lists would show greater benefits of repetition in the “measure present” than “measure absent” condition. That finding would provide strong evidence that detecting repetitions at the time of test was important for cued-recall performance just as was access to recursive traces that resulted in remindings during the presentation of List 2.

Further, we predicted that there would be an effect of spaced repetitions in the "measure present" condition with cued-recall of between-list repetitions producing higher cued recall than within-list repetitions. In contrast, between-list repetitions were not expected to hold an advantage over within-list repetitions in the "measure absent" condition. A common interpretation of spacing effects is to argue that subsequent memory performance reflects the difficulty of retrieving the earlier presentation of an item during its repeated presentation, with difficult retrievals contributing more to later memory performance than do easier ones (e.g., Benjamin & Tullis, 2010; Bjork, 1988). However, a finding that between-list repetitions hold an advantage in cued recall over within-list repetitions in the "measure present" condition but not in the "measure absent" condition could not be explained as due to differences retrieval difficulty. Rather, it would be necessary to conclude that a beneficial effect of spacing repetitions can be produced by means of manipulating retrieval orientation to encourage looking back at the time of test.

Method

Participants—Forty-eight Washington University students participated in exchange for course credit or $10 per hour. Twenty-four participants were randomly assigned to the repetition recollection conditions. They were tested individually.

Design, Materials, and Procedure—The design, materials, and procedure were identical to Experiment 2 with the following exceptions. We used a 2(Repetition Recollection Measure: Present vs. Absent) X 3(Item Type: Single vs. Within-list repetitions vs. Between-list repetitions) mixed design, with the repetition recollection measure being manipulated between subjects, and item type being manipulated within subjects. Participants were only told to read the List 2 pairs aloud and to study them for an upcoming test.

Cued Recall—Table 3 shows that including the repetition recollection measure at test increased performance for between-list repetitions, as indicated by a significant Repetition Recollection Measure X Item Type interaction, $F(2, 92) = 5.12$, $p = .008$, $\eta_p^2 = .10$. When the repetition recollection measure was present, cued recall was better for within-list repetitions than single items, and better for between- than within-list repetitions, $ts(23) \geq 2.32$, $ps \leq .03$. In contrast, when the repetition recollection measure was absent, cued recall was better for within-list repetitions than single items, $t(23) = 4.68$, $p < .001$, but numerically lower for between- than within-list repetitions, $t(23) = 1.07$, $p = .30$. These results provide strong evidence that inclusion of the repetition recollection measure increased performance for between-list repetitions in the *n*-back condition by encouraging noticing of repetitions at test.

We again found superadditivity for between-list repetitions, but only when the repetition recollection measure was present, $F(1, 46) = 6.40$, $p = .015$, $\eta_p^2 = .12$. Cued recall of between-list repetitions exceeded the independence baseline when the repetition recollection measure was present (.40 vs. .30), $t(23) = 2.56$, $p = .02$, but not when it was absent (.33 vs. .

36), $t < 1$. In addition, cued recall of within-list repetitions did not differ from the independence baseline when the repetition recollection measure was present (.32 vs. .30), nor when it was absent (.36 vs. .36), $F < 1$. These results join earlier results in showing that the finding of superadditivity is more likely at longer spacings.

Identification of Repetitions—Consistent with the *n*-back condition in Experiment 2, Table 5 shows that identification of repeated pairs was better for between- than within-list repetitions. Also, within-list repetitions were correctly identified more often than single items were incorrectly identified as repetitions, *t*s(23) ≥ 2.09, *p*s < .05. It is informative that correct identification of between-list repetitions was only a little higher in Experiment 3 than repetition recollection in Experiment 2 (.54 vs. 51). This suggests that requiring participants in Experiment 2 to engage in the within-list back task did little more to discourage the detection of between-list repetitions during List 2 than did differentiating List 1 and List 2 by means of the task of imagining what one would do if one were invisible.

Cued Recall Conditionalized on Identification of Repetitions—Also replicating Experiment 2, the bottom panel of Table 6 shows that cued recall benefitted more from repetition when repetitions were correctly identified than when they were not, $F(2, 44) = 13.72$, $p < .001$, $\eta_p^2 = .38$. These results provide evidence that identification of repetitions at the time of test is important for cued-recall performance just as are remindings that result from the detection of repetitions during study. Also, similar to results from Experiment 2, repetitions that were not identified as such produced a level of cued-recall performance that was not different from or less than that produced by single items, *largest* $t(23) = 1.59$, $p = .13$. Again, this result is similar to that reported by Asch (1969).

Item Effects—As in Experiment 2, the top panel of Table 7 shows that cued recall of between-list repetitions could not be fully explained by item selection effects. Using the same regression analysis as in Experiment 2 that included both looking back conditions and items as the unit of analysis, we found that item differences predicted cued recall, but repetition identification (recollection) improved prediction when controlling for item differences. The interaction did not improve prediction further. However, it should be noted that item differences could not be responsible for differences in cued-recall performance produced by the presence vs. absence of the measure of repetition identification. The study lists were the same for the two conditions, and conclusions did not rely on conditionalized data. Only the conclusion that repetitions that were not identified as such at the time of test did not enhance performance beyond that produced by single items relied on results gained by conditionalizing data.

Summary—The results of Experiment 3 are similar to those reported by Asch in showing that repetitions of a pair do not inherit the memory consequences of earlier presentations of the pair in the absence of the detection of repetitions at the time of test. As discussed in the next section, the finding that a manipulation of instructions at the time of test can influence the effect of spacing of repetitions is important for theory.

General Discussion

Results from the present experiments provide strong evidence that repetition effects can be enhanced by the detection and recollection of repetitions. Manipulating instructions to encourage looking back to List 1 during the presentation of List 2 (Experiments 1 and 2) encouraged the detection of between-list repetitions and enhanced their subsequent recall. This result shows that effects of within-list retrieval (remindings) were important for cued-recall performance without relying on conditionalized data, and, thereby, avoids the possibility that item differences fully accounted for the results. Further evidence that item differences were not responsible for effects of remindings on cued-recall performance was gained by means of hierarchical multiple regression analyses.

Results from Experiment 2 revealed that spacing effects on cued-recall performance paralleled those on recollection that an item had been repeated (frequency judgments). In the *n*-back condition, later recollection that an item had been repeated was greater for between-list repetitions than for within-list repetitions as was cued-recall performance. Analyses that conditionalized cued-recall performance on recollection of remindings revealed that performance was much higher when pairs were detected as repeated than when they were not, a pattern of results that is similar to that reported by Madigan (1969). Results from the within-list back condition in Experiment 2 suggested that repetitions were sometimes first detected at test, and that doing so was encouraged by asking participants to judge whether or not pairs had been repeated across the experiment as a whole. Results from Experiment 3 provided strong support for that conclusion. Further, results from Experiment 3 provided evidence that detecting between-list repetitions for the first time at test produced a cued recall advantage for between-list repetitions over within-list repetitions just as did detecting between-list repetitions when studying List 2. Similar to results reported by Asch (1969) each of the experiments showed that when pairs were not detected as being repeated, cued-recall performance did not differ from that produced by pairs presented singly.

In line with results from the meta-analysis reported by Benjamin and Tullis (2010), superadditivity of repetition effects was nearly always found for between-list repetitions. The only exception was that superadditivity was not found for the “measure absent” condition in Experiment 3, a condition that did not encourage the detection of between-list repetitions. Findings of superadditivity give reason to reject stimulus sampling theory (SST) in its simplest form as a general account of spacing effects (e.g., Benjamin & Tullis, 2010). However, the emphasis on the importance of encoding variability that motivated SST can be retained. As described in the Introduction, superadditive effects of repetition can be accommodated by not adopting the independence rule held by SST but, instead, holding that multiple traces produced by repetitions jointly contribute to repetition effects as assumed by Hintzman’s MINERVA 2 model (e.g., Hintzman, 1984). An account that is similar to that model but that emphasizes the importance of encoding variability can be used to accommodate for results from our experiments.

We argue that recursive remindings contribute to frequency judgments and cued-recall performance, because the two have the common basis of relying on the integration of multiple traces with, to varying degrees, the integration preserving the individuality of the traces. Retrieval of the subjective experience of earlier detecting that an item was repeated along with the difficulty of the retrieval of earlier presentations that is responsible for remindings may contribute to later cued-recall performance. However, to more fully account for the role played by recursive remindings in repetition effects further knowledge is needed regarding what is preserved about an earlier presentation of an item in the recursive representation that results from reminding. Results reported by Hintzman (2004, 2010) provide evidence that recursive representations preserve information about the frequency and the recency of the presentations of repeated items. However, it is not known what other details regarding the earlier presentation of an item are preserved. For example, suppose that the first and second presentation of an item were presented in different typescripts. It does not seem that it would be necessary for the recursive trace to preserve information about the difference in typescript to produce the results observed in the experiments reported here, but it might sometimes do so.

Our account of the role that recursive remindings play in producing the effects of spacing of repetitions differs from earlier accounts. Hintzman (2004) suggested that recursive remindings are important in producing the effects of spaced repetitions because they result in the retrieval of a prior presentation of an item when the item is not held in working memory, as it is when repetitions are massed. However, this account does not explain our results. The spacing for both within-list and between-list repetitions were well beyond the limit of working memory but an advantage of between-list repetitions was found. Benjamin and Tullis (2010) suggested that the difficulty of retrieval required for producing recursive reminding for spaced repetitions results in a more "potent" trace. In contrast, we seek to understand why that should be the case, and believe that doing so requires additional knowledge regarding the contents of the recursive representation that is created by remindings along with details regarding the nature of the integration process that results in creation of a recursive representation.

A variant of the MINERVA 2 model can be used to account for the importance of retrieval orientation in the form of looking back that is adopted at test. The finding that cued recall of between-list repetitions was higher in Experiment 3 for the condition that was asked to judge whether words were repeated than for the condition that was not asked to make that judgment can be explained by appealing to differences in looking back across lists at the time of test. The requirement to judge whether pairs were repeated in the experiment as a whole resulted in participants in the "measure present" condition being more likely to look back across lists than were those in the "measure absent" condition. For repetition to enhance cued-recall performance, the traces formed by repetition must be jointly activated, which was more likely for those in the "measure present" condition. In this vein, had we tested a condition that was asked whether a pair was repeated in List 2, rather than being asked whether a pair was repeated across the experiment as a whole, we would have likely found a reduction in recall for between-list repetitions. Perhaps, the level of cued recall for between-list repetitions would be even lower than that found for the "measure absent" condition.

A more difficult question is: Why was cued recall of between-list repetitions that were detected for the first time at test higher than that for within-list repetitions? One possibility is that when jointly activated traces resulting from repetitions were integrated at test, the benefits of the integration were greater when the redundancy of the information represented in the traces was reduced by the greater variability in the individual traces that resulted from the spacing of repetitions. This argument is similar to the encoding variability argument made by SST but implicates the importance of lack of redundancy in the content of multiple traces, including aspects of meaning, as well as changes in context. Further, it can be argued that the integration of the traces preserves their individual attributes and gives rise to awareness of the repetitions. Doing so differs from the MINERVA 2 model that holds that only a composite echo strength results from interrogating memory.

Given the arguments made to explain the effects of spacing repetitions that are detected for the first time at test, it might be thought that there is nothing special about recursive remindings that occur during study. However, the recursive representation produced by remindings during study preserves information gained from the integration of traces along with the subjective experience accompanying that integration. This is important because traces produced by repetition may not be simultaneously activated at the time of test when a long delay intervenes between study and test, with the result that repetitions are not detected at the time of test. When this is the case, recollection of remindings provides a means of accessing the earlier integration of the traces along with the earlier subjective experience of repetition. As an example, suppose that one tested conditions such as the *n*-back condition used in Experiments 1 and 2 and the “measure present” condition employed in Experiment 3 but delayed the test by several hours. We would predict that the drop across delay in identification of between-list repetitions and cued-recall performance would be greater for the “measure present” condition, for which the detection of between-list repetitions during study was not encouraged, than for the *n*-back condition that encouraged the detection of between-list repetitions during study. This is because the long delay would make it less likely that participants could successfully look back across lists to detect repetitions for the first time at test in the “measure present” condition. The loss of that ability would be less important for participants in the *n*-back condition because they would be better able to rely on recollection of remindings as a basis for responding.

Positing a role for reminding in repetition effects has implications for learning strategies suggested to be useful in applied settings such as education. Research has shown that the majority of undergraduates use rereading to prepare for exams (Karpicke, Butler, & Roediger, 2009), but rereading does not always improve performance beyond reading just once (e.g., Callender & McDaniel, 2009). It is possible that for rereading to improve performance, reminding of earlier reading must occur. This reminding is a form of self-testing, and testing has been shown to enhance performance in educational contexts (for a review, see Roediger & Karpicke, 2006). How does testing enhance performance? The answer to that question is likely to have much in common with the answer to the question of how spacing of repetitions has its effects. In that regard, it is found that testing after a delay enhances subsequent memory performance more than does immediate testing. This is similar to the finding that effects of spacing repetitions are often greater at longer lags. We suggest that testing effects rely on recursive reminding just as do effects of repetition.

Prior research examining effects of spacing repetitions has focused on the importance of effects of spacing for the memory consequences of study. Our results are unique in showing that a manipulation at the time of test can be sufficient to determine whether or not an effect of spacing of repetitions is observed. In addition to resulting from recursive remindings, effects of spacing repetitions can arise from traces of a repeated item being integrated and, so, detected at the time of test (cf. Asch, 1969), showing that recursive reminding is sufficient but not necessary to produce effects of spacing of repetitions. Retrieval orientation in the form of variations of looking back is a determinant of event structure. For the within-list back condition, List 1 and List 2 were treated as separate events whereas the two lists were treated as parts of a single event by those in the *n*-back condition. As described above, this difference was important for the detection of between-list repetitions and their effect on cued-recall performance. We believe that the reported results and arguments contribute to the understanding of the effects of spacing repetitions, and highlight the importance of processes involved at the time of test. However, we do not claim to be able to fully account for effects of spacing repetitions. Rather, it is likely that multiple processes underlie spacing effects (e.g., Greene, 1989).

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Table 1

Schematic of Item Types and Correct Looking Back Responses

	List		Looking Back	
Item Type	**List 1**	**List 2**	***n*-back**	**within-list back**
Single	--	A-B	No	No
Within-List Repetitions	--	A-B, A-B	Yes	Yes
Between-List Repetitions	A-B	A-B	Yes	No

Note: “A-B” is used to denote that word pairs were used in the present experiments.

Table 2

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

	Item Type		
Looking Back	**Single**	**Within-List**	**Between-List**
Experiment 1			
n-back	.08 (.02)	.94 (.02)	.74 (.03)
within-list back	.02 (.01)	.91 (.02)	.17 (.03)
Experiment 2			
n-back	.08 (.02)	.95 (.03)	.74 (.05)
within-list back	.02 (.01)	.93 (.03)	.17 (.05)

Note: "Within-List" refers to within-list repetitions, and "Between-List" refers to between-list repetitions. Standard errors of the means are presented in parentheses.

Table 3

Probabilities of Cued Recall as a Function of Item Type, Looking Back, and Presence of Repetition Recollection Measure: Experiments 1–3

	Item Type		
Looking Back/Measure	**Single**	**Within-List**	**Between-List**
Experiment 1			
n-back	.17 (.03)	.27 (.04)	.46 (.04)
within-list back	.15 (.03)	.27 (.04)	.33 (.04)
Experiment 2			
n-back	.22 (.03)	.34 (.05)	.55 (.05)
within-list back	.18 (.03)	.33 (.05)	.45 (.05)
Experiment 3			
Measure Present	.17 (.03)	.32 (.04)	.40 (.04)
Measure Absent	.23 (.03)	.36 (.04)	.33 (.04)

Note: “Within-List” refers to within-list repetitions, and “Between-List” refers to between-list repetitions. Standard errors of the means are presented in parentheses.

Table 4

Proportions of Variance in Recall of Between-List Repetitions in the *N*-Back Condition Explained by Item Differences and Repetition Detection: Experiments 1 and 2

	Experiment	
	1	**2**
Step 1		
Item Differences	.24*	.13*
Step 2		
Repetition Detection	.14*	.22*
Step 3		
Interaction	.00	.01

Note: Values displayed above are ΔR^2 on each step of the model computed at the item level collapsed across participants. Data are from the *n*-back condition in Experiments 1 and 2. "Item Differences" refers to item differences in single item recall performance, "Repetition Recognition" refers to differences in recognition of between-list repetitions in List 2, and "Interaction" refers to the interaction term for the aforementioned predictors.

* $p < .05$.

Table 5

Probabilities of “Yes” Responses Indicating Repetition Recollection at Test as a Function of Item Type and Looking Back: Experiments 2 and 3

	Item Type		
Looking Back/Measure	**Single**	**Within-List**	**Between-List**
Experiment 2			
n-back	.23 (.03)	.52 (.04)	.64 (.04)
within-list back	.14 (.02)	.49 (.04)	.51 (.04)
Experiment 3			
Measure Present	.23 (.03)	.47 (.03)	.54 (.04)

Note: “Within-List” refers to within-list repetitions, and “Between-List” refers to between-list repetitions. Standard errors of the means are presented in parentheses.

Table 6

Probabilities of Cued Recall as a Function of Item Type and Repetition Recollection: Experiments 2 and 3

	Item Type		
Repetition Recollection	**Single**	**Within-List**	**Between-List**
Experiment 2			
Yes	.30 (.05)	.54 (.04)	.71 (.04)
No	.17 (.03)	.10 (.02)	.17 (.03)
Experiment 3			
Yes	.29 (.06)	.53 (.05)	.62 (.06)
No	.13 (.02)	.11 (.03)	.13 (.03)

Note: "Within-List" refers to within-list repetitions, and "Between-List" refers to between-list repetitions. Values for Experiment 2 are collapsed across the Looking Back conditions. Standard errors of the means are presented in parentheses.

Table 7

Proportions of Variance in Cued Recall of Between-List Repetitions in the *N*-Back and Within-List Back conditions Explained by Item Differences and Repetition Recollection: Experiments 2 and 3

	Experiment	
	2	**3**
Step 1		
Item Differences	.35*	.27*
Step 2		
Repetition Recollection	.22*	.25*
Step 3		
Interaction	.00	.02

Note: Values displayed above are ΔR^2 on each step of the model computed at the item level collapsed across participants. Data from Experiment 2 are from the *n*-back condition. "Item Differences" refers to item differences in single item recall performance, "Repetition Recollection" refers to differences in recollection of between-list repetitions at test, and "Interaction" refers to the interaction term for the aforementioned predictors.

* $p < .05$.