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On the Relationship Between Recognition Speed and Accuracy for Words Rehearsed Via Rote Versus Elaborative Rehearsal

Aaron S. Benjamin
University of Toronto and the Rotman Research Institute
at Baycrest Centre for Geriatric Care

Robert A. Bjork
University of California, Los Angeles

Tacit within both lay and cognitive conceptualizations of learning is the notion that those conditions of learning that foster "good" retention do so by increasing both the probability and the speed of access to the relevant information. In 3 experiments, time pressure during recognition is shown to decrease accessibility more for words learned via elaborative rehearsal than for words learned via rote rehearsal, despite the fact that elaborative rehearsal is a more efficacious learning strategy as measured by the probability of access. In Experiment 1, participants learned each word using both types of rehearsal, and the results show that access to the products of elaborative rehearsal is more compromised by time pressure than is access to the products of rote rehearsal. The results of Experiment 2, in which each word was learned via either pure rote or pure elaborative rehearsal, exhibit the same pattern. Experiment 3, in which the authors used the response-signal procedure, provides evidence that this difference in accessibility owes not to differences in the *rate* of access to the 2 types of traces, but rather to the higher *asymptotic level* of stored information for words learned via elaborative rehearsal.

A ubiquitous notion in commonsense and scientific conceptualizations of learning and memory is that some forms of learning are better than others and, consequently, that memories vary along a unidimensional continuum of strength. Good learning, by whatever means, produces strong memories—information that is readily accessible and available for immediate use. Furthermore, a failure of memory is seen as the hallmark of imperfect learning—a standard used by any instructor who has ever administered an examination of his or her students' knowledge.

A problem facing contemporary cognitive psychologists is how to reconcile this pervasive (and often valid) notion with the burgeoning set of results that provide evidence for important dissociations in learning and memory. These dissociations are in evidence in the language of cognitive psychology, in which we refer to implicit and explicit learning, episodic and semantic memory, and so forth. Such distinctions are also critical to influential ideas and concepts, such as transfer-appropriate processing (Morris, Bransford, & Franks, 1977; Roediger, Weldon, & Challis, 1989). The critical aspect of such approaches is that performance on tasks involving memory reflects more than a unidimensional level of learning or memory strength: Rather, performance derives from aspects of both study situations and test situations and, to a considerable degree, from the interaction of the two. Deeper levels of processing (Craik & Lockhart, 1972), for example, elicit superior recognition performance (an explicit test) but lead to poorer performance on a test of perceptual identification (an implicit test; Blaxton, 1989; Jacoby, 1983).

In this article, we examine two measures that are typically highly correlated and are considered basic measures of degree of learning: retrieval probability (or accuracy) and retrieval speed. In general, it is indeed true that effective learning strategies do make later retrieval of the learned information both more likely and more rapid (see, for example, Hintzman, 1969; Vincent, Craik, & Furedy, 1996). It is perhaps not all that surprising, then, that experimental participants use the ease or speed of retrieval as an index of what they are likely to be able to recall in the future, even in experiments in which the two measures are contrived to be negatively related (Benjamin & Bjork, 1996; Benjamin, Bjork, & Schwartz, 1998).

As noted by Dosher (1984), however, the experimental evidence regarding the speed of information retrieval is limited. This poverty of relevant evidence is illustrated by the fact that whereas certain prominent computational models of memory incorporate features relevant to the prediction of response time (RT) data (e.g., Atkinson & Juola, 1974; Chappell & Humphreys, 1994; Hockley & Murdock, 1987; Murdock, 1982, 1983; Ratcliff, 1978), other influential models bypass such properties (e.g., Gillund & Shiffrin, 1984; Hintzman, 1988; Raaijmakers & Shiffrin,

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Aaron S. Benjamin, Department of Psychology, University of Toronto and the Rotman Research Institute at Baycrest Centre for Geriatric Care, Toronto, Ontario, Canada; Robert A. Bjork, Department of Psychology, University of California, Los Angeles.

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Correspondence concerning this article should be addressed to Aaron S. Benjamin, Department of Psychology, University of Toronto, Toronto, Ontario, Canada M5S 3G3. Electronic mail may be sent to aaron@psych.utoronto.ca.

1981). Critically, all such models are oriented toward the prediction and explanation of accuracy data.

Some theorists have argued that RT distributions are a potentially important source of relevant data in efforts to understand the properties of retrieval and thus are a necessary focus of any canonical model of human memory (e.g., Hockley, 1984; Hockley & Murdock, 1987). It is not, however, the mission of the present article to take a stance on such issues. Instead, we focus on the evidence that response accuracy and response speed are occasionally, and perhaps even frequently, dissociable. Indeed, we hope to convince the reader that one fruitful avenue of investigation is an analysis of when speed and accuracy of retrieval appear to increase with an experimental manipulation (e.g., Vincent et al., 1996) and when they appear to dissociate, as in the research reported herein. In the General Discussion, we discuss a potential reconciliation between these types of findings.

At an experimental level, some evidence suggests that there may be subtle differences in the factors that affect retrieval speed and those that affect probability of retrieval. Dosher (1984) demonstrated that retrieval speed increases with degree of learning only when that learning is engendered by additional exposures to the study item and not when the duration of a single exposure is increased. Corbett (1977) provided evidence that paired-associate terms learned via a visual imagery mnemonic were more often successfully retrieved than were pairs studied via rote repetition, but that the retrieval of such terms occurred at a somewhat slower rate. In addition, Mulligan and Hirshman (1995) showed that recognition performance following semantic and phonological encoding conditions (in a levels-of-processing paradigm) differed less under speeded recognition testing than under unspeeded conditions. Moreover, a number of authors have demonstrated how some components of the recognition decision are more immediately accessible than others (Benjamin, 1999; Benjamin & Craik, 1999; Hintzman & Curran, 1994; Jacoby, 1999).

The premise underlying the present research is that certain encoding conditions that effectuate superior subsequent recall or recognition performance do so by creating a complex but novel series of associations that allow the rememberer to retrieve the trace in question more reliably, but only after a more prolonged retrieval operation. As a commonsense example, consider the recall of a list of unrelated words encoded via the popular mnemonic procedure of the method of loci. This method can enhance recall accuracy considerably—the robustness and magnitude of the effect are so strong, in fact, that the technique makes a popular classroom demonstration. However, the speed of retrieving words encoded with the loci method suffers; in fact, the latency to retrieve any particular item in a list (and its corresponding location cue) varies linearly with the item's serial position in the list (Lea, 1975). One goal of the present research was to see whether some conditions that elicit greater memory performance by encouraging complex elaboration do so at the cost of eventual retrieval speed.

Although the results from Corbett (1977) and Mulligan and Hirshman (1995) suggest that such a conceptualization may have some validity, many other findings indicate that manipulations that serve to increase retrieval accuracy also increase retrieval speed. For example, when measuring RT on a recognition test, Vincent et al. (1996) showed that deeply processed words were recognized both more accurately and more quickly than were shallowly processed words. Shea and Morgan (1979) reported a similar result in a motor learning task—random practice led to superior and faster later performance than did blocked practice. On tasks for which participants were allowed to trade off performance speed and accuracy, it does appear that those manipulations of learning that supported better retention also supported faster responding. Because faster RTs do not necessarily imply faster retrieval, but may reflect only increased accuracy, the present experiments use a slightly more complex testing procedure—one in which participants are forced to comply with a recognition deadline. In the General Discussion, we speculate on a source for the apparent differences between RT experiments and the experiments presented in this article.

From a practical perspective, trade-offs with retrieval speed may often outweigh the benefits of a particular mnemonic technique. A coach who trains his quarterback to read multiple types of blitzing schemes accurately will find that such knowledge is useless unless the player can also retrieve the appropriate information quickly. Being able, therefore, to distinguish between those factors that improve memory accuracy only at the expense of retrieval speed and those that improve both the speed and reliability of access is thus of some practical importance.

For the purposes of generality, the paradigms we use in the experiments reported here use a very broad manipulation. In each experiment, the accuracy and speed of retrieval are compared between items that participants have attempted to learn only for the short term and items that participants have attempted to commit to memory for the longer term. We have specifically chosen paradigms that induce reliable control processes corresponding to rote and elaborative rehearsal. The exact nature of the experimental procedures is discussed in the appropriate sections of this article, but we digress here briefly to discuss the general differences between control strategies used in the temporary maintenance of information and those used in the process of attempting to commit information to long-term storage.

Rote and Elaborative Rehearsal

In general, when attempting to maintain information for only short periods of time (after which the information will presumably not be important or relevant), humans engage in *rote rehearsal.* Rote rehearsal refers to the rote or cyclic repetition of information, usually subvocally, as when people repeat a phone number to themselves as they walk from a telephone book to a telephone to dial the number. *Elaborative rehearsal,* however, incorporates all of the varied processes that an individual may use to foster long-term retention of an item. These processes are often thought of as involving the integration of the to-be-learned item with other information in long-term storage, thereby increasing the probability that the item may be accessed in the future.

Whereas it is the degree of elaborative rehearsal that affects the probability of access as measured by a test of recall, it has been shown that performance on a recognition test is also affected by the amount of rote rehearsal (Craik & Watkins, 1973; Geiselman & Bjork, 1980; Glenberg, Smith, & Green, 1977; Woodward, Bjork, & Jongeward, 1973). It is also clear, however, that those items processed by elaborative rehearsal demonstrate a clear advantage in their later recognition over items processed by rote rehearsal. Thus, whereas both types of rehearsal lead to increased recognition accuracy for the involved study item, there is an advantage of elaborative over rote rehearsal in terms of its potential to foster long-term retention.

A recent study indicated that there may be qualitative differences in the phenomenology of recognition between words rehearsed via rote versus elaborative rehearsal. In the remember–know recognition paradigm, Gardiner, Gawlik, and Richardson-Klavehn (1994) demonstrated that the amount of elaborative rehearsal affected the proportion of remember responses but that know responses varied with the amount of rote rehearsal. Such an apparent difference in the subjective quality of remembering provides a further impetus for the investigation of retrieval times for the products of these two types of rehearsal.

Because the primary goal of the present work is to establish whether access to the mnemonic products of elaborative rehearsal is more compromised by time pressure than is access to the products of rote rehearsal, the experimental paradigms of Experiments 1 and 2 are oriented toward the measurement of recognition accuracy under conditions of differential time pressure. In Experiment 3, we make use of the response-signal procedure (Reed, 1973) to attempt to tease apart more subtle aspects of the dynamics of retrieval.

Experiment 1

In this experiment, we made use of the same procedure that Gardiner et al. (1994) used to induce differing degrees of rote and elaborative rehearsal. After a word was presented to the participants and removed, there was a variable delay (2 or 5 s) before participants were shown a cue informing them that they needed to learn that word or that they could forget that word. In the intervening time, participants had to engage in whatever rehearsal activities they deemed necessary to keep that word available. Typically, such activities consist of rote rehearsal of the item (Woodward et al., 1973).

After receiving a cue to learn the word, participants, for the remaining interval, presumably engaged in the type of elaborative rehearsal of the item that is known to foster superior memory performance (e.g., Craik & Watkins, 1973). After receiving a cue to forget the word, we presume that active processing of that particular item ceased and that participants either turned their attention toward rehearsing previous to-be-learned items or entered a cognitive stupor until the next item appeared.

During the recognition test, participants were tested under both speeded and unspeeded conditions. On the unspeeded test, there was no time pressure for participants to make a decision, whereas there was an 800-ms deadline for the judgment on the speeded test. If the hypothesis is correct that the products of rote rehearsal are more readily accessible than the products of elaborative rehearsal, then hit rates (HRs) for to-be-learned items should increase as a function of post-cue rehearsal interval only on the unspeeded test. On the speeded test, HRs for those items should most likely be unaffected. However, because precue and postcue intervals were intentionally confounded to be of opposite, long/short or short/long durations—so as to keep the total rehearsal interval constant—HRs on the learned items might actually decrease as the postcue rehearsal interval increases on the speeded task. This decrease could occur if performance on the speeded task was dominated by retrieval of the information laid down by rote rehearsal, which would have had less time to operate as the postcue elaborative rehearsal interval increased.

Method

Participants. Sixty-four undergraduates (36 women and 28 men) from an introductory course in psychology at the University of California, Los Angeles participated in the experiment to fulfill a course requirement.

Design. The experiment used a completely within-subjects 2 (test type: speeded or unspeeded) × 2 (item type: to-be-learned or to-be-forgotten) × 2 (delay condition: long/short [LS] or short/long [SL]) factorial design. In addition, new items (foils) were presented at test but are analyzed separately for reasons presented in the *Results* section.

Apparatus and procedure. Participants were tested in groups of 2 and 3 in a small, well-lit room with no windows. We introduced the study phase by explaining to the participants that they would be seeing a series of words, only some of which they would need to learn for an upcoming test of their memory. They were told that the words that they would need to learn would be followed by a learn cue (LLLL), and the ones that they would not need to learn would be followed by a forget cue (FFFF). We further explained that this cue would sometimes appear soon after an item's presentation and other times after a somewhat longer delay. After answering any questions that the participants posed, the study phase was initiated with the press of the space bar. The entire experiment was implemented on a 386DX computer.

Each word in a series of 80 was presented to the participant for 1.5 s and then disappeared from the screen. After either 1 s (in the short precue delay condition) or 5 s (in the long precue delay condition), the cue to learn or to forget the item was presented. This cue remained on the screen for the duration of the trial interval, which was held constant at 6 s. Thus, in the short precue delay condition, the cue remained for 5 s (long postcue delay; rote[]ELAB condition), and in the long precue condition, the cue remained for 1 s (short postcue delay; ROTE[]elab condition).[1] The precue and postcue delays were thus intentionally confounded to keep the trial interval constant.

Of the 80 words, 20 were assigned to each participant under the following four conditions: SL delay with a forget cue (rote[F]ELAB items), SL delay with a learn cue (rote[L]ELAB items), LS delay

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[1] In this notation, capital letters indicate the long rehearsal interval, and lowercase letters indicate the short interval. A letter in brackets between the two rehearsal types indicates the cue type.

with a forget cue (ROTE[F]elab items), and LS delay with a learn cue (ROTE[L]elab items). Across participants, each item appeared in each condition an equal number of times, including serving as distractor material.

The test phase started with instructions that explained the basic premises of a yes/no recognition test. Participants were also instructed that they were to recognize both learn and forget items, despite the earlier instructions. Furthermore, they were told that the test would be blocked into four groups of trials, each of which would be preceded by an announcement of "QUICK SPEED" or "NORMAL SPEED," which referred to the speeded and normal test conditions, respectively. In the speeded condition, response times were limited to 800 ms, after which the response keys (*Y* and *N*) were timed out. They were instructed to respond to all items and to attempt to do so within the deadline when tested under speeded conditions.

Of the 160 items on the test, 80 were the previously studied set and 80 were new. The order of the items was constrained such that the following conditions were met. First, each block of 40 items contained an equal number of targets and distractors. Second, each group contained an equal number of targets from the four encoding conditions. Third, no target was followed by another target from the same encoding condition. Fourth, there were never more than 4 targets or distractors in a row. Half of the participants received the speeded test during the first and third blocks, and half received the unspeeded test during those blocks.

Results

The data from 4 participants were discarded because of a computer error (2 cases) or because they had failed to complete the recognition test (2 cases). On the speeded test, participants responding after the key lockout was a quite rare event, averaging 4.4 (out of 80) per participant.

Mean HRs and false-alarm rates (FARs) are presented in Figure 1, with the unspeeded test results presented on the top and the speeded results on the bottom. Because there was a single FAR for each of the two rehearsal conditions within the speeded and unspeeded tests, the pattern of d' values within a test condition mirrors the presented HRs. Furthermore, because there were many individual cells in which the HR was either 1 or 0, or the FAR was 0, d' was undefined for a number of cases. For the purposes of analysis, d' values were approximated by substituting .99 for values of 1 and .01 for values of 0 and were then analyzed nonparametrically. When important comparisons are made between test types, collateral parametric analyses on HR and nonparametric analyses on d' are presented. The d' values for Experiments 1 and 2 are presented in the Appendix. All results presented in the remainder of this article are significant at the $p < .05$ level unless otherwise noted.

Overall, there was a main effect of test type such that participants were more likely to endorse studied items on the unspeeded than speeded test, (.72 vs. .67), $t(59) = 3.60$. More important, the opposite effect of testing condition is apparent in FARs, $t(59) = 6.20$, with speeded test conditions eliciting a higher FAR (.24) than unspeeded test conditions (.14). The effect of test speed is also evident in a Mann–Whitney analysis of d' scores: Accuracy is higher under unspeeded than speeded conditions (2.17 vs. 1.57; $z = 15.489$).

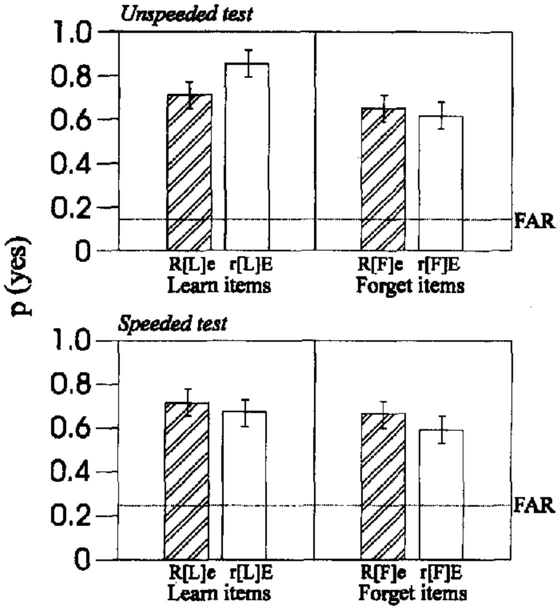

Figure 1. Mean hit rate and false-alarm rate (FAR) as a function of delay condition and cue type for the unspeeded test (top panels) and speeded test (bottom panels; Experiment 1). Error bars represent 95% confidence intervals estimated using the within-subjects error term (see Loftus & Masson, 1994). R[L]e = long rate and short elaborative rehearsal intervals with a learn cue in between, r[L]E = short rate and long elaborative rehearsal intervals with a learn cue in between, R[F]e = long rate and short elaborative rehearsal intervals with a forget cue in between, r[F]E = short rate and long elaborative rehearsal intervals with a forget cue in between, p(yes) = proportion of "yes" responses.

There was also an effect of cue type such that to-be-learned items evoked more "yes" responses than did to-be-forgotten items, (.77 vs. .64), $t(59) = 7.55$. There was no main effect of delay, but this result is qualified by the fact that delay interacted with test type, $F(1, 59) = 5.43$, $MSE = 0.02$. Mean HR was higher in the rote[]ELAB conditions (.73) than in the ROTE[]elab (.69) conditions on the normal test but was lower in the rote[]ELAB conditions (.64) than in the ROTE[]elab conditions (.69) on the speeded test. The interaction between delay and cue type was also reliable, $F(1, 59) = 5.24$, $MSE = 0.03$. Mean HR was higher for rote[L]ELAB than for ROTE[L]elab items (.76 vs. .72) but was lower for rote[F]ELAB than for ROTE[F]elab items (.61 vs. .66).

On the unspeeded test, mean HR was higher for items in the rote[L]ELAB condition (.84) than for items in the ROTE[L]elab condition (.73): simple effect of delay, $t(59) = 2.52$. ROTE[F]elab and rote[F]ELAB items showed no such difference (.62 vs. .65), and the simple interaction between cue and delay condition was reliable, $F(1, 60) = 9.94$, $MSE = 0.02$.

On the speeded test, the pattern of HR for learn items was the opposite of the pattern in the unspeeded test case. Mean HR for ROTE[L]elab items was slightly higher (.71) than for items in the rote[L]ELAB condition (.68); however, this difference was not reliable. More critical, the simple interaction between test type and delay condition was reliable for learn items, $F(1, 59) = 4.98$, $MSE = 0.02$. The interaction revealed that there was a greater HR in the rote[L]ELAB condition than in the ROTE[L]elab condition on the unspeeded test, but this difference disappears on the speeded test.

Discussion

The predicted patterns are borne out in the results of Experiment 1. A longer delay after a learn cue enhanced recognition under unspeeded conditions but, presumably because the length of the postcue interval is irrelevant following a forget cue, no such enhancement was apparent following such a cue. In fact, the advantage appears to reverse somewhat, reflecting the increase in precue (rote rehearsal) time. These findings replicate the phenomenon that both rote and elaborative rehearsal enhance recognition performance (e.g., Geiselman & Bjork, 1980) and that additional elaborative rehearsal is more effective in promoting later recognition than is additional rote rehearsal.

The results on the speeded test support the hypothesis that the complete products of rote rehearsal can be accessed more quickly than can the complete products of elaborative rehearsal. The advantage provided by a long postcue delay for learn items disappeared and even reversed somewhat on the speeded test of recognition. The pattern for the forget items did not change qualitatively, consistent with the idea that forget items undergo no elaborative processing and should thus be unaffected by the time pressure manipulation. Additionally, there was a small advantage in recognition for long precue over short precue forget items both on the speeded and unspeeded tests. This offers some support to the notion that the products of rote rehearsal are indeed fully accessible under speeded and unspeeded conditions, whereas access to the products of elaborative rehearsal is compromised by time pressure. Increasing the amount of elaborative rehearsal (as measured by the postcue interval) improved recognition performance on the unspeeded test but not on the speeded test. Furthermore, increasing the amount of rote rehearsal (as measured by the precue interval) did improve performance on the speeded test. Moreover, for forget items, increasing the precue interval improved performance both on the speeded and unspeeded tests.

Experiment 2

The pattern of results evident in Experiment 1 is generally supportive of our hypothesis, but is subject to certain interpretive difficulties. Experiment 2 used a different paradigm in which any one item was to be processed via rote, elaborative, or both types of rehearsal. The latter items, henceforth referred to as *mixed* items, allow a conceptual replication of Experiment 1. Because the manner by which the words were presented was quite different from that used in Experiment 1, such a replication was necessary to show that the induced processes have similar mnemonic effects. In Experiment 1, we examined the effects of rote and elaborative rehearsal by partially covarying the precue and postcue interval; in Experiment 2, we attempted to further tease apart the effects of these two processes by nesting, for a given participant, particular study words in conditions of pure rote and pure elaborative rehearsal. The goal of this nesting was to eliminate any complicated interactive effects between the two processes, as well as to replicate the finding in a different paradigm.

The replacement paradigm involves the concurrent presentation, in the top two quadrants of a box, of two items, of which only one is to be learned for the future test. By varying the interval after the removal of the words and before participants are informed as to which word is to be learned, differing degrees of rote rehearsal are induced. The manner by which participants are informed is through the presentation of a third word in a quadrant directly below one of the two quadrants used for the first two words. The particular quadrant informs participants that they are to replace the word that appeared in the quadrant above it with the new word, and they are to learn the new word and the other (nonreplaced) word from above for the upcoming test. Varying the duration after the replacement word appears allows the induction of differing degrees of elaborative rehearsal.

Thus, the replaced word (i.e., the one in the quadrant above where the third word appears) undergoes only rote rehearsal, the replacement word (i.e., the third word) only elaborative rehearsal, and the nonreplaced word (i.e., the one in the quadrant under which the third word does not appear) both rote and elaborative rehearsal. This condition allows us to evaluate whether this new encoding procedure replicates the effects evident using the procedure from Experiment 1. Figure 2 illustrates an example trial in this paradigm.

Again, recognition memory was tested under both speeded and unspeeded conditions. On the unspeeded test, HR was expected to increase with the duration of the elaborative rehearsal interval, as well as with the rote rehearsal interval, but to a lesser degree. On the speeded test, HR was expected to only increase primarily with the duration of the rote rehearsal interval.

Method

Participants. Sixty-four undergraduates, 40 women and 24 men, from the University of California, Los Angeles participated to partially fulfill a course requirement.

Design. The experiment used a 3 (rehearsal type) × 2 (delay length) × 2 (test type) completely factorial within-subjects design.

Apparatus and procedure. As illustrated in Figure 2, participants fixated on a rectangle divided into four quadrants during each of the 24 trials. At the onset of each trial, after a 1-s presentation of a "Get ready" signal above the rectangle, two words were presented in the top two quadrants of the rectangle for 1 s and were replaced by dashed lines. Then, after a variable delay of 2 or 7 s, an additional word appeared in one of the bottom boxes and a quotation mark (") appeared in the other. After an additional 1 s, the new word and the quotation mark were also replaced by dashed lines, which remained on the screen for either 2 or 7 s, after which the next trial was initiated. As in Experiment 1, the two delays were intentionally confounded to equate trial duration across conditions. Therefore, if the initial delay after the first two words was 2 s, then

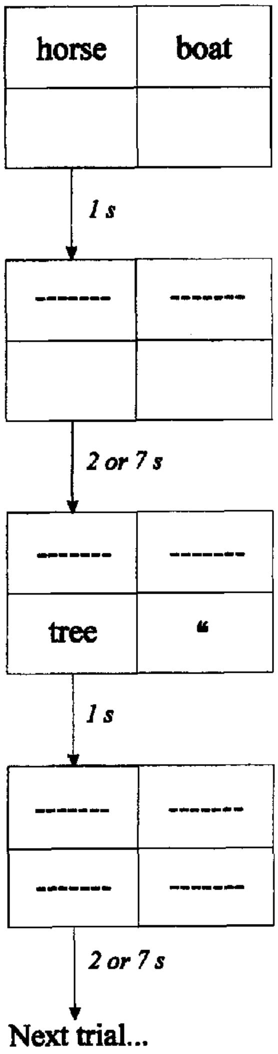

Figure 2. A sample trial from the encoding procedure used in Experiment 2.

the later delay (after the third word) was 7 s, and vice versa. Because the task for the participants was fairly complex, the instructions read to them are reprinted below. These instructions were read while a diagram of the screen layout and an example trial was shown by the experimenter.

> In this experiment, you will be memorizing a number of words. On each trial you will see a "Get ready" message followed by two words. These two words will appear in the top two boxes on your screen. The words will disappear, however, so make sure to read them as quickly as possible. There is a trick, however. After a few seconds, one more word will appear in one of the bottom boxes. If it appears in the left box, then it "replaces" the left word from above, and you need to learn the previously presented right word and the new left word. If it appears in the right box, then it replaces the old right word, and you need to learn the previously presented left word and the new right one. So, on each trial, you only need to learn two of the three total words presented. You will need to hold in mind the first two words until you know which one to keep and which one to replace, but remember that you do NOT need to memorize both of the initially presented words. So, it makes sense to keep the first two in mind until you see the new word, and then try to commit to memory the two words you need to keep. If you have any questions, ask them now, because you may not talk once the experiment begins.

After completing the study phase, participants engaged in a short distractor interval (about 1 min) and then had the test of their recognition. To create the recognition list, 72 additional foils were added to the 72 studied items from the study phase. The test was blocked into four sets of 36 test trials. In each block, an equal number of old and new items were presented and, of the 18 old items, 6 were from each of the three rehearsal conditions. Of those 6, half were from each of the potential delay conditions for that particular rehearsal type. All items appeared in each condition an equal number of times across participants. The order within each block was random subject to the constraint that no more than 3 old or new items could appear sequentially. As in Experiment 1, half of the participants performed the unspeeded test in the first and third blocks (SNSN), and half performed in the second and fourth blocks (NSNS). Prior to each block, the participants were cued to the test type by a message of "Normal speed" or "QUICK SPEED." As in Experiment 1, there was an 800-ms deadline on the speeded test and no deadline on the unspeeded test. Participants were instructed to attempt to recognize all of the words from the prior study period, including those which they had been told that they did not need to know. After the test, participants were debriefed and given credit for their participation.

Results

Figure 3 shows the data from the mixed encoding condition as well as the FAR from the entire test. Again, the mixed item results should have replicated the effects seen for the learn items in Experiment 1. As before, the FAR was higher under speeded (.25) than unspeeded conditions (.14), $t(63) = 6.46$.

On the unspeeded test, the simple effect of delay approaches our criterion for reliability (.73 vs. .80), $t(63) = 2.20$, $p = .06$, but such a difference was not obtained on the speeded test (.67 vs. .69, *ns*). The simple interaction between delay and test type was not reliable.

The results from Experiment 2 corresponding to the pure rehearsal conditions are presented in Figure 4. On the unspeeded test, there was a simple effect of delay such that longer rehearsal times led to better retention both for rote rehearsal (.61 vs. .53), $t(63) = 2.53$, and for elaborative rehearsal (.77 vs. .69), $t(63) = 2.40$. Also, performance

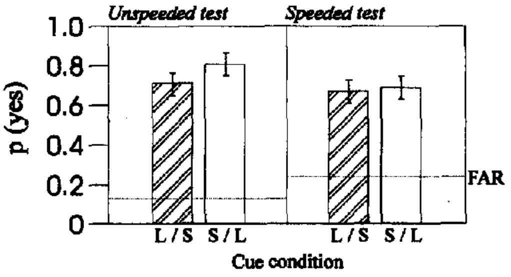

Figure 3. Mean hit rate and false-alarm rate (FAR) as a function of delay condition and test type for the mixed encoding conditions (Experiment 2). L/S = long/short, S/L = short/long, p(yes) = proportion of "yes" responses.

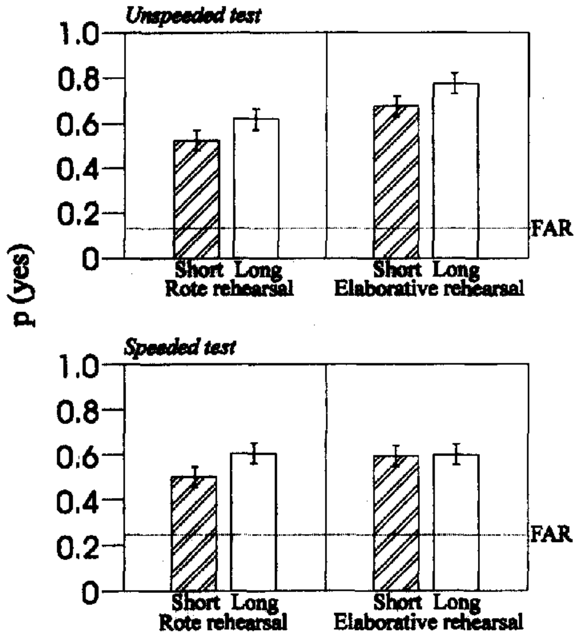

Figure 4. Mean hit rate and false-alarm rate (FAR) as a function of encoding type and delay length for the unspeeded test (top panels) and the speeded test (bottom panels; Experiment 2). P(yes) = proportion of "yes" responses.

under conditions of elaborative rehearsal was higher (.73) than under conditions of rote rehearsal (.57), $t(63) = 5.68$.

On the speeded test, there was an interaction between rehearsal type and delay, such that longer rehearsal times led to better retention only for rote rehearsal (.60 vs. .52) but not for elaborative rehearsal (.60 vs. .60), $F(1, 63) = 2.37$, $MSE = 0.04$. Also, effects of speeding the test were evident for recognition performance of items learned via elaborative rehearsal (.72 vs. .60) but not for items learned via rote rehearsal (.56 vs. .57), simple interaction, $F(1, 63) = 4.70$, $MSE = 0.04$.

Discussion

First, we see from the data presented in Figure 3 that the mixed rehearsal condition from the replacement procedure nicely replicates the effects of the directed-forgetting procedure used in Experiment 1. There is an advantage for increasing the postcue elaborative rehearsal time (in this case, the delay after the presentation of the third word) only on the unspeeded test of recognition. On the speeded test, no such advantage was apparent.

More critical, Figure 4 shows that the pure rehearsal conditions revealed effects clearly consistent with our hypothesis. On the unspeeded test of recognition, increasing the amount of either rote or elaborative rehearsal aided eventual recognition performance, although again elaborative rehearsal is more efficacious. However, on the speeded test of recognition, the beneficial effects of increasing the amount of rehearsal time disappeared on the speeded test selectively for those items learned via elaborative rehearsal. This result provides solid evidence that time pressure during recognition more dramatically affects performance on words learned for the long term than on those temporarily maintained with rote rehearsal.

The results of Experiment 2 are again consistent with the hypothesis that the memorial products of elaborative rehearsal are less accessible under conditions of speeded than unspeeded recognition and that this attenuation of accessibility is not evident for the products of rote rehearsal. The fact that the mixed words have an even greater level of recognition accuracy on the unspeeded test than do those processed by elaborative rehearsal likely owes to the overall greater amount of processing time for those items.

Experiment 3

The experiments presented here support the hypothesis that access to the products of rote rehearsal is less disrupted by time pressure than is access to the products of elaborative rehearsal during a recognition decision. However, as noted by Reed (1973) and others (Corbett, 1977; Dosher, 1976; Hintzman & Curran, 1994), the interpretation of such an effect depends critically on the particular model of information retrieval that one uses. In general, this difference could result from several different causes. It could be the case that the rate at which information is accrued during the recognition decision differs between words processed via rote and elaborative rehearsal. It is also possible that because the eventual asymptote of such a function differs between the two types of rehearsal (as evidenced by the differences in performance under unspeeded conditions), speeding the test differentially affects access to the products of the two types of retrieval: Information regarding words processed via rote rehearsal is accessed in full, whereas only a portion of the total information regarding words processed by elaborative rehearsal is available.

The response-signal procedure provides a method to disentangle these two effects. The technique is described briefly here, but for a fuller treatment, the reader is referred elsewhere (Dosher, 1976; Gronlund & Ratcliff, 1989; Hintzman & Curran, 1994; Mulligan & Hirshman, 1995; Reed, 1973). During the recognition test, participants were cued to respond with their decision at varying intervals after the onset of the word. The first of these intervals was typically sufficiently short such that performance was around chance levels, and the final interval was sufficiently long so as to allow asymptotic accuracy. Recognition performance (as measured by d', for example) is plotted as a function of the interval condition plus the average RT for that interval. This correction is necessary because RTs tend to be higher for the shorter intervals. These data are then fitted to the MacArthur–Wilson growth equation (also sometimes referred to as Mitcherlich's Law or the shifted exponential function) with three parameters: the degree of the shift or intercept (I), the rate of approach to asymptote (R), and the asymptote itself (A).

In Experiment 3, we make use of the response-signal procedure to attempt to elucidate the locus of the effect evident in the results of Experiments 1 and 2. The study procedure of the items was the same as in Experiment 2, but the delay manipulation was eliminated and recognition was tested at intervals varying from 100 ms to 2,000 ms after the presentation of the word.

Method

Participants. Forty-five participants (29 women and 16 men) took part in the experiment. All were undergraduates from the University of California, Los Angeles and participated to partially fulfill a course requirement.

Design. The experiment used a 3 (rehearsal type) × 8 (lag condition) × 2 (test item status: old vs. new) completely factorial within-subjects design.

Apparatus and procedure. The study phase proceeded as described for Experiment 2 with the exception that the delay manipulation was eliminated. Thus, on each trial, the replacement (third) word appeared 4 s after the initial two words, and there was a delay of an additional 4 s before the next trial began.

The 144 tested items were evenly distributed among the eight lag conditions (100, 200, 300, 400, 500, 750, 1,200, and 2,000 ms). Of the 18 words in each lag condition, half were old and half were new, and the 9 old items were composed of 3 items from each rehearsal condition. The order of the items was random subject to the constraint that no more than two trials from a given lag appeared in a row.

On each test trial, after a brief (1-s) "Get ready" signal, a word appeared in the center of the screen. After the appropriate lag corresponding to that word, the word disappeared and an arrow appeared slightly to the right of the previously presented word. At this point, participants entered their response (*Y* or *N*) as quickly as possible. On trials in which the participant responded before the arrow cue, they were reminded to wait for that cue before entering their response. In addition, for all trials in which participants took longer than 300 ms to respond, they were encouraged to attempt to make their responses more immediately after the cue was shown in the future. All responses were kept and subjected to analysis. After reviewing their performance, we debriefed each participant and gave them credit for their participation.

Results

Following the example of Hintzman and Curran (1994), performance at each lag interval was converted to a logistic measure of recognition accuracy (d_L; Snodgrass & Corwin, 1988) for each condition:

$$d_L = \ln\left(\frac{\mathrm{HR}[1 - \mathrm{FAR}]}{[1 - \mathrm{HR}]\,\mathrm{FAR}}\right) \tag{1}$$

In Figure 5, the mean d_L values are shown as a function of rehearsal condition and lag + mean RT for that lag. A function having the form

$$\hat{d}_L = \begin{cases} A(1 - e^{-R(t-I)}) & \text{for } t \geq I \\ 0 & \text{for } t < I \end{cases} \tag{2}$$

was fitted to the accuracy data for each of the three rehearsal conditions (see Corbett, 1977, Dosher, 1984; Hintzman & Curran, 1994). In this equation, *A* represents the asymptote of the function, *R* represents the rate, and *I* represents the intercept (i.e., the point at which performance rises above 0).

One analytic strategy is to fit this function to the data from each participant individually and then hierarchically test models of increasing constraint using a between-subjects error term. We have not used that approach here. Whereas prior experiments have used fewer participants and maximized the amount of data per participant (e.g., Hintzman & Curran, 1994), our experiments involved many participants but a relatively small number of data per participant. This design difference leads to highly unstable individual estimates of the parameters in Equation 2. Because the fitting procedure (described in more detail below) is nonanalytic, the search through parameter space is highly subject to adverse effects of local minima. This problem is com-

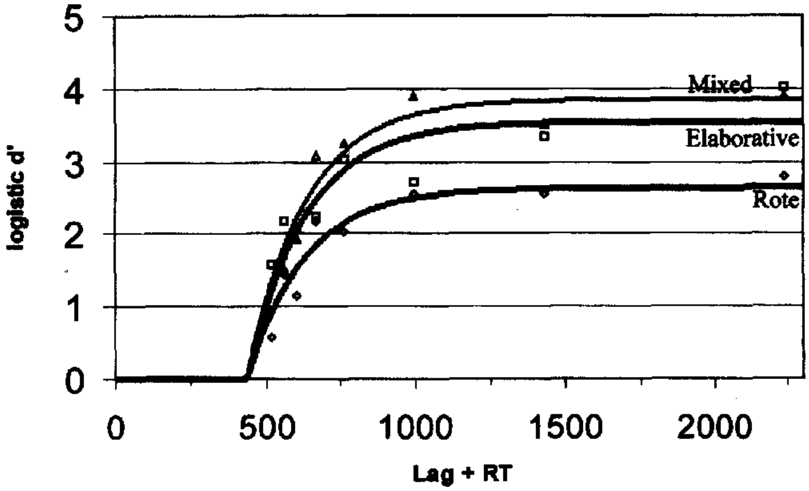

Figure 5. Recognition accuracy as a function of rehearsal type and lag + response time (RT). Curves show the fit of a shifted exponential function (Experiment 3).

pounded by the large within-subjects variability owing to the small number of observations per cell.

Thus, we have collapsed across our participants and pooled the individual data into the set shown in Figure 5. These data were then fit using a Marquardt nonlinear least-squares grid search procedure to estimate the nine parameters of the full model (three *I*s, three *R*s, and three *A*s). A partial model was then tested in which the parameter set was reduced to those for which the 95% confidence intervals for the three different encoding condition values did not overlap. Inference regions for this nonlinear model were calculated using the derivative matrix evaluated at the parameter estimates that minimized the sum of squares. This procedure is analogous to the computation of a confidence interval in linear regression but uses the derivative matrix evaluated at each parameter estimate instead of the design matrix (Bates & Watts, 1988, p. 53). This nested model had five parameters—R, I, A_p, A_s, and A_m. In other words, only the values for the asymptote parameter reliably differed between conditions. The entire procedure was implemented using the SAS NLIN program, and the derived curves are overlaid on the data in Figure 5. The top curve fits the data from the mixed rehearsal condition, the middle curve fits the data from the elaborative rehearsal condition, and the bottom curve fits the data from the rote rehearsal condition. The parameter values are shown in Table 1 both for the full and the restricted model. The variability accounted for by these two models was not reliably different as assessed by a likelihood ratio test, $F(4, 9) < 1$, *ns* (Draper & Smith, 1981).

Discussion

The results of Experiment 3 suggest a mechanism by which the pattern of results evident in Experiments 1 and 2 can be interpreted. Although information accrues at the same rate independent of the encoding or rehearsal type, time pressure establishes an absolute ceiling on such accrual. This pressure differentially affects the products of rote and elaborative rehearsal: The latter, more frequently than the former, are not retrieved to their full potential. The implications for this mechanism are explored further in the General Discussion.

Table 1
Parameter Estimates for the Full and the Restricted Model of the Response-Signal Process in Experiment 3

	Rehearsal type		
Parameter	Rote	Elaborative	Mixed
Full model ($k = 9$)			
I	504	620	480
R	.009	.011	.008
A	2.67	3.60	3.77
Restricted model ($k = 5$)			
I	437	437	437
R	.005	.005	.005
A	2.64	3.55	3.86

Note. I = intercept, or the degree of the shift; R = rate of approach to the asymptote; A = asymptote. k = number of parameters.

General Discussion

We hope to have convinced the reader of the fact that the benefits of elaborative rehearsal are not without cost. Namely, Experiments 1 and 2 have shown that retrieval of words learned via elaborative rehearsal is more disrupted by time pressure during recognition than are the memorial products of rote rehearsal. We presume that this result arises because of the very nature of elaborative rehearsal: Creating a unique, perhaps linked, set of associations does indeed foster more likely retrieval, but mentally traversing those links is a time-consuming (and perhaps resource-consuming) process.

In general, it may be the case that some of the techniques used to foster probable retrieval do so at the expense of potential quick retrieval. Dosher (1984) has shown, for example, that increasing the number of study opportunities of a word increases both the asymptotic accuracy and rate of later retrieval, but that increasing the duration of a single study trial increases only the accuracy. We suggest that such an effect arises because of different control processes involved in the two cases. In the latter, additional study time encourages participants to devise increasingly elaborate retrieval routes, thus mimicking our elaborative rehearsal case. In the former case, an additional study opportunity encourages the retrieval of old routes (in Dosher's terms, increasing the strength of the item). This case is more similar to rote rehearsal as we have implemented it, although Dosher encouraged all participants to use elaborative rehearsal in learning the study set. Presumably, multiple study events enhance retrieval more than rote rehearsal because the spacing between those study trials encourages forgetting and thus makes the second retrieval more effective. Such an interpretation of the effect leads to the interesting prediction that a spacing manipulation should promote probability of retrieval without affecting access speed.

The results of Experiment 3 suggest a mechanism that may underlie the patterns of results evident in Experiments 1 and 2. It seems that the time pressure at retrieval allows for full retrieval of memories for items processed via rote rehearsal but only incomplete retrieval of those processed via elaborative rehearsal. Consistent with this notion is one subtle aspect of the data from the results: In the pure processing task (Experiments 2 and 3), it was never the case that absolute levels of recognition performance were lower for items processed via elaborative as opposed to rote rehearsal. That is, despite the fact that those words learned via elaborative rehearsal were recognized relatively less well under time-pressured recognition, there were no conditions under which recognition accuracy for those words falls below that for words learned via rote rehearsal. Our result, however, differs from that of Corbett (1977) who found different rates for the retrieval of information learned via rote or visual imagery mnemonics. However, in his experiments, participants learned associated pairs of items, and it is plausible that there are quite different dynamics underlying associative and item recognition (cf. Clark, Hori, & Callan, 1993).

Our results suggest a potential resolution of the apparent paradox mentioned earlier in this article: Under many circumstances, better learning leads to higher accuracy and faster responding, yet in our experiments, those conditions that led to higher accuracy suffered the most by time pressure at test. In RT experiments, it is not possible that a simple retrieval criterion is set, either in terms of time or in terms of information accrual. In the first case, such a criterion would lead to different accuracies but equivalent RTs, whereas in the second case, it would lead to different RTs but equivalent levels of accuracy. Such a relationship can be seen simply by imposing a vertical line (for a time criterion) or a horizontal line (for a retrieved-information criterion) on the data in Figure 5.

It must be the case that, at the time of retrieval, different standards are imposed for different types of items. It might seem at first glance that a participant would need to remember the original encoding condition for each word to use such a strategic difference, but in fact, all that they need be sensitive to is the differences in the dynamics of information accrual. In essence, two criteria are set: one for accuracy and one for speed. If the information retrieved for a given item surpasses a threshold for accuracy, a response is made; otherwise, the process continues until a time threshold is met.

Such a process is consistent with the Atkinson and Juola (1974) model of word recognition in which a deliberate search process is only initiated if a fast familiarity-based response cannot be made. Moreover, it explains why in RT paradigms, words learned via rote rehearsal evoke longer RTs: They do not meet the initial accuracy threshold as often as do items learned via elaborative rehearsal. However, in our paradigm, in which a time criterion of 800 ms is set on the recognition decision, performance comes closer to reaching asymptotic accuracy for words learned via rote rehearsal than for words learned via elaborative rehearsal. Again, however, one must note that absolute levels of recognition performance are still higher for the latter items. Our findings suggest that, in a practical sense, a potential disadvantage of elaborative rehearsal may be metacognitive in nature. Retrieval of words learned via rote rehearsal are more impervious to speeding demands during recognition, thus, under most conditions, we are able to retrieve what we expect to retrieve—the full extent of our knowledge. However, for words learned via elaborative rehearsal, the retrieval for which suffers under degradation of testing conditions, we may find that our performance is up to neither our own expectation nor the standards of others. Such a dissociation may be critically important for skills that are necessary during conditions of stress, such as fire fighting or executing the 2-min drill in football. In particular, two cognitive failures—one of memory and one of metamemory—can compromise performance. First, retrieval of important procedural skills and information under stressful conditions may be incomplete. Second, performance under those conditions may be below one's expectations, leading to a false sense of security or at least to a false sense of ability.

Our own word-learning laboratory-based results are at best suggestive of such dissociations of skill in real-world settings. Whether such linkages prove warranted or not, our findings illustrate that an evaluation of the cases in which retrieval accuracy and speed go hand in hand and the cases when they dissociate has the potential to inform theories of memory, particularly our understanding of the control processes that learners and rememberers use, which can provide a basis for understanding why some trainers, trainees, and conditions of training are more successful than others in fostering performance under real-world conditions.

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Appendix

Values of d' for All Conditions in Experiments 1 and 2

Table A1
Experiment 1 Values

Test type and delay condition	Cue type	
	L	F
Unspeeded test		
ROTE[ ]elab	2.44	1.92
rote[ ]ELAB	2.56	1.82
Speeded test		
ROTE[ ]elab	1.90	1.62
rote[ ]ELAB	1.75	1.10

Note. Capital letters indicate the long rehearsal interval, and lowercase letters indicate the short rehearsal interval for the delay conditions. L = learn; F = forget.

Table A2
Experiment 2 Values

Test type and interval length	Rehearsal type		
	Rote	Secondary	Mixed[a]
Unspeeded test			
Short interval	1.35	1.98	2.43
Long interval	1.68	2.30	2.17
Speeded test			
Short interval	1.00	1.29	1.65
Long interval	1.38	1.35	1.59

[a] The interval duration on the left indicates the amount of rote rehearsal during the mixed condition; thus, the duration of elaborative rehearsal was long when rote was short and short when rote was long.

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