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# THEORETICAL IMPLICATIONS OF DIRECTED FORGETTING[1]

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We sometimes speak of "good encodings" or "long-term encodings" of to-be-remembered items as if those terms denoted particular encodings that were "good" or "long-term" in some absolute sense. It is largely a relative matter, however, whether a particular encoding of a to-be-remembered item in terms of certain features or associations will result in the long-term storage and reliable retrieval of that item. A particular encoding of a particular item in a particular context by a particular person may uniquely characterize that item, but the same encoding of the same item in a different context, or by a different person having a different verbal history, may lead instead to confusion and interference with other similarly-encoded items in memory. And the goodness of an encoding is not invariant with time either: An encoding that is good at some particular time may become not so good at some later time as a result of subsequent inputs to memory.

There is no doubt that the effective utilization of one's memory depends in a critical way on one's ability to discriminate specific items-as-coded from other items-as-coded. The problem of understanding the nature of coding processes in memory is completely intertwined with the problem of understanding the mechanisms by which items in memory are differentiated (or not differentiated) from other items in memory. This paper is concerned with one aspect of the general problem of how items and sets of items are differentiated in memory. The aspect of concern is how current to-be-remembered information is discriminated from past to-be-forgotten information. In other words, how do we update our memories?

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That we need to update our memories is clear: We would degenerate to a proactive-interference-induced state of total confusion otherwise.

## THE DIRECTED-FORGETTING PARADIGM

One promising approach to the problem of understanding how we keep our memories current, and the approach of interest in this paper, is through research on directed forgetting. The directed-forgetting paradigm involves the use of signals to subjects to forget particular items they have been presented. The various phenomena exhibited by subjects in such experiments have implications not only as to the mechanisms by which subjects are able to take advantage of signals to forget some items in order to facilitate their processing of other items, but also as to the general problem of how items are differentiated in memory.

Much of the interest in the directed-forgetting paradigm has been motivated by the feeling that it reveals some curious and previously unappreciated abilities. In my opinion, however, the paradigm is important not primarily because it raises new questions or illustrates surprising capacities, but rather because it has the potential of contributing new leverage on some old and important problems in the study of memory. There is no doubt that the effects of a cue to forget can be quite amazing in some situations, but to anyone who has kept up with the growing literature on directed forgetting it should be apparent that the issues involved are not unique—they are clearly related to those involved in other lines of research. An adequate analysis of directed forgetting will involve interference mechanisms, rehearsal processes, mechanisms by which lists and sets of items are differentiated, the relative roles of storage and retrieval in producing memory failures, and other factors.

From a subject's standpoint in an experiment on directed forgetting, a cue to forget is not such a strange event. The cue simply informs him that he is free to forget the cued material, that his memory for that material will not be tested. Intentional forgetting is a frequent event in one's everyday life; it is probably, in fact, more frequent than is intentional remembering. We overhear conservations, we see things in newspapers and store windows, we add up numbers, we dial phone numbers, we pay attention to advertisements, and so on—nearly all of which we have no use for beyond the point at which we attended to them. To the degree that we have any intentions at all with respect to that information, we intend to forget it rather than remember it.

A number of different procedures, motivated by different purposes and interests, have been employed in research on directed forgetting. In order to provide background for the theoretical questions of main interest, the procedural variations and basic results in research on directed forgetting are reviewed below.

## PROCEDURAL VARIATIONS IN DIRECTED FORGETTING

Although experiments on directed forgetting differ in many ways in terms of what types of materials, tests of performance, and timing of events are involved, their primary differences fall on two dimensions: (*a*) whether subjects are cued to forget or remember sets of items or are cued item-by-item, and (*b*) the temporal position of the cue relative to the to-be-remembered items (R-items) and the to-be-forgotten items (F-items).

### Cuing of Item Sets

Sets of items (defined, for example, by type of item, color of item, or temporal grouping) are presented and subjects are cued to forget one of the sets. It is assumed in the following (as has been true in every published case) that the number of sets is limited to two.

*Intraserial cuing.* Subjects are presented a series of items one by one and are cued at some point in the series to forget the items presented prior to the signal. Such experiments are designed (by including lists without any forget-signals, for example) so that subjects can not anticipate when or whether a forget cue (F-cue) will occur; they must, therefore, attempt to memorize each item as it is presented. The sets of items before and after the F-cue may be defined only by being prior or subsequent to the cue, respectively, or they may differ in type of item, input modality, or some such. The procedure has been used in paired-associate probe experiments (e.g., Bjork, 1970a), free recall experiments (Bruce & Papay, 1970), continuous paired-associate experiments (e.g., Elmes, 1969a, b; Elmes, Adams, & Roediger, 1970), ordered recall tasks (e.g., Block, 1971), and in other situations.

*Postinput cuing.* Rather than present the F-cue prior to the R-items, the cue is delayed until after the input of both item sets. That is, subjects are presented a postinput cue to forget one of the sets. This procedure has been used extensively by Epstein and his co-workers (Epstein, 1969, 1970; Epstein, Massaro, & Wilder, 1972; Shebilske, Wilder, & Epstein, 1971). In their experiments, the task is to learn two successive short lists (typically, six items) differentiated by temporal grouping, item type, or input modality, and the postinput cue specifies whether one or both of the lists is to be recalled. The procedure has also been used by Reed (1970) in a modification of the Brown-Peterson short-term memory paradigm (e.g., Peterson & Peterson, 1959).

*Preinput cuing.* A possible procedure that has not been used in published reports on cued forgetting would involve cuing subjects prior to the presentation of two sets of items to forget (not learn) one of the sets. Such a procedure does occur in incidental learning paradigms and in standard memory paradigms, as, for example, when subjects are required to shadow but not recall a list of distractor items in the Brown-Peterson paradigm.

It is possible, of course, to conduct experiments that involve combinations of the procedures outlined above. An example is an experiment by Bjork (1970a, Exp. III), in which both intraserial and postcuing were used.

### Item-by-Item Cuing

In these procedures, subjects are cued whether to remember or to forget each item in turn.

*Cuing at onset.* In some cases, the cue to remember or to forget an item is coincident with the onset of the item. Such a procedure has been used by Weiner and Reed (1969) and by Roediger and Crowder (1972). In their experiments, subjects were cued simultaneously with the presentation of a consonant trigram at the start of a Brown-Peterson trial whether to remember or forget the trigram. Subjects are typically required to say each item aloud in such experiments to insure that they attend to F-items.

*Cuing after offset.* In other cases, the cue to remember or to forget an item is delayed until after the offset of the item. This procedure has been used in experiments employing modifications of the Brown-Peterson paradigm by Bjork, LaBerge, and LeGrande (1968), Turvey and Wittlinger (1969), Pollatsek (1969), and Block (1971). Woodward and Bjork (1971), Davis and Okada (1971), and Bugelski (1970) have used the procedure in free recall experiments. With this procedure, the delay from the offset of an item to the cue to forget or remember the item is an important variable and has been manipulated in several of the studies mentioned above.

### Implicit Cuing

The procedures of primary interest to this paper are procedures that involve explicit cues to forget, but it is worth pointing out that many memory paradigms involve implicit F-cues. In many paradigms (the standard Brown-Peterson paradigm, for example), there is an implicit cue to forget at the end of each trial. Also, as mentioned earlier, memory paradigms often require subjects to attend to, but not remember, distractor items of some kind.

The foregoing organization of experimental procedures in research on directed forgetting is presented for organizational purposes. It is not difficult to think of possible experiments that do not fit neatly within the organization, but nearly all experiments to date are exemplars of one or more of the procedures described above.

## BASIC PHENOMENA

Two kinds of data are of primary interest in research on directed forgetting: (*a*) the effects of an F-cue on items to be remembered, and (*b*) the effects of an F-cue on items to be forgotten. In the former case, one is interested in the extent to which performance on R-items is facilitated by the F-cue in comparison with cases in which there is no such cue. Knowledge of the extent to which an F-cue reduces interference owing to F-items on the recall of R-items in various situations is relevant to a number of issues, especially issues having to do with interference mechanisms in memory. In the latter case, one is interested in the extent to which F-items remain in memory as measured directly, by recall or recognition tests, or indirectly, by intrusion rates, transfer effects, subsequent repetitions of F-items, and so forth. Knowledge of what happens to F-items under various cuing circumstances is relevant to questions about interference processes, effects of rehearsal, differences between recall and recognition, and other issues.

The following review of the basic results deriving from research on cued forgetting is selective, and some specific results relevant to questions considered later in the paper are introduced there and are not reviewed in this section.

### Effects of F-Cues on R-Items

Depending on the situation, the effectiveness of an F-cue can vary from completely effective to completely ineffective in eliminating interference owing to F-items on the recall of R-items. The effectiveness of an F-cue can be judged by noting where performance on the R-items falls between two controls, one in which there are no F-items and the other in which there is no F-cue. If performance is as good as when there are no F-items, the F-cue is completely effective, and if performance is no better than when there is no F-cue, the cue is completely ineffective.

Except for certain special cases, a cue to forget has been demonstrated to be completely effective when the cue follows the items to be forgotten and precedes the items to be remembered (intraserial cuing). The proactive interference attributable to the first set on the recall of the second set that would normally obtain if there were no F-cue can be completely eliminated by the F-cue. Two examples of this result are shown in Figures 1 and 2. The data shown in Figure 1

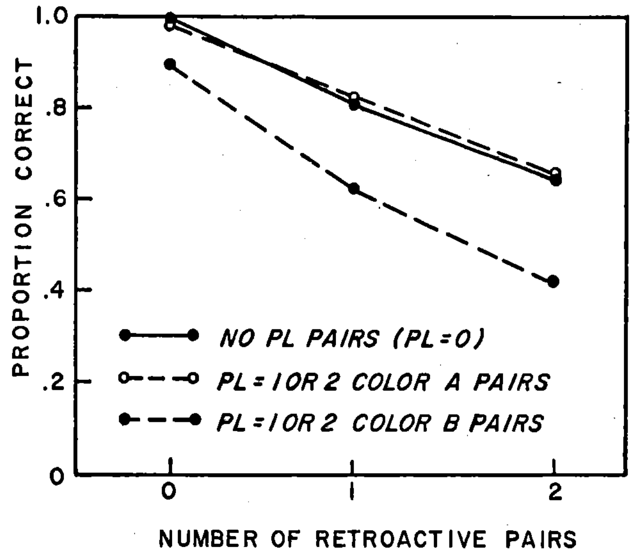


FIG. 1. Proactive interference resulting from to-be-forgotten (color A) pairs versus proactive interference resulting from to-be-remembered (color B) pairs (after Bjork, 1970a).

are from an experiment by Bjork (1970a, Exp. I). Subjects were presented lists of consonant-vowel-consonant (CVC) trigrams paired with words. The lists varied in number of pairs and each list was followed by a single probe test of one of the pairs. Some of the lists contained a signal to subjects to forget the pairs presented prior to the signal. The signal consisted of a change from color A to color B (green to yellow or yellow to green) in the background on which the pairs were shown.[2]

[2] It turns out to matter very little what the cue to forget is, as long as it is salient Color changes, tones, changes in spatial position, the word "forget," and other cues have been used with apparently equal efficacy.

In Figure 1, performance when there were no proactive pairs is contrasted with performance when there were one or two proactive color A (F-cued) pairs and when there were one or two color B (to-be-remembered) pairs. It is clear from Figure 1 that the F-cue, in effect, truncated the color A items from the list as far as their interference with the recall of color B pairs is concerned.

The second example is an experiment by Block (1971). In his experiment, subjects were presented lists of six words. On some trials two lists were presented and subjects were cued at the end of the first list to either forget the first list, in which case their recall of the second list was tested (F2 trials), or to remember the first list, in which case they were cued at the end of the trial to recall either the first list (P1 trials) or the second list (P2 trials). On other trials, subjects were presented single lists corresponding to either a first list (C1 trials), in which case they could not anticipate that they would be required to recall the list after it was presented, or to a second list (C2 trials), in which case they could anticipate (by virtue of a cue presented at the start of the list) that they would be required to recall the list after it was presented.

Block's results are shown in Figure 2. The fact that performance is about as good in the F2 case as in the C2 case indicates once again that the F-cue was very effective. The average correct-recall proportions were .41, .58, and .60 in the P2, F2, and C2 cases, respectively.

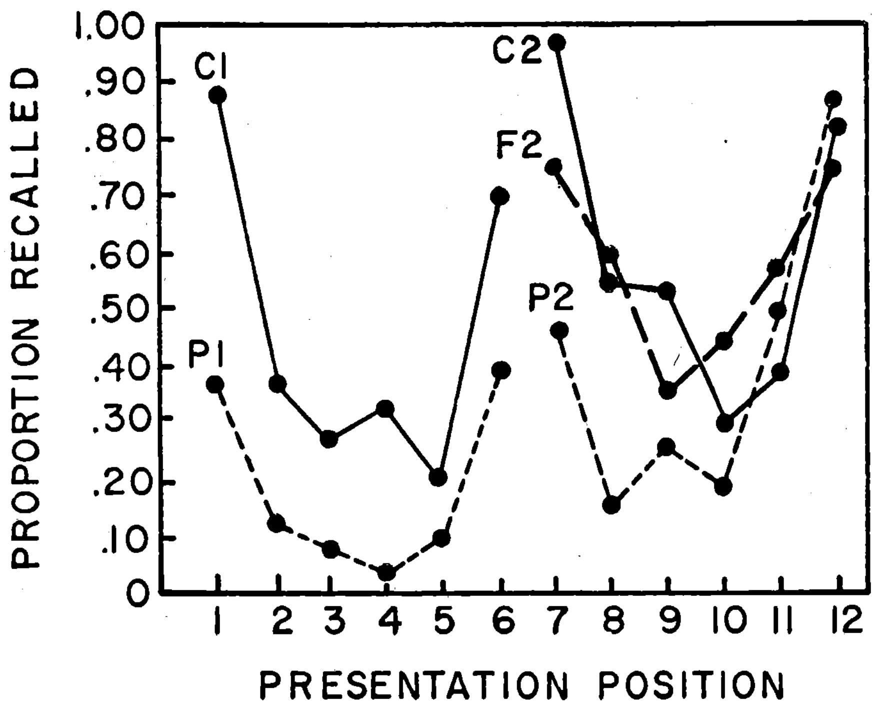


FIG. 2. Mean proportion recalled as a function of presentation position (after Block, 1971).

Similar findings have been obtained by Bruce and Papay (1970) with a free-recall paradigm, and by Bjork, Abramowitz, and Krantz (1970) with a memory-search paradigm. In the latter case, response latency rather than recall probability was shown to be unaffected by F-items. Elmes and his co-workers (e.g., Elmes, 1969a, b; Elmes et al. 1970; Elmes & Wilkinson, 1971) have also found that an F-cue facilitates performance on R-items subsequent to the cue in continuous paired-associate tasks. Whether F-cues in their experiments were completely effective in eliminating proactive interference owing to pairs prior to the signal is difficult to judge, because their experimental designs did not include the control condition in which there are no pairs corresponding to the F-pairs in the F-cue condition.

Postinput cues to forget are not as effective in reducing interference owing to F-items as are cues that precede the items to be remembered. The difference in effectiveness between intraserial cuing and postinput cuing is illustrated by the results of an experiment by Bjork (1970a, Exp. III). In Bjork's experiment, a single trial consisted of the following sequence of events: Two CVC-word paired associates were shown on a yellow background, there was a first instruction, two CVC-word pairs were shown on a green background, there was a second instruction, and the trial concluded with a single probe test (on a white background) of one of the pairs. Five different list types were generated by the following combinations of first and second instructions: RY:RG (remember yellow, remember green), RY:FG (remember yellow, forget green), RY:FY (remember yellow, forget yellow), FY:RG (forget yellow, remember green), and FY:FG (forget yellow, forget green). The last condition was included so that a "forget yellow" first instruction would not predict a "remember green" second instruction. Following FY:FG lists, the probe test was replaced with a presentation of "no test."

The results of the experiment are shown in Figure 3. The difference in performance on tests of the green pairs in the RY:FY and FY:RG conditions demonstrates the differential effectiveness of an F-cue presented prior to the R-pairs and an F-cue presented subsequent to the R-pairs. That is, the only difference between the RY:FY and FY:RG conditions is the location of the FY instruction.

With a postinput cuing procedure, one can attempt to attenuate either proactive interference or retroactive interference by cuing subjects to forget either the first or second set, respectively. In Figure 3, it appears that the postinput cues did attenuate both proactive and retroactive interference somewhat. There is some question, however, whether postinput cues are effective at all. There are other cases in which facilitation of R-item recall owing to a postinput F-cue has been demonstrated (e.g., Epstein, 1969, 1970; Reed, 1970, Exp. II; Shebilske et al., 1971), but there are also cases resulting in no facilitation (e.g., Reed, 1970, Exp. III; Block, 1971, Exp. I).

One problem in deciding the question is that performance in a postinput F-condition can be compared with one of two different control conditions. An experiment by Reed (1970, Exp. III) serves to illustrate clearly the two different types of controls, because both were included in the design. Reed's study employed a variation of the Brown-Peterson paradigm. In the conditions of interest, subjects were shown two three-consonant (CCC) trigrams, there was an interpolated activity,

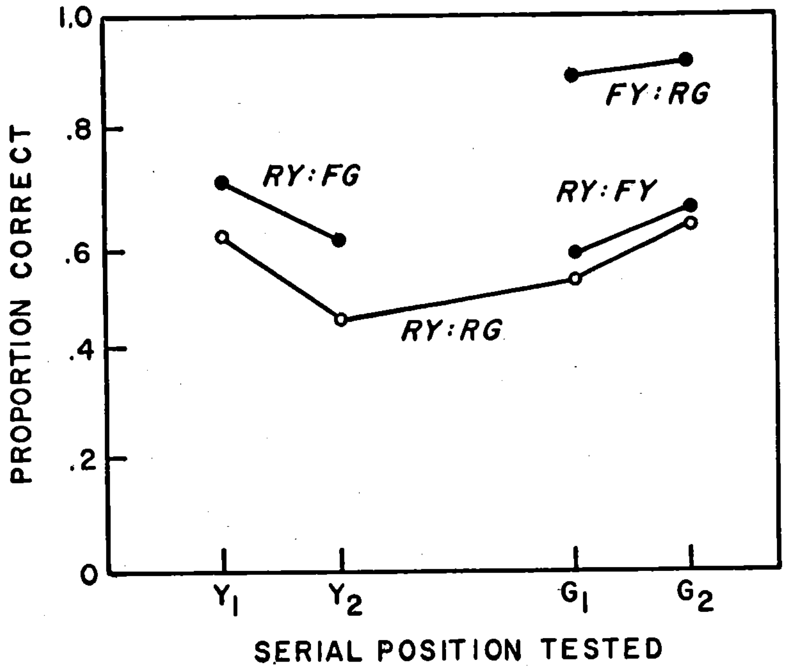


FIG. 3. Proportion correct responses as a function of instructional combination (after Bjork, 1970a).

and the trial concluded with a recall test. In one such condition, a cue to forget the second trigram was presented immediately after the second trigram was presented; in another condition there was no F-cue, but the recall cue at the end of the trial instructed subjects to recall only the first trigram; and in a third condition, there was no F-cue and the cue at the end of the trial specified that both CCCs were to be recalled, in the order first CCC, second CCC. The probability of correct recall of the first CCC was .68, .67, and .52, respectively, for the three conditions specified above. Thus, if the appropriate control is the condition where both trigrams were recalled, then the F-cue did facilitate performance. On the other hand, if the appropriate control is the condition where the recall cue required recall of only the first CCC, then the F-cue did not facilitate performance.

An argument can be made for or against either type of control condition. The condition in which complete recall is required can be criticized on the grounds that comparisons between such a condition and an F-condition confound differences in amount to be recalled and conditions. Use of the other control condition can be criticized on the grounds that the control condition itself constitutes a kind of F-condition in which the F-cue is administered at the time of recall, hence using such a control constitutes a comparison between F-conditions differing only in the delay of the F-cue.

It is not clear which control is the more appropriate; in fact, the choice may be completely theory-specific. It is clear that one's conclusion with regard to the effectiveness of a postinput F-cue is heavily dependent on which control is used. Whether the individual studies listed above found or did not find facilitation with postinput cuing is heavily correlated with the type of control employed.

In the experiments reviewed thus far, the F-items and R-items have been temporally blocked. It is of obvious interest whether such temporal blocking is a necessary condition for an F-cue to be effective in facilitating performance on R-items. The answer to the question depends on the cuing procedure. If F-items and R-items are intermingled during presentation and postcuing is used, there is no facilitation even when performance is contrasted with a recall-everything control (Epstein, 1969). If R-items and F-items are intermingled during presentation, but are cued item by item, there is substantial facilitation. The latter result was demonstrated by Woodward and Bjork (1971) and was replicated by Davis and Okada (1971).

An interesting case in which an implicit F-cue seems not to be very effective is the standard Brown-Peterson paradigm. The fact that there is substantial proactive interference from trial to trial in such experiments, even though there is an implicit cue to forget at the end of each trial, is well documented (see Wickens, this volume). It may be that an item can be processed to a point after which a cue to forget the item has little effect. Thus, after a subject has studied an item during its presentation, attempted to retain the item during an interfering activity, and endeavored to retrieve the item at the time of recall, it may be too late to administer an F-cue. Some support for such a notion derives from an experiment by Turvey and Wittlinger (1969). In their experiment, an F-cue administered at the time an item was presented resulted in a significant attenuation of the proactive interference attributable to that item, as measured by recall performance on the next item. They also found that a cue to forget (not recall) an item at the start of its recall period did not significantly attenuate proactive interference traceable to that item.

### Effects of F-Cues on F-Items

The fate of F-items, in terms of the nature of their existence or nonexistence in memory has been evaluated by a number of different techniques. As mentioned earlier, some of those techniques involve direct measures of F-item recall and recognition, other techniques involve indirect measures, such as intrusion rates and transfer effects.

*Recall of F-items.* Several different procedures have been used to assess recall of F-items. The most straightforward procedure, but possibly the most problematical as well, was introduced by Weiner and Reed (1969). They simply cued subjects at the onset of an item in a Brown-Peterson paradigm whether to forget the item or remember the item, and required them to attempt to recall the item in either case. A second procedure (Bjork, 1970a; Bruce & Papay, 1970; Davis & Okada, 1971) involves testing recall of F-items on the last trial or two of the experiment, by which time subjects presumably believe F-cues and are always trying to forget F-items; since the experiment proper is over, destroying their faith in an F-cue by testing F-items can do little harm. A third procedure, similar to the second, involves a delayed recall test of all items presented during the course of the experimental session (e.g., Woodward & Bjork, 1971). A final procedure, used by Reitman, Malin, Bjork, and Higman (1971), involves practicing subjects on trials during which F-items are never tested, and then informing them that during the subsequent trials there will be infrequent tests of F-items, that such tests will be designated by a special signal, and that their best strategy is to attempt always to forget F-items.

The reasons for wanting to test F-items, and the problems in doing so, are both obvious. In my opinion, the best of the four procedures mentioned above is the last one mentioned. With the Weiner and Reed (1969) procedure, subjects are told to forget items they know they will have to recall, and hence one can never be sure that they are attempting to forget when instructed to do so, or, for that matter, whether they are recalling F-items when instructed to do so. The second procedure has the problem of not generating very much data on the recall of F-items, and, in addition, the test of F-items is a surprise to the subject, which may in turn, through delay or disruption of his recall attempt, result in impaired performance. The third procedure is useful, but a delayed attempt to recall all items shown during the experiment does not provide a reasonable measure of the status of the F-items during any one trial of the experiment. With the Reitman et al. (1971) procedure, F-items can be tested on a number of different individual trials during the experiment, the tests of F-items do not come as a surprise, and if performance on the normal trials is characteristic of performance in an equivalent experiment not involving tests of F-items, one has some evidence that subjects were consistently trying to forget F-items.

The complete pattern of results from the different experiments and procedures in which F-item recall has been tested is very complex. The following summary statements convey some of the general findings.

1. In those experiments where it is possible to test for the recall of F-items without informing subjects that such a test is occurring, recall of F-items is negligible. Such tests are possible and have been included in paired-associate probe experiments (Bjork, 1970a; Reitman et al., 1971), but are not possible in the other (nonprobe) experiments that have been employed in research on directed forgetting.

2. When subjects are aware that F-items are to be tested, recall depends on the experimental paradigm, and on the delay from the presentation of an F-item to the cue to recall the item. With the Weiner and Reed (1969) procedure, and with the paired-associate probe procedure, F-item performance varies from about 90 percent of performance on comparable R-items at very short retention intervals (2 or 3 seconds) to about 40 to 50 percent at long retention intervals. In free recall, when cuing is item by item, intentional recall of F-items is only about 10 to 15 percent of the level of recall for R-items.

3. The experiment by Reitman et al. (1971) provides evidence that F-items can interfere both proactively and retroactively with each other even though they do not interfere with the recall of R-items. In their experiment, lists of paired associates were presented and at the end of each list a single pair from the list was tested. Some of the lists contained a signal to forget the pairs prior to the signal. On tests of R-pairs, recall averaged .75, .73, .76, and .72 when there were 0, 1, 2, or 3 F-pairs in the list, respectively. On tests of F-pairs, when there were 0, 1, or 2 F-pairs preceding the tested F-pair in the list, recall averaged .55, .49, and .24,

respectively; when there were 0, 1, or 2 F-pairs succeeding the tested F-pair in the list, recall averaged .55, .33, and .27, respectively. Thus, recall of R-pairs was not influenced by the number of F-pairs in the list, but recall of F-pairs was influenced heavily by both the number of other proactive F-pairs in the list and by the number of other retroactive pairs in the list.

*Recognition of F-items.* The results of experiments including tests for the recognition of F-items are particularly interesting. In three experiments (Block, 1971; Elmes et al., 1970; Gross, Barresi, & Smith, 1970), the delayed recognition of F-items was not significantly different than the delayed recognition of R-items. Block's data are shown in Figure 4. The F2 curve is the delayed recognition probability for items that had been presented in a first list on trials where there was a first list, a cue to forget the first list, a second list, and a cue to recall the second list. The P2 curve is for items presented in a first list on trials where there was a first list, a cue to remember the first list, a second list, and a cue to recall the second list. The C2 value is the false positive rate for words that had not been presented during the experiment.

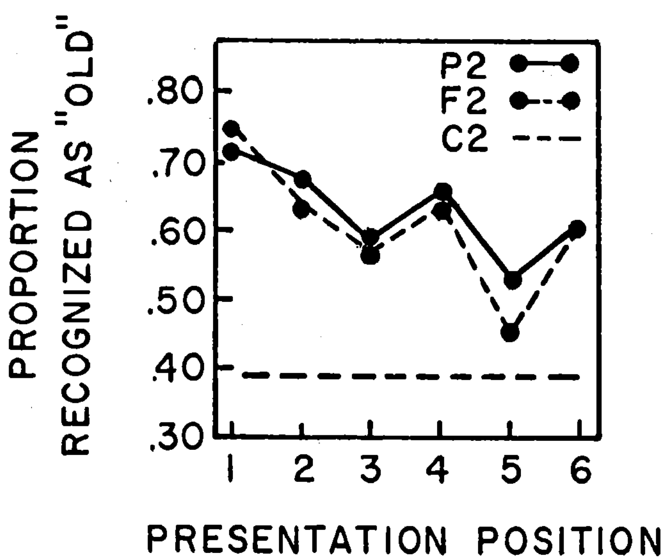


FIG. 4. Mean proportion recognized as "old" as a function of presentation position (after Block, 1971).

In contrast to the results just mentioned, Davis and Okada (1971) found a clear difference between the immediate recognition of F-cued words and R-cued words following a free-recall list in which the words were cued word by word.

An unpublished experiment conducted by Paul Winchester at the University of Michigan suggests that there are situations in which the recall of F-items may be clearly inferior to the recall of R-items, whereas the recognition of F-items is equal to the recognition of R-items. Winchester employed a paired-associate probe design and found that the delayed recognition of F-pairs did not differ from delayed recognition of comparable R-pairs, even though the delayed recall of F-pairs was about one-half the level of recall of R-pairs.

*Intrusion of F-items.* The rate at which F-items are intruded during the recall of R-items has been analyzed in a number of exeriments. In general, in those conditions where an F-cue is effective in eliminating interference attributable to F-items, intrusions are very infrequent. In conditions where an F-cue is less effective, intrusions are more frequent. Supporting data for this generalization have been reported by Bjork (1970a, Exp. III) and Block (1971, Exp. I). Reitman et al. (1971) have also shown that when F-items are tested, the frequency of intrusions of other F-items is much higher than is the frequency of F-item intrusions when R-items are tested. Of the intrusions of response members from other pairs in the tested list, only 6 percent were from F-pairs when an R-pair was tested, whereas 75 percent were from F-pairs when an F-pair was tested.

*Repetition of F-items.* Another method that has been used to indirectly assess F-items is to re-present an F-item subsequent to its initial presentation and to contrast the effects of that repetition with an appropriate control. An example of one such procedure is found in Reed (1970). In a modified Brown-Peterson design, Reed examined the recall of CCC items following a second presentation as a function of whether they had been F-cued or R-cued following their first presentation. It turned out that the probability of recall of initially F-cued items (.86) was as good as the recall of initially R-cued items (.86).

Weiner and Reed (1969) also obtained a similarly striking equality of performance following the repetition of R-items and F-items, but the extent to which inferences can be drawn from repetition results is quite limited. Such procedures depend on the assumption that performance following a repetition of an item is a reliable indicator of the status of the item in memory prior to the repetition. That such an assumption is not tenable is indicated clearly by research on the effects of spacing of repetitions in memory. The fact that two spaced presentations of an item usually result in clearly superior performance following the second presentation in comparison to performance following two massed presentations, even though recall of an item at the time of a second spaced presentation is clearly inferior to recall of an item at the time of a second massed presentation, indicates that recall after a repetition is an imperfect indicator of the representation of an item in memory prior to the repetition (for discussions of this issue, see Bjork, 1970b, and Melton, 1970).

*Pupillary responses to F-cues.* An intriguing result has been obtained by Johnson (1971), who monitored subjects' pupillary reactions during an experiment involving F-cues. Johnson presented a series of five-word lists, some of which contained an F-cue inserted between two adjacent words in the list. The subjects were required to recall all five words in lists containing no F-cue, and they were required to recall the postsignal words in lists containing an F-cue. For the no-cue lists, Johnson found the characteristic gradual increase in pupil size during list input (the "loading" function), and the characteristic gradual decrease in pupil size during recall (the "unloading" function). The terms "loading" and "unloading" are due to Kahneman and Beatty (1966), and are meant to reflect the covariation of pupil size and memory load. During lists with an F-cue, Johnson found an increase in pupil size during the presentation of precue words, a momentary further increase in response to the onset of the F-cue, a decrease following the F-cue, and a standard loading and unloading pattern during the presentation and recall of the postcue words. Thus, on the surface at least, Johnson's results imply that the F-cue in his experiment functionally deleted the to-be-forgotten words from the subject's memory load.

## MECHANISMS OF DIRECTED FORGETTING

Subjects might invoke a number of different information-processing mechanisms, singly or in combination, when they are cued that certain items need no longer be remembered. Three possibilities (Bjork et al., 1968) are (*a*) active erasure or dumping of F-items from short-term memory, (*b*) differential rehearsal of R-items following the cue, and (*c*) differential grouping of R-items to functionally separate them in memory from F-items. A fourth possibility (Weiner, 1968; Weiner & Reed, 1969) is active inhibition of the retrieval of F-items (repression) at the time of recall. Finally, in those procedures where a postinput F-cue reduces the amount to be recalled, Epstein (1969, 1970) has proposed that the F-cue facilitates retrieval by eliminating output interference owing to circulation of yet-to-be-recalled items during the prior recall of other items.

Only two of the five possibilities mentioned above are considered seriously in this section: the differential rehearsal and differential grouping mechanisms. The active erasure notion is a dramatic and interesting possibility, but it is untenable in view of the ample evidence that F-items exist unerased in memory. The retrieval-inhibition mechanism is less easily discounted, but the full pattern of results on tests of recall and recognition argues against it, and the mechanism is somewhat specific to Weiner and Reed's (1969) procedure, which is problematical for the reasons discussed earlier. Epstein's output interference notion is both reasonable and supported by considerable data, but the notion is specific to comparisons between F-conditions and R-conditions in which the amount to be recalled differs. Such procedures are a kind of special case in research on directed forgetting and, although interesting in their own right, are not considered in this section (see Epstein, in press, for a thorough consideration of such procedures).

### A Two-Process Theory

According to a theory proposed by Bjork (1970a), subjects take advantage of an F-cue in two ways: (*a*) They devote all further rehearsal, mnemonic, and integrative activities exclusively to R-items, and (*b*) they differentially group, organize, or code R-items in a way that functionally segregates them from F-items in memory. Neither mechanism alone is sufficient to account for existing results in research on directed forgetting, and to some extent the mechanisms coimply each other. That is, efficient selective rehearsal of R-items in memory depends on their being differentiated as a set, and the differentiation of R-items as a set may depend on their being rehearsed together.

According to the theory, whether an F-cue is effective in attenuating interference owing to F-items in a particular situation is determined by the extent to which the situation permits differential rehearsal of R-items and the differentiation of R-items as a set. For example, an F-cue in the following case should be quite effective: Present set A; cue to forget A; present set B; recall set B. The cue to forget set A occurs before set B is presented, and set A and set B are blocked temporally. Thus, the situation permits differential rehearsal of set B following the F-cue, and set A and set B are not difficult to differentiate. In such a situation, as reviewed earlier, an F-cue is typically completely effective in eliminating interference owing to F-items. If set A and set B were made highly similar and confusable, and if rehearsal opportunities were minimized, an F-cue should not be completely effective. The results of experiments by Bjork et al. (1968) and Block (1971, Exp. I) support this interpretation. In Block's experiment, for example, an F-cue was not completely effective when the F-items and R-items were highly similar.

An F-cue in the following case should not be very effective: Present set A; present set B; cue to forget set A or set B; test recall of remaining set. In such a case, subjects must attempt to rehearse both lists during input because the F-cue does not occur until after input. That an F-cue in such a condition is less effective than an F-cue in the preceding condition is demonstrated in the results shown in Figure 3 (Bjork, 1970a, Exp. III). When set A and set B are intermingled rather than temporally blocked, a postinput F-cue is completely ineffective (Epstein, 1969), and when rehearsal following the F-cue is prevented by a distractor activity, a postinput F-cue is also ineffective (Reed, 1970, Exp. III; Block, 1971, Exp. I). Both results make sense in terms of the theory.

In general, the theory predicts the basic effects of an F-cue on the recall of R-items quite well. With respect to the effects of an F-cue on F-items, the theory in the general form postulated above lacks the specificity to make clearcut predictions. The overall evidence that F-items exist in memory at the time of R-item recall, even in those cases where the F-items are noninterfering, is in accord with the theory, because the theory asserts that F-items are not absent from memory, but are segregated in some manner.

### A Modest Elaboration of the Theory

Although the theory as stated is promising, it is also unsatisfying in that it is not specific enough to yield predictions with respect to certain phenomena. The following assertions are an attempt to further specify the theory.

1. We come equipped with a short-term memory system and a long-term memory system, and both systems have the general properties typically attributed to them as far as capacity, format of storage, rate of forgetting, and likelihood of retrieval are concerned.

2. Rehearsal is a control process consisting of activities such as rote cycling of items, and efforts to associate items. Rehearsal schemes operate primarily on the contents of short-term memory, though items may be entered into a rehearsal scheme from long-term memory. A rehearsal scheme is a rehearsal routine over a particular set of items, but it is to be thought of as more flexible, variable, and changeable than a fixed-capacity buffer.

3. The time an item remains in short-term memory and the extent to which it is stored in long-term memory are straightforward increasing functions of rehearsal.

The entry of an item into long-term memory, as measured by a recognition test, requires very little rehearsal; any additional rehearsal of the item may improve recognition memory somewhat, but its principal effect is on retrievability in recall.

4. Long-term memory can be thought of as a large structure having many different storage locations or regions. When items in a particular rehearsal scheme are entered into long-term memory, they are entered at the same storage location.

5. When a subject is presented an F-cue, he starts a new rehearsal scheme involving only R-items, to the degree it is possible to do so. The new rehearsal scheme automatically opens up a new storage area in long-term memory into which any items entered into it from the new rehersal scheme are stored. Finally, when a new rehearsal scheme is started, any items in the prior rehearsal scheme are lost from short-term memory at the rapid rate characteristic of unrehearsed items.

### Some Predictions of the Elaborated Theory

It should be clear that the foregoing specification of the theory retains the differential rehearsal and differential grouping mechanisms. Thus, the theory's predictions of the effects of an F-cue on R-items are essentially the same as those of the original theory discussed above. The elaborated theory does make some predictions not derivable from the original theory with regard to the effects of F-cues on F-items.

*Recall of F-items.* According to the theory, F-items should be retrievable from long-term memory to the extent that they were rehearsed, and they should be differentiated from R-items in storage to the degree that an experimental situation does not require them to be rehearsed together with R-items.

One experiment providing considerable detail on the recall of F-items is the paired-associate experiment carried out by Reitman et al. (1971). The basic features of their data on the recall of F-items are predicted quite well by the model. They found much better performance on informed tests of F-items than on uninformed tests of F-items; on the uninformed tests, performance was essentially zero. This is explicable in the theory in terms of subjects searching the wrong storage area on uninformed tests. On trials when a single F-pair was presented and, following a variable number of R-pairs, was tested, performance was very sensitive to the number of R-pairs. When there was only one R-pair, the probability of correct recall on the test of the F-item was .75. When there were 2, 3, or 4 R-pairs, the probability of correct recall was .34, .19, and .09, respectively. In terms of the theory, the F-item is no longer rehearsed once the F-cue occurs, and is, therefore, lost from short-term memory at a rapid rate. The .75, .34, .19, and .09 values represent that loss rate. That performance on the F-item appears headed toward zero as the number of R-items increases indicates a very low likelihood that the F-item is retrievable from long-term memory, which should be the case according to the theory, because the item was rehearsed very little before the F-cue occurred.

The results of a test of F-item recall by Bruce and Papay (1970) can be interpreted similarly. In their experiment, a cue to forget was administered after the first 15 words in a free-recall list. After 20 more R-words, subjects were asked to recall both

R-words and F-words. Recall of the F-word presented just prior to the F-cue was only about 5 percent, whereas recall of the first F-word in the list was about 25 percent.

*Intrusions of F-words.* The general finding that the less effective an F-cue is in attenuating F-item interference during R-item recall the greater the frequency of F-item intrusions is consistent with the theory. Forget-items should not interfere with R-item recall to the extent that they are differentiated (are stored in a different memory area) from R-items. Thus, frequency of intrusion of F-items and amount of interference owing to F-items should be closely related.

The findings of Reitman et al. (1971) that F-items interfered with the recall of other F-items even though they did not interfere with the recall of R-items, and that the frequency of intrusions of other F-items when an F-item was tested was much greater than the frequency of intrusions of F-items when an R-item was tested, are also consistent with the set differentiation notion in the theory.

*Recognition of F-items.* The theory assumes that the principal effects of rehearsal are on retrieval from long-term memory rather than on storage in long-term memory. Thus, even though R-items are rehearsed more and are better recalled than F-items in a particular experimental situation, the likelihood that R-items and F-items are stored in long-term memory may not differ substantially, and recognition performance on tests of F-items may approximate recognition performance on R-items. As reviewed earlier, Elmes et al. (1970), Gross et al. (1970), and Block (1971)–Block's data are in Figure 4–found near equality of recognition of R-items and F-items.

Davis and Okada (1971) found substantially better recognition of R-items than of F-items. In their experiment, however, words in a free-recall list were F-cued or R-cued word by word. With such a cuing procedure, subjects need not rehearse a word seriously until, and if, an R-cue is presented after the word. Many F-words might not be given even the minimal rehearsal required to enter them in long-term memory.

## THE UPDATING OF MEMORY

There are some properties of the theory that merit comment, especially those having to do with possible mechanisms involved in the updating of memory. Much of what is assumed in the theory is not novel, but there are several aspects of the theory that have implications with respect to the problem of how we keep (or fail to keep) our memories current. Those properties and implications are discussed below.

### Role of Short-Term Memory

Almost by definition, short-term memory is critical to the updating of memory. At any one point in time, the contents of short-term memory consist of information that is in fact current or is related in some important way to information that is current. When information is lost from short-term memory it is assumed to be completely lost and, hence, incapable of providing proactive interference with the storage or handling of subsequent information within the short-term memory system.

### Interaction Between Short-Term Memory and Long-Term Memory

A very important property of the theory is that short-term memory and long-term memory are assumed to interact in a structural and organizational way. The notion that both the length of time an item resides in short-term memory and the extent to which the item is stored in long-term memory are rehearsal-dependent is familiar, but the theory assumes in addition that how items are grouped or differentiated in long-term memory is a function of rehearsal, and that, conversely, the pre-existing structure of information in long-term memory influences rehearsal schemes.

According to this view, rehearsal processes are important to the updating of memory in two different ways. Because rehearsal is assumed to be a control process of great flexibility, and one that can maintain items in short-term memory, it provides a means of keeping available those items that are most current or important. And since starting a new rehearsal scheme is assumed in the theory to lead to differentiated storage in long-term memory of the information involved in that rehearsal scheme, rehearsal provides a means to segregate relatively current from relatively old information in long-term memory.

### Role of Set Differentiation in Long-Term Memory

Probably the most important and least well defined notion in the theory is that subjects are able to differentially group two sets of items in memory in a way that prevents interference between the sets. The total evidence suggesting such a mechanism is formidable, but the basis on which an arbitrary set of items is differentiated in memory from other sets of items is not clear at all. Assuming such a mechanism exists, it is still not clear how sets of relatively up-to-date information would be identified as such. If it is the case, however, that rehearsal operates primarily on retrieval rather than on storage, and that information in long-term memory becomes less retrievable with time, it is possible that the degree to which information is retrievable would provide a basis (even though somewhat fallible) for identifying relatively current information. The fact that such a system would not be perfect does not argue against it: Subjects are not perfect either.

## SUMMARY AND CONCLUSIONS

This paper is based on the argument that the problem of understanding coding processes in memory is intertwined with the problem of understanding how items are differentiated in memory, and that one promising approach to the latter problem is through research on directed forgetting. More specifically, research on directed forgetting is particularly relevant to one very important aspect of differentiating items in memory: the processes by which current to-be-remembered information is discriminated from to-be-forgotten information. That is, how do we keep our memories current?

The directed-forgetting paradigm involves the use of signals to subjects that they can forget some or all of the items they have been presented. The principal procedural variations in research on directed forgetting differ (*a*) in whether subjects are cued to forget individual items or sets of items defined in some way, and (*b*) in the temporal position of the cue to forget (F-cue) with respect to the to-be-remembered and to-be-forgotten items.

The effectiveness of an F-cue can be judged both in terms of whether subjects can take advantage of the cue to facilitate their processing of to-be-remembered items, and in terms of whether subjects lose access to the to-be-forgotten items. The degree to which an F-cue is effective, in either sense, depends on the particular procedural variation employed and on the way in which performance is tested. As a function of the situation, a cue can vary from completely effective to completely ineffective in eliminating interference owing to to-be-forgotten items on the recall of to-be-remembered items. Also, as a function of the situation and whether performance is assessed by a recall test, a cued-recall test, or a recognition test, to-be-forgotten information can vary from completely unavailable to completely as available as comparable to-be-remembered information.

The implications of the full pattern of results in research on directed forgetting can be summarized by the following statements. (*a*) Whether items are differentiable in memory depends on whether they were rehearsed differentially and on whether they were organized (grouped) differentially. (*b*) Whether such differential rehearsal and organization is achieved depends on the interaction of short-term memory and long-term memory, which, in turn, depends on situational factors such as rate of presentation, similarity of materials, and so forth; in particular, the nature of rehearsal processes in short-term memory influences the structural organization of information stored in long-term memory, and the structure of long-term memory influences the nature of rehearsal processes in short-term memory. (*c*) The retrieval of an item from long-term memory depends heavily on the degree to which that item was rehearsed and interrelated with other times in long-term memory; the existence of an item in long-term memory as measured by a recognition test requires neither extensive rehearsal nor association with other items in long-term memory. (*d*) Finally, the processes by which items become nonretrievable are interrelated with the processes by which items become noninterfering.

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