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INTERFERENCE AND FORGETTING

Human long-term memory is characterized by a storage capacity that is, for all practical purposes, unlimited. At any one point in time, however, much—probably most—of the information in long-term memory (names, numbers, facts, procedures, events, and so forth) is not recallable. Why do we forget information that was once recallable? The principal answer to that question is that access to information in memory is subject to interference from competing information in memory. Before characterizing such interference processes in more detail, it is necessary to introduce some terminology.

First is *transfer*. The process of learning—that is, adding knowledge and skills to our memories—does not take place in a vacuum. After some early point in our lives we rarely, if ever, learn anything that is entirely new. We bring to any "new" learning process an accumulation of related knowledge, skills, and habits from our past. Such prior learning influences the qualitative and quantitative character of the new learning process. We refer to these influences as *transfer effects*. Such effects may be positive or negative, depending on whether our prior experiences facilitate or impair our new learning.

Second is *retroactive interference*. Whereas transfer, as defined above, refers to the effect of earlier learning on later learning, retroaction refers to an effect in the opposite direction: the impact of some *interpolated* (intervening) learning experience on one's memory for something learned earlier. Once again, such effects may be positive or negative (*retroactive facilitation* and *interference*, respectively), depending on the similarity of the original and interpolated learning tasks. It is the negative case—where retroactive interference causes forgetting—that concerns us here. Thus, if our ability to recall the maiden name of a woman friend is impaired by virtue of having learned her married name, we are suffering—by definition—retroactive interference.

Third is *proactive interference*. It is also the case that something learned earlier may impair our ability to recall something learned more recently. If, for example, we are less able to recall a woman friend's married name by virtue of having learned her maiden name at an earlier time, we are suffering—by definition—proactive interference.

Research on Forgetting: A Brief History

Rigorous research on the possible causes of forgetting dates back to the turn of the century when two German researchers, Müller and Pilzecker (1900), first demonstrated retroactive interference under controlled conditions. The history of that research is interesting, partly because it is a history where intuition served as a poor guide to theorizing.

Early Theories That Proved Inadequate

Consolidation. Müller and Pilzecker (1900) found that subjects' memory for a series of nonsense syllables (consonant-vowel-consonant nonword syllables, such as DAX) was impaired by subsequent activity, such as learning a new series of nonsense syllables (compared with a condition where subjects simply rested for a similar period of time). They put forward a *perseveration-consolidation hypothesis* to explain their results. They argued that the changes in the nervous system that result in true learning were not complete by the end of training—that activity in the brain perseverated after learning, and that during that perseveration the memory traces corresponding to learning were consolidated. A subsequent activity, particularly if demanding and close in time to the original learning task, could produce retroactive interference by disrupting the perseveration-consolidation process. (See MEMORY CONSOLIDATION.)

That subsequent activity could cause forgetting by disrupting a consolidation process seems plausible, especially given the evidence that certain traumas, such as electroconvulsive shock or a head injury, can produce retrograde amnesia (loss of memory for events occurring just prior to the injury), and that a period of sleep after a learning session produces less forgetting than does a comparable period of waking activity. The consolidation idea proved unsatisfactory, however, as an explanation of most, if not all, forgetting. Among its inadequacies are the following: (1) It cannot explain why, even long after the perseveration-consolidation process should be complete, interpolated learning nonetheless produces substantial retroactive interference; (2) it cannot explain why increasing the intensity of entirely unrelated interpolated activity results in little or no increase in forgetting; (3) it does not provide a natural account of the important role of intertask similarity in forgetting; and (4) it does not explain proactive interference.

Decay. An explanation of forgetting that seems particularly plausible was put forth by Edward THORNDIKE (1914) as his so-called *law of disuse.* The thrust of his "law" is straightforward: Unless we continue to access and use the memory representations corresponding to skills and information, those representations decay. Learning processes create memory representations, and practice maintains those representations; they fade with disuse.

However much the decay theory is in general agreement with our introspections as to how memories are formed and lost, it proved entirely inadequate as a theory of forgetting. Thorndike's law was thoroughly discredited in a devastating critique by John MCGEOCH (1932). Among the problems with the theory are (1) that forgetting is a function not simply of disuse across some retention interval but also of the nature of the activity in that interval (particularly its similarity to what is being remembered); (2) that information appears not to be lost from memory in some absolute sense, as implied by the theory, but, rather, becomes nonrecallable except under special circumstances; and (3) that it does not account for proactive interference.

The Emergence of Interference Theory

As an alternative to the consolidation and decay ideas, McGeoch (1932, 1942) put forth the initial version of what came to be called *interference theory.* That theoretical framework, as modified and refined over subsequent decades, constitutes the most significant and systematic theoretical formulation in the field of human learning and memory.

Reproductive Inhibition. McGeoch argued that human memory is fundamentally associative—that recall is guided by *cues* or *stimuli* to which items in memory are associated. As a consequence of a given individual's various experiences, however, multiple items in memory (responses) may become associated to the same cue. Recall of a given target response to a given cue, then, can suffer competition from other responses associated to that cue. Such competition, according to McGeoch, produces forgetting through *reproductive inhibition:* Recall of the target response is blocked or inhibited by the retrieval of other responses associated with that cue. Those other responses may have been learned before or after the response in question (proactive and retroactive interference, respectively), and—as observed—such interference should be a function of intertask similarity across learning episodes.

Another factor in forgetting, according to McGeoch, is that the stimulus conditions existing at the time recall is tested will differ to some extent from the conditions that existed during training. Such differences are likely to increase as the interval from training to test grows longer; and to the degree the stimulus conditions at test *do* differ, they will become less effective as cues for the response that was the target of training.

Unlearning and Spontaneous Recovery. In a pivotal study, Melton and Irwin (1940) took issue with McGeoch's analysis of retroactive interference. In their experiment, subjects learned two similar lists of verbal items and then were asked to relearn the first list. They found that the retroactive interference caused by the second list was, as predicted, an increasing function of the number of learning trials on the second list, but that the frequency of overt intrusions of second-list items during the relearning of the first list (a measure of response competition) actually *decreased,* given high levels of training on the second list. They argued that response competition at the time of test could not be the sole factor contributing to retroactive interference. They proposed a second factor: *unlearning* of first-list responses during second-list learning. Their (somewhat bizarre) idea was analogous to a basic result in the animal-learning literature: that learned responses are gradually extinguished when no longer reinforced by a reward of some kind. From that perspective, intrusions of first-list responses during second-list learning constitute unreinforced errors.

As if the unlearning idea were not strange enough by itself, it had an additional counterintuitive implication. Responses that are extinguished in animals show *spontaneous recovery* over time. To the degree that unlearning is truly like the extinction of learned responses in animals, unlearned responses should recover—become more available in memory—as time passes following the retroactive learning episode. Such an implication seems to violate a law of memory: that items in memory become less available with time. However unintuitive the unlearning/spontaneous recovery idea may seem, research carried out over the 20 years or so following the Melton and Irwin (1940) paper provided unambiguous support for the basic idea (see, in particular, Barnes and Underwood, 1959; Briggs, 1954; Underwood, 1957).

By the late 1960s the basic interplay of proactive and retroactive interference had become clear. The dynamics of that interplay are summarized below. More complete versions of the history and final state of "classical" research on interference and forgetting are available in Klatzky (1980), Bower and Hilgard (1981), Crowder (1976), and Postman (1971). In that order, those chapters are appropriate for the increasingly ambitious reader.

The Dynamics of Interference and Forgetting

Figure 1 summarizes the dynamics of interference and forgetting as presently understood. Assume that the original learning episode involves learning to associate each member, B, of a set of responses with a particular member, A, of a set of stimuli. Assume further that the new (interpolated) learning episode involves associating each member, D, of a different set of responses with a particular member, A′, of a set of stimuli that may vary from being only generally similar to the A stimuli to being essentially identical. At the time memory is tested, assume that a given member of stimulus set A or A′ is presented as a cue for the associated B or D response.

The A-B, A′-D notation is meant to be interpreted quite broadly. A given stimulus might be a person's face and the response that person's name, for example, and the number of A-B and A′-D pairings to be learned might vary from one of each to some large number (as in the case of a grade-school teacher learning the names of the students in each year's class). In certain cases the stimulus might actually correspond to a configuration of stimuli and the response might be a coordinated set of verbal or motor responses (A-B and A′-D, e.g., could refer to learning to operate two different automobiles, the first in the United States and the second in England). The time course of the A-B and A′-D learning episodes might vary from brief to very extended (as would be the case if A-B denotes learning to label objects in a first language and A′-D denotes learning to label those same objects in a second language).

Unlearning

During the new learning episode (A′-D), competing responses from the original learning episode (A-B) are gradually suppressed or extinguished. Such suppression facilitates A′-D learning by reducing the negative transfer from competing B responses, but it also impairs any subsequent efforts to recall B responses. On the basis of a considerable body of research (particularly McGovern, 1964; Postman et al., 1968), it appears that—depending on the relationship of the stimulus-response pairings in the two learning episodes—one or more of three distinct types of unlearning may take place. Forward associations (from A to B) can be unlearned (which facilitates A′-D learning), backward associations (from B to A) can be unlearned (which would, e.g., facilitate C-B learning, where C denotes stimuli that are not similar to A), and the entire set of B responses can be suppressed (which would aid A′-D or C-D learning).

Spontaneous Recovery

During the retention interval following A′-D learning (typically filled with other real-world activities

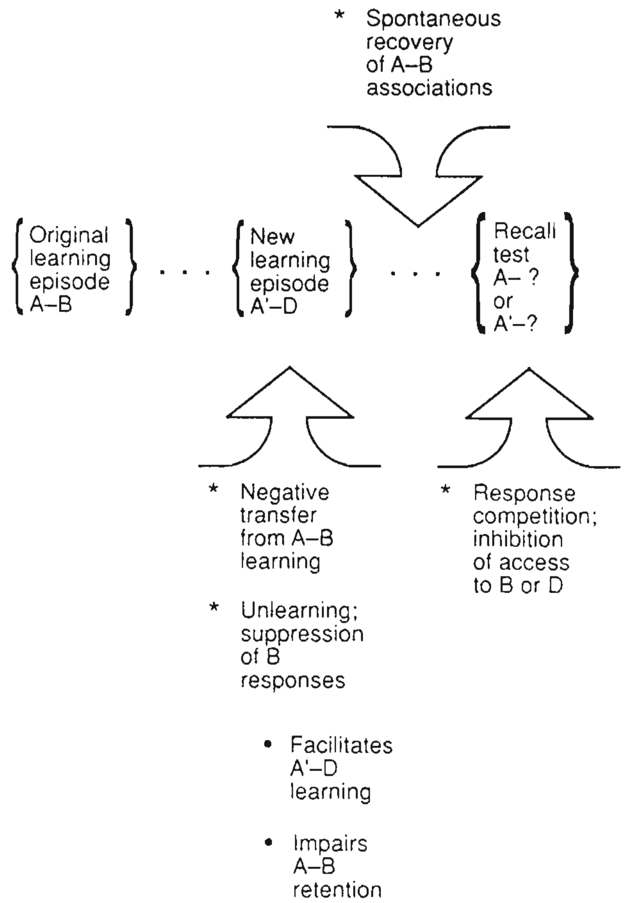

Figure 1. Summary of the processes underlying proactive and retroactive interference; A-B and A′-D denote associative learning tasks in which A and A′ are similar or identical stimuli and B and D are different responses.

on the part of the learner) the A-B associations that were suppressed during A′-D learning gradually recover in strength. Any other preexperimental associations to a given A or A′ stimulus that may have been learned prior to A-B or A′-D learning will recover in strength as well.

Thus, at the end of A′-D learning, the D responses will be highly accessible in memory and the B responses will be relatively inaccessible (the exact ratio of B and D strengths will depend, of course, on the initial levels of A-B and A′-D learning, and on the overlap of the A and A′ stimuli). As the retention interval from the end of A′-D learning increases, however, the pattern changes: The D responses become less recallable as the interval increases, and the B responses become relatively or absolutely more recallable. Whether the B responses themselves become more recallable in *absolute* terms appears to depend on whether those responses are also in competition with other (recovering) responses learned prior to the A-B episode. If a given A-B association is itself subject to proactive interference from one or more prior associations (A-E, A-F, and so forth), recall of the B response will tend to decrease, not increase, as the retention interval increases.

As the B responses (and any other prior associations to a given A′ stimulus) recover, recall of the D responses will suffer increasing proactive interference. One implication of such recovery is that the rate of forgetting of D responses after A′-D training should be a function of the number of preceding similar lists a subject has learned. In an analysis of the results of many experiments reported in the literature, Underwood (1957) found striking support for that prediction.

Response Competition

At the time a given A or A′ stimulus is presented as a cue for recall of the appropriate B or D response learned earlier, that target response will be in competition with any other responses associated to that stimulus. The impact of that competition is to inhibit access to the target response in memory. In general, recall of a given target response will decrease as the number and strength of competing responses increases. That generalization, in more modern terms, is the *cue-overload principle* (Watkins and Watkins, 1975). In the analysis of such response competition, however, an important distinction is relevant. It is the *functional* stimulus, not the *nominal* stimulus, that cues the retrieval of items in memory. Thus, A and A′ may be nominally identical or highly similar stimuli, but if the learning episodes involving those stimuli differ substantially—in terms of the environmental, temporal, or social context, or even in terms of the learner's emotional or physical state—the functional encoding of those stimuli may differ markedly. Thus, any stimulus, together with the context in which it is embedded, offers the learner a variety of aspects that may be "sampled" (Estes, 1955) or attended to, and that process determines the functional encoding of a given stimulus.

Consistent with the foregoing analysis, the degree to which different learning episodes result in later response competition depends on how discriminable—on one basis or another—those episodes are from each other at the time of test. The more such episodes are separated from each other temporally, for example, the less they will interfere with each other (Underwood and Ekstrand, 1967).

Output Interference

The results of somewhat more recent research add to the picture sketched above. There is abundant evidence that the recall process alters the relative accessibility of items in memory. The act of recall is itself a learning event in the sense that an item recalled in response to a given cue becomes more recallable in the future. One consequence of such response-produced strengthening of future access to recalled items, however, is that other items associated with that cue may become less recallable. That is, the recall process can alter the pattern of relative access strengths across the set of items associated to a given cue.

Consistent with the foregoing argument, there is evidence that recall is a "self-limiting process" (Roediger, 1978). When we attempt to recall the members of a category or list of items, we have difficulty recalling all the items in that set that actually exist in memory because the early items we recall impede the recall of subsequent items; by virtue of their having been recalled, the early items become more accessible in memory and block access to yet-to-be-recalled items.

Similar dynamics are probably at work in the inhibitory consequences of *part-list cuing.* When some members of a list or category of items are presented to subjects as cues to aid their recall of the remaining items, the recall of those remaining items is typically hindered rather than helped. Such inhibitory effects, considered an "enigma" in memory research (Nickerson, 1984), are at least in part a consequence of the cued items becoming *too* available in memory.

Concluding Comments

The processes of interference and transfer are fundamental to human learning, memory, and performance. After a period of almost 20 years during which research on interference and forgetting was not a dominant theme in experimental psychology, there has been a striking resurgence of interest in such phenomena over the last several years. Several contributing factors in that resurgence can be mentioned. First, there is renewed evidence of and appreciation for the role inhibitory processes play in human cognition. Second, in certain applied fields, such as research on memory factors in advertising and witness testimony, there is a need to understand how successive inputs to memory compete and interact. In research on witness memory, for example, an issue of intense current concern is how memory representations are modified by misleading postevent information (see RECONSTRUCTIVE MEMORY). Third, among researchers who are working to implement and test various types of mathematical and computer models of human memory, there is a growing realization that any plausible model must account for the basic patterns of proactive and retroactive interference (see, e.g., Mensink and Raaijmakers, 1988).

As a final comment, it is important to emphasize that forgetting is not simply a failure or weakness of the memory system. In terms of the overall functioning of the system, there must be some means to restrict what is retrieved in response to a given cue: Information that is out of date or inappropriate needs to be suppressed, or segregated, or eliminated in some fashion. During the attempt to recall one's home phone number, or where one left the car, for example, it is not useful to retrieve one's prior home phone number, or where one left the car yesterday or a week ago. In short, in terms of speed and accuracy of the recall process, we do not want *everything* that exists in our memories to be accessible, especially given the essentially unlimited capacity of human memory.

From that perspective, there are clearly some adaptive functions of the interference mechanisms that underlie forgetting. As we learn and continue to use new information, for example, access to the out-of-date information it replaces is inhibited. Such retrieval inhibition has several advantages over the kind of destructive updating of memory characteristic of computers (see Bjork, 1989). Because the old information is inhibited, it will tend not to interfere with the recall of the new information; because that information still exists in memory, however, it will tend to be recognizable and readily relearned should the need arise. And should we stop using the new information (e.g., how to drive in Britain), there will be some recovery of the old information (e.g., how to drive in the United States), which will often be adaptive as well.

In general, it appears that differences in accessibility across the vast number of items in memory acts as a kind of filter. The information and skills most readily accessible in our memories will tend to be those we have been using in the recent past. On a statistical basis, those are the same skills and knowledge we will tend to need in the near future.

(See also FORGETTING.)

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