

## **Interference theory: History and current status**

Colin M. MacLeod

*University of Waterloo*

Correspondence to:

Colin M. MacLeod  
Department of Psychology  
University of Waterloo  
Waterloo, Ontario N2L 3G1  
CANADA

[cmacleod@uwaterloo.ca](mailto:cmacleod@uwaterloo.ca)  
(519) 888-4567 ext. 32922

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**Abstract**

Interference profoundly influences learning and remembering, functioning as the major cause of forgetting. This chapter surveys the history of research on interference in learning and memory from the earliest empirical work at the dawn of experimental psychology to the most recent work in cognitive modelling. Several forms of interference at the time of learning are examined, most notably proactive and retroactive interference, which are respectively negative influences from learning that took place before or after a target episode. Also considered is interference that takes place at the time of remembering, notably output interference. Other mechanisms that may contribute to forgetting—in particular decay and inhibition—are briefly considered, and the role played by changes in context is highlighted. Overall, the goal is to characterize how interference influences both learning and remembering.

**Keywords**

interference; learning; remembering; forgetting; memory; proactive interference; retroactive interference; decay; inhibition; context

In 1967, John Ceraso opened his *Scientific American* article on interference and forgetting with an often repeated maxim credited to David Starr Jordan, the first president of Stanford University in the 1890s. Ceraso wrote that “An anecdote that has amused many psychologists concerns the professor of ichthyology who complained that each time he learned the name of a new student he forgot the name of a fish” (Ceraso, 1967, p. 11). Ceraso saw this story as “aptly illustrat[ing] the interference theory of forgetting.”

Everyone is also aware that when we try to remember a specific episode, all too often we instead recover something else—likely related in some way but not what we were looking for. This typically is a frustrating experience, particularly when repeated attempts produce the same incorrect answer. Interference would seem consequently to be a fundamental fact of memory. But what do we know about the role of interference in learning and remembering? How does it work and how important is it? The purposes of this chapter are, first, to portray how our understanding of interference in memory has grown and changed over the more than a century that interference has been empirically studied and, second, to characterize our current understanding of the concept. To begin, then, how and when did the influence of interference first enter thinking about and studying memory?

With his wax tablet metaphor for memory, Plato (1953) certainly recognized the possible disruption of an earlier impression by a later one, presaging what we now call retroactive interference. He also describes in the *Phaedrus* (Plato, 2005) how Socrates thought that writing would destroy memory and weaken the mind (Ong, 2002), possibly by interfering with the actual memory, presaging research on interference and reconstructive memory. About two millennia later, Descartes was even more clearly aware of the important role of interference in memory. In *L'Homme* (Descartes, 1662, p. 141, II.II.4), he wrote that “When the mind wants to open certain

traces but encounters other more familiar ones crossing them, it is misled.” Indeed, in an earlier letter on June 11, 1640, he wrote very plainly that “There is no doubt that the folds of the memory get in each other's way” (both of these quotations come from Sutton, 1998, pp. 111 and 64, respectively). Interference as a theoretical concept, then, appeared long ago.<sup>1</sup> On the empirical front, Ebbinghaus (1885) certainly was aware that one of his lists of nonsense syllables could intrude on another, given that he created nonsense syllables to avoid the influence of meaning that would be prevalent were he to have used words as stimuli. It was not long before researchers following up on Ebbinghaus’s seminal work began to explore interference directly in rigorous experiments.

### **Interference: The early years**

In 1893 and 1894, John Bergström published two articles exploring what he termed the “interference of associations” (Bergström, 1893, p. 356). In so doing, he would appear to be the first to have reported empirical studies of interference in memory. He set the problem as studying how “in changing from an accustomed way of doing a thing to a new way, the old habit resists displacement” (Bergström, 1893, p. 356). Today, we call this *proactive interference*—the cost to subsequent learning of prior learning; the top part of Figure 1 illustrates the general procedure for studying proactive interference. It is intriguing that this less intuitive form of interference—interference from before the target learning, not after it—was the first to be studied empirically, so perhaps not surprising that it did not reappear as a subject of study for several decades (Whitely, 1927). The actual term proactive interference was apparently first used by Maslow (1934b)—as *proactive inhibition*—and despite some relevant intervening research, the importance of the concept really did not come to the fore until the much later influential article by Underwood (1957).

Bergström's experiments were admirably simple (see also Kline & Owens, 1913; Pyle, 1919). He timed people sorting decks of 80 cards, each card containing one of 10 simple words or pictures, into piles according to the card content. He then had them sort the reshuffled deck again, but this time the locations of the piles were rearranged. What he observed was that the second sort took considerably longer than the first, with people frequently making errors of perseveration from the first sorting pattern. To ascertain whether the cost on the second sort was due to interference or fatigue, he introduced a control condition: He gave people two decks containing different words or pictures and again had them do the two sorting tasks. Observing virtually no difference in sort time when the items to be sorted were different on the two sorting tasks, he concluded that the problem in the initial situation was interference. By manipulating the time between the two sorts from 3 seconds to 8 minutes, he also noted that the amount of interference declined systematically as the interval increased. Bergström (1894, p. 441) concluded that "As regards the nature of the process, it has been shown that we are dealing with the interference of still persisting associations and not with the results of their effacement."

INSERT FIG 1 ABOUT HERE

Also in 1894, John Bigham reported several empirical studies of memory conducted with the following goal: "The special question is the influence of the time-interval between learning and recollection with regard to its length and its filling" (Bigham, 1894, p. 353). In his initial experiment, he presented series of 10 items either auditorily or visually, the items being digits, forms, colors, words, and syllables. He recorded errors of reproduction from memory as a function of time—an unfilled retention interval—from 2 to 10 to 30 seconds, finding a steady decline in performance: "The longer the unfilled interval between learning and recollecting, the weaker is the memory" (p. 455). But noting that "unfilled intervals represent a rare and artificial

condition for our memory,” (p. 458), he went on to carry out further experiments. Here, after the 10 items were displayed, subjects experienced three different conditions before being tested: (1) they read newspaper stories, (2) they had those stories read to them, or (3) they did neither.

Across 2, 10, 30, or 60 seconds of intervening activity, he observed more forgetting with intervening activity, concluding that “The filling of the intervals hinders the memory” (p. 459).

Remarkably, he even reported that there was specificity to the interference: “The most effective disturbance to recollection is homogeneous to the sense employed in perception” (p. 359). The only thing that Bigham did not do was name this filled-interval phenomenon: That had to await a much better known paper six years later.

In 1900, Georg Müller and Alfons Pilzecker introduced the concept of consolidation—the idea that fixing learning in memory is not immediate but rather requires active perseveration subsequent to exposure (see Lechner, Squire, & Byrne, 1999, for a summary of the Müller and Pilzecker article; see Moscovitch, this volume, and Nadel & Sederberg, this volume, for more on consolidation). Müller and Pilzecker used Ebbinghaus’s (1885) nonsense syllables as materials to investigate consolidation, which they saw as predicting that information should be vulnerable to interference in the period between experiencing it and fully consolidating it. They noted reports from the people in their experiments that previous syllables would sometimes come to mind instead of current ones, which they termed “perseveration.” To explore this, they had people in two groups study a list of paired nonsense syllables.<sup>2</sup> One group then studied a second list (or, in some experiments, three landscape paintings which they described) whereas the other group had no events intervening between study and test. The poorer memory for the syllables when another activity intervened substantiated people’s claims, providing clear evidence of interference. [Over the years, these two learning phases came to be called initial/original

learning and interpolated learning, with the test of interest when examining retroactive interference being for the initially learned material.] Müller and Pilzecker called the phenomenon “Rückwirkende Hemmung,” literally “retroactive inhibition,” thereby being the first to define *retroactive interference*—the cost to prior learning of subsequent learning.<sup>3</sup> The bottom part of Figure 1 illustrates the general procedure for studying retroactive interference.

It is abundantly apparent today that interference exerts a powerful influence on memory and is probably the principal cause of forgetting, whether over the short term or the long term. Proactive and retroactive interference (for classic definitions, see Melton & Irwin, 1940, pp. 173-174, footnote 2) remain the two most obvious and influential varieties of interference but others—notably output interference—also play critical roles. Shortly, consideration will turn to the history of the phenomenon and the concept, but first brief consideration of the principal early alternative to interference is warranted.

### **Forgetting conceived as decay**

There are two “watersheds” in the growth of interference as a crucial mechanism underlying forgetting: John McGeoch’s paper in 1932 emphasizing the key role of retroactive interference and Benton Underwood’s paper in 1957 emphasizing the key role of proactive interference. Until McGeoch’s paper, as he charmingly put it: “There are no warmly discussed theories of forgetting” (McGeoch, 1932, p. 352). Instead, it had long been an article of faith that forgetting was the result of time, time during which memories were not refreshed and consequently faded (see. e.g., Baldwin & Shaw, 1895). This was most clearly expressed in Thorndike’s (1914, p. 4) *law of disuse*: “When a modifiable connection is *not* made between a situation and a response during a length of time, that connection's strength is decreased.” Today,

we would call this the decay theory—that memories unretrieved over time consequently become progressively less retrievable.

The problem with decay theory is that it posits time itself as an explanation. Of course, decay could contribute to forgetting, but this is difficult to ascertain given the possibly insurmountable problem of eliminating all potentially interfering events and activity during a retention interval to avoid confounding decay and interference (see Reitman, 1974; Nairne, 2002; Oberauer & Lewandowsky, 2014). McGeoch (1932, p. 369) expressed this problem forcefully: “Ascription of effectiveness to time violates the usage of science and is logically meaningless.” Rather, he argued, “[I]nterpolated activities and changed stimulating conditions are the significant factors in the production of forgetting, factors which disuse, when it is correlated with functional loss, gives a chance to operate” (McGeoch, 1932, p. 356).<sup>4</sup> From this landmark paper on, interference became the dominant explanation of forgetting. This is still true today, although today we do not emphasize retroactive interference to the exclusion of other forms of interference, most notably proactive interference.

### **The beginning of empirical research on interference**

To preface this historical section, a note on terminology is warranted. As Stroop (1935, p. 643) wrote in the opening sentence of his dissertation, the classic article on color-word interference, “Interference or inhibition (the terms seem to have been used almost indiscriminately) has been given a large place in experimental literature.” In the early days, the term “inhibition” was indeed used quite interchangeably with the term “interference,” leading to the two terms becoming essentially synonymous in the literature for decades. A decade later in his own dissertation, Osgood (1946, p. 277, footnote 1) also spoke out on this issue: “Interference is a better term here than inhibition. As it is used in these connections (cf.



McGeoch), the term refers to an observed decrement in learning or recall and not to a process. The observed decrement may or may not be due to inhibition. Henceforth in this paper the term 'interference' will mean observed decrement and the term 'inhibition' will be reserved for the psychological process.” As a consequence of this decision, Osgood was also the first to use the actual terms *proactive interference* and *retroactive interference*.<sup>5</sup> Although replacing the word “inhibition” with the word “interference” in these two contexts really did not become the more common designation until the early 1960s, in this chapter the word “interference” will be used consistently, the arguments of Stroop and Osgood being seen as convincing.

We now generally recognize that interference and inhibition are different concepts, as will be evident from comparison of this chapter to the chapter by Marsh and Anderson (this volume). The term “interference” sometimes is used atheoretically to stand for the to-be-explained empirical phenomenon of a cost in memory performance, but it also sometimes is used as the label for a theoretical concept in its own right: The mechanism underlying the performance cost is the conflict created by some non-target information during encoding or retrieval of some target information. The term “inhibition,” however, is typically reserved today for an explanatory concept that describes the hypothetical mechanism whereby some target information is itself actually weakened due to competition from some non-target information (see Anderson, 2003; MacLeod, 2007; MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003).<sup>6</sup>

With Bergström (1893, 1894), Bigham (1894), and especially Müller and Pilzecker (1900) as foundations, studies of interference quickly became a regular feature of research on memory, indeed generalizing beyond memory to the acquisition of concepts, for example (e.g., Gengerelli, 1927). Despite Bergström’s initial foray, the work in the first half of the 20<sup>th</sup> century was overwhelmingly on retroactive interference, certainly the more intuitive form of

interference. As McGeoch (1932) notes, the early work was also primarily empirical. It is useful, consequently, to divide the first 60 years of the last century in half (roughly coincident with McGeoch's 1932 paper and Britt's 1935 review), separating the early empirical work from the subsequent more theoretically driven work.

### **1900-1930: The empirical foundation of retroactive interference**

Surprisingly, based on an extensive series of experiments, DeCamp (1913, p. 67) concluded "that the influence of retroactive inhibition is fairly unimportant and has been given too great prominence among psychological principles." This may in part have resulted from his use of quite different materials in the initial study phase (nonsense syllables) and subsequent interference phase (multiplications)—although others have certainly observed retroactive interference with quite different materials, going all the way back to Müller and Pilzecker's experiments with nonsense syllables at study and descriptions of landscape paintings as subsequent interference. DeCamp's study was not an isolated failure to observe retroactive interference, though: Despite most of his experiments providing evidence of retroactive interference, Tolman (1918) also did not observe retroactive interference in some of his experiments (see also Webb, 1917). Understanding interference still had a long way to go both in terms of the methods of study and the explanation of patterns of results.

More heartening was the work of Heine (1914), conducted in Müller's lab. Using nonsense syllables as the target original material, and pictures, numbers, or consonants as the interpolated material (compared to a period of rest), she showed in an extensive series of experiments that when the final test was recall, retroactive interference was robust, but when the final test was recognition, retroactive interference was never evident. This pattern provided a key clue for later theory development. Heine, interestingly, was also the first to demonstrate that

retroactive interference was reduced when the studied target material was followed by a period of sleep relative to a period of waking. But a study published a decade later would become much better known for this finding.<sup>7</sup>

Jenkins and Dallenbach (1924; see also Van Ormer, 1932) set out to demonstrate (1) that time by itself does not cause forgetting, and (2) that interference is a potent factor in forgetting. In so doing, they provided one of the key pieces of evidence that led McGeoch (1932) to argue for the overriding importance of interference. Their two student subjects (H and Mc) lived and slept in the laboratory, and functioned normally during the day. The lists were presented for study at several times during the night and day and were tested at several retention intervals—after either a period of waking or a period of sleeping. Figure 2 displays their data in the original graph: Forgetting rate was dramatically less when followed by sleep than when followed by waking. The concluding sentence of Jenkins and Dallenbach was crystal clear: “[F]orgetting is not so much a matter of the decay of old impressions and associations as it is a matter of the interference, inhibition, or obliteration of the old by the new” (p. 612).

INSERT FIG 2 ABOUT HERE

Müller and Pilzecker (1900) had made the counter-intuitive claim that the extent of retroactive interference was not a function of the similarity of the two sets of material—the initially studied material and the subsequently interpolated material. After conducting many experiments, Ranschburg (1905) argued that the learning and retention of lists was impaired more as the similarity of items on the lists increased. His experiments were, however, largely ignored initially, and it took a decade for others to reach the same, more intuitive conclusion (e.g., DeCamp, 1915). Robinson (1920) sought to explore this issue in greater detail because the small body of existing research had not been consistent. He had subjects spend 3 minutes

studying a set of 4-digit numbers, after which they did 3 minutes of one of 5 types of interpolated activity—studying more 4-digit numbers, multiplying 4-digit numbers, studying consonants or poetry, or reading prose (which he saw as most like a resting control condition). His 15 subjects performed all 5 conditions and he even did some counterbalancing. At the time of recall, he recorded errors and total response time. Simplifying, he showed that only the study of additional interpolated numbers produced considerably poorer recall of the originally studied numbers than did any of the other conditions, and concluded that interpolated learning had to be “highly similar” to result in reliable interference. He confirmed this in a second experiment including additional types of interpolated material: Again, only the highly similar materials produced reliable interference. In a third experiment, he showed a similar specificity of interference in examining memory for chess pieces (see also Skaggs, 1925).

Overall, Robinson (1920) concluded that “The degree of retroactive inhibition present in a given situation is a function of the similarity between interpolated activity and original learning,” (p. 51), but he asserted that measuring similarity was an exceedingly difficult proposition and that even interpolated material superficially dissimilar to the target material could cause interference. His work foreshadowed a vast enterprise to come in the interference literature examining degree of similarity effects, although Robinson (1927) himself came to doubt that similarity could be sufficiently quantified to make studying its influence on retroactive interference a tractable issue. This domain of research is reminiscent, at a deeper level, of the near vs. far transfer work in skill acquisition (see, e.g., Barnett & Ceci, 2002, for a review and Taatgen, 2013, for a theoretical analysis), where similarity is also a thorny issue. Pan and Bjork (this volume) review the related topic of contextual interference.

One other issue loomed large in this first epoch—the influence of the time between the target event and the interpolated event. This had been of interest to Müller and Pilzecker (1900) so it, too, was taken up by succeeding investigators. Although Robinson (1920) found no difference in interference moving from 5 to 10 to 15 minutes between the two events, that may well have been because these gaps were too large: Spencer (1924) found greater interference with a 9-second gap than with a 20-minute gap, and Skaggs (1925) also found more interference with immediate than delayed succession of events. Thus, research on the degree of interference as a function of the two most obvious variables—similarity and time course—was well under way as the second epoch of work on retroactive interference began.

### **1900-1930: The early theories of retroactive interference<sup>8</sup>**

#### *Perseveration theory*

Britt (1936) reviews the early accounts of interference and forgetting, considering three main explanations. The first of these was the *perseveration theory* of Müller and Pilzecker (1900). They theorized that the processes underlying perseveration and those underlying interference (retroactive inhibition) were effectively the same. After learning, the neural activity involved in that learning does not stop; rather, it gradually decreases as the newly learned information settles into memory. They viewed this post-learning period—consolidation—as critical to the eventual memory but also as a time of vulnerability (see Moscovitch & Gilboa, this volume, and Nadel & Sederberg, this volume, for more on consolidation). Consequently, new events could interfere with consolidation, reducing what was retained. In their view, the degree of interference was determined by the difficulty of the interpolated information and how soon after learning it occurred, with earlier and more difficult processing resulting in greater interference. Skaggs (1925, 1926) provided evidence that he saw as supporting this account.

### *Transfer theory*

Although the perseveration theory was prevalent early in the 1900s, others came to contest the basis of the interference. The second theory put forward, *transfer theory* (DeCamp, 1915) was essentially a variant of perseveration theory, sharing the idea of a critical period following learning in which interference operated. But DeCamp saw the active ingredient in interference not as difficulty but as similarity, a view that was soon supported by Robinson's (1920) studies and that came to be the dominant perspective on interference.

The third account, proposed by Webb (1917) questioned the paramount importance of the period immediately following learning. Essentially, Webb's account was a modification of transfer theory that deleted the consolidation piece and added a disruption piece. Webb recognized that interference could still exert a considerable influence well after what was seen as a reasonable window for consolidation (see also McGeoch, 1933a,b), and that sometimes interference was greater after a longer than after a shorter retention interval, entirely inconsistent with perseveration theory (McGeoch & Nolen, 1933; Whitely, 1927). The disruption element recognized the negative transfer from the initial learning that operated during the interpolated learning; the transfer element recognized that the interpolated learning intruded when trying to recover the initial learning. Taken together, these two elements led to the prediction of strong similarity effects in retroactive interference, for which the evidence continued to mount (e.g., Gengerelli, 1934; Johnson, 1933; McGeoch & McDonald, 1931). It was this third account that was most favored by Britt (1936), also in part because of the close connection between this account of interference and transfer effects more broadly. It is also worth noting that Webb's account was effectively the first two-process explanation of interference, prefacing the theories to follow in the next epoch.

## 1930-1960: The growth of theory concerning retroactive interference

### *McGeoch's two-component transfer theory*

A major shift in thinking about forgetting as due to interference began with the theorizing of John McGeoch (1932), clearly influenced by Webb (1917) and grounded in studies of paired associate learning. A picture of McGeoch appears in Figure 3. McGeoch's contribution, also referred to as a transfer theory or as a response competition theory (see, e.g., Anderson, 2003), was a two-component account of forgetting: retroactive interference and change in context between learning and remembering. Interestingly, he recognized that forgetting had to occur even during learning—not only after learning—because that was how the learner eliminated incorrect or provisional steps during learning. He also marshalled the phenomena of spontaneous recovery and reminiscence, among others, to counter the ideas of disuse and decay. And he was very taken with the Jenkins and Dallenbach (1924) study of sleep after learning as pointing to the critical role of retroactive interference,<sup>9</sup> paralleled by the lesser-known study of Spight (1928) showing that sleep before learning also was beneficial, although McGeoch did not reflect further on this illustration of proactive interference. Most of his article was an argument for the critical role of retroactive interference in forgetting, as he summarized (p, 364):

“Forgetting is, then, not a passive matter, but a result of an active interference from interpolated events.”

INSERT FIG 3 ABOUT HERE

McGeoch's (1932) second component presages such ideas as cue-dependent forgetting (Tulving, 1974) and the importance of context to memory (Smith, 1988; Smith & Vela, 2001), as well as relating to models of retrieval that emphasize relative strength (e.g., Anderson, 1983). Here is how McGeoch put it (p. 365): “forgetting, in the sense of functional inability or loss,

may result from a lack of the proper eliciting stimulus, even when interpolated events have not been such as to bring the material below the threshold of recall at the time.” Thus, even without interference, if the cues at the time of remembering are inadequate, forgetting will be evident. And the presence of the right cue(s) can be seen as providing a supportive context for remembering (p. 365): “At least until learning has been carried far beyond the threshold, the learner is forming associations, not only intrinsic to the material which is being learned, but also between the parts of this material and the manifold features of the context or environment in which the learning is taking place.” Interference will be greater to the extent that more responses compete to be the one produced to a particular stimulus. McGeoch appears to have been the first to emphasize in theory the powerful role that context plays in remembering (but see Pan, 1926, for a precursor), which led subsequent researchers to explore how context similarity between initial learning, interpolated learning, and subsequent remembering influenced interference (e.g., Dulsky, 1935; Nagge, 1935). Figure 4 illustrates McGeoch’s theory of forgetting.

INSERT FIG 4 ABOUT HERE

### ***Melton and Irwin’s two-factor theory***

Eight years later, Melton and Irwin (1940) proposed their classic *two-factor theory* of forgetting, the two factors being competition and unlearning. A picture of Arthur Melton appears in Figure 3. The idea of competition was of course already well ensconced, having been at the core of the transfer theory of interference and forgetting (see DeCamp, 1915): That the different responses to the stimuli on the two lists competed with each other seemed self-evident. But on the basis of their experiments, Melton and Irwin argued that there had to be another influence—a “Factor X.” A key piece of evidence for this proposal came from manipulation of the number of trials on the interpolated list and subsequent observation of performance on the



ultimate test for the initial list. As the number of trials on the interpolated list increased, retroactive interference with the initial list increased yet overt intrusions from the interpolated list decreased. If competition was the whole story, why were there not more intrusions from the interpolated list when it had been studied more and was clearly increasingly disrupting retrieval of the initial list? Another process had to be involved and they proposed that this missing process was unlearning.

INSERT FIG 5 ABOUT HERE

Leo Postman and Benton Underwood were to become two of the major figures in the study of interference and its influence on learning and memory. Pictures of them appear in Figure 5. In their review of interference theory, Postman and Underwood (1973) highlighted the two characteristics that defined the unlearning—that the initial list became less available on a test subsequent to an interpolated list (vs. no interpolated list or a control list), and that this unlearning of the initial list occurred during learning of the interpolated list. Melton and Irwin (1940) clearly saw this outcome as a consequence of reinforcement: The initial list responses would come to mind (either overtly or covertly) during learning of the interpolated list but, because they were now incorrect, they would be unreinforced (or even punished) and would hence decline. Retrieval of these incorrect initial list responses during learning of the interpolated list was also seen as delaying learning of the interpolated list due to negative transfer (Melton & von Lackum, 1941). Melton and Irwin's original graph of the operation of the two factors is shown in Figure 6.

INSERT FIG 6 ABOUT HERE

In the ensuing years, two-factor theory became the dominant account of retroactive interference and consequently of forgetting, which led to a proliferation of research on

retroactive interference and the factors that governed its presence and magnitude. Despite numerous challenges (see, e.g., Osgood, 1946), particularly to the unlearning principle, in their critical analysis of interference theory, Postman and Underwood (1973, p. 37) concluded: “We see no reasons at this time to abandon abruptly the concept of associative unlearning or to jettison response-set interference as a possible contributor to retroaction and perhaps proaction.”

Throughout the 1940s and 1950s, a very substantial body of research on retroactive interference built up, the bulk of it using paired associate lists and variations on transfer designs like those in Table 1. In that same period, studies of proactive interference rose in frequency, spurred initially by the work of Maslow (1934b) but then by the more concerted efforts of Melton (e.g., Melton & von Lackum, 1941), Underwood (1945), and Osgood (1946), among others. The next section of this chapter will cover the proactive interference work; the current section will continue to concentrate on retroactive interference.

A key prediction of two-factor theory derives from the following logic: If only competition exists, then the interference between the two lists should be equivalent; if, however, unlearning of the original list is ongoing during learning of the interpolated list, then memory for the interpolated list should be superior to that for the original list. Of course, this is tantamount to saying that retroactive interference should exceed proactive interference. This is indeed what Melton and von Lackum (1941) observed using serial learning; using paired associate learning, McGeoch and Underwood (1943) observed a muted version of this pattern (see also Underwood, 1945). Still, both research teams concluded that the data supported two-factor theory, a conclusion that Postman (1952) later agreed with in showing that both recall and recognition were well handled by the theory. Most of the work involved recall or relearning, but Peixotto (1947) had shown that retroactive interference also occurred in recognition.

Using a large range of intervals between original and interpolated learning—from immediate succession to 16 days apart—Postman and Alper (1946) explored when the influence of retroactive interference was greatest. They used an A-B, A-A' design and tested with relearning of the original A-B list. They observed that retroactive interference was greatest when the interpolated list was learned one day after original learning or immediately before testing, leading them to suggest that this was because unlearning maximized after one day whereas competition maximized immediately before recall. This is another finding that aligns well with two-factor theory. Underwood (1948) tackled the same problem differently, using an A-B, A-C design with the two lists learned in quick succession. After five hours, he observed that recall of the second list exceeded that of the first list but that the first list showed no forgetting after two days whereas the second list did, resulting in equal recall of the two lists after two days. Because intrusions increased from five hours to two days and were then greater in recalling the second list, Underwood suggested replacing the concept of unlearning with the concepts of extinction and spontaneous recovery.

Postman and Kaplan (1948; see also Postman, Egan, & Davis, 1948) appear to have been the first to use response time to measure retroactive interference in an A-B, A-C paradigm; they suggested that although the overall pattern in response time corresponded to that seen in accuracy, response time might also index separate aspects of processing. Also using response time as the dependent measure, Osgood (1948) suggested that the two-factor theory needed to be supplemented with another factor, a true inhibition factor in which learning to respond to a stimulus in a particular way necessitates also learning not to respond to it in the opposite way: He gives the illustration of learning to respond by clenching one's fist as also learning not to respond by opening one's hand. Intriguingly, although researchers in the era used the term

inhibition for interference, Osgood may have been the first to suggest an actual inhibitory process as part of the explanation (see also Rothkopf, 1957).

Jenkins and Postman (1949), following Postman and Postman (1948), underscored the importance of set—learning procedure—in determining the amount of retroactive interference. The two learning procedures that they used were anticipation and recognition. When the learning procedure was the same for the two lists, retroactive interference was greater than when the learning procedure differed between the two lists, a finding prefaced by Nagge (1935), who used visual and auditory modalities in one experiment and hypnotic and waking states in another experiment to make the same point. Quite likely, this early work provided the basis for Postman's later work where he proposed the concept of response set suppression.

Underwood (1945) had suggested that differentiation of the two lists had to be accomplished for the learner to be able to give the correct response. He thought that temporal and contextual cues might provide the basis for this differentiation and that as this differentiation broke down over time, interference would increase. Response set suppression (Postman & Stark, 1969; Postman, Stark, & Fraser, 1968) was proposed by Postman as a way to handle differentiation. Consider an A-B, A-C paradigm. To successfully respond C to A during interpolated learning was held to require suppressing the original set of B responses. Then, when retrieval of B responses was demanded, this would be difficult due to persisting suppression, resulting in retroactive interference. Similar to Underwood's idea, this suppression was hypothesized to decrease with retention interval so that eventually neither response set would be favored. But the mechanism of suppression was not specified. In their HAM model, Anderson and Bower (1972) argued strongly against response set suppression, relying instead on the

critical role of context. The different list contexts provided the differentiation, which was strong initially but then broke down over time as more contexts were encountered.

Not only the nature of the materials on the two lists mattered; their context was also relevant, supporting McGeoch's (1932) suggestion that context was important in determining interference. Bilodeau and Schlosberg (1951) had people learn lists in the same context (a single distinctive room) or in two different contexts (two different distinctive rooms). After learning the interpolated list, recall of the original list was better when the two lists had been learned in the different contexts, a finding later replicated by Greenspoon and Ranyard (1957). These studies represent early work on context and memory, a domain that has continued to attract significant research attention (Smith, 1988; Smith & Vela, 2001). Changing context buffers learning and memory against interference.

With the goal of generalizing the findings with respect to retroactive inhibition to more educationally relevant materials, Hall (1955) used fictional anthropological texts in a classroom setting in a kind of A-B, A-C design. Like McGeoch and McKinney (1934) two decades earlier, however, he was unable to produce differential retroactive interference between a group with a second interpolated text and a control group without the second text. Ausubel, Robbins, and Blake (1957) suggested on the basis of their data that proactive, rather than retroactive interference was more problematic in learning text material. But Slamecka (1960) concluded on the basis of his experiments that retroactive interference findings with unconnected materials such as word lists did generalize to text, arguing that the interference shrank as study of the original list increased and grew as study of the interpolated list increased.

Using the A-B, A-C design, Briggs (1954) had developed a procedure known as MFR, for "modified free recall," in which an A probe was occasionally presented during or after List 2

learning and participants were asked to produce the first response (either B or C) that came to mind. He showed that (1) for probes presented during List 2, List 1 responses gradually decreased as List 2 learning progressed, and (2) for probes presented after List 2 learning, there was evidence of spontaneous recovery of List 1 responses. Taken together, these findings suggested that List 1 was being extinguished during List 2 learning but, of course, producing the C response could just be stronger given its current focus, and the B response might still have been available in memory when only one response was requested.

In an important study, Barnes and Underwood (1959) took MFR a step farther, creating the "modified-modified free recall," or MMFR, procedure in which participants were given A probes during List 2 learning and were asked to produce *both* B and C responses. If extinction was truly occurring, then recall of C responses should increase and recall of B responses should decrease with A-C learning. That is precisely what they found (and Martin, 1971, later showed that recall of B and C responses was independent). In the Melton and Irwin (1940) competition-plus-unlearning account, then, there is clearly a critical role for the unlearning component, although Barnes and Underwood saw this as more analogous to extinction, where the response tendency is reduced but the response itself is not forgotten, than to unlearning, where the response undergoes actual loss in memory.

There is a really quite voluminous literature on retroactive interference in the period 1930-1960, comprising much of the work on human learning and memory during that time. The current section has, as a result, only scratched the surface; for more, see Slamecka and Ceraso (1960) and Postman (1961). In Postman's (1961, p. 152) review, he concluded that "Interference theory occupies an unchallenged position as the major significant analysis of the process of forgetting." It is fair to conclude that the two-factor theory reigned supreme in this

period and that the key factors of similarity and retention interval received detailed consideration. Postman and Underwood (1973) and Hall (1971) cover this work in more detail. Suffice it to say that retroactive interference has, as intuition readily suggests, a profound effect on memory. Considerably less intuitive, though, is the very substantial effect that proactive interference—the topic to be considered next—has on learning and remembering. What came before—not only what came after—can certainly influence the learning and memory of a target event. It will become increasingly evident, though, that the apparently simple distinction between interference from before (proactive) and interference from after (retroactive) is, like so many dichotomies, not as simple as it initially appears to be.

### **Proactive interference 1930-1960**

Despite Bergstrom's (1893) early introduction of proactive interference, the concept received little research attention until the 1930s. As mentioned earlier, Maslow (1934b; see also Maslow, 1934a) pointed out the potential role of proactive interference in a study where he varied the interval between two lists and showed that recall of the second list increased as the interval between the two lists lengthened. He proposed that proactive interference—a term apparently first used by him (as “proactive inhibition”)—co-occurred with retroactive interference, and that the proactive effect declined as the two lists were further separated in time. In their classic article proposing the two-factor theory of retroactive interference, Melton and Irwin (1940, p. 203), noting the intrusions from the first list during learning of the second list, described these as “overt signs of proactive inhibition of the learning of the interpolated list.”

The 1940s brought increased attention to proactive interference, even in domains such as memory for advertisements (Blankenship & Whitely, 1941). Ray (1945) observed that proactive interference initially increased and then decreased as the lag between the first and second lists

increased from no lag to 2 days, and then on to 2 weeks. This fit with the idea that proactive interference should be greatest not when the first list is highly accessible immediately after study or when it is minimally accessible after a long retention interval, but when its strength is intermediate. Bugelski (1948) demonstrated that intrusions from a first list were still apparent in a tenth list, evidence of continuing proactive interference. Intriguingly, he also showed a “sawtooth” pattern across sequences of lists, with even-numbered lists more poorly recalled than odd-numbered lists. This fit, he argued, with the unlearning view because learning of the second list would suffer simultaneously from having to unlearn the first list and from the proactive interference due to the first list. As a result, the second list would not be as well learned as the first and would consequently require less unlearning and would interfere less with the third list, and so on.

Studies investigated many of the same factors as had been investigated in the earlier retroactive interference work, factors such as item study time (Underwood, 1950), retention interval (Greenberg & Underwood, 1950), and response similarity (Morgan & Underwood, 1950). But the breakthrough came in 1957, with an article by Underwood.<sup>10</sup> In an earlier study, Greenberg and Underwood (1950; see also Underwood, 1945) had observed that recall of a critical final list was poorer to the extent that more lists had been experienced previously, and that the decline with number of prior lists was quite precipitous. What Underwood did was a kind of meta-analysis,<sup>11</sup> examining all studies that he could find in which a critical final list was learned and then tested after 24 hours, and for which information was available about the number of prior lists that had been learned. Underwood’s original graph is displayed in Figure 7 and shows a striking pattern, which he summarized this way: “I interpret this to mean that the greater the number of previous lists the greater the *proactive* interference” (p. 53).



INSERT FIG 7 ABOUT HERE

Underwood (1957) went on further to assert that previous reports of the rate of forgetting were dramatic overestimates—perhaps three times the actual rate—because participants had virtually always learned multiple lists before the critical one. His analysis overturned the picture of very rapid, extensive forgetting going back to Ebbinghaus (1885), who had of course learned vast amounts of information in his self-imposed experiments. Underwood concluded that “it seems plausible to assert that this amount of forgetting could be produced from learning which has taken place outside of the laboratory. Furthermore, it seems likely that such interference must result primarily from proactive interference” (p. 55). He also argued that “similarity with other material and situational similarity are by far the most critical factors in forgetting” (p. 58). In essence, he saw competition and context as the crucial variables in forgetting, just as his graduate advisor had argued a quarter of a century earlier (McGeoch, 1932). For Underwood, however, the story was very much about proactive interference, not only retroactive interference.

Underwood’s (1957) paper fostered continuing work on proactive interference right up to the present (e.g., Redick, Wiemers, & Engle, 2019). To illustrate, one study that fit the picture outlined here was that of Postman and Keppel (1977), in which they showed that proactive interference build-up was apparent only when testing was via recall. They took this to be because competition increased and list differentiation decreased over time, both factors that strongly influenced the retrieval processes so fundamental to recall. These are, of course, the very same processes postulated by earlier investigators (e.g., Underwood, 1945), processes that have also been crucial in the development of computational models, to be discussed in an upcoming section of this chapter.

## Interference in Short-Term Memory

As the 1950s came to a close, the information processing perspective was taking hold in human experimental psychology, soon to be renamed cognitive psychology (Neisser, 1967). Research in the tradition of interference theory was declining but there was one stronghold: short-term memory, a concept that attracted renewed interest after Broadbent's (1958) book. There had been a few earlier attempts to study interference in immediate/primary memory, but these were isolated studies, not like the flood that was about to begin. Thus, Harden (1929) had demonstrated that the important role of similarity in interference extended to short-term memory as well, with less interference arising when similarity was also less. Pillsbury and Sylvester (1940) had shown this to be true for both proactive and retroactive interference, and had found both types of interference to quite severely reduce recall from short-term memory.

It took two studies to create a new domain of research—those of Brown (1958) and Peterson and Peterson (1959). Brown first showed that memory for pairs of consonants declined rapidly if rehearsal was prevented by presentation of pairs of digits that did not need to be remembered. Even for a single pair of consonants tested after 5 seconds, forgetting was seen. The better known study is that of Peterson and Peterson.<sup>12</sup> Like Brown, they used consonants as the to-be-remembered stimuli and digits as the rehearsal-preventing activity. A 3-consonant stimulus was read aloud on each trial, immediately followed by counting backwards from a 3-digit number to prevent rehearsal. Unlike Brown, they tested retention at a succession of retention intervals, ranging from 3 to 18 seconds in 3-second steps, the goal being to map out the short-term forgetting function. What they observed (see their original data in Figure 8) was an exponential decline in recall of the consonant trigram as the retention interval lengthened, from almost perfect at the shortest interval to below 10% at the longest interval. This became the

classic short-term forgetting function, analogous to Ebbinghaus's (1885) classic long-term forgetting function.

INSERT FIG 8 ABOUT HERE

Very quickly, this "Brown-Peterson paradigm" became the basis for extensive research on short-term memory. Murdock (1961) replicated the dramatic exponential Peterson and Peterson forgetting function using both consonant trigrams and word trigrams, but also showed a much shallower forgetting function for single words, in keeping with Miller's (1956) influential idea of "chunks." In a second experiment, Murdock demonstrated proactive interference in the paradigm as a function of the number of not-to-be-recalled words presented before the critical to-be-recalled word. The role of proactive interference in this paradigm became focal with the work of Keppel and Underwood (1962), who questioned the Peterson and Peterson claim that proactive interference did not play a role in short-term memory. In a series of experiments, Keppel and Underwood cleverly examined just the first three trials in the paradigm and demonstrated "a severe proactive effect produced by a single prior item" (p. 156). As trials progressed, it appeared that proactive interference was building up, a feature that could not be observed when all trials were averaged together, as Peterson and Peterson had done.

Shortly thereafter, Wickens, Born, and Allen (1963) pursued the proactive interference issue by investigating similarity across trials, long a critical manipulation in the long-term memory literature on interference. They replicated Keppel and Underwood's (1962) proactive interference-based forgetting but showed that while this was the pattern for similar materials, when the materials changed across trials, there was very little evidence of forgetting. It was as if changing the material cancelled the proactive interference, an idea that would shortly turn into a very productive line of research on what Wickens et al. were first to call "release from proactive

interference.” Wickens (1970; also 1972) saw this release as an index of the dimensions along which encoding proceeded in short-term memory, noting that meaningful changes (e.g., changing the semantic category of words) produced considerable release but non-meaningful changes (e.g., changing word length) typically did not (but see, e.g., Kroll, Bee, & Gurski, 1973; Turvey & Egan, 1969). The standard procedure for release from proactive interference studies became to present three trials involving the same sort of material (e.g., three different members of the fruit category on each of the first three Brown-Peterson trials) and then on the fourth trial to present either a further three members from the same category or to present three members of a different category (e.g., animals). Release was apparent in the contrast between the same category and the new category, with recall of the new category much better than that of the old category.

Other studies demonstrated that this release was not due to attention alone (MacLeod, 1975) or to differential rehearsal (Schendel, 1976). It was the case, however, that researchers generally assumed in the early going that the release phenomenon resulted from processes happening during encoding. It took an ingenious study by Gardiner, Craik, and Birtwistle (1972) to point to retrieval as playing a key role. They presented four trials that had three games on each trial. During study, only when participants were told in advance that the fourth trio of games were indoor games whereas those on the preceding three trials were outdoor games was release from proactive interference obtained on the fourth trial. But more critically, when the same instructional manipulation took place at the time of test (i.e., after the fourth trio of items had been presented), the same result was obtained. Release was therefore demonstrated to occur at the time of retrieval. Shortly thereafter, O’Neill, Sutcliffe, and Tulving (1976) extended the argument to suggest that both encoding and retrieval were implicated, consistent with the

concepts of encoding specificity (Tulving & Thomson, 1972) and transfer appropriate processing (Morris, Bransford, & Franks, 1977). By 1981, even Wickens (Wickens, Moody, & Dow, 1981) accepted the critical role of retrieval in the phenomenon, concluding that “results strongly support a response-set, list-differentiation, and an interference at retrieval interpretation of PI, in contrast to an encoding (perceptual) one, and stress the view that the initial retrieval act is retrieval of the address of the set and not of individual items” (p. 1).

Research using the release paradigm has continued in the years since, and has often emphasized the important role of the search set in producing release. Search set is an idea that Shiffrin (1970b) promoted: To recall successfully, we need to identify a limited set of items in which to search. In the context of the release paradigm, Wixted and Rohrer (1993) suggested that free-recall latency provides an index of the increasing size of the search set as proactive interference builds up, and the reduced size that accompanies the shift on the critical final trial. Most recently, Mewhort, Shabahang, and Franklin (2018) have presented a computational model of the release from proactive interference effect that can predict the amount of interference based on an analysis of the specific words used.

Release from proactive interference has certainly been a major thread in the study of interference in short-term memory. There are, however, numerous other threads, some of which will be considered next. Wickelgren (1965; see also Conrad, 1964) demonstrated retroactive interference based on similarity of sound among letters, implicating acoustic coding as a possible default mode for information in short-term memory. For quite some time, based on interference effects, short-term memory was seen as using primarily acoustic codes and long-term memory as using primarily semantic codes, providing one of the key differentiations between the two.

Eventually, though, this simplistic dichotomy broke down as both long-term and short-term memory were shown to be capable of handling multiple types of codes.

The directed forgetting paradigm also emerged during this period (for a review, see MacLeod, 1998). Initially applied to short-term memory, the idea was that telling participants that they could forget part of the presented material should reduce interference and improve memory for the part that they were told that they had to remember. Muther (1965; see Brown, 1954, for an early version) showed that if 10 items in a 20-item list were cued to be forgotten, performance on the 10 to-be-remembered items was not as good as performance on a list of just 10 items, indicating that the to-be-forgotten items did cause interference. But compared to a 20-item list with no to-be-forgotten items, performance of the 10 to-be-remembered items in the 20-item list was considerably better. This indicated that interference from the to-be-forgotten items was in fact reduced by allowing them to be forgotten. From this early work, a quite large and continuing literature on directed forgetting emerged (see Golding & MacLeod, 1998), with most of it, after the earliest work, devoted to investigations of long-term memory.

Theoretical development in the domain of directed forgetting initially emphasized three main mechanisms. The first was selective rehearsal (see Bjork, 1972)—the idea that to-be-remembered items were favored over to-be-forgotten items during rehearsal. The second was set differentiation (see Epstein, 1972)—the idea that the to-be-remembered and to-be-forgotten items were sorted into separate sets and search of the to-be-remembered set was favored. This second suggested mechanism led to the third: output interference (see Bjork, LaBerge, & Legrand, 1968)—the idea that not having to recall the to-be-forgotten items lightened the load at the time of retrieval. Although output interference fell away as an account of directed forgetting,

it is an important concept in the literature on interference, and will be considered in the next section.

Before turning to output interference, however, there is the important question of individual differences in how people handle interference, so a brief digression on this subject is warranted since the relevant work primarily deals with working memory differences. As the directed forgetting literature attests (see MacLeod, 1998), and as the famous quote from James (1892, p. 300) affirms “In the practical use of our intellect, forgetting is as important a function as remembering. ... If we remembered everything, we should on most occasions be as ill off as if we remembered nothing.” How do we edit memory? The evidence suggests that individuals with high working memory capacity resist intrusions more effectively (Rosen & Engle, 1998) and suffer less from proactive interference (Kane & Engle, 2000; Unsworth, 2010). Baddeley and Della Sala (1996) reported that individuals with higher working memory capacity are less susceptible to interference during retrieval, consistent with them having better executive control over encoding and retrieval processes. Executive control could take the form of enhanced inhibition (see Marsh & Anderson, this volume), but there are other reasonable possibilities. Intriguingly, Delaney and Sahakyan (2007) showed in a directed forgetting study that individuals with higher working memory capacity forgot more items from the set designated as to-be-forgotten when there was a context change between the to-be-forgotten and the to-be-remembered sets, suggesting that they might make better use of context information during encoding and retrieval. It certainly appears that, whatever the mechanism, those with greater working memory are better equipped to cope with interference. It may even be that it is interference that determines the apparent capacity limitation of working memory (Endress & Szabó, 2017).

## Output interference

Thus far, interference has been considered almost exclusively from the standpoint of what happens during acquisition, due either to preceding or succeeding information during encoding hampering the later recovery of some target studied information. But logic does not dictate that interference be restricted to encoding processes: It could also affect performance at the time of retrieval; we have indeed seen some hints of that already. Does initially retrieving some information reduce the likelihood of retrieving other information subsequently? In a little-known study, Peixotto (1947) showed that recognition accuracy declined as the recognition test proceeded, presumably evidence of an increasing build-up of test-based interference. Then Brown (1954, p. 141) reported in a recall experiment in which he manipulated recall order by instruction (e.g., recall numbers before letters) the basic finding that “The attempt to recall one part of the material presented interfered with, and was itself impaired by, the attempt to retain the part yet to be recalled.”<sup>13</sup>

In a series of studies more directly aimed at the phenomenon, Tulving and Arbuckle (1963, 1966; also Arbuckle, 1967) used the paired-associate learning procedure and showed that recall of a particular item suffered from prior input or prior output of other items, with outputs causing less apparent forgetting than inputs. Nevertheless, there was output interference, if only for the last few studied items. Although output interference was initially thought to affect only the last few studied items, and therefore to be a short-term memory phenomenon, this perspective soon changed. Norman and Waugh (1968) and Schulman (1974) extended the observation of output interference to recognition of longer lists (harking back to Peixotto, 1947), noting that as more items preceded a critical item during test, recognition performance grew poorer. Smith, D’Agostino, and Reid (1970; see also Smith, 1971; Dong, 1972; Roediger, 1973;



Roediger & Schmidt, 1980) then extended the finding to recall of longer lists. To illustrate, in the Smith et al. study, after studying 7 categories of 7 words each, participants were cued with a succession of category name cues: The later a cue was given in the test sequence, the poorer was the recall of the items in that category.

Roediger (1973, 1974) and Rundus (1973) offered the basic hypothesis that output interference is a simple function of number of prior items recalled. Roediger (1973) found that presenting category cues alone did not produce as much output interference as did presenting category cues and some of the items, connecting to the part-list cuing literature (e.g., Slamecka, 1968, 1969; see Nickerson, 1984, for a review) where presenting some of the to-be-recalled items as “cues” actually decreases recall of the remaining items. In these situations, he argued, cues at the time of test may function as outputs, contributing to subsequent output interference.<sup>14</sup> Roediger (1974, p. 265) also reported a kind of meta-analysis of existing studies consistent with this “the more, the worse” account. In his review, Roediger even points to the possibility of output interference in retrieving already known information (i.e., semantic memory) in studies reported by Brown (1968) and Karchmer and Winograd (1971). The output of the earlier items causes them to be intrusive later, interfering with the recall of other items.

Studies of output interference have made regular, if sporadic, appearances in the memory literature since the late 1960s. In the context of the considerable advantage for items generated versus simply read—the generation effect (Slamecka & Graf, 1978)—Hirshman and Bjork (1988) suggested that the effect was larger in within-subject manipulations in part because the stronger items (the generated items) tended to be output first, thereby interfering with the weaker items (the read items). Bauml (1998; see also Bauml & Hartinger, 2002) suggested that output interference results from retrieval suppression, thereby linking to the phenomenon of retrieval-

induced forgetting (Anderson & Spellman, 1995), in which practicing retrieval of some members of a category causes later reduced memory for other, unpracticed members of the category (see Murayama, Miyatsu, Buchli, & Storm, 2014, for a review of work on retrieval-induced forgetting). It is noteworthy that in the retrieval-induced forgetting paradigm, it is now quite standard practice to have participants recall the unpracticed items first to avoid any possible influence of output interference.

Criss, Malmberg, and Shiffrin (2011; see also Aue, Criss, & Prince, 2015) returned to recognition testing and reported robust output interference under a range of conditions including longer delays and different forms of recognition testing (Yes/No and forced choice). They concluded that other items do cause part of the forgetting evident in recognition testing, creating “item noise” as interference. They then modeled output interference in the “retrieving effectively from memory” (REM) model of Shiffrin and Steyvers (1997). In REM, an impoverished form of each studied item is stored in episodic memory, such that some features of the item are missing and some are incorrect (see Cox & Shiffrin, this volume, for a discussion of memory models).<sup>15</sup> Then at test, features of the test probe item are compared to those of all items in memory and a decision is made as to whether the best match is above threshold for responding “old/studied.” If an item is judged to be old, then its representation is updated; if an item is judged to be new, that item is stored. The result is increased storage as the test progresses, making any new test item less likely to match a studied item, and therefore resulting in output interference. What is clear is that, for output interference to occur, learning must be occurring during retrieval and there must be what Wilson, Kellen, and Criss (2020) refer to as a “response filter” that blocks recalling the same item repeatedly.

In the end, is output interference a unique form of interference in memory? Roediger (1974) saw output interference as related to retroactive interference, taking account of the idea that the retrieval of items can change their representations in memory, just as REM posits. He concluded “Therefore, [retroactive interference] and output interference appear to share the common feature of referring to decrements in recall of some target event(s) as a function of storage of some intervening events.” But one could instead take the view that it is proactive interference that has the most in common with output interference: The act of recalling some items earlier functions like study of a prior list, thereby creating interference that reduces the probability of recalling remaining items. In consideration of the fact that both study and test involve both encoding and retrieval (see Kolers & Roediger, 1984, for the proceduralist perspective), it becomes difficult indeed to distinguish proactive, retroactive, and output interference from each other.

### **Interference and the misinformation effect**

In 1974, in a now classic study on eyewitness memory (see Munsterburg, 1908, for the first consideration of this issue), Loftus and Palmer demonstrated that interference was certainly active in everyday memory. Participants watched a video of an apparent two-car crash. Afterward, among other questions, they were asked about the speed of the cars: “About how fast were the cars going when they \_\_\_\_\_ each other?” The verb was varied from “contacted” to “smashed” and the speed estimates made by participants varied along with the verbs. Clearly the query was interfering with memory for the original video. Even more impressively, a week later, participants returned and were asked more questions, the critical question being “Did you see any broken glass?” There was none, but those who had heard the word “smashed” earlier were more likely to say “yes.” In a follow-up study, even just using a definite article as opposed to an

indefinite article led to more incorrect reports of broken glass (Loftus & Zanni, 1975), and subsequent work showed that post-event questions incremented memory for both real and suggested "facts" in an earlier event (Loftus, 1975).

Together with the Loftus and Palmer (1974) study, the most often cited research on misinformation was the study by Loftus, Miller, and Burns (1978). Here, they showed a series of slides depicting a car-pedestrian accident, with the critical slide showing the car sometimes turning at a stop sign and sometimes at a yield sign. When a subsequent question suggested the wrong sign (e.g., "Did another car pass the red Datsun while it was stopped at the stop sign?" but it had actually been a yield sign), on a later two-alternative forced choice recognition test, participants were more likely to pick the suggested sign than when the question had incorporated the actually seen sign. Their conclusion was that "information to which a witness is exposed after an event, whether that information is consistent or misleading, is integrated into the witness's memory of the event" (p. 19).

Loftus (e.g., Loftus et al., 1978) initially argued that memory for an original event was altered by the subsequent questioning—that the two events were integrated into a single memory—and saw this as analogous to what could happen when police (or other) investigators questioned a witness following a crime. But another perspective is that two events were stored in memory, the original event and the post-event, and that preferentially remembering the post-event could have occurred because of retroactive interference biasing in favor of the post-event. This was the view taken by McCloskey and Zaragoza (1985), who showed that when the original event and another event other than the post-event were the two items on the recognition test, then there was no evidence of impaired memory for the original event. So what was happening when the original event and the post-event were pitted against each other was that subjects were

demonstrating source confusion between the two memories (cf. Johnson, Hashtroudi, & Lindsay, 1993), not integrating the two memories into one. The newer, post-event memory was interfering retroactively with the older, actual target event memory.

Research on what has come to be known as the misinformation effect continues to appear in the literature (see Davis & Loftus, 2007, and Chrobak & Zaragoza, 2013, for reviews), but most often studies are aimed at practical application issues rather than at fundamental theory. To date, the dominant explanation of the effect is, however, a version of interference in which “Memory involves a reconstructive process: It is vulnerable to interference from other experiences, especially from experiences that occur after a to-be remembered event” (Pickrell, McDonald, Bernstein, & Loftus, 2017).

### **Computational Models of Interference**

By the 1970s, with the cognitive perspective now dominant, new approaches to the understanding of interference effects in memory were being proposed, sometimes in the context of new memory phenomena but often also as formal models of memory. For a tutorial on models of memory, the interested reader should see Raaijmakers and Shiffrin (2002); for a more recent, detailed analysis of formal models as applied to memory search, the reader is referred to Kahana (2020). Such models have many virtues, among them the provision of specific predictions (that can sometimes run counter to what would otherwise be intuitive) and a more rigorous setting out of assumptions (that might otherwise be quite hidden in a descriptive theory). As it happens, they have had a lot to say about the role of interference in forgetting.

In this section, I will consider a series of models that have attempted as part of their goal to explain interference, presenting them mainly in chronological order, beginning with Anderson and Bower’s (1973) “human associative memory” (HAM), moving to Anderson’s (1976)

“adaptive control of thought” (ACT), and from there to Raaijmakers and Shiffrin’s (1981) “search of associative memory” (SAM), Murdock’s (1982, 1983) “theory of distributed associative memory” (TODAM), Eich’s “composite holographic associative recall model” (CHARM; Eich, 1982, 1985), Hintzman’s (1984, 1986, 1988) MINERVA 2, Mensink and Raaijmakers’ (1988, 1989) “contextual fluctuation” model (a version of SAM), and Dennis and Humphreys’ (2001) “bind cue decide model of episodic memory” (BCDMEM).

The first large-scale memory model to grapple with interference was Anderson and Bower’s (1973) “human associative memory” (HAM) model. They were dissatisfied with classic interference theory in large part because it failed to elucidate the associative processes on which it rested: There was no foundational explanation of associative memory, which was precisely what HAM set out to remedy: “What interference theory lacks is approximately what our theory, HAM, supplies; namely, a systematic theory about how the person brings his cognitive equipment to bear upon comprehending, storing, retrieving, and using propositional information” (p. 38).

In HAM, the basic units of storage in memory are propositions—“structured bundles of associations between elementary ideas or concepts” (Anderson & Bower, 1973, p. 3). To recover a specific proposition, HAM would narrow to a search set, along the lines of Shiffrin’s (1970b) proposal. Given constant updating of the propositions in memory as a function of their use, those most recently updated will be the ones most likely to be searched, thereby “burying” (their word) older propositions. The result is retroactive interference. Subsequent learning competes with earlier learning, reducing the likelihood of recovering that earlier learning, which also suffers from unlearning. Searches also terminate based on a cut-off rule that prevents long and likely unsuccessful memory searches. Essentially, both of the Melton and Irwin (1940)

mechanisms are in play, as well as additional mechanisms—notably context, as McGeoch (1932) had proposed. Substituting productions (essentially “if...then” statements) for propositions as the basic unit of memory storage in his ACT model (Anderson, 1976) did not substantially change the core analysis of interference in forgetting.

Anderson went on to study interference and forgetting in particular using a phenomenon called the fan effect (Anderson, 1974). Participants learned a set of people-place propositions, with some people and some places repeated. The more repetitions of the components, the slower people were to verify whether a particular test proposition had been learned. The additional information accruing from repetition of components was causing interference, here measured by response latency, consistent with the HAM and ACT perspectives. Whether this interference was proactive or retroactive was not clear, though, and indeed Anderson and Bower (1973) even mooted that the two varieties of interference might masquerade as each other. Anderson (1981) went on to demonstrate that even when an interference condition was provided with extra study trials to make its probability of recall equivalent to that of a control condition, a cost in terms of response time was still evident in the interference condition. This, too, fit with ACT, which proposed that the formation of memories is all-or-none but that their retrieval is a function of their strength, with that strength varying along a continuum. Essentially, probability of recall is influenced both by the all-or-none encoding and by the strength-governed retrieval, whereas response latency is influenced only by retrieval.

Raaijmakers and Shiffrin (1981; see also Gillund & Shiffrin, 1984) proposed a theory of retrieval from memory that they called SAM (Search of Associative Memory). In this model, deriving from earlier work by Shiffrin (1975), a short-term store communicates with a long-term store—the classic Atkinson and Shiffrin (1968) framing of memory—with retrieval directed first

to the contents of the short-term store and then to the contents of the long-term store. The representation in long-term store is in the format of context-item associative relations, where items are represented as nodes in memory and context—referred to as “list context”—is everything present at the time of encoding apart from the item information. In SAM, storage was local in the nodes, not distributed as would most often be the case for other later models.

SAM explicitly acknowledges that storage takes place both during study and during test: Retrieval, not just encoding, influences what is stored in memory. Retrieval consists of a search using cues assembled in short-term store that are then used to probe long-term store. The probability of sampling any given association stored in long-term memory is a function of the cue-to-association strength; only context and item information are used in cues. In this framework, retroactive interference is the result of reduced likelihood of generating appropriate retrieval cues. Forgetting increases as (1) cues are connected to more representations in memory, and (2) increasing changes in context occur. The first of these readily explains the kind of fan effects considered by Anderson (1974); the second readily explains the loss due to delay. Cue-dependent forgetting (McGeoch, 1932; Tulving, 1974) is integral to this theory.

With the foundation of signal detection theory, a straightforward way to conceptualize interference is as “noise” that makes the “signal”—the target information—harder to detect in memory. The most obvious type of noise would derive from other information in memory—item noise. Murdock (1982, 1983) put forth a model, eventually to be called “theory of distributed associative memory” (TODAM), in which items and associations are stored not as nodes but as random vectors in a common memory vector that is the entire memory system. Storage is assumed to be composite storage and is accomplished by convolution; retrieval is accomplished by the complementary process of correlation. Convolution is the merging of a



new vector, either an item vector or an already convolved pair of item vectors corresponding to an association, into the common memory vector. Retrieval involves correlating the retrieval cue with the memory vector, returning the best match to the decision mechanism. The decision mechanism deals with the noise in the memory vector and with random noise also present in memory to determine whether the recovered vector will be recalled or recognized.

In TODAM, interference arises as a “natural” outcome of mismatches of test probes with the information stored in the memory vector. To illustrate, output interference arises because items are added to the memory vector as they are retrieved, making a match with subsequent items less likely. As he developed the model, Murdock eventually added a working memory to hold representations while working on them and context to help explain differential forgetting rates for item and associative information (Murdock, 1997). He went on to show that the model could handle Remember/Know judgments—the distinction between actually recollecting something about an item (Remember) versus just feeling it to be familiar (Know) (see Yonelinas, 2002, for a review)—by assuming that “Remember judgments are based on associative information, whereas Know judgments are based on item information” (Murdock, 2006, p. 648).

The idea of item noise was also at the core of Eich’s “composite holographic associative recall model” (CHARM; Eich, 1982, 1985; Metcalfe, 1991). Like TODAM, CHARM stores items in a single composite trace. Non-target items in the composite trace add noise to the target item so “Quite literally, the composite trace produces interference” (Eich, 1982, p. 635). In an A-B, A-C interference design, as the A-C learning increases, CHARM increments the emphasis on C, thereby resulting in interference in retrieving B when cued with A. Metcalfe and Murdock (1981) had already shown the increase in noise as additional items were added to the composite trace. The result is, of course, interference—either proactive or retroactive—capturing the

essence of the Barnes and Underwood (1959) modified-modified free recall pattern. Although related items will cause more interference, even unrelated items distort memory for a given target by adding item noise, consistent with McGovern's (1964) finding that even learning a C-D list after an A-B list was worse than learning no additional list.

Hintzman (1984, 1986, 1988) proposed a simple model of memory, MINERVA2, that essentially amounts to an instance theory (see Logan, 1988) in that no derivations from items are stored: All that is stored is each occurrence of the individual items themselves, readily explaining the benefit of repetition. The form of representation is quite different from that of TODAM or CHARM in that, rather than a single memory vector, stored information is distributed in memory. MINERVA2, like SAM and TODAM, involves a working memory that communicates with a long-term memory. The long-term memory can send a retrieval cue to the working memory (a "probe"), and it can receive a reply to that probe from working memory (an "echo"). Despite their different storage schemes, the logic of retrieval in MINERVA2 is like that in TODAM: Retrieval involves matching the probe to all of the instances in memory simultaneously and receiving an echo that is the sum of all of their reactions, an idea that goes back to Semon (1923) who proposed the first account of memory retrieval. Better matches—instances that are more similar to the probe—will have a greater influence because unique aspects of instances will interfere with (and therefore effectively cancel) each other, leaving the shared aspects to stand out, effectively producing "the item" from its multiple instances.<sup>16</sup>

In 1988, Mensink and Raaijmakers developed a refinement of the SAM model that they referred to as the contextual fluctuation model (see also Mensink & Raaijmakers, 1989). Along with CMR2 to be described next, the context fluctuation model is perhaps the most relevant one for this chapter because it specifically focuses on the role of interference in forgetting. Its name

very clearly identifies what is unique about it—a process that results in context change over time which directly affects the goodness of retrieval cues for recovering memories. Put simply, the likelihood of a cue successfully recovering a target piece of information in memory is a function of the overlap between the context at encoding and the context at retrieval, where context consists of a set of elements. Because this overlap ordinarily declines as time passes, so too does successful retrieval. With this augmented model, Mensink and Raaijmakers were able to handle an impressive series of interference and forgetting findings, many of which have already been described in the foregoing. These included “results concerning retroactive inhibition, proactive inhibition, spontaneous recovery, independence of List 1 and List 2 recall, Osgood's transfer and retroaction surface, simple forgetting functions, the use of recognition measures, and the relation between response accuracy and response latency ” (p. 434). In the case of retroactive interference in an A-B, A-C design, the likelihood of recovering C increased and the likelihood of recovering B decreased in simulations, just as Barnes and Underwood (1959) had observed. In the model, this is because the associative strength of the link between the cue and the second list increases as practice of the second list increases. In the case of proactive interference in an A-B, A-C design, little interference in recovering the first list responses was evident shortly after acquiring the second list, but proactive interference emerged when the test of the first list was delayed, consistent with the results of Underwood (1949) and Koppenaal (1963). In the model, this is because the context overlap decreases as the delay increases. Essentially, context drifts with time resulting in cues becoming less “diagnostic” of desired targets.

The context, maintenance, and retrieval (CMR) model of Polyn, Norman, and Kahana (2009) is a retrieved context model that assumes contextual drift, with the current context providing the basis for retrieval. It readily accounts for episodic clustering patterns in recall

output using evolving temporal and source context, and for semantic clustering by relying on a history of relatively stable context-to-item associations. And degree of interference is realized as degree of shared context. Lohnas, Polyn, and Kahana (2015) further developed the model as CMR2 specifically to address how search is narrowed in memory, a problem that, in other models, had often been simply sidestepped by assuming that it is automatic. Here, temporal context is used to narrow search to a target episode (or list) and to preclude use of information that does not match the target list. This model does a good job of fitting proactive interference patterns, including buildup and release from proactive interference, by capturing semantic similarity as essentially the sharing of temporal contexts. It also readily predicts intrusions from other lists. Healey and Kahana (2015) extended the model to handle recognition as well as recall, modeling the changes in memory with age by lesioning the model fit to the performance of younger adults.

In discussing models, the distinction between item noise—noise created by the studied items—and context noise—noise created by the drift in context—has already been discussed. The models discussed to this point produce interference using either item noise or item noise plus context noise. Dennis and Humphreys (2001) relied on only context noise when attempting to capture recognition performance in their Bind Cue Decide Model of Episodic Memory (BCDMEM) model. In BCDMEM, interference for a given test probe item stems from the other contexts in which that item has appeared, not from the other items that appeared in the same context. To illustrate, there is the well-established effect of word frequency on recognition accuracy: Studied low frequency words are better recognized than studied high frequency words (see, e.g., Balota & Neely, 1980; MacLeod & Kampe, 1996). This makes sense in BCDMEM because low frequency words will have been associated with fewer contexts and hence will

produce less interference. It should be noted, though, that Dennis and Humphreys (p. 463) differentiate interference effects in recall from those in recognition, maintaining that “recognition is a context noise process whereas recall is an item noise process.” So it would seem, as with the other more recent models just described, that both types of noise contribute to interference. How Dennis and Humphreys’ model differs is in suggesting that the nature of the test determines the “active ingredient” in interference. Despite this dissociation being an intriguing and potentially simplifying idea, it must be recognized that it has not been universally accepted: Criss and Shiffrin (2004) argue, using a version of REM, that both types of noise contribute to recognition and to memory retrieval more generally.

Recent models have continued to grapple with sources of interference and particularly with the role of context. Thus, Osth and Dennis (2015) distinguished four situations with respect to retrieval cue(s): the self match (both item and context match the cue), item noise (the context matches but the item does not), context noise (the item matches but the context does not), and background noise (neither the item nor the context matches). Intriguingly, they found background noise to dominate in their model suggesting that, at least in recognition, interference results from experiences that took place before the specific learning.

Most recently, Yonelinas, Ranganath, Ekstrom, and Witgen (2019) proposed a model of episodic memory that relies on the binding together of context information and item information by the hippocampus. Considering a wide array of sources of evidence, they concluded that “forgetting is largely due to contextual interference” (p. 364) and argued against consolidation accounts. Instead, contextual drift is treated in their theory as resulting in activity after the target information had been encoded, such that contextual drift can be seen as creating a sort of retroactive interference. This idea of binding in the hippocampus is also the focus of the work of

Horner and Burgess (2013); although their idea is that multiple pairwise associations of the elements of an event are stored, they do see their account as in accord with contextual-drift ideas.

Overall, computational models of memory have helped to concretize the basis of interference. Impressively, they confirm as fundamental two of the mechanisms long proposed to underlie interference: competition, expressed as item noise, and change in context, expressed as context noise. The place of unlearning—or extinction—in such models is less apparent and has been contested (Shiffrin, 1970a), although it is not altogether missing (see, for example, HAM). As Criss and Shiffrin (2004, p. 807) conclude “models that incorporate both item and context noise seem simpler, more elegant, and better in accord with the data. One important potential consequence of this dialogue is the hope that the question will shift from a qualitative one concerning the existence of item and context noise to a quantitative one concerning the details of models that incorporate both.”

Explanations of the many interference-based phenomena of forgetting may well hinge on the relative balance of item and context noise, an idea ventured both by Murdock (1997), in contrasting item versus associative forgetting, and by Dennis and Humphreys (2001), in contrasting recall versus recognition. For the present, though, many of the basic interference patterns have been successfully targeted by these recent models. This can be seen as a tribute to the fundamental role of interference in memory, as well as to the important contribution of context. It is noteworthy that parallel modelling developments in the realm of working memory coincide in emphasizing these same features (e.g., Oberauer & Lin, 2017).

### **The Big Picture**

Where do we stand today? The concept of decay as a principal cause of forgetting was largely abandoned long ago: Since the time of McGeoch’s (1932) withering critique, few would

argue that forgetting is a direct consequence of the simple passage of time (but see Hardt, Nader, & Nadel, 2013, for a neuroscience perspective in support of decay as an updating mechanism). Some process (or processes) must occur in time that results in forgetting. A noteworthy possibility is inhibition or suppression. Proponents of inhibition as a form of forgetting, notably Anderson (2003), emphasize inhibition as a control process in memory, in keeping with the vast literature on cognitive control (see, e.g., Cohen, 2017, in Egner, 2017). Considerable evidence has been marshalled that some form of inhibitory process contributes to suppression of memories and hence to forgetting (see the next chapter by Marsh & Anderson), especially in the contexts of the retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994) and the think/no-think (Anderson & Green, 2001) paradigms. Although others have maintained that the evidence for inhibition is not definitive (see MacLeod et al., 2003; Raaijmakers & Jakab, 2013), the research in this domain has been very influential over the past 30 years.

The evidence for interference as a major cause of forgetting is, however, compelling. Although that does not preclude possible contributions from other mechanisms, it is possible that all forgetting is due to interference and to the resulting influence on the utility of cues. This chapter has traced the concept of interference from its empirical origins 125 years ago to current theoretical accounts in the form of computational models. In so doing, proactive, retroactive, and output interference have been given particular individual attention, yet it remains possible that these are all evidence of a single interference mechanism operating at different points along the learning-remembering continuum. The place for competition between memories is secure, and there is substantial empirical evidence for unlearning, perhaps in the form of extinction, as well, as McGeoch (1932) proposed.

Consequently, the Melton and Irwin (1940) two-process account continues to capture the essence of interference. This account emphasizes what we can call content interference (item noise), which surely is influential: As Zhao and Kuhl (this volume) argue in considering reinstatement of content during remembering, reinstatement of a target memory increases the likelihood of retrieval success, whereas reinstatement of a competing memory increases the likelihood of interference. But there is also increasing evidence for a critical role of context in interference as well (context noise), again as McGeoch (1932) hypothesized. As Crowder (1993, p. 156) summarized: “Each time an event occurs in a different context (time, place, and so on) a new trace is formed, but soon there are so many different contexts that none can individually be retrieved. What is common among the several exemplars is the knowledge, which we call abstract, but by default, by the massive interference attached to any individual context.” Cox and Shiffrin (2017, p. 796) put this even more succinctly: “In general, interference can arise as a result of overlap in either content or context.”

It seems very likely that these two sources of interference—content and context—operate in tandem. Episodes that have similar content and context will be the most likely to interfere with each other; episodes that only overlap on content or on context but not both will be less likely to interfere, and those that overlap on neither will be least likely to interfere. Indeed, there is emerging neuroscience evidence to suggest that the hippocampus plays two roles: distinguishing similar episodes from each other to limit interference, and linking episodes that share content and context (Libby, Reagh, Bouffard, Ragland, & Ranganath, 2019). It is heartening that this neuroscience evidence also articulates very nicely with the extensive empirical data summarized here and with the analyses set out by computational models of



memory. In just over a century, progress in understanding difficulties in learning and in remembering that derive from interference has been really quite remarkable.

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### Footnotes

<sup>1</sup>Sutton (1997, 1998) provides a wealth of information on Descartes' theory of memory and on its precursors.

<sup>2</sup>Paired associates, as these stimuli are usually called, were created by Calkins (1896) and became the stimuli of choice in many experiments on interference because they offered excellent experimental control of stimuli and responses.

<sup>3</sup>Müller and Pilzecker (1900) did briefly consider what we now call proactive interference in their concept of *generative inhibition*. They introduced the term *effectual inhibition* as well, intending it to cover situations of mutual co-interference between earlier and later events.

<sup>4</sup>In a footnote at the end of his paper, McGeoch (1932, p. 370) credits Foucault (1913) with having first suggested the idea that it is not disuse over time, but interference occurring in the time subsequent to learning, that is the principal cause of forgetting. In his review article, Britt (1935, p. 383, my translation) quotes Foucault: "We see therefore that what produces forgetting is not time, but the way in which it is filled."

<sup>5</sup>A year earlier, Waters and Vitale (1945) had used the term "retroactive interference" once at the end of their paper on studies of rats running mazes, although they primarily used the term retroactive inhibition in keeping with historical and then current practice.

<sup>6</sup>The debate about whether terms such as inhibition and interference refer to phenomena or to theoretical mechanisms intended to explain those phenomena is a longstanding one (see, e.g., Peterson, 1929, versus McGeoch, 1930).

<sup>7</sup>Extensive coverage of the research on sleep and memory is provided by Schechtman, Stickgold, and Paller (this volume).

<sup>8</sup>Conveniently, the end of the first epoch around 1930 also coincides with the first use of the subsequently prevalent designation “verbal learning” for the study of memory (Stoddard, 1929). The end of the second epoch around 1960 also coincides with the dramatic increase in research on proactive interference, spurred by Underwood’s (1957) classic analysis and by the beginning of the intensive study of short-term memory (e.g., Brown, 1958; Miller, 1956; Peterson & Peterson, 1959).

<sup>9</sup>For a more recent, better controlled replication, see Ekstrand (1967) and for a review, see Ekstrand (1972). Interestingly, even Ebbinghaus (1885/1964, p. 77) thought that sleep might buffer memory against forgetting.

<sup>10</sup>This was Underwood’s presidential address at the annual meeting of the Midwestern Psychological Association in St. Louis, MO.

<sup>11</sup>Waters (1941) had previously taken a similar approach to retroactive interference, but that earlier article is much less well known. Indeed, Underwood did not cite the Waters article.

<sup>12</sup>Daniels (1895) had in fact reported a study in which the to-be-remembered material was short digit strings and the rehearsal-preventing material was reading prose; he also showed rapid forgetting.

<sup>13</sup>Arguably, it was also demonstrated in a different setting by Conrad (1958), who observed that telephone operators asked to dial a zero before a phone number were considerably more error prone in dialing the number than were operators who did not have to dial the initial zero (see also the prefix/suffix effect, Crowder, 1967).

<sup>14</sup>Basden and Basden (1995) make a quite compelling argument that the part list cues, by being randomly selected, disrupt the retrieval strategy that the participant would otherwise have used.

<sup>15</sup>In fact, REM also incorporates storage of context information but, because Criss et al. (2011) set context to zero, I have not discussed context here.

<sup>16</sup>Intriguingly, Hintzman (2003) points to a lecture given by Robert Hooke in 1682 (see Hooke, 1969) in which he proposes a model that foreshadows modern memory models, including a kind of interposition account of retroactive interference.

**Table 1***Principal Transfer Designs*


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Designation	Description
A-B, C-D	no relation between stimuli or responses (often the control)
A-B, A-C	identical stimuli, unrelated responses
A-B, A'-C	related stimuli, unrelated responses
A-B, C-B	unrelated stimuli, identical responses
A-B, C-B'	unrelated stimuli, related responses
A-B, A'-B'	related stimuli, related responses
A-B, A-Br	identical stimuli; identical responses rearranged

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Note. The comma in the designation indicates the separation between two lists. This table is a briefer version of Table 10-2 in Hall (1971, p. 362).

## Figure Captions

**Figure 1.** Proactive and retroactive interference procedures, with time moving left to right. The curved arrows indicate which learning episode is tested; the arrows between the two learning episodes indicate the direction of interference.

**Figure 2.** The data for the two participants, H and Mc, from the classic study of Jenkins and Dallenbach (1924, Figure 1, p. 610). The results showed substantially less forgetting following sleep relative to waking, and were taken as evidence of reduced retroactive interference. From *The American Journal of Psychology*, copyright 1924 by the Board of Trustees of the University of Illinois. Used with permission of the University of Illinois Press.

**Figure 3.** John A. McGeoch (1897-1942); Arthur W. Melton (1906-1978).

**Figure 4.** McGeoch (1932) proposed that two factors determined forgetting of what was originally learned: interference and context change. For him, interference was conceived of only as retroactive interference, caused by interpolated learning competing with original learning. Context change was seen as a drift over time in the surrounding cues as activity changed. This drift is illustrated here by the four contextual cues surrounding original learning—A, B, C, and D—being supplanted by two continuing contextual cues—A and B—and two new cues—E and F—by the time of interpolated learning. Then, at the time of attempted retrieval of the originally learned material, not only will that material have suffered from retroactive interference, it will also be subject to further contextual drift, possibly resulting in the presence of some original contextual cues (A), some contextual cues associated with interpolated learning (F), and some new contextual cues (G and H).

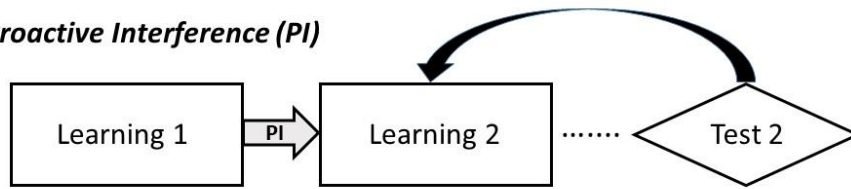
**Figure 5.** Leo J. Postman (1918-2004); Benton J. Underwood (1915-1994).

**Figure 6.** Retroactive interference as explained by the two-factor theory of Melton and Irwin (1940, Figure 3, p. 198). Total retroactive interference of the originally learned material in List 1 was due to two influences occurring during interpolated learning of the second list. The first influence was competition between the responses on the two lists, which rose early during interpolated learning and then declined. The second was due to unlearning of the first list responses, which increased monotonically during interpolated learning. From *The American Journal of Psychology*, copyright 1940 by the Board of Trustees of the University of Illinois. Used with permission of the University of Illinois Press.

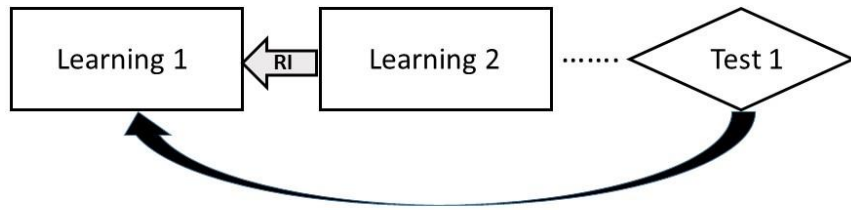
**Figure 7.** Recall of a critical final list as a function of the number of prior lists, plotted across a set of studies in the literature, taken from Underwood (1957, Figure 3, p. 53). As number of prior lists goes up, recall of the critical final list goes down, evidence of the build-up of proactive interference. From *Psychological Review*, copyright 1957 by the American Psychological Association. Reprinted with permission.

**Figure 8.** Recall of a consonant trigram after a retention interval of 3, 6, 9, 12, 15, or 18 seconds filled with counting backwards by 3 or 4 from a 3-digit number. Retention declines exponentially over the interval, the classic Peterson and Peterson (1959) short-term memory forgetting function. From *Journal of Experimental Psychology*, copyright 1959 by the American Psychological Association. Reprinted with permission.

***Proactive Interference (PI)***



***Retroactive Interference (RI)***





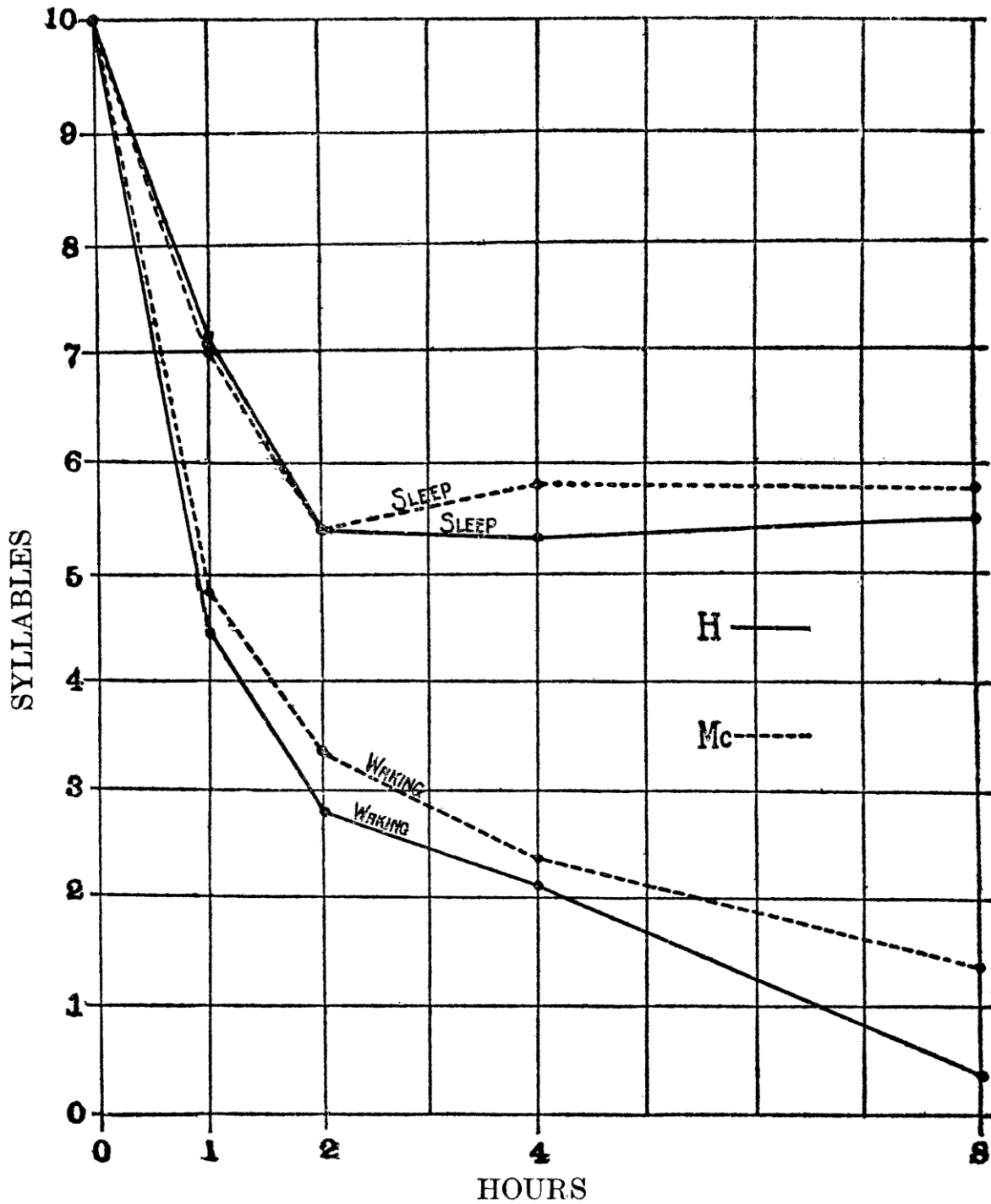
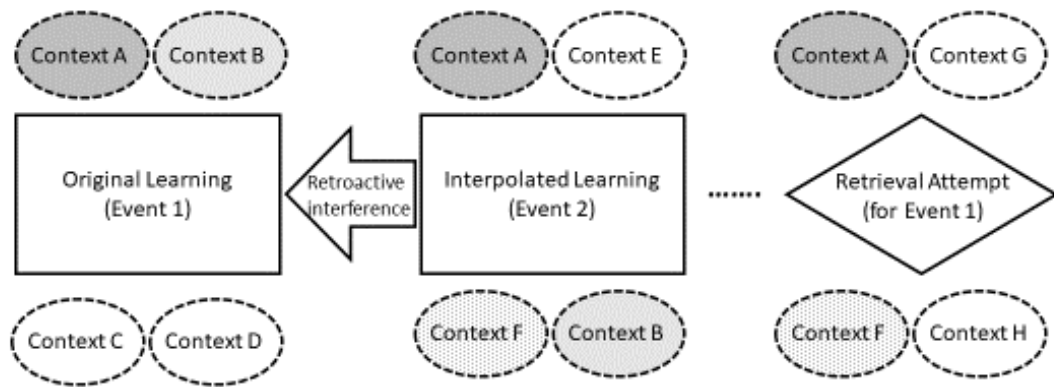


FIG. I. Average Number of Syllables Reproduced by each O after the Various Time-Intervals of Sleep and Waking







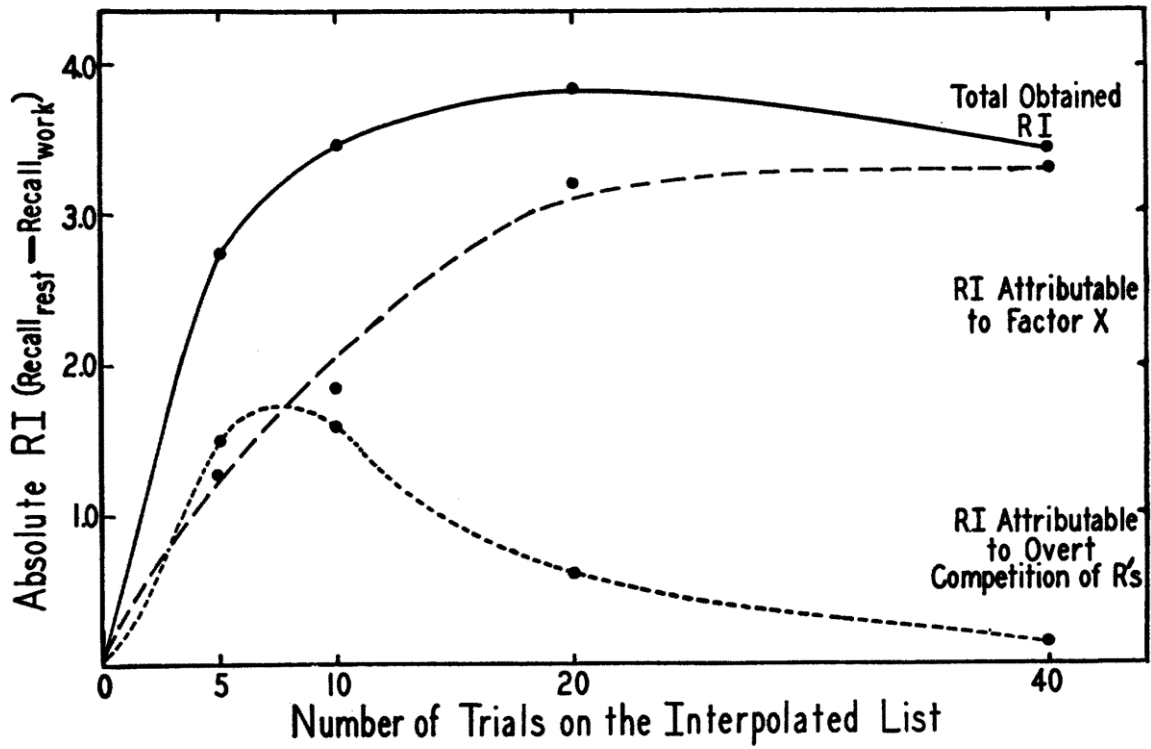


FIG. 3. RELATIONSHIP BETWEEN THE AMOUNT OF RI AND THE DEGREE OF LEARNING OF THE INTERPOLATED MATERIAL

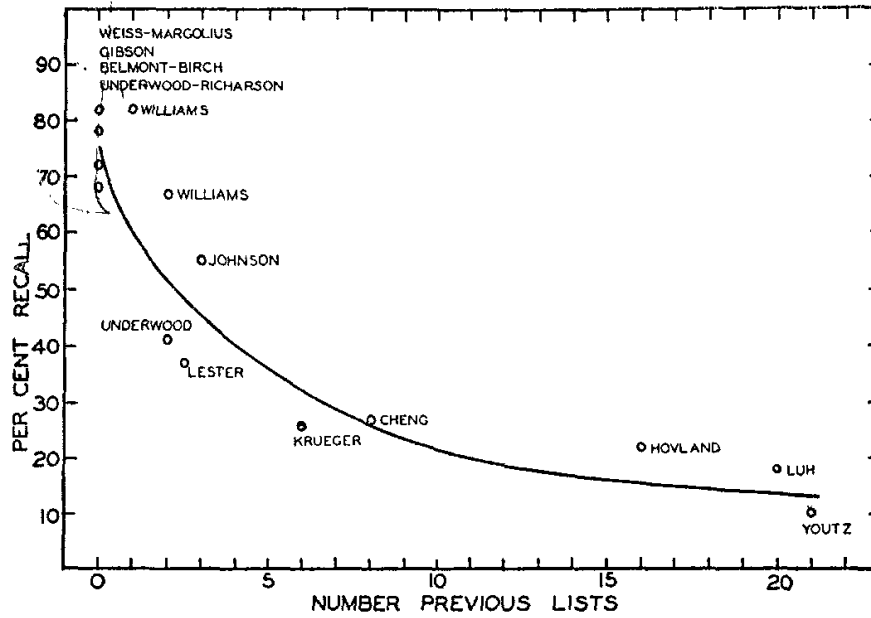


FIG. 3. Recall as a function of number of previous lists learned as determined from a number of studies. From left to right: Weiss and Margolius (35), Gibson (9), Belmont and Birch (3), Underwood and Richardson (33), Williams (36), Underwood (27, 28, 29, 30), Lester (17), Johnson (14), Krueger (16), Cheng (6), Hovland (11), Luh (18), Youtz (37).

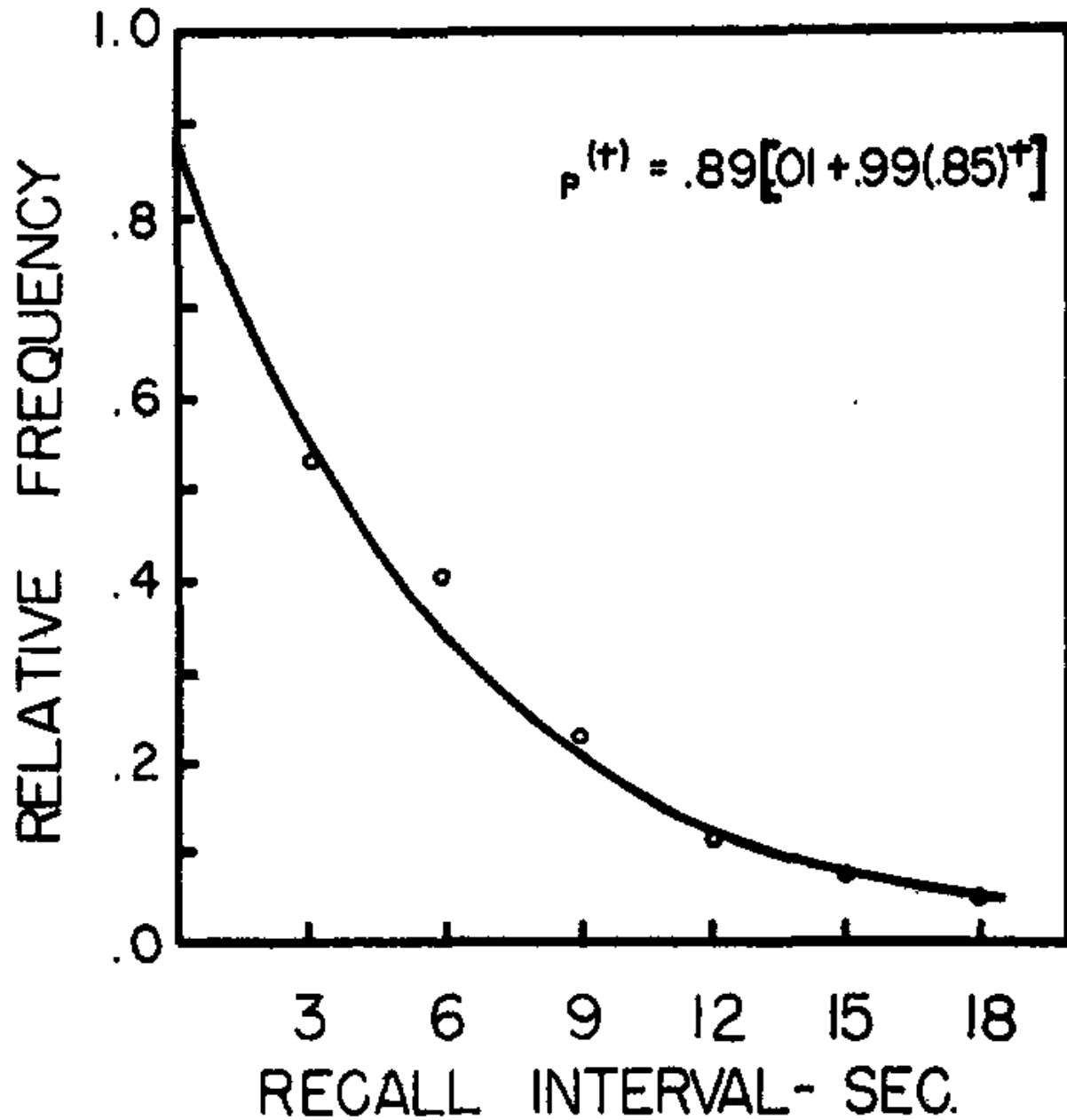


FIG. 3. Correct recalls with latencies below 2.83 sec. as a function of recall interval.