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Remembering and Forgetting as Context Discrimination

"The existence of forgetting has never been proved: We know only that some things do not come to mind when we want them to."

—Friedrich Nietzsche

Introduction

In a highly influential paper published in 1932, John A. McGeech (pp. 365–366) suggested that “forgetting, in the sense of functional inability or loss, may result from a lack of the proper eliciting stimulus.” As support for this idea, he gave the following examples: “The missionary, after being for some time in this country, loses his command of Chinese, but regains it, with almost no relearning, upon return to the stimulating environment in which he had learned and habitually used the language. One forgets the name of a person who appears unexpectedly, until some trick of speech, mannerism, or other aspect of the individual stimulates recall. The student fails to answer an examination question because it is phrased in a manner to which he is unaccustomed; perhaps the difference is only that synonyms for the familiar words have been used. In these and in many similar cases the material has not been lost from the subject’s repertoire, but it cannot be reinstated when wanted; it has been lost functionally for a certain period.”

Examples such as these could be taken to suggest that something once learned or committed to memory is never forgotten. Of course, this does not imply that every experience, no matter how trivial, is automatically and permanently registered and can be recalled perfectly at some later time. Only those events that are learned or otherwise encoded appropriately will be permanently retained. This view of memory directly contradicts the conventional connotation of the word “forget,” that something is lost permanently, a position adopted by Loftus and Loftus (1980). They argued that there are circumstances that cause information stored in memory to be irrevocably destroyed and suggested that the “permanent memories” position verges on the untenable because it can never be disproved: One can always suggest that under other circumstances the lost memory would be retrieved. However, the Loftus and Loftus position suffers from exactly the same sort of defect as the one we offer; that is, one should be cautious about inferring a lack of competence or memory from a lack of performance under a limited set of circumstances. As we detail below, there are many instances where such an inference, once widely accepted, has been shown later to be incorrect.

Because the issue of the permanence—or lack thereof—of stored information is so fundamental to theories of learning and memory, Loftus and Loftus (1980) argued, one necessarily has to choose between these alternatives. Unlike Loftus and Loftus, however, our approach in this paper is that all memory phenomena, without exception, can be best

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understood as involving permanent retention with remembering and forgetting being conceptualized respectively as successful recall and a temporary failure to recall as a result of what McGeoch called “altered stimulating conditions.”

Like forgetting, extinction, the decrement in performance when a previously learned response is no longer reinforced, has often been viewed by researchers as involving permanent loss. When a species becomes extinct, it is permanently and irrevocably lost, and calling the learning phenomenon “extinction” illustrates how many theorists infer complete and permanent loss from a simple lack of responding. There is a remarkable parallel between theories of extinction applied to animals and theories of forgetting applied to humans, a similarity that we will emphasize often in this paper. Some see response competition as being responsible for forgetting (McGeoch 1932) and extinction (Hull 1943), some see unlearning as responsible for forgetting (Melton and Irwin 1940) and extinction (Rescorla and Wagner 1972), and some see altered stimulus conditions as responsible for forgetting (McGeoch 1932) and extinction (Capaldi 1994a). We are certainly not the first to draw parallels between forgetting and extinction (see Hilgard and Marquis 1940, p. 127). Like forgetting, extinction can be profitably viewed as resulting entirely from stimulus change rather than from response competition or unlearning. As we show later, there are a number of extinction phenomena consistent with the hypothesis of permanent retention of the originally learned response that cannot reasonably be accounted for with an unlearning or response competition view.

Rather than viewing a lack of performance as permanent forgetting or extinction, we view both as a temporary performance deficit. By viewing learning and memory in this manner, one has a powerful framework for viewing a wide variety of phenomena, phenomena that would otherwise appear to be separate and disconnected. Whatever the shortcomings of our approach, the advantages, in our view, far outweigh the disadvantages.

There are literally hundreds if not thousands of studies that we could cite that demonstrate that material inaccessible at one time becomes accessible at some subsequent time. The well-known phenomenon of spontaneous recovery is a case in point: Weak responding on the later extinction trials of one day may recover substantially on the early extinction trials of the next day (Pavlov 1927). Another well-established phenomenon is the Kamin effect (Kamin 1957). After aversive conditioning, performance is relatively poor after an intermediate temporal interval but recovers substantially after a longer interval. As another example, rats that received electroconvulsive shock (ECS) showed no evidence of retention on tests given 24 or 48 hr later. However, on tests given 72 hr after ECS, they showed substantial evidence that they remembered the original learning (Quartermain et al. 1972).

It is clear that in all these cases the stored information was not forgotten, in the sense of permanent loss, but rather was temporarily inaccessible under a particular set of testing conditions. McGeoch (1932) offered a three-factor theory of forgetting that focused on response competition, set, and altered stimulating conditions. He assumed that old information coexists with new information and that neither retroactive interference, the passing of time, nor any other manipulation would

remove the original material from memory. Our position is that the single idea of altered stimulus conditions—a change in context—can subsume his other two factors and can provide a theoretical framework in which many disparate findings on forgetting can be organized. Viewed in this way, remembering and forgetting become a variety of discrimination learning. During acquisition, the organism not only processes the material to be learned, but also associates that material with a variety of internal and external contextual cues. What ends up being processed is a multidimensional complex of stimuli. Forgetting will occur if the stimulating conditions at test do not sufficiently discriminate between the desired memory and some other competing memories or if the stimuli at test elicit no memories at all. To the extent that the test cues do discriminate, then the organism will remember. Thus, forgetting is simply a performance deficit resulting from inadequate stimulus conditions. One advantage of this formulation is that it is extremely general; it can be fruitfully applied to a wide variety of phenomena ranging from classical and instrumental conditioning in animals on the one hand to recall of verbal material in humans on the other.

Although there are certain similarities between our position and that of classic Interference Theory, there are also important differences. Organisms are responsive to a wider array of stimuli than classical Interference Theory assumes. For example, in the prototypical paired-associate experiment, stimulus A is paired with B during the first phase and with D during the interference phase. Interference Theory represents this as A-B followed by A-D training, with the implication that stimulus A is the same in both phases. Our view, on the other hand, is that in the transfer phase, a variety of new stimuli may be introduced that transforms A-D into A'X-D, where A and A' may or may not be identical and X represents potential new stimuli, such as different processing as a result of changing physiological states. Our view is that it is difficult, if not impossible, to introduce some change in experimental conditions without also introducing variations in context. Even a simple change, from A-B to A-D, introduces many potential changes.

Context Alpha and Context Beta

According to the present view, a change in context necessarily results in altered stimulus conditions and changing the stimuli present from study to test can lead to retrieval failure (see Tulving 1983). Context can be thought of, then, as affecting the accessibility of the items (Tulving and Pearlstone 1966) by reducing the effectiveness of potential retrieval cues to discriminate between the target memory and other distractor memories (cf. Watkins and Watkins 1975; Watkins 1979; Eich 1989). We follow Wickens's (1987, pp. 135–136) distinction between two different manipulations of context. Context Alpha refers to “the environmental surrounds in which some event exists or occurs. . . [There is] no implication that the context or the environment influences the event or is related to it in any significant way.” This may be contrasted with context beta, which is the “situation in which one stimulus event combines with another stimulus event to define the correct response or meaning of the event.”

Perhaps the most well-known experiment that involved a manipulation of context alpha was reported by Godden and Baddeley (1975). Members of a university dive club learned a list of items either on land or underwater and were tested for recall either on land or underwater.

Subjects recalled more when the environmental context at test matched the environmental context at study than when it mismatched. Importantly, Godden and Baddeley conducted a second experiment. Half of the subjects again learned a list of words and were then tested for recall on land. The other half also learned the list and were tested on land, but they were required to enter the pool, swim a short distance, dive to a depth of 20 feet, and then return to land prior to recall. If the movement required to enter or leave the pool was the cause of the interference in the mismatch conditions, then there should be a difference in performance between the two groups. If the change in environment itself was the cause of the deficit, then there should be no difference. There was no difference; the disruption between study and test did not cause the decreased recall.

A good example of a manipulation of context beta was reported by Rescorla et al. (1985). Two contexts (marbled or striped) determined the meaning of two different stimuli. In context 1, stimulus A signaled food and stimulus B did not, whereas in context 2, the opposite contingencies prevailed. The birds responded appropriately in both contexts. The point is that the context determined the meaning of the stimuli.

Both of these examples may be considered external manipulations of context. Context alpha and context beta can also be manipulated internally. For example, Overton (1964) had rats learn a T-maze discrimination under a particular drug state (sodium pentobarbitol or saline). Animals performed almost perfectly when tested in the same state as training but performed at chance levels when tested in the opposite state. This can be considered an internal manipulation of context alpha. Internal manipulations of context beta most often involve changing the meaning of verbal stimuli. For example, Neath et al. (1993) played a sound to two groups of human subjects. One group (animal condition) was told that the sound was a recording of a sheep, whereas the other group (human condition) was told that the sound was a person pronouncing the onomatopoeic English word "baa." Even though the sound was physically identical in both groups, when interpreted as an English word the token interfered with other to-be-remembered items. When interpreted as an animal sound, however, there was no such interference. This example also illustrates that the effects of context need not always be direct: A change in context beta can affect not only direct recall of the item in question, but also can affect whether an ostensibly irrelevant stimulus will interfere with the to-be-remembered items. Other internal manipulations of context beta can be found in the schema-based recall studies of Bartlett (1932) with human subjects and in the many conditioning studies of Asratian (1965) with animals.

Memory is seen as the by-product of processing information in conjunction with a combination of internal and external cues. All of these cues together constitute the context. A change in context alpha typically influences memory by removing or altering potential retrieval cues. Thomas (1985) showed that pigeons that had learned a discrimination under a particular floor tilt exhibited poor performance when the floor tilt was altered (e.g., changing the tilt by 30°). A change in floor tilt results in a change of a variety of proprioceptive stimuli, angle of viewing, shadows, and so forth. Because so many cues are changed, it is not surprising that in test the appropriate response is

modified or even lost. A change in context beta typically influences memory by actually changing the meaning or the interpretation of the stimuli. Light and Carter-Sobell (1970) changed the meaning of the word "bank" by presenting it in the context of "river" or "money."

The next section examines the role of context in affecting the usefulness of retrieval cues as viewed from a discrimination perspective. Then, we illustrate the generality of the present view by focusing on delayed matching to sample in animals and the Brown–Peterson paradigm in humans.

Context- and State-dependent Memory

Context-dependent memory refers to the observation that memory performance is often better when the test context matches the learning context; when the context is determined by the pharmacological state of the subject, the phenomenon is called state-dependent memory. In state-dependent retention, learning acquired under a particular state fails to transfer when the retention test occurs in the absence of that state. We have mentioned previously a study by Overton (1964) as an example of an internal manipulation of context alpha. In Overton's investigation, rats learned a T-maze under either a drugged state (sodium pentobarbital) or a nondrugged state (saline). In subsequent test trials, rats made very few errors when tested in the training state but made random choices when in the nontraining state. Goodwin et al. (1969) demonstrated state-dependent retention in humans employing alcohol. In their study, people given alcohol in training and saline in testing did worse in a variety of tasks than same state groups (both alcohol–alcohol and saline–saline). As may happen in both animal and human studies, an asymmetry was obtained by Goodwin et al., the saline–alcohol group performing better than the alcohol–saline group.

It is important to note that the basic result is not attributable to anything specific to the drugged state. For example, Weingartner and Faillace (1971) conducted a state-dependent memory experiment with two different groups of subjects. One group was made up of chronic alcoholics with documented histories of long-term alcohol abuse. The other group was made up of an equal number of nonalcoholics who were closely matched to the alcoholic subjects with respect to various demographic variables. The test session was held 2 days after initial learning during which subjects tried to free recall as many of the target words as they could. The subjects from both groups were either intoxicated or sober at study and intoxicated or sober at test. In this experiment, intoxication was defined as having 1.6 ml/kg of body weight. Both groups of subjects showed state-dependent memory effects, better recall when the test state matched the learning state than when there was a mismatch, ruling out any objection to a specific role of alcohol.

There are also mood congruency effects. Bartlett and Santrock (1979) altered the mood or affective state of their subjects so that they were either in a happy or neutral mood at study and a happy or neutral mood at test. Again, performance was better when the moods matched rather than mismatched. Similar results have been reported by Bower (1981). The effects of mood on retention have attracted considerable attention recently. A recent review of the mood literature by Eich (1995) identified conditions favorable to producing mood-dependent memory. These include, not surprisingly, experiencing strong, sincere moods.

A similar set of results has been demonstrated using odors. Schab

(1990) filled a small room with the odor of chocolate either at study or test or both, and even after a 24-hr delay, subjects' performance on a surprise test was better when the odors matched. This experiment also provides empirical validation for the famous anecdote reported by Marcel Proust in the first novel of *Remembrance of Things Past*.

Given the approach favored here, it becomes legitimate to ask, Is state-dependent memory a unique phenomenon? (Overton 1982). Not surprisingly, perhaps, the answer we favor is no. We may regard state-dependent memory as involving a change in context. In state-dependent memory, the context that changes from training to test is internal, for example, drugs, mood, etc. In other studies, the context that changes is external, for example, floor tilt, brightness, or apparatus. The state-dependent memory literature is too extensive to be reviewed in detail here (but see Overton 1984; Eich 1987). However, several findings that emerge from that literature are noteworthy in view of the approach favored here. It appears that those drugs most capable of producing state-dependent retention are those that are most discriminable. The more discriminable a particular drug, the greater its removal alters the internal stimulus context.

It might be thought that the asymmetry found in many state-dependent memory studies is inconsistent with the claim that forgetting results from altered stimulus conditions. However, the interpretation advanced by several theorists to explain such asymmetry (e.g., Barry 1978; Eich 1980) is entirely consistent with the present view. For example, it may be assumed that drug injections simply add D or drug cues with N or normal state cues being little affected. The N to N or D to D groups fail to undergo a change in context from training to test and so show good retention. The N to D group performed well in test because the N cues present in training support responding in test. The D to N group shows deficient retention because the D cues present in training are absent at test.

Of particular interest here are a number of studies that show that state-dependent effects can be overcome in a manner predicted by the present hypothesis. Human subjects were asked to learn a list of words. If tested after a change in drug state, retrieval was poor. However, if in the altered state a category name was supplied (e.g., name the flowers that you can recall), recall was much improved (Eich and Birnbaum 1982). These findings exemplify exactly what the present view of memory asserts: Forgetting does not involve a permanent loss but rather an inability to retrieve information under a particular set of conditions.

Forgetting in Short-term Memory

Both the delayed matching to sample and the Brown–Peterson paradigms have historically been regarded as concerned with short-term memory, and the basis of forgetting in short-term memory, according to most interpretations, is the rapid decay of stimulus traces. According to the present view, however, phenomena attributed to rapid decay of stimulus traces may be better understood in terms of interference. Interference is best conceptualized as a variety of discrimination learning. The results obtained employing delayed matching to sample (DMTS) and Brown–Peterson are sufficiently similar so as to encourage the view that animal and human memory are regulated by highly similar if not identical processes. Finally, short-term memory and long-term memory may be understood in similar terms, as discrimination phenomena. As we shall

see, a number of variables have been manipulated in both the DMTS and Brown–Peterson paradigms. The superficial differences between these so-called different manipulations should not mislead us. At bottom, as we shall see, all of these manipulations are united by a common thread: To what extent does each variable make it difficult for the organism to discriminate the target memory from distractor memories?

DELAYED MATCHING TO SAMPLE

Five steps that are involved in DMTS are illustrated in Figure 1. The animal, often a pigeon or a monkey, sees a panel containing three keys on which stimuli may be projected. The panel also contains a center lamp that may or may not be illuminated. Response to the center lamp when illuminated (step 1) causes the lamp to be turned off (step 2) followed by the projection of a stimulus on the sample key, in this case an X (step 3). A retention interval ensues during which all keys are dark (step 4). Following the retention interval, the comparison keys may be illuminated (step 5). In the example shown in Figure 1, one comparison key contains the sample shown in step 3, the X; the other comparison key is a lure, the Y. By selecting the X, for example, by pecking it, the animal may receive a reward such as grain. If the lure is selected, reward is not given. Following the response, all keys are darkened and the intertrial interval (ITI) begins. Following the ITI, the center lamp is illuminated and the next trial occurs when the animal responds to the center lamp.

Figure 1: A schematic representation of a typical delayed matching-to-sample trial. The center key is illuminated (step 1), and the pigeon pecks on the center key. The key is turned off (step 2), and then the sample is presented (step 3). There is a delay (step 4) before the two test stimuli are presented (step 5). The animal is rewarded if it pecks on the key that shows the same stimulus as the original sample, in this case the letter “X.”

Prior to a seminal paper by Benton Underwood in 1957, it was widely believed that retroactive interference was a major cause of forgetting. Retroactive interference refers to forgetting caused by conflicting memories acquired between original acquisition and subsequent testing of the target memory. Retroactive interference may be represented symbolically as learn A, then learn B, and then test A. What Underwood demonstrated was that a far more potent cause of forgetting was associated with proactive interference rather than retroactive interference. Proactive interference refers to forgetting caused by conflicting memories acquired prior to the acquisition of the target memory. Proactive interference may be represented as learn B, then learn A, and then test A.

Figure 2 shows data presented by Underwood (1957) concerned with recall as a function of the number of prior lists learned. The studies included in Figure 2 consisted of various materials (geometric forms, nonsense syllables, etc.), learned under different conditions (paired-associative, serial presentation) and so on. The greater the number of previously learned lists, the greater the forgetting of the target list. Where no previous list was learned, retention is ~80%. Where 20 or so previous lists were learned, retention dropped to ~20%.

Before considering DMTS findings, let us be clear about what we mean by proactive interference. We mean that attempts to recall the target memory, T_n , result in the recall of memories acquired prior to T_n (T_{n-1} , T_{n-2} , etc.), memories that are not discriminated from T_n . Failure of discrimination occurs because T_n , T_{n-1} , T_{n-2} , etc., were processed under similar stimulus conditions with various of these stimulus conditions occurring at test. For example, T_{n-2} , T_{n-1} , and T_n may all have been acquired in the same room and under the same instructions. It is even possible that at the time of test for T_n the current stimulus conditions may be more similar to those prevailing when say T_{n-2} was processed rather than when T_n was processed. For example, the person's mood at the time of test for T_n may be more similar to that when T_{n-2} was processed rather than when T_n was processed.

In DMTS, three potential sources of proactive interference may be identified. Proactive interference may arise from immediately prior trials, within the trial itself, or from the entire experimental session. Consider a case in which only two stimuli are employed as the samples and

Figure 2: Benton Underwood's (1957) famous plot of data from 14 different studies showing the proportion correct as a function of the number of previous trials.

comparison stimuli. On successive trials, the same or different samples may be presented. When the samples are different, conflict will exist to the extent that the current and the prior samples fail to be discriminated. We may call this “the what did I see last phenomenon.” A number of studies have examined proactive interference in DMTS by assessing accuracy on the current trial as a function of the stimuli presented on the prior trial. This is called the intertrial proactive interference procedure. In some investigations, a stimulus is present prior to the sample, a preexample stimuli, and the effect of this on choice accuracy is assessed. This is called the intratrial procedure. The proactive interference associated with the intratrial procedure is typically quite small, in the range of 5%–8% (e.g., Zentall and Hogan 1974; Medin 1980). This small proactive interference effect, as Wright et al. (1986) have indicated, may be the result of a floor effect. Choice accuracy on control trials is often quite low, so much so that little room for reduction in choice accuracy may exist. Wright et al. (1986) suggest, quite reasonably in our view, that choice accuracy on control trials may be low (~65% in some studies, 50% being chance) because of the proactive interference associated with the entire experimental session.

Positive and negative trial transitions are identified in the intertrial procedure. In a positive trial transition, the samples on two successive trials remain the same. In a negative trial transition, a change in samples occurs from one trial to the next such that a reversal occurs in the correct and incorrect choices. Moise (1976) investigated intertrial proactive interference over five retention intervals, 0, 1, 5, 10, and 20 sec. As the retention interval increased, the difference between positive and negative trial transitions tended to increase. For example, the difference was ~5% at the 5-sec retention interval and ~12% at the 20-sec retention interval. These differences arose because of a steeper drop in accuracy on the negative trial transition than on the positive trial transition.

The effect of ITI on choice accuracy is consistent with a proactive interference analysis. As ITI increases, competing memories from prior trials are likely to be less accessible. The basis of this so-called forgetting is identified as a discrimination phenomena by D’Amato (1973). According to D’Amato, performance should be regulated by the ratio of the ITI to the retention interval. This is the case, according to D’Amato, because the animal must discriminate between the interval when it should be remembering (the retention interval) from the interval when it should be not remembering (the ITI). As the ITI exceeds the retention interval, the discrimination becomes easier and performance should improve. As indicated, results consistent with this view have routinely been obtained in several species, for example, pigeons (Grant 1975), monkeys (Jarrard and Moise 1971), and dolphins (Herman 1975).

The effect of sample set size has a profound effect on choice accuracy in DMTS, one entirely consistent with an analysis in terms of proactive interference. Essentially, the greater the number of samples the less likely it is that memories from prior trials will conflict with memories from current trials. In an experiment by Mishkin and Delacour (1975) using monkeys and a 10-sec retention interval, choice accuracy was much greater when trial unique stimuli were employed relative to a single pair of samples (junk objects). Overman and Doty (1980) obtained a similar finding with monkeys over a wide range of retention intervals and, very

importantly, reported that with trial unique stimuli, choice accuracy was above chance when trial unique stimuli were employed even at a 24-hr retention interval.

Strong evidence for proactive interference is not limited to the DMTS situation. For example, Wright et al. (1986) have shown that the serial probe recognition task (SPR) supplies strong evidence for proactive interference. In SPR, several items to be remembered are shown in sequence. Following the last item in the list, a probe item is presented. The task is to classify the probe as either an item in the list (same) or not in the list (different). One may construct successively presented lists from a small number of items or a large number. In SPR, consistent with DMTS, as the number of items (samples) increases, accuracy improves in humans, monkeys, and pigeons (see Wright et al. 1986). Other variables manipulated in SPR that support a proactive interference analysis may be found in Wright et al. (1986).

BROWN—PETERSON

In the original Brown—Peterson studies (Peterson and Peterson 1959; see also Brown 1958), the experimenter read aloud a consonant trigram (three consonants in a row, such as DBX) and then read a three-digit number out loud. The subject's task was first to count backwards (by three or four) from the three-digit number for a certain amount of time. At the end of this period, the subject was then asked to recall the three consonants in order. The purpose of the distractor task was to prevent rehearsal, and counting backwards was chosen to avoid overt interference, the digits being sufficiently different from the to-be-remembered letters. Peterson and Peterson varied how long the subject counted backwards, including conditions of 3, 6, 9, 12, 15, and 18 sec. The total proportion of consonants correctly recalled as a function of the duration of the distractor activity is shown in Figure 3. What is most noteworthy is that after as little as 18 sec of counting backwards, subjects could recall only ~10% of the items. These results were interpreted as demonstrating the very rapid decay of information in short-term memory when rehearsal is prevented. Murdock (1961) demonstrated that these results were not attributable to the type of information that was being tested: Subjects did just as poorly when three words were used and followed by 18 sec of counting backwards as when three consonants were used.

Figure 3: Proportion of consonant trigrams correctly recalled as a function of the distractor task duration (Peterson and Peterson 1959).

An important challenge to the decay interpretation of the Brown–Peterson results appeared in a series of experiments reported by Keppel and Underwood (1962). As mentioned previously, Underwood (1957) had demonstrated that proactive interference is related to the number of previous trials (see Fig. 2). Keppel and Underwood (1962) looked at performance on the first few trials individually and found that on the very first trial, there was no difference in recall between the 3-sec and 18-sec conditions. They replicated this result in a second experiment, and many other studies have also demonstrated equivalent performance after varying intervals of distracting activity (Wright 1967; Cofer and Davidson 1968; Turvey et al. 1970; Baddeley and Scott 1971; Fuchs and Melton 1974; Gorfein 1987). For Keppel and Underwood (1962; see also Melton 1963), the critical issue was whether or not long-term memory (LTM) and short-term memory (STM) required fundamentally different principles. Their conclusion was that the principles are the same, interference.

If forgetting in Brown–Peterson is attributable to proactive interference, then it should be possible to increase performance by introducing a manipulation that makes the target item more discriminable or more different from the previous items. This can include changing the type of stimulus, increasing the ITI, and providing additional information that affords better discrimination.

Wickens et al. (1963; see also Wickens 1970) had subjects hear three consonants, perform some distractor task, and then recall the consonants on the first three trials. On the fourth trial, half of the subjects were switched from consonants to numbers. Performance in the switched group was much better than in the control group, a phenomenon called release from PI. Turvey and Egan (1970) changed two dimensions at the same time and found performance on trial 4 was equal to performance on trial 1, regardless of whether the retention interval was 5 or 15 sec. Gunter et al. (1981) have demonstrated release from PI when testing subjects' memory for news items taped off the evening news. The news stories were classified as being either domestic or international, and recall was always better following a change in type.

This finding from Brown–Peterson, the release from PI, obviously has a number of counterparts in the DMTS literature. Viewed theoretically, the release from PI means that when the similarity between prior memories and the target memory is reduced, recall of the target memory improves. Reduction in the similarity of prior and target memories occurs in DMTS when the samples on two successive trials differ and, of course, when many samples rather than only a few are employed. As we have seen, having samples differ over successive DMTS trials results in better performance.

Loess and Waugh (1967) found that performance in Brown–Peterson was inversely related to the duration of the ITI, and with very long intervals (e.g., 180 and 300 sec), there was virtually no proactive interference. Again, the same result holds in DMTS.

Gardiner et al. (1972) suggested that release from PI was a retrieval effect and examined this idea using two categories of items, each of which could be divided into a subgroup. Some subjects received types of games, others types of flowers. Unnoticed by the subjects, the first three trials would all be indoor games (or wildflowers), and the fourth trial would be outdoor games (or garden flowers). All subjects received this

subtle change in categories, but only two of the groups were informed. One group was informed prior to presentation of the fourth trial, and the other group was informed after presentation of the fourth trial but prior to recall. Nothing extra was said to the control subjects. The control subjects were affected by the buildup of PI, and this continued through trial 4. If the change goes unnoticed, then there will be no release from PI. Both the presentation and recall groups showed an equivalent release from PI. Gardiner et al. argued that this release must be a retrieval effect because that is the only place both groups had the category change information at the same time: The recall group could still take advantage of the change, even though they were unaware at encoding.

Baddeley (1976) offered an explanation that depended on the relative duration of the distractor activity rather than the absolute duration. Imagine three groups of subjects who receive two trials in a Brown–Peterson procedure. The first item is presented at time 0, and the second item is presented after 20 sec. The second item is recalled either 10, 20, or 30 sec after it was presented. This is illustrated in Table 1.

The duration between the presentation of the first item (P1) and the test for the second item (R2) is 30 sec for group A, 40 sec for group B, and 50 sec for group C. The duration between the presentation of the second item (P2) and the test for the second item (R2) is 10 sec for group A, 20 sec for group B, and 30 sec for group C. These figures and the resultant ratios are also shown in Table 1. The prediction is that the group with the largest ratio will show the best performance. The reason, Baddeley suggested, is that at the time of the recall attempt for item 2, what will primarily determine recall is the ability of the subject to distinguish the second item from the first item. The closer in time the recall test is to the presentation of the second item and the further away the recall test is from the presentation of the first item, then the better the recall of the second item. It is this idea that the ratio is capturing.

A similar retrieval hypothesis explains many other results. The change in category (i.e., from outdoor to indoor sports) in the Gardiner et al. (1972) study made the fourth item more discriminable from the third item. The increase in ITI in the Loess and Waugh (1967) study made the subsequent trial more discriminable from the previous trial. Finally, Turvey et al. (1972) manipulated the duration of the retention interval (how long the subjects performed the distracting activity) between subjects. One group counted backwards for 10 sec, one for 15 sec, and one for 20 sec. The proportion of items correctly recalled was equivalent

Table 1: *Temporal distinctiveness in the Brown–Peterson paradigm*

Group	Time ^a						P1–P2	P2–R2	Ratio
	0	10	20	30	40	50	(sec)		
A	P1		P2	R2			30	10	3:1
B	P1		P2		R2		40	20	2:1
C	P1		P2			R2	50	30	1.67:1

^aP1 is the presentation of the first item; P2 is the presentation of the second item; R2 is the recall test for the second item.

on the first trial (0.85, 0.93, and 0.93, respectively). The proportion of items correctly recalled was also equivalent on the fourth trial (0.33, 0.30, and 0.30, respectively). These results are inconsistent with a decay explanation, because more decay should have occurred with the longer intervals. They are consistent with the relative discriminability view, however, because if a ratio is calculated, the time from the presentation of one item to the next is constant. On the fifth trial, Turvey et al. (1970) shifted all groups to a 15-sec retention interval. Consistent with Baddeley's (1976) analysis, performance on the fifth trial increased for the 10-sec group, remained constant for the 15-sec group, and decreased for the 20-sec group.

Recall that D'Amato (1973) suggested that the ease of discriminative target from prior memories in DMTS depends on the ratio of the retention interval to the ITI, and results consistent with this suggestion were obtained. Several researchers have suggested that in Brown–Peterson, retrieval is based on the discriminability of temporal cues (Bennett 1975; Baddeley 1976; Crowder 1976). According to this view, the task is to select the most recently presented item from among a larger set of earlier presented items.

Stimulus Change, Memory, and Performance in Learning

To illustrate the generality of the concepts of altered stimulus conditions and memory discrimination, we apply them in this section to a number of animal learning acquisition and extinction phenomena. These phenomena are quite different in many instances from those so far considered. We shall examine these phenomena within a theory of stimulus change and memory developed by Capaldi called sequential theory (see e.g., Capaldi 1994a).

A major premise of sequential theory is that on a given instrumental learning trial, animals remember one or more prior events. Those memories then become a signal on the given trial for the reward outcome contingent upon the current instrumental response. Moreover, as a result of such pairing of memories and reward outcomes, the memories give rise to an anticipation of the appropriate reward outcome. Memories of prior events are sometimes referred to as retrospective memories. Anticipated events are sometimes referred to as prospective memories. Discussion of memory from a retrospective–prospective viewpoint may be found in several recent sources (e.g., Wasserman 1986; Chatlosh and Wasserman 1992; Capaldi 1994b; Capaldi et al. 1995). According to the sequential model, instrumental performance is controlled both by memories of prior events and representations of anticipated events (see e.g., Capaldi 1994a). Capaldi (1994b) suggested that learning models that emphasize both memory and anticipation are becoming increasingly popular (see also, Amsel 1994; Bitterman 1994).

Whereas animals have been shown to be capable of remembering a wide variety of events, the sequential model has emphasized memory for reward events such as large and small reward, nonreward, and so on. There is by now substantial evidence that memories of reward events exercise substantial control over performance in instrumental learning situations. By considering a simple case in which consistent reward (i.e., all responses are rewarded) is followed by extinction, it is possible to begin to appreciate how altered stimulus conditions and memory control instrumental performance. On each trial of the consistent reward acquisition phase, the memory of prior rewards becomes a signal for a

current reward and so responding is strong. However, in extinction, the memory of nonreward becomes a signal for nonreward and so responding weakens. As the example illustrates, the shift from acquisition to extinction may be characterized as a discrimination task in which the animal learns that the memory of reward signals reward (respond) whereas the memory of nonreward signals nonreward (do not respond).

Thus, the altered stimulus conditions view is adequate to explain extinction, and we need not postulate either response competition (e.g., Hull 1943) or unlearning (Rescorla and Wagner 1972). According to the sequential analysis, learned relations acquired in acquisition are not destroyed or opposed by extinction and vice versa. This view explains why animals given successive phases of acquisition–extinction–acquisition, etc., show very rapid reacquisition and very rapid reextinction (for review, see Capaldi 1994a). This finding, of course, is inconsistent with both the response competition and unlearning views.

When only some responses are rewarded, the remainder being nonrewarded (partial reward), subsequent extinction is considerably retarded relative to consistent reward. Many theories find this partial reward extinction effect, as it is called, difficult to explain, but this is not a problem for the sequential view. Essentially, the partial reward extinction effect occurs because in acquisition, under partial reward but not consistent reward, the memory of nonreward becomes a signal for reward. Thus, in extinction, the memory of nonreward elicits stronger performance following partial reward than consistent reward. Eventually, reduced responding in extinction occurs following partial reward for the following reason: As more and more extinction trials are experienced, the memory of nonreward is progressively modified and becomes increasingly different from the partial memory or memories of nonreward that become a signal for reward under partial reward acquisition. That is, the modified memories of nonreward, which occur later in extinction have little capacity to signal reward, and so performance is weakened. There are many phenomena consistent with the idea that memories of either successive rewarded or nonrewarded events are progressively modified and so become distinctive stimuli (see Capaldi 1994a).

There are several ways of demonstrating that the memories of reward and nonreward are representations that are stored and retrieved rather than, as some have suggested, short-term decaying traces. For one, it is possible to show that the memories of reward events can regulate performance even at long retention intervals including 24 hr. For another, it has been shown that reward produced memories are better retrieved to the extent that conditions at retrieval are similar to those at storage (Capaldi 1994a).

The sequential model has been applied to a wide variety of instrumental learning phenomena, only a few of which were mentioned above. However, our intention was not to demonstrate that the model has scope; rather, it was to indicate further that the concepts of altered stimulus conditions and memory are able to explain a wide variety of learning and memory phenomena.

Remembering and Forgetting in Other Paradigms

Numerous studies from a wide variety of paradigms supply evidence supporting the present view. Evidence obviously consistent with the view that memories are not permanently lost comes from studies that

examine memory for information over considerable retention intervals. Wendt (1937) conditioned an avoidance response, withdrawing a foot upon the presentation of a tone, until the dog responded accurately on 97% of the trials. Two and one-half years later, the animal received three reminder trials (footshock only) but no other opportunities to learn or practice. The dog responded on 80% of the test trials. Skinner (1950) trained pigeons to peck a key whenever a particular geometric pattern was illuminated. Four years later, the animals were placed back in the original chamber and all subjects pecked at the key when the geometric pattern was illuminated. In all of these cases, performance was not perfect, but this is not surprising given the substantial changes in context over the years; for example, the internal state of the animal has no doubt changed considerably due to age. What we emphasize is that the information was retained exceptionally well despite these large changes.

Bahrack et al. (1975) demonstrated that although memory for people who attended the same high school >50 years ago may be very poor when tested with recall, when tested with a cued-recognition test, performance was surprisingly accurate. For recognition tests of pictures of high-school classmates, accuracy remained as high as 80%–90% for >35 years. Similar feats of retention (in what has been dubbed the permastore) have been demonstrated for Spanish (Bahrack 1984), mathematics (Bahrack and Hall 1991), and for city streets and locations (Bahrack 1983).

The view offered here characterizes memory as a discrimination process (see also Craik 1994). The memory deficits of healthy elderly compared with younger subjects are also often characterized as a discrimination problem attributable to a deficit in processing contextual information. For example, Craik and Simon (1980, p. 110) state that “older people process events less deeply and elaborately and that the resulting memory traces are thus less distinctive and discriminable.” If this is the case, then elderly subjects should be less likely to produce effective cues than younger subjects. Micco and Masson (1992) tested this by asking one set of older and younger subjects to generate a set of one-word cues that would enable another person to produce the target item. A second group of both young and elderly were then given the cues and asked to produce the appropriate target word, which they had not seen. Consistent with Craik and Simon’s (1980) hypothesis, the younger subjects were more successful in producing the target word than the older subjects, but more importantly, the cues produced by the first set of elderly were less effective for generating the target item than the cues produced by the younger subjects.

A similar conclusion has been drawn with regard to amnesic patients. Kinsbourne and Wood (1982, p. 214), for example, give perhaps the strongest statement: “In amnesics, the process by which distinctive aspects of a situation are selectively attended and selectively reconstituted from their elements (cues) is compromised.” Amnesia also represents an excellent example of apparent permanent forgetting with some types of tests but apparent permanent retention with others. The most famous is Edouard Claparède’s (1951) hiding a pin in his hand and then shaking hands with a Korsakoff’s patient. The next day, the patient withdrew her hand at the last minute. Although she had no recollection of Claparède himself, she apparently had some awareness of the prior incident. Under more controlled conditions, Schacter et al. (1984)

presented a series of trivia questions to amnesic patients. Several answers were offered, and the patient had to choose one. If the patient did not know the answer, the experimenters provided the correct response and then, unbeknownst to the subject, put the same question back in the stack. As the experiment continued, the subject would be asked a question for a second time. On ~40% of the trials, the patients could report the answer but were unaware of the source of the information.

Memories are conceived of as a complex of multidimensional stimuli. A lot of work on human memory has focused on the dimension of time. According to our view, relative time is far more important than absolute time. A good example of this is the ratio rule in free recall. This empirical relationship, first suggested by Bjork and Whitten (1974), is an example of a general principle based on Weber's Law, applied to the discriminability of items in memory. The ratio rule relates the magnitude of the recency effect, the enhanced recall of the last few items, to the spacing between items. Specifically, the log of the ratio of the interpresentation interval (IPI) and the retention interval (RI) is proportional to the slope of the last three items. This relationship holds whether the duration of the IPI and RI is on the order of a few seconds or a few days (Glenberg et al. 1983). In fact, lists that have to be retained longer can be recalled more accurately than far shorter lists if the temporal spacing increases the discriminability of the items (Neath and Crowder 1990). Furthermore, these principles apply when a five-item list takes >1 min to present (Neath and Crowder 1990) or when a five-item list takes ≤ 1 sec to present (Neath and Crowder 1995).

Neath (1993) has offered the beginnings of a formal model that captures temporal distinctiveness. One important prediction is that absolute performance can increase as the retention interval increases. This is not simply a slowing down of the forgetting rate, but a reversal. Stimuli were chosen that minimized verbal rehearsal, and four items were presented at a rate of 1 per second, with a 1-sec IPI. Recognition memory was assessed using a single-item probe technique. With a short retention interval (0 or 1 sec), memory for the first item was poor but memory for the last item was almost perfect. As the duration of the retention interval increased, memory for the first item improved and memory for the last item became worse. This absolute increase in performance over time, without the opportunity for further learning or rehearsal, occurred in both between- and within-subject designs (Neath and Knodler 1994) and with pigeons and monkeys (Wright 1985).

Similar effects of relative temporal spacing have been reported in both Pavlovian and instrumental paradigms. In a Pavlovian situation, for a given interval between conditional stimulus (CS)-offset and unconditional stimulus (US)-onset, conditioned responding increases as the ITI increases (Gibbon and Balsam 1981; see also Jenkins et al. 1981). In an instrumental situation, the memory of a reward outcome stored at a particular temporal interval is better retrieved at that interval than at a different interval, longer or shorter (Capaldi et al. 1986).

Ebbinghaus (1885) introduced a test of memory generally known as the method of savings. In this method, a previously learned list is relearned and the difference in learning the list to criterion the second time from that of originally learning the list represents the savings attributable to memory. When relearning certain stanzas from Byron's *Don Juan* after a 30-year interval, Ebbinghaus still noted a savings.

Similar long-lasting savings can be found with many perceptual-motor as well as more traditional memory tasks (Kollers and Roediger 1984). Another method of measuring savings is known as repetition priming. Subjects are typically presented with a word fragment that can be completed with only one valid word. For example, toboggan might be the target word and _o _ogg _might be the word fragment. Some subjects have recently seen the word toboggan on a prior list and others have not. Repetition priming refers to the finding that those subjects who have seen toboggan recently are more likely to complete the word fragment correctly than those subjects who did not, even if the former subjects are unaware of their prior exposure to the word. Effects of repetition priming can be detected after a delay as long as 16 months in college students (Sloan et al. 1988) and after a delay as long as 12 months in amnesics (Tulving et al. 1991).

There are many studies that demonstrate subjects can recognize words that they cannot recall; nobody finds this result particularly surprising. The complementary result, recall of words that cannot be recognized, has generated much more controversy (Hintzman 1992; Tulving and Flexser 1992). Our point is simply that where one memory test might indicate something has been forgotten, a different test often reveals a different answer.

There are many other instances, documented by Miller and Grahame (1991; see also Miller et al. 1986), in which an absence of responding does not mean the absence of previously learned information. Blocking refers to the reduced responding to a stimulus (CS_1) when it is presented in compound with another stimulus (CS_2) that has already been paired with a US. Blocking is normally seen as an acquisition failure (Rescorla and Wagner 1972; Mackintosh 1975; Pearce and Hall 1980) in which learning about CS_2 -US relationship blocks learning about the CS_1 -US relationship. However, Miller and his colleagues have shown that blocking is better characterized as a performance deficit. In a conditioned suppression task, a blocked response can be recovered by a post-training reminder treatment consisting of a brief exposure either to the blocked CS, the US outside of the training context, or the training context itself.

Disinhibition refers to the restoration of an ostensibly extinguished response resulting from the sudden presentation of a novel distracting stimulus (Pavlov 1927). Similarly, renewal refers to the fact that a Pavlovian reaction conditioned in one context and supposedly extinguished in another different context may be restored when the CS is presented in the original context (Bouton 1991). The summation of undetected excitation is a phenomenon in which a purportedly extinguished stimulus, which fails to elicit a response by itself, elicits a strong response when presented in compound with a mild excitator, that elicits a relatively weak response by itself (see Reberg 1972). A similar phenomenon, reported by Hendry (1982), found that two excitators that were separately conditioned and then separately extinguished still evoked fear when presented in compound.

Finally, there are many studies in which presentation of a reminder cue that precludes new learning facilitates retrieval of an apparently forgotten response. For example, Miller and Springer (1972) demonstrated that giving experimental animals a second footshock after the initial footshock-ECS treatment but before the retention test reduced or

eliminated the memory impairment seen with ECS. A conceptually similar situation involves reinstatement, where simple exposure to the US alone after extinction partially restores an extinguished CS (see Bouton 1991).

Critics of the Present View

There are four criticisms that have been raised against the view that something once learned or committed to memory is never unlearned or forgotten. Changing context, according to the present view, usually results in poorer performance, but some researchers do not believe that context effects can be seen either with recognition studies or with infants. If this objection were correct, it would limit the present view. For example, semantic theorists (e.g., Reder et al. 1974) argue that changing context also changes the semantic meaning of the to-be-remembered stimulus and that it is this change in meaning (context beta) that reduces performance. However, Feenan and Snodgrass (1990) have demonstrated that context effects can be found in recognition of pictures, even when the change in context did not affect the meaning of the to-be-remembered item (context alpha). According to two different models (two-high-threshold and signal detection), there is a true decrease in discrimination for stimuli that have few, if any, alternate semantic interpretations. Similarly, although it is often thought that infants do not encode contextual information (e.g., Nadel et al. 1985), a series of experiments by Hayne et al. (1991) clearly demonstrate that infants as young as 3 months encode contextual information about the place where learning occurred and, the results suggest, this information can affect whether a particular memory is expressed at a later time.

A second potential problem concerns infantile amnesia, the finding that most adults have difficulty in remembering events of their infancy. The fact of infantile amnesia is often taken as suggesting that some material that is learned can be irretrievably lost. Of course, the change from preverbal processing in infancy to verbal processing later on is probably a major factor in the difficulty in recalling early experiences. Even so, Myers et al. (1987) report data that suggest that children aged between 2 and 3 years old remembered certain action sequences from a prior experiment conducted two years earlier when the children were between 6 and 40 weeks old. In addition, there are many instances in which earlier memories can be reinstated in infants (see Rovee-Collier and Hayne 1987).

As important as the change from nonverbal to verbal processing may be, it is not sufficient to explain infantile amnesia in rats, monkeys, wolves, and other altricial mammals (Spear and Riccio 1994). There is some evidence that infantile amnesia is related to brain growth. For example, guinea pigs are precocial and, compared with rats, undergo very little brain growth before adulthood. Guinea pigs that learned an avoidance response in infancy retain it when tested as adults (Campbell et al. 1974). This is consistent with the idea that at least part of the basis of infantile amnesia is attributable to maturational factors unique to infancy. Maturation development can be considered a form of internal context. The contextual changes that occur from infancy to adulthood may be quite dramatic, and thus, as a practical matter, memories processed in infancy may not be recoverable in adulthood.

A third, related criticism concerns amnesics and data from lesion or extirpation studies. For example, there are many documented cases of retrograde amnesia where the patient appears unable to recall

information learned prior to the trauma. This can be taken as evidence that under certain circumstances, even well-learned information can be permanently lost (e.g., Spear and Riccio 1994). As another example, there are many animal studies that demonstrate that lesioning of the hippocampal formation or other structures impairs memory for earlier events (e.g., Winocur 1990). In both of these situations, however, there is extensive structural damage, and whether the damage is solely responsible for memory failure is open to question. For example, the structural damage undoubtedly introduces many collateral changes in context, ranging from the perceptual to the motivational, which may themselves result in apparent forgetting.

The final potential problem concerns findings from the eye-witness misinformation memory paradigm, upon which Loftus and Loftus (1980) base their claim that memories can be permanently erased. They argue that information learned after an event can overwrite or be substituted for parts of established memories. For example, Loftus (1979) showed subjects a slide of a green car passing a red car; the red car was later involved in an accident. Subjects in the misleading condition were asked the following question: "Did the blue car that drove past the accident have a ski rack on the roof?" These subjects were far more likely to pick a color closer to blue than subjects who received a consistent question, one that described the car as green. McCloskey and Zaragoza (1985) offered a biased-guessing account for the same data. They argued that the design used by Loftus and her colleagues placed subjects in a situation where the discrimination task was harder for the misled subjects than for the control subjects: The misled subjects may remember both a green and a blue car. When the discrimination task was made less difficult, by having subjects choose between the original information (e.g., green car) and novel information (e.g., white car), there was no difference between the misled and control subjects, and this null result has been replicated many times (see Greene 1992). With a different form of testing, the data do not support the substitution hypothesis.

Summary

In 1929, H.C. Blodgett reported the results of a seminal maze learning experiment using rats. In that experiment, hungry rats ran in a complex maze but were not rewarded on reaching the goal box. Not surprisingly, the performance of the hungry rats did not improve over trials. However, with the introduction of reward, the error scores of the rats suddenly dropped to the level of the control rats that were rewarded from the outset. This finding indicates that the experimental group had learned the maze despite the absence of reward but that the learning was latent rather than manifest. With Blodgett's findings, the distinction between learning and performance became firmly established, if not as widely appreciated as it might be.

Blodgett's (1929) early experimental finding of latent learning could well serve as a paradigm for the approach taken here. That is, we have emphasized the principle that a lack of performance does not necessarily indicate a lack of either learning or memory. This principle is much more than an empty admonition: We have shown it can have a firm theoretical basis, one that has been confirmed repeatedly by experiments cited throughout this paper. That is, it has been shown numerous times that a failure to perform either in a Pavlovian or instrumental learning task or

to remember in an animal or human memory task under one set of conditions could be alleviated under another set of conditions.

Forgetting was viewed here as a failure of performance resulting from the cues at test retrieving a memory other than the target memory or retrieving no memory at all. According to this view, memory involves discrimination learning. Essentially, memories are stored in the presence of an elaborate set of interoceptive and exteroceptive stimuli, a context. Whether at test the target memory is retrieved depends on how well the cues at test discriminate between the target memory and other memories. This approach suggests that forgetting does not occur: There is only a failure to perform because of a difference between the stimulus conditions prevailing at encoding and at test. It was demonstrated that this approach is at least as reasonable as that which suggests that true forgetting occurs, but certainly more useful.

At least three advantages adhere to our view that memory is a discrimination problem. First, in almost numberless cases, it has been shown that failure of performance under one set of stimulus conditions can be alleviated under some other set of stimulus conditions. Second, the proposition that altered stimulus conditions are responsible for forgetting is one of wide generality. Thus, the altered stimulus conditions approach can serve as an explanation not only for various human memory findings but also for various animal memory and learning findings. Finally, and perhaps most importantly, the present approach provides investigators with a powerful and proven working hypothesis. It tells us not to accept failures of performance as indicating an absence of learning or a loss of memory but rather to seek conditions favorable to improving performance, a strategy that should lead to a better fundamental understanding of memory and learning. This position is obviously a type of optimality theory, of which evolutionary theory is one of the more outstanding examples. In optimality theory, any deviation from some ideal state or condition prompts the investigator to seek the reasons for deviation. This approach may prove as successful when applied to learning and memory as it has to other areas of science.

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