Journal of Experimental Psychology:
Learning, Memory, and Cognition
1994, Vol. 20, No. 1, 51-66

0278-7393/94/$3.00

Reducing Retroactive Interference: An Interference Analysis

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In 4 experiments on retroactive interference (RI), we varied paired-associate learning lists that produced either appreciable or negligible forgetting. When the category of the stimulus word predicted its response word category, and the response was relatively unique within its category, learning was extremely rapid, and negative transfer and RI were negligible. The more the competing primed items in the predicted response category, the slower the learning and the greater the RI. If cues and responses were unrelated, learning was very slow, and RI was appreciable. Thus, predictive relations that help stimuli retrieve unique responses greatly alter forgetting in RI paradigms.

This research returns to a fundamental question in the psychology of memory: Why do people forget things they have once learned? One of the oldest, most widely accepted theories of forgetting is associative interference, that people forget some target material because it is interfered with by other material in memory. Traditionally, the principles of associative interference have best been laid bare by studying learning and retention of paired associates, where, in successive lists, subjects learn different responses to the same cues—the so-called A–B, A–C paradigm. The second-learned response, C, is alleged to compete with successful recall of the first-learned response, B. The A–C association supposedly intrudes or wins out in competition with the requested A–B association (for reviews, see Keppel, 1968; Postman, 1961; Postman & Underwood, 1973).

Since the classic experiment by Barnes and Underwood (1959), this response competition principle has been supplemented with the principle of unlearning. That is, as the second association, A–C, is learned, the first association, A–B, supposedly undergoes progressive weakening. Thus, on a later modified modified free recall (MMFR) test that asks subjects to recall both list responses to each cue, recall of the first-list, A–B, association should decline in proportion to the amount of training on A–C. Because MMFR tests are considered noncompetitive, the declining recall of A–B with greater A–C training has been viewed as evidence for greater A–B unlearning as A–C learning increases (for an alternative interpretation, see Mensink & Raaijmakers, 1988).

These two factors of traditional interference theory—response competition and unlearning—have provided a platform from which the theory has been successfully extended to many different memory domains, including animal learning and forgetting, short-term memory, recognition latency, serial learning, free recall, list differentiation, and text memory (see Anderson & Bower, 1973; Keppel, 1968). Besides explaining retention phenomena in human verbal learning, interference theory has also derived some of its support from elementary learning-and-retention experiments with animals (e.g., Spear 1978), describing, for example, the response selections of an animal learning to turn left in a maze after it had earlier learned to turn right. The two principles of interference theory have proven so useful that one or both of them have been incorporated into most learning theories, including neobehavioral stimulus–response (S–R) theories (Hull, 1954), stimulus sampling theory (Bower, 1972b; Estes, 1959), expectancy theories (Tolman, 1959), information-processing theories the adaptive control of thought [ACT*] model of Anderson, 1976, 1983; the elementary perceiver and memorizer model [EPAM] of Feigenbaum & Simon, 1961), and nearly all parallel distributed processing (PDP) or connectionist theories (e.g., Rumelhart & McClelland, 1986). In fact, unlearning is so ingrained in most connectionist architectures for associative learning that connectionists have difficulty avoiding "catastrophic unlearning" in their model formulations (McCloskey & Cohen, 1989; Ratcliff, 1990).

As this list of applications illustrates, one appeal of two-factor interference theory was that because it concentrated on single S–R connections, it could be applied to many diverse settings, from a rat learning to turn left or right in a T maze to a primate choosing the red or green food cup, from a child choosing a square or circle in a discrimination task to a college sophomore learning to say "CUF" or "MIB" to a nonsense syllable in a paired-associate list. The theory enabled investigators to abstract out the single A–B, A–C associations from the swirling melange of complex events occurring in learning situations and apply to these associative units the basic principles of the theory.

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Gordon H. Bower's research was supported by Grant MH-47575 from the National Institute of Mental Health and Grant 87-0282 from the U.S. Air Force Office of Scientific Research. Endel Tulving's research was supported by Grant A8632 from the Natural Sciences and Engineering Research Council of Canada. Experiment 1 was reported by Endel Tulving at the annual meeting of the American Association for the Advancement of Science on December 30, 1967, in New York. Experiments 2 and 3 were carried out by Sharon Thompson-Schill in 1992 under Gordon H. Bower's guidance; Experiment 4 was carried out by Ellen Levy in 1993 under Gordon H. Bower's guidance. We thank Ellen Levy for her suggestions and help.

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Difficulties With the Unlearning Hypothesis

The unlearning hypothesis was not without its own problems and detractors.[1] An initial difficulty was that the MMFR test could not for long be argued to be a competition-free test that provided an uncontaminated measure of unlearning. First, retroactive interference (RI) was found to be nearly as great when assessed by MMFR as when assessed by a first-list-only recall measure (e.g., Houston, Garskof, Noyd, & Erskine, 1965; Postman, 1962). Second, evidence from other sources indicated that the act of retrieving some initial responses created interference with retrieving later responses (e.g., Tulving & Arbuckle, 1963; M. J. Watkins, 1975), a principle incorporated into several memory models, such as the search of associative memory (SAM) model (Mensink & Raaijmakers, 1988; Raaijmakers & Shiffrin, 1981). Third, contrary to expectations, proactive interference (poor recall of A–C because of prior learning of A–B) was still evident on MMFR tests (Ceraso & Henderson, 1965, 1966; Koppenaal, 1963); because A–C could not have been unlearned, the only viable explanation of such proactive effects within interference theory was to suppose that the MMFR test involved response competition.

The notion of cue-specific unlearning in the A–B, A–C paradigm also came under attack from several quarters. First, Martin (1971) reported that in a contingency analysis of A–B and A–C recall from MMFR results, the two responses to a given cue tended to be recalled or not recalled almost independently. He argued that unlearning theory would expect a negative correlation: The stronger A–C was, the weaker A–B should be. Hintzman (1972, 1980) questioned Martin's interpretation of the independence result, showing that pooling heterogeneous items with positive or negative correlations could yield an aggregated 2 × 2 table with a zero correlation. Although granting Hintzman's point in principle, the field nonetheless viewed Martin's argument as unsettling for the unlearning hypothesis.

Second, using an unpaced associative matching test, Postman and Stark (1969) found almost no retroactive interference for A–B pairs following interpolated A–C learning but found substantial RI with a recall test; they suggested that interference in recall was largely due to loss of availability of first-list responses due to interpolated learning, but the availability obstacle was circumvented by the recognition test.

Third, Newton and Wickens (1962) and Postman, Stark, and Fraser (1968) showed generalized interference and forgetting in an A–B, C–D paradigm in which unlearning of specific A–B associations was precluded. In fact, in several cases, RI was as large in the A–B, C–D condition as in the A–B, A–C condition. Such results led the authors to question the notion of cue-specific unlearning and propose instead that interpolated learning causes general suppression of the entire set of first-list responses. That is, during second-list learning subjects learn to suppress the first-list responses in order to give the more recent, second-list responses. In this theory, RI arises when subjects later try to recall first-list responses because their selector mechanism has inertia, persisting for a while in selecting primed responses from the most recent response set while continuing to suppress the earlier set of responses.

Thus, by the early 1970s, the concept of stimulus-specific unlearning was in trouble and was being replaced by the theory of the maladaptive persistence of interpolated sets or whole repertoires of responses. We return to this historical record after we have introduced another factor that affects recall and have described our experiments demonstrating its potency in moderating the degree of A–B retention in standard interference designs.

The Structure of A–B, A–C Lists

In 1933, von Restorff, in a classic paper, reported a series of experiments designed to analyze the effect of isolation and massing of items on the learning and retention of paired-associate lists. She varied the degree of material-specific isolation and massing within lists by using pairs of different kinds, such as nonsense syllables, geometric figures, and two-digit numbers. In one of her paired-associate experiments, for example, subjects studied a list of eight pairs for three trials. The list comprised six pairs of one kind of material (massed) and one pair each of two other kinds (isolated). (Individual pairs were properly rotated through the experimental conditions.) Recall was requested after 6 min or 40 min and showed 25% correct recall for the massed pairs and 87% correct recall for the isolated ones, with no difference between the two retention intervals (von Restorff, 1933, Table 4).

These striking findings revealed what appeared to be a fundamental fact: The learning and retention of a single A–B association depend greatly on whether other associations of the same kind are also learned. Given the magnitude of this effect reported by von Restorff (1933), it was natural to inquire into its empirical limits and theoretical implications for other processes, such as interference and forgetting. Indeed, von Restorff noted that if the presence of pairs of a certain kind in the study list weakens memory for other pairs of the same kind in the list, a similar effect would probably also occur when a given pair is separated in time from others of the same kind, as happens when separate lists are learned in studies of retroactive and proactive interference.

In support of this analysis, von Restorff (1933) then demonstrated that retroactive and proactive interference was material specific: Interference was largely limited to the classes of materials shared by the critical list and the interpolated lists. (A similar outcome was reported later by Postman, Keppel, & Stark, 1965.) But these latter results of von Restorff's were less compelling, logically providing little information beyond what was known from experiments using lists of similar items.

The kinds of lists that von Restorff (1933) used can be conceived as having different organizational structures, defined in terms of relations between pairs. In one case, a number of pairs belonged to the same category; in the alternative case, each pair belonged to a different category. Von Restorff's findings suggested that overall list organization or intralist context of a to-be-learned pair is an important determinant of acquisition and retention of A–B associations.

Inspired by these early, generally overlooked findings, Tulving, back in 1967, decided to examine again the role of

[1] We thank Douglas Nelson for suggesting this and related points in his review of a draft of this article.

organizational factors in association formation and retention. At that time, the concept of organization played a central role in analyses of memory in free recall (Tulving, 1968), so the question about organization and interference in paired associates seemed timely.

In addition, it seemed appropriate to find out what would happen if the method used in an A–B, A–C experiment departed from what by then had become the almost universal practice of using like-pair lists, that is, lists in which either all the A, B, and C members of individual pairs belonged to the same category or all the A–B and/or A–C pairings were of the same type. This practice had evolved without much explicit argument in its favor. The implicit rationale for it probably was the objective of slowing down the overall learning process so it could be studied more easily, while accumulating a large sample of homogeneous observations (or replications) of learning and forgetting of the basic A–B, A–C memory units. In later years, a further rationale for having subjects learn multiple pairs was that subjects' performance over successive presentations of a given item would not be seriously contaminated by short-term memory of its prior presentations.

Experiment 1

Experiment 1 was undertaken to examine the significance for interference theory of the nearly universal use of the like-pairs procedure. We were especially interested in whether a modification of the list structures in the A–B, A–C paradigm would alter the degree of RI and unlearning. To this end, the RI created by standard lists of all-same pairs was compared with the RI created by multi-item lists in which each of the pairs was composed from very dissimilar materials. The basic idea of item construction in the two cases is illustrated by the three A–B, A–C pairs in Figure 1. In the all-same lists, all items are the same type (e.g., two-digit numbers); in the congruent list, each pair belongs to a unique form class of two-digit numbers, single-consonant letters, famous persons, etc. Furthermore, in the congruent list the pairs were also organized by a simple principle—that the stimulus and response of each pair belong to the same form class. To investigate RI in each condition, we composed two lists to exemplify the A–B, A–C paradigm. To equate average difficulty of items, we had different subjects in the all-same conditions learn lists of different types—all digits, all consonants, all famous persons, and so on.

The question we asked was, How will the basic interference effects—slow learning of A–C and forgetting of A–B—play out with such congruent lists? Because the cues and their successive responses follow the A–B, A–C relationship in both congruent and all-same lists, interference theory applied at the level of individual pairs would predict equal amounts of unlearning and RI on a later MMFR test for the two list conditions. But that prediction clashes with our intuition that the congruent condition would show far less unlearning and forgetting.

One might argue that the all-same list would be more difficult to learn and show greater interference because of confusions among its similar cue terms and among its similar response terms (e.g., Gibson, 1940; Saltz, 1961). To assess the sufficiency of this explanation for the expected advantage for

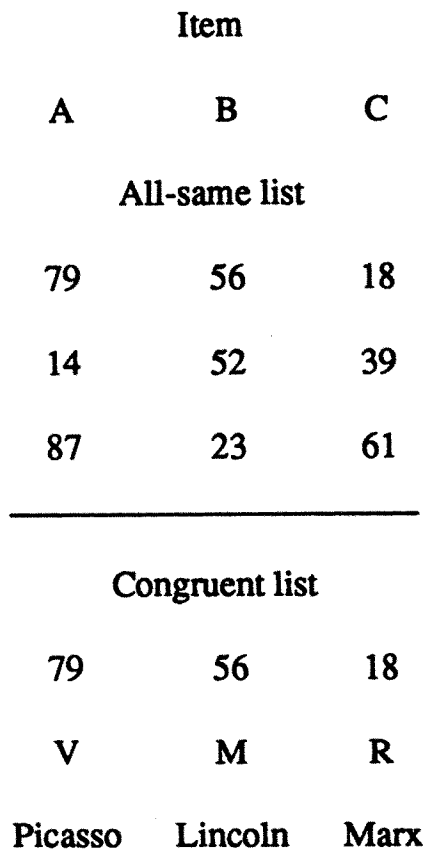

Figure 1. Three examples of A–B, A–C pairs in the all-same and congruent lists.

the congruent list, we added a third experimental condition, which we composed by randomly mispairing the stimulus and response items of the first (A–B) congruent list and mispairing them again in a different manner for the second (A–C) list. We refer to this as the mispaired list condition. This mispaired condition should be equivalent to the congruent condition in terms of reduced intralist stimulus generalization and response generalization if these items were to be considered separately. What differs between the two conditions is the organization of the stimulus-to-response pairings: The congruent list follows a systematic rule; the mispaired list is random.

In summary, in Experiment 1 three groups of subjects were trained and tested in the A–B, A–C paradigm before receiving a final MMFR test that assessed their degree of first-list (A–B) forgetting. On the basis of our theory (explained in the introduction to Experiment 2), we expected unlearning and forgetting to be least in the congruent condition and far greater in the all-same and mispaired conditions.

Method

Subjects. Sixty undergraduate students from the University of Toronto Psychology Department pool served as subjects. Twelve subjects were assigned to learn the congruent list, 12 were assigned to learn the mispaired list, and 36 subjects were distributed 6 each to learn six all-same lists composed of different materials.

Table 1
Mean Number of Original Learning Trials to Criterion and Modified Modified Free Recall (MMFR) Scores for the First (A–B) and Second (A–C) Lists in Experiment 1

Condition	n	Original learning trials		MMFR	
		A–B	A–C	A–B	A–C
Congruent list	12	2.3	2.2	5.8	6.0
Mispaired list	12	6.2	6.7	3.5	5.7
All-same lists					
Numbers	6	21.5	13.0	2.3	5.5
Eight-letter words	6	11.3	7.0	3.8	6.0
Famous people	6	10.8	7.3	4.5	5.7
Consonants	6	8.5	6.2	4.3	5.7
Geographic names	6	8.2	7.8	1.8	5.7
Three-letter words	6	6.2	7.0	2.8	5.5
Pooled mean	36	11.1	8.1	3.3	5.7

Note. MMFR scores were lenient in that they included any recalled response regardless of whether its list was correctly identified.

Materials. Each subject learned an A–B and then an A–C list, each of which was composed of six paired associates. The all-same lists were composed of six pairs drawn from one set of material: two-digit numbers, eight-letter words, names of famous people, single consonants, geographical names, or three-letter words. Within each list, the stimulus constituted one element of the category and the two responses to that stimulus were two other elements of that category. The format of the lists is illustrated in the top half of Figure 1 for the list of two-digit numbers.

The congruent lists were composed of one A–B, A–C pair from each of the six different all-same lists; the bottom half of Figure 1 illustrates such a list. We constructed six different versions of congruent lists by selecting different items from the all-same lists; each version was learned by 2 of the subjects assigned to the congruent condition. In this manner, the congruent lists were constructed of items selected from the all-same lists, so that all pairs occurred equally often across the two types of lists.

The mispaired lists were composed by randomly scrambling the S–R pairings of the congruent lists, so that the category of the correct response never matched the category of the stimulus term; moreover, the mispairings differed across Lists 1 and 2. Six versions of the mispaired lists were derived by mispairing the six versions of the congruent lists; each version was learned by 2 of the subjects assigned to the mispaired condition.

Procedure. Half the subjects in each group learned their two lists in one order (e.g., V to M; V to R), and the other half learned them in the reverse order (V to R; V to M). All subjects were tested individually using the anticipation method. Lists were presented by means of a memory drum. The cue would appear alone in the window of the drum for 2 s, at which time the subject was to recall the response term; then both elements of the pair were shown for a 2-s study time. A 4-s rest occurred between cycles through the list. Training on each list continued until subjects reached a criterion of two perfect cycles through the list. In the MMFR test that followed completion of the second-list learning, the stimulus terms were listed on a sheet of paper and subjects were asked to recall and write the response terms for both lists beside each stimulus. Unlimited time was allowed for MMFR recall; subjects were asked to try to identify the list of a recalled response term and were urged to guess if they were unsure.

Results

Initial learning. The mean number of original learning trials required to reach criterion for Lists 1 and 2 are shown in Table 1. There was considerable variability in both original learning and MMFR scores among the six different all-same lists. However, because our main concern is the comparison of the three different types of lists (all-same, congruent, and mispaired), we consider only the pooled mean of the six all-same lists (shown in the bottom row of Table 1), which across subjects included the same pairs as often as did the congruent lists. The number of trials to criterion on both the first and second lists was smallest for the congruent condition (an average of 2.3; the minimum possible was 2), higher for the mispaired condition (an average of 6.4), and highest for the all-same condition (an average of 9.6). Pooled over both lists, these averages differed significantly, $F(2, 57) = 16.4, p < .001$.

Forgetting. The MMFR scores are also shown in Table 1. The scores are lenient in that they include any recalled response regardless of whether its list was correctly identified. (List identification averaged 98% overall; even the poorest all-same learners averaged 93% correct identifications of their List 1 recalls.) Recall was uniformly high for the A–C lists in all conditions; this was expected because subjects had just reached criterion on A–C prior to MMFR testing. In contrast, the MMFR scores for the A–B lists were much lower, at around 3.5 items (58%), and practically identical for the all-same and mispaired lists, but A–B recall was considerably higher, at 5.8 items (97%), for the congruent lists, $F(2, 57) = 11.2, p < .001$. In fact, 10 of the 12 congruent subjects recalled all A–B associates perfectly, and the other 2 subjects failed just one item each. Among the 48 subjects in the other groups, only 4 showed perfect first-list recall on the MMFR test.

Discussion

The results were as expected. What was somewhat surprising was that practically no A–B forgetting occurred in the congruent condition, whereas it was substantial in the other two conditions. Because the pairs in the congruent condition were duplicates for a portion of the subjects who learned them in an all-same list, one would be hard-pressed to attribute the group differences to inherent learning difficulties of the individual pairs. Rather, the vast difference in outcomes emphasizes the principle that the difficulty in learning (or later recalling) a given pair depends on the context of the other items in the list being learned. That fact already calls into question the traditional theoretical analysis that abstracts out each A–B, A–C memory unit from the list context and attempts to describe its dynamics in isolation.

The poorer learning and List 1 retention of subjects in the mispaired condition indicates that stimulus and/or response confusions are not a sufficient explanation for the easy learning and absence of recall interference in the congruent condition. Although stimulus and response distinctiveness is undoubtedly an important factor in many learning situations, it does not suffice to explain the large advantage shown by the subjects in the congruent condition.

Why was the congruent list so easy to learn and so resistant to interference? One remote possibility is that items that belong to the same form class are simply easier to associate with one another than are items that belong to different classes. Perhaps consonants are more easily associated with

other consonants, numbers with numbers, and so on, than are the items in scrambled pairings. This is the familiar idea that the more two stimuli resemble each other, the more easily associated they are (e.g., Rescorla & Furrow, 1977; Testa, 1974). This explanation fails for the present results, however, because the all-same lists contained the most pairs that were highly similar, yet those lists were the most difficult for subjects to learn and recall.

The hypothesis we prefer is that the congruent list conferred its advantage by virtue of the easy systematicity of the abstract S–R mappings—that "like goes with like." Given the stimulus cue, a simple rule informs the subject about the class of the response term. And that knowledge somehow provides an enormous boost during learning of both lists and on the later MMFR test.

Experiment 2

How and why does knowledge of the rule relating a stimulus and its response classes help performance so greatly? For example, just knowing that the response term is, say, a famous name or a two-digit number should not greatly benefit recall because large numbers of such items exist. However, in the experimental context, subjects in the congruent-list condition study only one or two responses of a given form class, and we may suppose that presentation of those items primes and strengthens the association from the form category to the few items of that category included in the list. We suggest that the optimal performance rule for subjects in the congruent-list condition upon presentation of the cue term of each pair is as follows: (a) Classify the stimulus term, (b) retrieve the response items in that class that have recently been primed or strengthened, (c) edit them for the list, and (d) recall the form category item appropriate to the requested list.

If this view is correct, a major determinant of pair difficulty is whether subjects can predict the class of the response term just before they must respond to the stimulus cue. If they can, performance in the mispaired condition should be greatly improved if a clue is provided alongside the nominal stimulus informing subjects of the category to which the correct response belongs. In Experiment 2, we called this the cued condition and predicted that such cued pairs would be learned nearly as rapidly and retained nearly as well as those in the congruent condition. To test our prediction, we compared learning and retention by subjects in the cued condition with learning and retention by subjects in new but equivalent all-same and congruent conditions.

A second purpose of Experiment 2 was to extend the findings of Experiment 1 to different learning materials. Thus we used words belonging to 20 different semantic categories, such as animals, occupations, body parts, and so on. Because subjects naturally encode these materials in distinctly different ways, they were expected to achieve results resembling those obtained with the different form class materials of Experiment 1.

Method

Subjects. Twenty-eight Stanford University students were randomly assigned to the four testing conditions, 7 to each. One subject (in the congruent condition) withdrew midway through the experiment and was replaced. Students participated to fulfill a course requirement for introductory psychology and were tested individually.

Materials. The four conditions differed only in the nature of the study materials (presented in the Appendix). In each condition, subjects learned two lists of 20 items each, in an A–B, A–C relationship. The all-same lists comprised 20 items from one semantic category (e.g., ROBIN TO DOG, LION TO MONKEY, SNAKE TO GIRAFFE, etc.). Half the subjects learned animal names, and half learned occupation names. The congruent list comprised one item each from 20 different semantic categories, including animals, occupations, weapons, body parts, and so on. The congruent list was structured similarly to that used in Experiment 1: Both words in a pair were from the same semantic category, but each pair was drawn from a unique category within the list (e.g., ROBIN TO DOG, DOCTOR TO BAKER, ARM TO FACE). All subjects in this condition learned the same first and second lists. A constraint in selecting response words for all lists was to allow subjects to indicate their recall of a unique response word in the list by merely typing its first two letters on the computer keyboard.

The mispaired list was formed by randomly mispairing the stimulus and response terms of the congruent list (e.g., ROBIN to BAKER, DOCTOR to FACE, ARM to DOG, etc.). Moreover, the mispairing of category members differed across Lists 1 and 2 so that no useful knowledge could be transferred from List 1 to 2. All subjects in this condition learned the same first and second list.

The cued lists were identical to the mispaired lists with one exception: During learning and recall, subjects were provided with the semantic category of the correct response word as they were viewing each stimulus cue (e.g., ROBIN [occupation] to BAKER, DOCTOR [body part] to FACE, etc.). Subjects in the cued condition saw the category cue at the same time that the stimulus term was presented; the category cue appeared above the response term during study trials and above the space on the recall sheet where the missing response term was to be written during the MMFR test.

Procedure. During the initial study trial, pairs were presented one at a time for 2 s each. This study trial was immediately followed by anticipation-plus-study trials. The cue alone was presented for 3 s, followed by the cue and response word together for 2 s of study. A 6-s rest was imposed between successive cycles through the list of pairs. During the anticipation interval, subjects were to try to recall the response word and type on the keyboard its first two letters (which uniquely identified it in that list). Subjects continued anticipation-plus-study cycles through the list of pairs in random order either until all pairs had been correctly anticipated for 2 trials or until 10 test cycles through the list had been given, whichever occurred first. To prevent overtraining on items learned early, a "dropout" learning procedure was used: Once a pair had been correctly anticipated two times, it was removed from future repetitions. After completion of List 1 learning (or 10 trials), subjects immediately began learning the second list, using the same procedure and criterion for learning.

After studying the second list, subjects performed a distractor task for 5 min. This consisted of rating the humor and comprehensibility of a series of cartoons under the guise of another study. After this 5-min distraction, recall for the two lists of paired associates was tested by MMFR. Subjects received a booklet containing the stimulus words (one word per page) and were asked to recall and write both response words. Subjects had the option of indicating from which list each response term came, although this was not required. Subjects were allowed a maximum of 20 s to write both responses for a given stimulus term before a cue from the experimenter signaled them to turn the page in the booklet to the next item. In the cued condition, the category cues for the two correct responses appeared next to the stimulus term on each page.

During the learning phase, all instructions and materials were presented on an IBM PC, which was programmed to run the

Table 2
Mean Number of Trials to Criterion and Standard Deviations per Pair and Percentage of Pairs Reaching Criterion Within 10 Trials in Experiment 2

Condition	List 1			List 2		
	M	*SD*	%	*M*	*SD*	%
Congruent list	2.32	0.2	100	2.41	0.2	100
Cued list	3.17	0.7	100	3.21	0.7	100
Mispaired list	5.76	1.4	87	4.86	1.5	92
All-same list	6.32	1.4	76	6.53	1.6	76

experiment and collect the data. The distractor task and MMFR test were pencil-and-paper tasks.

Results

Initial learning. Because variations in the type of materials used in a condition (e.g., animal words vs. occupation words) caused no systematic performance differences, results were pooled for comparisons. The conditions differed systematically in the speed with which the lists were learned. Assigning a score of 10 trials to items that did not reach the criterion of two correct recalls, we calculated the mean number of trials per pair to reach criterion during initial learning (Table 2). Numbers of trials to criterion were about the same across the two lists but differed greatly between conditions, $F(3, 24) = 20.56, p < .001$. For both lists, subjects required more trials to learn in the all-same and mispaired conditions than in the congruent and cued conditions, $F(1, 24) = 111.95, p < .001$. However, as Table 2 shows, in even the slowest learning condition, subjects attained the learning criterion on a high percentage of items.

Forgetting. To assess forgetting, we counted the number of correctly recalled List 1 and List 2 responses on the MMFR task, ignoring the list assigned to the recalls. The means for each condition are given in Table 3. A repeated measures analysis between conditions across both lists revealed a significant interaction, $F(3, 24) = 9.51, p < .001$. For List 1, subjects in the congruent and cued conditions scored significantly higher than subjects in the all-same and mispaired conditions, $F(1, 24) = 142.71, p < .001$. This contrast was also significant for List 2, $F(1, 24) = 10.86, p < .01$, although Tukey's pairwise comparisons revealed significant differences only between the all-same and the congruent and cued conditions. As might be expected, the differences between conditions were considerably larger for List 1 than for List 2.

To correct for differences among conditions in original learning, we also calculated retention percentages conditional upon initial learning of the items. This analysis included only items that subjects had learned to criterion. These conditional percentages are shown in Table 3. Analysis of variance (ANOVA) of the arcsine-transformed percentages revealed a pattern of significances similar to that found for the raw recall scores. Retention percentages differed across the four conditions, $F(3, 24) = 26.5, p < .001$, and across the two lists, $F(1, 24) = 33.6, p < .001$; in addition, the differences were greater for List 1 than for List 2, $F(3, 24) = 6.5, p < .01$.

The preceding analyses were based on lenient MMFR scoring, which ignored whether subjects identified correctly the list of their recalled response. However, subjects were asked to try to indicate the list to which a recalled response belonged. These list identifications were very accurate, at 95% for List 1 and 97% for List 2 pooling across conditions. As expected, the all-same and mispaired conditions had the lower scores, 95% and 90%, respectively. In reanalyses with strict scoring of recall, none of the previous patterns of significance were altered, so the data from these reanalyses are not reported.

Discussion

The results support several conclusions. First, the essential results of Experiment 1 were replicated, showing rapid learning and little RI in the congruent condition but slow learning and substantial RI in the all-same and the mispaired conditions.

Second, the basic results were replicated by using semantic categories of words in place of the different form classes of materials learned by subjects in Experiment 1.

Third, providing a response category clue alongside the stimulus word (in the cued condition) conferred nearly full benefit on the otherwise scrambled word pairs: Subjects learned these cued pairs rapidly and showed little if any RI on the final MMFR test. In most respects, the performance of the subjects in the cued condition mimicked that of the subjects in the congruent condition.

These latter findings support our hypothesis that the advantage of the congruent condition over the other conditions in Experiment 1 depended at least to some extent on the same-category rule. That is, in the congruent list, the stimulus word informed subjects of the category of the response word, and it was this category information that constituted the functional (rather than the nominal) retrieval cue (Underwood, 1963). Subjects used this functional cue to retrieve the recently primed member(s) of that category.

During learning in the cued condition in Experiment 2, subjects presumably relied largely on the category name component within the nominal-stimulus-word-plus-response-category-cue compound. The category name probably acted as a prepotent cue overshadowing or blocking the strengthening of the association between the nominal stimulus word and the response term (Chapman & Robbins, 1990). At the time of the final MMFR test, too, the category name—implicit in the congruent condition but explicitly provided in the cued condi-

Table 3
Mean Number of Correct Responses (and Standard Deviation) Recalled on the Modified Modified Free Recall Test and Retention Percentages Conditional on Initial Learning of the Item in Experiment 2

Condition	List 1			List 2		
	M	*SD*	%	*M*	*SD*	%
Congruent list	19.7	0.5	95	20.0	0.0	99
Cued list	19.0	1.3	99	19.7	0.0	100
Mispaired list	9.7	2.8	56	17.4	4.0	92
All-same list	8.3	3.4	53	14.4	4.9	87

Table 4
Mean Number of Trials (and Standard Deviation) to Criterion per Pair and Percentage of Items Reaching Criterion in Experiment 3

No. of categories: Pairs per category	List 1			List 2		
	M	*SD*	%	*M*	*SD*	%
1: 20	6.3	1.4	81	7.6	2.2	93
2: 10	4.7	0.8	99	6.0	1.1	100
4: 5	4.8	1.5	93	6.1	1.5	99
10: 2	3.2	0.6	100	4.3	0.3	100
20: 1	2.3	0.3	99	3.5	0.6	100

tion—would probably serve as the functional retrieval cue to provide access to the appropriately encoded target word.

Experiment 3

The equivalence of the congruent and the cued conditions supports the idea that performance benefits when subjects know the category of the response term for which they are searching. That is, performance is facilitated when the stimulus complex predicts the category of the response term. But the congruent advantage must consist of more than that, because subjects in the all-same conditions could also predict the category of the response term, and yet they performed poorly and showed substantial RI. Why did the same-category rule for S–R pairs not help subjects in the all-same conditions?

A plausible answer identifies the number of relevant response alternatives in the implied category as the key difference between the congruent and all-same conditions. In the congruent case, the response category retrieved by the stimulus has one (or at most two) recently primed items usable as response terms; in contrast, in the all-same conditions, for each stimulus the response category has 20 (or later 40) recently primed items from which to choose. Presumably, selection of the correct item from the response set is easier the fewer the number of primed candidates. In fact, we should expect an inverse relationship between performance of the target response and the number of primed alternatives in the relevant response set.

Experiment 3 was undertaken to investigate this implication. The analysis suggests a range of number of primed response alternatives between the extremes of the congruent and all-same conditions. We set out to create lists exemplifying several points along this functional range and to assess their corresponding influence on learning and forgetting.

We varied the number of semantic categories represented in the lists learned by five different groups of subjects. All subjects learned 20 congruent paired associates in two lists conforming to the A–B, A–C scheme. The numbers of categories (C) exemplified by pairs in the two 20-pair lists were 1, 2, 4, 10, or 20 for the five list conditions. The number of competing incorrect responses within a cue's category on the MMFR test was $(40/C) - 2$. Therefore, the five list conditions can be designated by their number of categories and number of competing MMFR responses: 1–38, 2–18, 4–8, 10–2, and 20–0. Different groups of subjects learned these five lists in an A–B, A–C design before receiving a final MMFR test.

In summary, in Experiment 3 we predicted that the more pairs that exemplified a given category (i.e., the fewer the categories in the list), the greater the number of primed response alternatives for each congruent S–R pair and, therefore, the poorer the performance and the greater the resulting RI.

Method

Subjects. Forty Stanford University students were randomly assigned to one of five list-learning conditions. Students participated to fulfill a course requirement for introductory psychology and were tested individually.

Materials. The five paired-associate lists in this experiment differed from each other only in the size of the response class corresponding to a given stimulus. The lists with the smallest and the largest response categories were identical to the congruent and all-same lists, respectively, from Experiment 2. Three intermediate lists were constructed as follows: One list had 2 pairs of each of 10 different categories; one list had 4 pairs of each of 5 different categories; and one list had 10 pairs of each of 2 different categories. In these terms, the congruent list from Experiment 2 could be described as comprising one pair of each of 20 different categories, whereas the all-same list from Experiment 2 could be described as comprising 20 pairs of only one category (animals for half the subjects; occupations for the other half). Henceforth, the lists shall be referred to by their number of categories, ranging from 1 to 20. The number of pairs exemplifying a given category was equal to 20 divided by the number of categories in the list. The 1-category and 20-category lists were those used in Experiment 2. The 4-category list used animals, occupations, body parts, and musical instruments. The 10-category list used those 4 categories plus precious stones, types of cloth, fruits, earth formations, clothing, and metals. Examples of the 4-category and 10-category lists are shown in the Appendix. The distractor task and MMFR test were identical to those used in Experiment 2.

Procedure. Experiment 3 was identical to Experiment 2 with one exception: To produce more forgetting of List 1, we carried List 2 learning to the more stringent criterion of three correct recalls per pair or 15 trials, whichever occurred first. List 1 was studied to a criterion of two correct recalls per pair or 10 trials, the same as in Experiment 2. The same dropout learning procedure was used as in Experiment 2.

Results

Initial learning. The mean numbers of trials per pair needed to reach criterion during the learning phase of the experiment are shown in Table 4. Recall that the criterion for the first list was two correct responses, whereas that for the second list was three.

As the size of the response class corresponding to a given stimulus increased, so did the number of trials required to

Table 5
Mean Number of Correct Recalls (and Standard Deviation) for Each Condition and Retention Percentages Conditional on Initial Learning in Experiment 3

No. of categories: Pairs per category	List 1			List 2		
	M	*SD*	%	*M*	*SD*	%
1: 20	7.5	3.1	45	16.6	4.0	83
2: 10	10.9	2.4	55	18.1	1.1	91
4: 5	11.9	4.2	63	18.6	1.5	91
10: 2	14.4	3.6	73	19.8	0.3	94
20: 1	19.5	0.8	98	20.0	0.6	100

reach criterion. The group differences in number of trials to criterion were statistically significant, $F(4, 35) = 18.18, p < .001$. A linear trend across number of categories accounted for 94% of the variance between groups, $F(1, 35) = 68.06, p < .001$. Across all subjects, 94% of the pairs were learned to criterion before the maximum of 10 trials on the first list, and an average of 98% of the pairs were learned before the maximum of 15 trials on the second list. As expected, the one-category (all-same) condition caused the slowest learning.

Forgetting. Forgetting was assessed from the mean MMFR recall scores for Lists 1 and 2 for each condition (Table 5). A repeated measures analysis between conditions across both lists revealed reliable differences due to conditions, lists, and their interaction (all $ps < .001$). As with the learning data, the overall main effect for condition largely reflected a linear component, $F(1, 35) = 50.63, p < .001$. List 1 recall especially increased as the size of the response class decreased.

To correct for differing degrees of original learning, we calculated retention percentages conditional on items reaching criterion originally. These percentages are shown in Table 5; those for List 1 are also graphed in Figure 2. An ANOVA of these percentages (transformed by arcsine) revealed significant differences among conditions, $F(4, 35) = 16.3, p < .001$; the differences were greatly attenuated for List 2 recall because performance levels were near ceiling.

List discrimination for the recalled responses was scored but was so uniformly near perfect (averaging 98% overall on both lists) that no statistical analyses were performed.

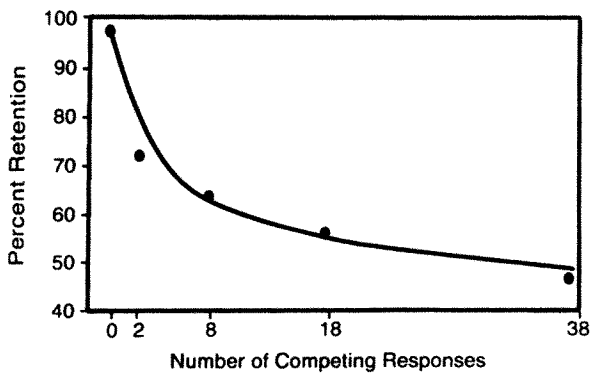

Figure 2. Probability of retention of List 1 associates, conditional on initial learning, as a function of the number of similar competing responses in the two lists. A smooth curve has been drawn through the *data points.*

Intrusion errors. Errors on the MMFR task were either omissions or intrusions of a word from another pair from the same category that appeared on the study list. (Nonlist words or words from wrong categories never intruded.) The mean numbers of intrusions and omissions and the percentages of all errors they constituted are reported in Table 6. Because the 20-category list had no other exemplars, intrusions never occurred in this condition, and thus this condition is not represented in Table 6. For the four remaining conditions, the rates of intrusion errors differed significantly between conditions, $F(3, 28) = 5.93, p < .01$. Tukey's pairwise comparisons revealed differences in the intrusion percentages between the 10-category condition and the 1-category and 2-category conditions. Table 6 shows that the total number of errors decreased with the size of the response class for a given stimulus, whereas the ratio of intrusions to omissions, as well as the number of intrusions, increased as the size of the response class decreased.

Discussion

The results accorded well with predictions. The number of pairs within a given category had a profound impact on the learning rate and RI for each of the pairs in that category. These results are quite compatible with the notion of interference via response competition, but the effective competition is confined to the restricted set of responses cued by the mediating category.

This view of response competition was bolstered by the error analysis presented in Table 6. As the number of within-class response alternatives was reduced, the percentage of errors that were overt intrusions increased. All these intrusions came from the correct category, and nearly all of them were other response terms on the appropriate list. That is, when subjects were trying to recall, say, the animal paired with an animal cue

Table 6
Mean Number of Intrusions and Omissions and Percentages of Total for List 1 in Experiment 3

No. of categories: Pairs per category	Intrusions		Omissions	
	M	% of total	*M*	% of total
1: 20	1.2	10	11.3	90
2: 10	1.7	18	7.5	82
4: 5	2.4	30	5.7	70
10: 2	2.8	50	2.8	50

in List 1, an animal response word appropriate to some other animal pair on List 1 was likely to intrude.

Experiment 4

In the first three experiments, we used congruent pairs that were related by virtue of their similar semantic category or type of material. However, theoretical analysis suggests that similar facilitation in learning and reduction in interference should occur whenever the list of pairs exhibits any obvious rule relating the cue terms to their unique response terms.

Another example of such a rule is phonetic rhyming of the word pairs, as in *pin–fin* and *ban–pan.* Earlier, Bower and Bolton (1969) demonstrated that a rhyming relationship between cue and response terms facilitated paired-associate learning largely because the relation restricted the set of response words the subject needed to consider as candidates for a given cue term.

Experiment 4 was designed to test whether a congruent rhyming relation among the cues and their responses would facilitate learning of A–B and A–C pairs and would reduce the RI of A–B caused by learning A–C. Accordingly, Experiment 4 was a replication of the congruent and mixed conditions of Experiment 2 except that the materials were rhyming word pairs rather than words from the same semantic category. Should the congruent list be easier to learn and cause less interference than the mixed list, one could not argue that the earlier results were determined by prior semantic associations in the congruent list.

We tested an additional condition in Experiment 4 to check a theoretical prediction regarding interference with first-list pairs in the mixed-list condition.[2] In the usual mixed-list condition, the stimuli and responses were randomly paired in List 1 and then randomly paired anew in List 2. We called this the *uncorrelated* mixed condition, because the List 2 pairings were uncorrelated with those in List 1. In the new, third, condition, the List 2 pairings used a C word that rhymed with the B word of the List 1 (A–B) pairs. For example, if List 1 had contained the mixed S–R pairs *pin–tar, mug–fin,* and *scar–jug,* the corresponding List 2 pairs would be *pin–jar, mug–bin,* and *scar–bug.* We call this the *correlated* mixed condition. The difference between the correlated and uncorrelated mixed conditions arises in second-list learning.

What does our hypothesis predict about the comparison of the correlated and uncorrelated conditions? The clearest prediction is that on the MMFR test the correlated mixed subjects should show less forgetting of their List 1 associates than do the uncorrelated mixed subjects. Why? Because in learning both the A–B and A–C pairs, subjects will have acquired the arbitrary association of the cue (A) term to the common rhyming class, for example, learning that *pin* is paired with -ar words, *mug* with -in words, and so on. It should be easy, therefore, for subjects to generate and recognize on the MMFR test the two response terms of that rhyming class that have been recently primed.

We also expected that among subjects in the mixed-list condition, the correlated List 2 would be learned more quickly than the uncorrelated List 2. This expectation was based on the idea that having struggled to learn the arbitrary List 1 associations between nonrhyming words (such as *pin–tar* and *mug–fin*), subjects would then notice the similarity of the List 2 response to the List 1 response for that cue and hence use that relation to mediate learning of the List 2 response for that cue. Accordingly, these predictions were evaluated by having three groups of subjects learn three different sets of A–B, A–C lists and then recall them on the MMFR test.

Method

Subjects. Thirty students from an introductory psychology class at Stanford University were assigned in rotation to the three groups (10 in each group) and were tested individually.

Materials. Two lists of 20 congruent rhyming word pairs were composed in an A–B, A–C relation. The words were three- or four-letter concrete nouns; the B and C response lists were equated on their frequency according to the norms of Kucera and Francis (1967) and approximately (on the basis of intuitive evaluation) on their concreteness. The A–B versus A–C roles of the two lists were reversed for half the subjects. We formed the mixed A–B lists by randomly re-pairing the cue and response terms of the rhyming A–B pairs learned by subjects in the congruent condition. For the A–C list, the cue was assigned either a C response that rhymed with the B response (the correlated mixed condition) or a randomly different C response that rhymed with neither the A cue nor the earlier B response (the uncorrelated mixed condition).

Procedure. After one study trial on the A–B pairs, subjects began anticipation testing; presented with cue words one at a time on the computer screen, subjects had 5 s to type the full response word. Their response was compared with the correct word, and a "correct" or "incorrect" sign was displayed, below which the subject saw the statement "The correct answer is [cue–response]" for 2 s. The 20 items were presented in random order using a dropout method: Upon reaching a criterion of three correct anticipations or 15 presentations, a pair was deleted from further presentations. After the slowest item of the first list met learning criterion, subjects read a set of brief instructions for List 2 and then, when ready, proceeded to learning the second list. Second-list learning was carried to the same criterion of three correct anticipations or 15 trials per pair.

There followed 5 min of distraction with a visual search task (counting the number of solid cubes in a visual field of overlapping polygons). After 5 min, the computer instructed the subject on the MMFR. Single cues were shown for 30 s, during which subjects typed their two responses and clicked a box with the mouse to indicate whether the recalled response word was from List 1 or List 2 or that they were uncertain. After finishing, subjects were debriefed and dismissed.

Results

Initial learning. All subjects met the learning criterion before 15 trials, except for 1 subject in the correlated mixed conditions who had not met criterion after 15 trials on one pair in List 1 and a different pair in List 2. A criterion score of 15 was assigned to each of these pairs.

The mean number of trials for an item to reach criterion on both lists and the MMFR scores are shown in Table 7. The groups differed reliably in their rate of learning the A–B list,

[2] Ellen Levy proposed this correlated mixed condition and the theoretical analysis of it. We thank her for allowing us to report her experiment and data.

Table 7
Mean Number of Trials to Criterion (and Standard Deviation) and Modified Modified Free Recall (MMFR) Scores for First and Second Lists for the Three Conditions of Experiment 4

Statistic	Congruent		Correlated mixed		Uncorrelated mixed	
	M	*SD*	*M*	*SD*	*M*	*SD*
Mean no. trials						
List 1	3.86	0.55	5.49	1.83	4.82	0.76
List 2	4.08	1.04	5.26	0.99	4.54	1.02
MMFR						
List 1	18.70	1.25	17.40	1.90	14.20	4.16
List 2	19.50	1.27	18.00	1.63	18.60	1.35

with subjects in the congruent condition learning the quickest, $F(2, 27) = 4.80, p < .016$. By chance, subjects in the correlated mixed condition were a bit slower than the uncorrelated mixed subjects in learning List 1, although not reliably so.

The groups also differed in their rates of learning List 2, $F(2, 27) = 3.45, p < .046$, with the congruent list learned the quickest. Contrary to expectations, subjects did not learn the correlated mixed (A–C) list faster than the uncorrelated mixed (A–C) list; in fact, the correlated list was learned a bit slower, although not reliably so. In the *Discussion,* we consider possible explanations for this failed prediction.

MMFR test. Recall of the A–B associates on the MMFR test confirmed the main predictions of our theory. Adjusting for the one noncriterion item for the 1 subject, the three groups differed overall in total A–B recall, $F(2, 27) = 7.17, p < .003$, and in total A–C recall, $F(2, 27) = 2.80, p < .078$. By Tukey's test, A–B recall in the uncorrelated mixed condition came in significantly below that in the congruent condition ($p = .05$). Also, in line with prediction, A–B recall in the correlated mixed condition came in significantly above that in the uncorrelated mixed condition (by Tukey's test). In fact, A–B recall in the correlated mixed condition was not significantly less than that in the congruent condition.

Recall of the A–C associates was uniformly high, as expected. However, subjects in the congruent condition recalled more A–C associates than did subjects in the combined mixed conditions, $t(27) = 2.18, p < .02$. Because of the high recall levels, the theory makes no strong prediction about these data.

Discussion

The MMFR results were as expected: The congruent condition showed very little forgetting relative to the uncorrelated mixed condition. This result replicates with phonetic rhyming pairs the analogous result found in Experiments 1 and 2 with semantic or same-materials relationships. The outcome supports the generalization that any obvious rule relating the unique response term to the cue term will facilitate paired-associate learning and greatly reduce interference in an A–B, A–C paradigm.

The theoretical analysis of the correlated mixed condition was partially confirmed, at least with regard to the final MMFR test. Recall of A–B by subjects in the correlated mixed condition was significantly elevated above that by subjects in the uncorrelated mixed condition to a level not reliably below that by subjects in the congruent condition.

We hypothesized that subjects in the correlated mixed condition would learn the rhyming class as an entire set of responses linked to the cue term. Some evidence for this abstract process was the finding that when these subjects overtly erred in recalling A–B during MMFR, it was due to intrusion of either both B and C rhymes as a paired set or the A rhyming-cue word as the B recall. To illustrate, if two triples in this condition had been *cot* (A)–*rack* (B)–*sack* (C) and *tack* (A)–*pan* (B)–*fan* (C), likely errors on MMFR would be something like *cot–pan–fan* (paired errors) or *cot–tack–sack* (A-word intrusion). If these kinds of errors were to be discounted in the MMFR test, then A–B recall by subjects in the correlated mixed condition would come even closer to that by subjects in the congruent condition.

One puzzle is why second-list learning was not facilitated by the correlated mixed condition. Perhaps an explanation is suggested by the intrusion-error analysis given earlier for MMFR performance in this condition. Several sources of difficulties can be detected. First, in learning *cot* (A)–*sack* (C), if subjects tried to mediate that association by their previously learned *cot* (A)–*rack* (B) association, they would have had to distinguish clearly the appropriate list in order to avoid having B responses intrude during A–C learning. In fact, such B intrusions occurred with appreciable frequency.

Second, knowing that the C word to *cot* rhymed with *rack* (the B associate) did not uniquely designate the C word *sack.* That rule could have just as easily designated the A word *tack,* which belonged to another pair being learned. Because the A words were also primed, they could have intruded or at least caused subjects to hesitate in recalling the correct rhyming word. In fact, a number of these A-word intrusions were observed in the correlated mixed condition during A–C learning. Thus, although the slow A–C learning by subjects in the correlated mixed condition upset our initial expectations, this more complex analysis of their difficulties perhaps reinforces the response competition theory that we offer in the General Discussion.

General Discussion

The results of our four experiments tell a coherent story. The difficulty of learning and later remembering a given paired associate depends greatly on the context of other materials that are being learned concurrently. In this sense, one can claim that whole-list organizational factors are relevant for acquisition and retention of material even in the classical A–B,

A–C interference paradigm, as they are known to be in many other paradigms (see reviews by Bower, 1972a; Tulving, 1968).

The existence of organizational/contextual determinants of associations makes it somewhat inappropriate to conceptualize the acquisition of a paired-associate list in terms of learning the set of individual cue–target associations independently. The multiple pairs in a homogeneous list provide far more than independent replications that increase the sample size of some abstract A–B pair. On the contrary, it appears that the multiple pairs themselves create mutual interference that retards learning of any given pair. The amount of such interference depends on the nature of the list: It can be massive in the standard all-same list but of dwindling magnitude in our congruent lists.

Our findings suggest that the advantage conferred by the congruent list stems from two intertwined factors: (a) Given the cue, subjects were able to predict the category of the response term and (b) the number of primed (episodically encoded) response terms in that predicted category was small (optimally, one or two). We can abstract these controlling factors into essentially one: response uncertainty to the cue. The greater the response uncertainty, the slower the learning, the greater the negative transfer, the poorer the retention, and the greater the RI. Within-list and between-lists organization of materials affects learning and retention of particular associations to the extent that such organization determines response uncertainty. The powerful influence of response uncertainty on memory was a dominant theme in the writings of Garner (1974; Garner & Whitman, 1965) as well as in the response competition formulations of interference theory by McGeogh (1933a, 1933b, 1942).

Further reflection suggests that response uncertainty is determined by the specificity of the cue: Response uncertainty describes the potency (distinctiveness) of the retrieval cue to specify the to-be-retrieved item of information. Learning consists of the enhancement of such potency; forgetting comes about as a consequence of its diminution. This formulation represents an extension of the concept of cue-dependent forgetting (Tulving & Psotka, 1971). One can escape from its apparent tautology by elaborating the basic idea analytically and empirically.

A Network Model

We may cast our ideas in terms of an associative network like that shown in Figure 3. Figure 3 diagrams the associations operative for, say, two pairs from the 10-category condition of Experiment 3. The pairs are numbered successively, as $A_1 \rightarrow B_1$, C_1 and $A_2 \rightarrow B_2$, C_2. The internal representations of the stimulus and response items are depicted inside the circles, and directed associations with strengths b, c, and d are depicted as arrowed lines.

We presume that studying the A_i–B_i and A_i–C_i pairs ($i = 1$ or 2) causes a strong directed association from Cue A_i to the two response terms, B_i and C_i, denoted by strengths b and c. In addition, each item has a preexisting association from the semantic category node, D; these associations are presumed to have been strengthened ("primed") to level d by their recent use throughout the learning trials. The associative strengths in

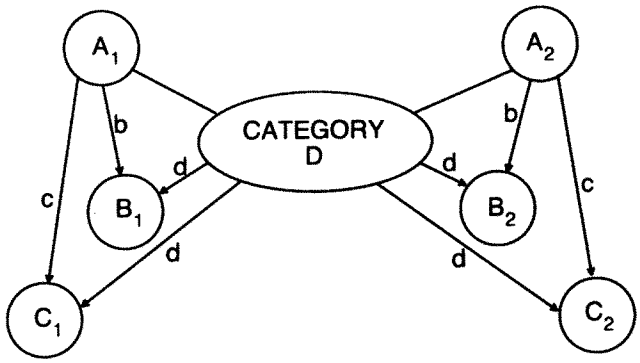

Figure 3. Diagram of hypothetical directed associations between cue words (As), the responses (Bs and Cs) of Lists 1 and 2, and the implicit category (D). Lowercase letters denote the strengths of the corresponding associations.

Figure 3 would presumably be large for the direct A_i–B_i and A_i–C_i associations but smaller for the category D–B_i and D–C_i associations (i.e., $c > b > d$).

Given this associative structure, how might the model (or the subject) respond to, say, A_1 on the final MMFR test? For simplicity's sake, let us assume that the category can always be retrieved given the cue term. We then compute the total strength of the activations of each of the four response terms aroused by A_1 and D. These turn out to be: $B_1 = b + d$, $C_1 = c + d$, $B_2 = d$, and $C_2 = d$. Next, we generalize the associative diagram to a list containing N pairs of the same category. Because each pair contributes two possible interfering response terms for a given B_1 target memory, the number of interfering associations will be $2(N - 1)$, each with strength d.

To relate this associative structure to recall performance, let us assume that the person chooses two responses according to Luce's (1959) response ranking rule; that is, a first response is selected and recalled with a probability given by its strength relative to the sum of all strengths; the chosen alternative is then set aside, and a second response is chosen on the basis of the relative strength of each element of the remaining set.

Because we are interested in the forgetting of the first-list response, let us assume that C_1 has already been recalled and thus eliminated from the response set. Thus, for N pairs of the same category, we may write the probability that any B_i will be recalled as approximately

$$Pr(B_i) = \frac{b + d}{b + d + 2(N - 1)d},$$

$$= \frac{1}{1 + h(N - 1)}, \quad (1)$$

where $h = 2d/(d + b)$. Importantly, in this simplification, MMFR recall of the first-list response depends only on a single parameter, h, which varies with the ratio of the direct cue strength (b) to the indirect category strength (d) of each primed distractor in the relevant response category.

Equation 1 formalizes the reciprocal relation between recall of any first-list response (B_i) and the number (N) of different

pairs of that type in the list. The function is generally consistent with the results as depicted in Figure 2, except the first few observed values fall off more rapidly than in the simple reciprocal function of Equation 1.

The analysis presented in Figure 3 also explains the intracategory confusions of Table 6 insofar as errors in the model arise through selection of competing response terms from the same category. However, this response model is incomplete in that it provides no explanation for recall omissions. One could augment the model by postulating associations from each cue, A_i, to an irrelevant response (junk) category whose selection causes omissions. However, a more elaborate response model would be needed to explain the increasing ratio of intrusions to omissions as the number of pairs per category decreases.

Although Figure 3 illustrates the model for semantic categories, a similar analysis could be applied to the rhyming categories used in Experiment 4. In this case, the category node would refer to the common phonetic ending of the rhyme class, and d would be the likelihood that subjects would generate the primed rhyming elements of the class from the two lists they had just learned.

An interesting question is what kind of S–R list rules facilitate learning and reduce interference. We have used obvious relations based on similar sounds, meanings, and materials. Our guess is that for an S–R rule to be facilitating, it needs to be easily discovered, easily used as a mediator, and potent for prompting recall of a unique response to the cue.

For example, a good rule for learning consonant trigrams pairs is that the B and C trigrams are always consistent permutations of the A trigram (e.g., DHP to PDH to HPD in Lists 1 and 2) or are consistent transformations of it (e.g., each B letter is one later in alphabetic order to each A letter, as in the A–B pair DHP to EIQ). An example of a poor rule for learning word pairs would be that the third letter of the stimulus and response words match (e.g., table to debar or death to claim). The weakness of such a rule is that the third letter is both difficult to notice and a poor retrieval cue for a unique word (although it could serve as an editing filter for recall candidates). In the semantic domain, the obviousness of a categorical relation between words of a pair is closely related to the concept of context-independent associations proposed by Barsalou and Ross (1986). Context-independent associations arise for words whose categorical relations are obvious to the modal language user and may be contrasted to context-dependent associations, for which special priming is required for the subject to notice the categorical relation of two words. For example, *diamonds* and *wedding rings* have common associations that are contextually independent, whereas *diamonds* and *family photographs* do not; however, the latter two items can be made to appear related after the subject has been primed with the ad hoc category of "things to save in case your home is on fire" (see Barsalou, 1983).

Unlearning?

Returning to the theme with which this investigation began, we note that the absence of RI in the congruent conditions only reinforces the difficulties for the concept of item-specific unlearning that were reviewed in the Introduction. In classical theory, unlearning was presumed to occur whenever subjects must inhibit an old response while learning an incompatible response to a given cue, and it was presumed to be automatic and inexorable regardless of what other S–R connections are being learned or inhibited at the same time. But even if we grant the premise that unlearning of first-list associates is properly assessed by their loss on the MMFR test, our results indicate that the amount of unlearning of a pair increases with the number of similar pairs that compete with retrieval of the target item (see Figure 2). This fact seems mainly to implicate further the power of response competition rather than unlearning in causing forgetting. Conceivably, more sensitive measures of unlearning, such as response latencies for pair recognition (e.g., Anderson, 1974, 1981), might reveal some absolute weakening of the A–B associations as a result of A–C learning. Unfortunately, models of response latency (e.g., Anderson, 1981, 1983) imply slowing in recognition latency due simply to response competition alone, so that result alone would not necessitate postulation of an unlearning process.

Response Set Suppression?

In their classic article, Postman et al. (1968) proposed replacing the concept of item-specific unlearning with the hypothesis that RI is caused by the unavailability of the entire set of List 1 responses. This unavailability was hypothesized to reflect inertia in a response-selector mechanism (Underwood & Schulz, 1960), leading to persistence of suppression of the entire repertoire of List 1 responses. The first-list responses supposedly had to be suppressed in order for subjects to learn and perform properly on the interpolated lists. As Postman et al. (1968) wrote,

> Generalized response competition, which we view as a consequence of the inertia of the selector mechanism, is not between alternative responses to a particular stimulus but rather between systems of responses, e.g., the repertoires of Bs and Cs. . . . The mechanisms of interference operate as much or more on repertoires or systems of responses as on specific stimulus-response associations. (p. 693)

Our results raise some difficulties for this hypothesis of response set suppression because it fails to distinguish between our conditions that lead to massive RI and those that lead to negligible RI. For example, both the congruent and the mispaired uncorrelated lists had exactly the same set of List 1 and List 2 responses, and subjects in both cases learned on cue to give the List 2 response and suppress the List 1 response. There is little in the response set suppression theory to explain why, then, there was such a large difference in RI in these two conditions. Moreover, why did the correlated mispaired condition of Experiment 4 not show as much inertial suppression of List 1 responses as the uncorrelated mispaired condition did? Why did the category cue in Experiment 2 dispel the suppression of the List 1 response set? Why did a pairwise relation disinhibit the suppressed response set?

The answers to such questions seem to require reference to the power of specific retrieval cues to call up a small collection of response words appropriate to those cues, thereby making them available for recall. Those retrieval cues were semantic categories in our first three experiments and phonetic rhymes

in the fourth; they were potent largely because they were more or less unique to the item to be recalled. To round out our theory, we would add a list tagging and editing process that guides performance; that is, we would assume that A–B associates would be associated to a List 1 context tag, and response words retrieved with such tags would be edited out (not exactly suppressed) as the subject learns to give the A–C associate in the context of List 2. However, such responses would be retrievable on the later MMFR test when subjects would be supplied with a retrieval complex consisting of the potent A cue plus the List 1 context tag.

An Expanded View of Competition

The present results implicate a somewhat expanded role for competition among memory units as it operates in interference experiments. Traditionally, competition has been believed to arise only among the overt response terms associated to the nominal cue, between the B and C terms associated to Cue A. However, none of our conditions differed in that regard (each cue had two responses, each list context had 20 response words, etc.). Our results suggest that the concept of competition should be expanded to include that existing among the primed responses evoked by a mediating or implicit associate of the nominal cue—in this case, the implicit semantic or rhyming category (evoked by the A cue) to which the response term belonged (see also Nelson, Canas, & Bajo, 1987).

That associates may be implicit but nonetheless effective competitors in recall is no longer a controversial assumption. That is, competing memories do not have to be either explicit or overtly recollected to create measurable interference in blocking recall of a target memory. Nelson, Schreiber, and McEvoy (1992) summarized many studies demonstrating that the power of an extra-list cue to evoke a given target memory is diminished progressively by more competing associates presumably evoked implicitly by the cue (see also Bahrick, 1970). Similar competitive set-size effects arise for letter-fragment-cued recall and primed completion of words as well as for their perceptual identification under conditions of degraded exposure (Nelson et al., 1992).

The central role we are according to response competition in controlling memory performance is hardly novel. The general idea has been accepted at least since Mueller and Pilzecker (1900) and is featured prominently in such concepts as associative interference (e.g., McGeogh, 1942; Postman & Underwood, 1973; Runquist, 1975), cue overload (e.g., O. C. Watkins & M. J. Watkins, 1975), and the FAN effect (Anderson, 1974). Response competition helps explain numerous memory phenomena, including the potency of a given letter cue to retrieve items from a word list (Earhard, 1967) and the value of various pairwise relations in facilitating associative learning.

If we include the role of associations from the experimental context to the list items, this expanded view of interference as competition would explain such familiar phenomena as the length–difficulty relation in learning, generalized negative transfer and generalized RI, the build up and release of proactive interference, and so on (see Postman, 1961).

Of course, the other side of the response competition concept is cue specificity or cue-to-target uncertainty. The more clearly a pattern of retrieval cues specifies a given target, the greater the probability that that pattern will succeed in retrieving the target. This idea is embodied in most retrieval theories, either formally or informally (e.g., Kolodner, 1983; Norman & Bobrow, 1979; Raaijmakers & Shiffrin, 1981; Tulving & Thomson, 1973). Clearly, the ability (potency) of a cue to specify a memory target depends on the other memory units from which that target must be sampled, discriminated, and selected.

Whole-list factors influencing associative performance are explained by this principle. Examples of the operation of this specificity principle include not only the learning ease of our congruent lists but also the familiar (and deleterious) effects of intralist cue similarity on learning rate and of interlist similarity on negative transfer and RI.

It is important to note that a retrieval specification that is adequate at one time may become inadequate as a result of later learning of similar memories (causing RI); the loss over time of a recency-based component of the cue complex (causing proactive interference); or a change in the subjective encoding of the usual retrieval cues, due perhaps to internal–contextual changes. Similarly, when a weak or somewhat general retrieval specification (e.g., "Recall the third list back") fails, supplying a more specific cue ("Recall the animals list") may succeed in retrieving the target (Tulving & Psotka, 1971). For example, Mantyla (1986; Mantyla & Nilsson, 1988) had subjects generate several specific associates (descriptive properties) to each target word; their later cued recall of a target word increased in proportion to the number of subject-generated associates (cues) the experimenter provided for that target and how uniquely the cues specified the target word out of the collection. In these cases, the cues practically "triangulated" idiosyncratically on the unique target item in the subject's associative network; in the best case, retention after one study trial of 600 words was virtually perfect over intervals as long as 6 weeks.

What our results show is that response uncertainty can have a powerful influence on measures of learning, retrieval, negative transfer, retention, and interference. The results raise a problem for the item-specific unlearning principle as well as the hypothesis of response set suppression. Perhaps an appropriate way to conclude our note is with a comment by Postman et al. (1968) expressing some doubts about their interference theory

> There are growing indications that the contrast between response systems and individual associations constitutes a critical specification of the components of learning that become subject to interference. It may turn out in the end that competition and unlearning are not independent and complementary mechanisms but that processes related to competition are largely responsible for the empirical fact of unlearning. If there is any merit in these speculations, the theoretical spiral may be returning to McGeogh's classical hypothesis of reproductive inhibition, but in a new form. (p. 693)

We could not have said it better.

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Appendix

Study Materials Used in Experiments 2–4

Experiment 2

Sample Congruent List

The items in each triplet denote, in order, the A, B, and C terms of the 20-paired associates in the two lists: diamond, emerald, ruby; aunt, uncle, father; iron, aluminum, steel; magazine, book, newspaper; dog, tiger, horse; cotton, wool, silk; blue, red, green; noun, adjective, pronoun; chair, table, bed; legs, head, arms; apple, banana, pear; sword, gun, rifle; vodka, whiskey, gin; hammer, nails, saw; dentist, lawyer, teacher; mountain, hill, valley; shirt, socks, pants; piano, drum, trumpet; robin, eagle, sparrow; car, bus, airplane.

Mispaired Lists

The mispaired lists were generated by interchanging the B terms in the triplets, and then independently changing the C terms, permitting none to be in the same category as the A term of the triplet.

Experiment 3

Example of a 4-Category Set of A-B-C Triplets

Five triplets were used in each of the four categories: dog, tiger, horse; buffalo, lion, whale; jellyfish, hamster, ostrich; ape, antelope, bear; turtle, rabbit, salamander . . . legs, head, arms; nose, eye, foot; mouth, knee, chest; tooth, hip, shoulders; abdomen, throat, ear . . . dentist, lawyer, teacher; electrician, surgeon, dancer; blacksmith, plumber, umpire; neurologist, painter, clerk; farmer, writer, soldier . . . piano, drum, trumpet; violin, flute, guitar; cymbals, oboe, accordian; xylophone, fiddle, cello; tambourine, organ, bassoon.

Example of a 10-Category Set of A-B-C Triplets

Diamond, emerald, ruby; sapphire, opal, jade . . . iron, aluminum, steel; platnum, brass, zinc . . . dog, tiger, horse; buffalo, lion, whale . . . cotton, wool, silk; tweed, velvet, nylon . . . legs, head, arms; nose, eye, foot . . . apple, banana, pear; tangerine, cherry, grape . . . dentist, lawyer, teacher; electrician, surgeon, dancer . . . mountain, hill, valley; river, canyon, cliff . . . shirt, socks, pants; skirt, hat, blouse . . . piano, drum, trumpet; violin, flute, guitar.

(*Appendix continues on next page*)

Experiment 4

Rhyming Triplets A-B-C in the Congruent Condition

Sink, rink, mink; cot, pot, dot; dart, tart, cart; file, pile, tile; hat, mat, rat; tack, rack, sack; cop, mop, pop; mug, jug, bug; dip, hip, lip; seed, weed, reed; van, pan, fan; dew, brew, stew; nail, jail, tail; ham, dam, jam; scar, tar, jar; hint, mint, lint; pin, fin, bin; trap, cap, map; gun, nun, bun; fig, wig, rig.

Mispaired Conditions

For the mispaired correlated condition, we rotated all the A terms of the triplets while leaving the B and C terms intact. In the mispaired uncorrelated condition, all three words of each triplet were mispaired; that is, none of the A-B-C words of a triplet rhymed with one another.

Received November 9, 1992
Revision received May 3, 1993
Accepted May 24, 1993 ■