Interference among memory traces*

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Several sources of interference in memory are identified. These sources may be grossly classified as processing interference, i.e., that due to disruption of whatever activity occurs during the input or output of to-be-remembered material, or trace interaction, i.e., that due to interference among the stored memories themselves. The latter would appear to be due to simultaneous activation of correct and incorrect associations mediated by confusion among cue stimuli. A consideration of the means by which interference is reduced suggests that interfering associates are not weakened, unlearned, or suppressed except possibly when nominal stimuli are identical and sets of target and interfering items are temporally discriminable. Discriminative encoding of cue stimuli may eliminate these associations, if it operates at the perceptual level. Otherwise, potential interfering associates are activated, but may be rendered functionally impotent by discriminating them from correct associations on the basis of either backward association with discriminative stimulus attributes or differential contextual attributes such as frequency, time, order, and strength.

The concept of interference in psychological theories of human performance is so ubiquitous that it is often taken for granted. While it is sometimes used as a synonym for task difficulty, it more commonly appears as description of performance decrements resulting from the learning or performance of other tasks. Whereas some theorists use the term as an explanatory concept, it should be apparent that it possesses limited power in this respect. Without further elaboration it does little more than provide an operational restriction on the cause of performance difficulty and provide a name for this class of behavioral phenomena.

This paper is directed toward the theoretical elaboration of a subset of these phenomena: manifestations of interference in the act of remembering. Scarcely a serious theory of memory has been proposed which does not assign all or some memory failures to interference. The theoretical problem is straightforward and involves two related questions: What are the mechanisms by which interference is produced, and how does the learner overcome interference in order to exhibit successful memorial performance? While both of these questions will be considered here, it is not the purpose of this paper to present a detailed and comprehensive model for interference and interference reduction. The focus instead will be on providing evidence for the existence of various processes involved in interference and considering how learners may be expected to cope with interference in some of its various manifestations.

The major emphasis in this paper may be further delineated by making a distinction between two broad classes of interference processes. One type of

interference is represented by the interruption of whatever psychological activity occurs during the input or output of to-be-remembered information. It is a widely held principle that an individual's ability to perform two symbolic activities simultaneously is limited. Accordingly, interference with memory can easily be obtained by providing the learner with some task to perform concurrently with the processing of information he is to remember. This source of interference may be termed "processing interference."

On the other hand, performance decrements are also attributed to the presence in memory of information which is related in some way to the to-be-remembered information. This source of interference may be termed *trace interaction* and will be the primary concern of this paper. Several papers (e.g., Peterson, 1969; Kerr, 1973) provide analyses of processing interference and a review of relevant research.

Complexities involved in the operational separation of the two sources of interference will not be belabored at length here. The purpose of the distinction is simply to place the entire interference problem in some perspective. Suffice it to say that in any task involving the storage of multiple units, the processing of one unit is affected by the necessity of "simultaneously" processing other units. The only point to be made here is to recognize that the theoretical processes to be discussed do not exhaust the domain of interference processes and to occasionally voice a concern that a particular phenomenon attributed to a trace interaction process might be due at least in part to processing interference.

TRACE INTERACTION

Interference among memory traces may be most clearly seen when there is some specific target memory to be retrieved, with the ability to retrieve that target being hampered by the existence of other memories.

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Accordingly, the laboratory vehicle for examining this source of interference is the paired-associate task, since a particular to-be-remembered item is uniquely specified by each nominal stimulus term.

In the analysis of interference phenomena, it is necessary to consider the psychological events which are assumed to occur when a specific cue stimulus is presented and recall of the unit associated with it is requested. The general notion is that the to-be-recalled item exists in some coded form in memory along with codes representing the stimulus. The exact nature of the code and the exact meaning of the term "along with" need not be of present concern. The term *code* simply refers to the means by which the item is represented in memory and can be described in terms of the appropriate physical and symbolic attributes of the nominal stimulus (Underwood, 1969).

There are several ways in which trace interaction may produce interference, although they are neither independent nor mutually exclusive. One mechanism is the classic notion of competing associations which has generally been accepted as a source of interference since it was clarified by McGeoch (1942). Presentation of a stimulus for recall simultaneously activates the correct association and one or more incorrect associations. The occurrence of the latter either blocks or replaces the correct association. While historically the conception of associative competition has been linked with associationistic theories of learning and stimulus-response theory, the basic idea does not depend upon any specific notion of how associations are activated or the specific form in which they are represented psychologically.

A second process has appeared in the literature in a variety of guises but may be best described as cue confusion. Essentially, cue confusion refers to stimulus coding errors. That is, a cue stimulus is encoded in such a way that it cannot be distinguished from other stimuli.

There are several ways in which cue confusion could mediate interference. Initial confusion among stimuli could provide for the development of competing associations. Also, cue confusion at recall could be one of the conditions involved in the activation of these associations. On the other hand, cue confusion could result in interference without the involvement of competing associations. If stimulus A is encoded as stimulus B, recall failure will occur whether or not the incorrect association is activated.

If the conceptual distinction between cue confusion and associative interference is to have any value, it must be given operational substance. Cue confusion will be considered first. Since the process essentially represents failure to discriminate among cue stimuli, it is logical that the operations for assessing cue confusion involve requiring Ss to make discriminations among stimuli.

One common procedure is to assess initial discriminability by some kind of psychological scaling procedure and then relate learning to the scaled discriminability values (Rothkopf, 1957). There are

several limitations to this approach. For example, the perceptual confusions necessary for scaling most classes of stimuli can only be obtained under conditions involving severe signal deprivation, such as tachistoscopic exposure of high levels of background noise. These conditions are hardly typical of the conditions under which the S functions in most learning experiments, where perceptual difficulties are minimized. Most importantly, the scaling approach always assumes that the processes used in performing the scaling operation are directly represented in memorial processing (Underwood, 1972a). Without independent verification, this is a risky assumption.

A second technique that has been used to assess stimulus discrimination is a measure of the accuracy with which the S can identify a given stimulus as coming from the list being learned. The test can be used with either verbal (Martin, 1967) or nonverbal (Ellis & Muller, 1964) stimuli. While the test may provide valuable information about the particular attributes involved in stimulus coding, it is not necessarily relevant as a measure of discrimination among the stimuli involved in learning. These tests require S to discriminate between list stimuli and stimuli not in the list. If S codes only certain select attributes of the task stimuli, he may be perfectly able to discriminate among list stimuli but fail to discriminate between list and extralist stimuli when the latter contain the coded attribute (Runquist & Evans, 1972).

Logically, the measurement of cue confusion has several properties. First, the measure itself should not involve the recall of the associated response term. Second, it should require comparison of the test stimulus with the representation of other potential test stimuli in memory. Third, it should only require that S discriminate among stimuli from within the set being used in learning. Fourth, any encoding activities that are required ought to be the same as those used for the memory task.

The following task would appear to meet the requirements. The procedure involves three separate steps. The first step is a study trial on a paired-associate list. The second step involves the presentation of *all but one* of the stimulus terms for recall of the associated responses. The third and crucial step is to present either one of the test stimuli again, or to present the missing stimulus as a probe. The S is required to first indicate whether the probe stimulus is a repeated or the missing stimulus and then attempt recall of the associated response.

The critical measure of cue confusion is obtained when the missing item is presented as a probe. If on the probe trial this stimulus is coded so that it cannot be discriminated from any previously tested stimuli in the list, the S will incorrectly classify this item as one which was previously seen. The complement of this measure, correctly identified missing stimuli, provides an index of, or defines, discriminative coding.

A simple experiment (Runquist, 1974a) will illustrate

the method, demonstrate the existence of cue confusion, and provide some indication of its relation to interference in recall. The Ss were given one, two, or five study trials on six paired associates followed by the test sequence. The stimuli were consonant trigrams structured so that there were three sets of two stimuli. In two sets the stimuli had two consonants in common; in the third set all consonants were different. Each S was tested on 40 lists, with the probe stimulus being a missing item on half of the lists. When the missing stimulus was from one of the high-similarity sets, the percentage of recognition errors was 48%, 31%, and 22% for the one-, two-, and five-trial conditions, respectively. Comparable values for low-similarity stimuli were 16%, 5%, and 8%. Moreover, when S correctly identified a missing stimulus, recall of the correct response did not depend upon similarity. That is, considering only items which were discriminatively coded, performance did not differ as a function of physical similarity.

Differences in recall of high- and low-similarity pairs did appear when missing stimuli were not correctly identified as such. While the difference could reflect some permanent effect of associative interference, it could also result from recall failures to missing stimuli which were correctly guessed as such. There are simply more "guessed" items with high similarity and, hence, more failures.

Associative interference may be separately assessed by a procedure which provides for the existence of a strong association between the stimulus and response of one pair of a paired-associate list prior to the beginning of learning. If recall to the test stimulus is affected by a strong association to similar stimuli, associative competition is indicated. On the other hand, if all interference is simply due to coding errors, ability to recall the correct response should not depend upon whether or not an association exists to the inappropriate stimulus.

A second experiment demonstrates the presence of the associative competition component of interference (Runquist, 1962). In this experiment, the Ss learned five pairs in which the stimuli were dissimilar geometric forms. Five new pairs were then added to the list, making a 10-pair list. Two of the new stimuli were similar to each other but dissimilar to any of the five previously learned pairs. Performance on the first three learning trials for these items averaged 47% correct responses. Contrasted with these pairs was performance on two stimuli, each of which was similar to a previously learned stimulus but dissimilar to each other. The percentage of correct responses was 35% for these items. In other words, given equal similarity between stimuli and, hence, equal cue confusion, the presence of a strong association to one of the stimuli will interfere with the recall of the association to the other stimulus; associative interference is present.

Is all interference associative or is there some which is

attributable solely to coding errors? Neither the interfering associates design nor the missing item recognition test can provide an unambiguous answer to this question. Since the cue confusion measure does not involve associative recall, its relation to interference can at best be only correlational. Thus, it can be used to indicate the extent of cue confusion, but the contribution of this process to recall interference remains problematical. The interfering associates design can indicate the presence of associative interference, but if this source of interference is present, it is not possible to estimate the extent to which it accounts for all interference. Thus, interference due purely to coding errors can be diagnosed only when associative interference is not present. No experiment has been found in which this result has been obtained, but there are few studies meeting the appropriate boundary conditions.

Nevertheless, the two experiments discussed above establish two operationally separable but dependent components of interference. The role played by these component processes in producing the interference commonly observed in specific situations remains open to question and will not be pursued any further here. Given that the techniques for analysis are available, it is a routine research problem to determine which mechanisms are involved in the interference produced by different attributes in different situations.

INTERFERENCE REDUCTION

Associative Interference

If cue confusion and associative interference are conceptually separable processes, two processes are suggested whereby learners reduce interference during learning in order to exhibit correct recall.

The classical view of interference reduction was based on the analogy between paired-associate type tasks and successive discrimination learning. By adhering to this analogy, it became possible to conceptualize the reduction of interference as the extinction of competing associations presumably produced by their nonreinforced evocation (Postman, 1961). Whether one chooses to make the analogy is immaterial to the central issue raised by such theories. They attempt to account for interference reduction by assuming that the erroneous associations become less available to produce interference as learning proceeds.

One must be careful to distinguish between loss in availability of interfering associations and a loss in their ability to produce interference. The very fact that perfect performance is eventually achieved indicates that competing associations do lose their effectiveness. The theoretical issue is whether this is accomplished by rendering the interfering association less recallable or whether it remains available and is simply suppressed in some fashion.

The evidence for the existence of weakening of interfering associations has been entirely obtained in situations in which interference results from associations learned in prior lists. The test list is constructed so that nominal stimuli are identical to those in some prior list, with response terms being different (A-B, A-C), and the fate of the A-B association as A-C is learned is assessed by requiring unpaced recall of associations from both lists without having to specify the source list of the recalled items (MMFR). Countless experiments (Keppel, 1968) have shown that first-list associations are less recallable following A-C learning than following a condition where the second list is unrelated to the first list (A-B, D-C) or a rest control which learns no second list.

The question to be raised in this section is whether such results are sufficient to establish the reduction in availability (unlearning) of interfering associations as a major mechanism of interference reduction.

The challenge will be offered on two bases. The use of the MMFR test in providing an unbiased estimate of the availability of first-list association depends upon its success in eliminating interference from the associations learned in the second list. The first issue, then, is whether this condition has been met.

Several extraneous sources of interference may provide a problem. The first source is output interference. It is known that Ss required to recall both lists remember more first-list items than Ss required to recall just the first-list responses with all of the second-list responses provided. It is as if providing all potential competing associations produces more interference than is obtained when only those which Ss are able to recall are present.

A second possible source of interference in the assessment of A-B availability is differential processing interference. Suppose, for example, A-B associations are rehearsed during second-list learning. If such rehearsal increases their recallability, measures of A-B recall would be biased by the extent to which this occurs. Surreptitious rehearsal of A-B would seem to be much more likely in the case of D-C than A-C or A-B_R, where task demands are such that the first-list associate should be inhibited. In fact, Postman and Parker (1970) have managed to virtually eliminate differences between A-C and D-C paradigms by requiring the recall of both responses on every trial. It is significant that there was little improvement in the D-C condition, while recall was enhanced under A-C. One interpretation of these results is that the necessity of retaining A-B demands that it be rehearsed during the A-C learning, while this rehearsal normally takes place anyway during D-C. In a similar vein, it is doubtful that in producing processing interference pyramid puzzles, as used in rest control groups, are in the same class as list learning.

In addition to the possibility that measures of unlearning are not free of interference effects,

unlearning may be challenged on the basis of generality. Again there are two arguments. First, the failure of losses to occur when memory is tested by multiple-choice procedures has led to the conclusion that unlearning is mediated by a reduction in availability of the entire set of first-list responses rather than specific associations (Postman, Stark, & Fraser, 1968). Apparently, the clear-cut temporal differentiation of interfering and target associations during second-list learning leads to list-wise organization (the so-called selector mechanism, Postman, 1963) which may render associative interference impotent. Some reduction in the availability of specific associations does occur, but the effect is quite small, except when stimulus and response terms are re-paired to make the second list or multiple lists are learned (Birnbaum, 1972, 1973). In short, losses in A-B availability are largely restricted to situations where there is some kind of organization of multiple associations into target and interfering sets of items.

Based on the principle that unlearning operates on list-defined sets of responses and the fact that such sets are not defined in situations involving intralist interference, there is little reason to expect unlearning of erroneous associations from within the list. Nevertheless, it is at least theoretically feasible that error tendencies to each individual stimulus are weakened to that stimulus as a result of nonreinforcement (e.g., Gibson, 1940).

There have been few experiments directed toward this problem. However, the research that has been done uniformly shows that it becomes *easier* to produce specific erroneous associations as learning proceeds, despite the fact that they produce less interference. These experiments have been reviewed elsewhere (Runquist, 1973a) and only the two most cogent will be described. The logic of one experiment (Runquist, 1968b) was to make previously incorrect associations correct after various amounts of learning. This was accomplished by using lists in which stimuli were categorizable. In these lists, errors tend to be restricted to within-stimulus categories. If these errors are weakened, it should be increasingly more difficult to learn a list in which responses are re-paired within a stimulus category when compared with re-pairing across categories. Note that this does not deny that within-category re-pairing might be superior overall due to the learning of response restrictions, but only that, as S learns to differentiate among items within the category, the weakening of errors should counteract the advantage. Quite the opposite occurred. While within-category re-pairing was easier, the difference became greater rather than smaller as degree of learning prior to re-pairing was increased.

In a subsequent unpublished experiment, Ss were required to give several associations to each stimulus following learning. Associations other than the correct one tended to come from stimuli within the same category, and more so as degree of learning increased

Fig. 1. Total correct responses on several different paired-associate lists. The stimuli for the lists are presented on each graph. Estimated mean square error = 159.0.

and the frequency with which these responses were given as errors was decreasing.

Finally, it is rather obvious that nonreinforcement (in the sense of overt or covert omission of errors followed by feedback) is not necessary for interference to be reduced. Most Ss can acquire a list in which there is considerable interference under conditions not involving any recall tests during learning and in which a rapid presentation rate is used with overt rehearsal of the correct response only (Runquist, 1960). It is obvious that all of these experiments admit to alternate interpretations. The point is simply that, if intralist erroneous associations become less recallable, no evidence of this exists at the present time.

Conclusions with respect to the effectiveness of an unlearning process in reducing associative interference during learning are somewhat uncertain. Clearly, however, if unlearning does serve a function in this respect, it is restricted to the list level and, hence, would seem to play a limited role in laboratory and real-life learning situations where to-be-remembered information is not as nicely organized.

Cue Confusion

If interference is not reduced by the weakening of competing associations, the establishment and utilization of discriminative cue codes would appear to be a likely candidate. The most influential theory involving this mechanism was proposed by Gibson (1940), who likened cue confusion to stimulus generalization and argued for the importance of differentiation in paired-associate and serial learning tasks. Several other

theorists have also considered stimulus discrimination as a component of paired-associate tasks (Battig, 1968; McGuire, 1961; Underwood, Ekstrand, & Keppel, 1965).

The validity of the hypothesis is indicated by the fact that conditions which increase the difficulty of establishing discriminative cue codes result in the persistence of interference during learning. Moreover, the establishment of these codes appears to act more like the learning of a rule for generating particular codes than the learning of a separate code for each stimulus (Runquist, 1973a). This is most clearly apparent with stimuli which are perceptually unintegrated, such as consonant strings. With these stimuli, which are presumably encoded by letter selection (Richardson, 1972), the amount of interference depends considerably on the overall structure of the set of stimuli. This is exemplified by the performance during learning of several sets of paired associates using consonant trigrams as stimuli. These results are shown in Fig. 1. Generally this graph shows that letter redundancy has less effect when there is some sort of regularity which defines the location of discriminative letters. For example, very little interference results despite considerable letter duplication when the positions of redundant and discriminative letters are consistent, as in the second group in the graph. Difficulty increases rather dramatically when *anything* is made more variable, not only as in the fifth group, where a discriminative letter varies in position, but also in the third and fourth groups, where there are inconsistencies of various kinds in the redundant letters. The fourth group shows more interference than the second group despite the fact that more letters are involved in the stimuli for this group.

Further evidence for the importance of rule-based discriminative coding is obtained when the results are compared with those found using word trigrams as stimuli. Structure appears to have little effect, although overall phonemic similarity will result in an increase in interference (Runquist, 1971). The effect is sometimes potent enough to counteract the usual advantage that meaningful words have as stimuli. In one experiment (Runquist, 1973b), stimuli consisting of rhyming words produced an average of 29.7 errors during learning, while consonant trigram stimuli with the same pattern of letter redundancy (first letter different, other letters identical) gave an average of 23.4 errors. These results are probably due to the tendency to encode words as pronounceable units, which interferes with letter selection coding. They have little to do with meaning, as stimuli composed of three words show structural effects identical to those produced by consonant strings (Runquist, 1974b).

On the basis of these findings, it seems reasonable to assert that learners resolve interference by utilizing the distinctive attributes of stimuli as retrieval cues, thus averting potential interference resulting directly from cue confusion and also indirectly from the associative competition which is mediated by stimulus similarity.

Essentially, high-similarity stimuli are made into low-similarity stimuli by selective encoding.

These experiments provide only indirect evidence for discriminative coding during learning. The missing item recognition test described earlier should provide a direct measure of cue confusion, and, if the discriminative coding hypothesis is correct, the confusion should covary with variations in overall interference as inferred from recall differences. The issue at stake is whether all interference reduction can be attributed to stimulus discrimination, and the answer is negative.

It only takes one negative instance to establish the fact that interference *can* be alleviated without a concomitant reduction in cue confusion. Fortunately, such an instance is available. In this experiment Ss learned eight paired associates composed of consonant trigrams and words. Stimuli were either high or low in similarity, as defined by redundant letters. Twelve study-test sequences were each followed by a variation of the missing item recognition test, in which all but one of the stimuli were presented followed by the repeat item or missing item probe. The procedure differed in two important ways from the test, as described earlier: (1) S was not required to recall responses to the stimulus during presentation of the $N - 1$ stimuli, and (2) S was instructed to make his decision as quickly as possible and latency was recorded. Finally, it should be noted that in the high-similarity lists the location of redundant and discriminative letters was inconsistent from stimulus to stimulus. The import of these factors will be considered later. For the nonce, the results from both the recognition and the standard recall test are shown in Fig. 2 in blocks of four trials. The critical result is that the differences between high- and low-similarity lists decreased over trials as all groups approached perfect performance. On the other hand, the differences in recognition of missing items remained relatively constant and, most importantly, showed little improvement for any group. On the last block of trials, recall performance was consistently higher than recognition, particularly in the longer list. Finally, the recall to nonrecognized stimuli did not differ significantly from the recall to recognized stimuli. The general pattern was that recall of the association and the recognition of the missing stimuli were independent.

The generality of this conclusion is not an issue here. The results are sufficient to establish the fact that discriminative coding does not appear to be necessary for the functional elimination of interference in performance.

A second way of examining the relation between cue confusion and recall performance is to attempt to directly manipulate the coding process and observe changes in interference. The issue at stake in these studies is whether discriminative encoding *always* eliminates interference. Again, the answer is negative.

The first experiment to be considered refers again to

Fig. 2. Percent correct recalls and recognition of the missing stimulus for lists high and low in stimulus similarity. Estimated mean square error for recall = 45.04 and for recognition = 5.98.

Fig. 1. The lists of import are 2 and 3. In both lists the middle letter can serve as a differentiating cue. The only difference is that in the second list the redundant letters are consistently placed, while in the third they were not. Despite the ready availability of a discriminative coding rule in both lists, the second list is considerably more difficult. In a separate experiment (Runquist, 1973c) using lists with the above structures, correct responses over a constant number of paired-associate test trials were 60.9 for List 2 and 40.8 for List 3.

It might be argued that it is more difficult to discover the rule defining the discriminative letter when redundant letters vary in position. Suppose, however, Ss in both groups are told about the discriminative function of the middle letter. In that case, the two lists should be functionally equivalent. However, List 2 produced 80.7 correct responses and List 3 produced 66.4 under instructed conditions.

The results of studies varying formal similarity among word stimuli also argue for the insufficiency of discriminative coding for the reduction of interference. Lists in which the stimuli rhyme are typically more difficult than lists in which stimuli do not rhyme. Despite the fact that word meaning provides a readily accessible discriminative code, interference effects are still obtained. Since the typical reaction to a word is to think of its meaning, the very presence of formal similarity effects with word stimuli is puzzling enough, but the surprising thing is that effects are obtained even though steps are taken to encourage coding by meaning. Two separate experiments (Runquist, 1971; Nelson, Brooks, & Fosselman, 1972) have obtained similarity effects even though response terms were meaningfully related to stimuli. Evans-Lutzer (1973) used an A-B, A'-B transfer paradigm to encourage Ss to utilize semantic relations between the stimuli to learn the

second list, then had them learn a third list which was A'-B, A''-B_R with respect to phonemic stimulus similarity but A'-B, C-D with respect to semantic similarity. Negative transfer was obtained. Finally, Nelson and Brooks (1973) instructed Ss to use imagery, but the effects of formal similarity were not reduced despite the usual massive facilitation in overall performance.

Of these experiments, only one (Runquist, 1973c) provided independent evidence that the stimuli were in fact discriminatively encoded, and one could always argue that, in general, the experimental manipulations have failed to accomplish this purpose. This seems unlikely, however, in view of large main effects of the instructional and set variables which were orthogonal to similarity.

These sorts of results are disconcerting, since the notion of discriminative coding enjoys a certain intuitive appeal, accounts for attenuation of both types of interference (cue confusion and associative interference), and is consistent with a considerable amount of data. It is not possible to rule out the possibility that the dependent variables used to assess cue confusion or the experimental control of the coding process are lacking in some important way. It should also be clear that these experiments are not to be interpreted as denying the importance of discriminative coding, but only that this mechanism is neither necessary nor sufficient to reduce interference.

This conclusion shifts the focus of theoretical endeavor to a consideration of the conditions under which discriminative coding will eliminate or attenuate interference and when it will not.

It would appear to be the case that discriminative coding is only successful when it operates at the perceptual level. That is, the learner must be able to inhibit the processing of redundant elements, components, or attributes at the time of perceptual registration of the stimulus. If redundant attributes must be processed in order to identify the stimulus, they will become involved in retrieval, even though eventual selective coding may permit the learner to discriminate accurately between stimuli when that is all that is required.

The empirical backbone for this principle is provided by the classic stimulus predifferentiation experiment, in which the learner is required to learn discriminations among stimuli, then, in a second task, acquire associations to those stimuli.

Not all of the many experiments using this paradigm are relevant, as the dominant theoretical interest has been in an issue only tangentially related to the present problem: the acquired distinctiveness of cues hypothesis based on verbal labeling. Moreover, the research has been plagued with failure to incorporate control groups and failure to experimentally control the various extraneous activities in which S may indulge during predifferentiation training.

Nevertheless, two different kinds of predifferentiation experiments provide data relevant to the attribute selection hypothesis. In one kind of experiment, Ss are allowed to inspect the stimuli to be used in the paired-associate task with instructions to discriminate between them. The control group is exposed to the same stimuli but performs some task in which discrimination is not relevant. Generally, multidimensional stimuli such as scribbles and fingerprints from which the S can learn to attend to distinctive features produce positive transfer to paired-associate learning (DeRivera, 1959; Dibble, 1948; Hendrickson & Muehl, 1962). Unidimensional stimuli (e.g., lights varying only in brightness), which cannot be discriminated by attribute selection, do not produce positive transfer (Goss, 1953).

Studies in which pretraining involves verbal labeling, while not directly to the point, can also be offered in support of the hypothesis, providing it is assumed that the learning of verbal labels forces the S to attend to discriminative features. Gibson (1969) has eloquently argued that this is the case, and Ellis and Daniel (1971) propose a closely related interpretation of labeling effects. Based on data which show that retention of discrimination is maintained while the labels are forgotten, their conclusion is that labels merely redirect the coding process in unique ways rather than being mediationaly involved. This interpretation of labeling effects is consistent with the attribute selection hypothesis, and it is again instructive to note that the labeling of unidimensional stimuli does not produce facilitation in later associative learning with those stimuli (Goss, 1953).

The second class of predifferentiation experiments utilizes the A-B, A-C transfer paradigm with variations in similarity among the stimuli within the list. The rationale for this experiment involves several assumptions. First, it is assumed that at least part of the learning of the A-B list involves forming discriminations among the stimuli. If the stimuli are relatively dissimilar, the relative contribution of discrimination will be small. As similarity increases, the role of stimulus discrimination becomes more and more important. If it is further assumed that any discrimination established during A-B will then transfer to the second list when the stimuli are nominally identical, the effect would be to modulate the usual negative transfer obtained with this paradigm. According to the attribute selection hypothesis, however, the positive effects should only occur if it is possible to selectively process distinctive attributes without processing redundant ones.

Once again, in experiments using stimuli varying in a single attribute, the results are negative (Del Castillo & Ellis, 1968) while, with 24-point random shapes or stimuli varying in a number of redundant attributes, positive transfer is obtained (Ellis, 1973). Results obtained with verbal stimuli are somewhat inconsistent. Underwood and Ekstrand (1968) using consonant trigrams did manage to obtain some positive effects, but

they were small and statistically questionable. Ellis (1973) also has obtained negative results using consonant trigrams but, when 3 by 3 letter matrices were used, the expected positive transfer appeared.

Generally, successful attempts to produce transfer of discriminative coding involve stimuli where the S may acquire a "perceptual rule" which enables him to reduce at least some of the redundancy. When stimuli involve only a single attribute, the similarity cannot be perceptually avoided and will result in interference when those stimuli are employed in paired associates. Discrimination may occur, and there is often independent evidence that it does (Ellis, 1973), but it cannot reduce interference unless it occurs by selective *perceptual* encoding.

While it would appear that spatially analyzable verbal stimuli such as consonant strings would meet the criterion necessary to obtain transfer of discriminative coding, this has not been the case. A closer examination of the structure of consonant trigram lists reveals the reason for this discrepancy. Typically, the letter redundancy pattern used to produce increased interference in these studies is complex in nature (e.g., List 5, Fig. 1). In these kinds of lists, it is difficult to devise a selection rule which allows processing of the appropriate distinctive element without processing the redundant elements as well. Even though a rule providing for complete perceptual discrimination is not possible, some reduction in functional similarity may occur. For example, Ellis (1973) obtained significant predifferentiation effects with nonsense shapes and letter matrices despite the absence of any reasonable perceptual rule. However, regardless of the fact that first-list learning was carried to three perfect trials, some similarity effects remained in second-list learning. Even the Underwood and Ekstrand (1968) experiment and Ellis's replication produced a small amount of facilitation. Thus, transfer of predifferentiation effects with consonant strings is not restricted to situations where a spatial position rule may be applied to *all* stimuli in the set but will occur to the extent that perceptual discrimination can be utilized at all. The more complex the stimuli (multiple redundant attributes, according to Ellis), the more likely some rule will be available, even if it does not perfectly differentiate among all stimuli.

The same mechanisms ought to be involved in single-list situations, in that the persistence of interference should depend upon whether redundant elements must be processed in arriving at selective codes. An experiment by Runquist (1973c) does provide relevant data. Referring again to Fig. 1, the stimuli in the lists were structured as in the fifth, i.e., there were two redundant letters and a distinctive letter, but the position of the discriminative letter varied from item to item. Learned under ordinary instructions, these lists produced 47.3 correct responses in 20 learning trials.

When Ss were told that each item contained a discriminative letter and what the redundant letters were, performance increased to only 52.8 correct responses. That is, telling S that the discriminative letter was "not V or J" did not help them significantly, presumably because they still had to process the common elements in order to find the discriminative letter.

On the other hand, when the discriminative letter can be located by position, considerable facilitation was obtained by telling S the location of this letter. It might also be noted that the special instructions produced a greater increase in the frequency of false recognitions of stimuli containing changes in the redundant letters in the "spatial rule" condition than in the "nonspatial rule" condition.

Even when a rule based on spatial position can be utilized, variability in either the redundant elements or their position may capture the learner's attention, causing him to process them and, hence, produce some interference in retrieval (see, e.g., Fig. 1, Lists 3 and 4).

Turning finally to the persistent effects of phonemic similarity with word stimuli, discriminative coding based on meaning may not be perfectly effective because the phonemic (or graphic) information must be processed, at least at the perceptual level, in order for the learner to identify the word before its meaning can be determined. In a broader sense, this hypothesis states that, whatever the mechanism by which elaborative coding such as imagery or associative mnemonics aids memorization, such codes cannot be selectively activated without also activating others which must logically precede them in the processing sequence.

If discriminative coding can reduce interference only when it is possible to perceptually isolate at least some nonredundant attributes, it is possible that in many interference situations differential coding does not occur at all. This would account for the results of the experiment reported earlier, in which no reduction in cue confusion occurred as associative learning proceeded. In this experiment, recall was also independent of successful recognition of the missing item, i.e., recall was identical for both recognized and nonrecognized items. Relevant to this point is the one that the structure of the list made it difficult to formulate any letter selection rule which would discriminate among stimuli.

The picture that emerges from this analysis is as follows: (1) When a cue stimulus is presented for recall, interference can result both from coding errors (cue confusion) and from the presence of competing associations (associative interference). (2) Interfering associations do not become less available during learning, except possibly when entire sets of target and interfering items can be temporally discriminated. (3) Discriminative coding reduces interference only when stimuli can be selectively coded at the perceptual

level. This process essentially eliminates both cue confusion and associative interference by making similar nominal stimuli functionally dissimilar. (4) Potential associative interference is often not reduced during learning despite discriminative coding of stimuli. Whatever attributes shared by stimuli are processed in order to generate distinctive stimulus codes, interfering associations will be activated. (5) While, in one sense, associative interference depends upon cue confusion for its existence, the two processes are independent in that successful differentiation is neither necessary nor sufficient to eliminate interference.

Response Discrimination

Neither discriminative coding of the stimuli nor weakening of the erroneous association appears to possess the generality necessary to account for the fact that usually and eventually learners will exhibit perfect memorial performance even with the most interference-laden materials. Thus, it is clear that some other mechanism or mechanisms must be involved when the above processes are insufficient.

Before consideration of a third possible interference reduction mechanism, however, it is necessary to provide a general conception of the recall process which allows for perfect recall performance despite the activation of competing associations. Several recent theorists (Anderson & Bower, 1972; Bahrick, 1970; Kintsch, 1970; Underwood, 1969) have reactivated versions of a two-phase theory of recall proposed by William James (1890). While these modern versions differ from James's introspective account of memory in a number of ways, the differences are of no import at the moment. The general idea behind the two-phase theory is that the retrieval of some associations is followed by a recognition test in which the association is checked against whatever criteria are important to determine if it qualifies as the target item. The model has been applied mostly to free recall, but it is equally appropriate for paired-associate recall, where the target memory is a specific item rather than an entire set.

If the presentation of a stimulus inevitably activates both correct and erroneous associations, the locus of interference reduction must lie in the second phase of the recall process, namely, the recognition of the correct association. In essence, then, learning to reduce interference involves learning to discriminate between correct and incorrect associations, given that they are both activated.

Interestingly enough, the differences between this conception of interference and modern interference theory (Postman & Underwood, 1973) are more apparent than real. The unpaced recall of an association with the interfering association physically present (MMFR) is presumed to eliminate associative interference, thus allowing a "pure" measure of the associative strength of the target item. The assumption

would seem to be that telling S that association C is "wrong" means that the other association which is activated is correct. In terms of James's theory, the above procedure simply eliminates the necessity of the recognition decision. There are, of course, some critical differences, one being the important role assigned to unlearning, but it is clear that discrimination among alternative associates is an important aspect of interference theory (Postman, 1963).

It is also an important and interesting question whether competing associations are simultaneously activated and S chooses the one he thinks is correct, or whether associations are activated and tested one at a time until a decision is reached. Analyses of interference in terms of classical theories of discrimination learning (e.g., Spence, 1956) are not formally different from the "parallel processing" conception as long as the added assumption is made that the decision is based only on relative associative strength. The "serial processing" conception appears to be more consonant with James's (1890) description of recall, in that he argued that the target item was searched for, with the search being terminated when an item which was retrieved was recognized as correct. Despite the fact that there are consequences of accepting either view, the issue will not be joined at this time.

Irrespective of these issues, there are several implications of the two-phase theory. One important consequence is that interference does not result from blocking the retrieval of the correct association but from failure to distinguish correct from erroneous associations. Testing for memory of the correct association with a multiple-choice procedure should eliminate retrieval failures and demonstrate the existence of interference resulting only from discrimination failures. It is thus critical for two-phase theory that interference occur in paired-associate recognition memory. While every instructor who uses multiple-choice examinations may suspect that this is a foregone conclusion, actual data on the matter are quite scarce.

Runquist and Runquist (1970) gave Ss five study-recall trials on a list of trigram-noun pairs, then five more study-test sequences with the test in multiple-choice format. When letter duplication among stimuli was minimal, the performance over the five multiple-choice trials was 92%. When there were redundant letters, performance was only 79%. Thus, this important implication of the theory is confirmed: Substantial interference results from inability to identify the correct response term.

The multiple-choice paradigm also provides data relevant to another issue. While the focus so far has been on interference at the time of retrieval, there is also the possibility that the presence of interfering associations inhibits the learning of the correct association. There are two experiments relevant to this issue. Postman and

Stark (1969) studied several different transfer paradigms using a multiple-choice format and obtained negative transfer in the A-C paradigm despite the fact that potential interfering associates (the B terms) were not included in the alternatives. A parallel finding emerged from a recent study conducted in the Alberta laboratory. The Ss were given a single study trial on 32 paired associates in which the stimuli consisted of four sets of eight rhymes. An unpaced multiple-choice test followed in which the incorrect alternatives included response terms from both an incorrect rhyming stimulus and an incorrect nonrhyming stimulus. When compared with performance on a list composed of nonrhyming stimuli, recognition performance on the rhyming list was impaired (67% vs 88%), but the incorrect choice was from the nonrhyming set as often as from the rhyming set.

The point of both studies is the same: It would appear that the interference obtained in both paradigms is not always attributable to the presence of interfering associations at the time of remembering but also results from interference with the processing (storage, coding?) of the correct association. In order to assess the amount of interference attributable to storage deficits and that due to associative interference with memorial performance, it would appear to be necessary to compare multiple-choice performance with and without competing associations present among the alternatives. No study making this comparison has been reported.

In any event, interference does occur in situations which demand that the correct association be discriminated from erroneous ones. It then becomes important to determine the basis of this discrimination. If, as is now commonly assumed, a memory is describable in terms of various attributes contained in its code (Bower, 1967; Underwood, 1969; Wickens, 1970), the problem then becomes one of identifying the attributes of the association upon which S can learn to base accurate recognition decisions.

In some cases, the response terms themselves, or more properly, their coded counterparts, are directly distinguishable and no further information is necessary. For example, in some transfer tasks there are changes in the form class of the response terms in the first and second lists from verbal to motor responses (e.g., Ellis & Mueller, 1964) or from one class of "verbal" responses to another, e.g., numbers to letters (Postman, Keppel, & Stark, 1965). Significantly, interference in learning the second list is considerably reduced.

When this type of differentiation is not possible, as in the case of intralist interference, the recognition decision must be based on attributes to the individual association. There are two classes of attributes which would seem to be important: stimulus attributes and context attributes. The distinction corresponds approximately to that introduced by Underwood (1969). Stimulus attributes

refers to attributes of the stimulus term associated with each response term. This corresponds to Underwood's task-dependent attributes but refers in this case to the nominal stimulus used as cue for each item rather than to the target item itself. Context attributes refers to those which Underwood calls task independent, such as frequency, strength, and temporal, spatial, or ordinal location, as well as the physical context and the context provided by the other items in the list being learned. Since the mode of action of the two kinds of attributes is somewhat different, they will be considered separately.

Stimulus Attributes. The fact of backward associations allows a reconsideration of the role of discriminative coding of the stimulus term in reducing interference. Within traditional verbal learning, it has never been clear why the presence of relevant backward associations should aid recall or the evocation of irrelevant ones should produce interference. Given enough time, however, it may be possible for S to use the backward association as an aid in making a recognition decision about the correct response. Thus, while it may be difficult for the learner to ignore redundant attributes of the cue stimulus when attempting to retrieve the target response term, he may be able to take the recalled associate and selectively check the attributes of the stimulus term against potential responses. A descriptive example may make this process clearer. Suppose the trigram CJX is presented to the S as a stimulus. If he processes all three letters, he may recall both "house" and "tiger" as potentially correct associates, then resolve the recognition problem by remembering that "tiger" is the one that goes with "J," while "house" goes with some other middle letter. The point is that selective coding depends upon the existence of the backward association between the retrieved associate and some stimulus attribute. The nominal stimulus may then be matched with the "backward associate," which is used as a criterion for whether a given retrieved response term is the correct one.

There are two at least conceptually separable processes involved in this mechanism. The first process involves activation of a discriminative stimulus code by the retrieved response term. We tend to forget that the response term is always present during the study period, and it is quite clear that the way in which the stimulus is coded depends upon the nature of the response term and its relation to the nominal stimulus (Ellis & Shumate, 1973; Runquist & Evans, 1972). Yet, on the recall test, support for the activation of this code is missing in that the response term is missing. It is quite possible that selection or elaboration of the nominal stimulus necessary for differential coding could be aided by the presence or memorial activation of the response term.

In order to demonstrate the existence of this

subprocess, it is necessary to show that stimulus discrimination depends upon response activation. An ingenious study by Richard (1965) demonstrates the process quite adequately. He had Ss estimate how many stimuli were being used for paired-associate learning with similar and dissimilar response terms. Although there were eight stimuli in each case, the estimated number was 6.8 for dissimilar responses and 5.8 for similar ones.

Evidence is also provided by the results of the experiment using the missing item recognition test described earlier (Runquist, 1974a). In this experiment, Ss were able to correctly identify the missing stimuli about 85% of the time when they recalled the correct associate and the effect was independent of stimulus similarity. When they could not recall the correct response, recognition dropped to 44% for similar stimuli but only to 73% for dissimilar ones. The evidence is only correlational but is nevertheless consistent with the fact that responses can help differentiate stimuli.

In one of the experiments reported earlier, the correlation between recognition of missing items and recall was not observed. It is instructive to reexamine the procedures of this experiment. Of interest to present considerations is the fact that the test for recognition was taken in the absence of response recall and with S set for a latency measure. Both procedures would have the effect of reducing the role of responses in recognition performance. Not only was recognition unrelated to recall, but also discriminative coding showed little improvement with practice.

Considering recognition as causally contingent upon correct recall reverses the usual way of conditionalizing the two performance measures. Moreover, Martin (1967) has shown that correct recognition is independent of recall by showing that performance on stimulus recognition tests improves over trials at the same rate, regardless of whether responses are kept the same from trial to trial or changed on each trial. There are two ways of countering Martin's interpretation of these results. First, his recognition test demanded that S discriminate list from nonlist stimuli and, therefore, may not be relevant to the issue at hand. Second, the use of a within-Ss manipulation of the consistency variable may have discouraged dependence on the response term for all items.

The results of experiments on transfer of stimulus differentiation are also relevant. Underwood and Freund (1968) have suggested that the failure of stimulus differentiation to transfer in the A-B, A-C paradigm is due to the fact that the B term is not available during A-C learning. They attempted to establish differentiation independent of the responses by prior free recall learning of the stimuli. While they were able to show that A-C learning was superior to D-C learning when free recall of stimuli preceded A-B, but not when free recall of *pairs* preceded A-B, this does not necessarily indicate a successful predifferentiation effect. The critical

comparison is between lists differing in intralist similarity. Since these investigators used only high-similarity lists, it remains possible that greater stimulus availability or some other factor depending on familiarity is the critical variable.

There would appear to be no reason to abandon the hypothesis that successful transfer of predifferentiation depends upon establishing perceptual discriminations that avoid further processing of redundant elements. While there is evidence that responses do aid in stimulus discrimination, there is no evidence that this discrimination transfers to a situation involving the learning of new associations. This is as it should be if the primary function of discriminative coding associated with the response is to edit particular associations in a second task, without the processing of nondiscriminative elements.

This point also clarifies a potential circularity of the recall process. If the response term is used to differentiate stimuli, how can such differentiation aid recall of the correct response? The answer is that it does not. Instead, retrieved (thought of) response terms activate discriminative aspects of stimuli. Nominal stimuli can then be checked to see if those attributes are present. Thus, the discriminative code merely serves to verify or reject responses, not retrieve them.

While there is little evidence to support the veracity of this hypothesized mode of action, some circumstantial evidence may be marshalled in its support.

Tulving and Thomson (1973) have provided an intriguing demonstration of the importance of stimulus recall in response recognition. After paired-associate learning, they presented free-association stimuli designed to produce list responses as well as many others. The result was a relatively massive amount of interference, to the extent that Ss could recognize only 30% of the list responses in the set of free-association responses. Significantly, for those correctly recognized items, stimulus recall was about 70%. One way of interpreting this correlation is that Ss try to solve the recognition problem by retrieving stimuli and using them as a criterion for recognition decisions.

The results of stimulus selection experiments may also be used as tentative support for the existence of the postulated process. Wichawut and Martin (1970) arranged learning to produce considerable stimulus selection. When single elements of the stimuli were tested for recall of both the response term and other stimulus elements, it was discovered that the recall of other elements was perfectly contingent on the recall of the response. Postman and Greenbloom's (1967) data using essentially the same procedure but with less perceptually isolatable stimuli showed the same contingency, although the relation is not perfect as it was in the Wichawut and Martin study. While other interpretations of the correlation are possible (Postman & Underwood, 1973), these results may indicate that Ss

Table 1
Correct Recall as a Function of Recall Time

Perceptual Difficulty	1 Sec	3 Sec	Difference	Coding Time*
Easy	80.7	105.5	24.8	477
Medium	66.4	103.5	37.1	469
Hard	52.8	95.6	42.8	604
MS Error	422.6	221.6		712

*In milliseconds

selectively encode the stimulus according to a spatial position rule, then utilize the redundant discriminative elements associated with response terms to aid in response recognition. Moreover, the so-called relaxation of stimulus selection which is thought to occur with over-learning may not represent less selection at retrieval, but simply an increasing use of the redundant elements for verification.

Whether S is making any use of the recallable letters is, of course, debatable. The point is that certain aspects of the stimulus are in some sense associated in a backward manner with the response. The exact functional significance remains to be determined, although these dependencies would be expected if response verification was being utilized.

Another fact consistent with the hypothesis is the well known facilitation of recall produced by instructions to code the associations as an interactive image. Suppose storage in interactive form makes it easier for S to determine the correctness of possible associates because the interactive form increases the likelihood that the appropriate image can be activated by the recalled response. Nelson and Brooks (1973) have demonstrated that interaction imagery will reduce the effects of phonemic similarity, while separate imagery will not, in accord with this interpretation.

Finally, there are several experiments in which the amount of time allowed for recall was varied. It has been commonly found that interference is greater when time restrictions are placed on recall (Nodine, 1963; Runquist, 1973). While these results are usually interpreted in terms of longer intervals allowing time for discriminative coding, this does not appear to be the whole story. Elimination of interference after retrieval has occurred should take longer than elimination of interference resulting from discriminative perceptual coding, since it involves an additional processing operation. Thus, not only should stimulus similarity produce more interference when less time is allowed for recall, but also the temporal effects ought to be greater when perceptual discrimination is not involved, forcing S to use the postretrieval check.

Data are in line with this result. In one experiment (Runquist, 1973c), lists were learned by anticipation with 1- and 3sec anticipation intervals. The stimuli consisted of consonant trigrams with two letters shared by all stimuli. Table 1 shows some of these effects for three lists which vary in difficulty of perceptual coding

(Lists 2, 4, and 6 of Fig. 1). The results indicate the presence of two separate factors. Recall performance showed more improvement in the more difficult lists when additional time was given for recall. Nevertheless, this cannot be entirely accounted for on the basis of longer perceptual coding time, as direct measurement of time taken to locate nonredundant letters did not perfectly correlate with the amount of interference produced.

In summary, then, it has not been clearly established that S uses the discriminative attributes of stimuli to differentiate responses. Nevertheless, enough data is consistent with the hypothesis to give it consideration as a major interference reduction mechanism.

Context Attributes. The role of context variables in memory has received increasing emphasis in recent research, and their involvement in interference reduction should not be underestimated. The discussion will focus on frequency, time, and ordinal position, with the understanding that these variables are often confounded with others (e.g., strength) or with each other. There is no intent here to unravel these knotty relations, nor to compile an exhaustive list of possible contextual attributes. It will suffice to demonstrate that such variables are involved in interference reduction and to indicate their mode of action.

There is considerable evidence from a variety of experiments that situational frequency is a judgeable attribute of memorial inputs (e.g., Hintzman, 1969) and that perceived frequency differences are causally involved in recognition performance (Underwood, 1972b; Underwood & Freund, 1970). The verbal discrimination task, in which Ss are required to choose which of two items is correct, represents a laboratory paradigm in which discrimination of correctness seems to be based primarily on context attributes (frequency).

More to the point, however, would be data showing that contextual attributes are involved in interference reduction. Several experiments (Runquist, 1965, 1967, 1968a) have manipulated relative frequency of presentation of items in paired-associate tasks. In these experiments, half of the pairs in the list were presented several times per trial and the remaining pairs once per trial. If only the once-presented pairs are considered, recall performance during learning is always better for Ss given this treatment than for Ss who learn lists with all items presented once. Moreover, a large proportion of overt errors involve confusion among the set of items defined by common frequency of presentation. Table 2

Table 2
Mean Errors: Asymmetry Experiment

	Before First Correct	After First Correct
Equal Frequency	7.4	14.3
Unequal Frequency	7.9	11.6
Low Similarity	5.4	10.8
MS Error	10.3	12.8

presents some results of one of the experiments (Runquist, 1967). An interesting feature of the data is that all facilitation on a given item occurs after the first correct response has appeared. The results correspond nicely to the hypothesis that Ss discriminate among correct and incorrect responses on the basis of frequency of the response, in that the frequency differential does not help them initially acquire the association. Only after the associations are available does any facilitation occur.

In this experiment, the stimuli consisted of trigrams of low association value with considerable letter duplication among them. The third row in the table represents a group in which stimuli were dissimilar and learning was by the standard procedure. Note that after the first correct response the frequency variable was strong enough to virtually eliminate the effects of similarity.

This pattern of results is not restricted to frequency. Ordinal position operates in the same fashion. Several studies (e.g., McGeoch & McKinney, 1937) have shown that presenting paired associates in the same order on each trial produces better performance during learning than the usual procedure of varying the order. Brown and Battig (1962) reported two experiments dealing with this effect. In one experiment, pairs were held in constant positions only after they were correctly recalled. Facilitation of performance was obtained mostly for items that were the last ones to be acquired. The authors argue that the data did not indicate serial learning, but rather that position represented a discriminative cue with which already learned pairs could be associated. In a subsequent experiment (Battig, Brown, & Nelson, 1963), it would found that the amount of facilitation obtained with position constancy contingent upon the appearance of a correct response was equivalent to that obtained with items in constant position from the outset. Serial position, like frequency, has effects only after associations have been acquired.

The dependence of facilitation on the existence of the association is a predictable consequence of the hypothesis that the attributes are not used as retrieval cues but as means of determining the correctness of associations once they have been retrieved. In the "ordinary" paired-associate type of task, where such position and frequency cues are controlled so that they do not provide S with much helpful information, there may still be attributes that can provide some support for the recognition of correctness. One such factor can be loosely described as "strength." Although not all theorists agree that there is such an attribute, in some sense the correct association to a given stimulus would seem to become more recallable than erroneous ones as learning proceeds. Thus, even though interfering associates were to be activated and were themselves to become more available in an absolute sense during learning, S recognizes the correct association in that it is

the "stronger" one, whatever that means. In a sense, he may not really reduce interference, he simply overpowers it.

An interesting implication of this notion arises if strength accrues over practice in a negatively accelerated fashion for both correct and erroneous associations. As learning proceeds, there should be a point where the strength differential between the two associations begins to decrease, leading to an increase in interference. Late appearing decrements in performance have seldom been reported, although it is more or less generally known among paired-associate researchers that in learning lists with highly similar stimuli there is considerable oscillation. Once an item is correctly recalled, it tends to exhibit considerable irregularity over the immediately succeeding trials, and often an item which has been successfully recalled for many trials will show an inexplicable series of failures. This phenomenon could indicate the breakdown of the discrimination based on strength as all associations begin to be learned.

The breakdown of strength differentials may also be reflected in the late appearance of negative transfer in the A-B, A-B' positive transfer paradigm. At this point, Ss apparently have difficulty discriminating which of two similar response terms is the correct one, although early in learning rejection of the strong first-list item is not difficult.

It has also been demonstrated that Ss can identify a wide variety of incidental attributes associated with the presentation of verbal items. Spatial location of information in prose text (Rothkopf, 1971), visual vs auditory modality (Bray & Batchelder, 1972), verbal vs pictorial representation (Light, Stansburg, Rubin, & Linde, 1973), and the relative spacing of items (Hintzman & Block, 1973) are some of the variables which are identifiable. Whether these variables aid recall is another matter, but the fact that frequency differentials facilitate learning makes it highly likely that similar effects would occur with other incidental information acquired during learning.

The notion that interference is alleviated by a discriminative process linked to list-specific context attributes was suggested for retroactive and proactive inhibition situations by Underwood (1945). He proposed that interference would be reduced if S identified some of the erroneous associations that had been activated as belonging to the wrong list. There are a number of phenomena involving retroaction which are consonant with this role of contextual attributes and, in fact, these variables have been given a large role in explaining the failures of certain theoretical predictions based on associative interference to be obtained (Underwood & Ekstrand, 1966). This exceptionally large body of quite relevant research will not be reviewed here, as the most cogent issues have been considered previously in the discussion of the concept of unlearning. The point may simply be reiterated.

Temporal or list differentiation is so effective that virtually all interference *at the level of individual associations* is alleviated as long as conditions are such that such differentiation is possible. Included among the conditions are temporal separation of lists (Abra, 1972), adequate time for recall (Underwood, 1950), or the use of physically different contexts for different lists (Strand, 1970). One of the critical context variables for differentiation may be that provided by other items in the list. For this reason, the A-B_R re-pairing situation is exceptionally difficult.

The effects of additional recall time are again particularly critical. Underwood's original studies (1950) on recall time have traditionally been interpreted in terms of a postretrieval recognition mechanism. The argument presented here is that Underwood's list differentiation mechanism ought to be broadened to include all situations where differences between conditions of first- and secondlist learning result in reduced interference. Factors other than simply being able to apply the appropriate list label to a retrieved response (Winograd, 1968) may be involved in the discrimination of correct and incorrect responses. The label per se may not be the critical attribute.

Other than the transfer and retroaction studies, evidence for the reduction of interference by the recognition of discriminative context attributes has involved the learning of lists in which stimulus terms may be categorized on the basis of various attributes. The interesting thing about the results is that facilitation resulting from this organization seems to occur only with variables like frequency, time, and order (e.g., Runquist, 1967). Over 10 experiments have been conducted by P. A. Runquist in which the stimuli in paired-associate lists were organized into *conceptual* categories. Not one of the experiments demonstrated facilitation in learning, despite ample evidence that the response terms were organized into categories consonant with those of the stimuli (Runquist, 1970, 1973). When some reduction in interference did occur (Runquist, 1974), it was entirely attributable to restriction of guessing probabilities. The point is that the identity of category membership increases the likelihood of retrieval of interfering associates. Since S must process the categorical attribute in order to retrieve the response, any elimination of alternative associations resulting from using the category name as a discriminative attribute is more than offset by the increase in activation of competing associations produced by the same attribute.

GENERAL DISCUSSION

A rather diverse set of data has been presented in order to document the existence of various processes involved in interference production and reduction. Incisive experiments directed toward the explication of these processes are often not available, so that, taken

one at a time, the experiments often admit to alternate interpretations. Taken together, however, they seem to point toward the general conception of interference outlined here.

The principles may be briefly recapitulated. A task may interfere with memory in two ways. It may disrupt the processing activity necessary for storage or retrieval, or the input from the task may interact with the to-be-remembered information in memory.

Interaction among traces may produce interference in several ways. The premier mechanism would appear to be the activation of erroneous associations. Their activation at the time of input may interfere with or modify the storage process. Moreover, there is some evidence that the learning of a new set of associations to nominally identical stimuli renders the earlier learned associations less recallable. When nominal stimuli are not identical and there is no temporal or contextual separation of target and interfering items, cue confusion is an important source of interference. The interference may result from an increase in the activation of erroneous associations or from coding errors.

Processing interference would appear to be controllable to the extent that processing activities can be shifted to more important material. This may be achieved via the use of so-called rehearsal strategies.

Several mechanisms would appear to be involved in the reduction of interference due to trace interaction. The unlearning of associations learned prior to the learning of target items, if it occurs at all, would appear to be restricted to the same situations described above. Discriminative encoding will alleviate interference only when selective coding of stimulus attributes can occur at the perceptual level. The inclusion of redundant or similar attributes in the representation of cue stimuli will always activate interfering associates. The interfering effects of the associates are eliminated by identifying them as erroneous based on either discriminative attributes of the nominal stimuli or on contextual attributes such as frequency, recency, ordinal position, and physical context.

Comparison With Other Views

None of the processes proposed to account for interference production or reduction are particularly novel. Indeed, it would be quite surprising after nearly 100 years of empirical research and countless centuries of thought about memorial processes if any conceivable mechanism had been overlooked. Research does seem to restrict the possibilities, however, and, while many details remain to be determined, the mechanisms described above appear to be promising in resolving some of the controversial issues that have recently encumbered orderly theoretical development.

One such issue involves classical interference theory, on the one hand (Postman & Underwood, 1973), and theories based largely on coding and active retrieval

mechanisms, on the other (Greeno, James, & DaPolito, 1971; Martin, 1971). While a detailed examination of the present view in comparison with each of these theories will not be conducted, a brief discussion will be useful in order to obtain some perspective on various issues.

Classical interference theory differs from the view proposed here largely in the role assigned to unlearning, either at the associative or response set level. While the existence of an unlearning *process* does not invalidate the analysis of interference presented here, it would certainly simplify the theoretical situation were it to prove superfluous.

It is clearly possible that in the A-B, A-C and A-B_R transfer paradigms there is no unlearning at all and that decrements in first-list recall merely reflect interference from second-list associations or response sets. Taken in conjunction with some of the difficulties discussed earlier, it is suggested that the evidence for unlearning is indeed ambiguous.

Martin (1971) has been the most articulate opponent of interference theory. For a variety of reasons which need not concern us here, Martin rejects unlearning and response set suppression as the major interference reduction mechanisms and proposes instead that, in the A-C and A-B_R transfer paradigms, the learner recodes the second-list stimuli, making them functionally into D-C and C-B paradigms.

Evidence that spontaneous recoding does occur in the transfer tasks is virtually nonexistent despite numerous attempts to demonstrate the principle (e.g., Goggin & Martin, 1970; Williams & Underwood, 1970). On the other hand, one might argue that, in the ordinary transfer task, interference is not sufficient to produce recoding. After all, overall transfer to a second list is usually positive due to learning to learn. If S thinks he is doing fairly well, he may not see any real reason to abandon an earlier and established code. Moreover, there is no a priori reason why Ss cannot hold two associations to *exactly* the same stimulus at the same time and reproduce one or the other upon demand by discriminating between them on the basis of appropriate attributes. While these attributes might be differential stimulus attributes (such as different letters in a trigram, different meaning, etc.), the identity of the nominal stimuli should make it much more difficult to use these attributes than the obvious and available temporal or "list organization" attributes.

The difference between Martin's hypothesis and the one suggested here is twofold. First, he assumes that activation of different cue codes occurs at the time of retrieval. Second, he places his emphasis on attributes of the stimuli *per se* rather than on the contextual attributes which are likely to be more important. This analysis is supported by the fact that negative transfer is not obtained in the A-C paradigm unless first- and second-list stimuli are identical (Wimer, 1964).

Differences in nominal stimuli may encourage the use of attributes other than or in addition to the contextual ones, enabling S to suppress interfering associates entirely.

Greeno et al (1971) have also proposed an alternative to interference theory. Essentially, they propose two stages of learning: associative learning and the learning of a retrieval plan. While the conceptual basis of the second stage is vague, their analysis is given some operational substance by a strong correlation between the associative state and errors before the first correct response and the retrieval plan and errors from the first correct response to the learning criterion.

Their model bears a superficial resemblance to the present formulation in that association formation is also assumed to comprise the initial stage of acquisition. However, they assign particular structural and functional properties to an association which are not implied by the initial stage of this theory. Association formation here refers to the acquisition of the ability of a stimulus to activate the correct association and, hence, does not deny the role of component processes such as response learning (Underwood & Schulz, 1960). Moreover, the theory replaces the Greeno et al notion of learning a retrieval plan with the learning of a discrimination between correct and interfering associates. While the two stages are also correlated with performance before and after the correct response, predictions as to the outcome of analyses using these measures are not the same. The only real theoretical resemblance is a concurrence with the concept of code persistence indigenous to the Greeno et al analysis.

This discussion has not considered several popular and important interference phenomena, notably, retroactive and proactive interference in free recall learning (Tulving & Psotka, 1971) and the buildup and release of proactive interference in the Brown-Peterson short-term memory paradigm (Wickens, 1970). The omission is intentional. The free recall paradigm offers no basic conceptual difficulties in terms of the analysis of interference processes. In fact, the basic idea of encoding specificity as set out by Tulving and Thomson (1973) provides a ready entry for the theory of the phenomena. This theory, which stresses the importance of particular retrieval cues for providing access to the items memorized in a free recall experiment, is consonant with the present view of interference to the extent that such cues represent a source of confusion in retrieving particular items. The situation is complicated in free recall by the fact that the target information is specified by list rather than by individual item and by the fact that there are a number of rather complex phenomena involving intralist associations and/or organization resulting from the specific task demands of free recall that must be considered. Analysis is possible, but ponderous, and deserving of separate development. The short-term memory task is really nothing more than the

learning and recall of multiple short serial lists and, while it has proven useful for some purposes, it has not yet provided significant insight into interference mechanisms per se.

A Last Word

The analysis presented here is not really associative. The term "activation of associations" has been consistently used to avoid the connotations of the more commonly used "evoke." Nevertheless, the theory does reverse a notable trend in contemporary memory theory in that the control the learner has over the coding process and, thus, indirectly over retrieval is seriously limited. If the mere perceptual processing of an attribute is sufficient to involve that attribute in the retrieval code and produce interference when the attribute is shared with other items, the memory system is not as flexible as some theorists would have us believe.

What are the limits of selective coding? Learners may be able to respond to instructions and task demands by activating certain coding systems such as implicit associative responses, images, etc., but be totally unable to inhibit the particular attributes involved in the code once that system is activated. There is an old joke about telling a person, "Think of anything you want to, but don't think of alligators." Whenever similarity is present, S must essentially perform a similar feat, that is, "Think of any association you want to 'tiger,' but don't think of 'animal'."

Once redundant attributes are "thought of," it is not so unlikely that associations acquired in their presence are activated. The fact that Ss will learn just about as much under incidental learning conditions as under intentional conditions as long as appropriate codes are elicited by the orienting task is consistent with this notion (Postman, 1964).

Once the erroneous association is activated, however, it is perfectly reasonable that discriminative attributes be brought into play to aid in the elimination of the erroneous associates.

The important role assigned to context attributes in performing this discrimination cannot be overemphasized. In real life, intellectually intact humans acquire large amounts of information and are able to retrieve specific items on demand with considerable accuracy. Yet it is relatively easy to confuse them thoroughly with memory loads only slightly above span in laboratory situations. Considering that in our learning and memory experiments we take great pains to eliminate the sources of contextual support available in real-life memorial situations, as well as provide them with little time to discriminate correct alternatives, it is not surprising that learning is painfully slow and interference appears to be everywhere.

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