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Experimental analysis of coding processes*

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The first part of the paper reports an investigation of the effects of the concreteness-imagery (C-I) value of stimuli and responses on the long-term retention of paired-associate lists. With degree of learning equated, the measures of retention after a 1-week interval showed a significant interaction of Stimulus by Response C-I: When the responses had a high value, recall was substantially better with low than with high stimuli; when the responses were low, there was no reliable difference as a function of stimulus value. Recall was best when abstract stimuli were paired with concrete responses. The second part of the paper is addressed to some current issues in the analysis of coding processes. Major emphasis is placed on the experimental and theoretical differentiation of encoding and decoding processes.

Let us begin by reporting an experimental investigation of a widely recognized and much studied system of coding: the transformation of words into visual images. There is persuasive evidence that the imagery value of words, which is strongly correlated with degree of concreteness, is a powerful task variable in associative learning. In the paired-associate situation, the influence of this variable is most pronounced on the stimulus side; a cue with high imagery value is said to be a very good conceptual peg for the attachment of responses (cf. Paivio, 1969). Speed of learning is maximized when both the stimulus and the response terms are concrete and permit the formation of a composite image that mediates the association between the verbal units.

We were interested in the effectiveness of this coding device for long-term retention. How good is the retrieval of responses from the imaginal peg after an interval of time? How stable is the composite image as a record of an association, and how resistant to interference is the learner's ability to read out the correct response from this record? There are no clear answers to these questions in the available literature. The few relevant studies failed to equate degree of learning for the different types of materials before assessing long-term retention (Butter, 1970; Butter & Palermo, 1970; Yuille, 1971). Thus, the effect of imaginal coding on retention remained to be determined.

RETENTION AS A FUNCTION OF IMAGERY VALUE

The learning materials were lists of 16 paired nouns. The degree of concreteness of the stimuli and of the responses was varied factorially, so that there were four types of list: high-high (H-H), high-low (H-L), low-high (L-H), and low-low (L-L). There was the usual strong correlation between degree of concreteness and imagery value. The mean C values were 6.77 for H and 2.44 for L; the corresponding I values were 6.34 and 3.31. Frequency of usage and meaningfulness were equated as closely as possible for the two groups of words.

The study comprised a pilot experiment and a main experiment. The purpose of the pilot experiment was to determine how many trials would be required on each type of list to equate the degree of original learning, such that the expected recall score (number of correct anticipations on the next trial) would be 12/16 in all cases. The rank order of the conditions in acquisition agreed with that reported by Paivio and others and showed concreteness to be a more potent variable on the stimulus than on the response side. The number of trials required to equate degree of original learning for the different lists was 4, 9, 6, and 13 for H-H, L-H, H-L, and L-L, respectively.

In the main experiment, interest centered on long-term retention as a function of item characteristics. The appropriate number of anticipation trials (at a 2:2-sec rate), as determined by the results of the pilot experiment, was given on each type of list. There were 16 Ss per group. The acquisition functions in the main experiment are presented in Fig. 1, which also shows the expected recall scores yielded by a probability analysis. The expected scores were closely similar.

Retention was tested 1 week after original learning. There were five paced recall trials without feedback, followed by two unpaced trials. On the paced trials, a 2:2-sec rate was again used, with a blank space presented in lieu of the response term; on the second unpaced trial, Ss were required to give a response to each of the stimulus terms, even if they had to guess. After the retention test, Ss filled out a questionnaire about the methods they had used in linking the stimulus and the response member of each pair and, in particular, about the frequency with which images and verbal mediators were employed.

Forgetting was measured in terms of losses from the projected values. The mean loss scores on the successive recall trials are shown in Fig. 2. The first paced trial will be considered first. The rank order of the conditions was clearly not the same as in learning, and it is apparent that stimulus concreteness did not have a favorable effect on retention. Specifically, there was a significant

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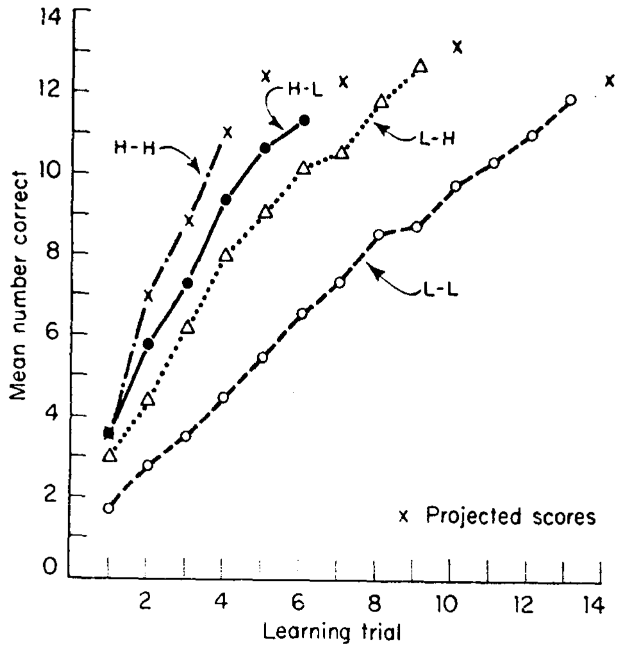

Fig. 1. Acquisition curves and projected recall scores for the four types of paired-associate lists.

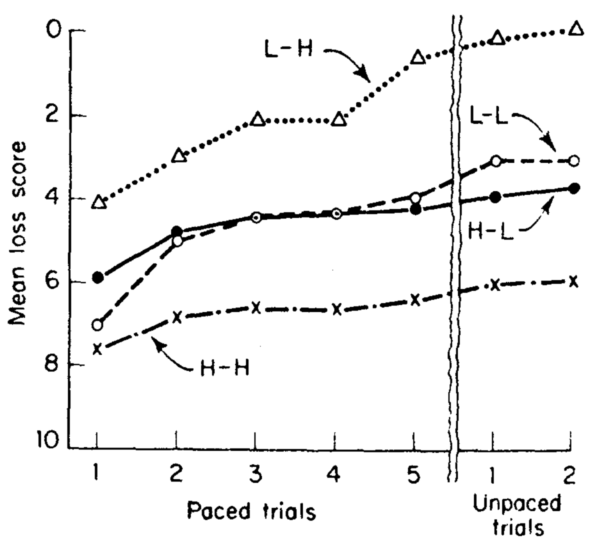

Fig. 2. Mean loss scores on successive test trials after a 1-week retention interval. (Note that the ordinate is reversed so as to reflect the level of recall.)

interaction of Stimulus by Response Concreteness [$F(1,60) = 10.08$, $p < .01$]. When the responses were high, recall was substantially better with low than with high stimuli ($p < .01$). When the responses were low, there was a slight and nonsignificant trend in the opposite direction. Thus, depending on the characteristics of the responses, an increase in the concreteness or imagery value of the stimuli either impeded recall or failed to influence it significantly.

All groups showed progressive improvements over the successive paced recall trials. The linear increases were significantly greater ($p < .01$) when the stimulus terms were low than when they were high, but the basic pattern of recall measures remained essentially intact. It is worth noting, however, that on the final unpaced trials the difference was in favor of the low-stimulus condition for both types of responses.

The number of intrusions from outside the list is summarized in Table 1. The corresponding mean percentages to the base of total emissions are also shown. The trends parallel those for the recall scores: many more intrusions for H-H than L-H and little separation between H-L and L-L.

In the postexperimental inquiry, the mediational devices mentioned most frequently were images and verbal linkages, in that order (Table 2). The relative frequency with which the use of images was reported increased with the concreteness of the verbal items. However, the expected difference between stimuli and responses in evoking imagery was not in evidence. There is no systematic relation between the reported use of imaginal mediators and long-term retention.

The validity of Ss' reports, which were obtained after the test of recall, is uncertain. After a week, Ss' memory for the method they used in learning individual pairs was obviously fallible. Some mediators may have been generated during recall or in the course of the postexperimental inquiry. In any event, it is likely that the characteristics of the imaginal transformations varied with the type of list. When a verbal referent is abstract, a straight conversion into a pictorial representation is usually not possible. A schematic image may be formed, or the abstract concept may be concretized by means of a specific image (cf. Paivio, 1971). In either case, the coding operation is more complex than for images of concrete objects and is more apt to encompass a verbal component. To the extent that Ss' reports referred to qualitatively different processes, a comparison of the sheer frequencies of imaginal mediators for the four types of lists may be misleading.

What general conclusions can be drawn from these findings? We note first of all that the imagery value of the responses by itself had no consistent influence on

Table 1
Frequency of Outside Intrusions on Paced Test Trials

Condition	Total	Mean Percent
H-H	85	13.4
L-H	5	0.6
H-L	27	5.3
L-L	28	3.9

Table 2
Mean Numbers of Imaginal and Verbal Mediators Reported by Ss

Condition	Imaginal	Verbal
H-H	10.8	2.1
L-H	9.3	4.1
H-L	7.3	4.7
L-L	5.5	7.2

retention. As for the imagery value of the stimuli, it was likewise of no consequence when the responses were abstract. Under these circumstances, an imaginal transformation usually cannot encompass a stable and immediately decodable representation of the prescribed response. Verbal encoding is likely to play some part in the development of the association. The long-term stability of the association that is finally formed does not depend on whether or not the stimulus arouses a visual image.

The characteristics of the stimuli become critical for retention when the responses are concrete. Now the stimulus value determines whether and to what extent the association is encoded in the form of a composite or interacting image that can be translated directly into its verbal equivalents. If the stimulus is a concrete word with high imagery value, the S will be disposed to rely on such a transformation. If the stimulus is an abstract word, however, the coding operation once again is likely to encompass a verbal component. The heavy losses in the recall of the H-H list indicate that the possibility of retrieval declines rapidly when the mediation is predominantly or exclusively imaginal and the verbal responses are read out directly from the coded representation.

When the association is carried by a composite visual image, two things are likely to happen as a function of time: (1) The image may change progressively, e.g., it may become "normalized" in the direction of a conventional juxtaposition of objects. Such changes would be analogous to the intrusions of preexperimental associations. Alternatively, the image may become blurred or noisy. (2) Even if the composite image remains more or less intact, the translation of the response component into its appropriate verbal equivalent may become uncertain and, hence, subject to error. Such read-out errors are to be expected because an image is a transformation that is likely to conserve some but not all of the distinguishing features of the verbal referent. The importations at the time of recall, which were by far most frequent for List H-H, are consistent with these assumptions. They were in many cases normative associates of the stimuli and synonyms of the responses.

Thus, when an association is encoded in the form of a composite image, the appropriate decoding of the response term is likely to become a serious difficulty at the time of recall. The emergence of this deficit in performance is closely linked to the reduction in the availability of the prescribed verbal responses as such. It is only when the entire repertoire is no longer immediately available, as it is during acquisition, that translation from image to response becomes a source of error. On this basis, it becomes understandable that the very characteristics of items that facilitate speed of acquisition—concreteness and high imagery value of both the stimuli and the responses—lead to inferior recall.

When we turn to List L-H, we find not only that it was retained much better than List H-H but also that there was a minimal amount of forgetting after a 1-week interval. The difficulties peculiar to purely imaginal encoding—the degradation of the composite image and the errors of read-out from such an image—do not apply to L-H pairs which are assumed to involve at least some verbal mediation. Two factors may contribute to the high absolute level of recall: (1) The juxtaposition of an abstract and a concrete word represents a unit sequence of low probability in the language; and (2) the long-term availability of the responses per se may be enhanced by their imagery value. Taken singly, each of these factors applies to other conditions as well; it is their combination that appears to create a high degree of resistance to interference. An interesting implication is that the relative potency of stimulus and of response imagery may be reversed as one proceeds from acquisition to recall. The indications are that the value of the stimulus is decisive for acquisition and that of the response for retention.

SOME CURRENT ISSUES IN THE ANALYSIS OF CODING PROCESSES

The results of this experiment bring into focus some of the important limitations as well as accomplishments of current analyses of coding operations in verbal learning and memory. The rapidly accumulating studies of imagery have identified and brought under a measure of experimental control a system of mediation that can drastically influence the speed of acquisition and the efficiency of immediate recall. However, relatively little attention has been given to the long-term consequences of this class of coding operations, i.e., to their effects on retention. When coding involves the transformation of the nominal units in a learning task, it is essential to differentiate sharply between the encoding and the decoding phase of the operation. No matter how easy the encoding and how effective for immediate recall, it has strictly limited value as a mnemonic device if long-term decoding is difficult. The experiment we have reported shows that imaginal coding is a case in point.

Difficulty of decoding places constraints on the utility of transformations of single units as well as of associatively related terms. This fact was demonstrated convincingly in the experiments of Underwood and Erlebacher (1965). The learning materials were letter sequences in the form of anagrams, and the coding transformation was from the anagrams to the solution words. This device is effective in aiding recall of the letter sequences only if there are no more than one or two rules for decoding the words back into their anagram forms. Again, no matter how easy the encoding, the mnemonic value of the transformation is limited by the possibility of decoding.

Transformation of nominal units into apparently more memorable equivalents is only one of the systems of coding that have been identified in recent studies of learning and retention. Let us comment briefly on two other types of coding that are anchored to different experimental operations and pose other problems of interpretation.

In selective coding the input is processed by the learner in such a way as to create a functional cue that is less complex or contains fewer elements than the nominal one. Experiments on cue selection are addressed to the examination of such coding operations. The basic experimental procedure for the determination of cue selection is the measurement of transfer to each of the redundant elements of which the complex nominal stimulus is composed. Such measures have provided ample evidence for the phenomenon of selection. In any given case, however, there is an intrinsic limitation on the inferences that can be drawn from the results: The distributions of the Ss' responses tell us which elements of the compound are functional at the time of test. We cannot tell, however, which elements have been used and discarded in the course of acquisition. The finding that selection is relaxed during overlearning attests to the lability of this coding operation. This limitation may not be serious since interest may center on the terminal selection of the functional cue. However, our attention is here called again to the constraints on inferences about encoding imposed by a particular set of measurement procedures. A transfer test typically tells us what an S knows after he has mastered a task but not how he learned it. We need only recall the inconclusive attempts to identify the functional stimulus in serial learning on the basis of transfer results to document the validity of this point.

Another type of operation attributed to the learner may be designated as multiple-attribute coding. Verbal units have manifold features that can be described and manipulated by the E. It is apparent that upon exposure to such units the learner can attend to, store, and retrieve more than one of these features. Thus, a verbal unit as encoded can be represented as a complex of attributes. One clear statement of this position has been made by Underwood (1969, p. 559), who views encoding as "the process by which the attributes of a memory are established." In the development of this position, the experimental approach has been to make specific assumptions about the attributes that are established during acquisition and about the sensitivity of particular tests of retention to the integrity of these attributes in storage. Within this framework of analysis, impressive evidence has been obtained for the decisive role of the frequency attribute in recognition memory. The experiments by Wickens (cf. 1970) on release from proactive inhibition in short-term memory have explored in depth the multiple dimensions in terms of which verbal units are encoded. The measures of retention have been used like a litmus test to identify the effective dimensions of encoding. The functional presence of a dimension is inferred when a change in the class of items results in a release from proactive inhibition (PI). The dimensions that have thus been identified are numerous but they also appear to vary widely in saliency and probability of usage.

It may be useful, for purposes of discussion, to restate the central findings of the studies of multiple-attribute coding as follows: Given appropriate conditions of testing, the S is able to discriminate among verbal units on the basis of specific predictable features. One reasonable inference is that the feature in question was encoded at the time of input. As Wickens (1970, p. 12) put it, "In the split second while the symbol is processed by the individual, it is granted a locus on many . . . dimensions or aspects–encoded, in short, in a multiplicity of ways."

There is, however, another alternative to which Wickens himself alluded in the theoretical discussion of his findings, namely, that the change in materials provides the S with a unique retrieval cue. Thus, the differentiation with respect to the critical dimension would first occur in many cases at the time of recall and not necessarily reflect the shifting pattern of encoding during the presentation of the successive items. We would like to urge further consideration of this alternative. One major reason is that a shift in emphasis to the conditions of retrieval might resolve a problem of interpretation that arises within the framework of a theory of multiple-attribute encoding. If each stimulus is, indeed, encoded at the time of perception along many different psychological dimensions, then a change in only one of these, unless it is a truly salient one, would not be expected to produce a major reduction in PI. Given continuous encoding of a large and rich variety of features, there would normally be considerable overlap among the representations of successive items, so that no one kind of change in the materials should have a powerful effect on retention.

We can only speculate about the ways in which a shift in a single attribute might provide a uniquely effective retrieval cue. Suppose that on the test for the most recent item several alternative responses are elicited by the contextual stimuli and whatever other retrieval cues are immediately available. Discrimination of relative recency is not perfect or there would be little PI on a test for short-term memory, but we know that the discrimination is better than chance. Now assume that in scanning the alternatives the S discovers (and the discovery need not be a conscious process) that there is a correlation between apparent oldness and the presence of a critical feature. That is, the item or items that are judged as old with some confidence have some feature in common with all other units except one. Consequently, the odd item that does not share this feature is likely to be the most recent and, hence, the correct one.

We are not questioning the assumption that words are encoded, possibly on a number of different dimensions, during the original presentation. That is, no implication is intended that words are stored as unanalyzed units and that the critical discriminations invariably occur at the time of retrieval. The point at issue is whether release from PI always forces the conclusion that the manipulated attribute was encoded during presentation. It is true that differentiation at the time of retrieval should be most readily accomplished on the basis of the inherent characteristics of items, e.g., their semantic features. Yet, changes in such physical properties of the stimuli as slide area and figure-ground arrangement have been found to produce more release from PI than changes in "marking-syntactic" features (Wickens, 1972).[1] The hypothetical process of differentiation at retrieval cannot be plausibly applied to incidental physical characteristics, and in such cases encoding during presentation can be inferred with confidence. A sudden shift in physical characteristics is likely to be perceptually salient and, hence, be noticed and encoded. That still leaves open the possibility that differentiation at retrieval occurs for various other characteristics of the input items. As Underwood (1972) has recently pointed out, the range of conditions under which release from PI is obtained may have led to an overestimation of the number of attributes normally encoded during the presentation of a single word. The exploration of alternative mechanisms of release may help to throw light on this question.

Our speculations about the temporal locus of differentiation are reminiscent of the time-honored argument about the mechanism of generalization–whether it represents the spread of habit strength or is a testing phenomenon. For some dimensions at least, it should be possible to decide between the alternative explanations experimentally. For example, can a dimension such as grammatical class, which under standard conditions fails to produce release from PI, be rendered effective by appropriate instructions calling attention to it just prior to the test of retention? If so, then prior encoding of this feature would be shown not to be essential. However that may be, our stress on the possible importance of discriminative processes initiated at the time of recall is in keeping with the general thrust of the present argument–that we focus our attention as sharply as possible on the separation between the input and output phases of the total mnemonic episode–encoding on the one hand and decoding and retrieval on the other.

We have considered three major classes of coding operations: transformational, selective, and multiple-attribute coding. What is common to these operations has been well stated in an important paper by Lawrence (1963) a number of years ago: "It is . . . assumed that all stimulus-response correlations are mediated; i.e., the correlation between the response and the proximal stimulus is never direct but always depends upon an intervening event. The conceptual device used to describe this intervening, or mediating, event is similar to the idea of coding [pp. 187f.]." Lawrence was concerned with the stimulus in the narrow sense, i.e., a cue to which responses are attached. In the analysis of learning and memory, we are concerned with the coding of both cues and of to be remembered items and, hence, with decoding as well as encoding. As we have tried to show for each of the major classes of coding operations, an important analytic problem before us is to increase the precision of our inferences about the encoding and decoding components of the hypothesized intervening process. We have been disposed to stress encoding at the expense of decoding, both in assessing the potency of symbolic transformations and in drawing inferences from the discriminative achievements of the learner on tests of retention. The processing of inputs may be less elaborate and complex than we are led to suppose by the S's achievements, and many of the subtle discriminations may reflect decision processes at the time of test. By the same token, the inherent limitations of coding systems are brought out into the open when we test the stability and endurance of the decoding process.

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NOTE

1. We are grateful to the Consulting Editor for calling this point to our attention.

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