Reports

Repetition and Paired Associates Learning

Abstract. Recent experiments have suggested that paired-associate items which are practiced and missed are equivalent to new items on future trials, supporting an all-or-none interpretation of the formation of associative bonds. Experiments reported here show that if correct items are discarded after each trial the probability of getting a missed item correct on the next trial is higher than the probability of getting a new item correct.

The rate of learning lists of paired-associate items by the traditional method in which each pair is presented on every trial is virtually identical to the rate of learning lists when those pairs missed on each trial are replaced by randomly selected, previously unpracticed pairs (*1*; see also *2*). Similar results have been obtained under differing conditions (*3*). From this finding, Rock concluded that associations are formed either completely or not at all in one trial and says: "It is as if pairs which are not retained by the time of the test leave nothing in the nervous system of any value for future use" (*1*, p. 192). In other words, his interpretation is that if a pair is practiced and then is missed on the following test, it is neither more nor less likely to be gotten correct on the next trial than is a new pair.

Estes (*4*) came to the same conclusion. In part, his conclusion is based upon his finding that paired-associate items which are practiced and missed on the first trial, following the conventional procedure, have approximately the same probability of being gotten correct on the second trial as do all the items on trial one. In this sense, again, items which are practiced and missed are equivalent to new items.

In the kinds of experiments mentioned above, the previously missed pairs were presented and tested along with pairs which had been gotten correct on earlier trials. It is pertinent to ask whether performance on the previously missed pairs might be influenced by the context of "gotten-correct" pairs in such a way as to mask the effect of an increment to their associative strength which was gained during the previous, unsuccessful practice. A result obtained by Dotson (*5*) strongly suggests that such an influence may exist. Dotson found that a greater number of previously missed items are gotten correct when they are presented in a list containing new items in place of previously correct items than when they are presented along with the previously correct items. This occurs even though the number of unlearned items is less in the latter case.

A simple test of this notion involves repeating the basic experiment designed by Rock but discarding the correct items after each trial instead of retaining them. Two experimental conditions are required. In one, condition A, the items presented on each trial are those missed by the subject on the preceding trial, while in the other, condition B, on each trial the subject is given new items equal in number to those missed on the previous trial. This paper reports two experiments, each of which applied, in turn, condition A and condition B. The two experiments differ in that 15 items comprised the starting list in experiment 1 while 12 were used in experiment 2. Also, in experiment 2 the subjects were required to pronounce presented pairs, while in the first experiment no response was required.

Items consisted of stimulus-response pairs of consonant-vowel-consonant nonsense syllables which were homogeneous in association value. A pool of 130 items was prepared on separate cards and a random set was selected for each subject at the beginning of his session. Each subject participated in only one experimental condition of one experiment. A total of 70 subjects were run, 15 per condition in experiment 1 and 20 per condition in experiment 2.

The data for both experiments are displayed graphically in Fig. 1, in which the cumulative percentage of correct items is plotted as a function of trials. In both experiments the percentage of correct items increases more rapidly for condition A, in which missed items were repeated on each following trial, than for condition B.

The mean number of trials required to complete the task in experiment 1 was 8.5 for condition A and 11.4 for condition B. A t-test of the significance of the difference between these means yielded a t of 1.83, which has an associated probability between .10 and .05. The results of experiment 2 are more conclusive, the mean for condition A being 8.2 trials and that for condition B being 12.4 trials. In this case t is 3.3 which is significant at better than the .01 level of confidence.

As soon as each subject in experiment 2 had completed his main task by reducing the length of his list to zero, the 12 items which he had gotten correct were shuffled and he was given a final test trial. For the subjects in both conditions each of these items had been responded to correctly once. The mean number of correct responses on this

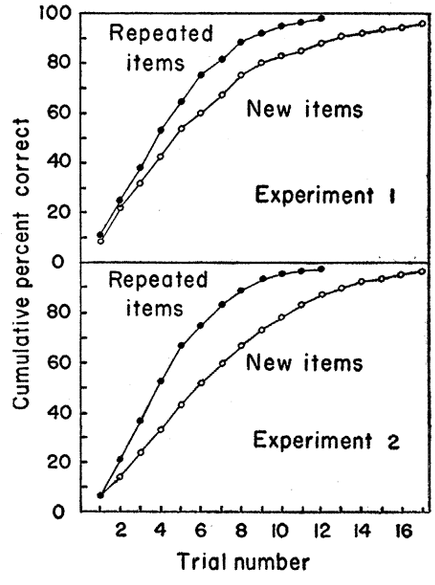

Fig. 1. Percentage of items correct as a function of trials for experiments 1 and 2.

Instructions for preparing reports. Begin the report with an abstract of from 45 to 55 words. The abstract should *not* repeat phrases employed in the title. It should work with the title to give the reader a summary of the results presented in the report proper.

Type manuscripts double-spaced and submit one ribbon copy and one carbon copy.

Limit the report proper to the equivalent of 1200 words. This space includes that occupied by illustrative material as well as by the references and notes.

Limit illustrative material to *one* 2-column figure (that is, a figure whose width equals two columns of text) or to *one* 2-column table or to *two* 1-column illustrations, which may consist of two figures or two tables or one of each.

For further details see "Suggestions to contributors" [*Science* **125**, 16 (1957)].

final test trial was 3.95 for condition A and 2.20 for condition B. The difference is significant statistically, t being 2.8.

These results suggest that the very general conclusions formulated by Rock (*1*) are unwarranted. The logical design of the present experiments differs from Rock's only in that items are discarded as soon as they are responded to correctly. Under this condition the probability of responding correctly to a previously missed item is clearly greater than the probability of getting an entirely new item correct. It appears, from these data and from Dotson's (*5*), that the difficulty of a previously missed item is greater in the presence of previously correct items than in the presence of unpracticed items or no other items. Therefore, until the necessary experiments have been done to control differential interactions among items, conclusions about the central theoretical problem of the role of repetition in the formation of associative bonds cannot be made with confidence (*6*).

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References and Notes

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2. ———, *Sci. American* **199**, 2 (Aug. 1958).
3. ———, and W. Heimer, *Am. J. Psychol.* **72**, 1 (195➡ L. L. Clark, T. G. Lansford, K. M. Dallenbach, *ibid.* **73**, 1 (1960). I have repeated the basic experiment also and obtained results similar to those reported in these references.
4. W. K. Estes, *Psychol. Rev.* **67**, 4 (1960).
5. J. M. Dotson, unpublished M.A. thesis, University of Cincinnati (1961).
6. The data presented in this paper were gathered by Charles Reinstatler. Experiment 2 was supported in part by contract AF 33(616)-7674 between the University of Cincinnati and the Wright Air Development Division, Air Research and Development Command, U.S. Air Force.

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Recommendations for the Nomenclature of Hemoglobins

There is now general agreement on the naming of the peptide chains of the major components of normal adult and fetal hemoglobins as the α, β, and γ chains; for example, adult hemoglobin is written as $\alpha_2^A\beta_2^A$ and fetal hemoglobin as $\alpha_2^A\gamma_2^F$. The superscripts A and F refer to the fact that the particular chain is the one found in the human adult and fetal hemoglobins. It is recommended that this practice be continued and that the symbols α, β, and γ, without superscripts, be reserved for those occasions when reference is being made to, for example, α chains in general.

Information concerning the structure of the chains of hemoglobin A_2 is now sufficient to indicate that one of the chains is identical with the α^A chain, whereas the second differs in a number of residues from the three foregoing chains. In addition, there is evidence (see, for example, *1*) to indicate that the genetic control of this unique chain is independent of the genes of the α, β, and γ chains. It is therefore recommended that this chain be designated as δ^{A_2}; Hb A_2 is then written as $\alpha_2^A\delta_2^{A_2}$. Again, one could refer simply to δ chains in the general case.

The simplest method of naming the tryptic peptides of a chain is to number them in the order in which they occur in the chain, beginning with the NH_2-terminus. The symbol for the chain is included as a part of the designation. The letters Tp are included to identify that these are the peptides obtainable by tryptic digestion. For example, the third tryptic peptide of the α chain would be αTpIII in this system. Where a lysyl bond is not attacked under the conditions used, the symbol for the resultant "dipeptide" or "double peptide" would contain the numbers appropriate to both tryptic peptides, for example αTpI,II. From the published structure of the α and β chains (*2*) and from the amino acid composition, it is evident that the α chain will contain the tryptic peptides αTpI to αTpXIV and the β chain the tryptic peptides βTpI and βTpXV. It so happens that the tryptic "peptides" αTpVIII and βTpVIII are lysine. In addition, the present methods of tryptic cleavage do not break the bond separating the expected tryptic peptides αTpXII and αTpXIII, nor the bond between the expected peptides βTpX and βTpXI. In view of the possibility that these bonds might be split in some experiments at a later date, it is felt that the numbering system should correspond with the theoretical number of tryptic peptides.

When the complete sequence of the chains is determined beyond question and is published, then a more specific designation involving residue numbers should be adopted. Thus, βTpI can be designated as βTp1–8.

An ideal nomenclature system for the abnormal hemoglobins would provide for adequate designation of the chemical structure at each stage of the investigation. The following system is an attempt to meet this requirement.

When only the chain in which the abnormality resides is known, then the hemoglobin may be written as $\alpha_2^A\beta_2^S$, or $\alpha_2^A\beta_2^{D\text{Punjab}}$. When the abnormality has been located in a particular tryptic peptide, as by fingerprinting, then the designation should be, for example, $\alpha_2^A\beta_2^{TpI}$. When the amino acid composition of the tryptic peptide indicates a particular amino acid substitution, then this will be indicated as $\alpha_2^A\beta_2^{TpI(Glu\rightarrow Val)}$ for Hb S. Finally, when the amino acid interchange has been located at a particular residue position in the chain, the fully descriptive formula, as in the case of Hb S, would be in the form: $\alpha_2^A\beta_2^{6Val}$.

Presumably, for use in formulas describing experiments such as reassociation, it will be necessary to define in a given paper a one-letter designation for a particular hemoglobin. For example, the formula $\alpha_2^I\beta_2^S$ could be used, provided that wherever possible the individual hemoglobins have been defined, as, for example, Hb I as $\alpha_2^{16Asp}\beta_2^A$ and Hb S as $\alpha_2^A\beta_2^{6Val}$.

It is strongly urged that no further letters be assigned to abnormal hemoglobins. Newly discovered hemoglobins, prior to their chemical identification, should be known by the letter designation of the previously described hemoglobin whose electrophoretic mobility they most nearly resemble. To the letter should be attached a subscript indicating the geographic origin of the new hemoglobin.

Proposals similar to the above originated during the Hemoglobin Structure Workshop held in Boston, 14–16 December 1960. These proposals have been modified at the suggestion of other workers in the protein structure field. In their present form they represent a compromise between the views of these two groups (*3*).

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3. These recommendations also appeared in *J. Biol. Chem.* **236**, 2155 (1961).

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