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HYPOTHESIS BEHAVIOR BY HUMANS DURING DISCRIMINATION LEARNING[1]

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Adult human Ss received 4-dimensional discrimination problems with intermittent reinforcement, i.e., E said "right" or "wrong" only after every 5th response. The S's hypothesis (H) was inferred from his pattern of choices during the nonreinforced trials. There were 2 major effects of right and wrong upon S's Hs: (a) Right produced retention and wrong produced rejection of the H manifested. (b) The size of the H set from which S sampled was reduced with each successive outcome. Right was more effective in this respect than wrong. An information-processing theory is presented to account for these results.

Data have accumulated rapidly (e.g., Bower & Trabasso, 1963; Kendler & Kendler, 1962; Levine, Leitenberg, & Richter, 1964) to indicate that choice responses made by the adult human during discrimination learning are organized by *S*'s hypotheses (*H*s). Levine (1963) has further demonstrated that when the stimuli are multidimensional, i.e., differing in size, shape, etc. (see Fig. 1 for stimuli which vary in four dimensions), the particular *H* held by *S* may be inferred if outcomes are withheld for a few trials. The mechanics of such inference will be described below. The necessary assumptions are:

1. At the outset of a trial *S* selects an *H* from some set. This *H* is a "state," and may be thought of as a prediction by *S*. Thus, *S* may predict that the larger stimulus is correct (regardless of its shape, color, etc.) or that the stimulus on the left side is always correct, etc.

2. The set of *H*s from which *S* samples is finite and is known exhaustively to *E*. In practice, it will be assumed specifically that each *H* is a prediction that one level of one of the dimensions is consistently correct. For the stimuli shown at the center of Fig. 1 there are, then, only the eight *H*s indicated by the columns. The justification for this specific assumption will be presented below.

3. If no outcome is given following *S*'s choice he keeps the same *H* for the next trial. During consecutive blank (i.e., no outcome) trials only one *H* will be maintained.

4. The *S* makes his choices in such a way that, if his *H* were in fact correct, he would always be right. For example, if an *S* predicts that one of the forms is correct he will choose that form, regardless of its size, color, or location, on every consecutive blank trial.

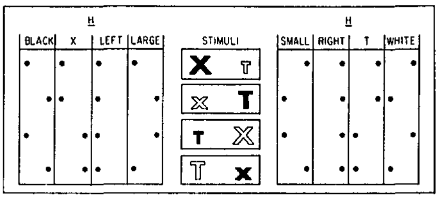

FIG. 1. Eight patterns of choices corresponding to each of the eight *H*s when the four stimulus pairs are presented consecutively without outcomes.

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Assumption 4 implies that over consecutive blank trials the pattern of responses will be perfectly correlated with the aspect of the stimulus corresponding to the *H*. The stimuli presented from trial to trial may be so constructed that the response pattern yielded by each *H* is unique. The four stimulus pairs at the center of Fig. 1 are so constructed. Suppose these stimuli are presented as four consecutive blank trials. The response patterns corresponding to the eight possible *H*s are shown in the columns of Fig. 1. If, e.g., *S* predicts that black is the basis for solution his responses will show the simple position-alternation pattern indicated in the column marked "black" (since the black stimulus also follows simple position alternation).

The response patterns described in Fig. 1 show either two or four responses to one side. According to the assumptions, no 3–1 combinations should occur. To treat the possible appearance of the eight 3–1 patterns the following will be assumed:

5. On any trial *S* has a certain constant probability of choosing incorrectly. For example, an *S* who predicts that the left side is the basis for solution may, "by accident," choose the right side on some trial. One such incorrect choice in a set of four blank trials will produce a 3–1 pattern. In practice, this probability is very small (of the order of .02) and this assumption may, with little distortion to the results, be ignored. It is necessary, however, for the complete treatment of all the data.

Unlike other hypothesis models (Bower & Trabasso, 1963; Restle, 1962) the present assumptions include nothing about the effects of outcomes ("right" and "wrong"). These effects were studied here empirically.

Method

Subjects.—Eighty volunteers from the introductory psychology courses served as *S*s. One other *S* was discarded because of failure to solve any of the preliminary problems.

Materials and procedure.—The experiment consisted of a series of four-dimensional discrimination problems with stimuli of the sort illustrated in Fig. 1. The stimuli were drawn in color 1½ in. apart on 3 × 5 in. cards. The large letter was 1 in. in height; the small letter was ½ in. A problem was composed of a set of stimulus cards all containing the same two letters and two colors. Different problems used different pairs of letters and of colors.

In order to meet Assumption 2, that *S* chooses *only the eight simple Hs* described in Fig. 1, a preliminary instruction-and-problem phase preceded the experimental series of problems.

The *S* was seated across from *E*, was shown a sample stimulus card, and received the following instructions:

> In this experiment you will be presented with several easy problems. Each problem consists of a series of cards like this one. Each card will always contain two letters, and the letters will be of two colors. You will also notice that the letters are of two different sizes, and, of course, that one letter is on the left and one is on the right. Every card will be like this one except that the letters and the colors will be different. One of these two stimuli is "correct" in the sense that I've marked it here on my sheet. For each card I want you to tell me which of these two you think is correct and I'll tell you whether you're right or wrong. Then you go on to the next card, again you make a choice, and again I'll tell you whether you are right or wrong. In this way you can learn the basis for my saying "right" or "wrong." You can figure out whether it's because of the color, the letter, the size, or the position. The object for you is to figure this out as fast as possible so that you can choose correctly as often as possible.

The first problem consisted of 10 trials in which the color (green) was the basis for solution. The *S* received the deck face up. He responded to the top card, the appropriate outcome was given, and he then turned the card face down out of the way. This procedure was followed for all 10 trials. The *E* then asked *S* what the solution was.

The *S* who said "green" received the instructions for the next problem. An *S* who verbalized any *H* other than the eight simple ones was told, "The problem is not as complicated as that. One of the letters, colors, sizes, or positions is consistently correct throughout." The nonsolving *S* then redid that problem. If he did not solve it the second time he was told simply that the green letter was always the correct one.

The *S* was then instructed for the next three preliminary problems with this statement:

> In the last problem I said right or wrong after each card. For the next problem I will not always tell you whether you are right or wrong. After some cards, I'll say nothing. Don't let that disturb you. Try to be right all the time.

The *E* also reiterated that one of the simple solutions would be consistently correct. The three problems were then presented. These had sets of blank trials interspersed among the outcome trials. For all *S*s large size, the letter O, and the left position were respectively correct.

The experimental problems.—Each *S* then received 16 16-trial problems in which an outcome was always presented at the first, sixth, and eleventh trial. The stimuli for each problem were arranged with special restrictions. In a four-dimensional simultaneous-discrimination problem there are exactly eight different stimulus pairs which may be presented. These may be grouped into two different sets of four pairs, the dimensions being perfectly counterbalanced within each set. Figure 1 shows such a set in which each level of every dimension appears exactly twice with each level of every other dimension. Such a counterbalanced set of stimulus pairs is described as *internally orthogonal.* The remaining set of four stimulus pairs may be produced by simply interchanging the positions of each stimulus. For the top pair, e.g., the small white T would be placed on the left and the large black X on the right. This new set of four pairs will also be internally orthogonal. Referring to one set as Set A and the interchanged set as Set B, Set A was used for all blank trials. That is, Trials 2–5 were composed of the four Set A stimuli, as were Trials 7–10, and Trials 12–15. The trial-to-trial order was different for each of the three sets. Set B was used for the remaining (outcome) trials. This arrangement had two virtues: The *S* never encountered a specific stimulus pair to which an outcome had previously been given, and the outcome cards, as well as the blank-trial sets, had the property of internal orthogonality.

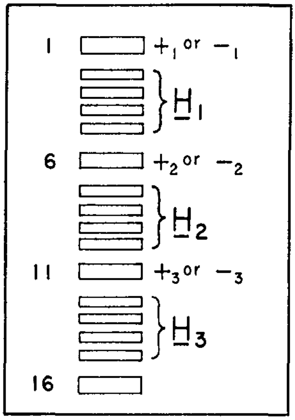

FIG. 2. A schematic of the 16-trial problem showing the trials on which *E* said right or wrong ($+_i$ or $-_i$) and the blank trials from which the hypotheses (H_i) were inferred.

The *E* said "right" or "wrong" on Trials 1, 6, and 11 according to a prearranged schedule and regardless of *S*'s response. Each of the eight possible right-wrong sequences which could occur on three trials was assigned to each of the first eight problems and again to each of the last eight problems. The sequences were assigned to different problems for each eight *S*s, forming 8 × 8 Latin squares. Trial 16, the last trial of each problem, was treated separately: The *S* was told right on half the problems; nothing was said on the other half. Figure 2 shows a summary of the procedure.

Results and Discussion

The blank-trials data.—The data from the sets of four blank trials fall into two classes: the eight patterns conforming to the specified *H*s, (cf. Fig. 1) and the eight patterns not conforming (the 3–1 patterns). The *H* patterns appear on 92.4% (3,550 out of 3,840) of the four trial sets. Thus, *S*'s behavior is strongly systematic, in the form predicated by the first four assumptions. The fifth assumption stipulates that *S* has a small probability of making an error on any one trial. This value, calculated from the result that 7.6% of the patterns are 3–1 patterns, is .02. Further verification of the assumptions comes from the response on each outcome trial. Each set of blank trials permits inference of the H which, in turn, permits E to predict the next response. For example, if the four-trial pattern indicates that S is hypothesizing that the large stimulus is correct, it is necessary only to see on which side the large stimulus is appearing in the next trial to predict the next response. This prediction was made for all the interpretable patterns (i.e., the non-3–1 patterns) and was correct 97.5% (3,461 out of 3,550) of the trials. Given that 2% of the responses will be erroneous on any one trial, this set of predictions is essentially perfect.

The effects of outcomes.—The consistency of these data attests to the plausibility of a general H model. Further confirmation can come from consideration of commonly presumed properties of H testing. Connotations of the concept of H testing are that an H when confirmed is retained for further testing, and when disconfirmed is rejected for another. Indeed, these connotations are incorporated as assumptions in Restle's (1962) theory. He assumes that when S is told right he keeps the H sampled; when he is told wrong he returns the H to the set and takes a new random sample. These presumed effects of right and wrong may be directly determined by comparing the Hs before and after each outcome. These effects are shown in Fig. 3. The top curve describes the probability that two successive Hs (the first and second or the second and third) are the same when E said right after the response on the intervening outcome trial.[2] The overall proportion, based on 1112 cases, is .95. The bottom curve in Fig. 3 shows the analogous set of probabilities when a wrong was said. The overall proportion, based on 1,027 cases, is .02. It is evident that the single outcome pushes S to one of two extremes. The H is conditioned and extinguished, so to speak, with almost perfect efficiency.

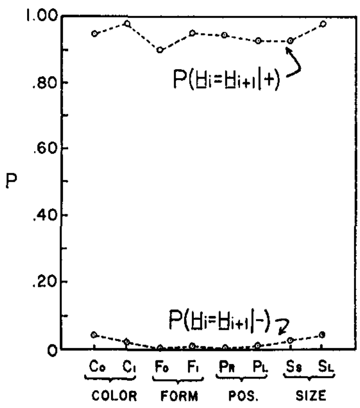

FIG. 3. The probability that an H is repeated after E says right (top curve) and wrong (bottom curve), when H_i is C_0, C_1, . . ., S_L.

This result shows that Restle's assumption, that the effect of right is to cause S to keep his H, is reasonable for the present situation. His assumption about the effect of wrong, however, is not. He assumes that S resamples with replacement, which implies that the mean of the bottom curve in Fig. 3 should be .125. The mean, of course, is much lower than this, indicating that S seeks a new H without first replacing the old. Further substantiating a nonreplacement

[2] The curve was computed only from the interpretable response patterns. The precise probability estimated is: $P(H_i = H_{i+1})$ *given* a right on the intervening outcome trial, the response pattern on Set i or $i+1$ is not 3–1, and the response on the intervening outcome trial is consistent with (i.e., predictable from) H_i. Except that a wrong is given on the intervening outcome trial, the bottom curve in Fig. 2 is based on the same conditions.

assumption is the result that the rejection of an incorrect H lasts beyond one outcome trial. If wrong is said after both the first and second H, H_3 not only will be different from H_2 but will also tend to be different from H_1: $P(H_3 = H_1 \mid {}_{-2-3}) = .04$.

The foregoing has established that the H is a viable concept. Hypotheses are detectable from choices and their responsiveness to outcomes is measurable. It is possible now to go beyond this description to the delineation of more complex processes. In order to appreciate the significance of the phrase "more complex processes" it is valuable to reconsider Restle's theory. In it whenever S resamples, i.e., following a wrong, he does so after replacing his hypothesis in the H set. After a wrong, S never analyzes the previous information received, and does not, therefore, reject Hs from consideration. In effect, the size of the set from which S resamples is constant and is the same as it was at the outset of the experiment.

The simplicity of this view provides a useful background against which to evaluate the ability of S to analyze information. As an illustration of such information analysis consider the selection of H_1 after E says wrong on Trial 1. By the nature of the stimuli four Hs are characterized as wrong and four by implication are right. The probability that H_1 is one of the four Hs designated as correct is found to be .873. If this probability were 1.0, the number of Hs from which S resampled, $N(H_1)$, would be a maximum of four; if it were .80, $N(H_1)$ would be a maximum of five (four correct Hs out of five). These results follow from the assumption that the probability of choosing one of the four Hs defined as correct after Trial 1 is equal to four divided by $N(H_1)$. Symbolically, $P(H_1+) = 4/N(H_1)$. Since $P(H_1+) = .873$, $N(H_1) = 4.6$. This value should, of course, be interpreted as the mean size of the functional H set when S resampled, i.e., after E said wrong, on Trial 1. It is natural to inquire next whether S utilizes information received over several previous trials when subsequently resampling. One expects, of course, that with succeeding outcome trials S can learn that more and more Hs are incorrect and, correspondingly, can reduce the size of the functional H set. When he resamples after a wrong, the later the wrong appears the smaller should $N(H_i)$ be. The equation just given generalizes quite naturally to $P(H_i+) = N(H_i+) / N(H_i)$, where $N(H_i+)$ is defined as the number of logically correct Hs after the ith outcome. With internally orthogonal stimuli $N(H_i+)$ is four after one outcome, two after two outcomes, and one after three outcomes. $P(H_i+)$ is taken from the obtained proportion of H_i which are logically correct.

The possible systematic reduction in $N(H_i)$ is not unlike the process described by Bruner, Goodnow, and Austin (1956) as focusing. In their experiments Ss worked on similar problems but were instructed to state (by writing symbols) their Hs at each trial. The focusing Ss wrote in such a way as to retain at each successive trial only those Hs indicated as correct on all the preceding trials. As Hs were shown to be incorrect they were permanently rejected. In the present experiment, because the stimuli are internally orthogonal, each outcome would permit a perfect focuser to reduce $N(H_i)$ by half. The task, then, of determining $N(H_i)$ after each wrong is essentially the task of determining the extent to which this focusing process occurs during the first three outcome trials of the present experiment.

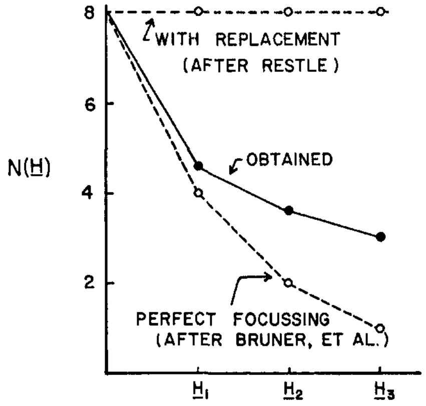

FIG. 4. The size of the set, $N(H_i)$, from which S is sampling H_i immediately following a wrong, i.e., after $-_i$—see text for the determination of $N(H_i)$.

The value of $N(H_i)$ following a wrong at the ith trial is presented in Fig. 4. This figure contrasts the obtained curve with that to be obtained if no information from outcome trials were utilized in resampling (the top curve) and that to be obtained if all Ss were perfect information retainers and analyzers (the bottom curve). A steady reduction in $N(H_i)$ is seen, although Ss are by no means perfect focusers. Each point is based on almost 600 observations, and the decrease is highly reliable. Thus, S is not only rejecting the H manifested after a wrong (cf. Fig. 3) but is rejecting other Hs not manifested.

The last finding evaluates the degree to which S retains and analyzes earlier information when he resamples, i.e., when E has just said wrong. The effects of a right will now be considered in greater detail. Figure 3 compellingly suggested that when E said right S simply retained the same H he had manifested. There is evidence, however, that S is doing more than this, that he is attempting to store the information of the trial and to collate it with that of previous outcome trials. He is, in a word, focusing. Figure 5 shows the probability of selecting H_3 correctly, after a wrong on the third outcome trial, as a function of the number of rights announced during the first two outcome trials. It is clear there that the more often E previously said right the more likely S is to select the only H consistent with all the preceding information. Since the probability of choosing the correct H is one (the number of logically correct Hs after three outcome trials) out of $N(H_3)$, $N(H_3)$ is the reciprocal of the obtained probabilities. For convenience this is scaled at the right of Fig. 5. $N(H_3)$ decreases from four after zero right to a mean of 2.25 after two right. The S, it is clear, not only uses the outcomes to reject several incorrect Hs, but he rejects more when he has been told right than when he has been told wrong. This effect has also been obtained by Richter (1965) in an experiment without blank trials. He found that the more the S received information by being told right rather than wrong, the more likely he was to be correct on a test trial. These results contradict an important implication in recent mathematical models. Bower and Trabasso (1963) and Estes (1964) have noted that their models imply that learning occurs only on errors. This statement

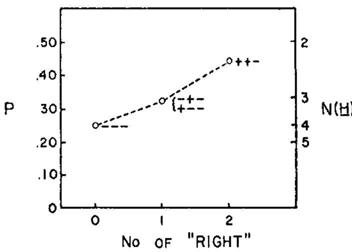

FIG. 5. The probability that H_3 is the correct H following wrong on Trial 3 and with 0, 1, or 2 rights on the first two outcome trials.

has reference to the process portrayed in Fig. 3, in which *S* resamples *H*s, and can go from the incorrect to the correct *H*, only when wrong. Figure 5 shows, however, that *S* not only is learning, in the sense of eliminating incorrect *H*s from the total set, when right, but that he learns more effectively when right than when wrong.

Outline of a theory.—It was assumed at the outset only that *S* samples *H*s and retains the *H* during blank trials. Clearly, other processes must be postulated to account for the effects of outcomes, particularly for the results that the size of the set was smaller after each successive outcome (cf. Fig. 4) and that the reduction was performed more efficiently following a right than following a wrong (cf. Fig. 5). These results, data from other experiments, and postmortems with *S*s suggest the nature of these processes.

1. The *S* codes the stimuli paired with an outcome. The coding process is probably of the sort proposed by Haber (1964), and by Glanzer and Clark (1964). Thus, *S* on being presented with a pair of stimuli (e.g., a large black X on the left and a small white T on the right), may silently rehearse "large black X on the left."

2. The *S* codes aspects of only the stimulus chosen. More specifically, he codes the intersect of the functional *H* set and the stimulus chosen. Consider these examples: (*a*) Example 1: On the first trial of a problem the pair of stimuli are a large black X on the left and small white T on the right. If the functional set initially consists in all eight *H*s, *S* choosing the left stimulus will memorize, i.e., code, "large black X on the left"; *S* choosing the right stimulus will code "small white T on the right." (*b*) Example 2: Suppose the stimuli just described are presented on the third outcome trial and *S*, from the previous two outcome trials, has eliminated everything but small, black, and X. He would code the intersect of this set with the stimulus chosen: Upon choosing the left stimulus he would code "black X"; upon choosing the right stimulus he would code "small."

3. Outcomes produce their effects upon the coded material. (*a*) If E says "right" *S* now stores the material just coded as the new functional *H* set, i.e., as the total set of correct *H*s. This automatically eliminates without further effort the incorrect *H*s. In Example 1, above, *S* who chose the left stimulus and was then told right might simply continue to rehearse "large black X on the left." (*b*) If *E* says wrong *S* must recode. He does this by eliminating the just-coded material from the functional *H* set, (or to put it another way, he finds the complement of the just-coded material in the *H* set held). Consider again Example 1. After a wrong on Trial 1, *S* must perform what the reader performs when told "large-black-X-on-the-left is wrong. What is right?" He must find the other levels.

A wrong, with the consequent need for recoding, produces three disadvantages relative to the effects of right. The recoding requires time, the translation may be incomplete, and the material first coded may not be completely erased. Following a wrong, therefore, the new functional *H* set will be more likely to have a larger proportion of incorrect *H*s than following a right. This, of course, is precisely what was demonstrated in Fig. 5. One would expect also that too short an intertrial interval, i.e., between the wrong and the next stimulus, would cut down the recoding time and would, therefore, impair learning. This result, although in the context of a four-response, successive-discrimination experiment, has been obtained several times by Bourne and Bunderson (1963) and Bourne, Guy, Dodd, and Justesen (1965).

In conclusion, it is proposed that a theory of information processing is needed to account for the present results. The presumed processes are: (*a*) the *S* codes the stimuli followed by an outcome; (*b*) he codes only the intersect of the stimulus chosen and the *H* set held; (*c*) if told right *S* takes the material just coded as the new *H* set from which to sample; if told wrong he tries to recode, i.e., tries to select for rehearsal and storage the complement of the just-coded material.

REFERENCES

Bourne, L. E., Jr., & Bunderson, C. V. Effects of delay of informative feedback and length of postfeedback interval on concept identification. *J. exp. Psychol.*, 1963, **65**, 1–5.

Bourne, L. E., Jr., Guy, D. E., Dodd, D. H., & Justesen, D. R. Concept identification: The effects of varying length and informational components of the intertrial interval. *J. exp. Psychol.*, 1965, **69**, 624–629.

Bower, G., & Trabasso, T. Concept identification. In R. C. Atkinson (Ed.), *Studies in mathematical psychology.* Stanford: Stanford Univer. Press, 1963. Pp. 32–96.

Bruner, J. S., Goodnow, J. J., & Austin, G. A. *A study of thinking.* New York: Wiley, 1956.

Estes, W. K. Probability learning. In A. W. Melton (Ed.), *Categories of human learning.* New York: Academic Press, 1964. Pp. 89–128.

Glanzer, M., & Clark, W. H. The verbal loop hypothesis: Conventional figures. *Amer. J. Psychol.*, 1964, **77**, 621–626.

Haber, R. N. Effects of coding strategy on perceptual memory. *J. exp. Psychol.*, 1964, **68**, 357–362.

Kendler, H. H., & Kendler, T. S. Vertical and horizontal processes in problem solving. *Psychol. Rev.*, 1962, **69**, 1–16.

Levine, M. Mediating processes in humans at the outset of discrimination learning. *Psychol. Rev.*, 1963, **70**, 254–276.

Levine, M., Leitenberg, H., & Richter, M. The blank trials law: The equivalence of positive reinforcement and nonreinforcement. *Psychol. Rev.*, 1964, **71**, 94–103.

Restle, F. The selection of strategies in cue learning. *Psychol. Rev.*, 1962, **69**, 329–343.

Richter, M. Memory, choice, and stimulus sequence in human discrimination learning. Unpublished doctoral dissertation, Indiana University, 1965.

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