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REVERSALS PRIOR TO SOLUTION IN CONCEPT IDENTIFICATION[1]

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These studies investigated the effects of reversal and nonreversal shifts before solution upon performance in a later concept identification task. In 2 experiments, a reversal or a nonreversal shift after an error on a critical trial had no interfering effect upon subsequent learning. The reversal and nonreversal groups made about the same number of errors and required as many trials to learn as did controls who were not shifted. In a 3rd experiment, 1 group of Ss received reversals on every alternate error, but still made the same number of informed errors as did controls who learned with no shifts. These results support the hypothesis that learning is insightful or an all-or-nothing event in simple concept identification.

In the typical two-category concept identification experiment, *S* is shown a series of complex patterns which vary in several, binary attributes. As each pattern is presented, *S* attempts to anticipate the correct classification; following his response, he is informed of the correct response. The patterns are divided into two mutually exclusive classes, R_1 and R_2. If, say, color (red or blue) is the relevant attribute, then red objects might be assigned to Response Class R_1 and blue objects to Class R_2. We will refer to this rule as a particular S-R assignment.

In recent studies (Bower & Trabasso, 1963a; Trabasso, 1963) of this situation with college students, *S*s appeared to learn suddenly. Backward learning curves were horizontal at the chance level of 50% correct classifications over all trials until *S*'s last error before solving. The performance of an *S* might be characterized by saying that on any given trial he is either in the presolution state or in the solution state, with corresponding probabilities of .50 or 1.00 of correctly classifying the stimuli. According to this two-state description of the performance, learning would be identified as a discrete, one-trial transition from the initial, presolution state into the terminal, solution state.

The theories of cue-selection learning proposed by Restle (1962) and Bower and Trabasso (1963a) imply this two-state description of individual performance. These theories assume that *S* is selectively attending to or sampling cues from the stimulus display and that he is testing hypotheses regarding the relevance of these cues to the correct solution. If *S*'s response is correct, it is supposed that he continues to use the same hypothesis; if his response is incorrect, he resamples at random from the set of possible hypotheses. Assume further that the proportion of correct hypotheses is c whereas the remaining proportion $1 - c$ is irrelevant hypotheses which lead to correct and incorrect responses half the time. By these assumptions, the probability

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that *S* solves the problem after any given error is a fixed constant, *c*. This elementary theory has been used successfully in predicting quantitative details of several sets of data (Bower & Trabasso, 1963a).

The present studies investigate whether *S* acquires partial knowledge about the solution to the problem. The all-or-nothing theory supposes that he does not. Specifically, it says that when *S* makes an error, he has not yet learned anything of relevance regarding the correct concept. Three experiments were performed to provide tests of this assumption; the first two are described now.

Experiments I and II

Experiments I and II are identical in design; Exp. II was a replication of Exp. I with an easier problem and different stimulus materials. The design resembles that used in several animal experiments conducted on the continuity-noncontinuity issue in discrimination learning theory (e.g., Krechevsky, 1938; McCulloch & Pratt, 1934). Control *S*s in Group C learned a problem with the same S-R assignments throughout (Cue A-R_1, Cue B-R_2). Two other groups worked on different S-R assignments initially and then were transferred to the assignments of the control group. This transfer occurred immediately after *S* made an error following a critical trial of the initial series. Group R, a reversal group, was trained initially with the opposite assignments, A-R_2 and B-R_1. Group NR, a nonreversal-shift group, was trained initially with Cues A and B present but irrelevant while another set of cues was relevant (C-R_1, D-R_2).

The question of interest is whether the initial wrong-way training retards performance of *S*s in Groups R and NR who are shifted to the final, transfer problem before solving their initial problem. If *S*s partially learn responses to the initially relevant cues before the shift, then such partial learning should induce negative transfer on the final problem. However, if *S*'s error initiating the shift indicates that nothing of importance has yet been learned, then the performance on the final problem should be the same for the three groups, independent of the initial S-R assignments.

Method

Experimental design.—A schematic outline of the design is presented in Table 1. Only two of the several stimulus attributes are represented in the left columns of Table 1. The rows give the combinations of stimulus values in the patterns and the correct responses to each pattern are listed under each condition. The Control and Reversal groups had Cues A and B relevant but they had opposite response assignments during initial training (10 trials in Exp. I and 5 trials in

TABLE 1

Design for Exp. I and II

Patterns		Response Assignments			
		Initial Trials			Final Problem
Dimension 1	Dimension 2	Control	Reversal	Nonreversal	
A	C	R_1	R_2	R_1	R_1
A	D	R_1	R_2	R_2	R_1
B	C	R_2	R_1	R_1	R_2
B	D	R_2	R_1	R_2	R_2

Exp. II). The Nonreversal group had one of the other dimensions (Cues C and D) relevant during initial training.

The *S*s who made an error on Trial 10 in Exp. I or Trial 5 in Exp. II or soon thereafter were immediately shifted to the final problem listed in the right hand column of Table 1. We wished to compare on this final problem only those *S*s who had not yet learned their initial problem by Trial 10 (or 5 in Exp. II). Consequently, if an *S* in any group began a criterion run of 16 consecutive correct responses on or before the critical trial (10 or 5), he was not shifted but was, as a result, excluded from the critical comparison between those *S*s who did get put onto the final problem. According to the theory, these latter *S*s were equalized at the start of the final problem since each *S* made an error before the shift was effected.

Procedure.—The same instructions were read to all *S*s. The *S* was to classify a set of patterns into two classes. In Exp. I, the classificatory responses were MIB and CEJ; in Exp. II, the numerals 1 and 2. The *S* was told that the patterns could be classified by a simple principle.

Patterns were presented one at a time on a card holder. The *S* paced his verbal responses and *E* then stated the correct classification. The *S* was allowed 4 sec. to view the pattern after reinforcement. A different order was presented each *S* by shuffling the cards before the session. Cards were reshuffled at the end of every 64 trials if *S* had not yet reached the learning criterion of 16 successive correct responses.

Stimulus materials.—For Exp. I, patterns were constructed by sampling a single letter from each of four pairs of letters, (V or W), (F or G), (X or Y), (Q or R). Thus, VFYQ was a pattern, WVXR was not. The four letters were printed in a diamond shape on a 3 × 5 in. card. The letters appeared fixed in the order given above, but their locations at the four diamond corners rotated randomly from trial to trial. Location was an irrelevant cue. For Groups C and R, the letter pair (V, W) was relevant; the classification depended on which one of the letters was present on the card. One of the other letter pairs was selected randomly to be initially relevant for each *S* in Group NR, whereas (V, W) was irrelevant. The final problem was with (V, W) as the relevant cues with response assignments V-MIB and W-CEJ.

For Exp. II, the stimuli were geometric figures drawn in crayon pencil from templates on white 3 × 5 in. file cards. There were six binary dimensions: color (red or blue); size (large or small); shape (square or hexagon); number (three or four figures); position (figures arranged along right or left diagonal); and colored area within each figure (upper-right and lower-left or upper-left and lower-right quadrants). There was one relevant dimension and five irrelevant dimensions for each group. Color was relevant for Groups C and R. One of the other five dimensions was randomly selected and made relevant during initial training for each *S* in Group NR.

Subjects.—For Exp. I, the *S*s were 65 students in the introductory psychology course at Stanford University. Eleven *S*s began a criterion run on or before Trial 10; there were 4, 3, and 4 *S*s in Groups C, R, and NR, respectively. These *S*s do not enter into the comparison on the final problem since they were not transferred. Setting aside these *S*s, 18 *S*s (13 males and 5 females) remained in each group.

For Exp. II, the *S*s were 46 students in the introductory psychology course at Stanford University. Since the problem was easier, a larger proportion of *S*s was expected to solve within a few trials. Hence, fewer initial training trials (five) were used so that the majority of *S*s would not have to be set aside. Sixteen *S*s, 5 in Group C, 4 in Group R, and 7 in Group NR, began a criterion run on or before Trial 5. These *S*s were excluded from comparisons on the final problem. There remained 10 *S*s (6 males and 4 females) in each group for comparison on the final problem.

Results

In Exp. I, one *S* in Group C and one in Group NR failed to reach criterion within 140 trials on the final problem; all other *S*s solved within 140 trials. In Exp. II, all *S*s solved the final problem. Comparisons among groups on final-problem performance refer to trials following the error trial that initiated the shift to the final problem for a given *S*. Average errors and trial of last error are shown in Table 2 for the three conditions in both experiments.

The group differences on mean errors and mean trial of last error on the final problem were negligible in both experiments. The learning-parameter estimates (reciprocal of mean

TABLE 2

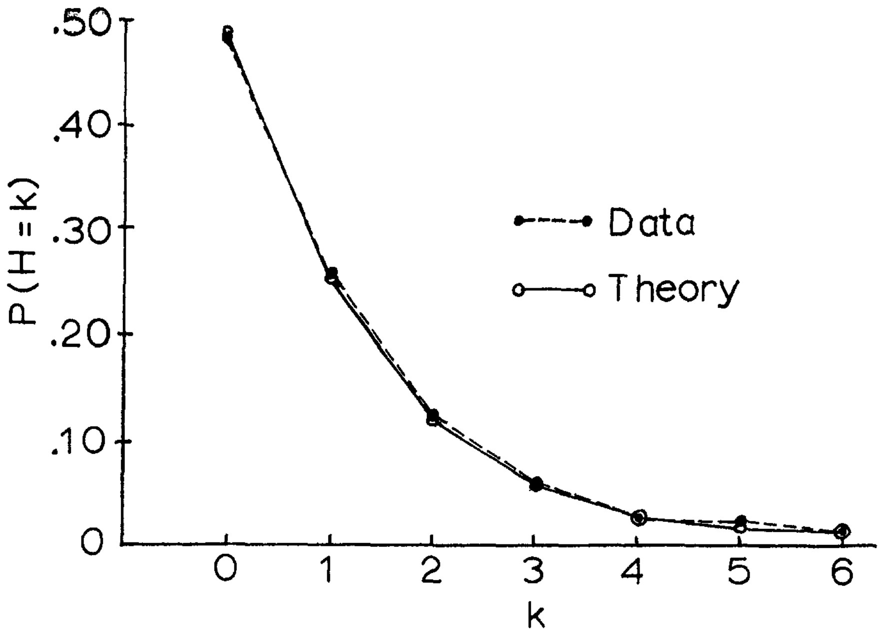
MEAN ERRORS AND TRIAL OF LAST ERROR, *SDs*, AND *c* ESTIMATES FOR THE FINAL PROBLEM

Group	N	c	Mean Errors	SD	Mean Trial of Last Error	SD
Exp. I						
Control	18	.052	19.11	19.01	38.33	32.50
Reversal	18	.052	19.11	16.42	39.56	32.27
Nonreversal	18	.055	18.28	19.28	36.94	38.23
Exp. II						
Control	10	.078	12.90	8.42	28.60	20.82
Reversal	10	.067	14.90	9.77	29.00	19.71
Nonreversal	10	.071	14.00	14.15	26.90	26.45

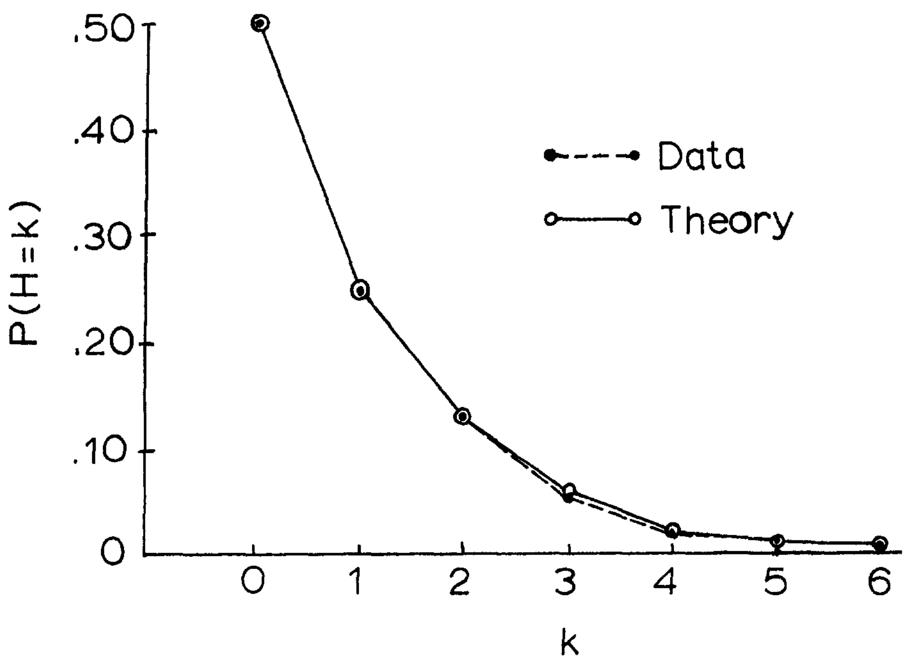
errors) are shown in Table 2; a likelihood ratio test for equality of c's was nonsignificant in both experiments. Further, a likelihood ratio test that each S's learning parameter, c_i, was equal to a common c was tested for all 65 *S*s in Exp. I and for all 45 *S*s in Exp. II. In each case, the null hypothesis could not be rejected—for Exp. I, χ^2 (64) = 53.3, $p > .05$; for Exp. II, χ^2 (45) = 42.4, $p > .05$ (Bower & Trabasso, 1963b). Thus, the data were consistent with the hypothesis of a common c for *S*s in each experiment; the differences among *S*s' error scores could be attributed to the variability inherent in the theoretical process.

The lack of group differences indicates that performance on the final problem was unrelated to the response assignments reinforced during the initial series. Correspondingly, there was no evidence for partial learning of the relevant cues or partial elimination of irrelevant cues (cf. Group NR). Effectively, we may rely upon a single error by S to indicate that he is "naive" about the correct solution. An error in this situation has the properties of an uncertain recurrent event (Restle, 1962); when S commits an error, we may, so to speak, reset him back to the starting point from which he began working on the problem. It should be noted that the null effects of reversal and nonreversal shifts before solution differ from the effects of such shifts after initial solution has occurred (Kendler & Kendler, 1962). What differs in the two cases is that after solution, S has a strong bias to attend to the formerly relevant cue, whereas before solution he is sampling cues at random to test (Kendler, Glucksberg, & Keston, 1961).

Presolution analyses.—The data prior to the last error of each S were analyzed according to the expectations of the all-or-none theory. In theory, the presolution responses of S may be represented as a stationary and independent binomial process. To test for a constant probability of success prior to the last error, backward learning curves (Hayes, 1953) were constructed. These were stationary near .50 in each experiment. Pooling the two experiments, the probabilities of a correct classification on Trials -1, -2 $\cdots$ -8 backwards from the last error were .50, .50, .52, .53, .54, .49, .51, and .50. Further-



1a. Data of Exp. I.



1b. Data of Exp. II.

FIG. 1. Distribution of number of successes intervening between two adjacent errors.

more, the curve was flat when analyzed in two-trial blocks for 40 trials backwards from criterion, χ^2 (19) = 19.31, $p > .05$.

Successive correct or incorrect responses prior to the last error were also statistically independent. For Exp. I, the conditional probability of a success was .52 following a success and .53 following an error; in Exp. II, the conditional probabilities were .50 and .52, respectively. Neither set of data permits rejection of the hypothesis of independence.

If presolution responses approximate a binomial series, then the number of successes between two successive errors should be geometrically distributed as qp^n, where p is the probability of a success and $q = 1 - p$. Figure 1 shows that this random variable has a geometric distribution in the data of the two experiments.

A number of numerical predictions has been made accurately for these data, and they are reported elsewhere (Bower & Trabasso, 1963a). The distribution of total errors should be geometric, i.e., $\Pr\{T=k\} = c(1-c)^{k-1}$, and this was observed in both experiments. The geometric distribution implies that the *SD* will be large but slightly less than the mean. Pooling all *S*s in Exp. I from Trial 1, the mean errors were 20.85; the observed σ was 18.49 with 20.30 predicted. Pooling all *S*s in Exp. II from Trial 1, the mean errors were 11.45; the observed σ was 11.02 with 10.96 predicted.

A criticism that might be made is that the theory asserts the null hypothesis, and what has been shown is that our experiments had inadequate power to reject the null hypothesis. The methodological status of such matters has been discussed elsewhere (Binder, 1963; Grant, 1962). Our opinion is that if the partial learning is of such small magnitude that it does not appear with a combined total of 28 *S*s in each condition, then indeed it may be considered a negligible effect. To provide a more severe test of the theory, Exp. III was conducted by extending the presolution reversal design. In Exp. III, the S-R assignments were reversed after every second error that *S* made. Thus, as *S* proceeded along through his series of trials, the S-R assignments were switching repeatedly back and forth.

Experiment III

The procedure will be illustrated briefly in order to make the theoretical predictions meaningful. Table 3 shows the first 14 trials for a hypothetical *S*. The stimulus patterns vary in five binary dimensions. Color is the relevant attribute and this *S* begins with the assignments "Red in Class VEK, Blue in Class CEJ." Suppose that his responses to the patterns on Trials 1 and 3 are correct according to these assignments, whereas his re-

TABLE 3

Correct (C) and Error (E) Responses of a Hypothetical *S* in the Reversal Group

Alternating S-R Assignments	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Red-VEK Blue-CEJ	C	E	C	E ↓				C ↑	E	E ↓			C ↑	E
Blue-VEK Red-CEJ				C	C	E	C	E		C	E	C	E	

sponses to the patterns on Trials 2 and 4 are wrong. The second error, occurring on Trial 4, initiates an immediate reversal of the S-R assignments, and *S* is told "Correct" for his response on Trial 4. According to the reversed assignments, the responses on Trials 4, 5, and 7 are correct whereas those on Trials 6 and 8 are errors. The second error of this subseries, occurring on Trial 8, initiates another immediate reversal back to the original S-R assignments, and the response on Trial 8 is called "Correct." The series of reversals on every second error continues in this fashion until *S* produces a string of 10 consecutive correct responses since his last reversal. A second group of control *S*s was never reversed; they simply learned a fixed set of S-R assignments by the conventional training procedure in which they were informed of every error.

The prediction from the theory is that the number of *informed* errors (those not arrowed in Table 3) before learning for the Reversal *S*s will be equal to the number of informed errors before learning made by the Control *S*s. That is, no interference should result from the multiple reversals that occur during training. This prediction follows from the assumptions that learning occurs in one trial, that opportunities for giving up an irrelevant hypothesis, and hence learning, occur only after *informed* errors, and that the probability of learning following an informed error is not affected by the past S-R assignments for the relevant cues. The point of the last statement might be phrased in terms of the cues to which *S* is attending: if *S* is selectively attending to irrelevant cues and is not "noticing" the color, then his behavior when he starts noticing color is unaffected by the past history of changing correlations between the reinforced responses and the unnoticed color values. In contrast to the equality prediction above, if any one of the three assumptions is wrong, the Reversal *S*s should make more informed errors than do the Control *S*s.

Method

Subjects.—The *S*s were 33 paid volunteers from elementary history and psychology classes at Foothill Junior College who were randomly assigned to two groups (10 or 11 males and 6 females each).

Procedure.—The instructions were the same as those used in Exp. I and II. The classificatory responses were VEK and CEJ. The learning criterion was 10 successive correct responses.

Stimuli.—The patterns were identical to those used in Exp. II with the exception that the area which was colored within each figure was kept constant. Thus, there were one relevant and four irrelevant binary dimensions. Color was the relevant dimension for both groups.

Design.—The Control group of 16 *S*s learned a problem with fixed S-R assignments throughout. For 8 of these *S*s, the assignments were Red-VEK and Blue-CEJ; the other 8 *S*s had the opposite pairings. The Reversal group of 17 *S*s learned the same color-relevant problem but the response assignments were reversed on every second error that each *S* committed. On alternate errors, *S*'s response was confirmed (called "Correct") in accord with the instantaneous reversal of the assignments which *E* made as soon as *S*'s second error of a subseries occurred. The procedure was discussed above in connection with Table 3. By this procedure, it would not be feasible to reverse *S* on every error since he would always be told "Correct" and *E* would forfeit any control over what *S* learns.

Results

All but two *S*s, one in each group, met the learning criterion. The two nonsolvers arrived late for their experimental session and had less time than the other *S*s to complete the problem; therefore, they are excluded from the following analyses. Since both *S*s made about the same number of errors, their exclusion does not affect the comparisons.

The remaining 16 *S*s in the Reversal group averaged 7.00 reversal shifts before meeting criterion. The average numbers of informed errors were nearly equal for the two groups. For the Reversal group, the average number of informed errors was 7.81; for the Control group, it was 8.00. The *SD* of errors for the Control group was 8.22. Thus, the difference of .19 informed errors is not significant.

Two *S*s in each group learned after only one error. As a result, two *S*s in the Reversal condition were never reversed because they learned their initial response assignments. Removing these two *S*s from each group, the mean number of reversals was 8.00; the mean number of informed errors was 8.79 for the Reversal group and 9.08 for the Control group, a nonsignificant difference.

On those trials where a reversal occurred, *S* was told "Correct" when in fact he made an error. Such a procedure should serve to maintain an irrelevant hypothesis for at least one more trial. The net effect of this procedure would be to produce more "correct" responses before the last error for the Reversal *S*s than for the Controls. The mean numbers of corect responses prior to criterion for the Reversal and Control groups were 21.1 and 9.6, respectively, $t\ (29) = 1.99$, $p = .05$.

The mean trial of last error can be predicted for both groups once the mean errors for the Control group are known. These predictions are made to rule out the possibility that (*a*) length of success runs increased over trials in the Control group and (*b*) successive reversals tended to become more spaced out in the Reversal group over trials. For both predictions, the probability of a success prior to the last error is assumed to be constant and the a priori one-half. Let T_c be the total errors made by an *S* in the Control group; then his expected trial of last error is $2T_c$. The predicted mean trial of last error for the Control group was 16.00; the observed was 17.60. The difference was not significant by a matched *t* test, $t\ (14) = 1.75$, $p > .05$.

For the Reversal group, let T_r be the number of informed errors and r be the number of reversals before learning. Then the average trial of last error, n', for the Reversal group should be

$$n' = T_r + r + 1 + 2(T_r - 1). \quad [1]$$

The first two terms, T_r and r, in Equation 1 count the number of informed error trials plus the reversal trials. The additional terms $1 + 2(T_r - 1)$ are the expected number of correct responses for an *S* who makes T_r informed errors in the Reversal group. The T_r informed errors partition the successes as follows: there is an average of one success before the first error, and an average of two successes between each of the $T_r - 1$ remaining informed errors. By hypothesis, the informed errors should be the same for both groups, so that $T_c = T_r$. Secondly, r is related to T_r, for if *S* makes T_r informed errors, then his number of reversals should be $T_r - 1$, assuming that he makes one more error after his rth and final reversal. (Note that the average number of reversals was 7, or exactly $T_c - 1$.) Substituting into Equation 1 the relations $r = T_r - 1$ and $T_c = T_r$, the following relation is obtained between T_c and the average trial of last error for the Reversal group:

$$n' = 4T_c - 2, \quad [2]$$

Substituting the observed $T_e = 8.00$ into Equation 2, the predicted mean trial of last error (n') is 30.00. For the 16 solvers in the Reversal group, the observed value was 28.81; the *SD* was 26.09. The prediction is thus not significantly discrepant from the data.

The results of Exp. III favor a one-step, all-or-none interpretation of two-category concept identification in adult *S*s. In addition, the results indicate that the effective information promoting learning in these problems occurs on informed error trials. Finally, the results are consistent with the notion that *S*'s probability of solving after any given informed error is unaffected by the past history of inconsistent reinforcements to the relevant cue on which he solves.

Again the criticism may be lodged that our experiment had inadequate power to reject the null hypothesis. To provide further power for the test, we presently are running the design of Exp. III with larger groups of *S*s, a different problem, and more explicit instructions to *S* regarding the dimensions of the stimuli, the form of the solution, etc. To date, with 24 *S*s in each condition, the mean numbers of informed errors in the Control and Multiple Reversal groups are 8.22 and 7.94, respectively. Thus, the qualitative results of Exp. III are being replicated.

Discussion

The Reversal and Control conditions in Exp. I and II resemble the standard ones used with this design on the continuity-noncontinuity issue. Judging from the review by Blum and Blum (1949), nearly all of the previous studies involved rats learning simultaneous discriminations with a small number of cues. On balance, that evidence favored a continuity position supplemented by constructs such as receptor orienting acts (e.g., Ehrenfreund, 1948). Whether such results should have a crucial bearing on a situational theory of adult human concept identification is a moot question. Writing for the continuity position, Spence (1940) pointed out early that the results from the animal studies may not be directly relevant to adult human learning mediated by complex symbolic mechanisms. Such mechanisms evidently are used by adults in solving concept problems, and current theorizing emphasizes such mechanisms (e.g., Bower & Trabasso, 1963a; Hunt, 1962; Kendler & Kendler, 1962; Underwood & Richardson, 1956). Our working hypothesis is that the extent to which an *S*'s discrimination learning fits the all-or-none as opposed to the incremental description depends on the extent to which symbolic mediating responses are available to *S*.

It would appear that one reason why the all-or-nothing model predicts accurately in these experiments is that the conditions promote "focus sampling" (Bruner, Goodnow, & Austin, 1956) because the memory load on *S* is otherwise overwhelming. The random-cue selection postulate implies that *S*'s selection following an error of a new focus sample of cues to test is not affected by the past history of response assignments for the various cues. Such random selection of a sample focus is reasonable only if *S*'s memory of specific past information is in some way impoverished. The experimental conditions presumably responsible for such poor memory include (*a*) the complexity of the stimuli, here 5 or 6 bits plus the 1-bit response, (*b*) the relatively rapid rate of presentation of this information (average time viewing each card was approximately 6 sec.), and (*c*) *S* has a specific set to identify the relevant cue, not to memorize and later recall the information he is seeing. In other experiments by us, direct tests of recall of specific information under these conditions showed the memory for six-card series to be very poor. Judging from the limited capacity of *S*s for quickly processing and storing such large amounts of information, it is not surprising to find that they resort to focus sampling of specific cues to test.

The present results extend previous findings (Trabasso, 1963) that single-cue concept problems can be characterized as a one-step learning process. However, it is clear that not all varieties of concept learning can be so simply described. Our aim was to explore initially the most elementary form of concept learning, in a situation similar to a conventional discrimination learning procedure. Obviously, the simple all-or-nothing model must be elaborated and extended before it will account for learning of compounds of simpler concepts (e.g., conjunctions or disjunctions of several cues). Such extensions are currently under investigation (Trabasso & Bower, in press).

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