DISCRETE-TRIAL ALTERNATION IN THE RAT^{1, 2}

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The acquisition and maintenance by rats of single alternation, double alternation, and four other repeating patterns of reinforced and non-reinforced trials was studied in a discrete-trial lever-pressing situation. The rats learned all these patterns in a small number of experimental sessions. Single alternation was learned more rapidly than the more complex patterns. Rate of learning single and double alternation decreased moderately as inter-trial interval increased. Abrupt changes in the scheduling of trials, either by doubling the inter-trial interval or by shifting from fixed to variable trial spacing, temporarily disrupted the patterned performance. Two hypotheses concerned with the means by which the rats could have learned to conform to the pattern were examined: (1) "timing" of the interval between successive reinforcements; and (2) control of responding on a trial by the outcome of preceding trials, depending on the consistency with which these outcomes were associated with reinforced or non-reinforced trials in the pattern and on how many trials back these outcomes occurred. The second hypothesis accounted for the relative frequency of errors on trials at various locations in the sequences, and predicted most of the changes in error frequency observed in experiments in which "inter-trial stimuli" were added to the sequences.

The early investigations of alternation behavior in animals were undertaken primarily to assess the comparative "intelligence" of different species and to explore their capacity for "symbolic" behavior. The history and current status of the double-alternation research carried out with this objective has recently been summarized by Warren (1965), who concluded that available evidence fails to show that double-alternation performance differentiates lower from higher phylogenetic levels.

The results with rats seem to show that rats could learn spatial double alternation, but could learn temporal double alternation only with great difficulty, if they learned it at all (Munn, 1950). Probably the most convincing

demonstration of double alternation in the rat (whether it should be called "spatial" or "temporal" is not clear) was provided by Schlosberg and Katz (1943) who trained rats to press a lever twice to the left and then twice to the right, for many successive sequences.

Recent research on single-alternation, double-alternation, and other patterns has been concerned more with identifying the factors controlling the sequential patterning of behavior (*e.g.*, Capaldi, 1967) than with issues of animal intellectual capacity. In keeping with this trend, the present paper examines relationships between pattern complexity, inter-trial interval, and stimulus contingencies on the acquisition and maintenance by rats of single-alternation, double-alternation, and four other temporal sequences of discrete-trial lever pressing. A hypothesis concerned with the factors controlling the patterned behavior is presented, and is used to predict the relative frequency of errors on the trials in the various sequences.

METHOD

Subjects

Male albino rats (Sprague-Dawley derived) obtained from the Simonsen Laboratories,

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White Bear Lake, Minnesota, were 90 to 120 days old at the beginning of the experimentation. Most were water-deprived and their lever presses were reinforced with sugar-water; they had free access to water for 5 min after each experimental session. The remainder were food-deprived, and responding in experimental sessions was reinforced with food pellets; they received occasional supplemental feedings immediately after the experimental session as needed to maintain approximate normal free-feeding weight.

Apparatus

Four similar lever boxes, constructed from a commercial (Grason-Stadler E3125) prototype, were used. The essential features of each box were: manipulandum—a single Gerbrands lever; trial signal—a compound stimulus consisting of the concurrent presentation of a 6-w off-white panel light and a 1000-Hz tone at approximately 80 db; and a reinforcement device—either a dispenser for 45-mg Noyes pellets or a mechanism for presenting drops of 9% sucrose solution. Automatic controlling circuitry and a system of counters and event recorders were located in an adjoining room.

Procedure

A discrete-trial procedure was used, in which reinforced trials (S^+) alternated in fixed sequence with non-reinforced trials (S^-). The pattern of reinforced and non-reinforced trials recycled continuously throughout the experimental session of 480 trials; there were no "breaks" or other indications that the pattern was repeated. The sequence was "non-correction": the order of presentation of reinforced and non-reinforced trials was not affected by the animal's behavior.

Six patterns of reinforced and non-reinforced trials can be obtained with sequences of two, three, or four trials. Three of these patterns were selected for extensive experimental examination: single alternation ($S^+S^- \dots$), double alternation ($S^+S^+S^-S^- \dots$), and "single-double" alternation ($S^+S^-S^- \dots$). The other three patterns ($S^+S^-S^-S^- \dots$, $S^+S^+S^- \dots$, and $S^+S^+S^+S^- \dots$) were used to examine specific hypotheses about the factors controlling alternation performance, and received less extensive experimental treatment.

For all sequences, the same stimuli—the 1000-Hz tone and the lighted panel light—

were always present during each trial. Neither stimulus was on during the inter-trial interval (ITI). In most of the experiments, a single response during a S^+ trial (CRF) produced a drop of sugar-water reinforcement and terminated the trial. However, in one series of experiments (on the relation between ITI duration and alternation learning) 10 responses during the S^+ trial (FR 10) were required for reinforcement; the reinforcer in these latter experiments was a food pellet.

The essential features of the trial sequence are presented in Fig. 1, which shows a segment of the single-alternation schedule. The schedule used with the other sequences was identical except for the order of presentation of reinforced and non-reinforced trials and for the response requirement (CRF or FR 10).

The maximum duration of a trial was 10 sec. S^+ trials terminated with delivery of the reinforcement, or after 10 sec if the rat did not make the required response during the trial. The S^- trials always lasted 10 sec whether or not the rat responded during the trial. The standard ITI was 10 sec except in an experimental series in which ITI duration was itself the independent variable. However, in order to minimize ITI responding, the onset of the next trial was postponed for the ITI duration (measured from the time of the response) whenever the rat pressed the lever during the ITI. (See example, Fig. 1)

The experimental procedure was designed specifically to separate the acquisition of lever

Fig. 1. Representation of trial sequence in 10-sec, CRF single alternation (*i.e.*, ITI was 10 sec, a single bar press during a trial was required for reinforcement, and responding on every other trial was reinforced). The "response" line shows simulated responding of a rat; the "trials" line shows effects of this behavior on the time of onset and duration of the alternation trials and on the duration of the intervals between trials (see text). The following features of the program are illustrated: termination of the trial and delivery of reinforcement when a response was made during a S^+ trial; 10-sec duration of all S^- trials whether or not the rat responded during the trial; and postponement of onset of the next trial for the ITI interval (10 sec in this example) if a bar press occurred during the ITI.

pressing (CRF or FR 10) and discrete trial performance from the acquisition of alternation *per se*. Accordingly, the procedure was divided into two distinct phases: (1) *preliminary training*, in which the rats were trained to press the lever on all trials, and (2) *alternation training*, in which the rats were trained to press the lever in accordance with the repeating pattern of reinforced and non-reinforced trials.

In *preliminary training*, responding on all trials was reinforced. Each rat remained in preliminary training until it pressed the lever (CRF or FR 10) on 90% or more of the 240 to 300 trials in each of three consecutive experimental sessions. The exact procedure during preliminary training varied somewhat among rats since they required different amounts of shaping to learn to press the lever, and different numbers of training sessions before attaining the 90% response criterion.

Alternation training usually began on the next session after the rat attained the preliminary training criterion. All alternation training sessions were 480 trials long. Each rat had the same trial stimuli, response requirement (FR 10 or CRF), ITI duration, *etc.*, as in its preliminary training. The only significant difference between preliminary and alternation training was that in the latter, responses in only some, rather than all, of the trials were reinforced, in accordance with one of the patterns of reinforced and non-reinforced trials. Thus, it could be assumed that differences between animals in learning the alternation patterns indicated differences in learning the pattern as such, uncontaminated by differences in adapting to the box, in initially learning to press the lever, or in learning to press the lever only during trials. These latter differences were presumably eliminated by bringing all the animals to a common criterion level of discrete trial responding during preliminary training.

Due to difficulties in scheduling experimental sessions, some of the rats that had reached criterion received additional preliminary training sessions before beginning the alternation phase. These extra sessions with responses reinforced in all trials probably did not affect subsequent alternation performance, since in a control experiment no differences in rate of single-alternation acquisition were found between a group which had the usual three criterion sessions at the end of prelim-

inary training and a group that had 21 criterion sessions.

RESULTS

Performance on six alternation sequences. Figure 2 shows the acquisition curves obtained during alternation training for all the rats run on single alternation, single-double alternation, and double alternation under the usual experimental conditions: ITI was 10 sec; a single bar press during an S⁺ trial produced reinforcement; and the reinforcer was a drop of sugar water. In Fig. 2, performance is plotted in terms of the ratio between the number of S⁻ trials on which the rat responded during a session and the number of S⁺ trials on which it responded. This ratio is expressed in Fig. 2 as S⁻/S⁺ for single alternation, and $S_1^- + S_2^- / S_1^+ + S_2^+$ for double alternation. In single alternation and double alternation, the rat received an approximately equal number of S⁻ and S⁺ trials (240 of each) during a session. Thus, the ratio was approximately 1.0 at the beginning of single-alternation or double-alternation training when the rat responded on nearly all its trials and gradually declined as the rat learned its pattern. In single-double alternation (S⁺S⁻S⁻), on the other hand, the rat received twice as many S⁻ as S⁺ trials during a session. Therefore, the number of S⁺ trials per session on which the rat responded in single-double alternation was doubled in order to obtain a measure of single-double-alternation performance comparable to that used for single alternation and double alternation, and single-double-alternation performance is expressed in Fig. 2 as $S_1^- + S_2^- / 2S^+$.

Clearly, each rat learned to respond in conformity to its particular alternation sequence and there was considerable similarity in performance between the different rats assigned to the same sequence. Figure 2 shows that acquisition of single alternation was more rapid than acquisition of double alternation (the slowest of the seven single alternation rats learned more rapidly than the fastest of the seven double-alternation rats) and the rate of acquisition of single-double alternation was intermediate. Acquisition of single-alternation patterned performance was superior not only when performance on the three patterns is compared with respect to the relative

Fig. 2. Alternation training curves for double alternation (DA) ($S_1^+S_2^+S_1^-S_2^-$), single-double alternation (SDA) ($S^+S_1^-S_2^-$) and single alternation (SA) (S^+S^-) for all of the rats trained on each of these three sequences. Except for the differences in sequence, experimental conditions were the same for all rats shown here. The curves for rats A22 in DA, A48 in SDA, and A4 in SA are specifically designated because the within-session performances of these particular animals are presented in Fig. 3.

proportion of S^- and S^+ trials on which the rat responded, as in Fig. 2, but also when the different number of times that the single-alternation, single-double-alternation, or double-alternation pattern was repeated during the 480-trial session is taken into account. For example, the single-alternation pattern was repeated twice as many times during a session as the double-alternation pattern; yet even if the number of sessions marked on the abscissa of the single-alternation plot in Fig. 2 was doubled to compensate for this difference, the acquisition rate of the single-alternation rats would still be generally superior to that of the double-alternation rats.

Figure 3 shows the within- and between-session performance of individual rats on the various S^+ and S^- trials of single alternation, single-double alternation, and double alternation. As illustrated, the rats responded about as often on S^- as on S^+ trials at the beginning of their first alternation session. As alternation training proceeded, the rats continued to respond on most of their S^+ trials but gradually ceased to respond on S^- trials. In double alternation, and most markedly in single-double alternation, the rats responded less often (made fewer errors) on the first S^- in the sequence than on the second S^- . This differential responding on the S^- trials eventually

Fig. 3. Between session (Part A) and within session (Part B) performance of representative individual rats on the S^+ (solid lines) and S^- (dashed lines) components of SA (S^+S^-), SDA ($S^+S_1^-S_2^-$), and DA ($S_1^+S_2^+S_1^-S_2^-$). The between-session performance of these same rats is shown as ratios in Fig. 2. The particular experimental sessions presented in Part B were selected in order to show the principal changes in S^+ and S^- responding that occurred during alternation training.

disappeared in double alternation, but persisted in single-double alternation.

Figure 4 shows the acquisition curves for representative rats trained on the remaining three patterns. Thus, the rats were able to learn all six repeating patterns obtained with groups of two, three, or four reinforced and

non-reinforced trials, although the rate of learning and number of trials to asymptotic performance varied considerably from pattern to pattern. Single alternation was learned more rapidly than any other pattern, while the $S^+S^+S^+S^-$ pattern was learned most slowly.

Fig. 4. Acquisition by representative rats of $S_1^+S_1^-S_2^-S_3^-$, $S_1^+S_2^+S_1^-$, and $S_1^+S_2^+S_3^+S_1^-$. Performance on S^+ trials is indicated by solid lines, performance on S^- trials by dashed lines.

It is evident from Fig. 3 and 4 that frequency of responding on a particular S^- component of the pattern depended on the pattern and on the location of the S^- trial within the pattern sequence. For example, if the pattern consisted of an S^+ trial followed by one or more S^- trials (e.g., $S^+S^-S^-$, or $S^+S^-S^-S^-$) a response was least likely to occur on the S^- trial that immediately followed the S^+ trial, and then became increasingly probable on the succeeding S^- trials. The differing probabilities of response on the various components of four of the patterns are shown more directly in Fig. 5 (solid lines).

Figure 5 also shows (dotted lines) how the probabilities of response on the pattern components were altered by sounding an 80-db white noise (the Inter-trial Stimulus) during a designated inter-trial interval in the sequence. As illustrated, the inter-trial stimulus produced marked changes in the probabilities of response on certain pattern components. These effects of the inter-trial stimulus were for the most part predicted by the "discrimination hierarchy hypothesis", discussed in detail below.

Effects of inter-trial interval (ITI). The acquisition of single alternation at various ITIs between 5 and 160 sec was studied with six groups of rats; and double-alternation acquisition at ITIs between 10 and 80 sec was studied with four groups of rats. Each group had the same ITI in preliminary training as in alternation training. The reinforcer in these experiments on acquisition at different ITIs was a food pellet, and 10 responses during a trial

were required for reinforcement. The results are presented in Fig. 6.

In addition to demonstrating once again that single alternation is learned in far fewer trials than double alternation, Fig. 6 shows that the rate of learning single alternation or double alternation decreased as ITI increased. Nevertheless, the rats were able to learn the pattern when the ITI was as great as 160 sec in single alternation, or 80 sec in double alternation (although they did not learn the pattern as well in the same number of sessions as the groups that learned at shorter ITIs). Presumably, the rats could have learned single alternation or double alternation at even greater ITIs than those shown in Fig. 6. Longer intervals were not examined, however, because lengthy experimental sessions would have been required and because at the longer ITIs the rats sometimes failed to respond on a number of consecutive trials.

The role of temporal cues (e.g., time since last trial or since last reinforcement) was examined in two ways: by abruptly increasing the ITI between regularly spaced trials; and by shifting from a fixed to a variable ITI without changing the average interval between trials. The effect of doubling ITI length on single-alternation performance is shown in Fig. 7. Five rats were first trained to stable single-alternation performance with an ITI of 5 sec, and then shifted successively to 10-sec, 20-sec, and finally to 40-sec ITI. Figure 7 shows that increasing the ITI from 10 to 20 sec, and from 20 to 40 sec temporarily disrupted performance, after which the performance grad-

Fig. 5. Performance on the various stimulus components of four alternation patterns, and effects on responding produced by the presence of an "inter-trial stimulus" (IS) during acquisition. The data points for each animal were obtained during its seventh alternation session. The filled circles were obtained from the individual rats that learned an alternation pattern without an inter-trial stimulus; the solid lines show the mean performance for these animals. The triangles or open circles show performance of each of the rats that learned one of the IS-sequences. The dashed lines show the mean performance of the animals trained with the IS.

Fig. 6. Acquisition of alternation by SA and DA groups trained at the ITIs indicated on the abscissae. The numbers above the day 1 SA and DA curves indicate the number of rats in the group trained at each ITI. The mean performance of each of the SA groups is shown for days 1, 2, and 3 of alternation training, and the mean performance of each of the DA groups is shown for days 1, 5, 10, 15, and 18 (the final day) of alternation training.

ually returned approximately to pre-shift level.

A similar study of the effect on double-alternation performance of doubling ITI was carried out with three rats initially trained on double alternation with an ITI of 10 sec, and then shifted successively from 10-sec ITI to 20 sec, from 20 to 40 sec, and finally from 40 to 80 sec. Each shift to a higher ITI substantially disrupted performance followed by a gradual return to the approximate performance levels of the groups separately trained on each ITI (*cf.* Fig. 6).

Figure 8 shows the effects on single-alternation performance produced by shifting animals from 10-sec ITI regularly spaced trials to a variable ITI trial schedule in which the mean ITI remained 10 sec, while intervals between trials varied between 5 and 20 sec; and by shifting animals from 40-sec ITI regularly spaced trials to a 40-sec variable trial schedule in which the interval between trials varied between 20 and 80 sec. Figure 8 shows that for both single-alternation groups, the shift from fixed- to variable-trial spacing markedly dis-

rupted alternation performance, following which there was a gradual and incomplete return to preshift levels. A similar set of experiments, in which double-alternation rats were shifted from fixed to variable spacing of trials, yielded inconclusive results. Performance of some of the double-alternation rats was poorer after the shift but the performance of others was apparently unaffected.

DISCUSSION

Groups of rats learned to respond on discrete trials in accordance with six different repeating sequences of reinforcement and non-reinforcement. Since the stimuli presented during the trial before the response were always the same, the animals, in order to respond correctly, must have discriminated between persisting consequences of responding and not responding on preceding trials. Two hypotheses concerned with the types of discrimination that the animals might have made will be considered: (1) discrimination of temporal stimuli, *e.g.*, of time since last reinforce-

Fig. 7. Effect on SA performance of abruptly doubling the time between trials. The same rats were shifted at the beginning of the sessions indicated by the arrow from 5- to 10-sec ITI, then from 10- to 20-sec ITI, and finally to 40-sec ITI. Each curve shows the session-by-session performance of an individual rat. Experimental sessions required for recovery of stable baselines, intervening between those shown for the three panels, have been omitted.

ment; (2) discrimination of internally carried ("remembered") prior trial outcomes in accordance with a "discrimination hierarchy hypothesis".

(1) *Temporal discrimination.* According to this hypothesis, the rat discriminated the passage of time since its last reinforcement, and was thereby able to respond appropriately when the trials, and particularly the reinforcements, were equally spaced. Wall and Goodrich (1964) presented evidence to show that lever pressing on the discrete trials of three "recursive" sequences: $S+S-$, $S+S-S-$; and $S+S-S-S-$ was controlled by temporal discriminations. They obtained the longest latency and lowest response probability on the trial immediately following the reinforced trial, with a progressive decline in response latency and increase in probability as proximity to the reinforced trial increased. On the basis of the similarity of their results to the free-operant fixed-interval (FI) "scallop", Wall and Goodrich argued that their discrete trial sequences were in essence "... FI schedules with limited opportunities for non-reinforced responding." Dews (1962) has shown that prob-

ability of responding during FI schedules depends primarily on the passage of time, and is independent of the presence or absence of opportunities to respond during the inter-reinforcement interval.

The present finding that single-alternation and double-alternation performance was usually disrupted by increases in ITI length (Fig. 7) or by shifts from fixed to variable ITIs (Fig. 8) could be regarded as evidence for the formation of temporal discriminations. However, the fact that temporal shifts disrupted alternation performance does not establish that the rats were making temporal discriminations before the shift. For example, double alternation performance was disrupted by temporal shifts; yet it seems unlikely that double alternation was controlled by temporal discriminations since the reinforced trials were not regularly spaced in time. Responding on the various sequences could have depended on other processes besides temporal discriminations that were also affected by changes in time, e.g., memory of whether or not reinforcement occurred on the last or second-last trial.

Fig. 8. Effects on SA performance of shifting from a fixed to a variable schedule of trials without altering the mean interval between trials. The shifts were made at the beginning of the sessions indicated by arrows. Each curve shows the performance over sessions of an individual rat. Left: 10-sec mean ITI. Right: 40-sec mean ITI.

In the present experiments, the rats were able to respond appropriately when temporal cues were absent or ambiguous. Rats learned three alternation patterns: S+S+S-, S+S+S-S-, and S+S+S+S-, in which the time between successive reinforcements varied within the sequence. They were able to perform adequately on single alternation and double alternation after they were shifted from fixed to variable scheduling of trials. Capaldi, Veatch, and Stefaniak (1966) have also reported that rats did not require temporal cues in order to learn single alternation in a straight runway. Their rats learned single alternation as rapidly when ITI varied as when it remained constant.

(2) *Discrimination hierarchy hypothesis.* Although it is possible that the rat uses temporal cues in responding on certain sequences, a more general hypothesis of sequential learning based on non-temporal cues is clearly required. Capaldi (1967) developed a hypothesis of "sequential stimulus after effects", which is based on the discrimination of non-temporal

cues. As the designation implies, Capaldi's hypothesis assumes that: (1) the outcomes of preceding trials persist to function as stimuli that control behavior on subsequent trials, and (2) the sequential ordering of reinforced and non-reinforced responding is of critical importance in predicting effects of preceding trial outcomes on subsequent behavior. With the aid of familiar associationistic principles, Capaldi and co-workers have been able to account for an impressive variety of discrete-trial straight runway phenomena, such as effect of reinforcement magnitude, variations in inter-trial interval, and, of particular interest here, single-alternation patterning. However, Capaldi's theory is closely tied to the conditions in the straight runway where, apparently, behavior patterning is much less readily obtained than in the present, lever box, situation. (For example, Bloom and Capaldi (1961) failed to obtain double-alternation performance with the straight runway).

A "discrimination hierarchy hypothesis" has been developed which accounts for the

Table 1

Representation of the six repeating sequences. The reinforced (S^+) and non-reinforced (S^-) trials appear in the order in which they occurred in the various sequences. The trials were numbered as indicated in accordance with their position in the sequence. The outcomes of the last (lag 0) and second last (lag 1) trials before each of the trials in the sequence are shown by "+" (for a reinforced trial) and "-" (for a non-reinforced trial). An inter-trial stimulus (IS) was inserted in some of the sequences at the inter-trial interval (ITI) indicated. These IS-sequences were designated as either Type A or Type B, depending on whether or not the added IS was expected to reduce errors on a trial in the sequence. An asterisk denotes those trials in the Type A IS-sequences for which a reduction in errors was expected (explanation in text).

		Position in Sequence							
		1 ITI	2 ITI	3 ITI	1 ITI	2 ITI	3 ITI	4 ITI	
		I (SA) ¹			II (DA) ²				
Sequence (NO IS)		S+	S-		S+	S+	S-	S-	
Outcome: Lag 0		-	+		-	+	+	-	
Lag 1		+	-		-	-	+	+	
Type A IS-Sequence					S+	S+	S-	S-* IS	
Outcome: Lag 0					IS	+	+	-	
		III (SDA) ³			IV				
Sequence (NO IS)		S+	S-	S-	S+	S-	S-	S-	
Outcome: Lag 0		-	+	-	-	+	-	-	
Lag 1		-	-	+	-	-	+	-	
Type A IS-Sequence		S+	S-	S-* IS	S+	S-	S-*	S-* IS	
Outcome: Lag 0		IS	+	-	IS	+	-	-	
Type B IS-Sequence		S+ IS	S-	S-	S+	S- IS	S-*	S-	
Outcome: Lag 0		-	IS	-	-	+	IS	-	
		V			VI				
Sequence (NO IS)		S+	S+	S-	S+	S+	S+	S-	
Outcome: Lag 0		-	+	+	-	+	+	+	
Lag 1		+	-	+	+	-	+	+	
Type A IS-Sequence		S+ IS	S+	S-*					
Outcome: Lag 0		-	IS	+					

¹SA—single alternation

²DA—double alternation

³SDA—single-double alternation

relative frequency of errors on trials at various locations in the sequences studied in the present experiments, and also predicts most of the changes in error frequency produced by altering the stimuli present in the sequence. As in Capaldi's theory, the present analysis treats the patterned behavior as a series of discriminations of preceding trial outcomes. The hypothesis also assumes that the rat can discriminate not only whether the immediately preceding trial (the "lag-0" trial) was one in which responses were reinforced or non-reinforced, but also, if necessary, whether the second trial back (the "lag-1" trial) or even the third trial back (the "lag-2" trial) was one in which responses were reinforced or non-reinforced. The outcomes of the lag-0 and lag-1 trials that precede each of the trials in the six

sequences studied are shown in Table 1. The trials in the sequences are designated as S^+ or S^- depending on whether or not responding on them was reinforced; the outcomes of the trials of various lags that precede each of the trials in the sequence are designated as "+" or "-" depending on whether or not responding on these preceding trials was reinforced.

The hypothesis asserts that responding on a particular S^+ or S^- trial in a sequence is controlled by the outcome of its "+" or "-" lag-0 trial if this "+" or "-" lag-0 outcome is consistently associated with S^+ or S^- whenever it is the lag-0 outcome on a trial in the sequence. If, on the other hand, the lag-0 trial outcome on a trial is *ambiguous*, i.e., if the lag-0 trial outcome, either "+" or "-", is as-

sociated as a lag-0 outcome with both S+ and S- trials in the sequence, then it is assumed that responding on trial will be controlled by the next higher lag trial outcome that is consistently associated with S+ or S-.

To illustrate: in single alternation (*cf.* Table 1), an S+ trial always precedes an S- trial and *vice versa*. Thus, in single alternation a "+" lag-0 trial outcome is consistently associated with S- trials, a "-" lag-0 outcome is consistently associated with S+ trials, and it is assumed that responding on the S+ and S- trials is controlled by the "-" and "+" lag-0 trial outcomes respectively. In double alternation, on the other hand, Table 1 shows that the lag-0 trial outcomes are all ambiguous: both "+" and "-" lag-0 trial outcomes are associated with both S+ and S- trials. However, the lag-1 trial outcomes for both the S+ and S- trials in double alternation are consistent: "+" as a lag-1 outcome in double alternation is always associated with S- and "-" as a lag-1 outcome is always associated with S+. In double alternation, therefore, the lag-1 trial outcome, whether the second trial back was S+ or S-, is assumed to control the behavior.

The hypothesis has specific implications concerning the relative frequency of errors on S- trials within the various sequences studied. (The rats seldom made errors on S+ trials, reflecting presumably a general tendency toward errors of commission rather than omission.) According to the hypothesis, the rats should respond more frequently (*i.e.*, make more errors) on those S- trials in the sequence for which the lag-0 outcomes are ambiguous. This result will be expected because responding on these S- trials will be controlled by higher lag trial outcomes that are consistent; and the higher the lag of the trial outcomes that control the behavior, the greater the possibility that responding can be evoked by lower lag trial outcomes associated with S+ elsewhere in the sequence.

In addition, the hypothesis also leads to definite predictions concerning the effects of experimentally manipulating stimuli in the sequence on the relative frequency of errors in the sequence. These predictions were tested in a series of experiments in which groups of rats learned alternation sequences in which a white-noise stimulus (the inter-trial stimulus) was sounded throughout an ITI in the sequence. The inter-trial stimulus

was introduced into the sequence at the beginning of alternation training, since it did not reliably affect responding if it was inserted after the rats had learned patterned responding without the inter-trial stimulus.

In the "Type A" sequences in Table 1, the inter-trial stimulus was placed in the ITI preceding a S+ trial. According to the hypothesis, the inter-trial stimulus at this location was expected to decrease the frequency of errors on certain specified S- trials in the sequence; these S- trials are designated by an asterisk in Table 1. Note that the decreased errors were predicted for S- trials that did not directly follow the inter-trial stimulus; on the contrary, most of the S- trials for which decreases in errors were expected immediately preceded the inter-trial stimulus.

For the two "Type B" (control) sequences in Table 1, the inter-trial stimulus was placed in an ITI in the sequence where the ambiguity of the lag-0 trial outcomes was left unchanged by introduction of the inter-trial stimulus. Hence the inter-trial stimulus was expected *not* to change the distribution of errors on trials in these sequences.

The extent to which the discrimination hierarchy hypothesis provided an accurate description of the relative frequency of errors on S- trials within the different sequences, and the extent to which differences in errors on S- trials between groups trained with and without the inter-trial stimulus conformed to theoretical expectation can be evaluated by examining the various sequences in turn.

S+S-S- (Table 1, Sequence III). The "+" lag-0 trial outcome associated with S- on Trial 2 (as designated in Table 1) of this sequence is consistent and should control responding on this trial; but the "-" lag-0 trial outcome associated with S- on Trial 3 of this sequence is ambiguous because a "-" lag-0 trial outcome is also associated with S+ on Trial 1. Responding on Trial 3 will therefore be controlled primarily by its consistent lag-1 trial outcome. Consequently, more errors would occur on Trial 3 than on Trial 2 because the lag-0 trial outcome on Trial 3 is associated with reinforcement on 50% of its appearances in the sequence and would be expected to evoke some responding.

In the S+S-S- IS Type A sequence, in contrast, the inter-trial stimulus is the lag-0 trial outcome for Trial 1. The "-" lag-0 trial out-

come for Trial 3 is now consistently associated only with an S⁻ trial and should control the behavior on this trial. Hence, there should be fewer errors on Trial 3 of the Type A IS-sequence than on Trial 3 of this same sequence with no inter-trial stimulus. Figure 5 shows that this prediction was confirmed.

The S⁺ IS S⁻S⁻ Type B sequence was studied to test whether the inter-trial stimulus reduced errors not by eliminating ambiguity, as asserted by the discrimination hierarchy hypothesis, but rather by "marking" the rat's place in the sequence. The inter-trial stimulus was placed in the sequence where the lag-0 trial outcome for the following trial was consistent when there was no inter-trial stimulus in the sequence. If the inter-trial stimulus served primarily to orient the animal in the sequence, it should have reduced errors no matter where it was in the sequence. According to the hypothesis, on the other hand, placing an inter-trial stimulus after S⁺ in this sequence should not have affected performance because it did not change the ambiguity of lag-0 stimuli: as indicated in Table 1, one consistent lag-0 stimulus (the inter-trial stimulus) merely took the place of another consistent lag-0 trial outcome. Figure 5 shows, in support of this latter interpretation, that the inter-trial stimulus placed after the reinforcement did not alter the pattern of responding.

S⁺S⁺S⁻S⁻ (Double Alternation: Table 1, Sequence II). During both acquisition (Fig. 3) and maintenance (Fig. 5) of double alternation, the rats made many more errors (*i.e.*, responded more frequently) on Trial 4 than on Trial 3. As previously explained, double-alternation responding is controlled by lag-1 trial outcomes. Table 1 shows that the lag-0 and lag-1 trial outcomes are the same (both "+") on Trial 3, whereas on Trial 4 the controlling lag-1 outcome is "+" while the lag-0 trial outcome is "-". This "-" lag-0 trial outcome on Trial 4 has been associated with S⁺ on 50% of its appearances as a lag-0 outcome in the double-alternation sequence. Hence, more responding would be expected on Trial 4 than on Trial 3, due to the incompatible lag-0 trial outcome present on Trial 4.

Introduction of the inter-trial stimulus between Trial 4 and Trial 1 of the double-alternation sequence eliminates the ambiguity of the lag-0 outcome on Trial 4, since, in the IS-sequence, a "-" trial outcome is associated

as a lag-0 trial outcome only with Trial 4. Hence, responding on Trial 4 of the inter-trial stimulus sequence should be controlled by this lag-0 outcome, whereas in the double-alternation sequence with no inter-trial stimulus, responding on Trial 4 is controlled by a lag-1 trial outcome. Figure 5 shows that, as predicted, the rats made fewer errors on Trial 4 of the IS-sequence than on Trial 4 of the double-alternation sequence with no inter-trial stimulus.

S⁺S⁻S⁻S⁻ (Table 1, Sequence IV). Table 1 shows that the lag-0 outcomes on Trial 3 and 4 of this sequence are ambiguous, and, in addition, the lag-1 trial outcome is also ambiguous on Trial 4. The lowest lag trial outcome that is consistent on Trial 4 is the lag-2 trial outcome. Therefore, errors should occur on Trial 3 due to the incompatible lag-0 trial outcome for that trial, and a still greater number of errors should occur on Trial 4 due to interference by both the lag-0 and lag-1 outcomes. Figure 5 shows that, as expected, errors rarely occurred on the trial immediately following reinforcement, and then increased progressively with succeeding S⁻ trials.

Table 1 shows that inserting an inter-trial stimulus between Trial 4 and Trial 1 of this sequence eliminates the ambiguity of the lag-0 trial outcome for *both* Trial 3 and Trial 4. Consequently, there should be fewer errors on each of these trials in the Type-A IS-sequence than in the sequence with no inter-trial stimulus. The results presented in Fig. 5 confirm this prediction.

However, the results obtained with the Type-B IS-sequence (S⁺S⁻ IS S⁻S⁻) were only partially predicted. As expected, Fig. 5 shows that errors on Trial 3, immediately following the inter-trial stimulus, were decreased by the inter-trial stimulus; but it was not predicted that errors would also decrease on Trial 4 of this sequence. The "-" lag-0 trial outcome for Trial 4 remains ambiguous in the Type-B IS-sequence: it is associated with S⁺ as a lag-0 trial outcome for Trial 1 as well as with S⁻ for Trial 4. However, it might be noted *post hoc* that the inter-trial stimulus could have converted the controlling trial outcome for Trial 4 from a lag-2 to a lag-1 outcome (the inter-trial stimulus), thus accounting for the modest reduction of errors on Trial 4.

S⁺S⁺S⁻ (Table 1, Sequence V). The hypothesis predicted unequivocally that an inter-trial

stimulus placed between Trial 1 and Trial 2 should decrease errors on Trial 3. With no inter-trial stimulus, the "+" lag-0 trial outcome associated with S- on Trial 3 is also associated with S+ on Trial 2. Hence, replacing the "+" lag-0 stimulus on Trial 2 with the inter-trial stimulus should have made the lag-0 trial outcome for Trial 3 consistent, responding on Trial 3 would then have been controlled by the lag-0 trial outcome, and errors should have decreased. But, according to Fig. 5, the results failed to support the prediction. The rats that learned the sequence with the inter-trial stimulus present made as many errors on Trial 3 as those that learned the sequence without the inter-trial stimulus.

Evaluation of the discrimination hierarchy hypothesis. The hypothesis has been shown to be useful for describing, predicting, and controlling the patterns of responding in the various sequences. Nevertheless, unequivocal failure of prediction was specifically noted for one IS-sequence, and partial failure of prediction was reported for another IS-sequence.

More general inadequacies of the theoretical analysis should also be noted. The generally high level of performance on S+ trials was not satisfactorily explained. Nor was it stated precisely what aspect of the "outcome" of the S+ trials controlled behavior on subsequent trials, whether it was the responding, the reinforcement, or perhaps the mere occurrence of the S+ trial irrespective of the behavior and its consequences. The conceptual status of the S- trials, also, was vague: what were the stimulus properties of S- trials on which the rat failed to respond, in contrast to the stimulus properties of S- trials on which the rat did respond? In presenting the hypothesis it was simply assumed, without explicit theoretical justification, that the stimulus properties of these two types of S- trials were identical.

The discrimination hierarchy hypothesis is a trial-by-trial rather than a "pattern as a whole" approach to sequential patterned responding. Nevertheless, in order to predict the pattern of responding, it was necessary to con-

sider the control of responding on individual trials in the context of all the trials in the sequence. The contingencies that controlled the rat's behavior on a given trial depended on relations between the outcomes of the preceding one, two, or even three trials.

Hence, a different type of hypothesis might also have been examined, one that emphasizes learning of the "general pattern". For example, Restle (1967) described experiments in which human subjects learned repeating patterns by "grouping" the trials. It should be possible to devise analogous experiments to discover if rats, like Restle's humans, also "recode" sequences and learn to respond in accordance with rather general "rules".

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