THE ROLE OF REINFORCEMENT IN CONTROLLING SEQUENTIAL IRT DEPENDENCIES¹

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Sequential dependencies were investigated with two rats in a mixed and in a tandem differential-reinforcement-of-low-rate-responding schedule. In each schedule, 5-sec and 15-sec components were presented in fixed alternation. In the mixed schedule, a 5-sec interresponse time followed a 15-sec interresponse time and a 15-sec interresponse time followed a 5-sec interresponse time in predictable sequence. The correlation between prior and subsequent interresponse times, however, existed only when the prior interresponse time resulted in reinforcement. In the tandem schedule, an interresponse time greater than 5 sec in the differential-reinforcement-of-low-rate 5-sec component was not associated directly with reinforcement. One subject demonstrated sequential response patterns similar to those noted in the mixed schedule, even though the prior 5-sec interresponse time was not reinforced in the tandem schedule. The results indicate that the prior interresponse time length alone is not sufficient to influence the subsequent interresponse time length. Implications are, however, that a temporal response pattern arises when an interresponse interacts with schedule contingencies to control the interreinforcement interval.

In the investigation of interresponse time (IRT) patterns, a correlation of sequential response intervals suggests that a prior IRT interval functions as a control or temporal discriminative stimulus for a subsequent IRT. Unfortunately, it is not an easy task to isolate the temporal influence of the IRT. A reinforcement schedule is a complex set of interacting variables in which any number of events can and often do occur within the bounds of adjacent IRTs. While duration is a discriminable property of the IRT, Morse (1966) argued that the complex nature of any reinforcement schedule obscures the contribution of temporal discrimination to response rate. On the other hand, the prior IRT has been shown to control the choice of reinforcement schedules (Stubbs, 1968) and to influence the response rate in a subsequent schedule (Reynolds, 1966). In these studies, however, the relation between sequential IRTs was not an object of investigation. There is actually little evidence to indicate in what manner and under what conditions the subsequent IRT is a function of discriminative control of the prior IRT length. Previous studies of IRT dependencies (Ferraro, Schoenfeld, and Snapper, 1965; Weiss and Laties, 1965; Kintch, 1965; Wertheim, 1965; Williams, 1968) designate generally whether or not a particular reinforcement schedule pro-

duces sequential IRT patterns; but, as Williams (1968) concluded, specification of the variables maintaining these response patterns requires a great deal of further investigation.

The purpose of the present study was, first, to establish strong sequential dependencies and, second, to examine these dependencies under the conditions of reinforcement and nonreinforcement. Sequential IRT dependencies were accessed by differential-reinforcement-of-low-rates (DRL) 5-sec and DRL 15-sec components presented in fixed alternation. It was predicted that a sequence of 5-sec and 15-sec IRTs would be emitted to correspond with the sequence of the components. To reduce some of the complexity of interacting variables, mixed and tandem schedules were both used because discrete stimuli are not correlated with the components of these schedules. The IRT length and whether or not the response is reinforced are the only clues indicating the operating DRL component.

METHOD

Subjects and Apparatus

Two male albino rats (S-81 and S-84) were deprived of water on a 24-hr cycle. In addi-

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tion to water reinforcers received during the experimental session, the subjects received 0.5-hr access to water after each session. The experimental chamber was a standard Grason-Stadler operant box housed within a sound-attenuating refrigerator shell. Water reinforcers (.04 ml) were delivered into a tubular trough adjacent to the response lever. A solenoid water valve, mounted external to the refrigerator shell, controlled the water in a gravity flow system. Because the water delivery was silent, a buzzer was used to facilitate bar-press training and was disconnected after Session 30. Continuous white noise was introduced at this time. This substitution enabled the experimenter to examine the dependency of the behavior upon the buzzer.

An IBM 024 card punch recorded the schedule component in effect at the time of the IRT, whether or not the IRT was reinforced, and the length of the IRT in 0.1 sec up to 52 sec. The response measurement, the card punch, and the experimental dependencies were controlled by solid state logic circuits.

Procedure

The subject received a single session of water magazine training followed by a session of continuous reinforcement for bar pressing. In the mixed schedule, the two DRL components were scheduled without correlated stimuli so that an IRT greater than 5 sec resulted in reinforcement whenever the DRL 5-sec component was in effect, and an IRT greater than 15 sec resulted in reinforcement whenever the DRL 15-sec component was in effect. The two components followed each other in simple alternation.

Following the mixed schedule, the subjects were placed on a tandem schedule. This schedule was similar to the mixed schedule; that is, in the DRL 5-sec component, responses terminating an IRT greater than 5 sec initiated the DRL 15-sec component. However, the 5-sec IRT was not explicitly reinforced; reinforcement occurred only in the DRL 15-sec component. Both subjects received 75 mixed and 20 tandem sessions, 2.5 to 3 hr long.

RESULTS

Mixed Schedule

Each subject's performance stabilized by the twentieth session, and no serious disruption

in this performance resulted from the elimination of the response-dependent buzzer. Inter-response time transition matrices of the last two consecutive sessions for each subject are shown in Fig. 1. These matrices display the conditional probability of subsequent IRTs, given the occurrence of a particular prior IRT. The prior IRT is indicated by the matrix row and subsequent IRT by the matrix column. To the right of the matrices, the marginal probabilities illustrate the IRT distribution independent of the prior IRT. In the following text, mention of a specific IRT refers to a 5-sec class interval of which the name IRT is the lower bound value (the last interval, however, represents IRTs greater than 15 sec).

Fig. 1. The rows and columns of each matrix represent class intervals of time which are interpreted from the table at the top of the figure. The column of values to the right of each matrix contains absolute IRT probabilities with regard to the row intervals. Total number of responses are shown below these columns.

The two largest conditional probabilities in each matrix are circled and are related to the subject's behavior following a 5-sec IRT and a 15-sec IRT. With the emission of a prior 5-sec IRT, the most probable class of IRTs is 15 sec. The pattern is reversed if the prior IRT is 15 sec. The probability of reinforcement for a response is high as long as the cycling DRL 5-sec and DRL 15-sec components coincide with a sequence of 5-sec and 15-sec IRTs. The matrix, however, fails

to disclose the relationship between the IRT reinforcement and the particular DRL component.

Figure 2 illustrates the transition data in greater detail. Transition probabilities here depend on whether the prior 5-sec IRT was reinforced or nonreinforced. The relationship of the DRL component and the IRT is shown in this analysis. For example, the 5-sec IRT could be reinforced only if the DRL 5-sec component was in effect. When the prior 5-sec IRT is reinforced, the subjects demonstrate a high probability of emitting a subsequent 15-sec IRT. Figure 3 illustrates separate transition probabilities for the prior 10-sec IRT. These probabilities differ as a function of whether or not the prior IRT was reinforced. In Fig. 2 and 3, it may be seen that short IRTs (0 sec) seldom are emitted when the prior IRT is reinforced, but their emission increases when the prior IRT is nonrein-

forced. In further comparison of these figures, reinforcement of the prior 5-sec and prior 10-sec IRTs, although occurring in the same DRL 5-sec component, lead to quite different predictions of the most probable IRT class. Breakdown of prior 0-sec IRTs and of prior 15-sec IRTs are not shown, since these IRTs were invariably nonreinforced or reinforced, respectively.

A schedule component will not change or cycle to the other component as long as the IRT fails to be reinforced. Thus, a series of nonreinforced IRTs may occur during a single cycle of a particular component. However, the foregoing analyses indicate only the relation between pairs of IRTs. The question arises as to whether or not the subject's behavior changes during a sequence of nonreinforced IRTs. In Fig. 4, beginning with the establishment of the component cycle, the first response indicates the subject's distribu-

		Subject 81					
		SUBSEQUENT IRT					
		0	5	10	15		
Reinforce	5sec	.00	.05	.43	.52	Sess 74	
Nonreinf.	5sec	.30	.06	.43	.21		
Reinforce	5sec	.02	.07	.32	.59	Sess 75	
Nonreinf.	5sec	.18	.03	.36	.43		

		Subject 84					
		SUBSEQUENT IRT					
		0	5	10	15		
Reinforce	5sec	.00	.04	.12	.84	Sess 74	
Nonreinf.	5sec	.12	.07	.31	.50		
Reinforce	5sec	.01	.03	.12	.84	Sess 75	
Nonreinf.	5sec	.12	.05	.40	.43		

Fig. 2. Two sets of conditional probabilities are shown for each subject and each of the last two sessions. Both sets of values are conditional upon a 5-sec prior IRT. The first set is also dependent upon the reinforcement of the prior IRT, while the second set is dependent upon the nonreinforcement of the prior IRT.

		Subject 81					
		SUBSEQUENT IRT					
		0	5	10	15		
Reinforce	10 sec	.00	.75	.15	.10	Sess	74
Nonreinf.	10 sec	.25	.01	.35	.39		

		Subject 74					
		SUBSEQUENT IRT					
		0	5	10	15		
Reinforce	10 sec	.00	.85	.15	.00	Sess	75
Nonreinf.	10 sec	.19	.01	.40	.40		

		Subject 84					
		SUBSEQUENT IRT					
		0	5	10	15		
Reinforce	10 sec	.12	.72	.00	.16	Sess	74
Nonreinf.	10 sec	.35	.07	.18	.40		

		Subject 75					
		SUBSEQUENT IRT					
		0	5	10	15		
Reinforce	10 sec	.11	.89	.00	.00	Sess	75
Nonreinf.	10 sec	.30	.06	.32	.32		

Fig. 3. Two sets of conditional probabilities are shown for each subject and each of the last two sessions. Both sets of values are conditional upon a 10-sec prior IRT. The first set is also dependent upon the reinforcement of the prior IRT, while the second set is dependent upon the nonreinforcement of the prior IRT.

tion of first IRTs in that component. If any first IRT is less than the criterion interval, then a second response is required, and so on until the IRT is reinforced. It is known that the IRT antecedent to the first IRT in a component must be reinforced, since this is the only way in which the subject can enter a component. Furthermore, it is known that, beginning with the second response and until the subject quits the component, the earlier IRTs in the series were nonreinforced. In considering the distributions in which the prior IRT was nonreinforced, it is noted

Fig. 4. Relative frequency distributions of ordered IRTs for Session 74. The order is based upon the sequence of responses following the initiation of the DRL 5-sec and DRL 15-sec components. In the first distributions of first responses, the prior IRTs were reinforced. In the DRL 15-sec component, beginning with the second distribution through the fifth distribution, the prior IRTs were nonreinforced. Similarly, for the second and third distributions in the DRL 5-sec component. Only three distributions are shown for the DRL 5-sec component, for each succeeding distribution represents a reduced sample of IRTs and there were fewer nonreinforced IRTs in this particular component.

that these distributions are somewhat similar to one another but contrast sharply with the first distribution in which the prior IRT was reinforced. A factor contributing to the similarity among distributions is the low 5-sec probability when the prior IRT is not reinforced.

Tandem Schedule

Results of the mixed schedule indicated that a subsequent IRT is influenced by whether or not the prior IRT is reinforced. The purpose of the tandem schedule was to determine if a nonreinforced prior IRT can exert control over the probability of occurrence of various subsequent IRTs.

The transition matrices for the twentieth session are presented in Fig. 5. For S-84, a subsequent 15-sec IRT is likely to follow a 5-sec IRT. When the prior IRT is 15 sec, there is a tendency for a subsequent 5-sec IRT. The general performance pattern of the matrix is somewhat similar to the pattern observed with the mixed schedule. One difference between earlier and later performance is the smaller probability of the 0-sec IRTs in the tandem schedule. The transition matrix for S-81 clearly deviates from the pattern characteristic of the mixed schedule. However, the 0-sec IRTs show a decrease in probability with respect to the values of these IRTs in the mixed schedule. This decrease is parallel to that shown by S-84 in the present schedule.

Subject - 81		Subject - 84	
	0 5 10 15		0 5 10 15
0	.09 .09 .17 .65	0	.00 .00 .14 .86
5	.00 .00 .64 (36)	5	.02 .00 .11 (87)
10	.07 .01 .28 .64	10	.05 .00 .12 .83
15	.03 (03) .29 .65	15	.01 (44) .22 .33
(n=119)		(n=611)	

Fig. 5. IRT transition matrices for both subjects. The class intervals are represented in the table at the top of Fig. 1. The column of values to the right of each matrix contains absolute IRT probabilities with regard to the row intervals. Total number of responses are shown below these columns.

DISCUSSION

The transition matrices of the mixed schedule demonstrate sequential dependencies in free-operant bar pressing (Fig. 1). This dependency, however, is not controlled solely by prior IRT duration. Reinforcement of the prior IRT is found to influence the following IRT. The problem posed by the obtained relationship is that of attributing the source of dependency or at least proportioning its influence between reinforcement and the prior IRT.

Cruse, Vitulli, and Dertke (1966) have shown in a two-component schedule that a quantitative difference in reinforcement at the start of a component will control the rate and pattern of performance. In the mixed schedule of the present study, a different response rate is associated with the start of each component cycle. Reinforcement does not, however, differentiate a particular component. The only distinguishing factor of reinforcement is the associated IRT length. Reinforcement indicates only that the component has changed and that a different response pattern is required of the new component; but the direction of the change, that is, which component is in effect, must be indicated by the prior IRT length. On the other hand, information calling for a different response pattern is potentially represented by certain nonreinforced prior IRTs. Nonreinforcement of a 5-sec IRT means that the DRL 15-sec component is in effect and will remain so for the next IRT. In a similar manner, reinforcement of a 5-sec IRT means that the DRL 15-sec component follows. Both events indicate, at least to the experimenter, that only a subsequent IRT greater than 15 sec will be reinforced. The expectancy that similar distributions of subsequent IRT would be evident as a function of either event is not verified. The probability of the 15-sec IRT is greater when the prior 5-sec IRT is reinforced and less when it is not (Fig. 2).

Contrast between distributions is even greater when a prior IRT is 10 sec (Fig. 3). A reinforced prior 10-sec IRT occurs in the DRL 5-sec component. Although the DRL 15-sec component follows this event, the most probable subsequent IRT is 5 sec and is in the direction opposite to the current reinforcement criterion. However, the distribution of subsequent IRTs associated with reinforced prior 10-sec and prior 15-sec IRTs are similar in pattern. This similarity suggests common controlling properties with regard to the prior IRTs; but, depending on whether the prior IRT was 10 sec or 15 sec, the subsequent behavior involves a different reinforcing outcome, since the components are not the same. In a multiple schedule, specific components are indicated by discrete events. In the mixed schedule, these events are not present, but the subject's own behavior may serve as a stimulus in the manner of a multiple sched-

ule (Ferster and Skinner, 1957). The discriminative stimuli generated by the subjects in the mixed DRL schedule are temporal. A reinforced long IRT length, defined by the 10-sec and 15-sec class intervals, sets the occasion for the subsequent 5-sec IRT, revealing simply that the subjects may be failing to discriminate accurately whether a long IRT is short of the 15-sec reinforcement criterion or greater than this criterion. In this discrimination, the feedback is delayed at least 5 sec.

In the transition matrices, the IRT distributions associated with nonreinforced prior IRT are similar in pattern. Furthermore, following nonreinforced IRTs, successive IRT distributions remain approximately the same (Fig. 4). This consistency in the distributions indicates a non-sequential IRT pattern. That is, the length of a nonreinforced prior IRT does not influence the length of subsequent IRTs. This finding is at odds with Logan's (1967) suggestion that when two values of the DRL components are different, the subject learns to maximize reinforcement by responding first after the shorter interval and then waiting the longer interval if indicated (*i.e.*, in the case where the prior IRT is nonreinforced). Logan noted different responding following reinforced and nonreinforced prior IRTs; however, he did not extend this observation to the response pattern associated with a sequence of nonreinforced IRTs. If the subjects in the present study were maximizing reinforcement, then the general length of IRTs in each successive distribution in which the prior IRT was nonreinforced would be shifted more and more towards the criterion interval.

In summary of the mixed schedule, reinforcement and the prior IRT length interact in some manner to control sequential behavior. Comparison of the mixed and tandem schedule dependencies suggests that these variables systematically influence the rate of reinforcements per unit time. In the tandem schedule, sequential dependency was maintained even though reinforcement was not always associated with the prior IRT; however, these nonreinforced IRTs are related to the reinforcement of the subsequent IRT. An IRT less than 15 sec in the DRL 5-sec component can increase the rate of reinforcements per unit time. The interreinforcement interval for S-84 was often 20 sec (*i.e.*, combination of 5-sec and 15-sec IRTs). While sequential de-

pendency was indicated for this subject, the other subject (S-81) did not demonstrate this response pattern; the interreinforcement interval was generally 30 sec. A criticism of this study is the failure to extend the number of tandem sessions beyond 20.

In the mixed schedule, reinforcements per unit time was operating differentially. First, while it was possible for the subjects to emit a continuous sequence of 15-sec IRTs and be reinforced for each response, a 10-sec period would be wasted on every alternate 15-sec IRT. Evidence demonstrates that the probability of a 15-sec to 15-sec IRT sequence was very small. Second, unlike the tandem schedule, no change in the mixed DRL components occurred when the prior IRT was not reinforced. All nonreinforced IRTs in the mixed schedule only extended the duration of the interreinforcement interval. Under these conditions, behavior was found to revert to a non-sequential pattern.

The results suggests that sequential IRT dependency is enhanced when the prior IRT acts to reduce the interval of reinforcement under which the subsequent IRT is reinforced. Conversely, a substantial measure of sequential IRT dependency will not be evident in schedules that program the interreinforcement interval independent of the sequential IRT. For example, in variable-interval and fixed-interval schedules, nonreinforced IRTs do not affect the time of reinforcement. While Kintch (1965) and Williams (1968) report that sequential IRT dependencies occur with statistical significance in the variable-interval schedule, Kintch indicates that the degree of association of these dependencies is very small. In the free-avoidance schedule, a low level of sequential association should be found with nonshocked IRTs. An avoidance response in no way changes the subsequent shock interval that is controlled by an external clock. Although Wertheim (1965) reported sequential IRTs associated with a number of prior class intervals in a free-avoidance schedule, Angle (1969) found IRT dependencies a function of IRTs directly associated with shock. On the other hand, for example, it may be possible to enhance sequential IRT dependencies in an avoidance schedule if arranged as a limited-avoidance schedule (Sidman, 1967) and designed in the manner of the mixed schedule of the present study (*i.e.*,

two components of different reinforcement criteria presented in fixed alternation). In this instance, a successful avoidance response would control the subsequent interreinforcement interval. Finally, it may be suggested that a second-order IRT dependency, in which two IRTs comprise the prior event, will arise when each of the IRTs directly control the interreinforcement interval. This type of schedule contingency was not the case in the present study, and, in results not reported, there was little evidence of significant second order dependency.

Another condition of the contingencies of the tandem schedule may be related to the low probability of short IRTs (0 sec). Morse (1966) raised the problem of accounting for the frequency of short IRTs when these IRTs are not reinforced. In the mixed schedule, the probability of these short IRTs were moderately high. Furthermore, they are similar to the "bursting" response pattern of the DRL schedule reported by Sidman (1956). Holz and Azrin (1963) attributed the source of these short IRTs to the nonreinforced prior IRT. However, the results of the tandem schedule, that is, the low probability of short IRTs, link the explanation of these IRTs to the subsequent IRT. In the DRL 5-sec component of this schedule, the contingencies prevented a 0-sec IRT from being chained directly to a reinforced IRT. IRT chaining, in which a terminal IRT is reinforced, may account for the frequency of a preceding nonreinforced IRT in the mixed schedule, but answers of this nature require that the reinforcement pattern of a sequence of IRTs be controlled. A particular IRT sequence mentioned in regard to the mixed schedule is that of the 5-sec IRT following a 15-sec IRT. Both IRTs were regularly reinforced in this sequence. The 5-sec IRT can, of course, freely follow any class of IRT; but given this opportunity, the 5-sec IRT seldom occurs unless preceded by a 15-sec IRT (or a reinforced 10-sec IRT), even though the 5-sec IRT has a high relative frequency of reinforcement and is reinforced approximately as often as a 15-sec IRT.

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