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CONCURRENT SCHEDULES OF REINFORCEMENT: THE EFFECTS OF AN UPPER LIMIT OF REINFORCEMENT AVAILABILITY ON CHANGEOVER BEHAVIOR

by

Ivor Durham Groves

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Approved by

Dissertation Adviser

APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of the Graduate School at the University of North Carolina at Greensboro.

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Pigeons partition total response output and time between both schedules of a concurrent variable-interval pair. A large amount of data has been reported which suggests that responses and time are partitioned so that they are proportional to the relative rates of reinforcement provided by concurrent variable-interval schedules. In order to obtain all programmed reinforcers, subjects must emit responses (changeover responses) which bring them into contact with each of the alternative schedules. The temporal distribution of the changeover response in the presence of each schedule has been implicated as an important factor in the matching relationship. The present study examined the relationship between changeover behavior and the occurrence of reinforcers in order to elucidate the variables affecting the temporal distribution of changeover behavior. The results demonstrated that changeover behavior occurred most frequently immediately following the point in time at which the highest frequency of reinforcement was obtained. The results are discussed in terms of the discriminative control of changeover behavior and the role of changeover behavior in concurrent schedules of reinforcement.

ACKNOWLEDGMENTS

I wish to express my appreciation to the members of my Doctoral Committee, Dr. Robert Eason, Dr. Richard Shull, Dr. Kendon Smith, and I would like to particularly thank Dr. Aaron J. Brownstein for his advice and guidance throughout my graduate career. I also wish to thank Peter Balsam for his assistance, counsel and friendship.

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INTRODUCTION

Concurrent schedules of reinforcement program reinforcers for two or more mutually exclusive response classes. Each response class is associated with an independent schedule of reinforcement which specifies when reinforcers for that response will be arranged. The reinforcement schedules are continuously available and the subject may change from one schedule to another at any time except during reinforcement.

The data generally obtained from concurrent procedures show that the proportion of responses made to one of the two available schedules is approximately equal to or "matches" the proportion of reinforcements obtained on that schedule (Herrnstein, 1961). This relationship is expressed by the following equation:

$$\frac{R_A}{R_A + R_B} = \frac{r_A}{r_A + r_B} \qquad \text{(equation 1)}$$

where R_A equals the number of responses emitted on key A and R_B equals the number of responses emitted on key B; r_A and r_B equal the number of reinforcements obtained on key A and key B respectively.

A second consistent finding is that the proportion of time allocated to one schedule equals or "matches" the proportion of reinforcements obtained on that schedule

(Baum & Rachlin, 1969; Brownstein & Pliskoff, 1968). The following formula expresses this relationship:

$$\frac{T_A}{T_A + T_B} = \frac{r_A}{r_A + r_B} \qquad \text{(equation 2)}$$

where T_A and T_B equal the time spent in the presence of stimuli associated with schedules A and B respectively; r_A and r_B are the same as in equation 1.

A third relationship usually obtained from concurrent schedules is that the number of times the subject changes from one schedule to the other, designated "changeovers," decreases as a function of the increasing discrepancy in the proportion of reinforcements assigned to each schedule (Brownstein & Pliskoff, 1968; Herrnstein, 1961; Stubbs & Pliskoff, 1969).

Several different conceptualizations have been proposed as the appropriate manner in which the relationships should be considered. Herrnstein (1970) considers the relationship between response output and relative reinforcement to be of major significance in concurrent schedules. Herrnstein has proposed a molar model of choice behavior which is based on the empirical matching observed in concurrent schedules. Basically, the molar model emphasizes the relationship between response output and reinforcement input. In the long run, the subjects' responses are distributed in proportion to the reinforcement value obtained in the different alternatives (Baum, 1973). The emphasis is on the long run outcome which results from exposure to a set of alternatives over a period of time. Consider, for example, a subject exposed to concurrent schedules which provide 70% of the reinforcers on one schedule and 30% of the reinforcers on the other schedule. In the long run, the subject will respond in such a manner that 70% of his responses and time will be allocated to the 70% schedule and 30% of his responses and time will be allocated to the schedule which provides 30% of the reinforcers. The molar position concludes that this outcome is obtained because the subject's behavior is determined by the overall distribution of reinforcers.

Catania (1966), Brownstein and Pliskoff (1968), and Baum and Rachlin (1969) have argued that the matching of relative time allocated to a schedule to the relative rate of reinforcement on that schedule is of primary importance in concurrent schedules. Catania (1966) suggested that, if the organism's rate of responding is approximately constant, the matching of time to relative rates of reinforcement would also produce response matching. It has been demonstrated that time matching is obtained when no explicit responses are required for reinforcement (Baum & Rachlin, 1969; Brownstein & Pliskoff, 1968). Bauman, Shull, and Brownstein (1975) demonstrated that time matching is obtained when responses are required in only one of two available reinforcement schedules. These data suggest that time matching is obtained independently of specific main key response requirements.

A third conceptualization of concurrent schedules places emphasis on the strength of the changeover (CO) operant (Schull & Pliskoff, 1967). The time allocated to each schedule in a concurrent situation is mathematically related to the ratio of the changeover rates obtained on each schedule. The measure for the ratio of the changeover rates is $\frac{\frac{CO_a}{T_a}}{\frac{CO_b}{T_b}}$, where CO_a and CO_b represent changeovers from each of the schedules and T_a and T_b represent time spent in each schedule. The formula for the ratio of the time measure is $\frac{T_a}{T_b}$, where T_a and T_b are the same as in the preceding equation. The ratios of the terms in the changeover formula are inversely proportional essentially to the terms in the relative time formula: CO_a and CO_b are usually large numbers which cannot differ by more than one unit. If the ratio of the rate of CO_a and CO_b is changed, then the ratio of the time measure must also change.

It follows from the above relationship that, if the CO rate ($\frac{CO_a}{T_a}$) on one schedule can be affected differentially, then the overall time allocation function will change in proportion to the change in the relative CO rate. Thus if the CO rate on one schedule is tripled, relative to the CO rate on the other schedule, then the amount of time allocated to that schedule will decrease proportionally.

If CO behavior is of key importance in the relationships observed in concurrent schedules, then it is important that the factors which control CO behavior be examined. At this time, the variables controlling the rate of occurrence of CO behavior are not clear. Several procedures have been developed, however, which do affect the rate of CO behavior when used with concurrent schedules. One such procedure is the changeover delay (COD). The COD is a period of time following a CO response during which responses on the main key cannot produce programmed reinforcers. Reinforcers arranged during the COD are held until the COD elapses. Generally, each CO response initiates the delay period.

Shull and Pliskoff (1967) varied the duration of the COD from 0 to 20 sec with each of two pairs of concurrent variable interval schedules. One concurrent pair programmed 50% of the reinforcers on each schedule and the other concurrent pair programmed 30% of the reinforcers on one schedule and 70% on the other schedule. CO rate decreased as the duration of the COD increased. The decrease was the same for both schedules which programmed equal rates of reinforcement. On the schedule which programmed unequal rates of reinforcement, the larger the COD, the more rapid the changeover from the 30% to the 70% schedule relative to the changeover from the 70% to the 30% schedule. In other words, with unequal concurrent schedules, increasing the COD value affects the rate of CO from the schedules differentially. Shull and Pliskoff concluded that the time and response partitions became increasingly extreme as a result of the increase in the ratio of CO rates.

Todorov (1971) conducted a similar experiment in which electric shock and timeout were programmed in place of the COD. A changeover key concurrent procedure was employed in which first shock and then timeout were made contingent on CO responses. The rate of CO behavior decreased as shock intensity was increased. The relative time and relative response measures deviated from matching when unequal reinforcement schedules were in effect. Similar results were also reported when timeout was substituted for the electric shock CO contingency.

Other investigators have reported that fixed ratio changeover requirements (Brownstein, Donaldson, & Shull, 1972) and variable interval changeover contingencies (Brownstein, Jones, & Shull, 1971) disrupt the matching of responses and time.

The data obtained from concurrent schedules in which CO contingencies are manipulated show that CO contingencies can affect the rate of occurrence of changeover behavior. In addition, in some circumstances interchangeover time on the respective schedules may be affected differentially. In general, the data suggest that whether or not response and time matching is obtained from a concurrent situation is dependent on the variables affecting the occurrence of changeover behavior.

Pliskoff and Green (1972) reported data which demonstrated that CO responses can be brought under stimulus control. A multiple schedule procedure was used. Generally, multiple schedules are programmed so that two or more schedules of reinforcement are arranged sequentially. Each schedule is associated with a particular key color which signals which schedule is available at that time. The duration of each schedule's availability is determined by the experimenter. Pliskoff and Green programmed a multiple schedule in which each schedule component consisted of two concurrently available VI schedules of reinforcement. During one component, a stimulus was correlated with the availability of a reinforcer arranged by one of the VI schedules. The stimulus was programmed to appear only when the other VI schedule was assigned to the main key. Thus, the stimulus signalled the availability of a reinforcer which could be obtained by a CO response followed by a main key response. During the other component of the multiple schedule, routine concurrent VI schedules were programmed.

The investigators reported that discriminative control of the CO response was established. Eighty-five to ninety percent of the time spent in the signalled component was allocated to the schedule which provided stimuli signalling the availability of reinforcement on the alternative schedule. Time allocation in the no-stimulus component corresponded to that predicted by the matching function.

Pliskoff and Green discussed the lack of information on the momentary determinants of changeover behavior. They had demonstrated that COs could be brought under the control of a discriminative stimulus but could only speculate on the controlling variables in routine concurrent schedules. It was suggested that CO responses might be occasioned by the occurrence of reinforcers in regular concurrent schedules.

In concurrent schedules of reinforcement, the subjects change over to a schedule, respond on the schedule for a period of time and then change over to the other schedule. During a relatively small number of the times that a subject changes to a schedule and responds, reinforcement occurs. The small proportion of interchangeover intervals which contain reinforcement suggest that while the termination of reinforcement may be one stimulus which occasions change-over responses, there are many instances in which COs occur in the absence of the termination of reinforcement. If the occurrence of CO behavior is correlated with a specific parameter or stimulus in the concurrent situation, then one might expect a detailed examination of the distribution of CO behavior to reveal possible determining variables.

The present experiment obtained the relative frequency distribution of interchangeover intervals and examined the probability of a CO, conditional on the opportunity to CO, at 1-sec intervals. These measures provided for a more detailed examination of the conditions in which CO behavior occurs. In order to explicate the effects of the occurrence of reinforcement on the occurrence of CO behavior, lower and upper limits were placed on the availability of reinforcement following a CO response. The lower limit was equivalent to the CODs programmed by other experimenters. The upper limit insured that reinforcement could be obtained only during a short period of time following a COD.

METHOD

Subjects

Eight White Carneaux and two White King pigeons were maintained at about 80% of their free-feeding weight throughout the experiment. When a subject did not obtain enough Purina pigeon grain in the experimental chamber to maintain 80% body weight, additional grain was given in the home cage immediately after the daily session. Water and grit were available in the home cage. All subjects had a history of previous experimental experience.

Apparatus

The experimental chamber was a standard Lehigh Valley two-key pigeon chamber, 30 cm by 35 cm by 40 cm. The houselight fixture used miniature bayonet bulb #1829 and was deflected. The grain hopper was centered on the response panel 7.5 cm above the floor of the chamber. When the grain hopper was operated, illumination was provided by a miniature bayonet bulb #1829. The response keys were transilluminated by Lehigh Valley Inline Visual Display Units.

In addition to the standard electromechanical programming and recording apparatus, a Technical Measurement Corporation teletype (model 535) was used for data recording.

Three Dormeyer p8-2L solenoids were mounted above the key board (see Christopherson, 1970). The solenoids were connected to the electromechanical apparatus and operated from a standard 24V electrical pulse. When the solenoid was operated, it pressed a key which operated the tape punch on the teletype.

Procedure

Three subjects were placed on concurrent VI 1-min VI 1-min schedules of reinforcement immediately as a result of their previous history on concurrent schedules. The other seven subjects were exposed to four sessions in which each response on the left key operated the feeder until forty reinforcements had been obtained. During two of the sessions, the key color was amber and during two of the sessions, the key color was red. Each subject was then exposed to three sessions of a multi VI 1-min VI 1-min schedule of reinforcement with 20-sec components. All subjects were then run on a conc VI 1-min VI 1-min schedule for twelve sessions. Condition one began at this point with five of the subjects on a conc VI 1-min VI 1-min schedule of reinforcement and five of the subjects changed to a conc VI 4-min VI 4-min schedule of reinforcement.

Throughout all conditions, the following basic arrangements were in effect: both schedules of the concurrent pair functioned simultaneously, each arranged reinforcers independently,and each was associated with a particular color (red or amber) of the left-hand (main) key. Programmed reinforcers were held until they were obtained. Responses on the main key produced a three-second hopper presentation if a reinforcer had been arranged by the schedule associated with the color on the key at that time. Reinforcers arranged by the other schedule were not available to the subject until the color associated with that schedule was present. A single response on the right-hand (CO) key, which was transilluminated by a white light in the form of either a horizontal or vertical bar, changed the color and schedule assignment on the main key. When the main key was red, a horizontal bar of white light was transilluminated on the CO key and when the main key was amber, a vertical bar of white light transilluminated the CO key.

The experimental manipulations consisted of placing various constraints on the availability of reinforcement following a CO response. Columns 1, 2, and 3 in Table 1 show the conditions to which each subject was exposed and the number of sessions the subject spent in each condition. The constraints on the availability of reinforcement may all be considered to be changeover contingencies. Three categories were used: (1) No constraints: programmed reinforcers were available at any time that the appropriate schedule was in effect. (2) Changeover delays: programmed reinforcers were available after a specified time had

Table 1

Summary data for the experiment. The entries in columns four through ten are averages over the last five sessions of each of the experimental conditions shown in the first column.

CO contingency						Rel Freq ICTs (3-sec period)		Rel Freq CRTs (3-sec period)		Rel Reinf (obtained)
COD	upper limit	Sess	Rel Resp	Rel Time	CO Rate (sec)	Amber	Red	Amber	Red	
Bird G-1: Conc VI 1-min VI 1-min										
		48	.47	.50	.40	.89	.91	.73	.85	.50
1.0	4.0	30	.45	.50	.28	.80	.80	1.00	1.00	.50
5.0	8.0	53	.42	.61	.09	.43	.49	1.00	1.00	.50
5.0	0.0	34	.47	.57	.08	.35	.34	.85	.78	.50
1.0	0.0	40	.53	.52	.19	.63	.67	.87	.77	.50
Bird G-2: Conc VI 1-min VI 1-min										
		49	.50	.49	.46	.94	.94	.96	.96	.50
1.0	4.0	28	.49	.51	.28	.82	.88	1.00	1.00	.50
5.0	8.0	55	.53	.50	.11	.46	.58	1.00	1.00	.50
5.0	0.0	36	.52	.50	.06	.46	.45	.79	.70	.50
1.0	0.0	39	.56	.54	.15	.62	.69	.71	.94	.50
Bird G-8: Conc VI 1-min VI 1-min										
		46	.52	.49	.51	.96	.94	1.00	.92	.52
1.0	4.0	27	.48	.51	.32	.83	.89	1.00	1.00	.50
5.0	8.0	49	.53	.49	.10	.59	.57	1.00	1.00	.50
5.0	0.0	33	.46	.45	.05	.38	.31	.77	.59	.50
1.0	0.0	38	.51	.54	.28	.86	.94	.94	.99	.50

Table 1 (continued)

CO contingency: COD	CO contingency: upper limit	Sess	Rel Resp	Rel Time	CO Rate (sec)	Rel Freq ICTs (3-sec period): Amber	Rel Freq ICTs (3-sec period): Red	Rel Freq CRTs (3-sec period): Amber	Rel Freq CRTs (3-sec period): Red	Rel Reinf (obtained)
Bird G-4: Conc VI 1-min VI 1-min										
		48	.42	.46	.38	.91	.86	.92	.88	.50
1.0	4.0	26	.51	.52	.30	.86	.85	1.00	1.00	.50
5.0	8.0	54	.58	.58	.08	.35	.43	1.00	1.00	.50
5.0	0.0	37	.35	.62	.05	.27	.33	.51	.61	.51
1.0	0.0	41	.57	.56	.18	.39	.54	.79	.69	.57
Bird G-6: Conc VI 1-min VI 1-min										
		49	.43	.50	.40	.92	.91	.96	.92	.50
1.0	4.0	29	.40	.47	.33	.68	.75	1.00	1.00	.50
5.0	8.0	54	.56	.46	.10	.38	.51	1.00	1.00	.50
5.0	0.0	37	.45	.42	.04	.29	.43	.47	.67	.50
1.0	0.0	41	.49	.51	.19	.58	.51	.81	.81	.50
Bird G-3: Conc VI 4-min VI 4-min										
		49	.50	.49	.46	.67	.68	.85	.89	.50
1.0	4.0	29	.47	.45	.27	.64	.65	1.00	1.00	.50
5.0	8.0	56	.60	.62	.07	.18	.50	1.00	1.00	.50
5.0	0.0	37	.56	.62	.06	.13	.15	.61	.74	.50
1.0	0.0	40	.40	.68	.07	.39	.58	.68	.75	.50
Bird G-7: Conc VI 4-min VI 4-min										
		50	.50	.50	.22	.63	.69	.73	.76	.50
1.0	4.0	29	.51	.50	.27	.63	.46	1.00	1.00	.50
5.0	8.0	55	.50	.47	.08	.50	.40	1.00	1.00	.50
5.0	0.0	36	.45	.43	.05	.13	.12	.64	.57	.50
1.0	0.0	41	.45	.47	.15	.31	.33	.71	.58	.50

Table 1 (continued)

CO contingency						Rel Freq ICTs (3-sec period)		Rel Freq CRTs (3-sec period)		
COD	upper limit	Sess	Rel Resp	Rel Time	CO Rate (sec)	Amber	Red	Amber	Red	Rel Reinf (ob-tained)
Bird G-9: VI 4-min VI 4-min										
		48	.48	.52	.35	.78	.83	.61	.75	.50
1.0	4.0	28	.55	.57	.32	.84	.80	1.00	1.00	.50
5.0	8.0	56	.49	.51	.09	.19	.28	1.00	1.00	.50
5.0	0.0	36	.48	.48	.08	.20	.22	.72	.77	.50
1.0	0.0	41	.57	.58	.23	.56	.73	.79	.88	.50
Bird I-1: Conc VI 4-min VI 4-min										
		49	.59	.58	.32	.65	.83	.87	.93	.50
1.0	4.0	26	.57	.57	.29	.67	.75	1.00	1.00	.50
5.0	8.0	51	.50	.51	.10	.37	.36	1.00	1.00	.50
5.0	0.0	34	.53	.48	.06	.14	.14	.78	.70	.50
1.0	0.0	36	.56	.58	.23	.65	.88	.89	.98	.50
Bird I-4: Conc VI 4-min VI 4-min										
		48	.53	.53	.44	.82	.89	.89	.96	.50
1.0	4.0	28	.54	.53	.28	.81	.76	1.00	1.00	.50
5.0	8.0	54	.44	.52	.12	.34	.53	1.00	1.00	.50
5.0	0.0	33	.46	.51	.10	.29	.28	.87	.93	.50
1.0	0.0	39	.60	.58	.25	.67	.87	.86	.98	.50

elapsed following a changeover response. The COD went into effect when the subject responded on the CO key. A reinforcer arranged before the changeover, or arranged during the changeover delay, was produced by the first response on the main key after the changeover delay expired. If another changeover occurred during a COD, the delay was reinstated. (3) Changeover delay bands: programmed reinforcers were available after a minimum specified time had elapsed and prior to the passage of a maximum period of time. The procedure was essentially the same as the COD procedure except that an upper time limit was added after which no reinforcers could be obtained until the next time the subject entered that schedule and responded during the band.

Experimental sessions were conducted daily and each session was terminated after 40 reinforcements. The reinforcer was mixed grain, and the duration of the hopper operation was 3 seconds. The grain was illuminated with white light when the hopper was presented, and the rest of the chamber was dark.

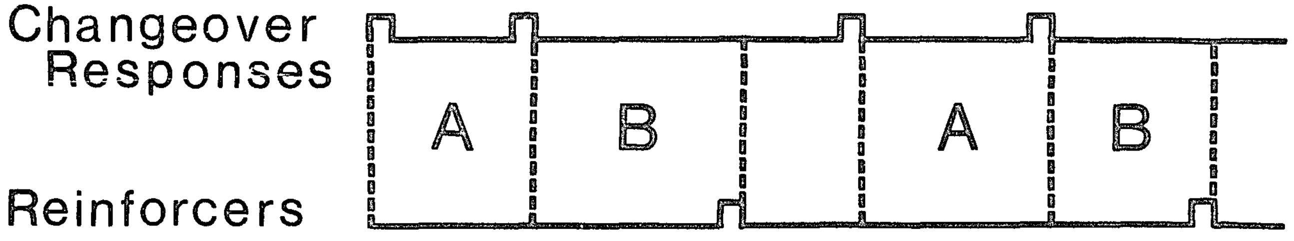
Data Analysis

During each experimental session, the number of responses and amount of time spent in each schedule was recorded. From these data the relative response rate, $\frac{R_A}{R_A + R_B}$, and relative time, $\frac{T_A}{T_A + T_B}$, measures were calculated.

The number of reinforcements obtained in a schedule was recorded and the relative reinforcement rate, $\frac{r_A}{r_A + r_B}$, was calculated from these data. The total number of changeovers was recorded and the changeover rate was calculated as follows: $\frac{\text{number of changeovers}}{\text{total time } (T_A + T_B)}$.

In addition to these routine measures, the actual sequence of occurrence of CO responses and reinforcers was recorded on paper punch tape, during the last five days of each condition. Figure 1 demonstrates the sequence of events and the intervals used in further calculations. Interval A represents the time between two changeover responses, designated ICT. Interval B represents the time from a CO response to the occurrence of a reinforcer. The CO-to-reinforcer time is designated CRT. A computer was used to establish the relative frequency distributions of CRTs and ICTs from 1 sec to 200 secs, in 1-sec intervals. The relative frequency distribution of ICTs was computed by dividing the number of ICTs in a 1-sec interval by the total number of ICTs. The relative frequencies of CRTs were determined analogously. It is important to note that the ICT distributions included only interchangeover times during which reinforcement did not occur. The conditional probability of a CO at each 1-sec interval was computed by dividing the number of ICTs in each interval

Figure 1. Sequential representation of events used to determine Interchangeover Time and CO-to-Reinforcer Time.



Intervals noted by A are designated Interchangeover Time (ICT).

Intervals noted by B are designated Co-To-Reinforcer Time (CRT) by the number of ICTs which occurred in that and all subsequent intervals. These functions are designated CO-per-Opportunity functions. Occasionally two reinforcers were obtained on a schedule without a CO response intervening. These intervals were excluded because they occurred very infrequently.

RESULTS

Table 1 presents the summary data calculated from the performance of each subject during the last five days of each condition. Columns 4, 5, and 6 show the overall relative measures and the CO rate. These measures are routinely reported for concurrent performance. Columns 7 through 10 present the data obtained from the analysis of the ICTs and CRTs. The measure presented in columns 7 and 8 is the relative frequency of ICTs terminated during the first three seconds reinforcement was available following a CO response. An interval of 3 sec separated the upper and lower limit when they were programmed together. Because 3 sec separated the upper and lower limits, the 3-sec interval following the lower limit is examined whether or not an upper limit was programmed. For example, in condition 1 reinforcement was available immediately following a CO response. In condition 3 reinforcement was available beginning 6 sec after a changeover. Columns 7 and 8 show the relative frequencies of ICTs terminated from 1-3 sec following a changeover in condition 1 and 6-8 sec following a changeover in condition 3. ICTs terminated during the schedule signalled by an amber key light are shown in column 7 and ICTs terminated during the schedule signalled by a red key light are shown in column 8. The remainder of the paper will refer to the point where reinforcement is first available as the point at which reinforcement originates.

The relative frequency of occurrence of CRTs terminated during the first 3 sec after the point that reinforcement originated is shown in columns 9 and 10. Column 11 presents the overall obtained relative frequency of reinforcement.

Molar Measures

The relative response rates, relative time, and CO rates are considered to be molar measures of concurrent schedules.

Figure 2 presents the mean relative response rates obtained from all 10 subjects. The relative response rates were distributed around an approximate 50-50 distribution. Only two data points fell outside a $\pm$ 10% range. Examination of Table 1, column 11, demonstrates that the overall obtained relative rates of reinforcement rarely deviated from 50%. Figure 3 presents the relative time allocated to each schedule. The data show that time allocation generally approximated the overall obtained relative rates of reinforcement. The results demonstrate that there is not a systematic effect of adding an upper limit on relative response rates or time.

Figure 2. Mean relative response rates obtained from ten subjects.

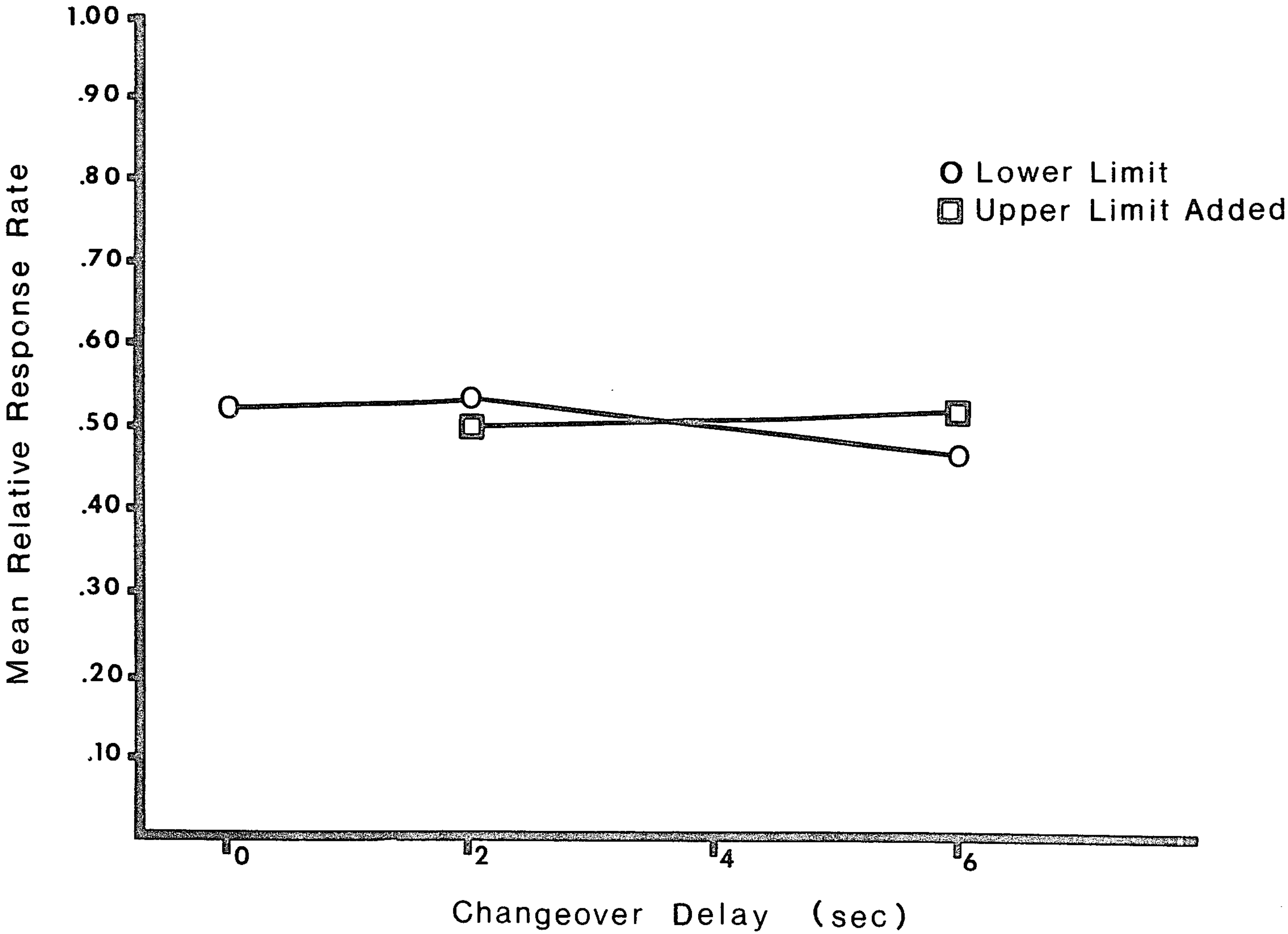

Mean Relative Response Rate
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
2
4
6
Changeover Delay (sec)
Lower Limit
Upper Limit Added

Figure 3. Mean relative time allocated to each schedule obtained from ten subjects.

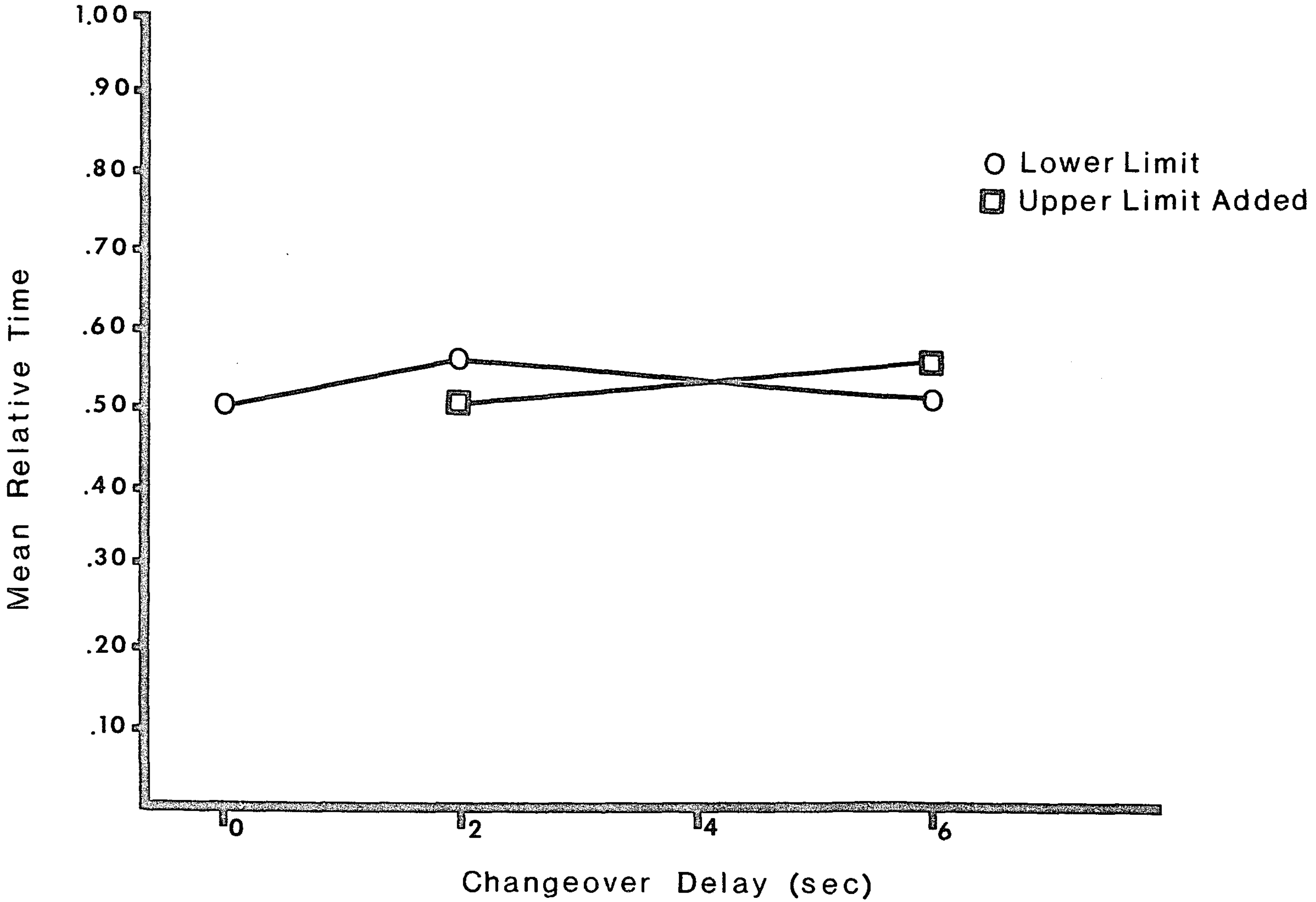
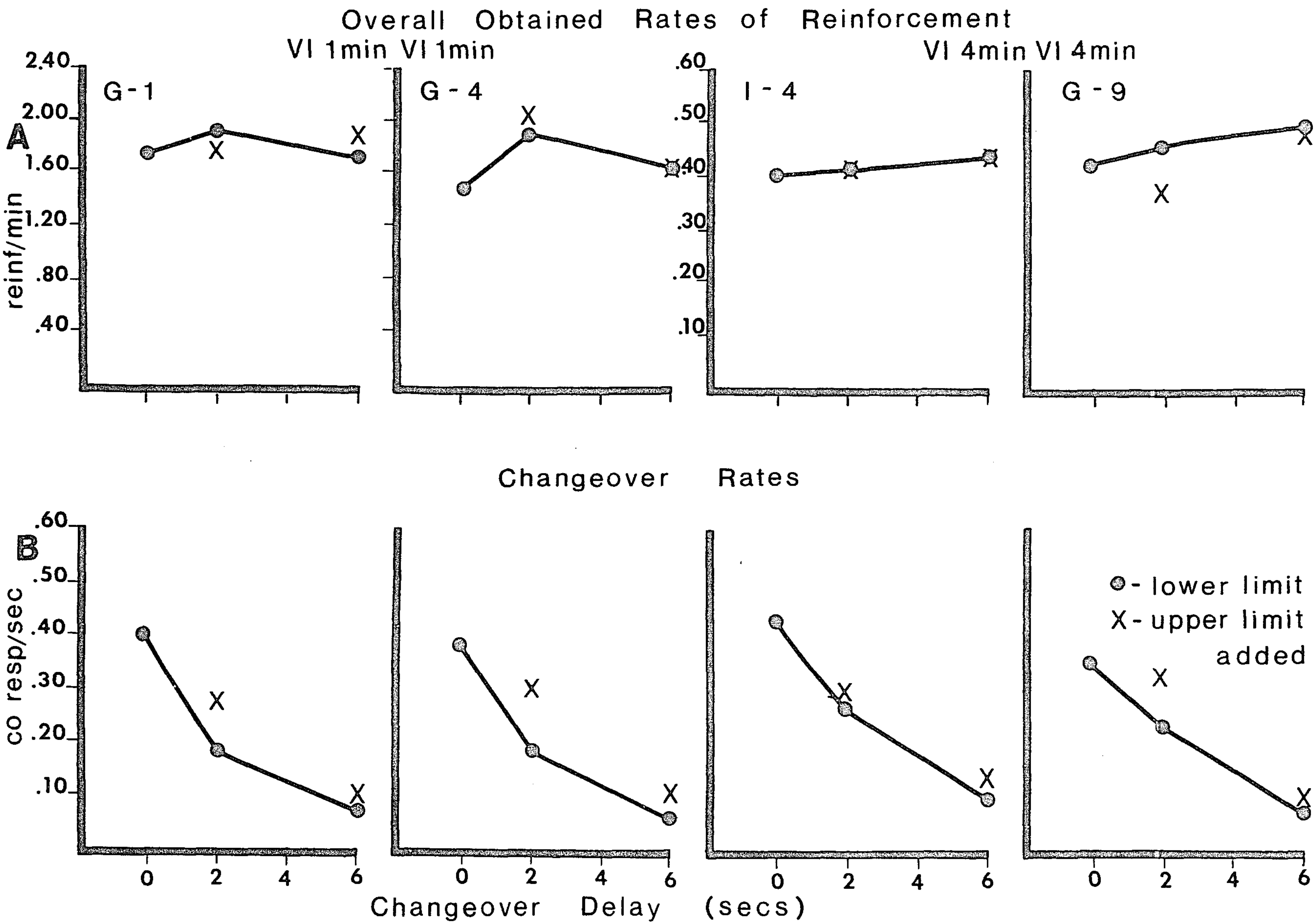

1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
Mean Relative Time
0
2
4
6
Changeover Delay (sec)
Lower Limit
Upper Limit Added

Figure 4, part A, presents the overall obtained rate of reinforcement for four representative subjects. Subjects G-1 and G-4 were exposed to VI 1-min VI 1-min schedules and subjects I-4 and G-9 were exposed to VI 4-min VI 4-min schedules. The overall obtained rates do not show systematic changes across the points of origin of reinforcement. If any trend existed for subjects reinforced on the VI 1-min VI 1-min schedules, the obtained rate increased with reference to the zero point of reinforcement origin and then began to decrease. The data obtained from subjects reinforced on the VI 4-min VI 4-min schedules increased with reference to the zero point of reinforcement origin. The unconnected points are those from conditions in which an upper limit on reinforcement availability was imposed. Imposing upper limits did not appear to have systematic effects on the overall obtained rates of reinforcement. Part B of Figure 4 shows the CO responses per sec as a function of the points of origin of reinforcement. The CO rate decreases sharply as the distance between a CO response to a schedule and the reinforcement availability on that schedule increases. The unconnected points are those from conditions in which an upper limit on reinforcement availability was imposed. The imposition of an upper limit consistently is associated with a higher CO rate at that point of reinforcement origin than is maintained by the COD without an upper limit.

Figure 4. Overall obtained rate of reinforcement for four representative subjects (Part A). CO responses per sec as a function of the changeover delay (Part B).



Overall Obtained Rates of Reinforcement
VI 1min VI 1min
VI 4min VI 4min
A
B
G - 1
G - 4
I - 4
G - 9
reinf/min
2.40
2.00
1.60
1.20
.80
.40
.60
.50
.40
.30
.20
.10
Changeover Rates
co resp/sec
.60
.50
.40
.30
.20
.10
● - lower limit
X - upper limit added
0
2
4
6
Changeover Delay (secs)

Comparison of the CO rates for G-1 and G-4 to the CO rates of I-4 and G-9 do not show any substantial differences as a function of the different overall rates of reinforcement.

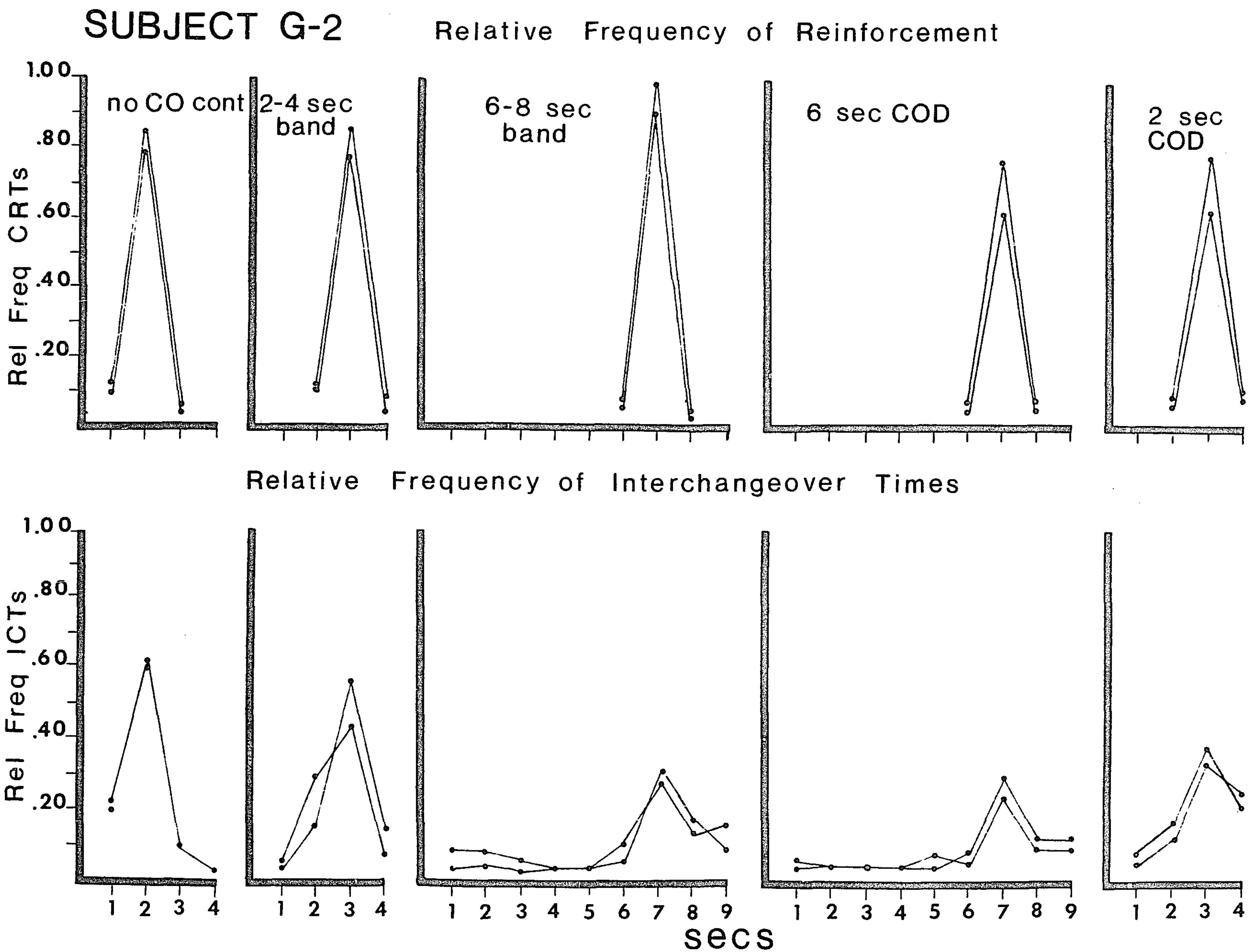
The relative response rates and relative time measures do not show any systematic effects from the imposition of constraints on the availability of reinforcement. CO rates are the only measures which did change systematically across conditions. These changes are more clearly represented by the more molecular measures of relative frequency distributions of ICTs and the CO-per-Opportunity functions.

Molecular Measures

The molecular measures examined in this study were the relative frequency distribution of reinforcement (CRTs), the relative frequency distribution of ICTs and the CO-per-Opportunity functions.

Figure 5 presents the relative frequency distribution of reinforcement and the relative frequency distributions of ICTs in each of the conditions for a representative subject. Examination of the relative frequency distribution of reinforcement (CRTs) shows that both the COD and upper limit contingencies effectively limited the temporal periods of reinforcement availability. The relative frequency distributions of ICTs demonstrate that

Figure 5. The relative frequency of reinforcement and the relative frequency distribution of interchangeover times in each of the conditions for a representative subject.

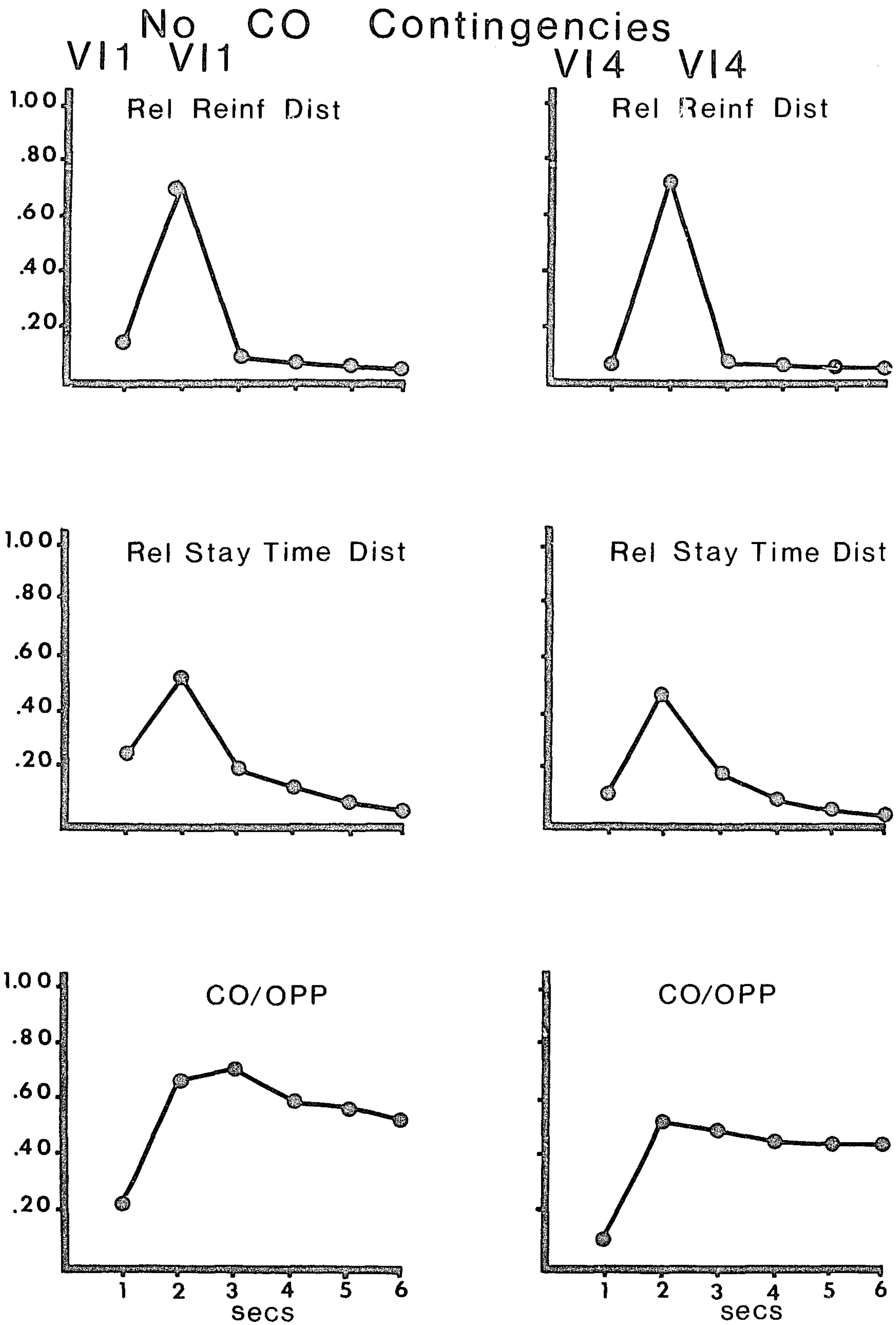

SUBJECT G-2
Relative Frequency of Reinforcement
Rel Freq CRTs
1.00
.80
.60
.40
.20
no CO cont
2-4 sec band
6-8 sec band
6 sec COD
2 sec COD
Relative Frequency of Interchangeover Times
Rel Freq ICTs
1.00
.80
.60
.40
.20
1 2 3 4
1 2 3 4
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4
secs

the modal frequency of ICTs occurred at approximately the same point in time that the highest frequency of reinforcement was obtained.

The relative frequency distributions of CRTs, the relative frequency distribution of ICTs, and the CO-per-Opportunity functions for the condition with no CO contingencies are presented in Figure 6. It should be noted that these distributions were obtained for each schedule. The distributions were combined because there were no substantial differences between the distributions. The functions in part A were obtained from five subjects on conc VI 1-min VI 1-min schedules of reinforcement. The functions in part B were obtained from five subjects on conc VI 4-min VI 4-min schedules of reinforcement. The solid lines represent the mean performance of the five subjects in parts A and B respectively. The relative frequency distributions demonstrate that there is a strong correlation between the CRT distribution and the ICT distribution when they are both free of external constraints.

The majority of reinforcers were obtained at approximately 2 sec following a CO response. Approximately 50% of the ICTs were terminated at approximately 2 sec. The CO-per-Opportunity functions show that the highest probability of a CO occurred at approximately 2 to 3 sec. The CO-per-Opportunity functions show a low probability of

Figure 6. The relative frequency distribution of CO-to-Reinforcement Times, the relative frequency distribution of interchange-over times, and the CO-per-Opportunity functions for the condition without a CO contingency


No CO Contingencies
VI1 VI1
VI4 VI4
Rel Reinf Dist
Rel Reinf Dist
Rel Stay Time Dist
Rel Stay Time Dist
CO/OPP
CO/OPP
1.00
.80
.60
.40
.20
1 2 3 4 5 6
secs

CO before 2 sec and a relatively high probability following 2 sec.

Figure 7 shows that when the availability of reinforcement was limited to a 1-4 sec period following a CO response, the obtained frequency distributions showed a shift in the modal frequency. In this condition, 100% of the reinforcers were obtained between 2-4 sec following a CO response to a schedule. Figure 7 shows that the relative frequency distributions of the CRTs, ICTs and CO-per-Opportunity functions shifted so that the highest frequency and probability occurred at 3 sec. Figure 8 presents the same data obtained when reinforcement was available from 5-8 sec following a CO response. Again, the CRT distribution shifted so that the highest relative frequency of occurrence is within the 6th to 8th sec. The relative frequency of occurrence of ICTs peaks during the 6th to 8th sec, and the CO-per-Opportunity function is low prior to the 7th sec and relatively higher following the 7th sec. These basic relationships were obtained in all conditions. The only exceptions in the data involve the subjects on conc VI 4-min VI 4-min schedules when the origin of reinforcement is at 6 sec following a CO response. The data obtained from these subjects show that the modal frequency of ICTs and the highest probability of a CO tend to occur 1 or 2 sec beyond the modal frequency of the CRT distribution.

Figure 7. The relative frequency distribution for the condition with 1 sec COD and 4 sec upper limit.

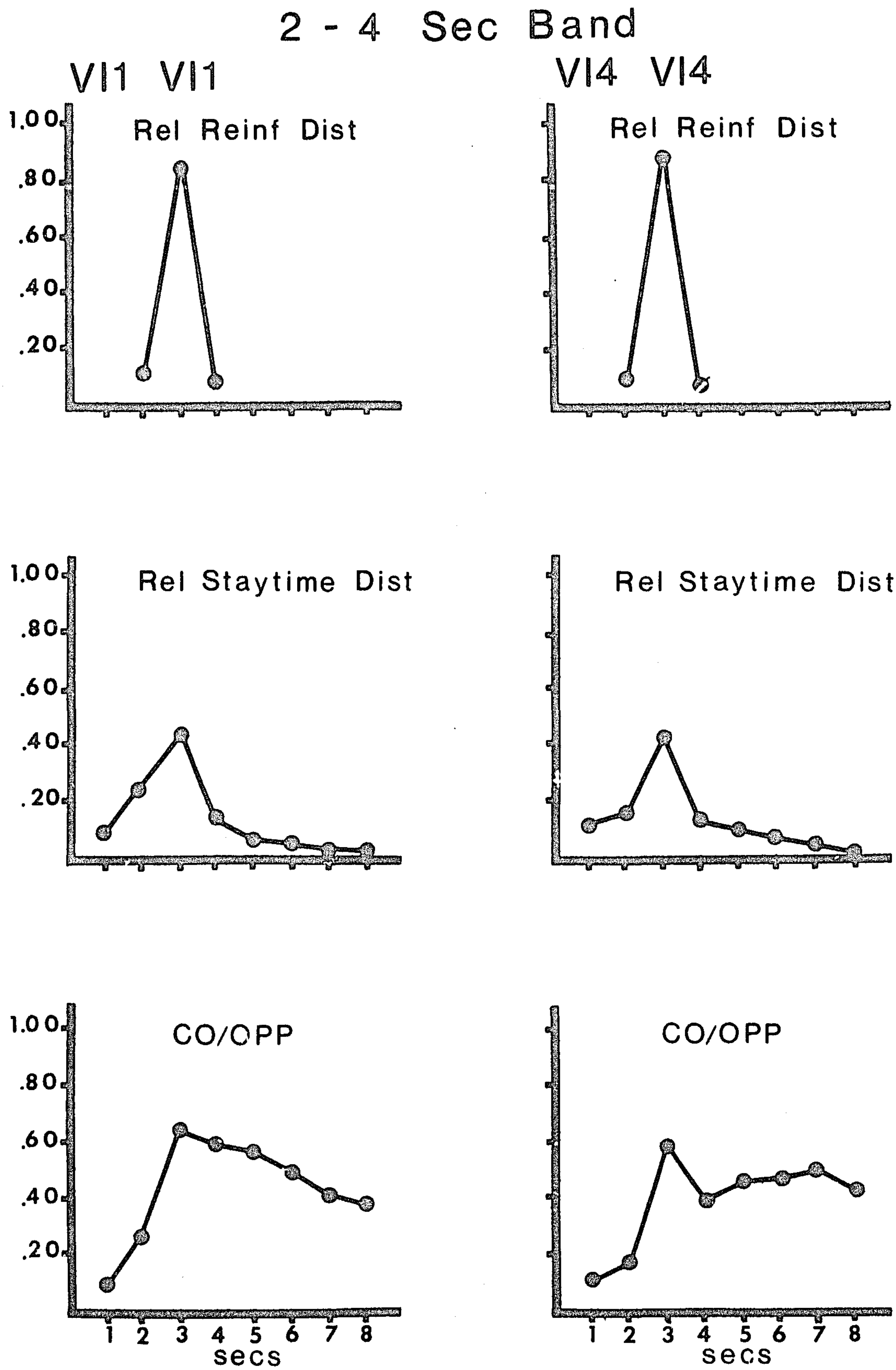

2 - 4 Sec Band
VI1 VI1
VI4 VI4
Rel Reinf Dist
Rel Reinf Dist
Rel Staytime Dist
Rel Staytime Dist
CO/OPP
CO/OPP
1.00
.80
.60
.40
.20
1 2 3 4 5 6 7 8
secs
1 2 3 4 5 6 7 8
secs

Figure 8. The relative frequency distributions of measures obtained from the condition with a 5 sec COD and an 8 sec upper limit.

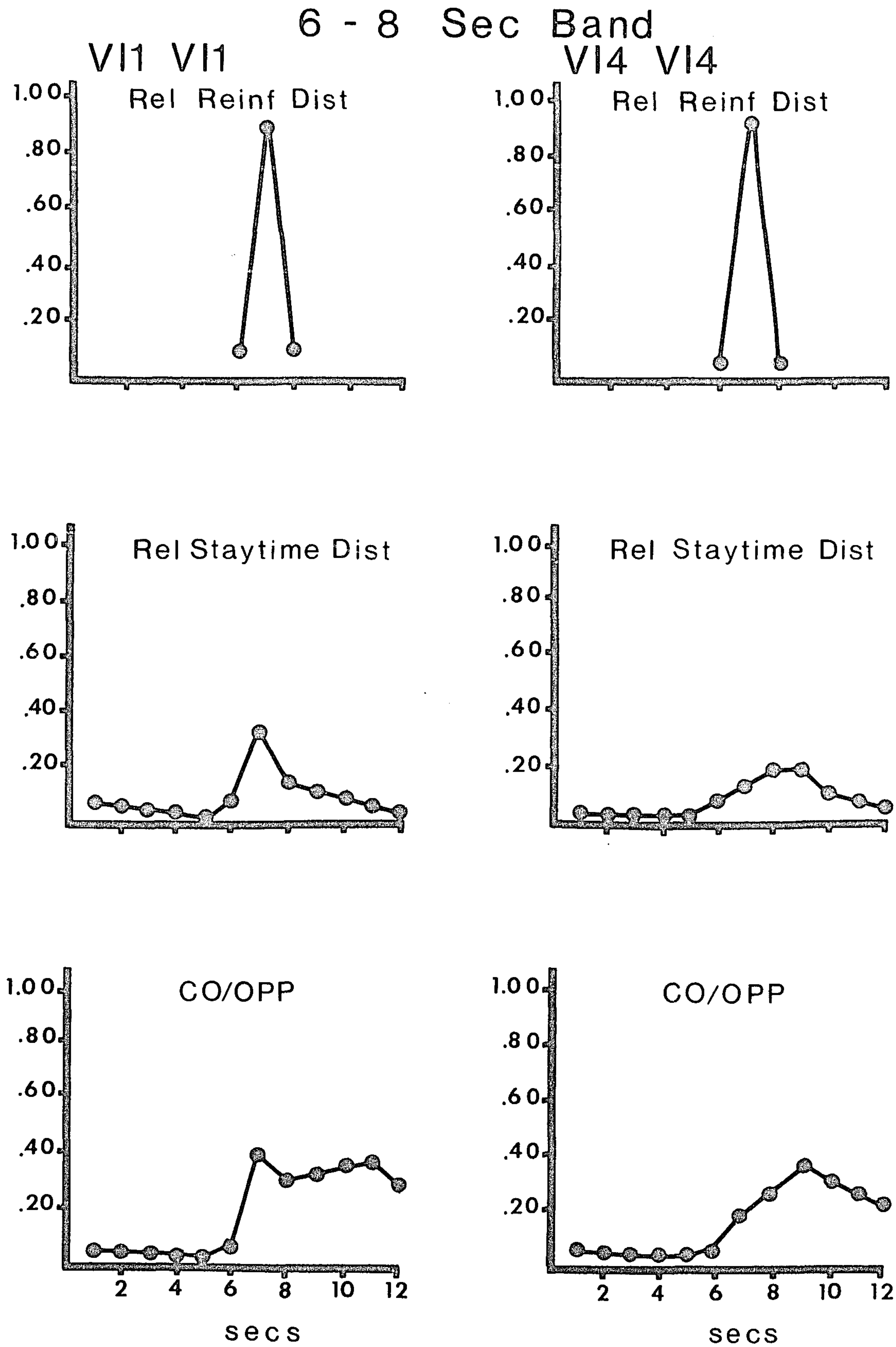
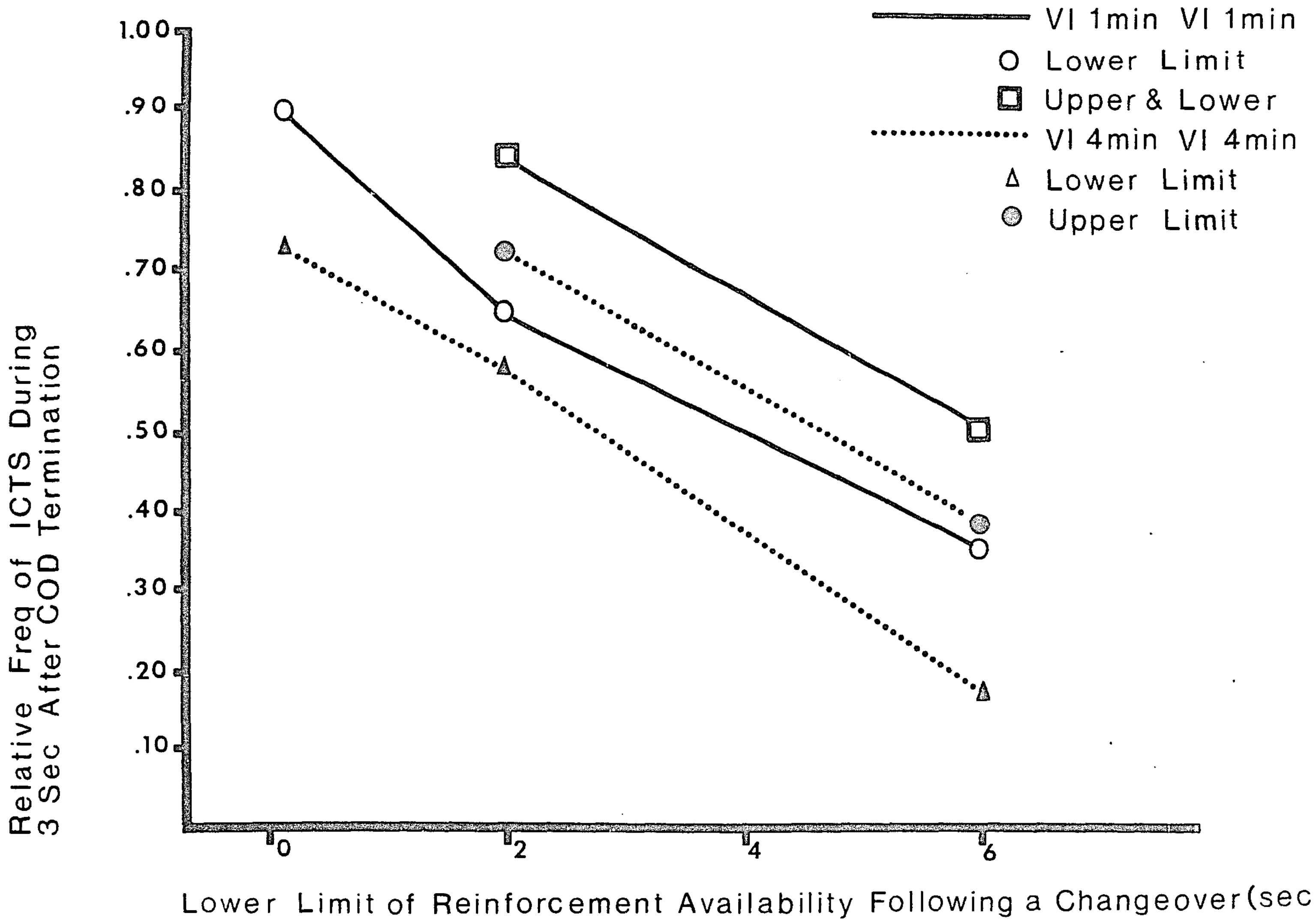

6 - 8 Sec Band
VI1 VI1
VI4 VI4
Rel Reinf Dist
Rel Reinf Dist
Rel Staytime Dist
Rel Staytime Dist
CO/OPP
CO/OPP
1.00
.80
.60
.40
.20
2
4
6
8
10
12
secs

Figure 9 presents the relative frequency of occurrence of ICTs during the first 3 sec following the point at which reinforcement originates. When an upper limit is added, reinforcement availability is limited to 3 sec. For this reason, the first 3 sec of reinforcement availability is compared across all conditions even though in some conditions reinforcement availability was not limited to a 3-sec period. The data are plotted on the horizontal axis in terms of the points of origin of reinforcement. The dotted lines connect data obtained from subjects exposed to VI 4-min VI 4-min schedules. The solid lines connect data points obtained from subjects exposed to VI 1-min VI 1-min schedules. Two consistent aspects of the data should be noted. First, the proportion of ICTs terminated during the 3 sec following the origin of reinforcement decreases as the time between the changeover response and the origin of reinforcement increases. Secondly, the upper limit of a band maintains a higher relative frequency of occurrence of ICTs during the 3 sec following the origin of reinforcement than the same lower limit without an upper limit. Comparison of these data with the CO-per-Opportunity functions shows that the decrease during the 3-sec interval results from increasing the number of long ICTs and that the frequency of short ICTs remains relatively constant. A third consistent aspect of Figure 9 is that the proportion of ICTs in the

Figure 9. The relative frequency of interchangeover times occurring during a 3-sec interval following the termination of the COD.


VI 1min VI 1min
Lower Limit
Upper & Lower
VI 4min VI 4min
Lower Limit
Upper Limit
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
2
4
6
Relative Freq of ICTS During 3 Sec After COD Termination
Lower Limit of Reinforcement Availability Following a Changeover (sec)

3-sec interval is lower for the subjects exposed to VI 4-min VI 4-min schedules than for subjects exposed to VI 1-min VI 1-min schedules.

DISCUSSION

The present experiment examined the effects on CO behavior of limiting reinforcement to specific temporal intervals following the occurrence of a CO. The availability of reinforcement following a CO was manipulated by varying the upper and lower bounds of the interval during which reinforcement was available. Another purpose of the experiment was to examine the effects of different overall rates of reinforcement on CO behavior. The effects of these manipulations were examined at both a molar and molecular level.

Molar Measures

The conditions during which only a lower limit was specified were the same as those for programming a COD. The data show that increasing the interval between a CO and the lower bound had no effects on both the relative response measure or the relative time measure. The present experiment programmed equal relative rates of reinforcement. The data obtained here are thus consistent with the results reported by other investigators who examined the effects of CO contingencies on relative response rates and relative time measures under conditions of equal rates of reinforcement (Brownstein & Shull, 1968; Shull & Pliskoff, 1967; Stubbs & Pliskoff, 1969).

Increasing the lower limit did have substantial effects on the CO rate. As the lower limit was increased the CO rate decreased. These results are consistent with other data which show a decrease in CO rate as a function of increasing COD values (Brownstein & Shull, 1968; Shull & Pliskoff, 1967; Stubbs & Pliskoff, 1969).

Adding an upper limit on the availability of reinforcement was the unique manipulation of the present experiment. Examination of the relative response rates and relative time measures show no effects from the addition of an upper limit.

CO rates were affected by adding an upper limit. Comparing CO rates when only a lower limit was programmed to conditions in which an upper and lower limit was programmed demonstrates that the upper limit maintained a higher CO rate than the lower limit. The lower limit tends to decrease CO rates, the upper limit appears to attenuate this effect and thus maintain a higher CO rate.

Overall rates of reinforcement of .5/min and 2/min were programmed. Comparing the relative response rates and relative times obtained with different overall rates of reinforcement show no consistent differences. The measures were similar enough to combine for the purposes of comparing the effects of varying the availability of reinforcement on the relative measures.

Examination of the CO rates obtained with a .5/min overall rate of reinforcement or a 2/min overall rate of

CO rates were approximately the same at these different overall rates of reinforcement. In Figure 4, part A, the overall obtained rates of reinforcement increase with a 2-sec lower limit and decrease at the 6-sec lower limit when VI 1-min VI 1-min schedules are programmed. These results are similar to the data reported by Pliskoff (1971), showing the overall obtained rate of reinforcement as a function of COD value when VI 3-min VI 3-min schedules were programmed. In the present study, the overall obtained rates of reinforcement generally increased as the lower limit increased when VI 4-min VI 4-min schedules of reinforcement were programmed.

In general, programming upper and lower limits on the availability of reinforcement affected only the CO rate measure at the molar level. Varying the overall rates of reinforcement did not affect the relative measures.

Molecular Measures

The relative frequency distributions of reinforcement and ICTs were obtained for each schedule of the concurrent pair. ICTs during which reinforcement occurred were not included in the ICT distribution. CO-per-Opportunity functions were also computed for each schedule of the concurrent pair. Because the distributions showed no differences between schedules, the data obtained from each schedule were combined. The effects of the independent variables can best be seen by considering the distributions as being composed of three parts: time prior to the lower limit, 3 secs after the lower limit, and the remainder of the distribution.

The effect of increasing the lower limit on the relative frequency distribution of reinforcement was to shift the peak in the distribution. The maximum peak in the distribution was always obtained during the 3 sec following the lower limit.

The peaks of the relative frequency distribution of ICTs also shifted as a function of increasing the lower limit. The maximum peaks occurred during the 3 secs after the lower limit with one exception. The subjects on VI 4-min VI 4-min schedules tended to peak about 2-5 sec after a 5-sec lower limit. As the lower limit increased the proportion of ICTs occurring at the peak decreased. The ICT distributions can be generally described as showing a low frequency of CO prior to the lower limit, a relatively higher frequency of CO during the 3 sec following the lower limit, and an intermediate level of occurrence during the remainder of the distribution. The distribution of ICTs shows that COs occur most frequently at the point at which reinforcement is most frequently obtained. The strong correlation was obtained with and without programmed limits on the availability of reinforcement.

The CO-per-Opportunity functions show similar effects of an increasing lower limit. The period prior to the lower limit consists of a low probability of a CO and the probability of a CO peaks during the 3 sec following a lower limit. Comparison of the probability of a CO during the 3 sec following the lower limit and the remainder of the function shows that increasing the lower limit decreases the probability of a CO during the 3-sec interval and increases the probability of a CO at longer intervals. In other words, the subjects tend to stay beyond the minimum limit of reinforcement availability as the lower limit increases.

The effect of the upper limit on the relative frequency distribution of reinforcement was to truncate the upper end of the reinforcement distribution. One hundred per cent of the reinforcers occurred during the 3-sec period between the upper and lower limit.

When the upper limit was programmed, the relative frequency of ICTs shifted so that a higher proportion of ICTs were terminated during the 3 sec following the lower limit. The CO-per-Opportunity functions show that when the upper limit was programmed, the conditional probability of a CO was higher during the 3-sec interval than it was without an upper limit. Generally, the effects of the upper limit may be described as decreasing the number of stays beyond the upper limit.

Comparison of the molecular measures under the two overall rates of reinforcement shows that the molecular measures were affected. The proportion to ICTs terminated during the 3 sec following the lower limit was higher for the subjects with a higher overall rate of reinforcement at all values of the lower limit and when upper limits were programmed. Examination of the relative frequency distributions of ICTs at the 6-sec lower limit shows less pronounced peaks and more dispersion around the peaks. There is a tendency for the peaks of the ICT distribution to shift 2-5 sec beyond the point that reinforcement is most frequently obtained when a 5-sec lower limit is programmed. A similar shift in peak and dispersion can be seen in the CO-per-Opportunity functions.

The subjects exposed to VI 4-min VI 4-min schedules showed considerably higher proportion of ICTs beyond the 3-sec interval than subjects exposed to VI 1-min VI 1-min schedules at the 5-sec lower limit. Obviously, the mean ICT increased substantially as a result of the increased proportion of long ICTs. The increased number of long ICTs results in a higher CO rate for subjects that obtained a lower overall rate of reinforcement. The change in rate is not reflected in the molar changeover rate. As a result of the method of computing CO rate, fairly large changes in the distribution of ICTs have very small effects on CO rate. Clearly, we should be cautious when interpreting the effects of overall rate of reinforcement on CO rate alone.

In summary, the data show that: (1) some aspects of CO behavior can be manipulated without affecting the relative response and time measures when equal proportions of reinforcement are assigned to concurrently programmed VI schedules of reinforcement, and (2) that CO behavior most frequently occurred at the point at which reinforcement was most frequently obtained.

The alternative conceptualizations of changeover behavior and the mechanisms which control it will be considered. The conceptualizations may be categorized in terms of the locus of control of the CO behavior. Two different response units will be considered in each conceptualization. The locus of control may be determined by variables on the schedule to which the subject is responding or may be determined by variables associated with the alternative schedule. One conceptualization considers the ICT ot be the response unit and considers the locus of control to be the alternative schedule. Specifically, the relative frequency distribution of ICTs is considered to be a function of the relative frequency of reinforcement which follows the termination of an ICT. A second conceptualization is to consider the response unit to be a CO response followed by a temporal interval. The relative frequency of reinforcement which follows the temporal interval on a schedule determines the relative frequency of occurrence of the temporal intervals. Variations on the above conceptualizations are based on the discriminative control of the CO response. Both accounts rely on the control of the CO response by temporal stimuli. In one conceptualization, CO responses occur when a temporal stimulus signals a high probability of reinforcement on the alternative schedule. The second discriminative account considers the CO response to occur when temporal stimuli on a schedule signal a period of low reinforcement probability on that schedule.

Each of these accounts is feasible when one considers the data obtained from concurrent VIs without a COD or upper limit. Considering the temporal interval to be a differentiable property of the CO response is suggested by the similarity between ICTs and interresponse times (IRTs). One can measure the temporal intervals which occur between CO responses just as one can measure temporal intervals which occur between responses on isolated schedules. The relative frequency distributions and CO-per-Opportunity functions obtained in the present study show marked similarities to data presented from experiments examining IRT frequency distributions (Anger, 1956; Shimp, 1967). When the ICT is considered to be the response unit the situations are analogous. In the present study, ICTs of certain lengths were reinforced more frequently by reinforcement obtained on the other schedule than other

ICTs. These data suggest similarities to explanations offered for IRT relative frequency distributions.

The frequency of occurrence of IRTs has been considered to be related to the relative frequency of reinforcement associated with a given IRT length (Anger, 1956; Shimp, 1967; Shimp, 1968). One difficulty in demonstrating the relationship between IRTs and the relative frequency of reinforcement is the dynamic relationship which exists between them. In regular VI schedules the subject's behavior could determine the most frequently reinforced IRT. If, for example, the subject responded only every 30 sec, the 30-sec IRT would become the most frequently occurring IRT. The same dynamic relationship exists in the present situation, both when one considers the ICT as analogous to the IRT situation and when one considers the CO response to initiate a differentiable temporal interval. When the CO response is considered to initiate a differentiable temporal interval, the lower and upper limits do place constraints on the dynamic relationship between that response and the relative distributions of reinforcement.

The data obtained in the present experiment support both conceptualizations of the temporal interval as part of the response unit to the extent that the relative frequencies of occurrence of the unit correlate with the relative frequency distributions of reinforcement. When the upper limit is programmed, the relative frequency of reinforcement in the band is the same both for the subjects on VI 1-min VI 1-min schedules and for the subjects on VI 4-min VI 4-min schedules. In addition, the relative frequencies of reinforcement are the same regardless of whether one considers the ICT of the response initiated interval as the response unit. The subjects on VI 4-min VI 4-min schedules of reinforcement show much more dispersion at the 6-sec lower limit both with and without an upper limit than the subject on VI 1-min VI 1-min schedules. The relative frequencies of reinforcement are the same for both groups of subjects when the upper limit is programmed; thus one would predict no differences based on relative frequency of reinforcement alone.

Shimp (1970) has shown that absolute rate of reinforcement does have effects on the relative distribution of IRTs over certain ranges of overall rates of reinforcement. In the present experiment, overall rates of reinforcement were different for the two groups of subjects and thus might account for the lower portion of ICTs terminated in the bands when lower overall rates of reinforcement were programmed. Shimp (1969) has reported that when IRTs of two different lengths are reinforced with equal relative frequencies and equal overall rates, the longer IRT occurs less frequently. The differences between the degree of control exercised by the 1-4 sec band and the 5-8 sec band in the present experiment may partially result from the size of the ICT.

The preceding analysis is compatible with an IRT-reinforcement theory and consequently demonstrates the possibility of the generality of the model. The present experiment does not, however, provide additional support in terms of the basic efficacy of an IRT-reinforcement theory (see Alleman & Platt, 1973; and Reynolds & McLeod, 1970, for further discussion of those issues).

One alternative to considering the temporal interval as a differentiable property of the CO response is to consider CO responses to be under the control of temporal stimuli associated with certain parameters of reinforcement. The question to be considered here is this: On which schedule does the locus of control reside? One can consider the CO response to be under the control of stimuli signalling the availability of reinforcement on the other schedule or under the control of stimuli signalling a low probability of reinforcement on the schedule in which the subject is currently responding.

Pliskoff and Green (1972) demonstrated that a stimulus correlated with reinforcement availability as an alternative schedule could control the CO response. In concurrent procedures, the longer a subject responds on one schedule, the greater the probability that a reinforcer has been programmed on the other schedule. The temporal stimuli might control CO behavior in concurrent procedures in the same manner as the explicit stimulus programmed by Pliskoff and Green.

In the present study, the subject changed over at approximately the same point as that at which the highest frequency of reinforcement was obtained on that schedule. When the lower limit was added and then increased, the subjects stayed on a schedule until the lower limit had been reached. The lower limit increased the delay of reinforcement on the alternative schedule; thus COs might increase in latency because of the delay of reinforcement. Pliskoff (1971) has shown that the duration of a COD which is programmed on the alternative schedule can affect the ICTs on a schedule. When a 1-sec COD was programmed on one schedule and the COD on the other schedule was varied from 1 to 27 sec, the ICTs on the schedule with a 1-sec COD increased as the COD on the other schedule increased. The ICTs increased on the schedule with the increasing COD, but not to the extent that the ICTs increased on the other schedule.

In the present experiment, the data showing that subjects do respond on a schedule until reinforcement becomes available at least suggest that the ICTs may be affected by reinforcement on that schedule. The relative frequencies of ICTs and CO-per-Opportunity functions also show that CO responses out of a schedule are highly correlated with the occurrence of reinforcement on that schedule. These data suggest a second conceptualization of the discriminative control of CO behavior which emphasizes that subjects CO in order to get out of a schedule and into a better schedule. Further support for this conceptualization is provided by the data obtained when an upper limit was programmed.

The discrimination model based on reinforcements obtained in the other schedule does not predict the effects of adding an upper limit on the relative frequencies of ICTs and the CO-per-Opportunity functions. Adding an upper limit does not substantially affect the probability of reinforcement at the end of the lower limit on the alternative schedules. Therefore, one would not expect the probability of a CO to increase during the 3-sec interval between the upper and lower limit. The data obtained when an upper limit was added clearly show that the probability of a CO increases during the 3-sec interval.

Examination of the relative frequency distributions of reinforcement shows that the highest proportion of reinforcers occurs about 1 sec after the lower limit expires and that relatively few reinforcers occur after that time. The addition of an upper limit both increases the number of reinforcements which occur in the interval and reduces the probability of reinforcement for a stay beyond the interval to zero.

The proportion of ICTs during the 3-sec interval was lower for subjects with the lower overall rates of reinforcement. Both the probability of reinforcement per ICT in the interval and the temporal density of reinforcement was lower. It is possible that one of these variables is important in determining the discriminability of the point at which reinforcement should have occurred.

Pliskoff (1971) suggests two functions of the COD. The COD imposes a lower limit which requires that a CO response not occur until the lower limit has been reached if reinforcement is to be obtained. Secondly, the COD postpones the availability of reinforcement on the alternative schedule for the duration of the COD. Pliskoff suggests that the COD punishes COs by limiting the availability of reinforcement on the alternative schedule. In the present experiment, the highest probability of a CO was correlated with the peak in the relative frequency distribution of reinforcement even when neither an upper or lower limit was programmed. The discriminative control of CO behavior by temporal stimuli which signal periods of low reinforcement probability describes the data even when a lower limit is not programmed.

Generally, the consequences of a transition are emphasized in considering possible controlling variables.

The data in this study suggest that the consequences of not making a transition are also an important input into CO behavior. The data obtained in this experiment also contribute further to our understanding of the effects of adding a COD to concurrent schedules of reinforcement. The COD affects CO rates in two ways: (1) It constrains the reinforcement distribution, thus affecting where the highest proportion of reinforcement will be obtained, and (2) it delays the availability of reinforcement on the alternative schedules.

The present analysis of CO behavior shows considerable orderliness at the molecular level. The data show highly consistent correlations between the reinforcement distribution on a schedule and the occurrence of CO behavior. These changes occurred without affecting the relative measures at the molar level. The mathematical relationship between the ratio of the CO rates and the time ratios was presented in the introduction. As a result of this relationship, the relative time measure is clearly related to the CO distribution. Variations in the changeover distribution can occur at the molecular level without affecting the relative time measure, but the relative time measure can not change without affecting the CO distribution at the molecular level. The results of this study do not provide a definitive answer concerning the determination of relative time by the molecular control of CO behavior, but they do suggest the possibility.

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