**TWO-KEY CONCURRENT RESPONDING:
RESPONSE-REINFORCEMENT DEPENDENCIES
AND BLACKOUTS¹**

EMILY W. HERBERT

UNIVERSITY OF UTAH

Two-key concurrent responding was maintained for three pigeons by a single variable-interval 1-minute schedule of reinforcement in conjunction with a random number generator that assigned feeder operations between keys with equal probability. The duration of blackouts was varied between keys when each response initiated a blackout, and grain arranged by the variable-interval schedule was automatically presented after a blackout (Exp. I). In Exp. II every key peck, except for those that produced grain, initiated a blackout, and grain was dependent upon a response following a blackout. For each pigeon in Exp. I and for one pigeon in Exp. II, the relative frequency of responding on a key approximated, *i.e.*, matched, the relative reciprocal of the duration of the blackout interval on that key. In a third experiment, blackouts scheduled on a variable-interval were of equal duration on the two keys. For one key, grain automatically followed each blackout; for the other key, grain was dependent upon a response and never followed a blackout. The relative frequency of responding on the former key, *i.e.*, the delay key, better approximated the negative exponential function obtained by Chung (1965) than the matching function predicted by Chung and Herrnstein (1967).

Chung and Herrnstein (1967) found, in a two-key concurrent variable-interval (VI) schedule, that the relative frequency of responding on one key matched the relative immediacy of reinforcement on that key. That is, the proportion of the total number of responses emitted on one key approximated the relative reciprocal of the duration of the blackout preceding grain on that key, *i.e.*, $(1/d_L)/(1/d_L + 1/d_R)$, where d_L and d_R were the durations of the blackouts preceding grain on the left and right keys respectively. In the Chung and Herrnstein study, reinforcers were arranged for both keys on identical, independent, VI 1-min schedules. When a feeder operation was primed for a peck on a key, the

feeder was automatically presented following a response-initiated blackout, the duration of which varied between keys.

Shimp (1969, Exp. II) replicated a portion of Chung and Herrnstein's study with one difference: when a reinforcer was assigned for a peck on a key, one response on that key initiated a blackout, and the next response on that key (after the blackout) was immediately reinforced. As in the earlier study, the relative frequency of responding on a key matched the relative immediacy of reinforcement on that key. From Shimp's results it appears that the importance of the blackouts in these two studies was independent of delay of reinforcement in the traditional sense, *i.e.*, as a time interval imposed between the last response and reinforcement. The relative frequency of responding matched the relative reciprocals of the blackout durations when reinforcement was delayed on both keys and when reinforcement was immediate on both keys. In the present research, the effects of the response-reinforcement dependency following blackouts was further examined when each response to a lighted key initiated a blackout. In Exp. I, blackouts on both keys were followed by response-independent grain on a VI schedule. In Exp. II, blackouts on both keys were followed by response-dependent grain on a VI schedule.

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Chung and Herrnstein considered their study to be an investigation of the delay-of-reinforcement function; however, a subject's choices were between different durations of reinforcement delay, rather than between delayed and immediate reinforcement. Because the blackout durations preceding grain were different on the two keys, the reinforcers per hour that could be obtained by responding on the left key did not equal the reinforcers per hour on the right key. In effect, a constant equal to the duration of the blackout was added to each interreinforcement interval arranged for each key. Thus, the maximum reinforcers per hour obtainable on the key with the longer blackout duration was less than the maximum reinforcers per hour on the key with the shorter blackout duration. An earlier two-key study by Chung (1965) was more appropriately an investigation of delay of reinforcement *per se*. In Chung's study, a blackout preceded response-independent grain on one key while responses on the second key were immediately reinforced. An equal number of blackouts of the same duration were arranged for each key, so that the maximum rates of reinforcement were equal on the two keys. Chung reported that the relative frequency of responding on the key for which a delay was scheduled was described by a negative exponential function of the duration of the blackout, a result compatible with the bulk of literature on delay of reinforcement (e.g., Anderson, 1932; Hull, 1943; Perin, 1943). As noted by Chung and Herrnstein (1967), a negative exponential function and a linear matching function are mathematically incompatible. Nevertheless, Chung and Herrnstein found that Chung's data could be incorporated in the matching paradigm when a constant was used as the "real" delay of reinforcement on the key for which no delay was scheduled. The constant was determined as a correction for the delay that occurs in nominally immediate reinforcement, *i.e.*, the time taken for the pigeon to get to the feeder. Although the relative frequency of responding in Chung's study did approximately match the corrected relative immediacy of reinforcement, the relative immediacies were all greater than 0.62, and the data points suggest a tendency to curvature (Chung and Herrnstein, 1967, Fig. 3, which shows relative delay). If a negative exponential function more adequately describes

Chung's data than does a matching function, use of a greater range of relative immediacies should produce relative frequencies of responding substantially discrepant from matching. The procedure used here in Exp. III was similar to Chung's, but the blackout durations were altered to extend the range of relative immediacies.

In the two-key studies by Chung, Chung and Herrnstein, and Shimp, grain was scheduled for each key by equal, independent VI tapes. However, the obtained relative frequency of reinforcement on a key (the proportion of the total number of reinforcers obtained on one key) depended on a subject's responding as well as on the schedule parameters. In the present experiments, a subject's responding did not affect the obtained relative frequency of reinforcement.

METHOD

Subjects

Three experimentally naive homing pigeons were maintained at approximately 80% of their free-feeding weights.

Apparatus

The experimental chamber was a modified picnic ice chest containing two 1-in. (2.5-cm) diameter plastic keys separated 5 in. (12.8 cm) from center to center and positioned 8.6 in. (22 cm) from the floor of the chamber. A 2-in. by 2.25-in. (5.1 by 5.7 cm) aperture, 3.2 in. (8 cm) from the floor and equidistant from the adjacent walls, provided access to mixed grain presented by a Lehigh Valley Electronics food magazine (model #1519C). Each key was transilluminated with red light from an Industrial Electronics Engineers one-plane readout mounted behind each key. A G.E. 1024 bulb above a plastic window in the ceiling of the chamber served as a houselight. The houselight and keylights were turned off during blackouts and presentation of grain. A minimum force of 12 g (0.118N) was required to operate the keys. Continuous masking noise was provided during sessions.

Reinforcement Dependencies for Exp. I, II, and III

A VI schedule of reinforcement was generated from a constant probability tape with 50 interreinforcement intervals and an average

interval of 1.0 min. The probability of reinforcement as a function of time since reinforcement was approximately constant at 0.1 every 6.65 sec except at long times after reinforcement (Catania and Reynolds, 1968). Feeder operations arranged by the VI tape were assigned between the two keys at random. That is, the sequence of feeder operations between the two keys was a sequence of Bernoulli trials with $p = 0.5$. When a feeder operation was assigned by the VI tape, the tape stopped until grain had been presented. For example, if a feeder operation had been assigned for a peck on the left key, pecks on the right key went unreinforced until a peck on the left key had been reinforced. The relative frequency of reinforcement obtained on each key was thereby maintained at 0.5, except for sampling fluctuations in the Bernoulli-trials process. This method of scheduling reinforcers has the advantage of equating the scheduled and obtained relative frequency of reinforcement on each key so long as the subject responds occasionally on each key (Shimp, 1969). In Exp. I and II, the VI tape continued to operate during blackouts and feeder operations. The feeder exposure time was 2.5 sec for reinforced responses on both keys. Reinforcement was postponed for 1.0 sec after key switching, *i.e.*, the changeover delay (COD, Herrnstein, 1961) was 1 sec, and the feeder did not operate during blackouts. Sessions were conducted seven days a week.

EXPERIMENT I: CONTINUOUS BLACKOUTS AND DELAYED REINFORCEMENT

The relation between relative frequency of responding and relative immediacy of reinforcement was evaluated when each response to a lighted key initiated a blackout and grain was presented automatically at the end of the blackouts. The durations of the blackouts were varied between keys.

Procedure

After key-peck training, subjects received 25 days on the VI 1-min schedule with a 1-sec COD. Next, a blackout dependency was added to the VI 1-min schedule such that *each response to a lighted key initiated a blackout*. When a feeder operation was assigned for a peck on a key, grain was presented automati-

cally when the blackout terminated. The COD was no longer specifically scheduled because reinforcement after key switching was automatically delayed for over 1 sec by the blackouts. The pairs of blackout durations were 8 sec-8 sec, 2 sec-8 sec, and 18 sec-8 sec on the left and right keys respectively. Subjects were trained for 10 days on each pair, by which time visual inspection of cumulative records and graphs of daily relative response frequencies indicated that responding had stabilized. Data from the last four days of each condition were selected for response evaluations. Responses during blackouts were not included in computations of relative response frequencies, and few such responses were emitted. From informal observation it was noted that the blackout responses that did occur were made within the first second of the blackout.

RESULTS AND DISCUSSION

Table 1 shows the original data summed for the last four sessions under each condition. All calculations were made from those sums. The variable-interval scheduling before blackouts were introduced was successful in producing approximate matching of relative response frequencies to the relative frequencies of reinforcement. The mean relative frequency of responding on the left key for the three subjects was 0.53 and the obtained relative frequency of reinforcement on that key was 0.48.

The introduction of blackouts produced a three- to seven-fold decrease in the absolute rates of responding computed as total responses on both keys over minutes when the keys were lighted. However, it should be noted that in the blackout conditions response rate is the reciprocal of latency of response following a blackout. Individual subject's responses per minute were roughly constant for the 8 sec-8 sec and 2 sec-8 sec conditions (range 7.2 to 18.1); however, response rates for all subjects decreased in the 18 sec-8 sec condition (range 5.3 to 9.2).

To assess the effects of the blackouts on responding between keys, the relative immediacy of reinforcement on the left key, *i.e.*, the complement (one minus . . .) of the relative duration of the blackout on the left key, was selected as the independent variable. The relative frequency of responding on the left key, *i.e.*, the proportion of the total number of responses emitted on the left key over the last

Table 1
The Original Data Totaled across the Last Four Sessions of Exp. I

	<i>Blackout Duration (sec)</i>		<i>Responses</i>		<i>Reinforcements</i>		<i>Time in Light (min)</i>	<i>Sessions</i>
	<i>Left</i>	<i>Right</i>	<i>Left</i>	<i>Right</i>	<i>Left</i>	<i>Right</i>		
P1	0	0	9334	8072	113	127	289.6	25
	8	8	634	831	107	133	103.6	10
	2	8	1451	562	122	118	173.4	10
	18	8	324	819	121	119	184.0	10
P2	0	0	9871	9909	117	123	253.3	25
	8	8	798	702	107	133	135.6	10
	2	8	1904	731	121	119	145.2	10
	18	8	457	710	126	114	127.3	10
P3	0	0	6278	5175	119	121	280.5	25
	8	8	725	714	107	133	150.6	10
	2	8	1313	427	121	119	241.2	10
	18	8	342	752	120	120	205.1	10

four days of training, was selected as the dependent variable. The upper panel of Fig. 1 shows the matching of relative frequency of responding to the relative immediacy of reinforcement for individual subjects, and the range of values reported by Chung and Herrnstein for corresponding conditions. Although every response in the present experiment initiated a blackout, whereas only reinforced responses in the Chung and Herrnstein study initiated blackouts, the relative frequency of responding in both experiments closely approximated the relative immediacy of reinforcement. All of the data points for the present study fall within the range obtained in the earlier study. The mean relative frequencies of responding are plotted in the lower panel of Fig. 1. Again, the means from the present experiment are barely different from the means obtained by Chung and Herrnstein. It may be concluded that the matching relation between relative frequency of responding and relative immediacy of reinforcement is not disturbed when every response initiates a blackout, only some of which terminate in response-independent grain.

EXPERIMENT II: CONTINUOUS BLACKOUTS AND IMMEDIATE REINFORCEMENT

Experiment I demonstrated that the matching relationship obtained by Chung and Herrnstein (1967) was unaffected when the number of responses initiating blackouts was

Fig. 1. The relative frequency of responding on the left key as a function of the relative immediacy of reinforcement on that key. The upper panel compares individual performance with the ranges (short horizontal lines) obtained by Chung and Herrnstein for corresponding conditions. The lower panel compares means from Exp. I with those of Chung and Herrnstein's experiment.

increased from 60 per session to between 240 and 780 per session. If the response-reinforcement dependency following blackouts is also unimportant for the production of matching, subjects should continue to match when every response initiates a blackout and reinforcement following blackouts is response-dependent.

Procedure

To recover approximately equal frequencies of responding on the two keys, the subjects were trained for 10 days on the VI 1-min schedule with a 1-sec COD and no blackouts. Next, all but the 60 responses producing grain initiated blackouts. When a feeder operation was assigned to a key and the last blackout had been initiated on that key, the next response was immediately reinforced. Except for the change in the terminal response-reinforcement dependency, the scheduling was the same as in Exp. I. Responses during blackouts had no scheduled effect and were recorded separately. The blackout durations were 8 sec-8 sec, 2 sec-10 sec, and 20 sec-5 sec on the left and right keys respectively. Subjects were trained from 10 to 16 days in each condition, depending on how quickly performance stabilized. The data reported were obtained from the last four days of each condition.

RESULTS AND DISCUSSION

Table 2 shows the original data summed for the last four sessions of each condition. Approximately equal frequencies of responding

on the two keys were recovered on the VI schedule before blackouts were introduced. The mean relative frequency of responding on the left key was 0.47 and the mean obtained relative frequency of reinforcement on that key was 0.51.

Few responses were made during blackouts, and most that were made appeared to be "run-overs" from bursts of responses initiated in the illuminated chamber. Between 93 and 100% of an individual subject's blackout responses were emitted within the first second of the blackouts.

The absolute response rates when the keys were lighted were quite stable across the different pairs of blackouts for individual subjects, and response rates were approximately three times greater than the rates in Exp. I (range 15.2 to 41.4 responses per minute).

Because reinforcement did not follow blackouts automatically, subject differences in latency of making a post-blackout response could affect the relative immediacy of reinforcement. That is, the interval between the beginning of a blackout and reinforcement included the blackout duration and the time from the termination of the blackout to the reinforced response (as in Shimp, 1969). Response latencies were recorded as the time from the end of a blackout initiated on a key to the next response on either key. Since two responses on a single key were required for reinforcement, this latency measure may not be as appropriate for correcting relative immediacies as the latency between the end of a

Table 2
The Original Data Totaled across the Last Four Sessions of Exp. II

	<i>Blackout Duration (sec)</i>		<i>Responses</i>		<i>Reinforcements</i>		<i>Time in Light (min)</i>	<i>Sessions</i>
	<i>Left</i>	<i>Right</i>	<i>Left</i>	<i>Right</i>	<i>Left</i>	<i>Right</i>		
P1	0	0	4162	5490	127	113	270.9	10
	8	8	1376	2475	114	126	114.4	15
	2	10	2220	1576	136	104	91.7	10
	20	5	1064	1549	123	117	70.6	12
P2	0	0	6444	7576	119	121	271.5	10
	8	8	1856	1042	114	126	77.5	15
	2	10	3360	927	129	111	107.8	10
	20	5	843	2065	129	111	85.8	12
P3	0	0	4948	4382	119	121	276.5	10
	8	8	1140	1588	114	126	112.0	15
	2	10	2226	1063	131	109	149.7	10
	20	5	854	1211	130	110	135.8	12

Table 3
Mean Latencies (sec) from End of Blackout to Next Response

Condition	Pigeon 1		Pigeon 2		Pigeon 3	
	Left	Right	Left	Right	Left	Right
8 sec-8 sec	2.13	1.61	1.48	1.82	2.51	2.43
2 sec-10 sec	1.51	1.37	1.46	1.70	2.94	2.30
20 sec-5 sec	1.86	1.46	1.78	1.76	3.93	3.00

blackout initiated on a key and the next response on that same key. However, sequential statistics for key changes indicated that for individual subjects, most responses on a key were followed by another response on that same key. The median probability of more than one response on either key before switching to the other key was 0.83, with a range of 0.50 to 0.96. The 0.50 occurred in the first condition for Subject P1 for changes from the left to the right key. The mean latencies computed from sums over the last four days of training are presented in Table 3, and, for the most

part, the latencies were quite similar between keys for individual subjects.

For each subject, the relative immediacy of reinforcement was corrected by adding the mean latency for a key to the blackout duration on that key. The relative frequency of responding as a function of this corrected relative immediacy of reinforcement appears in Fig. 2. The upper panel presents data for individual subjects with the ranges found by Shimp (1969, Exp. II) for corresponding conditions. The lower panel shows the means from this study and those from Shimp's investigation.

For individual subjects the matching in this experiment was not as close as in Exp. I. Moreover, when the blackout durations were equal on the two keys (8 sec-8 sec), the relative response frequencies were more variable among subjects than in Exp. I. Six of nine individual data points fall outside the range obtained by Shimp. The matching was close for Subject P2 when the blackout durations were different between keys. However, P1 and P3 made more responses on the key with the longer blackout duration than is predicted by matching. The mean data roughly approximate the matching function, but again the data points indicate somewhat too much responding on the key with the longer blackout duration. Although the present data suggest that for one subject, P2, the response-reinforcement dependency following blackouts is unimportant for the production of matching, the generality across birds is not clear.

EXPERIMENT III: DELAYED VS IMMEDIATE REINFORCEMENT

In the preceding two experiments, the relative frequency of responding on a particular key roughly approximated the relative immediacy of reinforcement on that key when the response-reinforcement dependencies follow-

Fig. 2. The relative frequency of responding on the left key as a function of the relative immediacy of reinforcement on that key. The upper panel compares individual performance with the ranges (short horizontal lines) obtained by Shimp. The lower panel compares means from Exp. II with those of Shimp.

ing blackouts were identical on the two keys, *i.e.*, when pecks on both keys produced either response-independent or response-dependent reinforcement. The purpose of Exp. III was to evaluate the delay-of-reinforcement function by changing the response-reinforcement dependencies between keys when blackout durations were equal on the two keys and the relative frequency of reinforcement was controlled. Chung's (1965) procedure was followed except for differences in the durations of blackouts and the scheduling of reinforcers.

Procedure

To recover approximately equal frequencies of responding on the two keys, subjects were trained for six days on the VI 1-min schedule with a 1-sec COD. Next, reinforcement on the left key was delayed by a blackout and reinforcement on the right key was immediate. As in the first two experiments, feeder operations were arranged by a single VI tape in conjunction with a random number generator that assigned feeder operations between keys with equal probability. When a feeder operation was assigned for the left key, the next response initiated a blackout that was followed by automatic presentation of grain. When a feeder operation was assigned for the right key, the next response was immediately reinforced. To equate the consequences of responding on the left and right keys, blackouts of the same duration as those on the left key were scheduled for the right key by an independent VI 2-min schedule. Pecks on the right key therefore produced approximately equal frequencies of blackouts and grain. When both a feeder operation and a blackout were assigned for the right key, the first response produced grain and the second a blackout. Responses on either key were ineffective during blackouts and few blackout responses were made. The VI tape scheduling feeder operations and the VI tape scheduling blackouts for the right key were halted during presentation of grain. A COD prevented either presentation of a reinforcer or a blackout for 1 sec after key switching. The principal difference between this procedure and the one used by Chung (1965) was in the scheduling of feeder operations. Chung used two independent VI 1-min tapes, and the obtained relative frequency of reinforcement depended in part on responding.

In the first series of conditions, the obtained relative frequency of reinforcement on the left (delay) key approximated 0.5; that is, the random number generator assigned feeder operations between keys with equal probability. The blackout durations, equal on both keys, were 0.2, 0.5, 1.0, 3.0, 5.0, and 15.0 sec. In the second series of conditions, the relative frequency of reinforcement on the left key was altered to approximate the values that would have been obtained using Chung's method of scheduling reinforcers. The blackout durations were 15, 5, and 10 sec and the relative frequencies of reinforcement arranged for the left key were 0.26, 0.46, and 0.35 respectively. These relative frequencies of reinforcement were taken from Chung, 1965, Fig. 3 for corresponding delays.

RESULTS AND DISCUSSION

Table 4 shows the original data summed for the last four sessions of each condition. All calculations were made from these sums. The relative frequency of responding plotted against the relative immediacy of reinforcement [as computed by Chung and Herrnstein (1967) for Chung's (1965) data] appears in Fig. 3. It will be recalled that those authors used a constant, 1.6 sec, as the "real" delay of reinforcement on the key for which no delay was scheduled. Thus, relative immediacy was calculated as $(1/d)/(1/d + 1/1.6)$, where d equals the duration of the blackout on the key for which a delay was scheduled. Figure 3 clearly contradicts matching. Even if a different constant were used as the "real" delay on the key for which no delay was scheduled, matching would be improved for only half the data points; *e.g.*, a constant of 2.7 sec would fit the relative response frequencies for delays greater than 1 sec, but at a 1-sec delay, the mean relative frequency of response would deviate 0.25 from the matching function. Because pigeons have been observed to collect some grain when the feeder exposure time was only 1 sec and reinforcement was immediate (Shettleworth and Nevin, 1965), it is difficult to justify the use of a constant greater than 1 sec as the time taken by the pigeon to get to the feeder.

Chung found that subjects responded more frequently on the delay key than on the key for which no delay was scheduled at a 1-sec delay. That is, subjects preferred a short delay

Table 4
The Original Data Totaled across the Last Four Sessions of Exp. III

	Blackout Duration (sec)	Responses		Reinforcements		Time in Light (min)	Sessions
		Left	Right	Left	Right		
P1	0	6506	9616	115	125	267.1	6
	1	9045	12874	121	119	270.4	16
	3	9221	14432	116	124	240.3	10
	0.5	11525	13402	122	118	269.1	10
	0.2	11476	11577	140	100	261.7	10
	5	12527	14171	124	116	274.4	10
	15	2858	11689	115	125	306.6	10
	15	1196	18225	61	179	386.5	6
	5	7213	13331	109	131	265.0	6
	10	4759	17759	81	159	272.6	7
P2	0	10214	7207	116	124	252.3	6
	1	10085	10409	120	120	251.1	16
	3	7254	8754	118	122	234.1	10
	0.5	7335	7777	121	119	262.0	10
	0.2	7966	8056	128	112	261.7	10
	5	4279	9244	130	110	259.8	10
	15	2540	16484	115	125	317.6	10
	15	1791	12900	67	173	293.8	6
	5	4309	9272	117	123	255.2	6
	10	2223	10259	91	149	238.5	7
P3	0	6716	5289	122	118	283.8	6
	1	11199	8549	121	119	261.5	16
	3	10333	8362	106	134	252.5	10
	0.4	9565	6573	121	119	258.0	10
	0.2	8147	9627	138	102	265.1	10
	5	6652	7899	125	115	264.8	10
	15	5395	8093	115	125	313.9	10
	15	2887	8033	61	179	264.8	6
	5	7123	8422	110	130	273.0	6
	10	4795	10363	81	159	267.7	7

Fig. 3. The relative frequency of responding on the delay key for individual subjects as a function of the corrected relative immediacy of reinforcement. The squares indicate responding when the relative frequency of reinforcement on the delay key was less than 0.5.

to immediate reinforcement, perhaps because the short delay permitted them to orient toward the feeder before the hopper was presented. Figure 4 shows the relative frequency

Fig. 4. The relative frequency of responding on the delay key for individual subjects as a function of the delay duration. The squares indicate responding when the relative frequency of reinforcement on the delay key was less than 0.5.

of responding plotted against the delay intervals for individual subjects. In the present study, there was no consistent preference for a short delay over immediate reinforcement; however, the data points between delays of 0 and 1 sec were variable among subjects. In general, the relative frequency of response was a decreasing function of the length of the delay. Reducing the relative frequency of reinforcement on the key for which a delay was scheduled to values that would have been obtained using Chung's method of scheduling reinforcers also decreased responding on that key, especially at the 15-sec delay.

Figure 5 compares the mean relative frequency of responding as a function of the delay interval for the subjects in the present experiment with (a) the function predicted by Chung and Herrnstein for matching to relative immediacy of reinforcement (as computed in Fig. 3), and (b) the best-fitting function obtained by Chung. Clearly, the negative exponential function obtained by Chung more closely approximates the data from the present experiment than does the matching function.

A delay-of-reinforcement function more

Fig. 5. The relative frequency of responding on the delay key as a function of the duration of the delay as predicted by Chung and Herrnstein for matching-to-relative immediacy, as obtained by Chung, and as obtained in Exp. III. The solid circles indicate the means when the relative frequency of reinforcement on the delay key was equal to 0.5, and a straight line was fitted to these means by the method of least-squares. The squares indicate the means when the relative frequency of reinforcement on the delay key was less than 0.5.

similar to Chung's than to the matching function was obtained both when the relative frequency of reinforcement was constant at 0.5 and when it was decreased at long delay intervals. However, decreasing the relative frequency of reinforcement on the delay key increased the slope of the function and clearly influenced the relative frequency of response on the delay key. This result suggests that Chung's data were at least partially dependent upon the relative frequency of reinforcement obtained on the delay key. That is, the effects of relative frequency of reinforcement were confounded with the effects of delay of reinforcement, and as a representation of only delay-of-reinforcement effects, the exponential function obtained by Chung is probably too steep. The method used to schedule reinforcers in the present study did not permit a subject's responding to affect the relative frequency of reinforcement. Thus, the effects of delay *per se* were not confounded with the effects of relative frequency of reinforcement when the relative frequency of reinforcement was maintained at 0.5.

In Chung's study, the mean total response rates were roughly constant across the different delay intervals, ranging from approximately 70 to 88 responses per minute. For the three subjects in the present experiment, the mean total response rates ranged from 64 to 80 responses per minute for delay intervals shorter than 15 sec. At both 15-sec delays, the mean total response rates were slightly lower at 53 responses per minute.

GENERAL DISCUSSION

The present results delineate some of the conditions under which a matching relation holds between the relative frequency of responding and the relative immediacy of reinforcement. Matching was obtained when each response initiated a blackout and reinforcement following blackouts was response-independent. A rough approximation to matching was obtained when each response initiated a blackout and reinforcement was response-dependent. However, matching was not obtained when response-reinforcement dependencies were different between keys.

Chung and Herrnstein (1967) emphasized the importance of the delay in the response-reinforcement dependency for the production

of matching-to-relative-immediacy. However, from the results of Shimp (1969, Exp. II) and from the data of P2 in Exp. II it appears that blackouts may affect choice responding in some other way. That is, matching was not restricted to the condition of a delay interval imposed between the last response and reinforcement. The results of Exp. III further question the viability of Chung and Herrnstein's interpretation of matching as a function of reinforcement delay. When the response-reinforcement dependencies were different between keys, the relative frequency of response was similar to the negative exponential delay-of-reinforcement function obtained by Chung (1965), rather than the matching function predicted by Chung and Herrnstein.

In these studies of concurrent responding, it appears that the relative frequency of response will be best described by either matching to the relative immediacy of reinforcement or a delay-of-reinforcement function depending on the relation between the independent variables and responses on each of the two keys. Matching was obtained when different durations of blackouts were associated with responses on the left and right keys, and a subject's choices did not affect the response-reinforcement dependency or the percentage of responses initiating blackouts. A delay-of-reinforcement function was obtained when different response-reinforcement dependencies were associated with responses on the two keys,

and the duration of blackouts was independent of a subject's choices.

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