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THE REINFORCEMENT OF FOUR INTERRESPONSE TIMES IN A TWO-ALTERNATIVE SITUATION[1]

CHARLES P. SHIMP

UNIVERSITY OF UTAH

Pigeons pecked for food in a two-key procedure. A concurrent variable-interval variable-interval schedule of reinforcement for two classes of interresponse times was arranged on each key. A visual stimulus set the occasion for potential reinforcement of the four operant classes: shorter and longer interresponse times on left and right keys. In Exp. I, the relative frequency of respones on a key equalled the relative frequency of reinforcement on that key. In Exp. II, the relative frequency of an interresponse time equalled the relative reciprocal of its length. In Exp. III, the relative frequency of an interresponse time was a monotonically increasing function of its relative frequency of reinforcement. These functions relating the relative frequency of an interresponse time to its relative length and to its relative frequency of reinforcement were the same as if there had been no second key. Also, the distribution of responses between keys was independent of the relative frequency of an interresponse time on either key. Experiment IV replicated Exp. I except that choices between keys were controlled by a stimulus that signalled the availability of reinforcement on the right key. A comparison of Exp. I and IV suggested that the relative frequency of an interresponse time on one key generally was independent of behavior on the other key, but that the number of responses per minute on a key did depend on behavior on the other key.

Concurrent variable-interval variable-interval (*conc* VI VI) schedules of reinforcement provide orderly functions in both one-key and two-key contexts. For example, in a one-key *conc* VI VI for two classes of reinforced interresponse times (IRTs), the relative frequency of an IRT approximately equals the relative reciprocal of its length (Shimp, 1969). In such a schedule, the relative frequency of an IRT is also a monotonically increasing function of the relative frequency of reinforcement for that IRT (Shimp, 1968; Staddon, 1968). In a two-key *conc* VI VI for choices between keys, the relative frequency of responding on a key approximately equals the relative frequency of reinforcement on that key (Herrnstein, 1970). No two of these three functions from one-key and two-key experiments have been obtained simultaneously in a single experiment. One may specifically ask, therefore, if either of these functions from one-key experiments can be obtained simultaneously with the matching function from two-key experiments.

The basic paradigm used here to answer this question was a generalization of a procedure recently used by Moffitt and Shimp (1971) to study relationships between choice behavior and IRTs. Their procedure was a two-key concurrent paced VI paced VI, with one class of IRTs reinforced on one key and a second class of IRTs reinforced on the second key. Here, the procedure was generalized by adding a second class of reinforced IRTs to each key. That is, here there was a *conc* VI VI for two IRTs, on each of two keys. It was asked if the relative frequency of an IRT depended on the relative reciprocal of its length and on the relative frequency of reinforcement for that IRT in the same way as it would if there were only one key. It was also asked if the relative frequency of responding on a key depended on the relative frequency of reinforcement on that key in the same way as it would if there was an ordinary VI schedule on each key, instead of a *conc* VI VI for two IRTs.

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GENERAL METHOD

Apparatus

The experimental chamber was a Lehigh Valley Electronics two-key pigeon chamber. A white, green, or red light could be turned on behind each translucent pecking key. Electromechanical devices in a separate room arranged stimuli and reinforcements and counted responses. White noise helped to mask extraneous sounds.

Procedure

The reinforcement schedule was a two-key *conc* VI VI, modified so that there were just two classes of reinforced IRTs on each key. Four operant classes were studied: the shorter and longer IRTs on the left key, and the shorter and longer IRTs on the right key. The two classes of IRTs on the left key were correlated with a red light on the left key, and the two classes of IRTs on the right key were correlated with a red light on the right key. The schedule consisted of several parts: a VI schedule that determined the minimum interreinforcement intervals; a mechanism to determine which one of the four classes of IRTs was to be reinforced next and a mechanism to sort IRTs into classes, including the four classes of reinforced IRTs. The various parts of the reinforcement schedule are described below in detail.

Stimuli

One of the two keys was always green. A peck on the green key was a changeover response, which initiated the sequence of events depicted in Fig. 1 on that key and made the other key green. A peck at any time on either key darkened that key if it previously had been lighted. Then, as time elapsed without a subsequent peck, the sequence of events depicted in Fig. 1 followed. As Fig. 1 shows, after a response on a key, that key successively was dark, red, dark, red, and dark. The sequence of events for a key shown in Fig. 1 was recycled by a peck on that key. If a bird pecked during the first presentation of the red stimulus after a response, it terminated an IRT belonging to the class of shorter, reinforced IRTs on that key. A peck during the second presentation terminated an IRT belonging to the class of longer, reinforced IRTs on that key. If no peck occurred before the end of the second presentation of the red key light, the key became dark and remained dark. That is, the sequence of stimuli was not automatically recycled if a bird failed to peck in either presentation of the red stimulus. In that case, a bird was required to peck the dark key to recycle the sequence depicted in Fig. 1. (A peck on the other key, the green key, would also initiate the same sequence on the other key.) A houselight illuminated the chamber except when either left or right key was red. Also, the

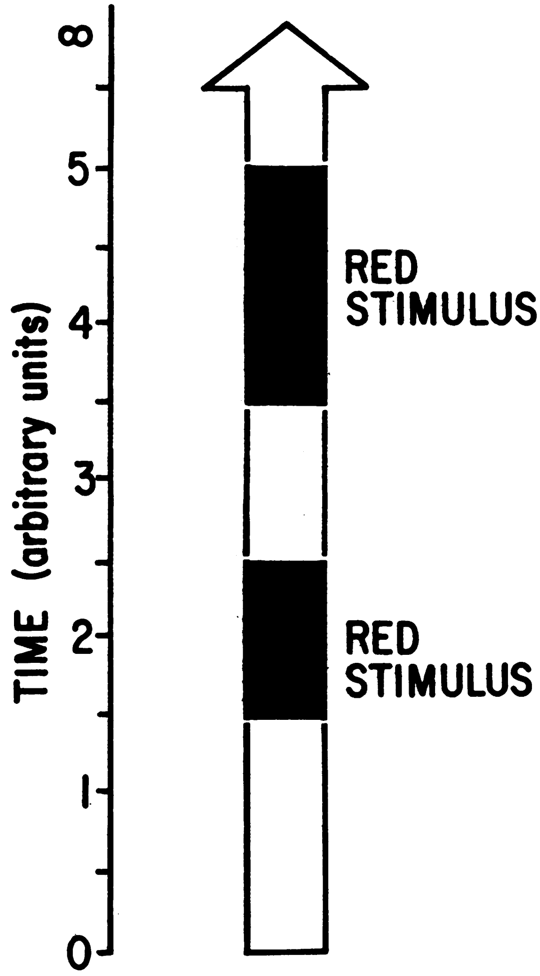

Fig. 1. Sequence of stimuli appearing on a key after a response on that key. Simultaneously, the other key was green. When either key was red the houselight was off. If the unit of time were 1 sec, then the figure would show the time relations for Exp. III. That is, in Exp. III, reinforcement was intermittently assigned to IRTs between 1.5 and 2.5 sec and between 3.5 and 5.0 sec in duration.

houselight was off during reinforcement, when the feeder light was on.

VI Schedule

The minimum times between successive reinforcements were arranged by a single, constant probability VI 1-min schedule. When the VI tape assigned a reinforcement, the tape stopped until the reinforcement occurred. However, if a bird paused for an interval exceeding the longer reinforced IRT, the tape started to move again, and the previously assigned reinforcement was cancelled. The purpose of this cancellation was to reduce the frequency of reinforcement for the first IRT following a long pause. This cancellation did not affect which class of IRTs was to be reinforced next.

IRT Contingencies

A response could be reinforced only if it terminated a time interval (after the previous response on the same key) that belonged to one of two classes of reinforced IRTs. The shorter reinforced IRTs were always the same on left and right keys, and also the longer reinforced IRTs were always the same on both keys.

As a consequence of the IRT contingencies, the first response on a key, *i.e.,* a changeover response on the green key, was never reinforced. That is, the IRT contingencies provided a built-in changeover delay. This delay was always the same on both keys because the shorter IRT was the same on both keys.

The first response after a reinforcement could be reinforced if it terminated a time interval belonging to one of the four IRT classes (counting time from the end of reinforcement) and if it occurred on the same key as the just-reinforced response.

Reinforcement Selection Mechanism

A sequence of Bernoulli trials is one in which, on every trial, there are two possible outcomes, exactly one of which occurs. The probability of a given outcome is constant over trials and is independent of the outcome on the preceding trial. In this experiment, two such "trials" occurred at the end of each reinforcement. The "first trial" had as its possible outcomes the assignment of the next reinforcement to the left or right key. The "second trial" had as its possible outcomes the assignment of the next reinforcement to the shorter or the longer IRT. Together, these two Bernoulli trials assigned the next reinforcement to one of the four operants under consideration in the present paper: shorter or longer IRT on left or right key. The relative frequency of reinforcement on a key could be manipulated by varying the probability in the "first trial". The relative frequency of reinforcement for the shorter IRT could be manipulated by varying the probability in the "second trial".

The probability of reinforcement for the shorter IRT was always the same on both keys.

As noted above, the assignment of the next reinforcement to one of the four classes of IRTs was not affected by the cancellation of reinforcement by a long pause. Such pauses only restarted the VI tape.

Recording

IRTs were recorded on electromechanical counters; four counted the numbers of shorter and longer IRTs on left and right keys.

Other arrangements

Experimental conditions were terminated when the relative frequency of the major dependent variable for an experiment appeared stable for three or four days. All sessions were 50 min in duration.

EXPERIMENT I

In Exp. I, the distribution of reinforcements between the two keys was varied while the relative length of, and the probability of reinforcement for, an IRT was held constant. It was asked if the relative frequency of responses on a key matched the probability of reinforcement on that key. This matching is the result expected in ordinary two-key *conc* VI VI schedules (Herrnstein, 1970). It was also asked if the relative frequency of an IRT on a key equalled the relative reciprocal of its length. This matching is the result expected in one-key *conc* VI VI schedules of reinforcement for two classes of IRTs, when both IRTs are reinforced equally often (Shimp, 1969). More generally, it was asked if the relative frequency of responding on a key was correlated with the relative frequency of an IRT on either key.

METHOD

Subjects

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

Procedure

The lower and upper bounds for the class of shorter, reinforced IRTs were 1.0 and 2.0 sec. The corresponding bounds for the class of longer, reinforced IRTs were 3.0 and 4.5 sec. The relative frequency of reinforcement for the shorter IRT was 0.5 on both keys. Only the distribution of reinforcement between keys was varied, as shown in Table 1.

RESULTS

Table 1 gives the frequencies of shorter and longer IRTs on both left and right keys, on each of the last two days of each condition. The notation S and L in the table refers to shorter and longer IRTs. The relative frequency of responses on the left key equals the number of shorter IRTs plus the number of longer IRTs on the left key divided by the total number of shorter and longer IRTs on both keys. Note that responses not terminating a shorter or a longer IRT were not included in this computation. That is, responses to a dark or green key were excluded. Such responses often make up only a comparatively small fraction of all responses on a key, so their exclusion from the computations does not appreciably affect the results (Shimp, 1969; Shimp, 1970; Moffitt and Shimp, 1971). The resulting relative frequencies of responding on the left key, for each of the last two days of Conditions 2, 3, and 4 appear in Fig. 2. (Condition 1 was replicated by Condition 4.) The three panels in Fig. 2 for individual pigeons show that the relative frequency of responses on the left key approximately equalled the probability of reinforcement on the left key for each pigeon. The six relative frequencies for each condition in these three panels were averaged, and, as the fourth panel in Fig. 2 shows, the resulting relative frequencies of responses were virtually identical to the corresponding reinforcement probabilities.

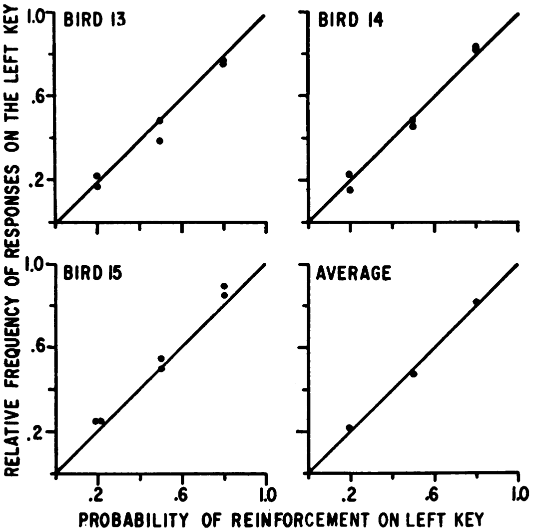

Fig. 2. The relative frequency of responses on the left key as a function of the probability of reinforcement on the left key.

The relative frequency of the shorter IRT on either key also can be computed from Table 1. The relative frequency of the shorter

Table 1

Number of Shorter and Longer IRTs on Each of Last Two Days of Each Condition

Condition Number	*Number of Days*	*Probability of Reinforcement on Left Key*	*Bird 13*				*Bird 14*				*Bird 15*			
			Left		*Right*		*Left*		*Right*		*Left*		*Right*	
			S	*L*	*S*	*L*	*S*	*L*	*S*	*L*	*S*	*L*	*S*	*L*
1	10	0.50	191	80	353	245	218	76	472	176	307	83	371	182
			242	81	245	259	250	94	466	175	313	88	427	138
2	8	0.80	375	313	152	50	545	245	122	29	552	194	105	30
			509	228	177	56	523	261	118	40	610	201	57	31
3	10	0.20	149	77	543	222	97	44	565	260	220	21	508	210
			124	61	525	306	145	52	471	203	222	37	579	217
4	13	0.50	249	165	246	187	301	144	349	115	376	156	286	153
			210	100	215	263	311	109	394	91	359	139	356	139

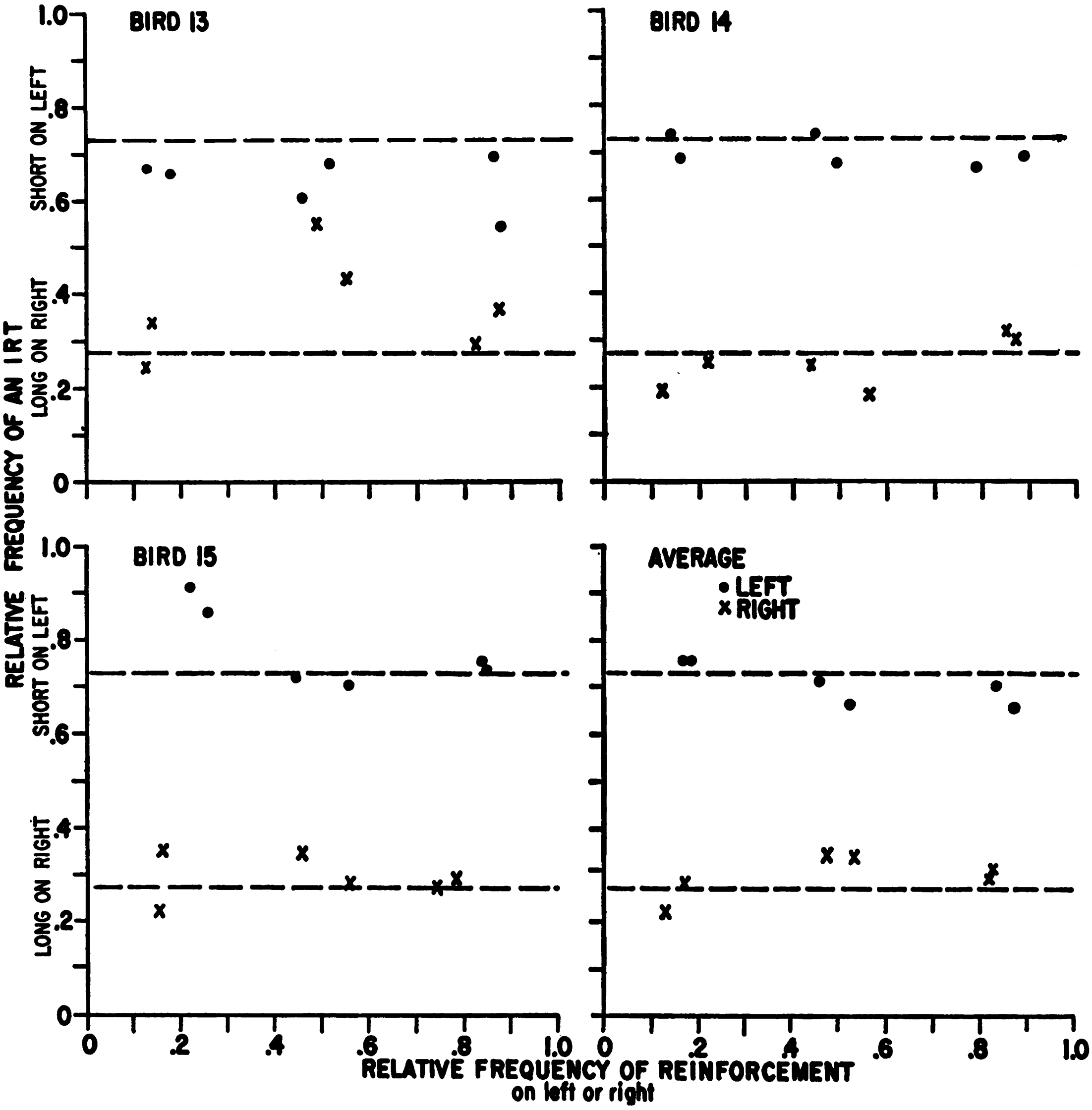

Fig. 3. The relative frequency of the shorter IRT on the left key and the relative frequency of the longer IRT on the right key, as a function of the relative frequency of reinforcement on the left and right key, respectively.

IRT on a key is the number of shorter IRTs on that key divided by the total number of shorter and longer IRTs on that key. Figure 3 shows the relative frequency of the shorter and longer IRTs on the left and right keys, respectively. Figure 3 shows that there was no systematic change in the relative frequency of an IRT on either key as the distribution of reinforcements between keys was varied. The data in Fig. 3 are consistent with those of previous one-key *conc* VI VI for two IRTs in that the relative frequency of an IRT approximately equalled the relative reciprocal of its length (Shimp, 1969). This relative reciprocal is indicated in Fig. 3 by a horizontal, dashed line.

DISCUSSION

Experiment I showed that the relative frequency of responses on a key approximately equalled the probability of reinforcement on that key, even when, on both keys, the relative frequency of an IRT remained fixed at a value approximately equal to the relative reciprocal of the length of that IRT. Thus, Exp. I showed that the matching function for choices between keys that is obtained with ordinary *conc* VI VI schedules can also be obtained when there are only two classes of reinforced IRTs on a key. The distribution of responses between keys and IRTs were independent in Exp. I in the sense that when the former distribution changed, the relative frequency of an IRT remained constant.

EXPERIMENT II

In Exp. II, the relative length of an IRT was varied while the various reinforcement distributions were held constant. The relative length of an IRT was varied over conditions but within any one condition it was always the same on left and right keys. It was asked if the relative frequency of an IRT matched the relative reciprocal of its length. That is, it was asked if the matching-to-relative-reciprocal phenomenon would be obtained in the present two-key context as it would be if there were only one key (Shimp, 1969). Also, it was asked if the distribution of responses between keys was affected by changes in relative frequencies of IRTs.

METHOD

Subjects

Three experimentally naive, White Carneaux pigeons served and were maintained at approximately 80% of their free-feeding weights.

Procedure

In Exp. II, the lengths of the reinforced IRTs were varied as shown in Table 2. The probabilities of reinforcement for the left key, and for the shorter IRT on both left and right, were all equal to 0.5.

RESULTS

Table 2 gives the frequencies of the shorter and longer IRTs on both left and right keys, on each of the last two days of each condition. Figure 4 shows the relative frequency of the shorter IRT on both left and right keys as a function of the relative reciprocal of the length of the shorter IRT. Figure 4 reveals greater variability in the individual data than was obtained in Exp. 1, but a tendency for the data to approximate the matching function is nevertheless clearly visible. For some unknown reason, the approximation was usually

Table 2

Number of Shorter and Longer IRTs on Each of Last Two Days of Each Condition

Condition Number	*Number of Days*	*Lower and Upper Bounds of the Two Classes of Reinforced IRTs (sec)*		*Relative Reciprocal of the Length of the Shorter IRT*	*Bird 17*				*Bird 18*				*Bird 19*			
					Left		*Right*		*Left*		*Right*		*Left*		*Right*	
		Shorter	*Longer*		*S*	*L*	*S*	*L*	*S*	*L*	*S*	*L*	*S*	*L*	*S*	*L*
1	11	(1.0,2.0)	(3.0,4.0)	0.720	332	100	330	77	280	121	337	119	235	150	461	173
					247	74	382	81	277	55	330	120	240	172	298	135
2	10	(1.0,2.0)	(3.0,4.5)	0.730	248	122	235	134	237	117	468	79	221	229	172	109
					215	118	262	146	180	121	457	104	250	224	245	50
3	6	(1.0,2.0)	(4.0,5.5)	0.776	255	134	180	90	312	109	181	50	285	134	361	30
					222	127	183	99	330	109	200	91	158	127	385	52
4	8	(1.0,2.0)	(6.0,7.5)	0.833	208	64	377	91	204	70	516	77	300	68	230	39
					230	79	353	67	160	98	399	86	308	116	291	32
5	5	(1.0,2.0)	(12.0,13.5)	0.905	168	27	224	25	215	24	446	17	245	21	231	0
					194	43	330	21	188	20	435	31	183	10	223	4
6	14	(1.5,2.5)	(4.0,5.5)	0.712	110	120	225	191	138	56	219	304	315	101	189	117
					104	129	208	206	174	86	212	153	177	84	301	128
7	9	(1.5,2.25)	(2.55,3.55)	0.622	214	103	206	141	132	175	212	161	201	176	228	98
					215	136	200	123	139	179	201	136	201	153	264	113
8	10	(1.5,2.25)	(4.0,5.0)	0.712	160	141	224	79	381	67	247	111	198	132	270	163
					208	111	192	102	281	80	271	111	198	104	257	175

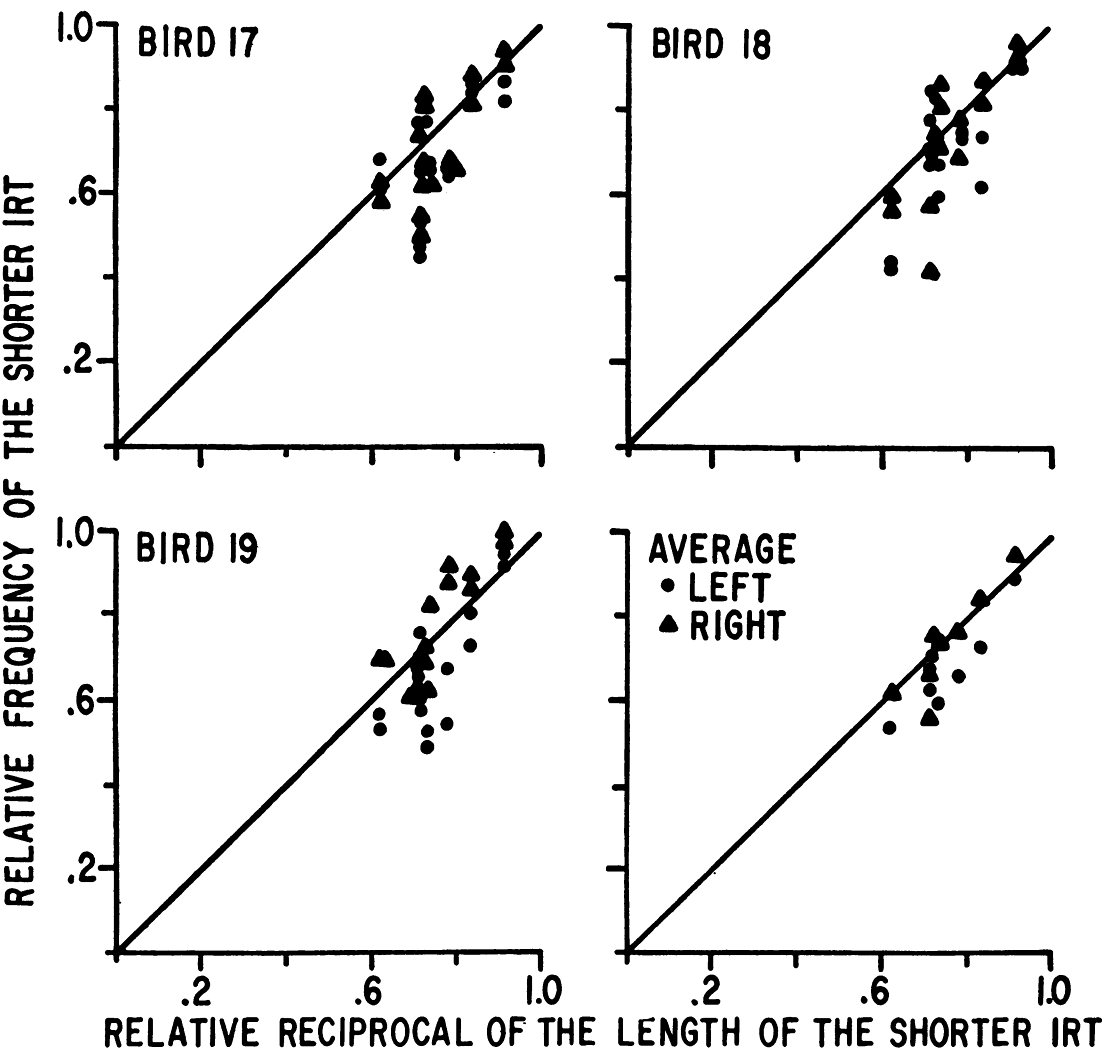

Fig. 4. The relative frequency of the shorter IRT as a function of the relative reciprocal of the length of the shorter IRT.

better on the right key than on the left. The relative frequency of the shorter IRT on the left key was often somewhat too low. In general, however, the relative frequency of an IRT did approximately equal the relative reciprocal of its length, on both keys.

Figure 5 is the converse of Fig. 3, which showed that the relative frequency of an IRT did not systematically vary as the distribution of responses between keys changed. Figure 5 shows that this measure of choice behavior did not systematically vary as the relative frequency of an IRT changed. It also shows that the relative frequency of responses on the left key approximately equalled the value of 0.5, *i.e.*, the probability of reinforcement on the left key (which is indicated by a horizontal dashed line).

Discussion

Experiment II shows that the previously obtained, one-key matching-to-relative-reciprocal phenomenon can be obtained on each key in a two-key *conc* VI VI schedule while the appropriate choice behavior is maintained. More generally, choice behavior was independent of the changing relative frequencies of IRTs.

EXPERIMENT III

In Exp. III, the probability of reinforcement for an IRT was varied while the distri-

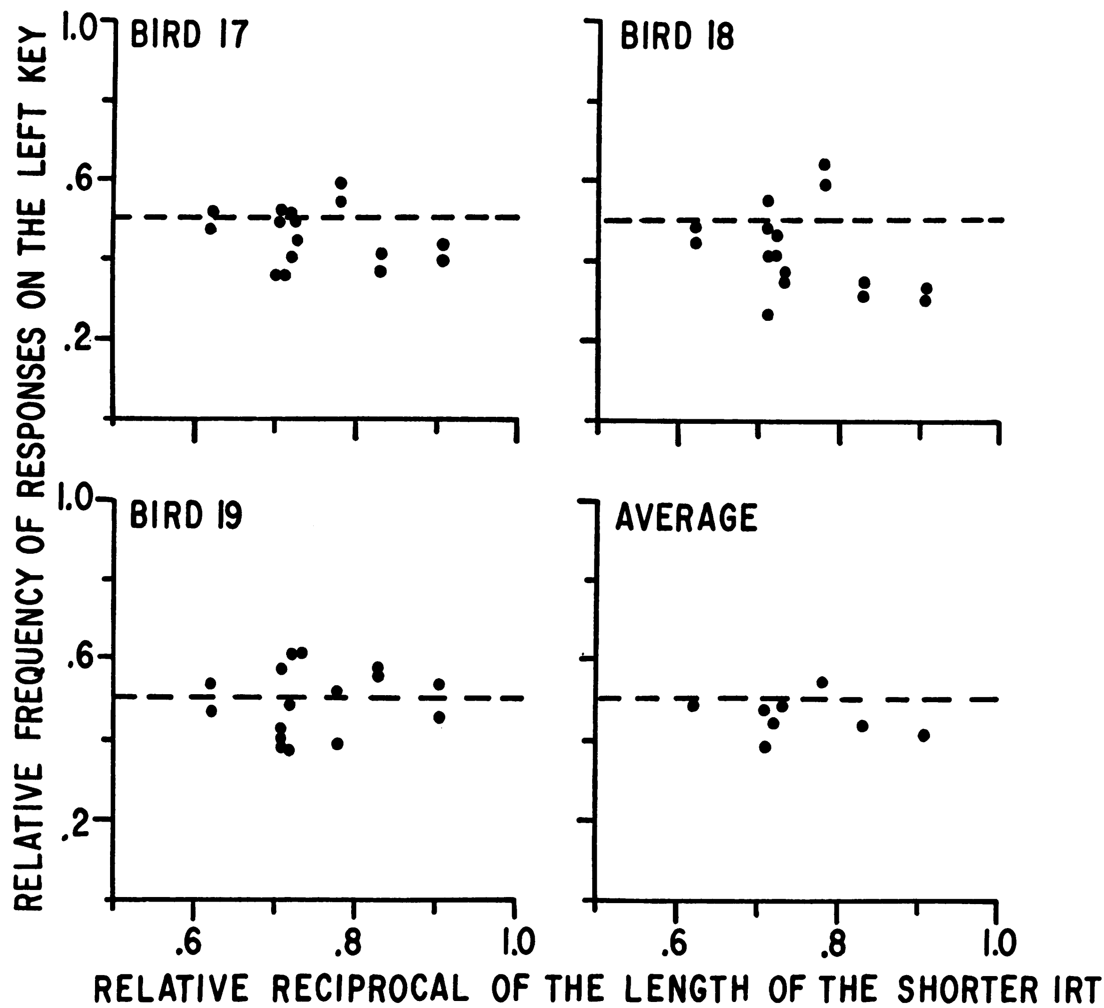

Fig. 5. The relative frequency of responses on the left key as a function of the relative reciprocal of the shorter IRT.

bution of reinforcements between keys and the lengths of the reinforced IRTs were held constant. It was asked if the relative frequency of an IRT would depend on its probability of reinforcement in the present two-key procedure in the same way as in an analogous one-key procedure (Shimp, 1968). It was also asked if the distribution of responses between keys changed when the relative frequency of an IRT changed.

METHOD

Subjects

The same three naive homing pigeons used in Exp. I were again utilized in Exp. III.

Procedure

Column 3 of Table 3 shows how the probability of reinforcement for the shorter IRT was varied. The probability of reinforcement for the shorter IRT was always the same on both keys. The probability of reinforcement for responses on the left key was held constant at 0.5. The lower and upper bounds for the shorter reinforced IRTs, on both left and right keys, were 1.5 and 2.5 sec. The bounds for the longer IRTs were 3.5 and 5.0 sec.

RESULTS

Table 3 gives the obtained frequencies of shorter and longer IRTs, on each key, on each of the last two days of each condition.

Table 3

Number of Shorter and Longer IRTs on Each of Last Two Days of Each Condition

Condition Number	Number of Days	Probability of Reinforcement for Shorter IRT	*Bird 13*				*Bird 14*				*Bird 15*			
			Left		*Right*		*Left*		*Right*		*Left*		*Right*	
			S	*L*	*S*	*L*	*S*	*L*	*S*	*L*	*S*	*L*	*S*	*L*
1	10[1]	0.8	181	78	339	92	268	27	255	101	240	65	530	66
			189	76	374	63	200	40	260	94	285	67	547	49
2	10	1.0	318	16	238	38	255	5	573	13	394	29	360	32
			306	22	249	37	257	1	500	29	378	30	415	21
3	9	0.8	214	84	231	95	242	56	359	80	325	27	420	123
			250	79	242	84	236	37	358	87	369	42	427	92
4	29	0.0	93	100	82	321	55	191	56	253	92	149	83	213
			110	149	54	247	143	214	75	209	83	117	44	140
5	10	0.2	135	228	137	182	200	127	181	207	192	80	280	132
			137	181	151	186	188	117	202	253	182	131	235	149
6	7	0.5	249	119	256	102	214	96	299	159	232	69	270	135
			205	112	337	96	296	106	268	132	272	35	351	129

[1] Data for Condition 1, Bird 15, are for Days 8 and 9 due to a failure of the data recording apparatus on Day 10.

In Fig. 6, the relative frequency of the shorter IRT is plotted against the probability of reinforcement for the shorter IRT. As can be seen from the figure, the relative frequency of the shorter IRT increased from approximately 0.3 when only longer IRTs were reinforced to 0.9 or above when only shorter IRTs were reinforced. Between these two limiting values, the relative frequency of the shorter IRT was a monotonically increasing function of the probability of reinforcement of the shorter IRT. The functions appear to be slightly negatively accelerated. The panel that shows the averaged data indicates that the only non-trivial difference between the relative frequencies of the shorter IRT on left and right keys was in the condition in which all reinforcements were of the longer IRT. In that condition, for reasons that are not apparent, the relative frequency of the shorter IRT was appreciably higher on the left key than on the right key.

Figure 7 shows that the distribution of responses between keys remained comparatively constant and did not systematically vary while the relative frequency of an IRT was changing in the manner just described. That is, the probability of reinforcement on the left key remained at 0.5 throughout Exp. III, and the relative frequency of responding on the left key also remained approximately constant, although there was a slight position preference in favor of the key on the right.

DISCUSSION

The filled circles and triangles in Fig. 6 show how the relative frequency of the shorter IRT depended on the relative frequency of reinforcement for the shorter IRT. We can ask if this function is the same as it would have been if there had been only one key. The question is easily answered because a previous one-key experiment (Shimp, 1968) used virtually the same procedure and parameter values as Exp. III. Two differences between Shimp's earlier experiment and Exp. III were: (a) the upper bound of the longer IRT in the earlier experiment was half a second shorter than here (4.5 *versus* 5.0 sec) and; (b) different stimuli were used in the earlier experiment to signal the different classes of reinforced IRTs, whereas in Exp. III, the same stimulus, *i.e.,* a red key, signalled both classes.

The procedural difference labelled (a) above changed the relative reciprocal of the shorter IRT only from 0.68 in Shimp (1968) to 0.69 in Exp. III. Figure 6 shows that neither procedural difference (a) nor (b), nor for that matter any other procedural difference between Shimp (1968) and Exp. III, affected the results displayed in Fig. 6. The open circles in Fig. 6 show the averages from the three birds in Shimp (1968). There is virtually perfect agreement between the earlier one-key experiment and Exp. III. Thus, the relative

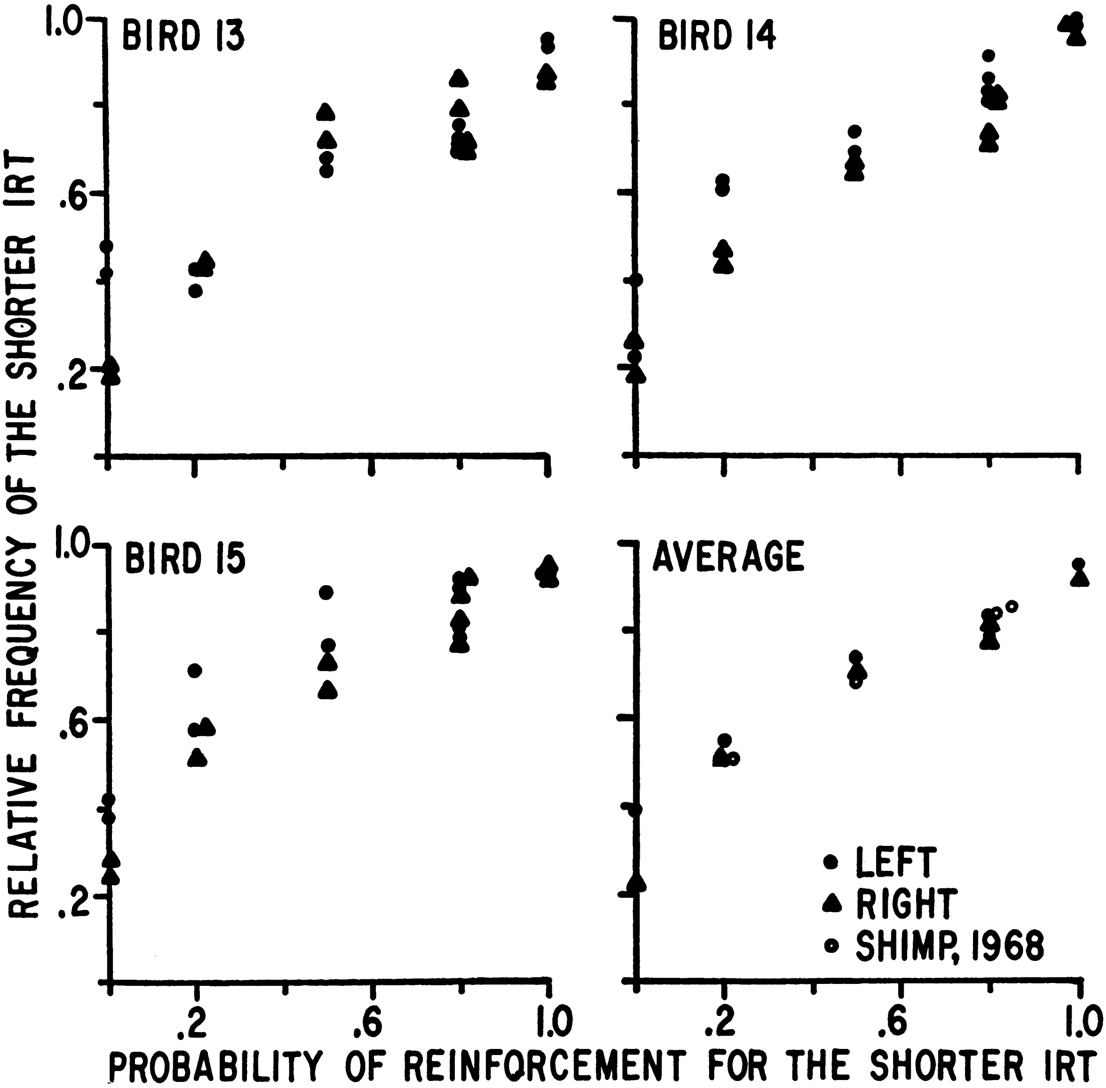

Fig. 6. The relative frequency of the shorter IRT as a function of the probability of reinforcement for the shorter IRT. The open circles in the bottom right panel are from an earlier experiment.

frequency of an IRT depended on its relative frequency of reinforcement in Exp. III in the same way as it would have if there had been no choices between keys.

Figure 7 shows that as the relative frequency of an IRT was changing in the manner described by Fig. 6, there was no systematic change in the distribution of responses between keys, although there was a slight preference for the key on the right.

Figures 6 and 7 together show that the relative frequency of an IRT and the distribution of responses between keys in Exp. III were independent, and that the relative frequency of an IRT was dependent upon its relative frequency of reinforcement in the present two-key context in the same way as it would have if there had been only one key.

EXPERIMENT IV

The results of Exp. I, II, and III suggest that the relative frequency of an IRT and the distribution of responses between keys are independent in the present context. Experiment IV studied the generality of this independence. In Exp. IV, the distribution of re-

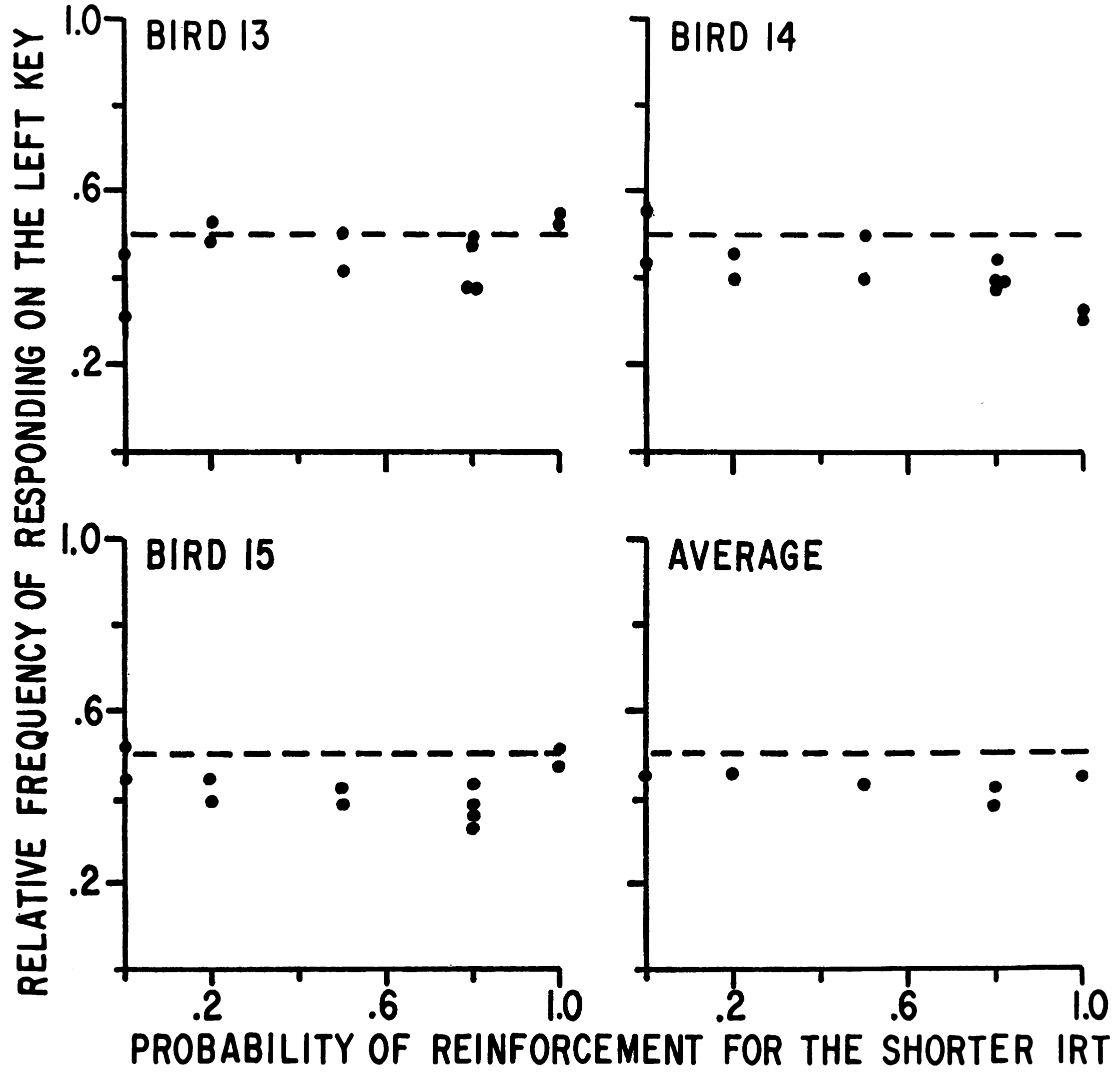

Fig. 7. The relative frequency of responding on the left key as a function of the probability of reinforcement for the shorter IRT.

inforcements between keys was varied as in Exp. I. However, in Exp. IV, an added cue signalled the availability of reinforcement on the right key. Thus, changeovers to the right key were brought under control of the added cue with the result that the response rate on the right key remained low and relatively constant and no longer conformed to the matching relation.

This method of controlling behavior on one key of a two-key *conc* VI VI was adapted from a similar method in earlier experiments by Catania (1963) and by Rachlin and Baum (1969). They showed that the number of responses per minute on one key depended on the number of seconds of access to food per hour on the other key in the same way, regardless of whether or not reinforcements on the other key were signalled by an added cue. They concluded that behavior on one key in a *conc* VI VI depends on the reinforcements but not on the behavior on the other key.

METHOD

Subjects

Two male White Carneaux pigeons were maintained at approximately 80% of their free-feeding weights.

Procedure

The procedure was identical to that for Exp. I, with one major exception. In Exp. IV, a white stimulus was presented on the right key to signal the availability of reinforcement on that key. That is, a white stimulus appeared on the right key when the left-*versus*-right Bernoulli-trials generator had assigned the next reinforcement to the right key and the VI tape had arranged a reinforcement. This white stimulus was in addition to any other stimulus scheduled on the right key by the contingencies described above in Exp. I, II, and III. Suppose, for example, that the left-*versus*-right Bernoulli trials generator had assigned the next reinforcement to the right key. Then, the white light behind the right key would be turned on as soon as the VI tape arranged a reinforcement, regardless of which key the bird currently was pecking on. The added white stimulus would remain on until the reinforcement occurred. If, as was invariably the case in Exp. IV, the bird was responding on the left key when reinforcement became available on the right, the white stimulus on the right would be in addition to the already-present green stimulus. The resulting stimulus appeared as a less saturated green. A peck on the right key would then turn off the green light behind the right key and would initiate, on the right key, the sequence of stimuli depicted in Fig. 1, with the difference that now the white light behind the right key remained on throughout the sequence. The added white stimulus on the right key did not seem to interfere with either subject's ability to terminate shorter or longer IRTs, which then were cued by the red light in conjunction with the white light.

Table 4 shows the experimental conditions, which varied only in the distribution of rein-

Table 4

Number of Shorter and Longer IRTs on Each of Last Two Days of Each Condition

Condition Number	*Number of Days*	*Probability of Reinforcement on Left (Unsignalled) Key*	*Bird 12*				*Bird 6*			
			Left		*Right*		*Left*		*Right*	
			S	*L*	*S*	*L*	*S*	*L*	*S*	*L*
1[1]	11	0.50	480	184	288	135	322	71	470	50
			435	136	343	188	370	105	239	144
2	22	0.50	812	194	49	20	822	140	75	17
			644	110	68	14	490	283	51	15
3	13	0.20	274	238	116	29	418	281	56	17
			379	262	120	28	321	293	84	25
4	12	0.05	258	282	167	23	150	178	77	30
			244	288	217	26	201	265	105	36
5	13	0.95	1046	449	36	7	1077	308	5	5
			702	382	37	7	689	466	1	1
6	10	0.70	763	342	23	18	860	300	17	5
			770	362	15	24	926	352	18	4
7	12	0.35	753	235	61	19	749	300	59	28
			861	225	37	20	545	367	66	29
8	11	0.05	531	347	116	37	396	113	6	5
			451	216	236	68	331	158	71	32
9	10	0.95	1231	208	4	2	783	391	4	3
			1338	164	27	6	721	491	4	2
10	10	0.05	315	203	135	76	307	301	66	41
			434	164	113	75	406	218	112	44
11	9	0.50	740	342	22	10	675	267	19	8
			445	279	71	59	762	318	9	19
12	10	0.20	578	314	86	33	589	154	39	19
			545	286	104	28	649	339	56	17

[1] In Condition 1, reinforcement was not signalled on either key.

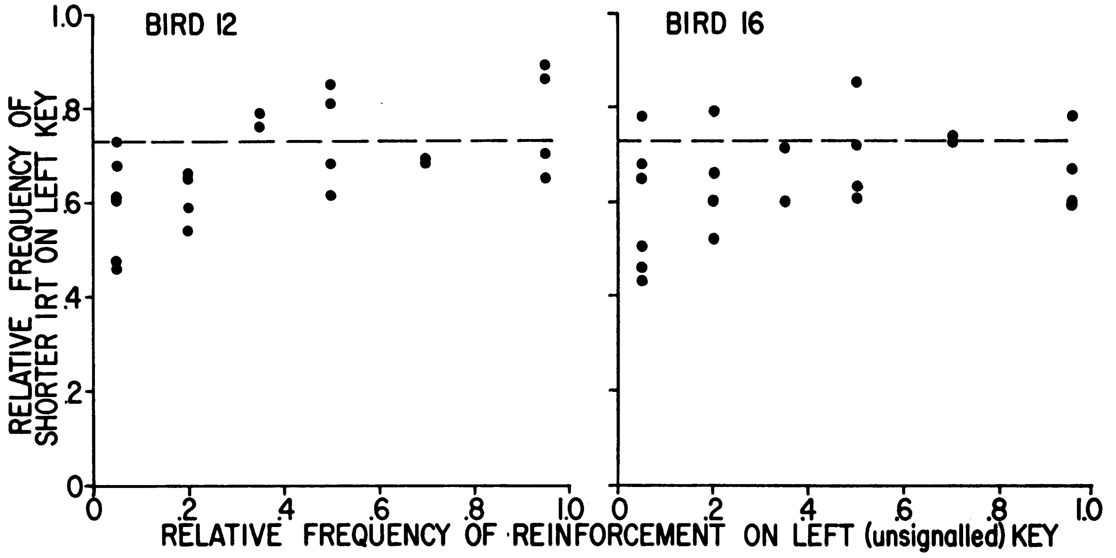

Fig. 8. The relative frequency of the shorter IRT on the unsignalled key as a function of the probability of reinforcement on that key.

forcements between the two keys. The reinforced IRTs on both left and right keys were the same as in Exp. I. The probability of reinforcement for the shorter IRT was 0.5 on both keys throughout Exp. IV, as in Exp. I.

Results

Table 4 gives the frequencies of shorter and longer IRTs, on each key, on each of the last two days of each condition. Figure 8 is the analogue for Exp. IV of Fig. 3 for Exp. I. It shows the relative frequency of the shorter IRT, on the left key, computed from Table 4 for Conditions 2 to 12. (In Condition 1, reinforcement on the right key was not signalled by the added white stimulus.) Figure 8 shows that the relative frequency of the shorter IRT did not depend very much on the distribution of reinforcements between keys. However, there did appear to be a tendency for the relative frequency of the shorter IRT on the left key to decrease slightly when only 5% of the reinforcements were scheduled on the left key. In general, however, Fig. 8 shows that when a bird did respond on the left key, it responded in very nearly the same way, independently of the distribution of reinforcements between keys. The frequencies of responses on the signalled key were too low to provide reliable estimates of behavior on that key.

The left and center panels of Fig. 9 show the number of responses per minute on the left key for the two subjects. These response

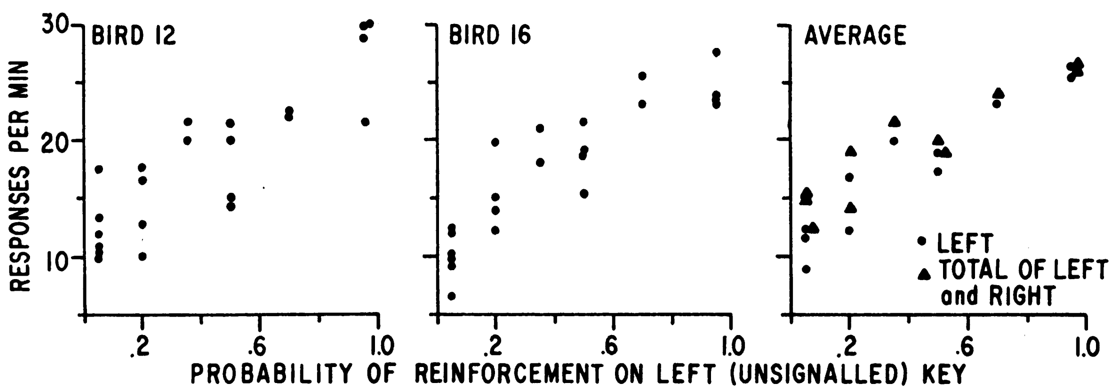

Fig. 9. The number of responses per minute (number of shorter plus the number of longer IRTs) on the left key (filled circles) or on both keys (triangles) as a function of the probability of reinforcement on the left key.

rates were computed from Table 4 by adding the frequencies of shorter and longer IRTs on the left key and dividing by the session duration. The response rate on the left key increased from approximately 10 responses per minute when 5% of the reinforcements were on the left key to approximately 25 responses per minute when 95% of the reinforcements were on the left key. The filled triangles in the right panel show the total number of responses per minute, *i.e.,* the number of shorter and longer IRTs on both keys, divided by the session duration. The right panel shows that the average total response rate increased from between 12 to 15 responses per minute to over 25 responses per minute when the percentage of reinforcements on the left key increased from five to 95.

The difference between the response rate on the left key (filled circles) and the overall response rate (filled triangles) in the right panel of Fig. 9 gives the response rate on the right key. This difference increased as the percentage of reinforcements on the left key decreased. That is, part of the decrease in the response rate on the left key when the percentage of reinforcements on the left key decreased was probably due merely to a bird's spending more time responding on the right key as a result of the greater number of reinforcements on the right key. However, the overall response rate also clearly decreased as the percentage of reinforcements on the left key decreased. Figures 8 and 9 together suggest that a bird tended to respond in approximately the same way on the left key when it responded at all, *i.e.,* the relative frequency of the shorter IRT changed only a little; but that as the percentage of reinforcements on the left key decreased, a bird spent less and less time responding at all.

DISCUSSION

Figure 8 shows that the relative frequency of the shorter IRT on the left key was nearly independent of the distribution of reinforcements between keys, although for both birds, the relative frequency of the shorter IRT was a little lower when the probability of reinforcement on the left key was extremely low. This same independence was also obtained in Exp. I (see Fig. 3). In Exp. IV, response rate on the right key was nearly zero: In Exp. I, the response rate was comparatively high. Thus, the relative frequency of the shorter IRT on a key generally was independent of the distribution of reinforcements between keys, regardless of the amount of responding on the other key. In this sense, behavior on one key was virtually independent of behavior on the other key.

In a second sense, behavior on one key was not independent of behavior on the other key. Figure 10 shows the responses per minute on the left key as a function of the number of reinforcements per hour on the right key. Figure 10 compares the averaged function from Exp. I (filled circles) with the averaged function from Exp. IV (filled triangles). In both cases, the responses per minute on the left key decreases as the reinforcement on the other key increases. (Here, it must be remembered that the total reinforcement rate was constant, so that as the reinforcement rate on the right went up, it went down by an equal amount on the left.) The important feature of Fig. 10 for present purposes is not the particular shape of either function, but rather the fact that the functions are not the same. That is, in the present two-key *conc* VI VI, the way in which responses per minute on the

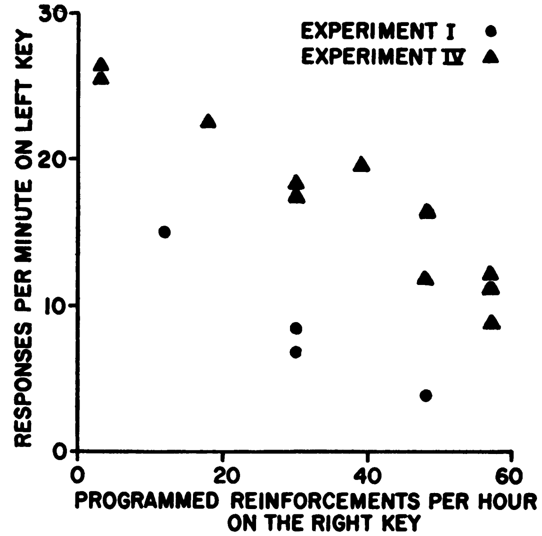

Fig. 10. The number of responses per minute on the left key as a function of the number of scheduled reinforcements per hour on the right key. In Exp. IV, the reinforcements on the right key were signalled, whereas in Exp. I, they were not. Otherwise, Exp. I and IV were identical. The total number of reinforcements per hour was 60 in both experiments. Each filled circle and triangle represents the average of three birds and two birds, respectively.

left key depended on reinforcements on the right key in turn depended on the behavior on the right key. Thus, in this second sense, behavior on one key was not independent of behavior on the other key.

It is instructive to compare the present results with those of Catania (1963) and Rachlin and Baum (1969), since the method used in Exp. IV to control the distribution of responses between keys by an added cue was adapted from these earlier experiments. In their experiments, the response rate in one component of a *conc* VI VI depended on the number of seconds of access to food per hour in the other component but not on the response rate in the other component. Procedural differences between the earlier experiments and the present experiments preclude direct comparisons of response rates. For example, they held the reinforcement rate in one component constant, whereas in the present experiments the overall reinforcement rate was held constant. In addition, the relative frequencies of reinforcement for different IRTs on a key depended on a pigeon's behavior in the earlier experiments, whereas in the present experiment, they were experimentally controlled. Despite these procedural differences, the earlier conclusions are not altogether inapplicable to the present data. Here, the relative frequency of an IRT on one key was largely independent of the behavior on the other key. This independence seems to agree with the earlier conclusions. However, here the number of responses per minute on one key was not independent of the behavior on the other key. Thus, the present findings are only in partial agreement with the conclusion that responding in one component of a *conc* VI VI is independent of responding in the other component. Indeed, in some ways the present results may be viewed as opposite to the earlier results. That is, in Catania's experiment, the responses per minute on the unsignalled key was invariant while the pattern of behavior on that key depended on the behavior on the other key (see Fig. 7 in Catania, 1963). Here, the responses per minute on the unsignalled key depended on the behavior on the other key, but the pattern of behavior on the unsignalled key, as measured by the IRT relative frequency distribution on that key, was comparatively invariant.

REFERENCES

Catania, A. C. Concurrent performances: reinforcement interaction and response independence. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 253-263.

Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 243-266.

Moffit, M. and Shimp, C. P. Two-key concurrent paced variable-interval paced variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1971, **16**, 39-49.

Rachlin, H. and Baum, W. M. Response rate as a function of amount of reinforcement for a signalled concurrent response. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 11-16.

Shimp, C. P. Magnitude and frequency of reinforcement and frequencies of interresponse times. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 525-535.

Shimp, C. P. The concurrent reinforcement of two interresponse times: the relative frequency of an interresponse time equals its relative harmonic length. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 403-411.

Shimp, C. P. The concurrent reinforcement of two interresponse times: absolute rate of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 1-8.

Staddon, J. E. R. Spaced responding and choice: a preliminary analysis. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 669-682.

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