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CHOICE BETWEEN CONCURRENT SCHEDULES[1]

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Six pigeons pecked for food in a three-key experiment. A subject at any time could choose the left or right key and receive reinforcement according to one two-key concurrent variable-interval variable-interval schedule of reinforcement, or it could peck the center key. A peck on the center key arranged the complementary two-key concurrent variable-interval variable-interval schedule on the left and right keys. The two different two-key concurrent schedules arranged reinforcements concurrently and were signalled by two different colors of key lights. Choice behavior in the presence of a given color conformed to the usual relationship in two-key concurrent schedules: the relative frequency of responding on a key approximately equalled the relative frequency of reinforcement on that key. Preference for a two-key concurrent schedule, which was equivalent to preference for a color, was measured by the percentage of all responses on the left and right keys in the presence of that color: this percentage approximately equalled the percentage of all reinforcements that were delivered in the presence of that color. Thus, choice between concurrent schedules conforms approximately to the same relationship as does choice between alternatives in a single concurrent schedule.

A pigeon chooses between the two alternatives in a two-key concurrent variable-interval variable-interval (*conc* VI VI) schedule in such a fashion that the relative frequency of responses on a key tends to equal the relative frequency of reinforcement for responses on that key (Herrnstein, 1961).

An experimental paradigm for the study of choice behavior in more complex concurrent schedules is a concurrent schedule, each component of which is itself a concurrent schedule. Behavior in such a complex concurrent schedule was described by Shimp (1971), who arranged a one-key concurrent schedule of reinforcement for two classes of interresponse times on each of two keys. Thus, there were four classes of operants: shorter and longer interresponse times on the left and right keys. It was found that the relative frequency of responses on a key approximately equalled the relative frequency of reinforcement for responses on that key. Choice of a key was equivalent to choice of a concurrent schedule (of reinforcement for two classes of interresponse times). Therefore, the matching behavior obtained there showed that in one particular context, choice between concurrent schedules obeyed the same relationship as does choice between the two alternatives within a conventional two-key concurrent schedule. In addition, interresponse times were distributed within a particular concurrent schedule of reinforcement for two interresponse times in the same way as they would have been had there not also been a second concurrent schedule of reinforcement for two interresponse times arranged concurrently. Thus, in the context of that experiment, behavior in one concurrent schedule was not affected by the presence of a second concurrent schedule arranged concurrently.

The present experiment further investigated the nature of behavior controlled by compound concurrent schedules of reinforcement in which each component is itself a concurrent schedule. Here, there were two two-key concurrent schedules of reinforcement instead of two one-key concurrent schedules of reinforcement for two classes of interresponse times. At any time, one of the two two-key concurrent schedules of reinforcement was arranged on the left and right keys of a three-

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key experimental chamber. Responding on a center key arranged the other two-key concurrent schedule on the left and right keys. The two different two-key concurrent schedules of reinforcement were signalled by two different colors of keylights and were complementary in the sense that if the probability of reinforcement on the left key was p in the presence of red, it was 1-p in the presence of green.

Two questions were asked corresponding to the two results obtained by Shimp (1971). First, are choices distributed between the two two-key concurrent schedules in the same way as choices are distributed between the two alternatives of a single two-key concurrent schedule? Second, are choices distributed between keys in a single two-key concurrent schedule as they would be if there were not a second two-key concurrent schedule arranged concurrently?

METHOD

Subjects

Six male White Carneaux pigeons were maintained at approximately 80% of their free-feeding body weights. Three of the six pigeons (Subjects 4, 5, and 6) were experimentally naive: the others (Subjects 1, 2, and 3) had served in an experiment on probabilistic discrimination learning that used tilted lines for stimuli (Shimp, 1973*a*).

Apparatus

The experimental chamber was a Lehigh Valley Electronics three-key pigeon chamber. Colors and various tilted lines could be made to appear on each translucent key. Electromechanical relay equipment, including a punched-paper tape reader, arranged the stimuli and reinforcements and counted responses. The punched-paper tapes were generated on a PDP 12 laboratory computer.

Procedure

Reinforcements were arranged for pecks on the left and right keys by a single VI schedule that determined the distribution of interreinforcement intervals and by a random mechanism that assigned each reinforcement to one of four different classes of responses: a peck on the left or right key when all the keys were red and a peck on the left or right key when all the keys were green.

A peck on the center key changed the color of all three keys and complemented, *i.e.*, reversed, the probabilities of reinforcement on the left and right keys. For example, if all three keys were red and the relative frequencies of reinforcement were 0.80 and 0.20 on the left and right keys, respectively, a peck on the center key changed the color of the keys to green and changed the probabilities of reinforcement on the left and right keys to 0.20 and 0.80, respectively. A horizontal line and a vertical line were superimposed on red or green on the center key to further discriminate the center key from the side keys.

The center key in the present experiment was analogous to the switching key in a procedure used by Findley (1958). In the Findley procedure, either one of two VI schedules of reinforcement was arranged at any moment on a single main key and a bird could switch between the two schedules (each signalled by a different color) by responding on a second, or switching key. In the present experiment, one of two two-key *conc* VI VI schedules was arranged at any moment on the side keys and a bird could switch between the two two-key *conc* VI VI schedules (each signalled by a different color) by responding on the center key.

VI schedule. The distribution of interreinforcement intervals was arranged by a single, constant-probability, VI schedule. The constant probability that reinforcement would be arranged was 0.2 every 3 sec so that the average scheduled interreinforcement interval was 15 sec. Ordinarily, when reinforcement is arranged by a finite punched tape, the probability of arranging a reinforcement depends on the time since the last reinforcement, even in a constant-probability, VI schedule. In such cases, the probability of assigning a reinforcement equals 1.0 at some maximum post-reinforcement time. Here, this difficulty was avoided by programming the schedule with an electronic timer and a Bernoulli-trials generator (see Shimp and Wheatley, 1971). Once the VI schedule arranged a reinforcement, the electronic timer stopped. The reinforcement-selection mechanism described below was employed just once for every interreinforcement interval arranged by the VI schedule.

Reinforcement-selection mechanism. At the beginning of a session and after every reinforcement, a reinforcement-selection mechanism determined to which one of the four response classes the next reinforcement would be assigned. Once the next reinforcement was assigned to a particular response class, reinforcements could not be assigned to any other class until the VI schedule arranged a reinforcement, the organism emitted a response belonging to the appropriate class, and reinforcement was collected.

The schedule of reinforcement used here may be viewed as a variation of a schedule in which reinforcements are arranged by a single VI schedule and a random selection mechanism that probabilistically assigns each reinforcement to one of four response alternatives. This procedure was used by Shimp (1971) when he arranged a concurrent schedule of reinforcement for two interresponse times on each of two keys. However, a disadvantage of this procedure is that the obtained relative frequency of reinforcement for a response alternative often deviates from the programmed probability of reinforcement for that response alternative. Therefore, this general procedure to arrange reinforcements was modified here so that the obtained relative frequency of reinforcement for each response class exactly equalled the programmed probability of reinforcement for that response class.

There were 100 reinforcements in each day's session. Each reinforcement was assigned to one of the four classes of reinforced responses by a punched-paper tape containing a sequence of codes that determined which response class would be reinforced on each of the 100 trials. For each session, there was a different tape for each of the six birds. How these tapes were generated by the computer is conceptually identical to the following method. Consider an urn containing 100 balls, each marked "red-left", "red-right", "green-left", or "green-right". Thus, each ball corresponded to one of the four classes of reinforced responses. The proportion of balls of each type exactly equalled the desired proportion of reinforcements for the corresponding class of responses. A ball was randomly selected from the urn, and its corresponding response class was noted. This response class then occupied the first location in a sequence of 100. Then, a second ball was randomly selected from the remaining 99 balls and this response class then occupied the second location in the sequence of 100. Sampling was "without replacement": a selected ball was not returned to the urn and so could not be resampled. This process continued until all 100 balls were selected and a sequence of length 100 was obtained. Finally, the sequence of reinforcements for the four response classes was rearranged. The contents of locations 1, 11, 21, . . . , 91, 2, 12, 22, . . . , 92, 3, 13, 23, . . . , 100 of the original list were placed in locations 1, 2, 3, . . . , 100 in the second list. After all 100 assigned reinforcements were rearranged in the second list, they were punched out on a paper tape. In summary, each punched tape contained the exact desired proportions for each of the four categories, yet the sequence of reinforcing events presumably appeared to a pigeon to be a random sequence.

Changeover delays. There were two different delay contingencies in effect. Each was 1 sec in duration. The first contingency was for a response on one side key after a response on the other side key. Such a response is defined here as a changeover response. The second delay contingency was for a response on a side key following a response on the center key, which is defined here as a switching response.

The changeover delay procedure was the same as that often used in two-key *conc* VI VI schedules of reinforcement (*e.g.,* see Herrnstein, 1961). In the present experiment, a changeover, that is the first response on a side key after a response on the other side key, started a 1-sec changeover delay. A subsequent response on the same key was followed by reinforcement, provided that the 1-sec changeover delay had timed out and provided that reinforcement was available for that particular response class. Therefore, a response on one of the two side keys could not be reinforced if that response followed a response on the other side key. The changeover-delay procedure prevented the reinforcement of changeovers and separated responses on one side key in the presence of a given color from reinforcements arranged for responses on the other side key in the presence of the same color.

The delay procedure initiated by a switching response was the same as that used in the kind of concurrent schedule developed by Findley (1958). A switching response, that is a peck on the center key, started a 1-sec delay. A subsequent response on a side key was reinforced provided the 1-sec switching delay had timed out and provided reinforcement was available for that particular response class.

Table 1

Experimental Conditions and Numbers of Responses

Probability of Reinforcement on the Left Key in the Presence of a Particular Color		*Probability of Reinforcement in the Presence of a Particular Color*		*Average Number of Responses Over the Last Three Days of a Condition*				*Number of Days*	*Subject*	*Condition Number*
				Red		*Green*				
Red	*Green*	*Red*	*Green*	*Left*	*Right*	*Left*	*Right*			
0.50	0.50	0.50	0.50	238	260	359	277	15	1	1
0.50	0.50	0.50	0.50	616	593	387	389	15	2	
0.50	0.50	0.50	0.50	490	425	483	382	15	3	
0.50	0.50	0.50	0.50	644	384	698	347	10	4	
0.50	0.50	0.50	0.50	566	426	541	359	10	5	
0.50	0.50	0.50	0.50	393	518	442	624	10	6	
0.20	0.80	0.50	0.50	109	480	408	143	35	1	2
0.20	0.80	0.50	0.50	316	855	605	331	35	2	
0.20	0.80	0.50	0.50	368	596	830	290	35	3	
1.00	0.00	0.50	0.50	847	3	5	652	20	4	
1.00	0.00	0.50	0.50	724	7	1	482	20	5	
1.00	0.00	0.50	0.50	683	7	4	1139	20	6	
0.70	0.30	0.50	0.50	172	284	313	256	26	1	3
0.70	0.30	0.50	0.50	597	540	356	478	25	2	
0.70	0.30	0.50	0.50	671	349	558	514	25	3	
0.80	0.20	0.50	0.50	689	411	346	707	24	4	
0.80	0.20	0.50	0.50	621	234	316	495	23	5	
0.80	0.20	0.50	0.50	654	382	181	1006	23	6	
0.50	0.50	0.80	0.20	318	745	223	173	21	1	4
0.50	0.50	0.80	0.20	752	862	211	267	26	2	
0.50	0.50	0.80	0.20	722	912	331	213	26	3	
0.96	0.04	0.50	0.50	765	70	186	992	14	4	
0.96	0.04	0.50	0.50	850	65	102	641	14	5	
0.96	0.04	0.50	0.50	878	79	39	1113	14	6	

Table 1 (continued)

Experimental Conditions and Numbers of Responses

Probability of Reinforcement on the Left Key in the Presence of a Particular Color		Probability of Reinforcement in the Presence of a Particular Color		Average Number of Responses Over the Last Three Days of a Condition				Number of Days	Subject	Condition Number
				Red		Green				
Red	Green	Red	Green	Left	Right	Left	Right			
0.50	0.50	0.30	0.70	170	288	337	212	22	1	5
0.50	0.50	0.30	0.70	404	386	488	613	22	2	
0.50	0.50	0.30	0.70	223	325	444	817	22	3	
0.60	0.40	0.50	0.50	452	685	429	492	15	4	
0.60	0.40	0.50	0.50	511	444	569	297	15	5	
0.60	0.40	0.50	0.50	456	793	297	441	15	6	
0.40	0.60	0.50	0.50	132	375	488	221	19	1	6
0.40	0.60	0.50	0.50	507	839	481	488	19	2	
0.40	0.60	0.50	0.50	525	696	601	604	19	3	
0.50	0.50	0.90	0.10	688	1282	157	242	17	4	
0.50	0.50	0.90	0.10	1059	591	186	100	17	5	
0.50	0.50	0.90	0.10	639	987	84	84	17	6	
0.50	0.50	0.15	0.85	144	206	613	455	30	1	7
0.50	0.50	0.15	0.85	253	253	710	884	30	2	
0.50	0.50	0.15	0.85	230	207	803	1150	30	3	
0.50	0.50	0.60	0.40	378	955	515	909	39	4	
0.50	0.50	0.60	0.40	444	644	432	230	40	5	
0.50	0.50	0.60	0.40	454	538	352	337	38	6	
0.30	0.70	0.50	0.50	282	993	635	592	16	4	8
0.30	0.70	0.50	0.50	338	701	706	261	16	5	
0.30	0.70	0.50	0.50	332	614	516	292	16	6	

Notice that the first response on a side key after a switching response could be reinforced. This procedure separated switching responses from reinforcements for side-key responses. It also separated responses in the presence of one color from reinforcements for responses in the presence of the other color.

Experimental conditions. Table 1 provides two types of information about the experimental conditions: the probabilities of reinforcement for responses in the presence of red keys and in the presence of green keys (columns 3 and 4) and the probabilities of reinforcement for responses on the left key in the presence of either red or green keys (columns 1 and 2). (Note that for a given bird in a given condition, columns 1 and 2 sum to unity, and columns 3 and 4 also sum to unity.) As shown in Table 1, Condition 1 was the same for all six birds; however, Conditions 2 through 8 for Birds 1, 2, and 3 were different from Conditions 2 through 8 for Birds 4, 5, and 6. The purpose of having different sets of experimental conditions for the two groups of birds was simply to enable the completion of the experiment in less time than if each bird had experienced each condition.

The following is an example of how the number of reinforcements for each response class may be obtained from the probabilities shown in Table 1. For Bird 1 in Condition 2, the probability of reinforcement for responses in the presence of red keys was 0.50 (see column 3). Therefore, 50 of the 100 reinforcements were for responses on the left or right keys in the presence of red keys and 50 of the 100 reinforcements were for responses on the left or right keys in the presence of green keys. When the keys were red, the probability of reinforcement for responses on the left key was 0.20 (see column 1) and the probability of reinforcement for responses on the right key was 1.00 minus 0.20, or 0.80. That is, when the keys were red, 20% of the 50 reinforcements or 10 reinforcements, were assigned for responses on the left key and 80% of the 50 reinforcements, or 40 reinforcements, were assigned for responses on the right key.

Table 1 shows that in any one condition, either the probability of reinforcement for responses in the presence of red keys was equal to 0.50, or the probability of reinforcement for responses on the left key in the presence of either color was equal to 0.50. That is, either columns 3 and 4 are 0.50, or columns 1 and 2 are 0.50.

Other contingencies. A brief blackout of approximately 0.3 sec followed each response and provided the pigeons with visual response feedback. Also, the houselight and keylights were darkened during reinforcement, which consisted of 1.75-sec access to mixed grain.

Summary and discussion of procedure. At any time, a subject could respond on the left or right key and receive reinforcement according to a concurrent schedule in which interreinforcement intervals were arranged by a single VI schedule and in which reinforcements were arranged for responses on the left and right keys in a pseudo-random fashion. The sequence of reinforcements was restricted so that the obtained relative frequency of reinforcement for a response class equalled the corresponding programmed probability of reinforcement. At any time, a subject also could respond on the center key and thereby arrange a concurrent schedule of reinforcement in which the probabilities of reinforcement on the left and right keys were reversed. These two complementary concurrent schedules were signalled by different colors.

The method used here to arrange a two-key concurrent schedule is different from the older, traditional method. According to tradition, a *conc* VI VI schedule is arranged by two separate VI schedules. Each runs until it assigns a reinforcement, then it alone stops until that reinforcement is collected. Such a schedule is different in a number of ways from that used here. First, the successive left-right positions of reinforcement in a two-key concurrent schedule are independent with the present method, whereas there is no guaranteed independence when two separate VI schedules are used (see Moffitt and Shimp, 1971). Second, the relative frequency of reinforcement for an alternative is experimentally controlled with the present method: unlike the usual arrangement, there is no day-to-day variation in the obtained relative frequency of reinforcement. Third, switching responses are essential with the present method. That is, if an animal never switched, it sooner or later would go into extinction. With the traditional method of arranging a concurrent schedule, switching is encouraged because the probability of reinforcement increases on one alternative while an organism responds on another, but switching is not essential. Unfortunately, switching behavior maintained by the traditional two-key concurrent schedule remains largely unknown, but switching has been described in great detail for the method used in the present experiment (Menlove, 1972).

The schedule used here is appropriately called, by analogy with other schedules of reinforcement (Anger, 1954; Shimp, 1973*b*), a kind of synthetic *conc* VI VI schedule, *i.e.*, a schedule of reinforcement for concurrent responding that duplicates some but not all of the properties of a *conc* VI VI schedule, and in which the relative frequency of reinforcement for a response class is experimentally controlled, rather than dependent upon behavior.

Any of the differences between the two ways of arranging a concurrent schedule might produce differences in behavior. However, available data suggest the two methods are equivalent with regard to the relationship between the relative frequency of responding in a component and such reinforcement parameters as: the relative frequency of reinforcement in that component (compare Herrnstein, 1961, with Menlove, 1972, Experiment III in Shimp, 1966, and Stubbs and Pliskoff, 1969), and; the relative immediacy of reinforcement in that component (compare Chung and Herrnstein, 1967, with Herbert, 1970). Corresponding relationships also hold for one-key concurrent schedules arranged both ways (compare Staddon, 1968, with Shimp, 1968 and Moffitt and Shimp, 1971). Perhaps the two methods produce the same relationships because the major difference between them arises only when a subject persists in responding to one alternative for a relatively long time; only then do the two procedures differ dramatically. However, subjects on both kinds of concurrent schedule tend to switch relatively often, *i.e.*, every few seconds, so that the major difference between

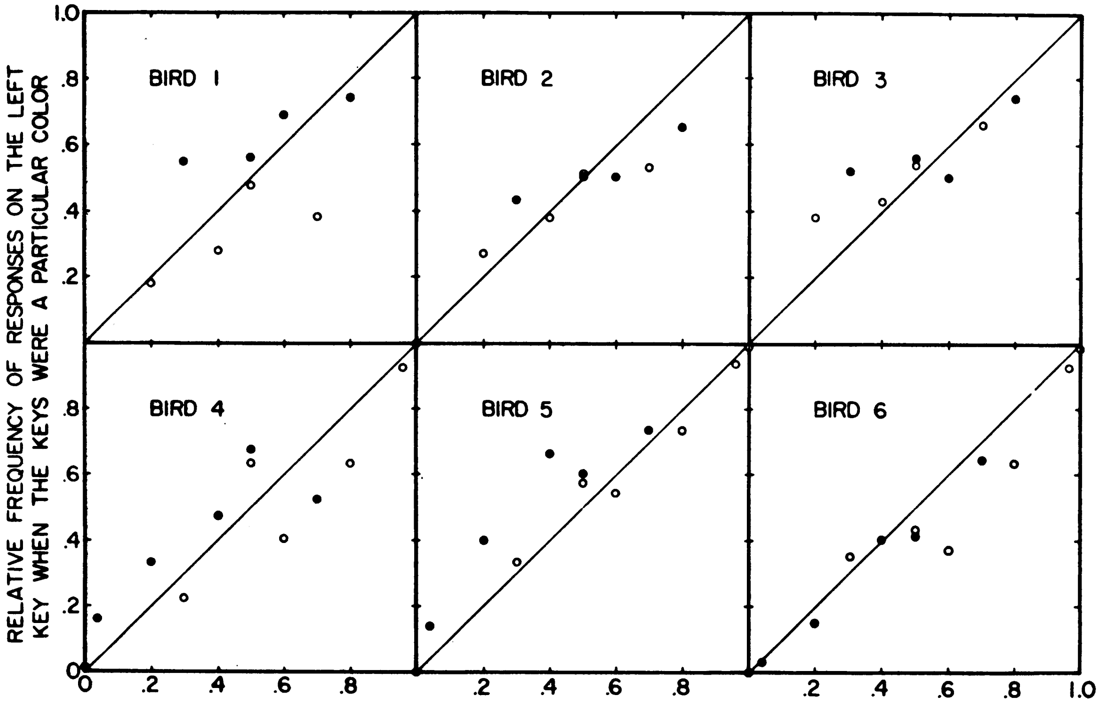

Fig. 1. Relative frequency of responses on the left key when the keys were a particular color plotted against the probability of reinforcement for responses on the left key when the keys were that color. For example, the frequency of responses on the left key when the keys were red divided by the total frequency of responses on the left and right keys when the keys were red plotted against the frequency of reinforcement for responses on the left key when the keys were red divided by the total frequency of reinforcement for responses on the left and right keys when the keys were red. Each panel shows the data for an individual subject. Open circles represent data obtained when the keys were red; dots represent data obtained when the keys were green. The diagonal line in each panel represents the matching function.

the methods may not come in contact with behavior. In any event, on the basis of available data, one may tentatively assume that the relationships obtained in the present experiment between relative responding and relative reinforcement would be the same if the two-key concurrent schedules were arranged by separate VI schedules.

The present procedure is equivalent to that used by Shimp (1971) in terms of the extent to which a subject had access to the four reinforced response classes. In the present experiment, a subject had equal access to the two response classes reinforced by the particular concurrent schedule momentarily arranged for the responses on the left and right keys, but a subject could emit a response belonging to one of the other two reinforced classes only by first making an intermediate switching response on the center key. In the schedule used by Shimp (1971), there was a concurrent schedule of reinforcement for two interresponse times arranged on each of two keys. The choice of a key in that schedule was a choice of a concurrent schedule and was conceptually equivalent to the switching response in the present experiment. In particular, in the earlier experiments, a subject at any time had equal access to the two classes of responses (interresponse times) reinforced on a particular key, *i.e.*, the next response could terminate either a shorter or longer interresponse time on that key, but the subject could terminate an interresponse time belonging to one of the other two reinforced response classes only by making an intermediate switching response on the other key. This switching response initiated an interresponse time on the other key, which then could terminate either during the class of shorter or longer interresponse times on that key. In short, in both Shimp (1971) and the present experiment, a subject had to emit a switching response, which was never itself reinforced, in order to pass from one concurrent schedule to the other.

Both in Shimp (1971) and the present experiment, preference for a concurrent schedule was measured by the number of responses maintained by that concurrent schedule divided by the total number of responses maintained by both concurrent schedules. In the previous experiment, this measure meant that the total number of shorter and longer interresponse times on one key was divided by the total number of shorter and longer interresponse times on both keys. Here, the total number of responses on the left and right keys when the keys were one color was divided by the total number of responses on the left and right keys when the keys were both colors. The latter demoninator is simply the total number of responses on the left and right keys. In both Shimp (1971) and the present experiment, what are here called switching responses were not included in these computations measuring preference between concurrent schedules.

RESULTS

Columns 5 to 8 in Table 1 show the frequencies of each of the four response classes averaged over the last three days of each condition. All of the figures presented here are based on the information in Table 1.

Figures 1 through 4 present data from the conditions in which the probability of reinforcement for responses on the left key when the keys were red was varied. Therefore, the

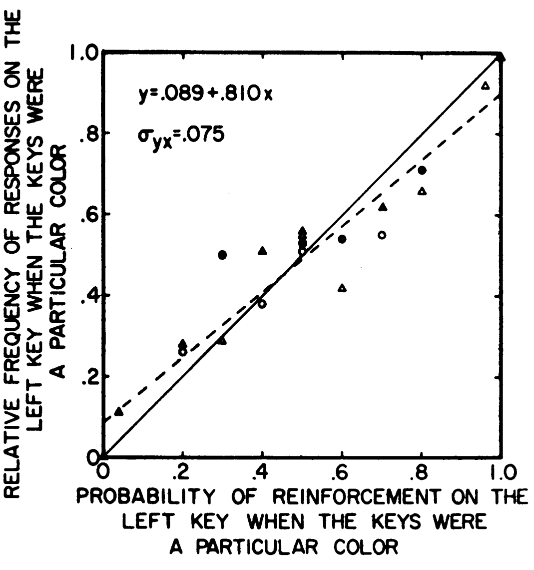

Fig. 2. Relative frequency of responses on the left key when the keys were a particular color plotted against the probability of reinforcement for responses on the left key when the keys were that color. Circles represent data averaged over Birds 1, 2, and 3; triangles represent data averaged over Birds 4, 5, and 6. Open forms indicate data obtained when the keys were red; filled forms indicate data obtained when the keys were green. The solid diagonal line represents the matching function. The dashed line is a least-squares best-fitting straight line. The parameters and standard error of estimate for the best-fitting line are given at the top of the figure.

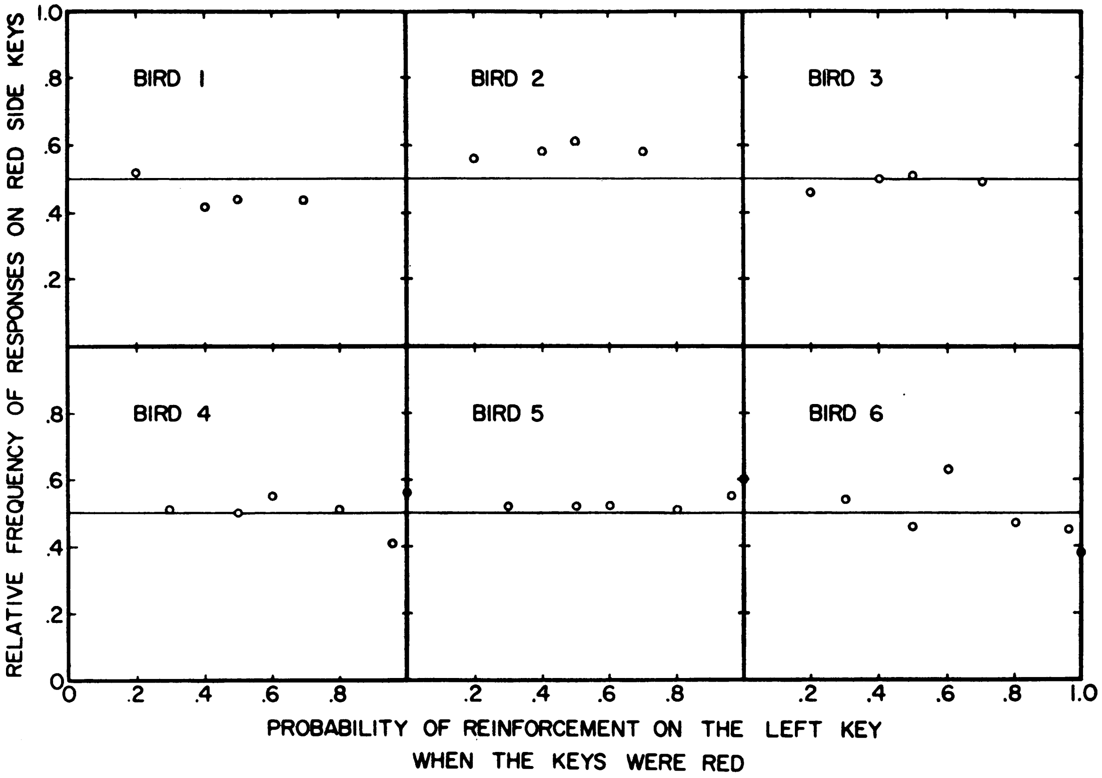

Fig. 3. Relative frequency of responses on red side keys plotted against the probability of reinforcement for responses on the left key when the keys were red. That is, the frequency of responses on the left and right keys when the keys were red divided by the total frequency of responses on the left and right keys plotted against the frequency of reinforcements for responses on the left key when the keys were red divided by the total frequency of reinforcements for responses on the left and right keys when the keys were red. Each panel shows the data for an individual subject. The horizontal line in each panel represents the matching function between relative frequency of responses on red side keys and probability of reinforcement for responses on red side keys.

probability of reinforcement for responses on the left key when the keys were green also was varied because it was complementary to the probability of reinforcement for responses on the left key when the keys were red. In each of these conditions, half of the reinforcements were for responses in the presence of red keys and half were for responses in the presence of green keys. In short, Figures 1 to 4 present data from conditions for which columns 1 and 2 in Table 1 are 0.50.

Figures 1 and 2 show the relative frequency of responses on the left key when the keys were red as a function of the probability of reinforcement for responses on the left key when the keys were red (open circles). They also show the relative frequency of responses on the left key when the keys were green as a function of the probability of reinforcement for responses on the left key when the keys were green (filled circles). The relative frequency of responses on the left key when the keys were a particular color was computed by dividing the number of responses on the left key when the keys were that color by the total number of responses on either the left or right key when the keys were that color. The solid lines in Figures 1 and 2 represent the matching function and the dashed line in Figure 2 is the least-squares best-fitting straight line. Figure 1 shows the individual data and Figure 2 shows the averaged data for Birds 1, 2, and 3, and for Birds 4, 5, and 6. (It will be recalled that these two sets of birds experienced different experimental conditions.)

Figure 1 shows that the individual data points tended to cluster near the matching-line: of the 60 points, almost one half are within 0.05 of the matching-line, over two thirds are within 0.10, and nearly all are within 0.20. However, Figure 1 also shows a slight but systematic deviation from the matching-line: for all but Bird 1, the empirical points corresponding to values below 0.50 on the X-axis tended to be somewhat too high and the points corresponding to values above 0.50 on the X-axis tended to be somewhat too low. In short, the data points tended slightly to undershoot the matching-line. This systematic undershooting can be seen clearly in the averaged data shown in Figure 2. However, the absolute deviations from matching typically are small in both Figure 1 and Figure 2 and so the data can be roughly summarized as follows: the relative frequency of responses on the left key in the presence of a color approximately equalled the probability of reinforcement for responses on the left key in the presence of that color, when half of the reinforcements were arranged for responses in the presence of each color.

Figures 3 and 4 show the relative frequency of responses on red side keys as a function of the probability of reinforcement for responses on the left key when the keys were red. The dependent variable in Figures 3 and 4 was computed by dividing the total number of responses on the left and right keys when the keys were red by the total number of responses on the left and right keys when the keys were red and when the keys were green. Figures 3 and 4 reveal a relationship approximating the matching relationship. That is, a subject responded on red and green side keys approximately equally often over the conditions in which reinforcements were arranged equally often for responses on red and green keys. This relationship did not depend on the way in which reinforcements were distributed between the left and right keys when the keys were a particular color.

Figures 5 to 8 represent data from the conditions in which the proportion of reinforcements arranged for responses in the presence of a particular color was varied but the probability of reinforcement for responses on the left key when the keys were a particular color was 0.50. That is, Figures 5 to 8 present data from conditions for which columns 3 and 4 in Table 1 was 0.50.

Figures 5 and 6 show the relative frequency of responses on red side keys as a function of the probability of reinforcement for responses on red side keys. The relative frequency of responses on red side keys was computed the same way as in Figures 3 and 4. The individual data points in Figure 5 cluster near the matching-line, and the best-fitting straight line in Figure 6 also falls close to the matching-line. Thus, the relative frequency of all responses that were in the presence of red keys approximately equalled the relative frequency of all reinforcements that were delivered for responses in the presence of red keys.

Figures 7 and 8 show the relative frequency of responses on the left key when the keys were a particular color as a function of the proportion of reinforcements that were delivered for responses in the presence of that color. The relative frequency of responses on the left key when the keys were a particular color was computed in the same way as in Figures 1 and 2. It will be recalled that over the conditions for which data appear in Figures 7 and 8, the probability of reinforcement on the left key when the keys were a particular color was 0.50. Figure 7 reveals a tendency for individual data points to fall near the horizontal matching-line at 0.50. The deviations from this line were greatest for Birds 1, 4, and 5, but even for these birds, the matching-line is about as good a

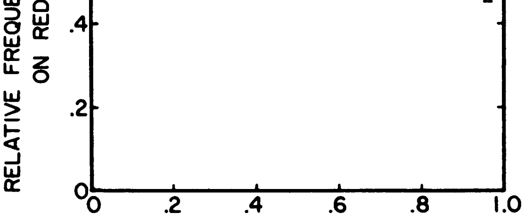

Fig. 4. Relative frequency of responses on red side keys plotted against the probability of reinforcement for responses on the left key when the keys were red. Circles represent data averaged over Birds 1, 2, and 3; triangles represent data averaged over Birds 4, 5, and 6. The solid horizontal line represents the matching function between relative frequency of responses on red side keys and probability of reinforcement for responses on red side keys. The dashed line is a least-squares best-fitting straight line. The parameters and standard error of estimate for the best-fitting line are given at the top of the figure.

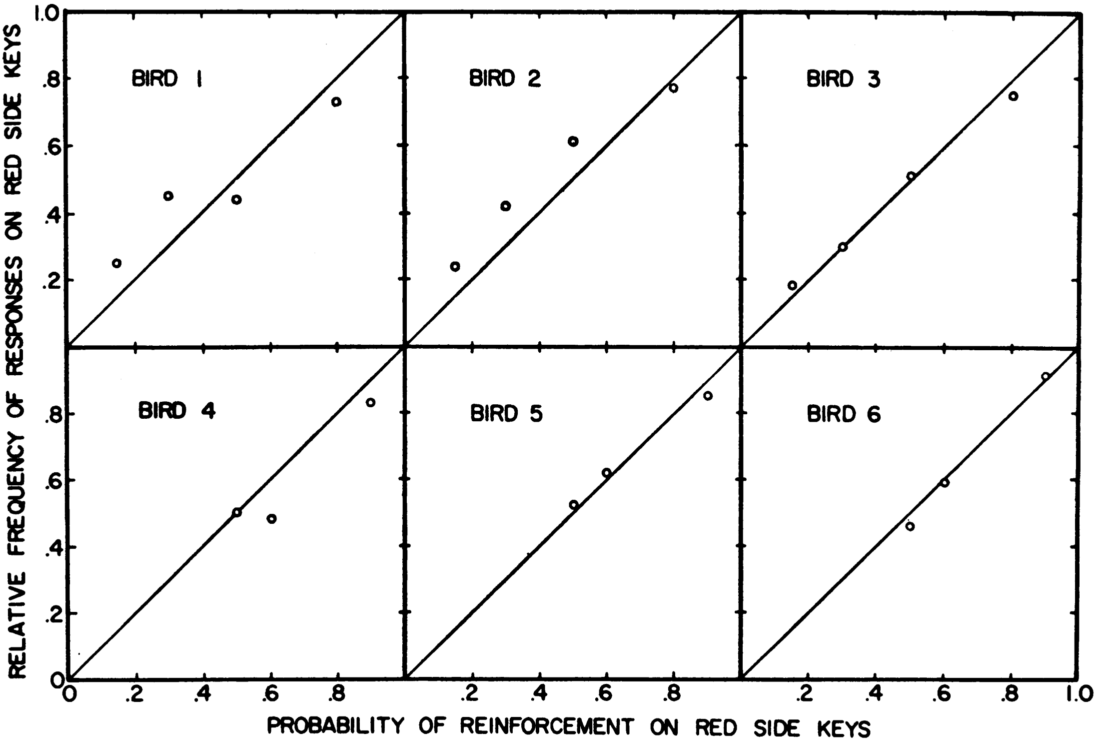

Fig. 5. Relative frequency of responses on red side keys plotted against the probability of reinforcement for responses on red side keys. That is, the frequency of responses on the left and right keys when the keys were red divided by the total frequency of responses on the left and right keys plotted against the frequency of reinforcements for responses on the left and right keys when the keys were red divided by the total frequency of reinforcements for responses on the left and right keys. Each panel shows the data for an individual subject. The diagonal line in each panel represents the matching function.

summary of the data as any straight line could be. Figure 8 shows that the averaged data were described quite well by a best-fitting straight line that approximated the matching-line. Thus, Figures 7 and 8 reveal that a subject responded approximately equally often on the left and right keys in the presence of a color over the conditions in which reinforcements were arranged equally often for responses on the left and right keys in the presence of that color. This relationship did not depend on the proportion of reinforcements delivered for responses in the presence of a particular color.

The frequency of the switching response, *i.e.*, responses on the center key, are not reported here, as they did not seem to depend in any orderly way on the various reinforcement probabilities manipulated here.

DISCUSSION

Two questions were asked regarding the present results. First, does choice between two two-key concurrent schedules conform to the matching relationship, as does choice between alternatives within a single two-key concurrent schedule? Second, does choice between alternatives within a single two-key concurrent schedule conform to the matching relationship, as it would if there were no second two-key concurrent schedule? These questions are the analogues of two questions asked by Shimp (1971) who, as noted above, found that the answer to each was affirmative within the context of a two-key schedule in which there was a one-key concurrent schedule of reinforcement for two interresponse times arranged on each key.

First, consider choice between concurrent schedules. Figures 5 and 6 showed that the proportion of all responses that were in the presence of a particular color closely approximated the proportion of all reinforcements that were delivered for responses in the presence of that color. There was a one-to-one correspondence between colors and two-key *conc* VI VI schedules, so that this matching relationship describing preference between colors also describes preference between concurrent schedules. Thus, choice between concurrent schedules conformed to the same matching relationship as does choice between components in a concurrent schedule. This result corresponds to that obtained previously by Shimp (1971), where the proportion of all responses that were maintained by one *conc* VI VI schedule (for two interresponse times) approximately equalled the proportion of all reinforcements that were obtained by responses maintained by that concurrent schedule.

Figures 3 and 4 in the present paper show that this matching relationship describing preference between concurrent schedules did not depend on the way in which responses and reinforcements were distributed between the left and right keys in either two-key concurrent schedule. The corresponding result was obtained by Shimp (1971), who found that the matching relationship describing preference between one-key concurrent schedules of reinforcement for two interresponse times did not depend on the way in which responses and reinforcements were distributed between the shorter and the longer interresponse times in either one-key concurrent schedule. However, note that Figures 3 and 4 in the present experiment, and the corresponding figures in Shimp (1971), show this independence only for a value of 0.5 on the y-axis. The generality of this independence for other values is unknown.

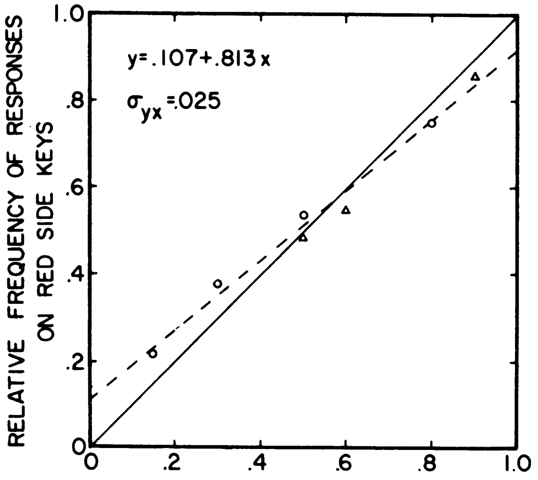

Fig. 6. Relative frequency of responses on red side keys plotted against the probability of reinforcement for responses on red side keys. Circles represent data averaged over Birds 1, 2, and 3; triangles represent data averaged over Birds 4, 5, and 6. The solid diagonal line represents the matching function. The dashed line is a least-squares best-fitting straight line. The parameters and standard error of estimate for the best-fitting line are given at the top of the figure.

Now consider the second question, that dealing with choice between the two alternatives in a two-key concurrent schedule. The present Figures 1 and 2 show that the relative frequency of responses on a key in the presence of a particular color approximately equalled the probability of reinforcement for responses on that key in the presence of that color. Thus, choice between alternatives in a two-key concurrent schedule was approximately the same here as it would have been had there been no second two-key concurrent schedule. The small but systematic deviation from matching in Figures 1 and 2 may be attributable to the fact that the two-key concurrent schedules corresponding to red and green were complementary. Any generalization of response tendencies, for whatever reason, from one concurrent schedule to the other might therefore have tended to produce the slight undershooting obtained here. In the previous experiment by Shimp (1971), the two concurrent schedules were the same, not complementary, and no undershooting was obtained there. In this earlier experiment, the relative frequency of occurrence of an interresponse time in a one-key concurrent schedule of reinforcement for two interresponse times depended on the corresponding probability of reinforcement in the same way as it would have had there been no second one-key concurrent schedule of reinforcement for two interresponse times.

Figures 7 and 8 in the present paper show that the matching relationship describing preference between alternatives in a two-key concurrent schedule did not depend on the way in which responses and reinforcements were distributed between the two two-key concurrent schedules. The corresponding result was obtained by Shimp (1971). Notice that this result, like the one in Figures 3 and 4, was obtained only for a y-axis value of 0.5, and may not hold for other values.

The present results, when compared to those obtained by Shimp (1971), provide evidence for a certain degree of equivalence between choices and interresponse times. In both experiments, a complex concurrent schedule of re-

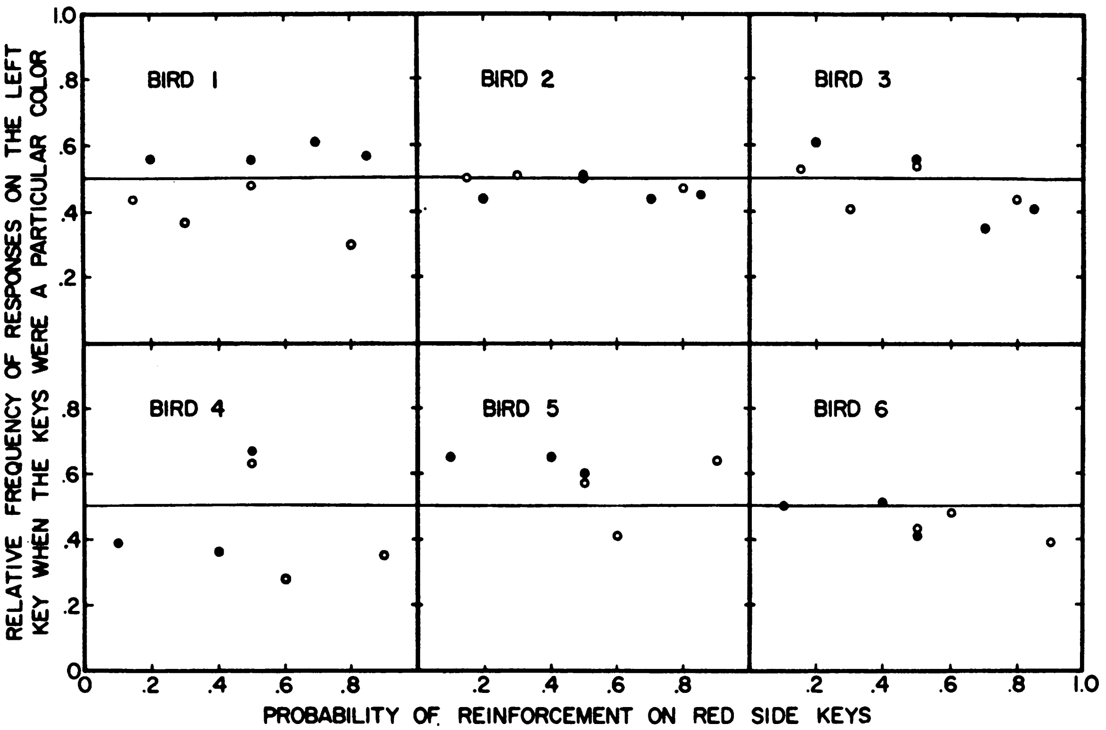

Fig. 7. Relative frequency of responses on the left key when the keys were a particular color plotted against the probability of reinforcement for responses on the left and right keys when the keys were that color. For example, the frequency of responses on the left key when the keys were red divided by the total frequency of responses on the left and right keys when the keys were red plotted against the frequency of reinforcement for responses on the left and right keys when the keys were red divided by the total frequency of reinforcements for responses on the left and right keys. Each panel shows the data for an individual subject. Open circles represent data obtained when the keys were red; dots represent data obtained when the keys were green. The horizontal line in each panel represents the matching function between relative frequency of responses on the left key when the keys were a particular color and probability of reinforcement for responses on the left key when the keys were that color.

inforcement was studied. Each component of the concurrent schedule in both experiments was itself a concurrent schedule. In the previous experiment, the alternatives within a component concurrent schedule were shorter or longer interresponse times on a single key, and in the present experiment the alternatives were choices between left or right keys. In both instances, preference between concurrent schedules conformed to a matching relationship and behavior in a concurrent schedule was, in certain limited ways described in detail above, independent of the presence of a second concurrent schedule. This specific functional equivalence between one-key concurrent schedules for interresponse times and two-key concurrent schedules for choices is in addition to several other specific ways in which choices and interresponse times are equivalent. For example, it is known that in a one-key *conc* VI VI schedule for two interresponse times, the relative frequency of occurrence of an interresponse time approximately equals the relative reciprocal of its length, so long as the two interresponse times are reinforced equally often and the overall density of reinforcement is sufficiently high (Shimp, 1969, 1970). This matching relationship is precisely the same as that which describes the relation between choice behavior and delays of reinforcement in two-key *conc* VI VI schedules (Chung and Herrnstein, 1967; Herbert, 1970). Furthermore, Moffitt and Shimp (1971) found that the way in which the relative frequency of an interresponse time depends on the corresponding relative frequency of reinforcement is the same, regardless of whether each interresponse time is arranged on a separate key, or both interresponse times are arranged on a single key.

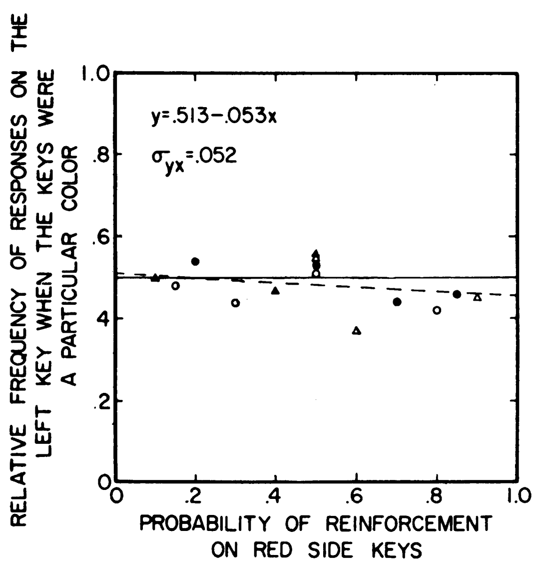

Fig. 8. Relative frequency of responses on the left key when the keys were a particular color plotted against the probability of reinforcement for responses on the left and right keys when the keys were that color. Circles represent data averaged over Birds 1, 2, and 3; triangles represent data averaged over Birds 4, 5, and 6. Open forms represent data obtained when the keys were red; filled forms represent data obtained when the keys were green. The solid horizontal line represents the matching function between relative frequency of responses on the left key when the keys were a particular color and probability of reinforcement for responses on the left key when the keys were that color. The dashed line is a least-squares best-fitting straight line. The parameters and standard error of estimate for the best-fitting line are given at the top of the figure.

A complex concurrent schedule in which the components are themselves concurrent schedules is only one of many possible kinds of complex concurrent schedules that could be devised. Indeed, it already is known that the matching relationship applies to choice behavior in a concurrent schedule, one component of which is a VI schedule and the other component of which is a multiple VI VI schedule (Pliskoff, Shull, and Gollub, 1968). The full extent to which multiple and concurrent schedules may be combined while preserving relationships such as matching remains for future research to determine.

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