PREFERENCE FOR MIXED-INTERVAL VERSUS FIXED-INTERVAL SCHEDULES: NUMBER OF COMPONENT INTERVALS[1]

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Six pigeons were trained under a concurrent chains procedure so that preference for fixed-interval *versus* mixed-interval schedules with varying numbers of component intervals could be examined. The smallest and largest intervals in the terminal links were the same value as those used by Davison (1969). Relative choice in all cases approximated the relative means of the squares of the harmonic intervals to reinforcement in the terminal links, and no effect of number of component intervals was demonstrated. Mixed-interval *versus* fixed-interval choice could not be predicted from extant data on fixed-interval *versus* fixed-interval choice.

Using the concurrent chains procedure, Autor (1960) and Herrnstein (1964a) showed that when pigeons choose between pairs of variable-interval (VI) or variable-ratio schedules of reinforcement, they appear to do so on the basis of the reinforcement rate calculated from the arithmetic average interval to reinforcement. That is, the relative number of responses (*i.e.*, the number of responses on one key over the number of responses on both keys) in the initial concurrent links of the concurrent chains equals the relative number of reinforcements (*i.e.*, the number of reinforcements from one key over the number of reinforcements from both keys) in the mutually exclusive terminal links. However, Herrnstein (1964b) did not obtain matching between relative response measures and relative reinforcement parameters in the choice between fixed-interval (FI) and VI schedules. Herrnstein's suggestion that this finding resulted from non-arithmetic averaging of the intervals to reinforcement in the terminal links was supported by Killeen (1968). Killeen found that preference for VI *versus* FI schedules was described by the following equation with the exponent, r, equal to -1:

$$\frac{P_1}{P_1 + P_2} = \frac{x^r}{x^r + \frac{1}{N}\sum_{i=1}^{N} y_i^r} \quad \ldots(1)$$

where P_1 and P_2 are the numbers of responses in the initial links preceding the FI and VI terminal links respectively, x is the value of the terminal link fixed interval, y_i is the value of the ith interval in the terminal link VI schedule, and N is the number of intervals comprising the terminal link VI schedule. This expression may be interpreted as harmonic averaging of the terminal link intervals to reinforcement.

Davison (1969) studied the choice between FI and two-valued mixed-interval (MI) schedules. An MI schedule consists of two or more FI schedules that alternate randomly with no exteroceptive stimulus indicating which interval is in effect. In the present study, and in Davison's (1969) experiment, each interval was presented equally often. An exponent of $r = -3$ in Equation (1) was necessary to give matching between relative initial link response measures and terminal link reinforcement parameters. Davison suggested that the difference between his and Killeen's results could be due to the number of intervals comprising the MI and VI schedules (respectively 2 and 10 or 12). However, Duncan and Fantino (1970), who examined the choice between two FI or two fixed-ratio schedules, found that the smallest interval to reinforcement in the terminal links was related to the value of the exponent r in Equation (1). As the smallest interval in-

creased in value, so the value of r decreased from -1 to -5. This seems to explain the difference between Davison's and Killeen's results and, by implication, to rule out control over choice by the number of intervals comprising the terminal links.

The present experiment utilized the same temporal parameters as Davison (1969) and systematically investigated the effect of number of intervals comprising the terminal link MI schedule in MI *versus* FI choice. There was only one procedural difference between the present experiment and that previously reported by the author. Davison (1969) used a changeover delay of 0.5 sec in the initial links of the concurrent chains to prevent the development of concurrent superstitions. The present experiment used no changeover delay, bringing the procedure into line with that used by other experimenters.

METHOD

Subjects

Six experimentally naive homing pigeons were maintained at 80% ± 15g of their free-feeding body weights. They were numbered 307, 308, 315, 317, 318, and 319.

Apparatus

Conventional relay equipment, situated remote from the experimental chamber, controlled all experimental events. All data were recorded on impulse counters.

The sound-attenuated experimental chamber was fitted with an exhaust fan, which helped mask external noise, and contained two response keys 0.75 in. (2 cm) in diameter, 5 in. (13 cm) apart and 9 in. (22.5 cm) from the floor. Each key could be illuminated with various colored lights. Two sources of feedback for key pecks exceeding approximately 0.098 N were arranged: firstly, a 30-msec offset of the keylight; secondly, the click of a relay situated inside the experimental chamber. No illumination was provided in the chamber apart from the keylights. A grain hopper was situated midway between the two keys and 4 in. (10 cm) from the floor. During reinforcement, the keylights were extinguished and the magazine illuminated.

The reinforcer consisted of a nominal 3-sec access to wheat, and sessions were terminated in blackout after 60 reinforcements. Supplementary feeding (of maize) was given, if required, immediately after daily sessions.

Pecks on darkened keys were ineffective in all parts of the experiment.

Procedure

In the initial sessions, the pigeons were trained to eat from the food magazine when it was presented independently of responding. Key pecking was then shaped by successive approximation in the presence of two white keys. After shaping, the animals were exposed for two sessions to two independent VI 30-sec schedules, one associated with each white key (concurrent VI 30-sec VI 30-sec), and then to concurrent VI 120-sec VI 120-sec for 10 sessions. In these procedures, the VI schedules were entirely independent.

After training, the concurrent chains procedure (see Duncan and Fantino, 1970) was instituted. In the initial links, the animals were presented with two white keys, each associated with an independent VI 60-sec schedule. When the left key timer had timed an appropriate interval, the next response on this key turned the left key green and simultaneously the right key blacked out and became inoperative for the duration of the terminal link on the left key. After one reinforcement according to an interval schedule on the green key, both keys became white and the initial link condition began. When the right key timer had timed an interval, the next response to this key turned it red and simultaneously the left key blacked out and became inoperative for the duration of the terminal link on the right key. Again, after one reinforcement according to an interval schedule on the red key, the initial link condition was reinstated. Neither timer associated with the initial links was operative during the terminal links.

In all except one of the experimental conditions, the timing of an interval by one timer during the initial links did not affect the other timer. For example, if both initial link timers had timed intervals before the animal entered one terminal link, only the timer leading to that terminal link was restarted when the initial links again commenced. However, in one condition, when one timer had timed an interval the other timer immediately stopped and remained stopped until reinforcement. This latter procedure (Stubbs and Pliskoff,

1969) ensures equal numbers of entries into the two terminal links.

The initial link schedules consisted of two arithmetic VI schedules with randomised intervals from the progression a, a + d, a + 2d, *etc.*, with a = 5 sec and d = 10 sec.

Performance was assumed stable when each animal had reached a defined criterion five (not necessarily consecutive) times. The criterion was that the median of the relative numbers of responses in the initial links in the last five sessions did not differ by more than 0.05 from the median of the previous five sessions. When all animals had met this criterion five times, the experimental parameters were changed for all animals as a group. Table 1 shows the sequence of experimental conditions and the numbers of sessions of training given each animal.

The initial baseline condition sought to replicate one data point from Herrnstein's (1964a) experiment. Following this condition, the red terminal link schedule was *mixed* FI 15-sec FI 30-sec FI 45-sec [MI(15,30,45 sec)] with all intervals equally frequent. The green terminal link schedule was varied from FI 10-sec to FI 30-sec. A determination for FI 10-sec was also carried out using non-independent, initial-link concurrent schedules in order to equalize entries into the terminal links. The red terminal link was then changed to MI (15, 20, 25, 30, 35, 40, 45 sec) with all intervals equally frequent while the green terminal link FI schedule was varied. Finally, the red terminal link schedule was MI (15, 45 sec) and three more determinations with FI schedules in the green terminal link were carried out. These final conditions correspond to the parameters of Davison's (1969) experiment.

In all conditions the numbers of responses on the two keys during the initial and terminal links, and the numbers of entries into each terminal link, were recorded. Additionally, during the FI *versus* three-valued MI condition, the time in seconds spent responding on each key in the initial links was measured. Timing for each key commenced when that key was first pecked and continued until the other key was pecked.

RESULTS

All measures of performance for individual animals (Table 1) are presented as the sum of each measure over the final five sessions of each experimental condition. Relative numbers of responses for the group data are calculated from the sum of five-session sums for all animals.

The first condition replicated part of Herrnstein's (1964a) results. The predicted relative number of responses on the left key in the initial links is 0.50, and the obtained group value was 0.47. The difference, 0.03, represents a slight overall preference for responding on the right key.

The group data for FI *versus* MI choice were analyzed according to equation (1) to find the best-fitting r values for each of the three different MI schedules used. Equation (1) was solved for r values of -1.5 to -2.5 in steps of 0.1 and the predicted choice values were tested against the group data using the least squares method. Best fitting r values were: for the three-valued MI, $r = -2.2$; for the seven-valued MI, $r = -2.2$; and for the two-valued MI, $r = -2.0$. Because of unequal entries into the terminal links at FI 10-sec and FI 30-sec, the exponent for the three-valued MI is based on FIs of 15, 20, and 25 only. Also, because of the procedural variation, the point for FI 10-sec *versus* the three-valued MI schedule using the Stubbs and Pliskoff procedure was not used in the determination of r.

Figure 1 shows the relative number of responses on the FI key in the initial links as a function of the relative reinforcement rate in the terminal links on that key calculated from the mean of the squares of the reciprocals of the intervals to reinforcement. The value of $r = -2$ in Equation (1) used here was chosen arbitrarily as the nearest whole number to the three r values found. This leads to a slight inaccuracy for the three- and seven-valued MI schedule data plotted in Figure 1, for which r was empirically assessed at -2.2. As a result, the two-valued MI data, for which $r = -2$ is appropriate, are slightly above the three- and seven-valued MI data.

The group data points fall close to the diagonal, although the outermost points do deviate somewhat, probably as a result of unequal entries into the terminal links when choice was overwhelmingly for one of the terminal link schedules (Table 1). The use of the Stubbs and Pliskoff procedure was an attempt to eliminate this effect. Under this procedure, the data

point for this pair of parameters was brought below the diagonal and became more consistent with the other data points.

For the group as a whole, the key bias evident in the initial VI 30-sec *versus* VI 30-sec choice seems to be maintained throughout, though this is not so clear for individual animals. The animal showing the greatest bias in the choice between identical VI schedules

(Bird 318) showed a deviation of similar magnitude from the matching diagonal after transformation of the terminal link intervals according to Equation (1) with $r = -2$ (Figure 1).

Relative time allocation in the initial links, measured under the FI *versus* three-valued MI condition, correlated well with relative response allocation in the initial links under this condition.

Table 1

Sequence of experimental conditions, number of sessions training, numbers of responses to initial and terminal link schedules, time on each key in the initial links and the number of entries into the green terminal links in the final five sessions of each experimental condition. Initial link schedules were concurrent VI 60-sec VI 60-sec. The asterisk denotes a special condition in which both timers controlling the initial link schedules stopped when either one of them stopped. If the terminal links were entered equally often, the number of entries into green in the last five sessions sum to 150. All times are in seconds.

Bird	Green Terminal Link	Red Terminal Link	No. of Sessions	Initial Link Responses		Initial Link Time		Terminal Link Responses		Green Terminal Link Entries
				Green	Red	Green	Red	Green	Red	
307	VI 30	VI 30	47	1966	1956	–	–	7801	8371	148
308				2085	2054	–	–	3906	5308	149
315				2143	3187	–	–	4397	6684	150
317				3273	2499	–	–	4285	4447	148
318				2074	3871	–	–	4454	6510	149
319				3523	3718	–	–	7958	7972	148
307	FI 30	Three-valued MI	37	2003	3332	2436	5392	10150	10966	148
308				2393	2249	4129	4253	4455	5679	152
315				1435	3307	2146	5211	3548	5303	149
317				1574	4773	1563	7040	2151	3579	148
318				843	4950	1009	7791	3696	4747	141
319				456	7544	529	8786	6962	11232	124
307	FI 10*	Three-valued MI	21	4668	2226	5981	2215	4911	10042	150
308				6368	943	8594	1021	3581	6198	151
315				4028	1652	6449	1575	2037	5429	150
317				7449	1466	6967	1377	3865	4864	148
318				4206	1884	5793	2192	1868	4993	150
319				7628	766	8056	898	5053	8739	151
307	FI 25	Three-valued MI	35	2696	3193	3799	4249	7571	11640	151
308				2808	2292	3987	3864	3999	5742	152
315				2491	3239	3284	4345	3358	5162	151
317				3965	4053	2989	4903	6044	4354	150
318				1576	4929	1538	6482	2889	3132	144
319				1858	4112	2080	5836	7981	9185	148
307	FI 15	Three-valued MI	19	2577	2160	4691	3382	5203	9909	152
308				4726	1479	6003	2012	2240	4647	155
315				3577	2566	4982	2824	2378	4874	152
317				6282	2155	5182	2702	5691	4916	153
318				3740	3181	4048	3727	1904	2920	151
319				4714	2216	5470	2356	5852	9610	150
307	FI 20	Three-valued MI	25	3028	2743	3738	4117	5201	9390	151
308				4356	1745	5850	2086	1738	4405	156
315				3231	2886	4787	3194	2262	4685	151
317				4829	4026	3952	3778	5359	6041	153
318				2600	4703	2650	5236	1503	2016	148
319				3357	2853	3637	4218	6793	8869	151

Table 1—Continued

Bird	Green Terminal Link	Red Terminal Link	No. of Sessions	Initial Link Responses		Initial Link Time		Terminal Link Responses		Green Terminal Link Entries
				Green	Red	Green	Red	Green	Red	
307	FI 10	Three-valued MI	32	7296	493	8571	454	5126	7943	170
308				8881	673	7988	736	950	3727	172
315				4337	1702	6288	1727	1421	3770	153
317				8088	1111	7308	917	4261	4975	159
318				4470	2364	5165	2673	524	1496	154
319				10738	468	8813	610	5042	7298	181
307	FI 30	Seven-valued MI	28	2252	2382	–	–	5367	7723	148
308				2078	3260	–	–	3044	3656	148
315				2239	2885	–	–	2286	4730	150
317				3246	5275	–	–	7223	4804	151
318				1351	5673	–	–	1562	1602	146
319				2269	4196	–	–	8129	8152	147
307	FI 15	Seven-valued MI	19	4687	2237	–	–	4163	7322	154
308				4276	2119	–	–	1574	3559	151
315				3856	1952	–	–	1606	3767	154
317				6340	2088	–	–	4638	4415	152
318				3225	3562	–	–	846	1732	150
319				5453	1322	–	–	5650	7573	154
307	FI 25	Seven-valued MI	23	3154	2421	–	–	4825	7644	152
308				2655	2712	–	–	2489	4269	150
315				2689	3408	–	–	2343	4318	150
317				3040	4201	–	–	5283	4124	148
318				1797	4252	–	–	1050	1752	149
319				3106	3463	–	–	7202	9379	151
307	FI 25	Two-valued MI	23	2202	1977	–	–	3956	7183	149
308				2641	2791	–	–	2672	5588	153
315				2350	2886	–	–	2102	4227	149
317				2355	4130	–	–	4505	4273	147
318				1491	4702	–	–	996	1244	146
319				1844	2756	–	–	5448	10551	145
307	FI 15	Two-valued MI	26	3695	1320	–	–	2662	6178	154
308				5050	1964	–	–	2060	5160	152
315				3237	1854	–	–	1624	4018	151
317				5233	2742	–	–	4555	6651	150
318				2766	3575	–	–	668	1468	149
319				4075	1800	–	–	4893	9539	152
307	FI 20	Two-valued MI	19	2827	2013	–	–	3055	7586	151
308				2728	3134	–	–	1553	4319	147
315				2833	2465	–	–	1980	3725	151
317				3716	3691	–	–	4065	6359	151
318				2238	4069	–	–	1203	3105	148
319				3227	2421	–	–	6414	10845	151

Informal observation of the experiment showed that the pattern of responding in the FI terminal link was typical well-trained (break and run) performance (Schneider, 1969). In the two- and three-valued MI schedules, successive accelerations to high response rates occurred at times that corresponded to the schedule values arranged (Catania and Reynolds, 1968). In the seven-valued MI schedule, after an initial pause of about 10 sec, responding occurred at a relatively constant rate.

DISCUSSION

The present experiment shows that an exponent of about −2 in Equation (1) produces matching between relative number of responses and relative interreinforcement intervals in the choice between MI and FI schedules, when both the smallest and largest intervals in the MI schedules are kept constant. The number of intervals comprising the MI schedule did not, as had been suggested by Davison (1969), affect the value of r neces-
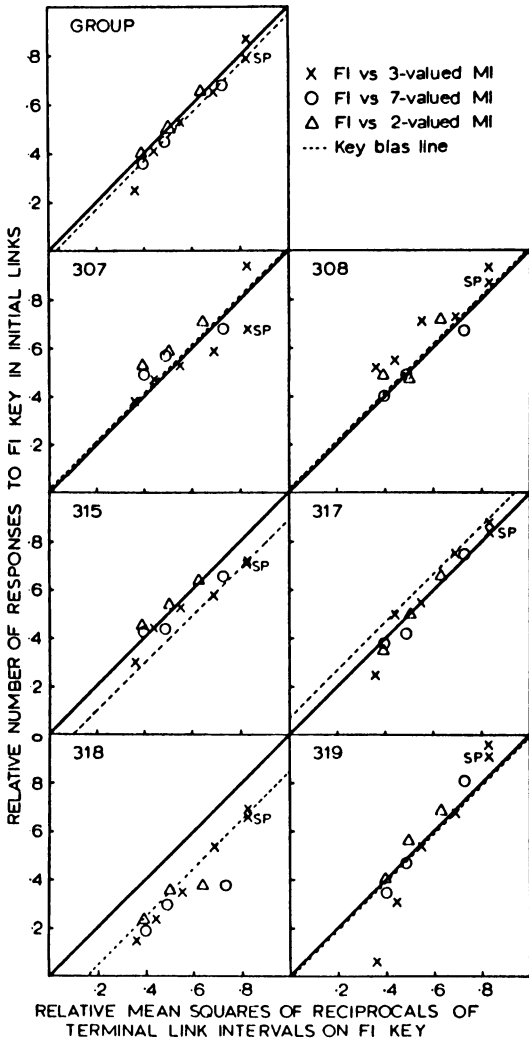
Fig. 1. Relative numbers of responses on the FI key in the initial links as a function of the relative mean squares of the reciprocals of the intervals on the FI key in the terminal links. Data are shown for all conditions, not just those points used to calculate r. The broken line shows the amount of key bias predicted from the condition with identical VI 30-sec schedules in the terminal links. SP denotes the use of non-independent initial link schedules.

sary to produce matching. Furthermore, the present results are inconsistent with those of Davison (1969), who found an r value of −3 necessary to produce response-reinforcement matching in FI *versus* two-valued MI choice with the same temporal parameters as used here. The apparently small procedural difference between the two experiments (the use of a 0.5-sec changeover delay in the initial links in the earlier experiment) probably accounts

for the different results, as Killeen (1970) also suggested. This suggestion is consistent with the known effects of changeover delay on concurrent schedule performances (Shull and Pliskoff, 1967), which is to increase preference for the schedule providing the greater reinforcement rate. Such an effect in concurrent chain schedules would lead to an increase in r values.

These results generally support Duncan and Fantino's (1970) suggestion that the different r values obtained in FI *versus* VI choice (Killeen, 1968) and FI *versus* MI choice (Davison, 1969 and the present results) are due to different smallest intervals in the terminal links. Killeen used smallest intervals of 2.7 and 4.3 sec in various experiments and found an r value of −1. In the present experiment, except when FI 10-sec was scheduled in the green terminal link, the smallest interval was 15 sec and an r value of −2 was found. The r values necessary to produce response-reinforcement rate matching in Killeen's (1968) and the present experiment differ in the *direction* predicted by Duncan and Fantino (1970). But the present results do not fit at all well on the function relating r value to the smallest terminal link interval given by these experimenters. A value of r = −5 would be predicted for the schedule values of the present experiment. The obtained choice proportions differ greatly from the predicted choice proportions for r = −5 in Equation (1). The reason for this inconsistency is not at present clear.

The present finding of an exponent of −2 in Equation (1) to produce matching between responses and terminal link interreinforcement intervals reflects a differential weighting by the animal of different intervals to reinforcement. Briefly, as the exponent increases in absolute magnitude, small interreinforcement intervals in the terminal links are weighted relatively more than long interreinforcement intervals. When r is large, and the contribution of the smallest interreinforcement interval in each terminal link is overwhelming, the choice proportions will depend solely on the relation between the smallest intervals in each terminal link. If these are equal, the predicted choice proportion will tend towards 0.5. If they are unequal, choice proportions will tend towards 1.0 for the terminal link containing the smallest interval over-

all. The choice proportions predicted between these two extremes will be entirely dependent on the particular set of intervals scheduled in each terminal link.

The available data on preference in concurrent chain schedules (Duncan and Fantino, 1970) suggest, then, that the amount by which smaller intervals to reinforcement in the terminal links are weighted relative to longer intervals is a function of the length of the shortest interval occurring in *either* terminal link. That is, as the length of the shortest interval increases, so the value of r decreases. This weighting seems to be unaffected by the relative frequency of occurrence of the smallest interval or by the number of intervals comprising the terminal link schedules, at least under the conditions of the present experiment when smallest and largest intervals are kept constant. An effect of the range of reinforcement rates arranged in the terminal links has been implicated by Killeen (1970), but no such effect was reported by Duncan and Fantino (1970). Killeen's results can most likely be explained in terms of the smallest interval to reinforcement in the terminal links and the resultant differential weighting of all intervals to reinforcement.

Some discussion is in order on the use of non-independent concurrent VI schedules (Stubbs and Pliskoff, 1969) in one condition. A rather similar procedure (concurrent FI percentage reinforcement schedules) was used successfully by Schwartz (1969). By definition, these procedures equalize the number of terminal link entries. In the present experiment, one data point that was somewhat deviant, using the more usual independent concurrent initial links procedure, became consistent with other data when non-independent concurrent VI schedules were used in the initial links. For a shortest interval of 10 sec, Duncan and Fantino's data suggest an exponent in Equation (1) of about -3.5. This is closer to the value of r obtained throughout this experiment (-2) than Duncan and Fantino's predictions of $r = -5$ for shortest intervals of 15 sec. Thus, the use of the procedure reported by Stubbs and Pliskoff to equalize terminal link entries is equivocal, though further research is justified. It should be noted in passing, however, that the use of this procedure is necessarily incompatible with Fantino's (1969) model for choice behavior, which predicts ex-

clusive choice for one alternative when entry into the other terminal link signifies a delay of reinforcement greater than the average delay of reinforcement over the whole concurrent chain; this procedure, in effect, prevents exclusive choice.

Relative time allocation in the initial links, measured in one part of the present experiment, closely matched relative response allocation (see Table 1), suggesting that the former dependent variable may be as useful as the latter. Similar findings have been reported for concurrent VI VI performance (Brownstein and Pliskoff, 1968; Baum and Rachlin, 1969) and, recently, for concurrent chain performance (Ten Eyck, 1970).

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