PREFERENCE FOR FIXED-INTERVAL SCHEDULES: AN ALTERNATIVE MODEL[1]

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Pigeons were trained under concurrent chain schedules in which the initial links were equal aperiodic schedules and the terminal links were fixed-interval schedules. Choice proportions in the initial links were measured in 26 experimental conditions. The data showed the inadequacy of previous models of concurrent chain performance. A new model was suggested in which choice is a joint function of terminal-link times, overall reinforcement rates, and terminal-link entries. This model accounted for 94% of the variance in the present data and for substantial percentages of the variance in previously reported data. The model simplifies to matching between response ratios and obtained reinforcement rate ratios for simple concurrent schedule performance.

The concurrent chain procedure has been used to measure choice between two periodic or fixed-interval (FI) schedules of reinforcement. The concurrent, independent initial links of the two chain schedules are variable-interval (VI) schedules that occasionally allow access to mutually exclusive terminal-link schedules of reinforcement ending in food presentation. Preference for one terminal-link schedule is the number of responses emitted on that key in the initial links divided by the number of responses emitted in the other initial link.

Killeen (1970) reported that the number of pecks in the initial link leading to the shorter terminal-link FI schedule was greater than would have been predicted from a simple equality (matching) between the initial-link preference ratio and the ratio of reinforcement rates in the terminal links (Herrnstein, 1964). Duncan and Fantino (1970) found a similar effect and used a transformation of the terminal-link schedule values (Killeen, 1968; Davison, 1969) to produce matching between the initial-link preference ratio and this ter-

minal-link reinforcement rate measure. In this transformation, each terminal-link fixed interval was raised to some power before reinforcement rate ratios were calculated. The value of the power, which varied with the size of the shorter terminal FI schedule, was assumed to be constant for a given value of the shorter terminal-link interval. MacEwen (1972) confirmed the results of Killeen (1970) and Duncan and Fantino (1970), but did not assess the adequacy of Duncan and Fantino's model. He did find that an earlier model of concurrent chain choice (Fantino, 1969) generally underestimated preference ratios in the choice between FI schedules.

The present experiment investigated choice between FI schedules to evaluate existing models of concurrent chain choice behavior and, when these proved inadequate, to provide parametric data that would allow a new formulation.

METHOD

Subjects

The experiment commenced with the six homing pigeons used by Davison (1972), which were maintained at 80% ± 15 g of free-feeding body weights. After a rationalization in laboratory procedure, they were renumbered (in the same order as before) 31 to 36. During the experiment, 31 and 34 died and were replaced by 31b and 34b.

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 2 cm (0.75 in.) in diameter, 13 cm (5 in.) apart and 22.5 cm (9 in.) from the floor. Each key could be illuminated with various colored lights. Two sources of feedback for pecks exceeding approximately 0.1 N were arranged: first, a 30-msec offset of the keylight; second, the click of a relay situated inside the experimental chamber. No illumination was provided in the chamber apart from the keylights, and pecks on darkened keys were ineffective in all parts of the experiment. A grain hopper was situated midway between the two keys and 10 cm (4 in.) from the floor. During reinforcement, the keylights were extinguished and the hopper illuminated.

The reinforcer consisted of a nominal 3-sec access to wheat, and sessions were terminated in blackout after a fixed number of reinforcements had been obtained. This number was varied to give a maximum session time of about 50 min. Supplementary feeding (of maize) was given, if required, immediately after daily training sessions.

Procedure

Since the animals had extensive histories of responding on concurrent chain schedules (and, in the cases of 31b and 34b, on multiple schedules), no key-peck or schedule training was necessary. The standard concurrent chain procedure (Duncan and Fantino, 1970), with arithmetic VI 60-sec initial links as specified by Davison (1972) was in effect at all times. In the initial links, the animals were presented with two white keys, each associated with a 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 links were reinstated. When

the right-key timer had timed an interval, the next response on 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 links were reinstated. Neither timer associated with the initial links was operative during the terminal links.

The stability criterion used by Davison (1972) was used to determine when experimental conditions could be changed. Briefly, five-day medians of relative numbers of initial-link responses were compared, and when the medians had been within 0.05 on five (not necessarily consecutive) days for all birds, the conditions were changed.

The sequence of experimental conditions, which was designed to reverse preference between keys in most successive conditions, is shown in Table 1. In some of the conditions, an FI 0-sec schedule was arranged on one key, which allowed reinforcement for the first response emitted in the terminal link on that key.

Four experimental conditions were arranged to measure any bias (Baum and Rachlin, 1969) in performance to either key. The first two were FI 30-sec *versus* FI 25-sec and its reversal in the next experimental condition. Later in the experiment, two conditions with equal terminal-link schedules were arranged. In the first, the schedules were VI 30-sec, and in the second they were FI 5-sec.

In all conditions, the numbers of responses on the two keys in the initial and terminal links, and the number of entries into each terminal link, were recorded.

RESULTS

All measures of performance for individual animals (Table 1) are the sums of each measure over the final five sessions of each experimental condition. This Table shows that the preference for FI 0-sec *versus* FI 1-sec, measured as the geometric mean of the ratios of initial-link responses for each individual animal, was 1.019. This functional equivalence indicates that 1 sec is a good approximation to the time spent in the FI 0-sec terminal link, and this value was used in all subsequent figures and calculations.

Table 1

Sequence of experimental conditions, number of sessions training, number of responses to initial- and terminal-link schedules, and the number of entries into the green and red terminal-link schedules in the final five sessions of each experimental condition. Initial-link schedules were concurrent VI 60-sec VI 60-sec, and all other times are in seconds.

Bird	Terminal Links		No. of Sessions	Initial Link Responses		Terminal Link Responses		Terminal Link Entries	
	Green	Red		Green	Red	Green	Red	Green	Red
31	FI 20	FI 15	19	2136	2471	2443	2801	126	124
32				2987	2772	1985	2109	126	124
33				1915	2666	1364	1032	125	125
34				1254	2847	3710	3728	121	129
35				1371	4077	777	1043	120	130
36				1859	2375	4318	4623	122	128
31	FI 10	FI 15	18	3483	2154	1840	2299	128	122
32				5024	1432	2058	1300	129	121
33				2432	1894	1229	917	125	125
34				3522	2092	2807	5197	127	123
35				2363	2422	546	619	125	125
36				4536	1511	3895	5274	128	122
31	FI 30	FI 25	30	1547	4100	2476	1874	121	129
32				2136	2707	2464	2870	124	126
33				2109	2225	1980	1232	128	122
34				1806	3325	7123	4849	123	127
35				1416	2555	2452	3068	123	127
36				1886	2431	7379	7589	124	126
31	FI 25	FI 30	21	2200	2140	1674	1861	127	123
32				4212	1544	2117	1355	129	121
33				2422	1980	1551	1662	126	124
34				3856	3236	6428	6214	125	125
35				2174	1905	1437	2449	125	125
36				3544	1428	7491	7385	127	123
31	FI 45	FI 40	28	869	779	2332	2238	99	101
32				1662	2034	3002	1859	98	102
33				1156	1877	2704	1997	99	101
34				1487	3049	4705	5779	100	100
35				630	1283	1949	2151	99	101
36				1455	1616	8848	8001	99	101
31	FI 55	FI 65	22	466	614	1990	2248	66	84
32				1097	1378	2597	2172	79	71
33				1468	628	2519	2369	78	72
34				760	1764	2754	4421	70	80
35				711	739	1445	2835	78	72
36				1027	492	8341	9181	75	75
31	FI 0	FI 5	16	4193	1966	153	822	153	147
32				6099	1173	156	1648	156	144
33				5435	2199	153	1330	153	147
34				6453	2626	152	1677	152	148
35				2557	2468	150	986	150	150
36				6842	2254	151	3182	151	149
31	FI 10	FI 0	26	547	4965	857	176	124	176
32				573	7073	1571	176	124	176
33				1976	5427	1377	160	140	160
34				1175	5756	2683	169	131	169
35				1685	5617	765	158	142	158
36				1769	5003	4306	161	139	161
31	FI 0	FI 2	30	3991	3386	149	423	149	151
32				4476	2684	154	874	154	146
33				4484	3638	150	649	150	150
34b				4917	3078	156	831	156	144
35				4219	3410	150	417	150	150
36				4981	2302	150	1418	150	150

Table 1 *continued*

Bird	Terminal Links		No. of Sessions	Initial Link Responses		Terminal Link Responses		Terminal Link Entries	
	Green	Red		Green	Red	Green	Red	Green	Red
31	FI 15	FI 0	33	479	8163	1532	181	119	181
32				601	10751	1128	169	131	169
33				856	6808	1206	168	132	168
34b				200	12040	1227	207	93	207
35				609	6329	816	170	130	170
36				587	5346	4727	165	135	165
31	FI 0	FI 1	18	3714	3749	150	371	150	150
32				4306	3230	149	494	149	151
33				4241	3250	153	625	153	147
34b				3305	7417	147	884	147	153
35				3049	3581	151	329	151	149
36				4733	2768	150	666	150	150
31	FI 10	FI 60	30	4099	1167	1376	3441	104	96
32				5547	337	1336	2327	115	85
33				4871	240	952	2103	123	77
34b				5178	26	1902	596	168	15
35				4037	212	635	1662	116	84
36				7490	616	4296	8100	110	90
31	FI 30	FI 10	23	498	5948	1667	1400	83	117
32				756	4610	2269	1011	94	106
33				1161	2982	1430	926	96	104
34b				139	9051	1882	2767	58	138
35				211	5460	705	774	76	124
36				491	3477	5714	4691	88	112
31	FI 10	FI 45	21	3714	1215	1375	2961	106	94
32				4343	377	1497	2588	111	89
33				4614	395	907	2135	114	86
34b				5123	128	1944	1951	133	67
35				5513	137	1191	1187	128	72
36				11805	255	4917	7984	115	85
31b	FI 30	FI 0	16	39	6569	416	180	20	180
32				317	8330	2686	116	84	116
33				164	7369	915	156	44	156
34b				285	8546	1105	151	49	151
35				110	6964	772	155	45	155
36				181	9215	3282	150	50	150
31b	FI 20	FI 25	35	996	784	623	755	102	98
32				3376	1660	2241	2651	103	97
33				2383	1342	1130	1528	103	97
34b				3236	1341	1528	2553	101	99
35				1941	1704	978	1515	99	101
36				2756	1129	5893	6007	102	98
31b	FI 30	FI 20	29	192	2592	508	595	78	122
32				1480	3439	2061	1527	98	102
33				1398	2960	1497	1142	96	104
34b				1325	3563	1665	1900	97	103
35				314	2854	686	672	85	115
36				640	3015	5859	5931	93	107
31b	FI 20	FI 35	37	1490	300	439	505	112	88
32				3821	715	1959	2249	105	95
33				3000	1182	1402	1750	103	97
34b				5350	253	1479	2068	127	73
35				2163	1029	692	1151	103	97
36				5562	679	6424	6676	108	92
31b	FI 40	FI 20	27	200	2657	652	499	81	119
32				971	3163	2684	1772	95	105
33				1173	2675	2078	1057	98	102
34b				968	3751	1171	1522	95	105
35				341	3894	723	774	80	120
36				663	3569	5285	4804	92	108

Table 1 *continued*

Bird	Terminal Links		No. of Sessions	Initial Link Responses		Terminal Link Responses		Terminal Link Entries	
	Green	Red		Green	Red	Green	Red	Green	Red
31b	FI 20	FI 60	28	3113	58	728	500	149	31
32				3896	542	2247	3917	100	80
33				4284	116	990	2337	97	83
34b				5917	120	1916	3151	122	58
35				3335	502	607	2094	97	83
36				5894	417	5020	8177	97	83
31b	FI 100	FI 10	21	91	3616	988	826	39	131
32				464	5766	3634	1997	73	97
33				200	5226	3289	800	62	108
34b				167	7233	2518	1366	53	117
35				151	6820	1468	1108	31	139
36				178	6985	6270	3945	62	108
31b	FI 0	FI 90	17	5329	34	153	621	153	17
32				5091	187	106	4617	106	64
33				6825	123	119	2209	119	51
34b				8926	45	149	1426	149	21
35				6507	107	120	3450	120	50
36				12663	238	102	8345	102	68
31b	FI 60	FI 5	20	77	4705	600	676	49	176
32				693	6108	4918	1640	99	126
33				114	8570	1945	1084	48	177
34b				99	9895	885	923	49	176
35				53	10848	732	962	18	207
36				193	9326	5464	2914	70	155
31b	FI 30	FI 60	31	1563	337	706	1560	90	70
32				2757	1232	1801	3533	83	77
33				3189	667	1556	2344	86	74
34b				4907	465	2298	3137	98	62
35				2691	588	1156	3028	94	66
36				4022	855	5377	6685	85	75
31b	VI 30	VI 30	25	1034	1252	2321	3184	98	102
32				2624	1844	5090	4256	101	99
33				2583	1429	2762	3972	102	98
34b				4520	922	4378	4365	107	93
35				3059	1818	2250	3741	101	99
36				2460	1880	4312	5041	99	101
31b	FI 5	FI 5	14	1652	1381	521	358	112	113
32				3033	1711	1247	1285	112	113
33				2146	2467	812	1290	113	112
34b				3406	4887	1032	719	113	112
35				3738	3139	669	557	112	113
36				2909	2868	1887	2467	113	112

In Figure 1, the logarithm of the ratio of responses in the initial links is plotted as a function of the logarithm of the ratio of reinforcement rates in the terminal links (Baum and Rachlin, 1969) for each terminal-link condition. The group data are the geometric means of the individual initial-link response ratios from Table 1. The numerator of each ratio is the initial-link responses, or the terminal-link reinforcement rate, on the left (green terminal link) key. To facilitate subsequent analysis, the three series that used a constant shorter terminal-link interval (FI 0-sec, FI

10-sec, and FI 20-sec) are shown separately. Figure 1 shows that choice ratios generally increase as terminal-link reinforcement rate ratios increase. It also shows that, for the same terminal-link reinforcement rate ratio, preference generally increases as a function of the size of the shorter terminal-link interval to reinforcement. Both of these results are borne out by the data from most individual birds (Table 1).

The amounts of bias shown by individual birds in the conditions in which terminal-link schedules were reversed and in the equal ter-
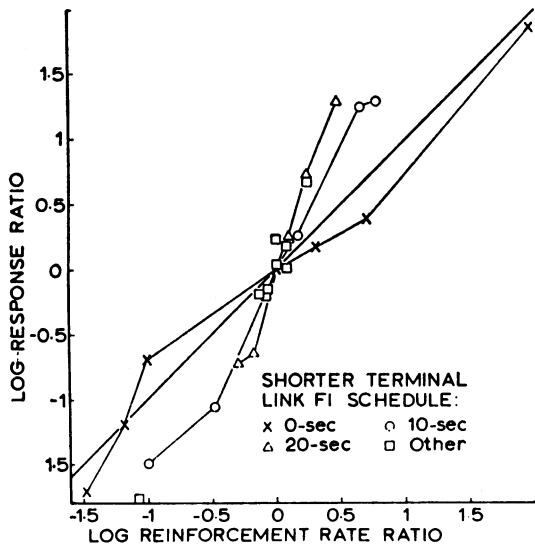
Fig. 1. Initial-link response ratios in the various experimental conditions as a function of the ratio of reinforcement rates in the terminal link. Both coordinates are logarithmic. If initial-link response ratios equalled terminal-link reinforcement rate ratios, all data would fall on the main diagonal. The data are geometric means of response ratios for the individual birds.

minal-link schedule conditions are shown in columns B, C, and D of Table 2. Column A in this Table shows bias values reported for these birds by Davison (1972). The values are not consistent between successive measures, and some large reversals occur.

Table 2

The value of bias to the green key measured in various experimental conditions shown as the ratio of green initial-link responses to red initial-link responses. In reversal conditions, bias is the square root of the product of the response ratios in the two conditions. The bias values in column A are from equal VI 30-sec terminal links (Davison, 1972), column B are from the reversal of FI 25-sec and FI 30-sec, column C are from equal VI 30-sec terminal links, column D are from equal FI 5-sec terminal links, and column E are bias values from the fitted lines in Figure 3.

Bird	A	B	C	D	E
31	1.005	0.623	–	–	0.715
31b	–	–	0.826	1.025	0.862
32	1.015	1.463	1.423	1.773	1.015
33	0.672	1.075	1.808	0.870	1.164
34	1.310	0.805	–	–	0.766
34b	–	–	4.902	0.697	0.879
35	0.536	0.795	0.627	1.191	0.822
36	0.948	1.387	1.309	1.014	1.260

Finally, as noted by Davison (1972), the number of times the animals entered each terminal link did not remain equal when choice ratios were large. Table 1 suggests that these unequal entries are related to decreases in the overall response rates in the initial links.

DISCUSSION

In analyzing the present data, it is important to assess whether bias needs to be removed. While the absence of bias may not be necessary to confirm the matching law for concurrent schedules (Rachlin, 1971), the presence of bias may give a distorted result when data are being analyzed to discover a law that is clearly more complex than the matching law (Duncan and Fantino, 1970; Killeen, 1970; MacEwen, 1972). The bias values in Table 2 are often large and show considerable variability between estimates from the same bird, but there is no clear trend over time common to all animals. Apart from random fluctuations, this variability could be caused by two effects. Firstly, each estimate could be in error through inertia from the previous experimental condition. Secondly, the variability could arise from a systematic fluctuation in bias over time that was idiosyncratic to each bird. Thus, the following strategy was adopted. The data were analyzed in terms of existing models of choice in the conventional manner, that is, without consideration of bias, but the group data were also analyzed in terms of these models using two different estimates of bias. The first estimate was the geometric mean of all bias ratios (columns A to D in Table 2) for the animals taking part in a particular condition. This will be termed the overall bias estimate. The second was the geometric mean of the most recent bias estimates for the animals taking part in a condition. In all cases, missing values were taken to be unity, and a bias value obtained in a condition was not used to modify data until the following condition. Bias values were all obtained to the initial-link key preceding the green terminal link, as in Table 2, and raw data were modified by dividing the response ratio to the green key by the bias ratio to that key (Baum and Rachlin, 1969).

Duncan and Fantino (1970) suggested that choice between FI terminal links in concurrent chains might be explained by a variant

of the matching law for concurrent schedules in which choice ratios match terminal-link reinforcement rate ratios raised to some power. Their data indicated that the value of this power was a curvilinear function of the duration of the shorter interval to reinforcement arranged in the terminal links. Duncan and Fantino's model predicts that if response ratios are plotted as a function of reinforcement rate ratios on log-log coordinates (Figure 1), the graphs for each set of smaller terminal-link intervals will be straight lines with slopes equal to the required power. The data for shorter terminal-link intervals of 0, 10, and 20 sec shown in Figure 1 do not deviate strongly from straight lines and, on this criterion, Duncan and Fantino's model is supported. As a further test, Duncan and Fantino's Figure 8 was used to obtain estimates of the required power for the shorter terminal-link intervals used in the present experiment, and quantitative predictions from their model were compared with the present data. The fit of the model to the data was measured as the difference between the variance of the data around the data mean and the variance of the data around the predictions as a percentage of the variance of the data around the data mean. All such calculations were carried out in log-

arithmic terms to avoid variances being inflated by large choice ratios and large predictions. Table 3 shows that the percentage of the variance accounted for by this model is small and unchanged by removing bias estimated by the methods discussed above.

A simpler model suggested by Killeen (1968), in which choice ratios match terminal-link reinforcement rate ratios calculated as the harmonic mean of the terminal-link intervals, is precluded by Figure 1. In the case of choice between two FI schedules, this model predicts that preference ratios would fall on the main diagonal in this figure. Table 3 shows, however, that this model did account for a substantial per cent of data variance. Again, the removal of bias estimates did not change the variance accounted for.

Squires and Fantino (1971) examined preference for terminal-link VI schedules in a concurrent chain procedure as a function of the values of the initial-link schedules. They found that initial-link preference ratios were a function of the decrease in the expected time to reinforcement on the two keys when the terminal links were entered. The present data were used to test the generality of Squires and Fantino's model, and response ratios as a function of the predictions of this model are shown in Figure 2. Data for the choice between FI 100-sec and FI 10-sec and between FI 0-sec and FI 90-sec are not shown in this figure. For these choices, this model predicts exclusive choice. This was not found. Squires and Fantino's model makes the present data more internally consistent, but the data deviate strongly from equality with the predictions shown by the main diagonal in this figure. Table 3 shows that the variance in the present data accounted for by this model is lower than that accounted for by predictions from the model discussed by Killeen (1968), and that the removal of bias does not affect the adequacy of the model. The calculations of variance on this particular model necessarily neglect the two predictions of exclusive choice.

Since none of the models closely fitted the present data, the authors searched for an alternative model. The models investigated all had the form of the theoretical matching law (Killeen, 1972) and were formed from a combination of the various parameters of the situation. The most promising of the models in-

Table 3

The percentage of data variance around the data mean accounted for by various models of concurrent chain choice. The last two rows show the variances accounted for if the group data are modified by the overall or the most recent bias estimates respectively (see text).

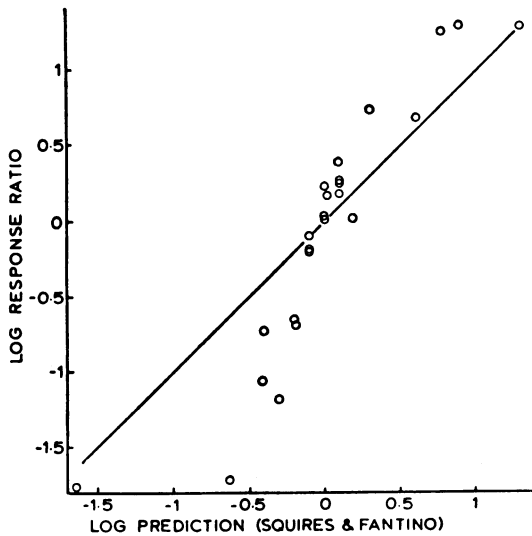| Bird	Duncan and Fantino (1970)	Killeen (1968)	Squires and Fantino (1971)	Equation 1
31	0	80	32	83
31b	21	78	78	93
32	0	88	61	88
33	7	82	83	93
34	0	40	12	67
34b	39	69	69	89
35	22	73	70	91
36	23	80	74	91
Group	17	84	76	94
Group (overall bias)	17	84	75	93
Group (recent bias)	17	84	76	94

Fig. 2. Initial-link response ratios in the various experimental conditions as a function of the initial-link response ratios predicted from the model suggested by Squires and Fantino (1971). Both coordinates are logarithmic. If initial-link response ratios were controlled by decreases in the expected time to reinforcement that occurred on entry into the terminal links, the data would fall along the main diagonal. The data are geometric means of response ratios for the individual birds. Two data points, for which this model predicts exclusive choice, are not shown.

vestigated, in terms of the percentage of the data variance accounted for, was:

$$\frac{P_1}{P_2} = \frac{R_1}{R_2} \cdot \frac{E \cdot t_2}{t_1} \qquad \ldots \ldots (1)$$

In this equation, P_1 and P_2 are the numbers of responses on the two keys in the initial links, R_1 and R_2 are the overall reinforcement rates arranged on each key (Squires and Fantino, 1971) and t_1 and t_2 are the times spent in the terminal-link schedules, inclusive of reinforcement time. E is a factor that describes the number of times the animal entered each terminal link relative to the number of entries arranged by the initial-link schedules. For example, if the initial-link schedules were VI 30-sec on key 1 and VI 60-sec on key 2, the arranged entries into the first terminal link would be two for every one into the second terminal link. If the animal then entered the first terminal link three times more often than the second, the value of E would be 1.5. In the present case, the arranged entries into each terminal link were equal, and E is simply the ratio of terminal-link entries in Table 1. Thus,

Equation 1 predicts that if the choice were between FI 10-sec and FI 80-sec in the terminal links, the initial links were both VI 60-sec, and the animal entered the 10-sec terminal link 40 times for 20 entries into the 80-sec terminal link, then, preference for the initial-link key leading to the 10-sec terminal link would be:

$$\frac{P_1}{P_2} = \frac{60 + 80}{60 + 10} \cdot \frac{40}{20} \cdot \frac{80 + 3}{10 + 3} = 25.5$$

if the duration of reinforcement on both keys was 3 sec.

This model accounts for 94% of the variance in the group data and this figure is virtually unchanged by the removal of key bias. It also accounts for more of the variance within the individual data than the models suggested by Killeen (1968), Duncan and Fantino (1970), or Squires and Fantino (1971). When the present data are plotted as a function of the predictions from Equation 1 on log-log coordinates (Figure 3), no strong deviations result and most of the data lie close to the main diagonal, which describes the equality in Equation 1. Straight lines fitted by the method of least squares to the logarithmic data give slopes close to unity and constants of small value. The antilogarithms of the constants of the fitted lines are a measure of bias over all experimental conditions, and these are shown for comparison in column E of Table 2. These measures are, again, rather inconsistent with the other measures of key bias. Of the birds that completed all experimental conditions, the fit to Equation 1 was worst for Bird 32 (88% of the variance accounted for) and many of the assessments of the bias in this bird's performance are moderately high (Table 2). The data for this bird were modified by both its most recent, and its overall, bias estimates as discussed above, and again compared with predictions from Equation 1. The most recent bias estimates decreased the accounted variance to 85%, and the overall estimate increased it to 89%. As these differences, and the differences in variance accounted for with and without bias in the group data, are so small, we conclude that our attempts to measure bias in specially designed conditions failed. The best measures of bias should be column E of Table 2, as these measures are based on all 26 experimental conditions. While these values are best predicted from column B (the reversed schedule condi-
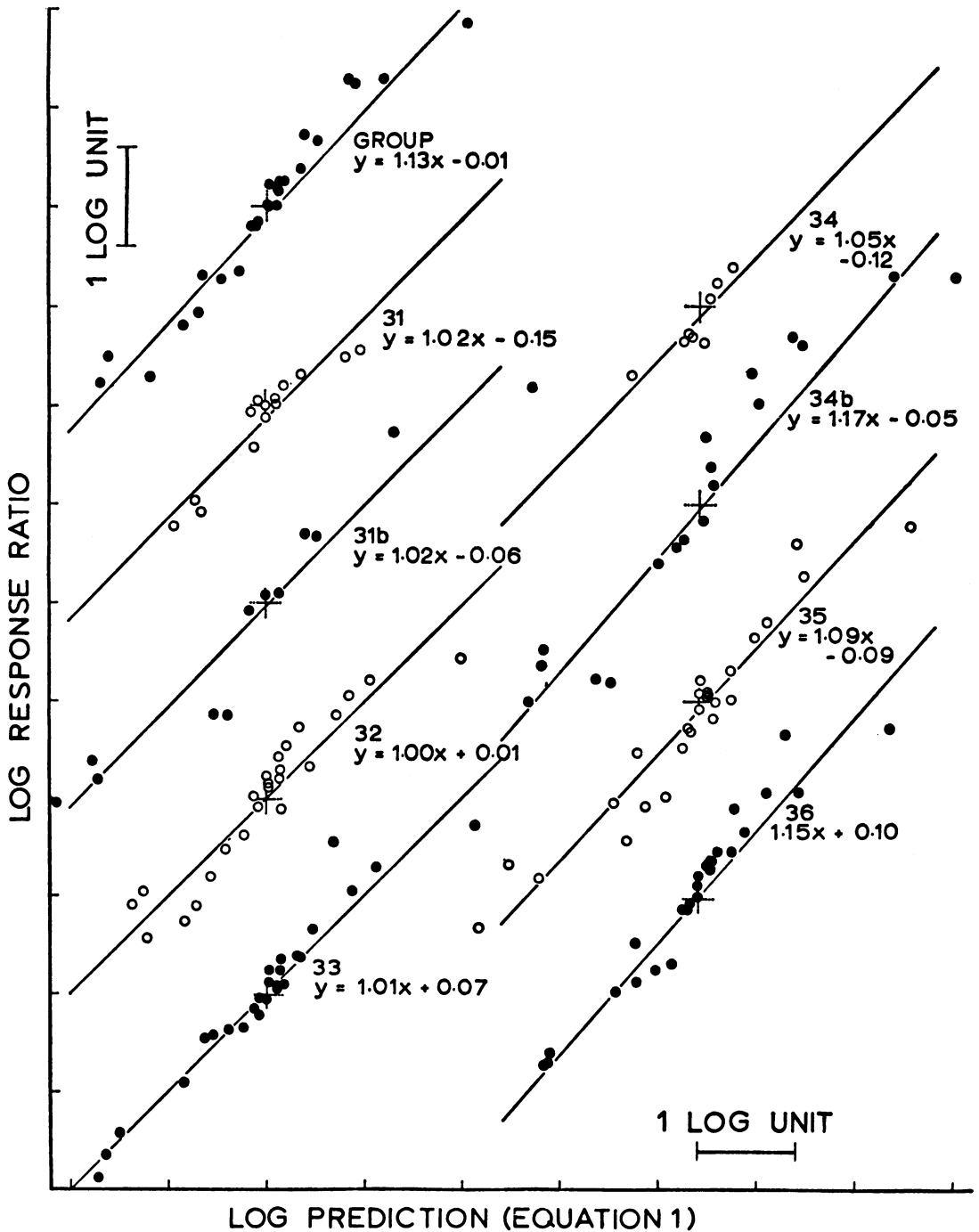
Fig. 3. Initial-link response ratios in the various experimental conditions as a function of the initial-link response ratios predicted from Equation 1. Both coordinates are logarithmic, and data from all individual birds, as well as the grouped data (geometric means of the individual response ratios) are shown. Each graph is displaced two log units down from the graph above, and 4.2 log units from the graph to the right or left. By each graph is the equation of the line fitted to the logarithmic data by the method of least squares.

tions), the use of bias values from column B would do little to increase the variance accounted for. This is shown by the fact that the most recent bias estimates were from column B in 21 out of 26 cases.

The bias estimates in column C of Table 2 appear to be inflated. This may be the result of some inertia in preference from the previous experimental condition, which controlled a high response ratio to the initial link leading to the green terminal link. These data could indicate that inertia was common in data from concurrent chain research and warrant further investigation. To this end, we are at present carrying out two experiments, one to enable us to measure and predict inertia if it occurs, and one to investigate a procedure in which it may be minimized.

The data reported by Duncan and Fantino (1970) cannot be compared with predictions from Equation 1, as these experimenters did not report the number of entries into each terminal link. Killeen (1970) did report data on entries, and an analysis of all the individual data reported by him shows that Equation 1 accounts for 83% of the variance in the data. MacEwen (1972) used a procedure in which the terminal-link entries were always equal, and Equation 1 can be applied to his data with E equal to one. When this was done, the equation was found to account for none of the data variance, all choice ratios being considerably higher than predicted. The reason for this may be a very large key bias that is evident in MacEwen's data. This is shown by an initial-link response ratio of about 28 in a control condition in which terminal-link entries were not held equal. The terminal links were VI 20-sec and VI 40-sec and, on the bias of the research reported by Herrnstein (1964), a response ratio of about two would be predicted.

Some indication of how Equation 1 may apply to other terminal-link schedules is provided by data on choice between FI and VI schedules reported by Killeen (1968). In this paper, Killeen did not report the number of entries into each terminal link, and for the present analysis E is taken to be unity. If the harmonic mean of the intervals comprising the VI schedules (as suggested by Killeen) is used to provide both R and t in Equation 1, this model accounts for 74% of the data variance. Had the number of entries to each terminal link been available, we believe this

value would be higher. In comparison, Killeen's own model accounts for 76% of the data variance. Equation 1 may therefore apply generally to the choice between VI schedules when the value of the schedules is taken as the harmonic mean of the component intervals.

Equation 1 simplifies to the matching law for concurrent schedules. When no terminal-link schedules are arranged, t_1 and t_2 become equal to each other and to the reinforcement time, and Equation 1 becomes:

$$\frac{P_1}{P_2} = \frac{E \cdot R_1}{R_2} \qquad \dots .(2)$$

In this case, R_1 and R_2 are the rates of reinforcement on the two keys arranged by the concurrent schedules. Equation 2 predicts matching between response ratios and obtained reinforcement rate ratios as found in concurrent schedule research (Herrnstein, 1970).

To summarize the present findings, these data demonstrate that previous models of concurrent chain performance do not accurately predict choice between FI schedules, but suggest a new model that is consistent with results of previous research on the choice between interval schedules and also with the results of concurrent schedule research. In conclusion, we look forward to modifications of Equation 1 to give even more accurate prediction of preference ratios and to extend it to other initial- and terminal-link schedules.

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