THE EFFECTS OF DIFFERENT COMPONENT RESPONSE REQUIREMENTS IN MULTIPLE AND CONCURRENT SCHEDULES

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Six pigeons were trained on multiple and concurrent schedules. The reinforcement rates were varied systematically (a) when lever pressing was required in one component and key pecking in the successive component; (b) when lever pressing was required in both multiple components; (c) when key pecking was required in both multiple components; and (d) when key pecking was required on one schedule and lever pressing was required on the concurrently-available schedule. Only the absolute level of responding was changed by different response requirements. Analyzed by the generalized matching law, performance under different response requirements resulted in a bias toward key pecking, and the measured response bias was the same in multiple and concurrent schedule arrangements. The bias in time measures obtained from concurrent schedule performance was reliably smaller than the obtained response biases. The sensitivity to reinforcement-rate changes was ordered: concurrent key-lever; multiple key-key; multiple lever-key; and, the least sensitive, multiple lever-lever. The results confirm that requirements of different topographical responses can be handled by the generalized matching law mainly in the bias parameter, but problems for this type of analysis may be caused by the changing sensitivity to reinforcement in multiple schedule performance as response requirements are changed.

Key words: multiple schedules, concurrent schedules, bias, contrast, lever pressing, key pecking, pigeons

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Beautrais and Davison (1977) investigated performance on concurrent schedules when different responses were required on each schedule. The responses they used were not topographically different, but comprised different fixed-ratio requirements reinforced on variable-interval (VI) schedules. They found that when the data were analyzed using the generalized matching law (Baum, 1974), performance was biased toward the smaller requirement in response-completion measures (but toward the larger requirement in time-allocation measures). Beautrais and Davison suggested that these results might also apply to topographically different response requirements. The present experiments were designed to investigate this possibility and to extend systematically the quantitative study of topo-graphically different operants to multiple VI VI schedules.

The experiment was composed of four parts, and in each part, the component reinforcement rates were varied over five or six conditions. Part 1 investigated multiple key-peck lever-press schedules (*mult* K VI x-sec L VI y-sec). Parts 2 and 3 were controls, in which similar responses were required in each multiple schedule component. Part 2 was *mult* L VI x-sec L VI y-sec and Part 3 was *mult* K VI x-sec K VI y-sec. In Part 4, standard concurrent schedules were arranged with lever pressing required on one schedule and key pecking on the other (*conc* L VI x-sec K VI y-sec). The same animals were used throughout.

METHOD

Subjects

Six homing pigeons were maintained at $80\% \pm 15$ g of their free-feeding body weights. They were numbered 161 to 166. Bird 162 died after three conditions of Part 4, and its performance in this part is not reported.

Apparatus

The standard sound-attenuated chamber was situated remote from solid-state control equipment, and external noise was masked by an exhaust fan. The chamber contained three response keys 2 cm in diameter, 9.5 cm apart, and 22.5 cm from the grid floor. Only the outer two keys were used in this experiment, and responses to them exceeding about 0.1 N when illuminated were counted and were followed by a relay click and a brief offset of the keylight. Below the left key, 6 cm from the floor, and projecting 6 cm, was a T-shaped lever. Depressions of this lever exceeding about 0.6 N were counted when the lever was illuminated and were followed by a relay click and a brief offset of the lever light. Lever illumination was provided by a 5-W bulb attached to the underside of an 8-cm square shield situated 8 cm above the lever. The shield was designed to make lever pecking unlikely. The arrangement of the lever is sketched in Figure 1. The food magazine, containing wheat, was situated below the center key 10 cm from the floor. During reinforcement, the tray was raised and the magazine illuminated for 3 sec; all other lights in the chamber were extinguished.

Procedure

After being food deprived, the birds were first trained to eat from the magazine, and then trained to press the lever with one foot by successive approximations to the required response, in a manner similar to that reported by Westbrook (1973). When the response was occurring reliably, training was arranged on a VI 5-sec schedule for five sessions, then a VI 15-sec schedule for five sessions, and then on a VI 30-sec schedule for five sessions. At this point, the birds were trained by successive approximation to peck the right key, illuminated white. When key pecking was occurring reliably, the first part of the experiment began.

Sessions were conducted seven days a week and ended in blackout when 24, 2-min alternating multiple schedule components had been presented, or in Part 4, when 50 reinforcements had been obtained. The birds were trained on a particular schedule combination until all birds had met a defined stability criterion five (not necessarily consecutive) times. The criterion was that the median relative
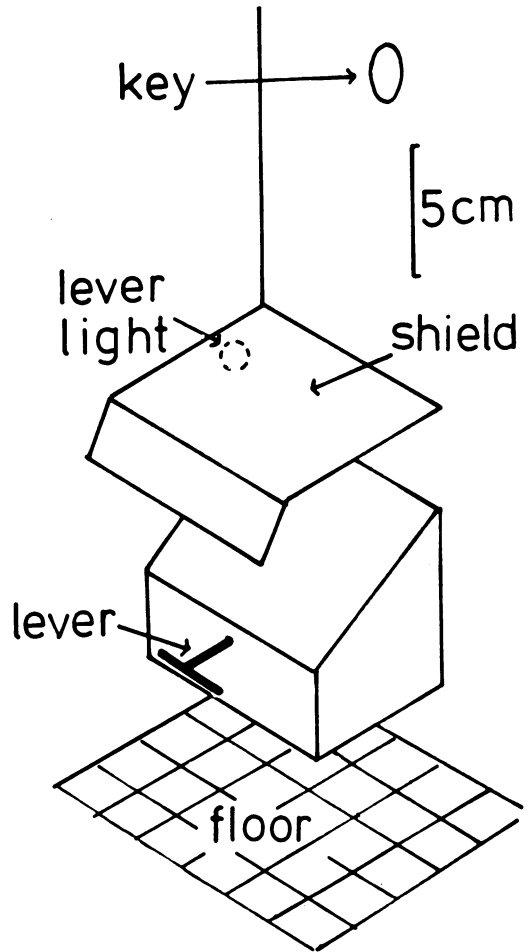

Fig. 1. Sketch of arrangement of lever.

number of responses to the two components or schedules over five sessions did not differ by more than 0.05 from the median of the five sessions preceding these. The sequence of experimental conditions, and the number of sessions training given on each, are shown in Table 1.

The VI schedules were composed of 12 randomized intervals taken from an arithmetic progression, with the shortest interval one twelfth the average interval.

Supplementary feed of mixed grain was given immediately after each experimental session to maintain body weights.

The sequence of experimental conditions is shown in Table 1. In Part 1, the key-pecking component was signalled by the right key being white with the lever light extinguished, and the lever press component by the lever light being on and the keylight off. In Part 2,

Table 1

Sequence of experimental conditions and numbers of sessions training given in each condition. All times are in seconds:

Condition	Schedule 1	Schedule 2	Sessions
Part 1: Multiple key-lever			
1.	VI 120	VI 30	38
2.	VI 60	VI 120	27
3.	VI 300	VI 30	24
4.	VI 30	VI 300	19
5.	VI 120	VI 30	19
6.	VI 30	VI 60	23
Part 2: Multiple lever-lever			
7.	VI 60	VI 30	21
8.	VI 60	VI 120	20
9.	VI 300	VI 30	34
10.	VI 30	VI 300	33
11.	VI 120	VI 30	20
12.	VI 30	VI 60	23
Part 3: Multiple key-key			
13.	VI 60	VI 30	24
14.	VI 60	VI 120	21
15.	VI 300	VI 30	19
16.	VI 30	VI 300	30
17.	VI 120	VI 30	25
18.	VI 30	VI 60	21
Part 4: Concurrent lever-key			
19.	VI 60	VI 60	32
20.	VI 30	VI 120	36
21.	VI 120	VI 30	26
22.	VI 30	VI 60	22
23.	VI 60	VI 30	17

the components of the lever-press schedules were signalled by green and red stimuli presented on the key directly above the lever, and the lever was continuously illuminated. In Part 3, the right key was illuminated green or red in the components, and responding on the key produced reinforcement. In all these parts of the experiment, out-of-order responding was also measured. In Part 1, this consisted of emitting lever presses when the keylight was on, or emitting key pecks when the lever light was on. In Part 2, this measure was any key pecking emitted, and in Part 3 it was any lever press emitted. In Part 4, the right key was always illuminated white, and the lever light was always on. In all parts, the number of responses emitted in the components or on the schedules and the number of reinforcements obtained were measured. Additionally, in Part 4, the time spent responding on both schedules was measured. Time allocation to a schedule commenced with a response to that schedule and ended with a response to the alternate schedule.

The multiple schedules alternated every 2 min and the availability of reinforcement was controlled by two independent tapes that ran only during the appropriate component. Reinforcements arranged, but not obtained, in any component again became available when that component recommenced. In Part 4, the concurrent schedules were arranged using the Stubbs and Pliskoff (1969) procedure, in which a reinforcement arranged on one schedule stopped both VI tapes until that reinforcement had been taken. A changeover delay (Herrnstein, 1961) of 2 sec arranged that a reinforcement on one schedule could not be obtained until the bird had been responding on that key for 2 sec.

Between Parts 3 and 4, all the birds' performances were reestablished on a multiple key-peck lever-press schedule so that videotapes could be obtained.

RESULTS

The number of responses emitted and reinforcements obtained, and in Part 4, the time spent responding, are shown in Table 2 averaged over the last five sessions of each condition. All birds maintained the appropriate lever-press response throughout Parts 1 and 2. However, during our training for video recording, and subsequently in Part 4, Bird 164 developed the behavior of pecking at the light beneath the lever shield, and operating the lever with its neck.

Figure 2 shows the number of responses per minute in each of the last five sessions of each condition for Bird 161. The major trends in this bird's data were typical of all birds (Table 2). The multiple schedule response rates are the number of responses per minute in each component and the concurrent schedule response rates are the number of responses on a schedule divided by total session time. The data are shown as a function of the relative rate of reinforcement obtained in the first schedule or component. In the multiple key-lever schedules, the rates of key pecking were always greater than the rates of lever pressing, except when the relative reinforcement rate for key pecking was very low. The same difference in general rates can be seen by comparing the multiple lever-lever conditions with the multiple key-key conditions (Parts 2 and 3) and in the concurrent lever-key conditions

(Part 4). In all parts of the experiment and for each response, increasing the relative reinforcement rate in one component or one schedule increased the response rate in that component and decreased the response rate in the other component or schedule ($p < 0.05$, trend test, Ferguson, 1966). However, because of the generally low rate of responding on the lever, absolute changes in the rate of lever pressing were hard to see. For example, for the multiple key-lever performance, shown in Figure 2, changing from equal schedules to reinforcement exclusively for lever pressing would, by interpolation and extrapolation, change the lever response rate from eight per minute to perhaps 11 per minute only. At the same time, the rate of key pecking would fall from about 40 per minute to about zero.

It appears from Figure 2 that the rate of lever pressing emitted when the alternated

Table 2

Number of responses emitted and reinforcements obtained averaged over the last five sessions of each condition. In Parts 1 to 3, multiple schedules were arranged with 24 min per component per session. In Part 4, concurrent schedules were arranged, and the time spent in each schedule is shown in minutes.

Part 1. Multiple key-lever schedules
(*L in K* refers to lever responses in the key component, and *K in L* to key responses in the lever component.)

Condition	Bird	Responses		Reinforcements		Responses	
		Key	*Lever*	*Key*	*Lever*	*K in L*	*L in K*
1	161	632	260	12.4	37.2	1	19
	162	601	205	13	34.2	1	2
	163	339	421	12.8	40.2	1	82
	164	943	208	12.8	35.4	3	58
	165	1438	283	13	37.6	2	5
	166	530	142	14	32.8	1	2
2	161	587	130	22.4	11.0	1	7
	162	588	138	23.4	11.8	2	1
	163	816	154	23.2	12	2	0
	164	1371	142	24	11.2	2	5
	165	1452	326	23.6	11.6	2	2
	166	1814	111	24	11	5	0
3	161	275	230	5	37.2	0	40
	162	440	318	5.2	36	1	4
	163	630	375	5	39.6	0	7
	164	293	177	5.4	35.8	1	26
	165	1137	209	4.8	34.6	2	12
	166	579	102	5.4	31.6	0	1
4	161	1674	98	41.4	5	3	0
	162	444	71	40.8	4	1	0
	163	1119	88	43	4	1	0
	164	2284	96	43.6	5.2	5	0
	165	1439	224	43.8	4.4	3	2
	166	1788	47	43.6	3.6	5	0
5	161	343	254	11.4	40.2	0	46
	162	395	190	12	38.2	0	2
	163	528	296	12	43.4	0	6
	164	838	147	12.2	37.8	2	10
	165	1684	374	12	44.2	1	20
	166	1419	101	12	34.8	2	1
6	161	1140	237	41.8	21	1	0
	162	555	49	43.6	14	10	0
	163	572	252	41	21.4	1	1
	164	1281	133	43.4	20.6	4	0
	165	2247	412	44.6	22.4	4	4
	166	1746	65	44.6	16.6	5	0

Part 2. Multiple lever-lever schedules

Condition	Bird	Lever Presses		Reinforcements		Pecks	
		Green	Red	Green	Red	Green	Red
7	161	193	212	20.6	34.6	0	0
	162	189	209	19.8	36.6	0	0
	163	311	338	21.8	40	0	0
	164	116	120	19.4	32.6	1	4
	165	388	375	22	39.2	0	0
	166	26	25	11.2	12.2	0	2
8	161	251	165	21	11	1	0
	162	223	192	20.4	11	26	6
	163	440	366	22.4	11.8	0	0
	164	123	116	19.4	11.4	0	1
	165	292	309	20.4	10.8	2	2
	166	39	45	13	8.6	2	1
9	161	98	344	4.4	35.6	1	2
	162	57	193	2.2	34.6	1	23
	163	141	317	3.2	38.8	2	0
	164	72	179	4.6	32.8	3	2
	165	274	303	3	34.8	4	0
	166	74	200	3.6	36	1	0
10	161	396	92	38.2	4.2	3	6
	162	164	53	32.8	3.2	25	3
	163	325	209	38	4.4	0	0
	164	159	124	32.4	4.4	4	8
	165	240	192	31.2	3.8	1	1
	166	214	66	35.4	3.8	8	2
11	161	163	281	10.6	40.8	2	3
	162	89	119	8.8	35.6	2	6
	163	205	376	11	45.2	0	0
	164	112	136	10	35.4	1	0
	165	123	92	10.2	30.2	1	0
	166	106	119	10.4	34.2	1	0
12	161	353	300	39.2	21.2	2	4
	162	73	56	26.6	15	19	10
	163	256	210	39.2	20.6	0	0
	164	251	275	37.2	22.4	1	0
	165	277	227	38.8	21.2	2	1
	166	173	167	36.6	20.6	0	0

component also required lever pressing was higher than when the alternated component required key pecking, but this result was not consistent across birds (Table 2). The data in Figure 2 generally show quite small variability across the last five sessions of each condition, although there is one clear failure of replication in the multiple key-lever data. In two conditions, the relative reinforcement rate on the key was about 0.67 (*mult* K VI 60-sec L VI 120-sec and *mult* K VI 30-sec L VI 60-sec). The key-peck data in the former condition fell well below the data in the latter, although no difference in the lever-pressing rates can be seen. This result was again not consistent between birds, and we can offer no explanation. The replication of *mult* K VI 120-sec L VI

30-sec (Conditions 1 and 5) was, however, satisfactory.

The way in which responses were allocated between the key and the lever components in Part 1 is shown in Figure 3. Here, the logarithm of the ratio of the numbers of responses in the two components is shown as a function of the logarithm of the ratio of the numbers of reinforcements obtained. To show the variability, the data from each of the last five sessions on each condition are shown. While some large variability is shown in some conditions for some birds, the trend toward increasing allocation of key pecking as the reinforcement rate for key pecking increases is clear. Straight lines were fitted to the data shown by the method of least squares, and the

Part 3. Multiple key-key

Condition	Bird	Pecks		Reinforcements		Lever Presses	
		Green	Red	Green	Red	Green	Red
13	161	406	1208	22	42.4	16	0
	162	659	719	23	44.2	4	0
	163	538	1077	23.2	46.6	5	0
	164	784	1077	22	46.8	2	0
	165	2007	2702	23.6	47	0	0
	166	1197	2321	22.4	46.6	0	0
14	161	1014	622	22.2	10.6	1	11
	162	802	525	22.6	10	2	4
	163	1063	651	23	10.6	1	6
	164	1161	1091	23.2	10.8	1	6
	165	2076	1238	22.8	11	0	5
	166	1990	1270	22.8	11	0	0
15	161	509	1906	4.6	38	13	2
	162	550	1013	3.8	39.6	6	0
	163	754	1534	4.2	39.6	8	1
	164	441	1883	4.8	39.8	30	0
	165	1062	2114	3.8	38.8	12	0
	166	1985	2263	4.4	39.4	0	0
16	161	2170	294	39	4.2	2	32
	162	1117	214	40.2	5	0	2
	163	1477	589	40.2	4.6	0	15
	164	1955	565	39.8	4.6	0	8
	165	1602	1031	39.6	4.8	0	36
	166	2031	557	38.8	4.8	0	0
17	161	769	2152	11.2	44.4	20	6
	162	546	1220	11	46.4	2	0
	163	576	1196	11.4	44.6	3	0
	164	778	2191	11.4	45.4	16	0
	165	1250	2481	11.4	47	32	0
	166	1133	2323	11.6	46.8	1	0
18	161	1352	1183	40.6	22.4	19	21
	162	1023	765	41	22.6	0	1
	163	1082	884	40.2	23.6	2	1
	164	1792	1016	40.6	23.4	3	6
	165	1612	1889	41.4	23.4	0	0
	166	2189	1703	41.2	23.8	0	0

equations of these lines and the standard errors of the estimates are shown in Figure 1. All fitted lines have positive slopes and all had large positive intercepts.

Similar data for Parts 2 and 3, in which, respectively, multiple lever-press lever-press and multiple key-peck key-peck were required, are shown in Figures 4 and 5. The variability in these figures is less than in Figure 3, perhaps representing the increased amount of training. The direct relation between increasing reinforcements obtained in a component and increasing allocation of responding to that component is again evident in all birds, but in these parts of the experiment, no consistent positive intercepts to the fitted lines were found.

Figure 6 shows both the response allocation and the time allocation in the concurrent key lever part. Both response and time allocation increased with increasing reinforcement on a schedule, and all the fitted lines had negative intercepts. The response intercepts were in every case more negative than the time-allocation intercepts.

The numbers of out-of-order responses (key pecks in lever components and lever presses in key components) are shown for Parts 1 to 3 in Table 2. The numbers of such responses were generally small. In the multiple key-lever schedules, the number of out-of-order responses was greatest in the higher reinforcement-rate component in 28, and in the lower reinforcement-rate component in two of the 36 cases.

Part 4. Concurrent lever-key schedules

Condition	Bird	Responses		Time		Reinforcements	
		Lever	Key	Lever	Key	Lever	Key
19	161	554	540	15.3	12.8	25.2	24.8
	163	479	864	14.4	12.9	25.6	24.4
	164	774	1758	10.6	15.7	24.8	25.2
	165	412	2254	11.2	19.2	24.8	25.2
	166	217	2804	8.9	39.4	23	23.4
20	161	494	337	18.3	5.4	40.8	9.2
	163	434	214	18.3	4.9	40	10
	164	1232	723	15.5	6.1	39.8	10.2
	165	415	1018	13.1	11.0	39.4	10.6
	166	260	1725	7.8	31.1	39.2	10.8
21	161	130	1649	3.3	21.1	9.8	40.2
	163	118	1749	3.9	20.6	10.4	39.6
	164	513	1689	5.8	16.7	10.4	39.6
	165	113	2185	2.5	24.1	10.6	39.4
	166	63	2360	1.7	27.5	9.6	40.4
22	161	371	546	12.7	7.1	33.8	16.2
	163	270	956	10.2	11	33.8	16.2
	164	913	788	10.9	6.5	33.2	16.8
	165	273	1151	8.2	12.8	34.6	15.4
	166	166	1876	4.5	26.1	33.8	16.2
23	161	163	1781	3.6	18.8	15.8	34.2
	163	153	1791	4.8	17.2	16	34
	164	699	1340	8.0	12.2	15.8	34.2
	165	109	2641	3.6	24	16.2	33.8
	166	84	2486	2.2	27.2	16	34

It was higher in the lever component in 14 of 36 cases. In the multiple lever-lever schedules, out-of-order responding was unrelated to reinforcement rates. In the multiple key-key schedules, out-of-order responding was higher in the lower reinforcement rate component in 28, and higher in the higher reinforcement-rate component in one of 36 cases. Such responses, then, bear no consistent relation to reinforcement rates, nor, in Part 1, to the type of response required.
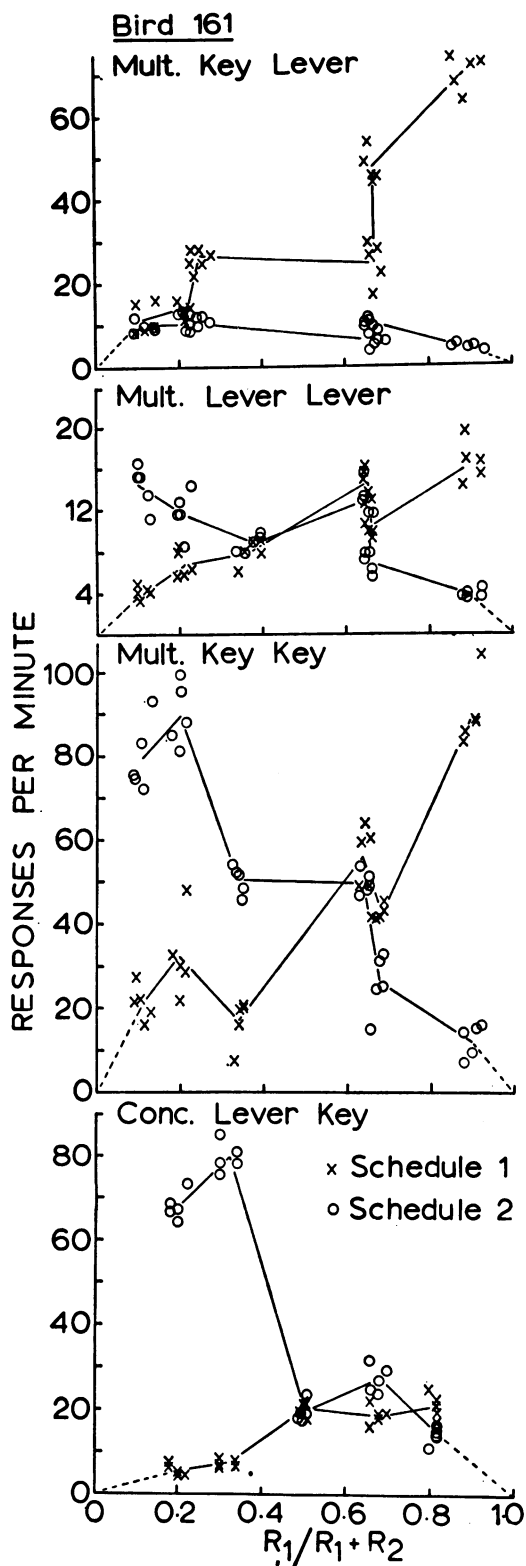
DISCUSSION

Absolute Response Rates

In both the multiple and the concurrent schedules, with both the key-peck and the lever-press responses, the absolute response rate in each component or schedule varied with the relative reinforcement rate in that component or schedule. In this respect, the lever-press data conform to the multiple and concurrent key-peck schedule results (Herrnstein, 1970), and confirm the similar conclusion reached by McSweeney (1975). One notable difference between the key-peck and the lever-press data was that in the latter case, responding occurred

at a much lower rate, and changed less than the rate of pecking when the relative reinforcement rate was changed (Figure 2). The low asymptotic rate of the lever-press response may be a parsimonious explanation for the apparent lack of behavioral contrast in the lever-press response (Hemmes, 1973; Scull and Westbrook, 1973; Westbrook, 1973). Figure 2 shows that we should expect the lever response rate to change by only a few responses a minute between equal schedules and multiple or concurrent VI Extinction schedules. McSweeney (1975) found that a transition from *conc* L VI 120-sec L VI 120-sec to *conc* L VI 120-sec L VI-240-sec produced a response-rate change in the constant component of only, on the average, 4.4 responses a minute. Since absolute response-rate changes of this size are well within both the session-to-session variation and the variation between a data point and its replication (Figure 2), detecting such changes in a single transition will be extremely difficult. McSweeney (1975), who arranged a number of transitions, showed contrast in concurrent lever-press schedules.

We conclude that the lack of contrast with the lever-press response in pigeons has not

Bird 161

Mult. Key Lever

Mult. Lever Lever

Mult. Key Key

Conc. Lever Key

× Schedule 1
○ Schedule 2

RESPONSES PER MINUTE

$R_1/R_1 + R_2$

been adequately proven, and that the detection of contrast with low-rate responses may be difficult and require procedures providing more than just two data points.

The present data on out-of-order responding do not replicate the results reported by Keller (1974). He found that if the stimulus signalling the components of a multiple schedule were displaced onto a second key, while reinforcements remained available on a first key, responding could be maintained on the stimulus key. Removing reinforcement in one component increased stimulus-key responding in the other component. In the present experiment, we might therefore generally expect that out-of-order pecking in the multiple lever-lever schedules would be greater on the higher reinforcement-rate schedule. No such effect was found. Out-of-order responding was positively related to component reinforcement rate in the multiple key-lever schedules, but this result is inconsistent with Keller's (1974) explanation of his results in terms of *pecking* elicited by food reinforcement. It remains possible that Keller's result occurs only when one component reinforcement rate is extinction.

Preference

The generalized matching law relates the ratio of response rates in two multiple or concurrent schedule components to the ratio of reinforcements obtained in the two components by:

$$\frac{P_1}{P_2} = c \left\{\frac{R_1}{R_2}\right\}^a ,$$

and when logarithms are taken of both sides of this equation, a straight line results with a slope of a and an intercept of log c. Such lines are shown in Figures 2 to 5. For both multiple and concurrent schedules, c (the bias) is usually 1.0. In multiple schedule performance, a (the sensitivity of behavior to reinforcement changes) is usually about 0.3 to 0.4 (Barron and Davison, 1972; Lobb and Davison, 1977; Lander and Irwin, 1968). For concurrent schedules, a is usually found to be be-

Fig. 2. The number of responses per minute emitted in each condition of the experiment as a function of the relative rate of reinforcement on the first schedule. The data are each of the last five sessions of each condition for Bird 161. Broken lines connect obtained data to assumed zero points.
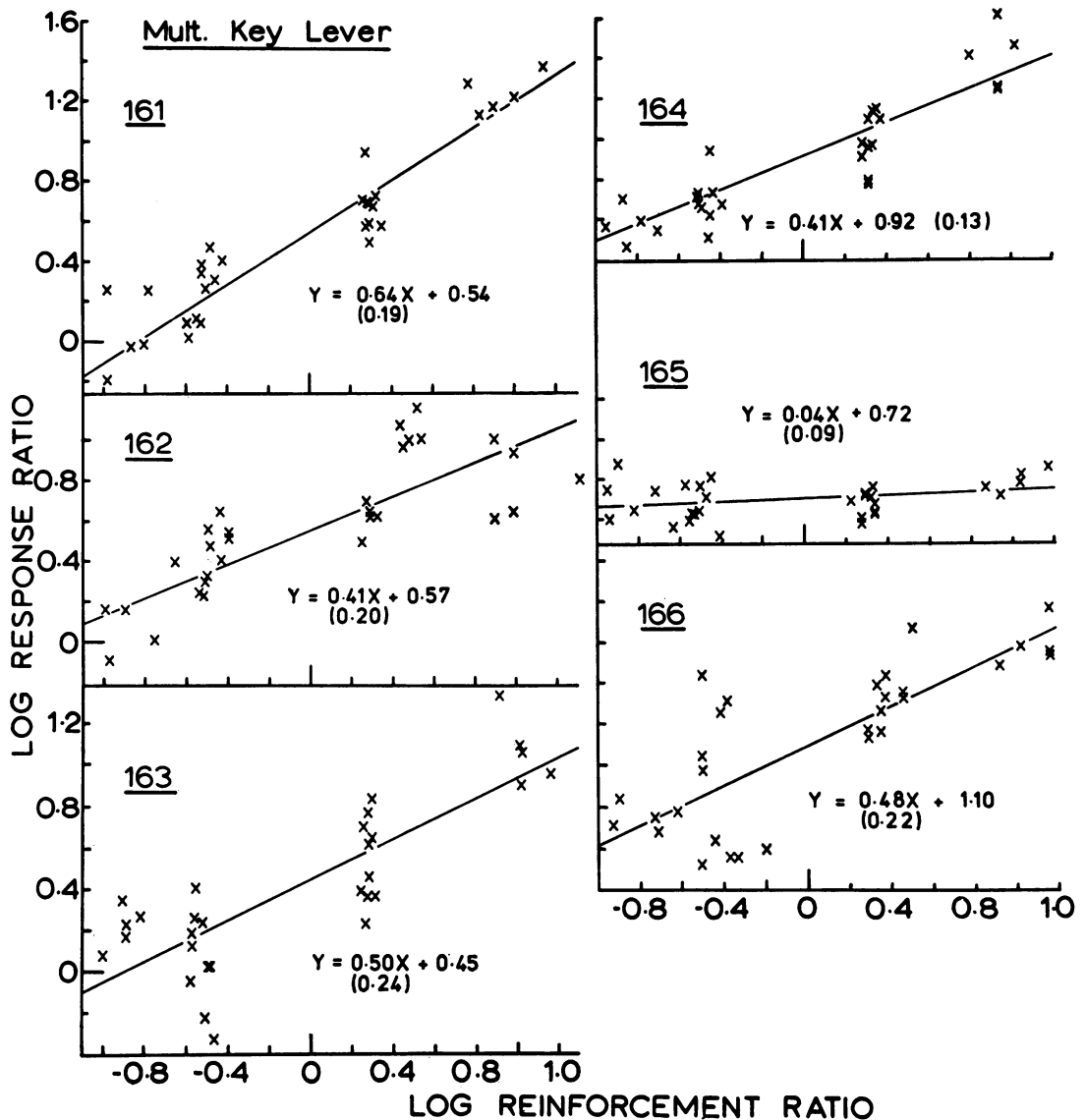
Fig. 3. Performance on multiple key-lever schedules for each bird. The logarithm of the ratio of responses in the two components is shown as a function of the logarithm of the ratio of reinforcements obtained in the components. The data are each of the last five sessions each condition. The equations of the fitted line by the method of least squares and the standard error of the estimate is shown for each bird.

tween 0.8 and 1.0 (Baum, 1974; Lobb and Davison, 1975; Myers and Myers, 1977). The present results are generally in accord with these previous results: the sensitivity measures for the multiple schedule performances average 0.43 (Figures 2 to 4), for the concurrent schedule responding they average 0.87, and for the time allocation, 0.87. For every bird in every comparison between multiple and concurrent schedule response sensitivities, the concurrent sensitivity was greater. While the

multiple schedule sensitivity measures appear to be similar whatever responses were required in the components, a further analysis of the slopes across Parts 1 to 3, using a Friedman analysis of variance by ranks (Siegel, 1956), shows a significant effect at beyond $p = 0.05$. The sensitivities were least in the multiple lever-lever conditions, and greatest in the multiple key-key conditions with the multiple key-lever conditions intermediate. The suggestion is, therefore, that some responses may be
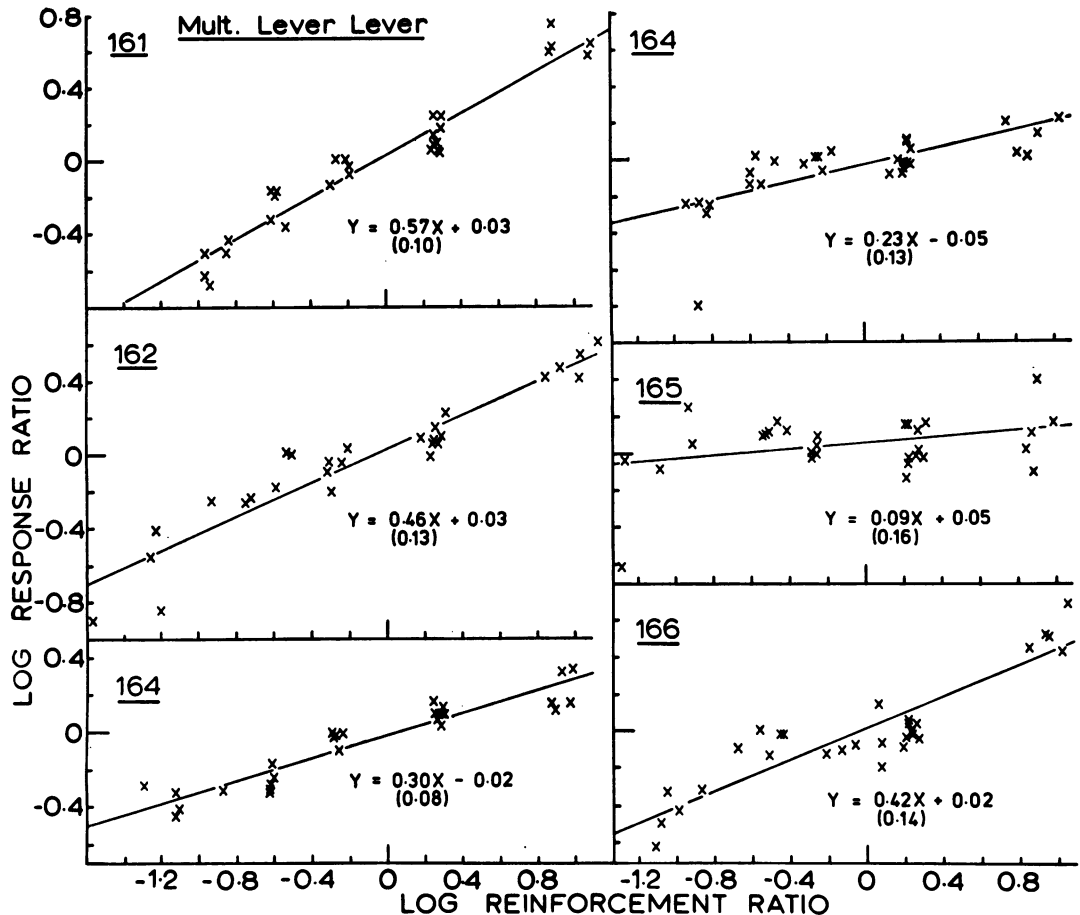
Fig. 4. Performance on multiple lever-lever schedules for each bird. The logarithm of the ratio of responses in the two components is shown as a function of the logarithm of the ratio of reinforcements obtained in the components. The data are each of the last five sessions of each condition. The equations of the tilted line by the method of least squares and the standard error of the estimate is shown for each bird.

more sensitive to reinforcement than others. An alternative explanation could be that the discriminability (Baum, 1974) of the components differed, the least discriminable case being when the component stimuli were presented on the keys in the multiple lever-lever conditions. The former explanation is supported by the similar results reported by Beautrais and Davison (1977) for topographically similar, but numerically different, responses.

In the multiple schedules, the bias term of the generalized matching law relation was close to one (*i.e.*, a logarithmic intercept of zero) when the required responses were the same in each component (Figures 4 and 5). But when the required response was different (Figure 3), a strong bias toward the key re-

sponse resulted. This bias averaged 0.72 in log terms (a ratio of 5.21) toward the response that required less force, and the value of the bias presumably relates to the inverse ratio of forces, 6.0. It is possible, then, that response allocation in multiple schedules might undermatch (a sensitivity of less than one) the inverse ratio of force requirements. Similarly, Beautrais and Davison (1977) showed undermatching in a concurrent schedule to the inverse of the required number of responses in a second-order fixed-ratio component.

It deserves to be noted that the various biases produced by similar and different responses in the multiple schedules did not relate to the values of the sensitivity of behavior to reinforcement ratios. Sensitivity changes were found to be correlated with bias changes
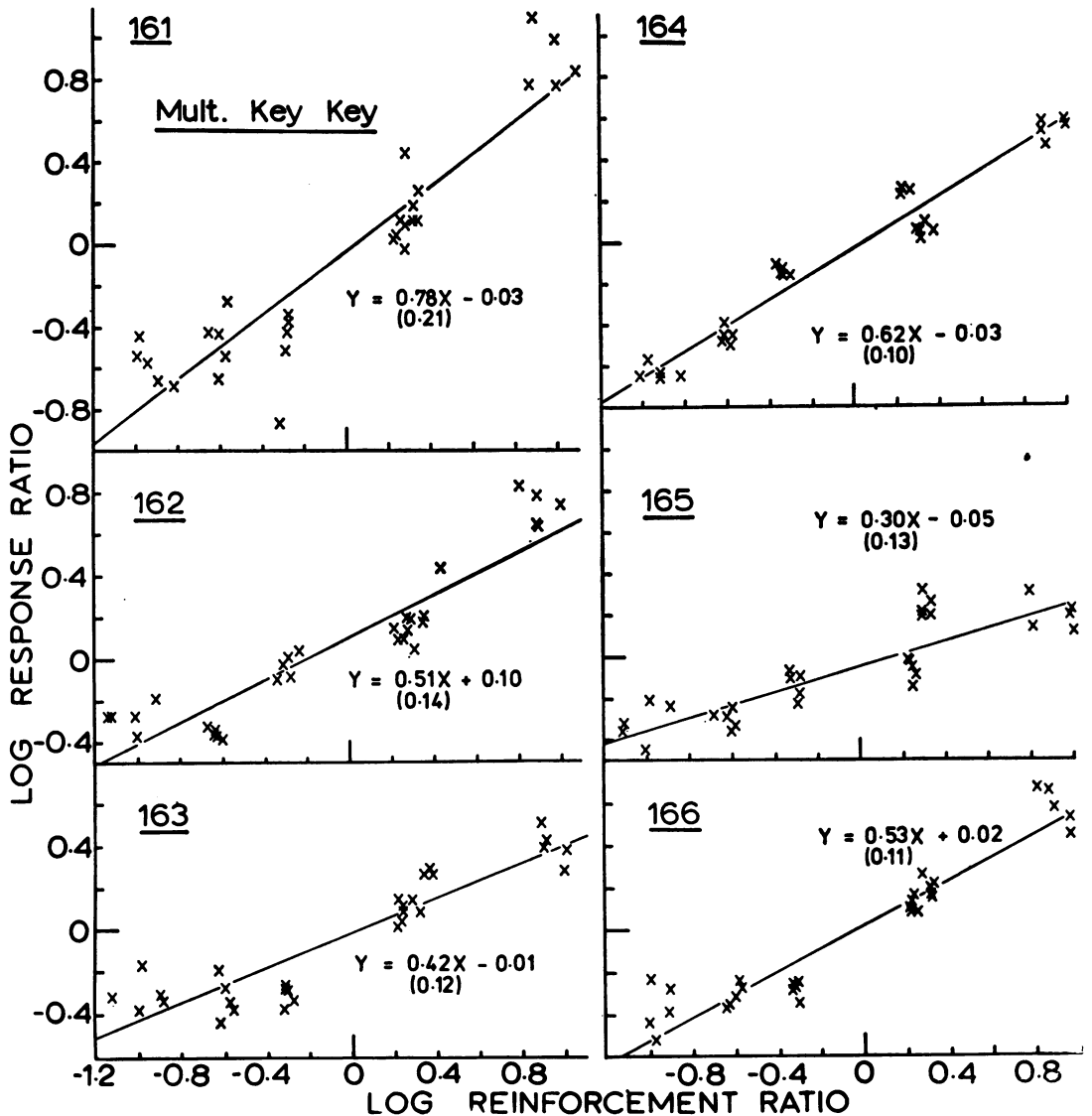
Fig. 5. Performance on multiple key-key schedules for each bird. The logarithm of the ratio of responses in the two components is shown as a function of the logarithm of the ratio of reinforcements obtained in the components. The data are each of the last five sessions of each condition. The equations of the fitted lines by the method of least squares and the standard error of the estimate is shown for each bird.

by Davison (1976), but the present result shows the two not to be associated.

Response and time allocation in the concurrent schedules follow the usual pattern (Baum, 1974), with some small differences. Using sign tests, the slopes of the response and time measures were not significantly different (often, response sensitivities have been found to be smaller than time sensitivities). Again using sign tests, significant undermatching is not present in either measure. Because

of the different required responses, both measures show a large intercept (negative here as the numerator is lever responding). However, the intercepts for response measures were significantly greater by a sign test (p < 0.05) than the intercepts for time measures. Beautrais and Davison (1977), in a similar situation, found that increasing a response requirement decreased the number of times that response was completed, but increased the time allocated to that response. In their situation, the
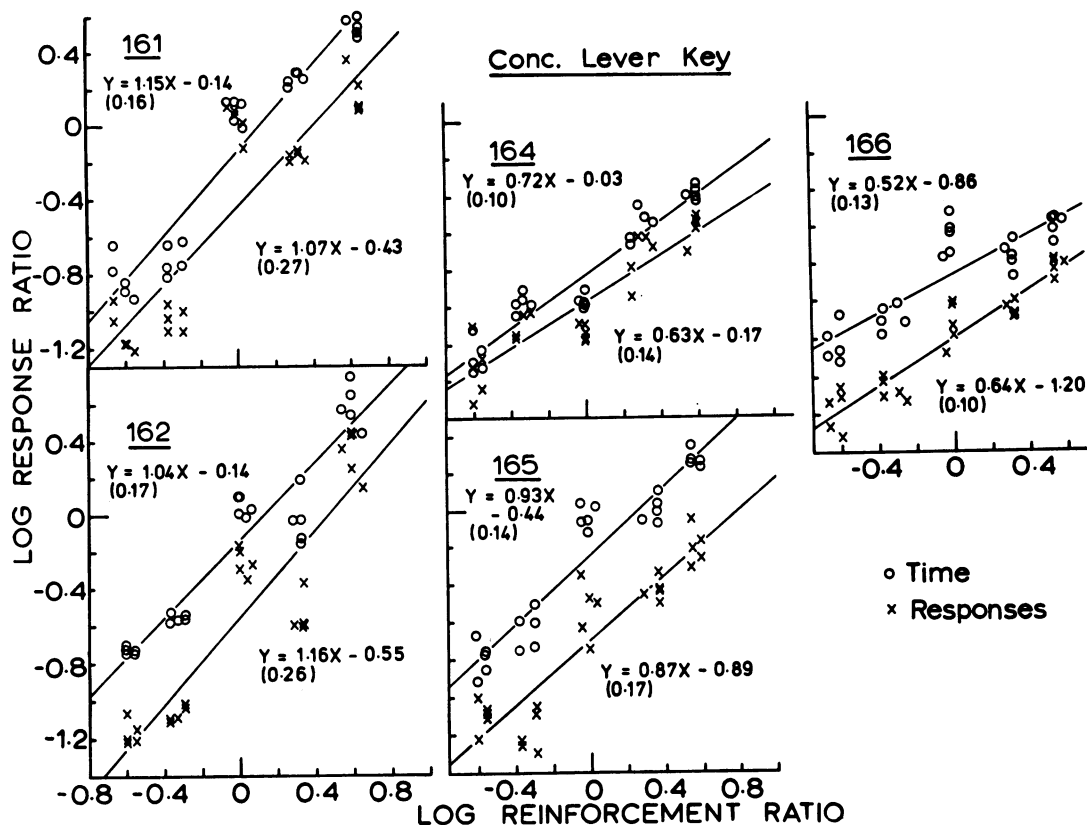
Fig. 6. Performance on concurrent lever-key schedules for each bird. The logarithm of the ratio of responses emitted and time allocated to each schedule is shown as a function of the logarithm of the ratio of reinforcements obtained on the schedules. The data are each of the last five sessions of each condition. The equations of the fitted lines by the method of least squares and the standard error of the estimate is shown for each bird.

increased requirement did necessarily take more time to complete. In the present experiment, a lever press did not take more time than a key peck, but still a similar effect was found, in that response measures showed a greater bias than time measures. Further, the size of the biases measured in the multiple key-lever and in the concurrent lever-key conditions were not significantly different (sign test) on response measures. But the multiple key-lever response measures of bias were significantly different in absolute value from the concurrent lever-key time measures of bias. These results therefore support Beautrais and Davison's (1977) preference for response measures of choice over time measures.

In conclusion, different component responses produced a bias, apparently toward the response requiring least effort (although effort and topography are confounded), and the bias measured in response terms is the same, whether observed in multiple or concurrent schedules. The present results generally conform well to the generalized matching law (Baum, 1974). However, the finding that biases caused by different responses in concurrent schedules are different when measured by response or time allocation, and more particularly the possibility that sensitivity to reinforcement is related to response requirement, may cause difficulties for the generalized matching law.

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