TEMPORAL PROXIMITY AND REINFORCEMENT SENSITIVITY IN MULTIPLE SCHEDULES

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Distributions of reinforcers between two components of multiple variable-interval schedules were varied over a number of conditions. Sensitivity to reinforcement, measured by the exponent of the power function relating ratios of responses in the two components to ratios of reinforcers obtained in the components, did not differ between conditions with 15-s or 60-s component durations. The failure to demonstrate the "short-component effect," where sensitivity is high for short components, was consistent with reanalysis of previous data. With 60-s components, sensitivity to reinforcement decreased systematically with time since component alternation, and was higher in the first 15-s subinterval of the 60-s component than for the component whose total duration was 15 s. Varying component duration and sampling behavior at different times since component transition may not be equivalent ways of examining the effects of average temporal distance between components.

Key words: short-component effect, component duration, sensitivity to reinforcement, generalized matching law, multiple schedules, variable-interval schedules, key peck, pigeon

One of the main assumptions of Herrnstein's (1970) analysis of performance in multiple schedules is that reinforcers produced by behavior occurring at one time can influence behavior occurring at another time (McLean & White, 1983). Further, the extent of that influence is said to weaken with greater temporal distance. Accordingly, interactions between successively presented components of multiple schedules are enhanced by temporal proximity between the components. Shimp and Wheatley (1971) tested this prediction by examining the effect of component duration on the extent to which the distribution of responses between components matched the distribution of reinforcers; making components shorter is equivalent to shortening the average time between components. Their conclusion was that short component durations (around 5 s) resulted in matching of response and reinforcer distributions, in contrast to the

more usual finding of substantial undermatching with long components.

More recently, Shimp and Wheatley's (1971) "short-component effect" has been challenged by Charman and Davison (1982). Nevertheless, the plausibility of the short-component effect is strengthened by the result of an alternative means of examining average temporal separation of components. By recording responses during successive subintervals within components, it is possible to sample behavior at different temporal distances from the previous component (Menlove, 1975). McLean and White (1981) did this and found progressively greater undermatching of response distributions with respect to reinforcer distributions as the component progressed. Undermatching was quantified by the exponent a in the power function relating ratios of responses in two components (P_1 , P_2) to ratios of reinforcers obtained in the two components (R_1 , R_2):

$$P_1/P_2 = c(R_1/R_2)^a. \quad (1)$$

In Equation 1, a measures the sensitivity of

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response ratios to changes in reinforcer ratios. Greater undermatching is represented by progressively smaller values for a , compared to $a = 1$ for perfect matching. The advantage of Equation 1 in quantifying multiple-schedule performance is that sensitivity can be measured independently of a constant bias or preference (given by c) that might exist between components.

In McLean and White's (1981) study, a decreased from about 0.8 at the beginning of 90-s components to about 0.3 towards the end of components (also see White, Pipe, & McLean, 1984, for a similar result). McLean and White's result appears consistent with the short-component effect in that short components may sample the strong response differentials that otherwise occur at the beginning of long components (McSweeney, 1982; Menlove, 1975). That is, the value for a should be about the same for a short 15-s component as for the first 15 s of a longer component. In the present experiment, we compared sensitivity of responding to reinforcement rates in multiple schedules with short 15-s components to the sensitivity of responding in the first 15 s of longer (60-s) components.

METHOD

Subjects

Five adult homing pigeons were maintained at 80% of their free-feeding weights. Birds R1, R2, R3, and R5 had previous exposure to multiple schedules and R4 had been trained in delayed matching to sample. Grit and water were available in the living cages and supplementary feeding ensured maintenance of the prescribed weights. Daily sessions were conducted for each bird unless its weight was outside $\pm 5\%$ of the prescribed weight.

Apparatus

A light-proof, sound-attenuating experimental chamber with internal dimensions of 32 by 34 by 36 cm contained an interface panel with a central 2.5-cm diameter response key, 25 cm from the grid floor, and also a second response key that remained unlit and inoperative. There was no houselight. The

center response key could be illuminated green, red, or white except during reinforcement. A force of 0.15 N was sufficient to operate the key and each response was followed by 0.04-s offset of the keylight. A central hopper opening allowed 2.5-s access to wheat, during which the hopper was illuminated. Experimental events were controlled and recorded by solid-state apparatus located in an adjacent room.

Procedure

All birds were introduced to the first experimental condition in the first session. In each session, red and green alternated in strict succession on the center key. In the presence of green, responses were reinforced according to one variable-interval (VI) schedule, and in the presence of red, responses were reinforced according to another, independent, VI schedule. Schedules were constructed from a constant-probability progression with 12 intervals. Reinforcers set up in a component but not obtained by the end of the component were held over until the next presentation of the same component. The values of VI schedules in the green and red components were varied over conditions. In one set of seven conditions, component duration was 15 s, and 96 green components alternated with 96 red components in each session, giving a total session duration of 48 min. In a second set of seven conditions, component duration was 60 s, and 24 green components alternated with 24 red components in each session. Responses were recorded in successive 15-s subintervals of the 60-s components.

Table 1 gives the nominal values of the VI schedules used in the different conditions, the order in which the conditions were conducted, and the number of sessions required by each bird for performance in each condition to become stable. Conditions 1 to 5 with the 60-s component duration were conducted as part of a study reported by Redman and White (*in press*). These conditions were followed by Conditions 8 to 14 in which component duration was 15 s. Then a further two conditions (Conditions 6 and 7) were conducted with the 60-s component duration to check the repli-

Table 1

Values (seconds) for multiple VI VI schedules with 60-s or 15-s component durations, order in which conditions were conducted, and number of sessions required by each bird (R1 to R5) to satisfy the stability criterion.

Condition				Order	Sessions				
					R1	R2	R3	R4	R5
60-s components									
1.	VI 240	VI 48	5	25	24	20	26	21	
2.	VI 120	VI 60	1	20	24	27	20	30	
3.	VI 80	VI 80	2	37	43	45	45	37	
4.	VI 60	VI 120	3	20	23	23	22	20	
5.	VI 48	VI 240	4	20	26	31	20	31	
6.	VI 240	VI 48	14	30	31	28	29	33	
7.	VI 48	VI 240	13	20	34	20	22	20	
15-s components									
8.	VI 240	VI 48	7	24	23	24	23	23	
9.	VI 240	VI 48	12	31	20	30	30	28	
10.	VI 120	VI 60	9	29	20	21	23	28	
11.	VI 80	VI 80	10	20	28	25	29	29	
12.	VI 60	VI 120	8	21	22	23	21	23	
13.	VI 48	VI 240	6	24	24	20	20	24	
14.	VI 48	VI 240	11	23	24	27	37	35	

cability of the earlier data. Overall, both sets of conditions included replications of the extreme reinforcer differentials. The stability criterion was that each condition should be conducted for at least 20 sessions and until the stage where, in each of five consecutive sessions, responses in the richer component as a proportion of total responses did not exceed $\pm 5\%$ of the mean response proportion for the five sessions.

RESULTS

Analyses for individual birds were based on the total response frequencies in each of the 15-s subintervals of 60-s components or in the 15-s component and also on total reinforcer frequencies obtained in each component. All data were summed over the last five sessions for each condition; these data represented stable performance, and are given in Tables 2 and 3. For both component durations, increasing reinforcer rate in one component produced a concomitant increase in response rate in that component, while reducing reinforcement rate in the alternated component reduced its response rate. There were no obvious differences between the patterns of responding for the two component durations.

The "short-component effect" is reflected in a larger value for sensitivity to reinforcement (a in Equation 1) for short components compared to longer components. To examine whether there was a short-component effect in the present data, logarithms of ratios of responses in Components 1 and 2 were plotted as functions of logarithms of ratios of reinforcers obtained in the two components. The logarithmic transformation of Equation 1 is a linear function with a slope of a and y -intercept of $\log c$. That is,

$$\log(P1/P2) = a \log(R1/R2) + \log c. \quad (2)$$

Figure 1 shows separate log ratio functions for the two sets of seven multiple VI VI conditions, one for the 60-s component duration and the other for the 15-s component duration. Straight lines were fitted to these data by the method of least squares, according to Equation 2. Values for a , $\log c$, and the standard error of the estimate for the best fitting lines are given in Figure 1. The values for standard errors (se) were generally very small, indicating excellent fits of Equation 2 to the data.

Figure 1 shows no evidence for the short-component effect. That is, values for sensitivity to reinforcement (a) were not reliably different for the two component durations. Aver-

Table 2

Response frequencies in successive 15-s subintervals and reinforcer frequencies in each component summed over the last 5 days of each condition for multiple VI VI schedules with 60-s components.

Condition	Component 1 Responses				Component 2 Responses				Reinforcers	
	1	2	3	4	1	2	3	4	Comp 1	Comp 2
<i>Bird R1</i>										
1.	1057	1318	1444	1406	1797	1822	1747	1805	28	119
2.	1162	1170	1175	1219	1668	1608	1618	1599	59	103
3.	1756	1473	1494	1568	1516	1538	1468	1457	82	74
4.	1688	1428	1386	1435	1017	1155	1205	1221	124	51
5.	1596	1561	1519	1547	822	1185	1196	1221	115	33
6.	959	1020	1122	1076	1284	1228	1237	1224	27	116
7.	1753	1729	1712	1687	928	1386	1450	1533	115	30
<i>Bird R2</i>										
1.	799	1549	1990	2083	1943	1854	1964	2116	25	117
2.	1934	1935	1869	1986	2018	2194	2363	2428	55	108
3.	1881	2163	2218	2392	1557	2033	2231	2266	92	72
4.	1892	2253	2313	2457	1197	1523	1717	1767	119	53
5.	2368	2580	2598	2747	989	1131	1421	1675	115	27
6.	702	1126	1571	1751	1434	1655	1821	1913	23	119
7.	2704	2730	2777	2810	743	992	1385	1566	115	19
<i>Bird R3</i>										
1.	1063	1326	1509	1543	2177	1906	1975	2026	24	120
2.	1594	1680	1671	1693	2206	1852	1932	1980	56	98
3.	2283	2352	2425	2519	2273	2257	2274	2319	88	71
4.	3011	2653	2465	2432	1277	1645	1779	2032	117	49
5.	2763	2571	2185	2106	983	1104	1208	1212	115	31
6.	661	1151	1333	1281	1866	1710	1698	1740	22	119
7.	1921	1737	1579	1486	825	1020	1026	1098	115	28
<i>Bird R4</i>										
1.	493	466	489	491	1109	1130	1126	1140	26	119
2.	1232	1190	1226	1155	1638	1754	1691	1693	55	103
3.	1456	1374	1461	1438	1056	1129	1139	1130	87	78
4.	1229	1228	1302	1320	764	910	831	834	116	51
5.	1501	1673	1406	1362	586	534	512	494	115	35
6.	434	564	644	610	609	775	882	885	31	118
7.	1267	1423	1288	1222	592	665	689	721	115	25
<i>Bird R5</i>										
1.	783	1094	1400	1474	2052	1858	1990	2116	23	117
2.	1786	2060	2182	2032	2763	2531	2692	2688	50	103
3.	2156	2405	2538	2411	1797	2300	2390	2355	84	73
4.	2090	2110	1834	2039	1165	1688	1757	1762	115	48
5.	1878	1876	1903	1962	1176	1371	1619	1577	115	33
6.	783	1081	1310	1329	1425	1080	1174	1432	24	117
7.	2097	2376	2283	2231	692	740	965	974	115	27

aged over birds, the mean *a* for 60-s components was 0.344, and that for 15-s components was 0.350.

In the above analysis, *a* was estimated for responding over the entire component. Does *a* change over the course of the longer compo-

nent? To answer this question, responses were recorded in successive 15-s subintervals of the 60-s components. Logarithms of ratios of responses in each subinterval of the two components are plotted in Figure 2 as functions of logarithms of ratios of reinforcers obtained in

Table 3

Response and reinforcer frequencies in Components 1 and 2 for multiple VI VI schedules with 15-s component durations, summed over the last 5 days of each condition.

Condition	Responses		Reinforcers	
	Comp 1	Comp 2	Comp 1	Comp 2
<i>Bird R1</i>				
8.	6512	7207	22	118
9.	5209	10183	23	119
10.	5594	6034	53	118
11.	5564	5756	76	73
12.	6565	5368	106	54
13.	7534	4304	115	27
14.	9806	4376	114	27
<i>Bird R2</i>				
8.	6935	9302	22	117
9.	7728	7157	22	119
10.	9339	8363	55	113
11.	9162	8044	75	74
12.	9843	6894	105	51
13.	12969	4330	115	29
14.	11669	6099	115	28
<i>Bird R3</i>				
8.	7087	9872	22	117
9.	5943	8194	22	119
10.	8550	8805	55	111
11.	6737	7305	75	80
12.	9121	6762	110	54
13.	12195	6369	115	28
14.	9891	5284	115	26
<i>Bird R4</i>				
8.	3382	4926	22	119
9.	3140	4172	26	117
10.	4740	4166	55	101
11.	4414	3309	73	69
12.	6918	3179	111	50
13.	6785	2515	115	29
14.	5665	2622	115	36
<i>Bird R5</i>				
8.	6820	9931	23	119
9.	5303	9950	22	118
10.	7969	10482	54	132
11.	9215	8589	74	82
12.	9716	7254	114	50
13.	9676	4728	115	26
14.	11649	4683	115	22

the components. Given in Figure 2 are the values of a , $\log c$, and the standard error of the estimate given by the straight lines that best fitted these data according to Equation 2. Again, low standard errors indicated that these data were satisfactorily described in Equation 2. With the exception of Bird R4,

Fig. 1. Logarithms (base 10) of ratios of responses as a function of logarithms of ratios of reinforcers in 60-s components (left panel) or 15-s components (right panel), shown separately for 5 individual birds. Values for sensitivity (a), bias ($\log c$), and the standard error of the estimate (se) are given for each best fitting linear function.

for whom sensitivity to reinforcement remained high over successive subintervals, sensitivity was high in the first subinterval and dropped to lower values as subintervals progressed.

To show the changes in sensitivity to reinforcement more clearly, a is plotted as a function of successive 15-s subintervals in Figure 3. In addition, Figure 3 includes the sensitivity value obtained for multiple VI VI schedules with 15-s components (squares). With the exception of Bird R4, Figure 3 clearly illustrates the systematic reduction in sensitivity over successive 15-s subintervals of 60-s components. Further, for all birds, sensitivity to reinforcement in 15-s components was lower than that for the first 15-s subinterval of 60-s components.

Fig. 2. Logarithms (base 10) of ratios of responses in successive 15-s subintervals of 60-s components as a function of logarithms of ratios of reinforcers obtained in the two components. Values for sensitivity (a), bias ($\text{Log } c$), and the standard error of the estimate (se) are given for each best fitting linear function.

DISCUSSION

Sensitivity to reinforcement in multiple VI VI schedules with 15-s component durations was no different from overall sensitivity for 60-s component durations, thus failing to demonstrate the short-component effect. Previous demonstrations of the short-component effect were assessed in terms of whether the proportion of responses in one

component matched the proportion of reinforcers scheduled for that component (Shimp & Wheatley, 1971; Todorov, 1972). It is important, however, to separate sensitivity to reinforcement from bias towards one component in evaluating whether matching is more likely with short components, and this can be done only by varying the reinforcer differentials over a range of values (Baum, 1974). Shimp and Wheatley (1971) did use five rein-

Fig. 3. Values of sensitivity to reinforcement shown by responding in successive 15-s subintervals of 60-s components of multiple schedules. These values (computed from Equation 2) are plotted as functions of successive subintervals. Corresponding values of sensitivity for the short 15-s component are indicated by square data points.

forcement conditions with a 5-s component duration, and our reanalysis of their data gave sensitivities of 0.89, 0.82, and 0.88 for their 3 birds. That is, sensitivity to reinforcement was high with short components. Williams (1983, Table 1) reanalyzed the data in Shimp and Wheatley's study for 2-s, 5-s, and 10-s components combined and also concluded that high sensitivity occurs with short components.

Yet it is important to compare, within subjects, sensitivity to reinforcement found for short components to that for longer components to establish the short-component effect. To date, no study has done this (for a range of several reinforcer differentials), and identifications of the effect seem to have been based entirely on cross-experiment comparisons. Hence the high sensitivity for Shimp and Wheatley's short components can be compared to sensitivity values averaging 0.42 for 90-s components in McLean and White (1981), to 0.53 for 120-s components in Davison and Ferguson (1978), and to 0.32 for 180-s components in Shettleworth and Nevin (1965). Cross-experiment comparison is nonetheless problematic because sensitivity may be high with short components in some studies but not in others. Cross-experiment comparison also has the problem of confounding the effects of component duration with the effects of other variables that may differ between studies. The mean sensitivity for single-key multiple schedules with 5-s components in a study by Merigan, Miller, and Gollub (1975) was 0.41, with a range of 0.30 to 0.54. Also, the mean sensitivity for 5-s components in an experiment by Charman and Davison (1982) was 0.44, with a range of 0.27 to 0.61. In the present study, the mean value for 15-s components of 0.35 with a range of 0.30 to 0.43 corresponds to the low values for short components in studies by Charman and Davison (1982) and Merigan et al. (1975). The mean sensitivity of 0.34 for 60-s components in the present study is consistent with the similarly low values found for multiple schedules with long component durations in previous studies. We therefore conclude that the data from our within-experiment comparison between short and long component durations are consistent

with the data from previous studies, with the exception of those of Shimp and Wheatley (1971), in failing to demonstrate the short-component effect.

It is possible that sensitivity to reinforcement in Shimp and Wheatley's (1971) experiment was generally high across all component durations as a result of their use of random-interval schedules and few sessions per condition. To examine this possibility, we reanalyzed data from Shimp and Wheatley's Table 2, treating separately the response rates and reinforcer frequencies given for the last two sessions of each condition in order to increase the number of data points contributing to the regression analysis. Large fluctuations in reinforcer frequencies across the two sessions in each condition also dictated treating separately the data for each session. For each bird, 10 points contributed to the analysis for 5-s components. The two conditions for 30-s components were combined with the two conditions for 60-s components to give 8 points for a second regression analysis. The results of these analyses, conducted in the same way as in the present experiment, are shown in Figure 4. Figure 4 supports the conclusion that sensitivity to reinforcement in Shimp and Wheatley's (1971) experiment was higher for the 5-s components than for the 30-s or 60-s components. It should be noted, however, that the conclusion is qualified by several factors: the large error variance in the fits to the data for the 5-s components; that only one condition was conducted with 5-s components where the log reinforcer ratio was positive; and that data for 30-s and 60-s components had to be combined to give a satisfactory number of data points for the regression analysis. In view of the theoretical importance of Shimp and Wheatley's result (Williams, 1983), and our failure to replicate it in a within-experiment comparison of short and long components, further attempts to establish the short-component effect would be valuable.

Occurrence of the short-component effect in the present study (and in studies by Charman & Davison, 1982, and Merigan et al., 1975) would have been expected according to the finding that behavioral contrast is greater with

Fig. 4. Reanalysis of data from Shimp and Wheatley (1971, Table 2) in terms of Equation 2 to show log response-rate ratios as functions of log ratios of obtained reinforcers for 5-s component durations (left panel) and 30-s or 60-s component durations (right panel). Values for slope (a), intercept ($\text{Log } c$), and the standard error of the estimate (se) for the straight lines best fitting the data are shown. The large crosses indicate the origin for each function.

shorter components. Studies reviewed by Williams (1983) convincingly demonstrate an inverse relation between contrast magnitude and component duration. It is possible, however, for component duration to influence absolute response rates in the richer component (and hence behavioral contrast) without influencing sensitivity to reinforcement of ratios of responses between components (McLean & White, 1981). When short components potentiate behavioral contrast without influencing sensitivity to reinforcement, the change in behavioral contrast must reflect an increase in bias towards responding in the constant (and richer) component rather than an increase in sensitivity to reinforcement. Williams (1983) has noted that a bias towards higher response rates in richer components may occur early in training and may be attenuated by further

training in which reinforcement schedules are reversed. The relation between contrast and undermatching in short components is a question that needs further investigation.

Although we did not find high sensitivity to reinforcement for 15-s components, we did replicate the finding that sensitivity is high at the beginning of a longer component (McLean & White, 1981; White, Pipe, & McLean, 1984). The aim of the present experiment was to examine the possibility that sensitivity in the first 15-s of the 60-s component would be the same as sensitivity in a short 15-s component, in that the short component effectively samples responding that otherwise occurs at the beginning of long components. Our data indicated that this was not the case, however. Sensitivity for 15-s components was reliably lower than that for the first 15-s subinterval of 60-s components. Varying component duration and sampling behavior at different times since component alternation are therefore not necessarily equivalent means of varying the average temporal distance between the components of a multiple schedule.

An account for the greater sensitivity to reinforcement in the first 15 s of a long component than in a short 15-s component could be based on the way in which reinforcers for responses other than key pecking are distributed throughout components of different durations (Staddon, 1982, 1983). McLean and White (1983) have demonstrated that the extent of undermatching in multiple schedules is a function of the frequency of concurrently available reinforcers from extraneous sources. According to this account, we would have to discover why extraneous reinforcers were more likely at the beginning of long components than in short components. One possibility concerns the rate of accumulation of unobtained extraneous reinforcers (cf. Staddon, 1983). As yet, we have no evidence for such an account, but it does make the interesting prediction that the extent to which sensitivity changes over the course of a component will depend on component duration.

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