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CONCURRENT SCHEDULES: SPATIAL SEPARATION OF RESPONSE ALTERNATIVES

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Four pigeons were exposed to independent concurrent variable-interval 20-second variable-interval 60-second schedules of reinforcement. A transparent partition was inserted midway between the two response keys. The length of the partition was systematically manipulated. Increasing partition length produced a decrease in changeover rate in Experiment 1. Overmatching was observed with a partition length of 20 centimeters. In Experiment 2 a four-second limited hold was added to the schedules. Increasing partition length produced a decrease in changeover rate that exceeded the decrease observed in Experiment 1. This manipulation produced nearly exclusive choice of the variable-interval 20-second component. The present results, together with results obtained in related research, suggest that deviation from matching is a function of procedural variables that determine the consequences of a changeover response.

Key words: concurrent schedules, matching, overmatching, changeover delay, key peck, pigeons

Preference in two-alternative concurrent schedules of variable-interval (VI) reinforcement is adequately described by the equation

$$\frac{B_1}{B_2} = b\left(\frac{R_1}{R_2}\right)^a \quad (1)$$

(Baum, 1974). B and R represent behavior (response rate, time spent) and reinforcement rate respectively, and the subscripts 1, 2 refer to the two response alternatives. Preference is biased if the constant b differs from 1.0. If both a and b equal 1.0, then Equation 1 reduces to Herrnstein's (1961, 1970) matching law:

$$\frac{B_1}{B_1 + B_2} = \frac{R_1}{R_1 + R_2}, \quad (2)$$

which states that the proportion of responses (time spent responding) to one alternative matches the proportion of reinforcements provided by that alternative. If the exponent a in Equation 1 is smaller than 1.0, then the behavior proportion is less extreme than the reinforcement proportion and undermatching is said to occur. If a is greater than 1.0, then the behavior proportion is more extreme than the reinforcement proportion and overmatching is said to occur.

Approximate matching of behavior proportions and reinforcement proportions has often been observed in studies of choice (see for review de Villiers, 1977). One may therefore consider values of the exponent a that differ from 1.0 as indicating a deviation from characteristic performance. Alternatively, matching is a result with no special significance if it can be obtained only when values of procedural variables are chosen from a relatively restricted range (Pliskoff & Fetterman, 1981).

One procedural variable is the changeover delay (COD). A COD specifies a minimum amount of time that has to elapse between a changeover to the other response alternative and a subsequently reinforced response. The presence of a COD effectively eliminates the possibility of immediately reinforcing response sequences that include a changeover response (Catania, 1966). It has been found that some minimum duration of the COD is necessary if matching is to occur. Undermatching occurs with CODs shorter than this minimum; if the minimum is exceeded, matching is obtained. Increasing COD duration beyond the minimum does not produce overmatching (Allison & Lloyd, 1971; Shull & Pliskoff, 1967). One may argue that the generality of the matching law is not impaired by these findings; matcthing is

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obtained when independence of the concurrent operants is achieved by some minimum COD (de Villiers, 1977).

Values of the exponent *a* significantly greater than 1.0 have been found, however, in studies that employed changeover contingencies other than a COD. Silberberg and Fantino (1970) used a blackout period instead of a COD and observed overmatching. Todorov (1971) found overmatching in a procedure in which a changeover response was followed by an inescapable shock. The same effect was observed in a procedure that arranged a timeout period after a changeover response. Pliskoff, Cicerone, and Nelson (1978) and Pliskoff and Fetterman (1981) investigated the effect of a fixed-ratio changeover requirement (FR CO) on choice behavior. They found that the degree of overmatching increased with the changeover requirement. The effects of spatially separating the two choice alternatives were investigated by Baum (1982). Baum used a partition between the two response keys in a pigeon operant conditioning chamber. Overmatching occurred when a relatively long partition was placed between the two keys.

The rate of changeover between response alternatives decreases as a function of COD duration, and the same effect is observed if shock intensity, timeout duration, a FR CO, or partition length is increased. However, whereas matching occurs with CODs greater than a certain minimum, other manipulations produce a transition from undermatching to overmatching.

The present study further explored the conditions under which overmatching occurs when a partition separates the two response alternatives. Baum (1982) investigated the effects of the length of such a partition using a procedure resembling one employed by Stubbs and Pliskoff (1969). In this procedure schedule components are interdependent; reinforcers are set up by a single VI schedule and are then assigned probabilistically to one of the two response alternatives. Differences between this procedure and the usual procedure of arranging concurrent schedules (Herrnstein, 1961) may generate differences in behavior. For instance, if reinforcers are assigned from a single schedule, changeover rate has a greater effect on overall reinforcement frequency (Heyman & Luce, 1979). Therefore, interdependent schedules may be more effective in maintaining changeover behavior.

Experiment 1 was conducted to see whether Baum's results could be replicated using Herrnstein's procedure.

EXPERIMENT 1

In this experiment, the effects of lengthening a partition between the response keys of a pigeon operant chamber were investigated. The usual procedure with two VI schedules running simultaneously was used. Both the relative rate of reinforcement and the length of the partition were manipulated within subjects.

METHOD

Subjects

Four experimentally naive homing pigeons served. They were maintained at approximately 80% of their free-feeding weights.

Apparatus

Four standard Lehigh Valley three-key pigeon testing chambers were used. The chambers were 36 cm high, 31 cm long, and 35 cm wide. Only the left and the right keys were operative during this experiment. Both keys were 2.5 cm in diameter and required a force of approximately .10 N to be operated. The keys were mounted 9 cm (to the center of the key) from the left and the righthand walls of the chamber, and they were spaced 16.5 cm apart. The right key could be illuminated by a green keylight, the left key by a red keylight.

Access to standard mixed pigeon grain was provided through a 5-cm by 6-cm aperture, centered on the intelligence panel, 11 cm from the floor of the chamber. Midway between the two side keys a transparent partition could be placed. The partition was 27 cm high and .25 cm thick. It extended either 10 cm or 20 cm from the intelligence panel into the chamber. In both cases the birds could easily pass from one key to the other. Full access to the feeder was possible through a notch in the partition.

A fan provided fresh air and some masking noise. A PDP 8/E minicomputer (Digital Equipment Corporation), located in an adjacent room, and SKED software (Snapper, Stephens, & Lee, 1974) were used to control the experimental procedures and data collection.

Procedure

After magazine training and shaping of the key peck, the animals were exposed to a sequence of seven conditions. In each condition a two-key procedure of concurrent schedules was employed (Herrnstein, 1961). The schedules used were either VI 20-sec or VI 60-sec, each consisting of 20 intervals constructed using the method of Fleshler and Hoffman (1962). The two schedules were independent and operated continuously except during reinforcement presentation (3 sec). A 0-sec COD was employed; the first peck of a run on a key was never reinforced.

In the first two conditions no partition was present, in Conditions 3 and 4 a partition of length 10 cm was used, and in Conditions 5 and 6 a partition of length 20 cm. These lengths correspond to three of the lengths used by Baum (1982). The last condition replicated the first one.

Table 1 shows the sequence of conditions and the number of sessions devoted to each. Conditions were changed when the range of the proportion of responses in one of the components did not exceed .08 over the last five sessions and no trends in changeover rates, response rates, or times spent responding occurred. Experimental sessions were conducted six days per week; a session ended after 20 minutes, excluding reinforcer time.

Results

Table 2 shows raw data averaged over the last five sessions of each condition and the proportions calculated from these averages. Coefficients of variation (standard deviations, expressed as percentages of the means) were calculated for the response and time data in Table 2. The coefficients for times and numbers of responses in the VI 20-sec component averaged 7%; the coefficients for data from the VI 60-sec component averaged 12%.

Table 1

Sequence of conditions showing the VI reinforcement schedules (sec) used in the red and green components, the partition lengths (cm) that were used, and the numbers of sessions in training. In parentheses: numbers of sessions in Experiment 2.

				Number of sessions: subjects			
	Red	*Green*	*Partition length*	*HB1*	*HB5*	*HB11*	*HB12*
1	20	60	0	18(11)	15(12)	15(15)	15(15)
2	60	20	0	22(18)	22(20)	20(20)	22(23)
3	60	20	10	14(13)	16(26)	15(14)	14(14)
4	20	60	10	12(23)	17(15)	11(21)	15(21)
5	20	60	20	21(13)	20(10)	21(10)	21(11)
6	60	20	20	16(21)	16(19)	16(14)	16(10)
7	20	60	0	14	14	14	14

Figures 1, 2, and 3 are based on Table 2. Figure 1 shows number of changeover responses to the right key as a function of partition length. Figure 1 shows that the number of changeovers decreased as partition length was increased. The transitions to the even-numbered conditions produced higher changeover rates. There is no apparent reason for this phenomenon. Presumably, it is not an effect of continued exposure to a partition of a certain length, because no trends in changeover rate were apparent during the five sessions preceding a change of conditions. Also, it is not the case that the even-numbered conditions differed consistently from the preceding odd ones in the assignment of a schedule to a response key.

Figure 2 shows deviations from perfect matching for both response and time measures. They were obtained by subtracting reinforcement proportions from response and time proportions. The proportions used in the calculations were averages of the proportions obtained with a given partition length in different conditions (three values for partition length of 0 cm and two for partition lengths of 10 cm or 20 cm). A positive deviation indicates overmatching: the behavior proportion is more extreme than the reinforcement proportion. A negative deviation indicates undermatching. Response overmatching occurred for three subjects when a partition of 20 cm was used. Response proportions that were more extreme than proportions of time spent responding resulted as partition length increased. The transition from partition length of 10 cm to partition length of 20 cm produced an increase in deviation from perfect matching in seven out of eight cases. Figure 3 shows the average number of responses for each partition length per interchangeover period (run length) that was observed. Each point in the figure represents an average of the run lengths obtained with a given partition length in different conditions. Run length in the VI 20-sec component increased as partition length increased.

Table 2

Experiment 1. Numbers of responses, time (sec) excluding reinforcement time, numbers of reinforcements, and numbers of changeovers to the right key are expressed as averages of the final five sessions of a condition (20 = VI 20-sec, 60 = VI 60-sec).

Condition	Partition Length (cm)	Responses		Prop. of Responses in VI 20	Time		Prop. of Time in VI 20	Reinforcements		Prop. of Reinforcements in VI 20	Changeovers
		20	60		20	60		20	60		
					Subject HB1						
1	0	1116	594	.65	900	276	.77	56.8	20.6	.73	263
2	0	1042	874	.54	683	482	.59	58.6	21.8	.73	366
3	10	1460	118	.93	1010	186	.84	56.2	13.8	.80	38
4	10	1356	299	.82	771	421	.65	54.8	18.2	.75	87
5	20	1575	185	.89	892	304	.75	54.4	16.4	.77	39
6	20	1467	341	.81	880	314	.74	55.6	18.8	.75	66
7	0	1565	576	.73	877	298	.75	59.8	20.8	.74	298
					Subject HB5						
1	0	989	337	.75	948	235	.80	56.2	19.2	.75	160
2	0	1144	732	.61	833	335	.71	59.0	22.2	.73	376
3	10	973	566	.63	736	438	.63	58.0	21.8	.73	311
4	10	939	630	.60	678	497	.58	55.6	21.0	.73	302
5	20	1031	284	.78	828	339	.71	56.6	19.6	.74	128
6	20	1151	535	.68	699	487	.59	55.8	21.0	.73	172
7	0	1407	803	.64	846	325	.72	60.4	21.2	.74	334
					Subject HB11						
1	0	765	495	.61	792	379	.68	54.0	20.0	.73	210
2	0	1075	467	.70	834	345	.71	58.0	20.0	.74	219
3	10	988	425	.70	799	394	.67	56.6	20.8	.73	173
4	10	649	689	.49	619	558	.53	55.6	21.8	.72	271
5	20	1010	214	.83	940	253	.79	57.6	18.6	.76	92
6	20	1107	269	.80	877	314	.74	57.4	19.6	.75	107
7	0	981	802	.55	701	469	.60	58.2	22.2	.72	352
					Subject HB12						
1	0	942	610	.61	661	514	.56	55.2	21.0	.72	255
2	0	1005	848	.54	666	505	.57	57.4	21.4	.73	340
3	10	1025	390	.72	818	372	.69	57.0	20.8	.73	129
4	10	904	458	.66	757	426	.64	56.6	20.4	.74	218
5	20	1503	81	.95	1090	109	.91	57.0	14.4	.80	26
6	20	1305	207	.86	919	279	.77	54.4	17.2	.76	43
7	0	1173	806	.59	782	395	.66	57.2	21.6	.73	273

Run length in the VI 60-sec component remained relatively stable across conditions.

Table 2 shows that reinforcement proportions were approximately constant. Consequently, if run length in the VI 60-sec component is constant, then deviation from response matching should covary with run length in the VI 20-sec component. A comparison of Figure 2 and Figure 3 shows that this is indeed the case.

Discussion

The effects on choice behavior of placing a partition between response alternatives were investigated with independent VI schedules. It was found that changeover rate decreased when the length of a partition between the two response keys was increased. Response overmatching occurred when a partition of length 20 cm was present; undermatching was generally observed in the conditions with a shorter partition. Deviation from response matching covaried with run length on the VI 20-sec schedule; run lengths on the VI 60-sec schedule were approximately constant.

These results are similar to those obtained by Baum (1982), who used interdependent schedules. It may be concluded that the effects of partition length on preference are similar to

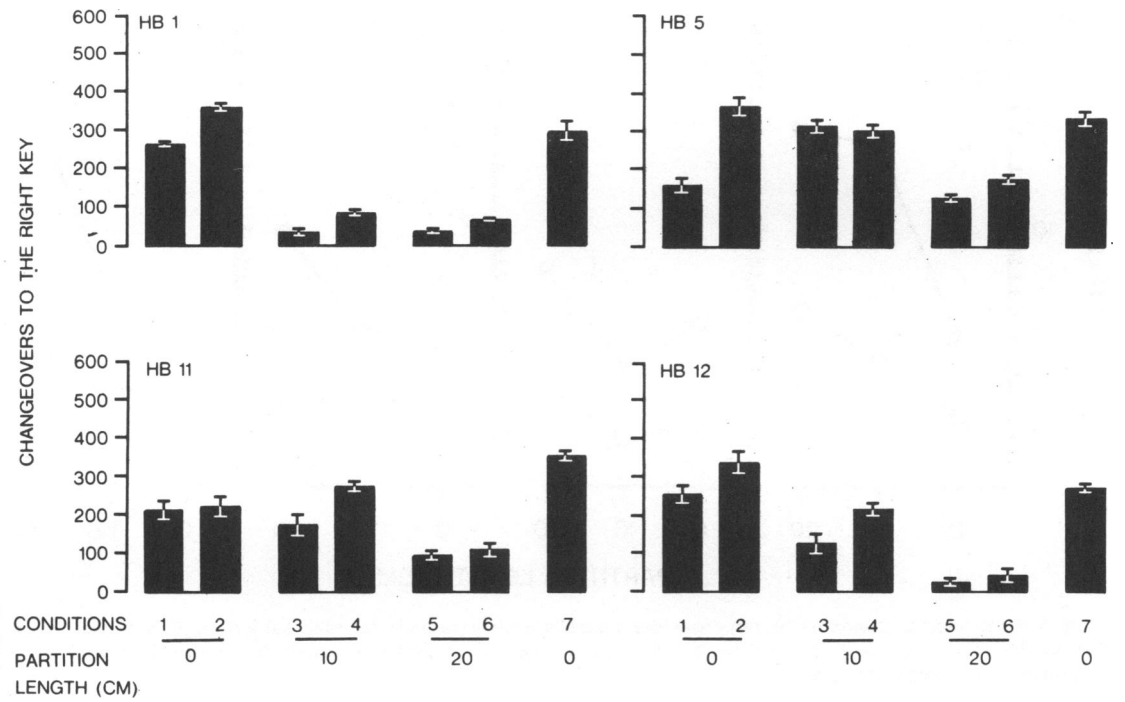

Fig. 1. Numbers of changeovers to the right key for each subject in Experiment 1. The vertical lines represent ±1 standard deviation.

those of timeout and shock contingent on changeover behavior (Todorov, 1971) and those of a FR CO (Pliskoff et al., 1978; Pliskoff & Fetterman, 1981).

EXPERIMENT 2

In independent concurrent VI schedules, the reinforcement rates provided by the compo-

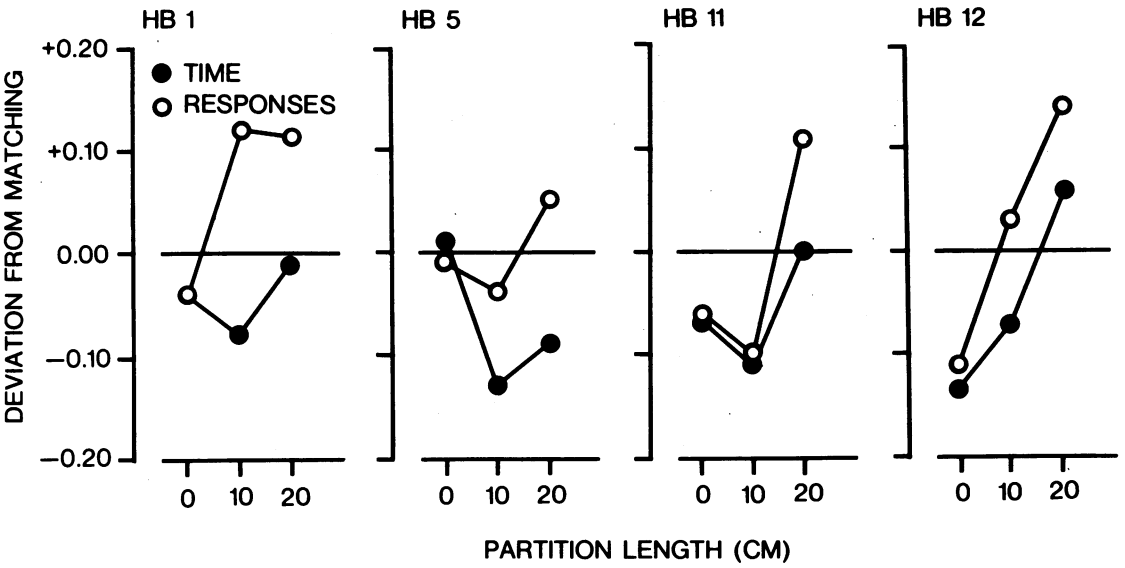

Fig. 2. Deviations from matching as a function of partition length for each subject in Experiment 1. Deviations were obtained by subtracting reinforcement proportions from choice proportions. Unfilled circles represent deviations from response matching; filled circles represent deviations from time matching.

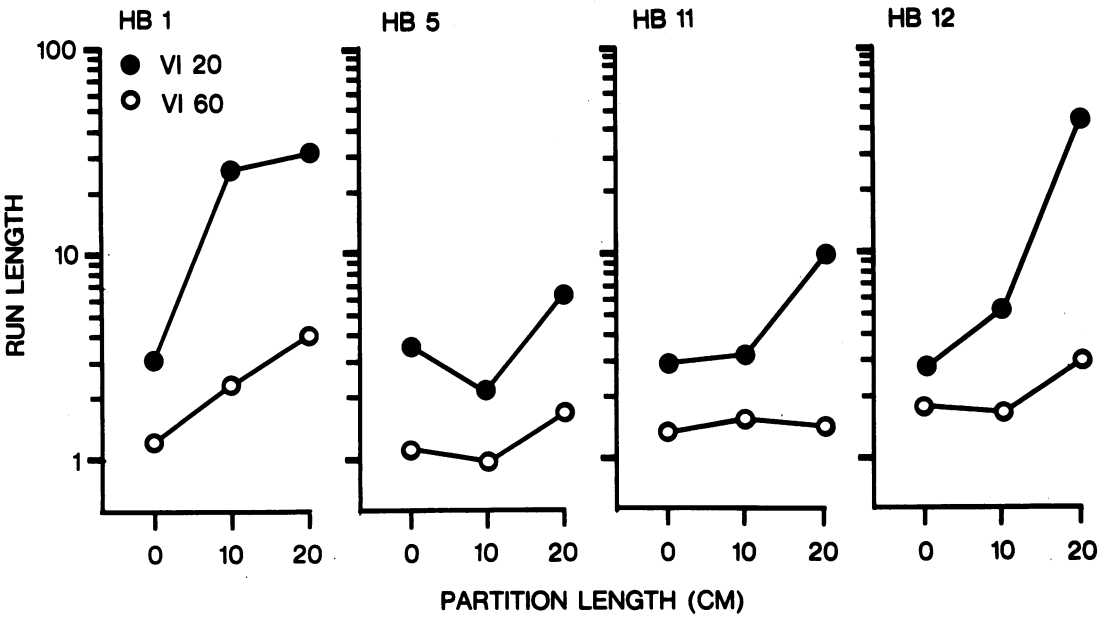

Fig. 3. Run lengths (numbers of responses per interchangeover period) for each subject in Experiment 1. Unfilled circles represent run lengths in the VI 60-sec component; filled circles represent run lengths in the VI 20-sec component. Note logarithmic axis.

nents are relatively independent of the rates of changeover to the components (Heyman & Luce, 1979). The results obtained in Experiment 1 reflect this property: changeover rates decreased, but reinforcement rates were approximately constant. It was the purpose of Experiment 2 to examine the effects of partition length when the rates of reinforcement provided by the VI components were more dependent on changeover rate. This dependency was introduced by adding a limited hold to both of the schedules that were previously employed.

Independent concurrent VI 20-sec, limited hold 4-sec, VI 60-sec, limited hold 4-sec schedules were used. As in Experiment 1, partition length was systematically increased.

Method

Subjects and Apparatus

Same as in Experiment 1.

Procedure

Experiment 2 immediately followed Experiment 1. A sequence of six conditions was presented, which was the same as the sequence of Conditions 1 to 6 in Experiment 1, except that a limited hold of 4 sec was added to both schedules in each of the conditions. The numbers of sessions devoted to each condition are shown in Table 1.

Results

Table 3 shows raw data averaged over the last five sessions of each condition and the proportions calculated from these averages. Coefficients of variation for times and numbers of responses in the VI 20-sec component averaged 5%; the coefficients for data from the VI 60-sec component averaged 26%. It can be seen in Table 3 that response and time proportions increased as partition length increased. Nearly exclusive choice of the VI 20-sec component resulted when partition length was 20 cm.

Figures 4, 5, and 6 are based on Table 3. Figure 4 shows the numbers of changeovers to the right key. As in Experiment 1, the number of changeovers decreased as partition length increased. The numbers of changeovers observed in the conditions with partitions (lengths 10 cm, 20 cm) were smaller than those in the corresponding conditions of Experiment 1.

Figure 5 shows deviations from perfect matching. Overmatching was not observed in the present experiment. As in Experiment 1,

Table 3

Experiment 2. Numbers of responses, time (sec) excluding reinforcement time, numbers of reinforcements, and numbers of changeovers to the right key are expressed as averages of the final five sessions in each condition (20 = VI 20-sec, 60 = VI 60-sec).

Condition	Partition Length (cm)	Responses		Prop. of Responses in VI 20	Time		Prop. of Time in VI 20	Reinforcements		Prop. of Reinforcements in VI 20	Changeovers
		20	60		20	60		20	60		
					Subject HB1						
1	0	1391	764	.65	757	409	.65	56.2	16.6	.77	387
2	0	1318	765	.63	769	393	.66	56.6	14.0	.80	406
3	10	2064	224	.90	1037	157	.87	54.8	4.8	.92	63
4	10	1842	61	.97	1131	64	.95	55.6	0.4	.99	38
5	20	2418	67	.97	1137	62	.95	53.8	0.6	.99	3
6	20	2097	24	.99	1179	21	.98	56.0	0.4	.99	1
					Subject HB5						
1	0	1415	653	.68	887	284	.76	56.6	13.6	.81	338
2	0	1217	553	.69	977	199	.83	57.0	14.0	.80	293
3	10	1088	614	.64	744	426	.64	55.2	14.0	.80	340
4	10	1336	186	.88	1047	145	.88	55.4	3.4	.94	88
5	20	1289	133	.91	1094	103	.91	53.0	3.0	.95	30
6	20	1575	180	.90	1040	155	.87	54.2	4.6	.92	60
					Subject HB11						
1	0	976	864	.53	678	492	.58	53.6	17.2	.76	354
2	0	1429	613	.70	830	345	.71	57.0	13.2	.81	285
3	10	1460	405	.78	899	291	.76	52.2	8.8	.86	123
4	10	1017	658	.61	720	461	.61	50.4	15.0	.77	217
5	20	1176	446	.73	847	345	.71	46.4	8.6	.84	102
6	20	1609	163	.91	1008	189	.84	50.6	3.6	.93	52
					Subject HB12						
1	0	1172	891	.57	698	474	.60	52.4	15.4	.77	330
2	0	1410	824	.63	785	384	.67	55.8	17.6	.76	366
3	10	1664	17	.99	1151	30	.98	55.8	0.0	1.0	13
4	10	1995	37	.98	1167	33	.97	57.2	1.4	.98	15
5	20	2122	7	1.00	1191	8	.99	58.0	0.0	1.0	1
6	20	1657	72	.96	1158	42	.97	55.4	0.4	.99	2

deviations from response matching tended to increase with increasing partition length.

Figure 6 shows the run lengths observed in Experiment 2. Run length in the VI 20-sec component increased sharply as partition length increased. The transition from partition length of 10 cm to partition length of 20 cm produced a relatively small increase of run length in the VI 60-sec component.

Discussion

Increasing partition length produced nearly exclusive choice of the component with the higher reinforcement rate. This result can be shown to be consistent with the results of Experiment 1 if (1) run length on the schedule with the lower reinforcement rate is independent of relative reinforcement rate and partition length, and (2) run length on the schedule with the higher reinforcement rate is an increasing function of both the relative reinforcement rate provided by the schedule and partition length. This leads to the prediction that the procedure of Experiment 2 produces a positive feedback effect: increasing partition length reduces changeover rate, which produces an increase in the relative reinforcement rate provided by the VI 20-sec schedule, which further reduces changeover rate, etc., leading to exclusive choice of the VI 20-sec component. The change in preference observed in Experiment 2 is in agreement with this prediction.

GENERAL DISCUSSION

The length of a partition between response alternatives and a limited hold mainly affected behavior in the schedule component with the

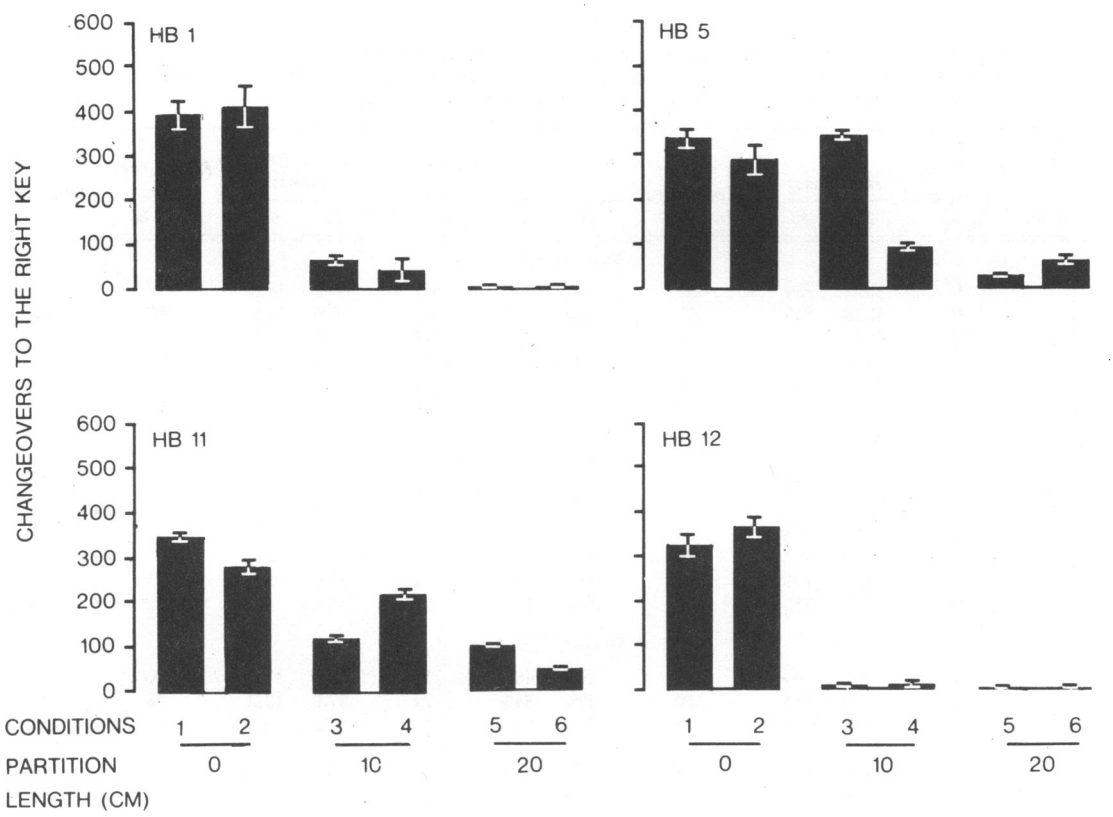

Fig. 4. Numbers of changeovers for each subject in Experiment 2.

higher reinforcement rate. Run length in this component increased when partition length increased. This effect was enhanced when a limited hold was added to the schedule components.

Response proportions were greater than time proportions when a partition of 20 cm was employed. This implies that the local rate of responding (the number of responses in a component, divided by the time spent in that component) was higher in the component with the higher reinforcement rate. However, this difference in local response rates might not be observed if the duration of changeovers (the interval between the last response on one key and the first response on the other key) is excluded from the total time base. Equal local response rates, or a rate that is higher in the component with the lower reinforcement rate, could result after this correction. In Experiment 1 mean durations of changeover were .8, 2.0, and 2.9 sec for partition lengths 0, 10, and 20 cm, respectively. Mean durations of changeover were .6, 1.7, and 3.7 sec in Experiment 2. However, these numbers present only a gross indication of changeover duration, because measurement occurred in 1-sec bins. The measures obtained did not allow for an accurate estimate of local response rates.

Independent VI schedules were used in Experiment I and overmatching developed as partition length increased. This finding presents further evidence for the proposition that the matching law has only limited validity. Apparently, it is not true, in general, that matching is obtained if some minimum degree of independence of schedules is ensured; a dependency exists between the type of changeover contingency employed and the occurrence of matching. A transition from undermatching to overmatching is observed if partition length is increased. Similar results may be obtained if the size of a FR CO is increased (Pliskoff et al., 1978; Pliskoff & Fetterman, 1981) or if the duration of timeout or the intensity of shock following a changeover is increased (Todorov, 1971). However, overmatching is not observed

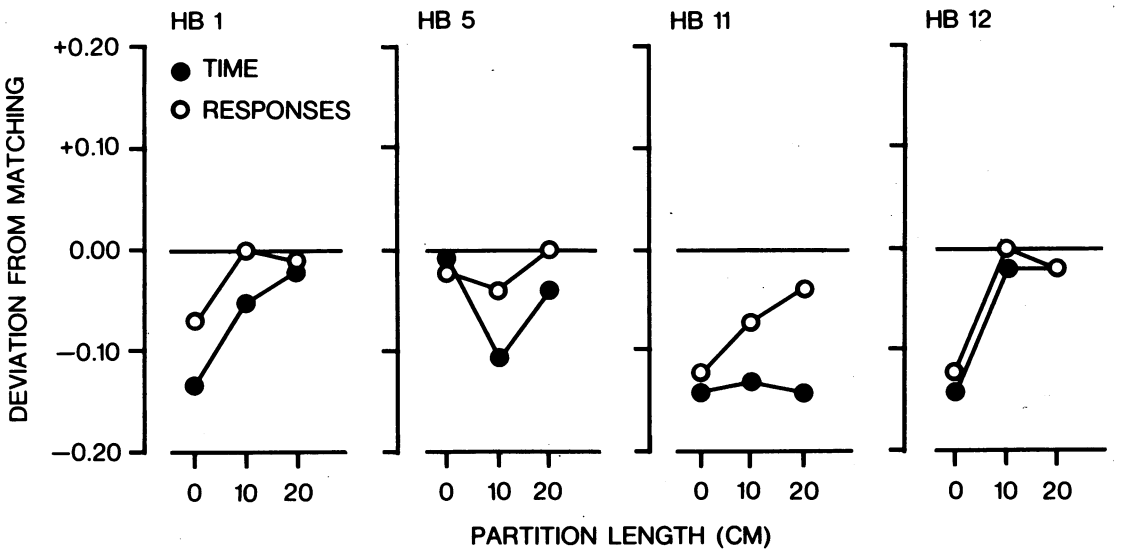

Fig. 5. Deviations from matching as a function of partition length for each subject in Experiment 2. Unfilled circles represent deviations from response matching; filled circles represent deviations from time matching.

in procedures employing a COD (see de Villiers, 1977).

Baum (1982) has suggested that the manipulations that produce overmatching have in common that they introduce (increase) a cost for changeover behavior. However, changeover rate seems the most plausible indicator of cost. If this indicator is used, then it must be concluded that the COD also arranges a cost for changeover behavior, since changeover rates decrease with increases in the duration of the COD. So it remains to be explained why increasing COD duration does not produce overmatching.

Perhaps an important difference between the COD and other procedures for separating schedule components is that the COD imposes contingencies not only on the changeover response but also on subsequent responding in a schedule component. The COD is contingent on a changeover response, but it also arranges a period of time during which the probability of reinforcement is zero and subsequently a stepwise increase of reinforcement probability to a value considerably greater than zero. In each of the other procedures, the changeover contingency is no longer in effect when responding in a schedule component is initiated: the first response in a schedule component may be reinforced. This difference between COD and other procedures may explain why local differences in responding may be produced. If a COD is employed, then a relatively high rate of responding during the COD is followed by a lower response rate (Pliskoff et al., 1978; Silberberg & Fantino, 1970). However, if a FR CO requirement is used, an elevated response rate occurs only during a very short interval (approximately 1 sec) after a changeover and is immediately followed by a sharp decrease (Pliskoff et al., 1978).

The fact that response overmatching does not occur with CODs of long duration may be explained by referring to the finding that response rates during a COD show indifference between schedule components and tend to be high (Silberberg & Fantino, 1970). Differences between the relative rates of responding to the two alternatives are attenuated by indifference during the COD and by the predominance of responding during this period. This attenuating effect is greater, the longer the COD.

Differential effects of time allocation on reinforcement proportions may also explain why overmatching is not observed with long CODs. Suppose unequal concurrent VI schedules are employed. Increasingly extreme reinforcement proportions will result if the proportion of time spent responding to the alternative that provides the higher reinforcement rate increases as COD duration increases (Shull & Pliskoff, 1967). Reinforcement proportions seem to be less dependent on time allocation in the other procedures for separating schedule

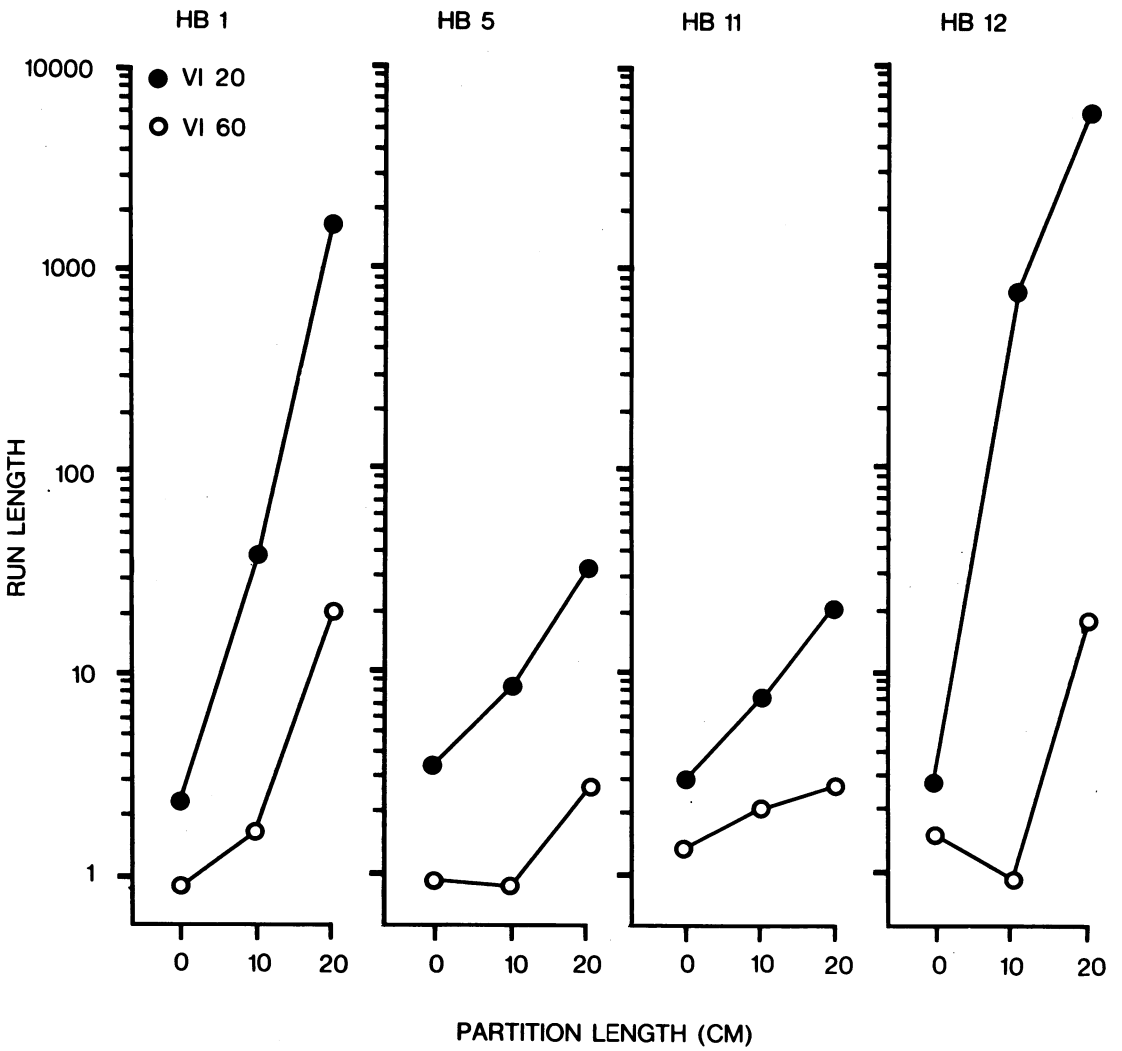

Fig. 6. Run lengths for each subject in Experiment 2. Unfilled circles represent run lengths in the VI 60-sec component; filled circles represent run lengths in the VI 20-sec component. Note logarithmic axis.

components. For instance, reinforcement proportions were relatively stable as behavior proportions increased in Experiment 1 of the present study. Approximate constancy of reinforcement proportions was also observed by Todorov (1971). Reinforcement proportions may be less free to deviate from behavior proportions in COD procedures.

Perhaps the effects of COD duration and other changeover contingencies are equivalent if only post-COD responding is taken into account. This leads to the prediction that the degree to which overmatching occurs with respect to post-COD response rates should be an increasing function of COD duration. Some indication that this is true can be obtained from data obtained by Silberberg and Fantino (1970, Experiment 2). Evidence of this nature substantiates the proposition that matching is a result with no special significance. It may well be that matching occurs only if a suitable value is chosen for a procedural variable that determines the consequences of a changeover response.

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