

**UNDERMATCHING AND OVERMATCHING:
THE FIXED-RATIO CHANGEOVER REQUIREMENT**

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Concurrent variable-interval two-minute and six-minute schedules were arranged while the fixed-ratio changeover requirement was varied among one, two, and four responses. A four-response requirement produced overmatching in the response and time data. A one-response requirement produced consistent undermatching in the time data but mixed results in the response data. The two-response requirement showed undermatching in the time data and overmatching in the response data. The results are discussed in relation to previous research using changeover requirements of five and ten responses, which produced clear tendencies toward overmatching, especially with response data. Taken together, these findings suggest that matching is not a unique result, and that undermatching or overmatching can be produced by continuous variation of the changeover requirements.

Key words: concurrent schedules, matching, over- and undermatching, fixed-ratio changeover, pigeons

Concurrent variable-interval schedules of reinforcement (conc VI VI) have been frequently employed in the study of choice behavior. In those experiments if the observed relative rates of responding and time partitions exactly equal the relative rates of reinforcement, then *matching* is said to occur. If the behavior measures are less extreme than the relative rates of reinforcement, then we speak of *undermatching* and, conversely, if the behavior measures are more extreme, we speak of *overmatching*.

Baum (1974) expressed the matter more precisely. When the data from conc VI VI schedules are plotted on logarithmic coordinates, matching may be evaluated according to the straight line:

$$\log \frac{B_1}{B_2} = a \log \frac{r_1}{r_2} + \log b,$$

where B represents the behavior measures, responses or time, and r represents rate of reinforcement; the subscripts 1 and 2 identify the schedules. Perfect matching occurs when $\log b$ equals zero (the line passes through the origin) and a , the slope constant, is equal to unity. If a is less than unity, undermatching

is indicated and if greater than unity, overmatching. (If the line does not pass through the origin, b is not equal to one and a bias is indicated—see Baum, 1974).

Two recent review articles have examined the question of matching vs. over- and undermatching. Myers and Myers (1977) speculated that matching might not be a general phenomenon, but rather “one of a family of functions” depending on procedural and parameter considerations. Based upon their analyses of extant data, Myers and Myers concluded that the most typical outcome of conc VI VI experiments is undermatching, both for response and time data.

Baum (1979) reviewed about 100 data sets and found undermatching to be the more frequent finding with response proportions and both under- and overmatching to occur about equally often for time proportions. His conclusions differ from those of Myers and Myers in that he did not find undermatching to be characteristic of time proportions.

A report by Pliskoff, Cicerone, and Nelson (1978) displayed data from three experiments on performances maintained by conc VI VI schedules of reinforcement. The first two experiments in that report are of interest at this point. The procedure employed a main key and a changeover (CO) key; the conc VI VI schedules were manipulated under the

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restriction that both combined provided 40 reinforcements per hour. In the first experiment, 10 responses were required on the CO key in order to alternate the schedule assignment on and color of the main key; in the second experiment, employing a different strain of pigeon, the CO requirement was reduced to five responses. In all other essential respects, the two experiments were intended to be identical.

The first experiment showed overmatching quite clearly for the response measure for all three birds; the time measure showed clear overmatching for two of the three birds. In the second experiment, response measures showed clear overmatching for two of three birds and clear time overmatching for one of three birds. There was, in short, virtually no evidence to suggest undermatching as a likely outcome. The results of both experiments were in conflict with the conclusions arrived at by Myers and Myers, but not with their speculation that matching might not be a general phenomenon.

If our results are examined in somewhat more detail, they appear to be in conflict also with Baum's conclusions. Aside from the fact that Baum found undermatching to be fairly general with response data, he found less undermatching—and perhaps even matching—to be fairly characteristic of time-partition data. In terms of the slope constant a of the above equation, Baum found that a was usually larger (nearer unity) for time data than for response data. Our findings, which strongly suggested more overmatching for response data than for time data, would show just the opposite relation between the a 's for time and response data.¹

But there is another way to look at our findings vis-a-vis Baum's conclusions. We both find that time data approximate matching better than response data. The difference rests primarily in the analyses of the response data—Baum finds undermatching to be the case, and we find overmatching.

There are obviously a number of questions that remain to be answered. We undertook the second experiment in our report because

¹In fact, one of the reviewers of our paper in manuscript form calculated the slope constants, which we had not done. He found that for all six pigeons, the slope constant for the response data was greater than for the time data.

we suspected that the strong overmatching observed in the first experiment might have been caused by too large a fixed-ratio change-over (FR CO) requirement. Given the results, it is entirely possible that the five-response requirement in the second experiment also encouraged some overmatching.

The purpose of the present experiment was to explore changeover requirements smaller than five responses. As noted later, there could very well be a transition from undermatching to overmatching as the FR CO requirement is varied between one and five responses. That finding would help to reconcile the differences between the findings of Pliskoff et al. (1978) and the conclusions reached by Myers and Myers (1977) and by Baum (1979). To that end, we employed one, two, and four responses in an experiment much like those reported by Pliskoff et al. (1978), except that only conc VI VI schedules that arranged reinforcement proportions of .75 to .25, .50 to .50, and .25 to .75 were studied.

METHOD

Subjects

Three White Carneaux pigeons with previous experimental histories served. None of their previous experiments involved conc VI VI schedules. The birds were maintained at about 80% of their free-feeding weights.

Apparatus

A Lehigh Valley Electronics pigeon chamber equipped with three Gerbrands keys was employed. The right-hand key was never used; the center key was the changeover key, and the left-hand key was the main key. These keys were spaced 7 cm apart on centers. The CO key could be transilluminated with white light, and the main key could be transilluminated with red or green light. The keys were located 22 cm above the mesh floor of the box, and a response on either key (a) required a force of about .15 N and (b) produced a sharp feedback click from a relay mounted on the vertical panel that supported the Lehigh Valley grain feeder. The keylights were turned off, and pecks had no programmed consequence when the feeder was operated. The opening to the feeder measured 6 by 6 cm, with the bottom of the opening 11 cm above the mesh floor. No houselight was used

during the experiment, the only light in the box being produced by either the keylights or the white lights illuminating the grain when the feeder was operated. The animal space measured 35 cm height by 35 cm width by 30 cm depth. An exhaust fan ventilated the box at all times.

Standard electromechanical equipment was used to arrange the experimental dependencies and record data: the number of responses on the red and green main key, the time during which the main key was red or green, the number of changeovers, and the numbers of reinforcements produced by pecking the red and green keys. This equipment was located in a room next to the one that contained the animal chamber. The chamber room was provided with a white noise of about 72-dB SPL, A-weighting, measured inside the chamber with its door open.

Procedure

Since the pigeons had served previously, no magazine or key-peck training was needed. They were placed immediately on a multiple schedule with VI schedules of 1.5-min average interreinforcement interval associated with both the red and green main keys. The key colors changed after each reinforcement, and sessions were terminated after 60 reinforcements. After about 15 sessions on the multiple schedule, all of the birds were placed on the conc VI VI shown as the first condition in Table 1.

The procedure for arranging the concurrent VI schedules associated each of the VI schedules with a different color of the main key. Responding on the CO key alternated the schedule assignment on and the color of the main key. Following a changeover, at least one response on the main key was required before another changeover could occur. If the FR CO requirement was larger than one response, the first response of the changeover FR darkened the main key and halted the progression of the VI programmers; the final response of the ratio relit the main key, restarted the programmers, and darkened the CO key, which became inactive until the first response on the main key. If only a single response was required to changeover, an FR-1 CO requirement, the VI programmers were not halted and the main key was not darkened. The VI schedules assigned reinforcement

independently; it was not necessary for a peck on one schedule to be reinforced before a peck could be reinforced on the other schedule.

During all of the conditions of the present experiment, the VI schedules were quasi-random arithmetic sequences of 13 intervals for the VI 2-min and VI 3-min schedules (used in only one condition) and 11 intervals for the VI 6-min schedule. Experimental sessions terminated after 60 reinforcements. The setting of the feeder timer was adjusted for each bird (2.5 to 5 sec) so that the 80% weight could be maintained without feeding in the home cage. Experimental sessions were conducted six days per week.

Columns 1 through 4 of Table 1 show the sequence of experimental conditions and the number of experimental sessions devoted to each. Relative reinforcement rates (arranged, not observed) are shown in the table with respect to the green key. The condition identified as .50 involved VI 3-min schedules; .25 and .75 involved VI 6-min and VI 2-min schedules.

Examination of the table shows that the experiment consisted of three parts. In the first, an FR-1 CO was arranged and the relative reinforcement rate for the green main key was varied among .25, .50, and .75. In the second part, the .25 and .75 relative reinforcement rates were studied with an FR-2 CO. The last part of the experiment compared the FR-1 CO and the FR-4 CO with the relative reinforcement rate for the green key fixed at .25.

RESULTS

Table 2 shows the raw data averaged over the final seven sessions of each condition, except for Bird 54 for which the final three sessions were averaged in Condition 12. The data shown were used to calculate relative response rates, time proportions, and relative reinforcement rates.²

²The same computations were made for the response and time data for each day of the seven used in each condition in Table 2. Standard deviations for each set of seven values were determined and a Coefficient of Variation was calculated. Each bird thus had 24 such statistics; 12 each for responses and time. The median Coefficient of Variation for each set of 12 was between 4% and 7%, which confirmed our impression of suitable stability having been observed during each condition of the experiment. Among the 72 statistics calculated, only 14 were at 10% or above; the worst case—19% for Bird 54, eleventh condition, response measure.

Table 1

The sequence of experimental conditions and the results arbitrarily referenced to perfect matching.

Condition	Relative Rein. Rate (Gr)	CO Ratio	Sessions	Bird 29		Bird 54		Bird 25	
				Resp	Time	Resp	Time	Resp	Time
1	.25	FR 1	87	-.23	-.17	+.05	-.10	-.01	-.15
2	.50	FR 1	50	.01	.01	.06	.00	.00	.00
3	.75	FR 1	111	-.05	-.08	-.22	-.12	-.03	-.14
4*	.25	FR 1	82	-.13	-.20	-.26	-.21	-.05	-.16
5	.25	FR 2	39	+.08	-.03	+.12	-.03	+.08	-.01
6	.75	FR 2	33	+.02	-.04	+.05	+.01	-.02	-.05
7*	.25	FR 2	39	+.03	-.05	+.11	-.03	+.06	-.06
8*	.75	FR 2	60	-.06	-.10	+.15	+.05	-.02	-.07
9*	.75	FR 1	62	-.04	-.07	+.14	-.05	-.02	-.07
10**	.25	FR 1	53	+.02	-.06	-.05	-.12	+.09	-.07
11	.25	FR 4	26	+.11	+.04	+.17	+.08	+.14	+.01
12***	.25	FR 1	28	+.08	-.02	-.09	-.16	+.10	-.08

Only 6 sessions were run in the last condition for Bird 54 since the trend was clear by that time. Asterisks identify replicated conditions: one asterisk represents the second exposure to that condition, etc.

For each experimental condition, subtractions were made between the relative behavior measures (responses, time) and relative reinforcement rate. The results of those calculations are shown in Table 1, columns 5 to 7. The numbers indicate deviations from a purely arbitrary criterion, perfect matching or the equivalence of a behavioral proportion and the reinforcement proportion. That outcome is represented by the entry .00 in the table. A negative entry indicates undermatching, where the reinforcement proportion is more extreme than the behavior proportion. More explicitly, undermatching with the reinforcement proportion about .25 involves a behavior proportion larger than .25; with the reinforcement proportion about .75, the behavior proportion is smaller than .75. In both instances, the behavior proportion falls on the ".50 side" of the reinforcement proportion. A positive entry in the table indicates overmatching, where the behavior proportion is more extreme than the reinforcement proportion (the reinforcement proportion falls on the ".50 side" of the behavior proportion). The degree of under- and overmatching is, of course, represented by the magnitudes of the entries.

Conditions 1, 3, and 4 from the first part of the experiment show clearly that FR-1 CO produced undermatching. The change to FR-2 CO in the second part of the experiment affected the response and time data differently. Most of the response entries show overmatch-

ing whereas almost all of the time entries show undermatching. Conditions 9 and 10 in the third part of the experiment represent a return to Conditions 1, 3, and 4. The time entries consistently show undermatching, as before, but now the response data are evenly split between over- and undermatching. Increasing the CO requirement to FR 4 produced overmatching for both time and response data for all of the birds. The return to the FR-1 CO in the last condition produced undermatching again for the time data and two out of three cases of overmatching for the response data.

Figure 1 shows in another way the effects of the FR-1 CO and the FR-4 CO on the response and time data. Behavior ratios are plotted on a logarithmic vertical axis. The horizontal axis shows the three final conditions of the experiment for each of the birds. The behavior ratios were calculated by dividing the response totals (times) for the green main key shown in Table 2 by the response totals (times) for the red key (Baum, 1974).

For all three birds, the behavior ratios were more extreme during Condition 11, which involved the FR-4 CO but the same VI schedules as Conditions 10 and 12.

DISCUSSION

The present experiment was motivated by the study reported by Pliskoff et al. (1978). That study employed FR CO requirements

Table 2

The Raw Data from which All Calculations were Made
(G = green, R = red, Rft = reinforcements)

Condition	Responses		Time		Rft		CO (total)
	G	R	G	R	G	R	
<i>Bird 29</i>							
1	1203	1260	36.4	48.8	15.7	44.3	2026
2	1091	1028	43.1	45.0	30.2	29.8	1963
3	2317	982	60.2	29.6	44.9	15.1	1707
4	1842	2980	40.5	47.9	15.4	44.6	1659
5	1248	5887	25.5	64.9	15.3	44.7	852
6	4727	1536	64.4	28.8	44.1	15.9	1217
7	1427	5377	26.7	63.9	14.6	45.4	886
8	3718	1677	59.3	32.7	44.9	15.1	779
9	3870	1567	60.9	28.4	44.9	15.1	1477
10	1281	4245	28.1	61.2	15.3	44.7	1263
11	948	6019	19.0	69.9	15.0	45.0	633
12	1011	5354	23.6	67.3	14.3	45.7	1119
<i>Bird 54</i>							
1	1268	5117	31.8	57.9	15.0	45.0	2300
2	1952	2513	43.8	43.4	29.9	30.1	3465
3	2376	2192	54.7	34.4	44.3	15.7	4194
4	2149	2097	41.2	47.5	15.0	45.0	3332
5	651	4296	24.9	64.9	15.0	45.0	821
6	4776	1340	70.3	24.5	44.0	16.0	787
7	1107	6535	25.8	65.7	15.1	44.9	1041
8	5453	588	71.3	17.0	45.3	14.7	970
9	4743	593	61.3	27.2	44.7	15.3	1303
10	1456	3424	33.3	55.3	15.1	44.9	1620
11	644	7396	15.2	74.2	15.0	45.0	697
12	1743	3254	36.5	52.4	15.3	44.7	1858
<i>Bird 25</i>							
1	1038	2767	35.7	51.2	15.9	44.1	1699
2	1534	1544	43.2	43.1	30.0	30.0	2814
3	3152	1245	53.4	34.0	45.0	15.0	2325
4	781	1704	38.2	51.9	15.6	44.4	1412
5	888	4291	23.3	66.8	14.9	45.1	1399
6	3833	1484	64.6	29.3	44.4	15.6	1642
7	1110	4386	30.4	62.3	15.9	44.1	1550
8	3125	1154	62.0	29.6	44.9	15.1	2231
9	2684	1019	59.6	29.5	44.6	15.4	1947
10	837	4170	28.2	59.6	15.3	44.7	1500
11	651	5190	22.3	68.2	15.3	44.7	594
12	784	4270	29.6	59.5	15.4	44.6	1241

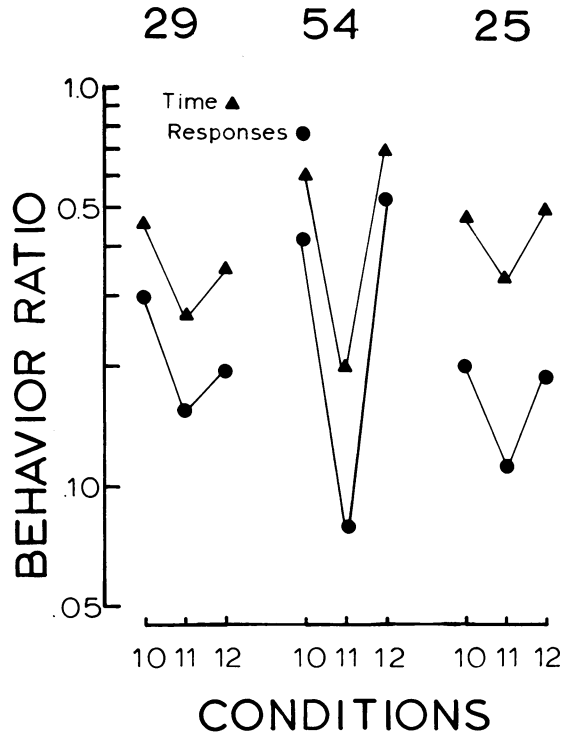


Fig. 1. The results for Conditions 10, 11, and 12 plotted as response and time ratios.

no smaller than five responses. Consistent response overmatching was reported along with smaller tendencies toward overmatching for the time-distribution data. A stated conclusion was that undermatching was not characteristic of performances on conc VI VI schedules of reinforcement (cf. Myers & Myers, 1977, and Baum, 1979).

The FR CO is not as often used in conc VI VI experiments as is the changeover delay (COD). The COD is an interval of time, initiated by a changeover, during which a peck on the main key cannot be reinforced. There

are several ways to arrange a COD, but with the CO-key procedure as used in the present experiment, the COD is most often initiated by a peck on the CO key. Thus arranged, it is possible for the first response on the main key to be reinforced provided the elapsed time between a changeover and that first main-key peck exceeds the duration of the COD. If the COD is set at zero seconds, then it is identical with the FR-1 CO. The purposes for including a COD in an experiment with conc VI VI schedules have been to (1) suppress superstitious "switching," and (2) guarantee that the VI schedules remain independent. It has been demonstrated often enough that a COD reduces the frequency of changeovers, and that fact presumably testifies to its efficacy in suppressing superstitious "switching." Schedule independence is harder to assess, however. More often than not, schedule independence is assumed, the assumption buttressed by data that approximate matching, with matching encouraged by the judicious selection of the COD duration. The circularity is apparent. Such points have recently been made by Navarick (1979).

The FR CO can be used to replace a COD. Manipulation of the FR size has been shown to affect the frequency of changeovers (Stubbs, Pliskoff, & Reid, 1977), and the FR CO may be assumed to guarantee independence between the VI schedules of a concurrent pair (See Findley, 1958).

A FR CO was used in the experiments reported by Pliskoff et al. (1978) because it was thought superior to the COD for the purpose of comparing local rates of responding on conc VI VI schedules. Specifically, we wished to determine whether local rates were the same for unequal VI schedules of a concurrent pair (Catania, 1966). Convincing evidence was found that they were not the same—the local response rate was greater for the VI schedule with the smaller average interreinforcement interval. Myers and Myers (1977) reported that the opposite result has usually been found.

The results of the present experiment support our findings reported in 1978. Consider Table 1 with respect to the results of the FR-4 CO condition. First, both the time and response data show overmatching. Second, the degree of overmatching for responses is considerably greater than for time. Third, if *local* response rates are calculated from data in Table 2, with few exceptions the local rate is greater for the VI 2-min schedule of a conc VI 2-min VI 6-min pair. The exceptions: Bird 29, Condition 1; Bird 54, Conditions 3 and 4.

We were not troubled in 1978 by the fact that the response data showed more overmatching than the time data. The third experiment in that report rationalized the result. The experiment compared an FR-5 CO with CODs of two and then five seconds. Main-key responding was found to be substantially different for several seconds after a changeover depending on whether a COD or FR CO requirement was arranged. We speculated on how that difference in responding might produce response undermatching with a COD and response overmatching with a FR CO. It accounted nicely for the finding that the response data overmatched more than the time data. It did not, of course, account at all for why the time data overmatched. We are now inclined to accept the suggestion of Myers and Myers that undermatching, and include overmatching, are tied to procedural variables. Apparently the COD in the range

of durations most often used is very likely to produce undermatching, whereas a FR CO as small as only five responses produces detectable overmatching. The FR-4 CO employed in the present experiment was adequate to produce that result.

As noted above, the FR-1 CO in our experiment would have been the same as no COD, which yields a high frequency of changeovers. Too high a frequency of changeover guarantees undermatching. In the extreme case, where a changeover occurs after each single peck on the main key, relative response rate is .50 regardless of relative reinforcement rate; in the absence of asymmetrical pausing, the time proportion also will be close to .50. That kind of total insensitivity to relative reinforcement rate is the most extreme form of undermatching, and we have rarely observed it in the laboratory.

It seems, therefore, that the range between one and five responses for an FR CO requirement should include a transition from undermatching to overmatching. The present results confirmed that expectation with regard to the time-distribution data that we obtained. The FR-1 and FR-2 COs produced undermatching but the FR-4 CO produced overmatching (although the deviation for Bird 25 was only .01). The response data also showed undermatching with the FR-1 CO during Conditions 1, 3, and 4 and substantial overmatching during Condition 11 with the FR-4 CO. In contrast with the time data however, the FR-2 CO seemed sufficient to produce overmatching in the response data. The return to the FR-1 CO during the last third of the experiment reinstated undermatching for the time data but not clearly so for the response data. Responding, apparently, was affected more permanently than time distribution by the prior exposure to the FR-2 CO.

In conclusion, it seems unlikely that there is a characteristic performance on conc VI VI schedules of reinforcement—procedural variables can produce either under- or overmatching; when carefully manipulated, they can produce neither of those results, i.e., matching (but, perhaps, not for time and response data both at once). There is no “real” result of conc VI VI schedules. Navarick (1979) discussed this issue and noted that one can either keep a result and change the model to suit, or one can keep the model and redo the experi-

ment (with suitable changes in procedural variables) to generate the "real" result that one may want. There has in recent years been a tendency in the experimental analysis of behavior toward the latter strategy, a point strongly made by Ferster (1978). For related reasons, the results of the present experiment were presented in terms of over- and undermatching with no allowance for variability, so that a deviation as small as, say, .02 could be considered neither under- or overmatching, but rather within an error band around .00 defining "perfect" matching. Unfortunately, no convention exists for choosing the width of an error band. One who believes that matching is a law can choose a wide error band and find ubiquitous matching. On the other hand, one might believe that matching is an arbitrary notion, imposed, when found, by a careful selection of procedural variables. Choose an error band suitably narrow and matching becomes a rare finding. Perhaps the most interesting feature of Table 1 is the pattern of pluses and minuses, which shows how performance can be altered by the size of the FR CO. As a rule of thumb in engineering the choice behavior of pigeons, an FR-2 CO seems a good way to produce what has come to be known as "matching."

REFERENCES

- Baum, W. M. On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*, 1974, **22**, 231-242.
- Baum, W. M. Matching, undermatching, and overmatching in studies of choice. *Journal of the Experimental Analysis of Behavior*, 1979, **32**, 269-281.
- Catania, A. C. Concurrent operants. In W. K. Honig (Ed.) *Operant behavior: Areas of research and application*. New York: Appleton-Century-Crofts, 1966.
- Ferster, C. B. Is operant conditioning getting bored with behavior? A review of Honig and Staddon's *Handbook of operant behavior*. *Journal of the Experimental Analysis of Behavior*, 1978, **29**, 347-349.
- Findley, J. D. Preference and switching under concurrent scheduling. *Journal of the Experimental Analysis of Behavior*, 1958, **1**, 123-144.
- Myers, D. C., & Myers, L. E. Undermatching: A reappraisal of performance on concurrent variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1977, **27**, 203-214.
- Navarick, D. J. Free-operant choice behavior: A molecular analysis. *Journal of the Experimental Analysis of Behavior*, 1979, **32**, 213-232.
- Pliskoff, S. S., Cicerone, R., & Nelson, T. D. Local response-rate constancy on concurrent variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1978, **29**, 431-446.
- Stubbs, D. A., Pliskoff, S. S., & Reid, H. M. Concurrent schedules: A quantitative relation between change-over behavior and its consequences. *Journal of the Experimental Analysis of Behavior*, 1977, **27**, 85-96.

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