RESPONSE AND TIME ALLOCATION IN CONCURRENT SECOND-ORDER SCHEDULES¹

P. G. BEAUTRAIS² AND M. C. DAVISON

UNIVERSITY OF AUCKLAND

Six pigeons were trained on two-key concurrent variable-interval schedules in which the required response was the completion of a fixed number of key pecks. When the required number of pecks was equal on the two keys, response- and time-allocation ratios undermatched obtained reinforcement rate ratios. A similar result was found when the required number of pecks was unequal, except that performance, measured in response terms, was biased to the shorter required number of pecks and was less sensitive to reinforcement-rate changes. No such differences were found in the data on time spent responding. When the variable-interval schedules were kept constant and the required numbers of pecks were systematically varied, response ratios changed inversely with the ratio of the required number of pecks, but time-allocation ratios varied directly with the same independent variable. Thus, on response measures, pigeons "prefer" the schedule with the smaller peck requirement, but on time measures they "prefer" the schedule with the larger peck requirement. This finding is inconsistent with a commonsense notion of choice, which sees response and time-allocation measures as equivalent.

Key words: concurrent schedules, second-order schedules, matching law, time allocation, pecking, pigeons

Performance in concurrent schedules is well described by the generalized matching law (Baum, 1974):

$$\frac{P_1}{P_2} = c \left(\frac{R_1}{R_2} \right)^a \quad (1)$$

where P refers to the frequency of responding and R to the frequency of obtained reinforcement on Schedules 1 and 2, and a and c are constants. Similarly, when time allocation to two choices (T_1 , T_2) is measured:

$$\frac{T_1}{T_2} = c \left(\frac{R_1}{R_2} \right)^a \quad (2)$$

The parameter c measures bias toward one key or color, and a measures the sensitivity of the measured behavior to changes in the reinforcement rate. Typically, the value of a is less than 1.0 (undermatching) for response measures,

and at, or close to, 1.0 for time measures (Baum, 1974; Lobb and Davison, 1975).

The generalized matching law has been successfully applied to performance when the two concurrent schedules are of different types (Baum, 1974; Nevin, 1971; Trevett, Davison, and Williams, 1972), and when the two reinforcers are of different types (Hollard and Davison, 1971). No attempts have yet been made to apply Equation 1 or Equation 2 to performance when the required responses differ on the two schedules, although Bauman, Shull, and Brownstein (1975) investigated concurrent performance when there was a response requirement for one choice and none for the other. The present experiment was designed to examine the effects of different response requirements on concurrent performance. In the first part of the experiment, concurrent variable-interval (VI) schedule performance was investigated when the basic requirement was that pigeons had to peck five times, rather than once, to obtain the reinforcer if it had been set up by the VI schedules. After each set of five pecks on a key, the key-lights were turned off, and the magazine illuminated, for a short period. Thus, the schedule was a concurrent second-order schedule (Stubbs, 1971) with fixed-ratio (FR) response

¹This work was carried out by the first author as part of the requirements for a Masters degree, and was supported by two grants from the University Grants Committee to the second author. We thank the cooperative of Stage 3, Masters and Doctoral students who helped conduct the experiments. Reprints and tables of individual data may be obtained from either author, Department of Psychology, University of Auckland, Private Bag, Auckland, New Zealand.

²Now at the Centre for Relationship Research and Therapy, Auckland.

requirements reinforced on VI schedules. The schedule can be written *conc* VI x-sec (FR 5:S^P) VI y-sec (FR 5:S^P), where S^P refers to the fact that the stimulus change at the end of each ratio requirement was aperiodically paired with reinforcement. The VI schedules were varied over a wide range, keeping the FR schedules constant. In the next part of the experiment, the FR requirement on one key was changed to FR 10, and again the VI schedules were varied. Finally, the VI schedules were kept constant and unequal and the FR requirement on the two keys was systematically varied.

METHOD

Subjects

Six homing pigeons, numbered 181 to 186, were maintained at $80\% \pm 15$ g of their free-feeding weights.

Apparatus

Solid-state scheduling equipment was situated remote from the experimental chamber and controlled all experimental events. All data were recorded on impulse counters.

The experimental chamber was sound-attenuated and masking noise was provided by an exhaust fan. It contained three response keys 2 cm in diameter, 9.5 cm apart, and 22.5 cm from the floor. In the present experiment, only the left and right keys were used. Feedback consisting of a relay click was arranged for responses to the keys exceeding about 0.1 N when the keys were illuminated white. A grain hopper containing wheat was situated directly below the center response key and 10 cm from the floor. During reinforcement, the keylights were extinguished and the grain hopper illuminated for a nominal 5 sec, and apart from the keylights and magazine lights there was no other illumination. Sessions ended after 40 reinforcements and supplementary feed of mixed grain was given, when necessary, immediately after daily training sessions.

Procedure

The animals had previously been trained to respond in the experimental chamber and had taken part in an experiment on matching to sample. Therefore, no key-peck or schedule training was necessary, and they were placed directly on the first experimental condition.

The variable-interval tapes ran continuously

throughout the session, except when one had set up a reinforcer and this reinforcer had not yet been taken, at which point both tapes stopped. The schedules were thus nonindependent (Stubbs and Pliskoff, 1969). The bird was placed in the blacked-out experimental chamber, the equipment was turned on, and the bird was presented with two white response keys. A single peck on either key turned the other keylight off and that key became inoperative. After four more pecks on the lighted key, one of two events occurred: if a reinforcer was available on this key, it was delivered; if a reinforcer was not available, the keylights were turned off, and the magazine lit (but not operated) for 0.2 sec. After reinforcement, or after illumination of the magazine, the two white keylights were again presented. A further contingency was added to prevent concurrent superstitions (Catania and Cutts, 1963). A reinforcer could not be obtained by pecking a key until at least 2 sec had elapsed after the first peck on a key following responding on the other key. If this changeover delay (Herrnstein, 1961) had not elapsed, the only consequence of completing the five responses was the 0.2-sec illumination of the magazine light and the offset of the keylights.

In the first part of the experiment, the VI schedules on the two keys were varied over successive experimental conditions with an FR 5 requirement on each key (Table 1). In the second part of the experiment, the right-key FR requirement was five pecks and the left-key requirement was 10 pecks, and again the VI schedules were varied. In the third part of the experiment, the VI schedules on the right and left keys were respectively VI 30-sec and VI 180-sec and the FR requirements on the two keys were varied from FR 2 to FR 8. Finally, two conditions in which the data seemed anomalous were replicated. It should be noted that one condition from each of the first two parts of the experiment was used in the third part of the experiment.

All VI schedules were randomized from the first 12 terms of the arithmetic progression $a, a + d, a + 2d$, etc., with $a = d/2$.

Experimental conditions were changed when each animal had met a defined criterion five, not necessarily consecutive, times. The criterion was that the median relative number of ratio completions (number of completions on the left key divided by total comple-

tions) over five days was within 0.05 of the previous five-day set. Thus, a minimum of 14 sessions were required for stability.

In all conditions, the following measures were taken: the number of FR completions on the right and left keys; the time spent completing the FRs on the right and left keys, commencing when the first ratio peck was emitted and ending when the last of each ratio was emitted; the total session time; and the numbers of reinforcements on the right and left keys. Cumulative records of performance were also occasionally obtained.

RESULTS

The results shown in Table 1 were averaged across birds and across the final five sessions of each experimental condition. Individual data tables are available from the authors.

Table 1 shows that the number of FR completions, and the time spent responding on the FR schedules, was controlled by both the VI reinforcement rates and the FR requirements. The fine details of the concurrent second-order schedule performance is shown in Figure 1, which is a cumulative record of performance on *conc* VI 180-sec (FR 5:S^P) VI 30-sec (FR 10:S^P). Since only one cumulative recorder was available, the records for the two keys

were from different sessions. This record, which was typical of all the birds, shows the burst-and-break pattern of FR performance within the ongoing steady rate maintained by the VI schedules (Stubbs, 1971).

The data obtained when the VI schedules were varied, keeping the FR requirements either equal or unequal, are shown in Figure 2. The ratios of the number of FR completions (S_r/S_l) are plotted as a function of the ratio of obtained reinforcement rates on the two keys (R_r/R_l) on double-logarithmic coordinates (Baum, 1974) for each bird. In this figure, the slopes of the lines fitted by the method of least squares are a in Equation 1, and the intercepts are the logarithms of c in the same equation. Beneath the equations of the fitted lines are shown the percentages of variance in the data accounted for by the fitted lines, which exceed 90% in all but one case. Lines were fitted to the FR 5 *versus* FR 5 and the FR 5 *versus* FR 10 data separately, and Figure 2 shows that for every bird, the data from the latter conditions were displaced above those from the former. A sign test (Siegel, 1956) applied to the difference in intercepts between the equal and unequal FR requirement conditions was significant at the 5% level. Figure 2 also shows that for all six birds the slopes of the lines fitted to the equal FR requirement

Table 1

Sequence of experimental conditions, number of sessions training, numbers of FR completions, time spent emitting FR schedules, and number of reinforcements on the right and left keys. All data have been averaged over six birds and over the last five sessions of each condition.

VI Schedules (sec)		FR Schedules		Sessions	FR Completions		FR Times (sec)		Reinforcements Obtained		Session Time (sec)
Right	Left	Right	Left		Right	Left	Right	Left	Right	Left	
120	120	5	5	37	306	365	431	473	19.73	20.10	2336
60	120	5	5	33	368	157	423	255	27.13	12.87	1765
120	90	5	5	26	278	328	322	442	16.4	23.17	2071
180	60	5	5	24	136	417	204	499	10.33	29.67	2088
60	180	5	5	20	367	178	481	236	30.23	9.77	1699
180	30	5	5	20	55	330	91	358	5.73	34.27	1063
30	180	5	5	20	255	77	354	106	34.13	5.87	1090
120	120	5	10	23	331	185	477	625	19.00	21.00	2330
120	60	5	10	16	188	157	283	518	13.83	26.17	1726
60	120	5	10	17	305	117	436	362	25.83	14.17	1741
180	30	5	10	21	87	128	131	424	4.93	35.07	1146
30	180	5	10	22	256	38	322	110	34.17	5.83	1086
30	180	10	5	24	144	63	438	104	34.13	5.87	1158
30	180	2	8	14	456	37	182	103	34.20	5.80	930
30	180	8	2	26	166	153	399	80	34.53	5.47	1059
180	30	5	10	20	81	135	129	459	5.47	34.53	1174
180	30	5	5	21	58	225	101	378	5.60	34.40	1039

Fig. 1. Cumulative records of performance, in two different sessions, on *conc* VI 180-sec (FR 5:S^P) VI 30-sec (FR 10:S^P). Diagonal slashes show the occurrence of the magazine light, and food reinforcement is not separately shown. The data are for Bird 183.

data were greater than those fitted to the unequal FR requirement data. This difference is again significant at the 5% level on a sign test.

Figure 3 shows the data on time spent emitting the FR requirements treated in the same way as Figure 2. In this case, the slopes of the fitted lines measure a , and the antilogarithms of the intercepts measure c , in Equation 2. The percentages of data variance accounted for by the fitted lines were again greater than 90% in all but one case. Contrary to the data on FR completions in Figure 2, the time data showed no consistent differences in either the slopes or intercepts of the fitted lines between the equal and unequal FR requirement conditions.

In Figures 2 and 3, the effects of varying the reinforcement rates on the VI schedules have been shown when the FR requirements were kept constant and were either equal or unequal. The present data also allow an assessment of the effects of changing the two FR requirements while keeping the VI schedules

constant but different. The ratios of the numbers of completions of the FR requirements, and the ratios of time spent responding, are shown in Figure 4 as a function of the ratio of the numbers of FR pecks required on the two keys. The axes are again logarithmic. The independent variable is the left-key FR requirement divided by the right-key FR requirement, since this measure will give a line of positive slope if the birds preferred shorter over longer requirements (*cf.* Chung and Herrnstein, 1967). The lines fitted to the FR completion data, which in all but one case account for over 90% of the data variance, all have positive slopes under 1.0. This result shows that preference, measured by the ratio of FR completions, is controlled by the FR requirements, and that the birds preferred short requirements over long requirements (*cf.* Figure 2). If these lines had been of unit slope, halving the FR requirement would have doubled the preference, and the total number of pecks emitted per session would have remained constant. The slopes of less than 1.0 show that halving the FR requirement increased, but did not double, the preference ratio of FR completions. It also shows that the ratio of the numbers of pecks on each key fell when the requirement on the first key was decreased.

The fitted lines for the time-allocation data in Figure 4 all have a negative slope of smaller absolute value than the positive slopes for the FR completion data. The fits are also less satisfactory. If these lines were horizontal (a slope of 0.0) the data would show that the total time spent responding on one key relative to the other was independent of the FR requirements, a result suggested by Figure 3. But since the data from all animals gave negative slopes, Figure 3 clearly does not tell the whole story. Negative slopes on this graph show that increasing an FR requirement relative to the other increased the total time allocation to that key relative to the other.

In all the fitted lines in Figure 4, the intercepts have a large positive value. This was because the reinforcement rate on the right key (VI 30-sec) was six times that on the left key (VI 180-sec). Reflecting this and undermatching of FR completion and time measures to reinforcement rate ratios (Figures 2 and 3), the antilogarithms of the intercepts varied from 1.5 to 5.9.

Fig. 2. The ratio of completions of the FR requirement on the right and left keys as a function of the ratio of reinforcements on these keys. The equations of the best-fitting straight lines, and beneath these the percentages of data variance accounted for by them, are shown separately for the equal and unequal FR requirement conditions.

DISCUSSION

This discussion focuses on group data (geometric means of individual ratios) only for the sake of simplicity. Because of the consistency among the performances of individual animals, the conclusions apply equally to the individuals.

The data on completions of FR requirements (Figure 2) show clearly that when the requirements were equal (both FR 5), performance corresponded closely to that reported when the concurrent schedule requirements are single pecks (Baum, 1974; Lobb and Davison, 1975). To three places of decimals, all birds showed performance with sensitivity values (a) less than unity (undermatching; Baum, 1974), with individually idiosyncratic biases to both right and left keys (positive and negative intercepts). As a group, the performance was characterized by the following relation, where S refers to the number of FR completions:

$$\frac{S_r}{S_l} = 0.92 \left(\frac{R_r}{R_l} \right)^{0.81} \quad (3).$$

The multiplier, 0.92, is the antilogarithm of the fitted line to the grouped data. As a multiplier of 1.0 indicates no bias, the group data showed a small bias to the left key.

When the left-key requirement was changed to FR 10, the ratio of FR completions (Figure 2) was displaced upwards and showed a smaller value of a . For the group,

$$\frac{S_r}{S_l} = 1.95 \left(\frac{R_r}{R_l} \right)^{0.65} \quad (4).$$

The multiplicative increase in bias of just over 2.0 represents the fact that the FR schedule on the left key was doubled. Neglecting, for a moment, the change in sensitivity values in Equations 3 and 4, the quantitative way in which bias changed with changing FR requirements is shown in Figure 4. There, with the VI schedules kept constant and the FR requirements varied, the slopes of the fitted lines were a direct measure of the way bias changed with changing values of the FR requirements. For the group data, bias measured in completion

Fig. 3. The ratios of times spent emitting the FRs on the right and left keys as a function of the ratio of reinforcements on these keys. The equations of the best-fitting straight lines; and beneath these the percentages of data variance accounted for by them, are shown separately for the equal and unequal FR requirement conditions.

terms (c_s) varied with the ratio of FR requirements according to:

$$c_s \propto \left(\frac{FR_1}{FR_r} \right)^{0.85} \quad (5).$$

Equations 3 and 5 may be combined into one equation to show the joint effects of reinforcement rates and FR requirements:

$$\frac{S_r}{S_1} = 0.92 \left(\frac{FR_1}{FR_r} \right)^{0.85} \left(\frac{R_r}{R_1} \right)^{0.81} \quad (6).$$

This composite equation shows that preference measured as ratios of FR completions increases toward both higher reinforcement rates and lower FR requirements. The form of Equation 6 is the same as that given by Baum and Rachlin (1969) for the concatenation of independent variables such as reinforcement rate, reinforcement immediacy, and reinforcement magnitude. It differs from their suggestion only in that the exponents of the independent variables are not 1.0.

However, it is hard to maintain the generality of Equation 6 when the sensitivity of the relations for FR completion measures changed as the ratio requirements were changed (Figure 2 and Equations 3 and 4). If, as our results

show, sensitivity changes when FR requirements are changed, the latter cannot be taken as simply biasing concurrent performance, as is suggested by Equation 6. An interaction between FR requirement and reinforcement rate is implied. Further research will be needed to clarify this effect.

Baum (1974) suggested that the available concurrent schedule data supported the proposition that "... whatever may be the factors affecting preference in a situation, as long as they are invariant, (bias) will be invariant". The present data (Figure 2) support this proposition, in that they are well fitted by straight lines. They do not support a corollary to that proposition that changing response requirements changes *only* bias. A similar situation occurred in research on concurrent schedules using different schedules. Trevett *et al.* (1972) reported that if a fixed-interval schedule, rather than a VI schedule was arranged on one key, a simple bias was produced toward the VI schedule. A subsequent replication (Lobb and Davison, 1975) found a sensitivity change as well as a bias change.

Before discussing the time-allocation data (Figure 3), it must be noted that the present

Fig. 4. The ratio of completions of the FR requirement, and the ratio of times spent completing these requirements, as a function of the ratio of the values of the arranged FR requirements (FR_1/FR_2). The data are from conditions in which the VI schedules were VI 180-sec and VI 30-sec and the FR requirements were varied. The equations of the best-fitting straight lines, and beneath these the percentages of data variance accounted for by them, are shown separately for each measure.

data were obtained by a method of measurement different from that normally used in the study of two-key concurrent performance. The usual measure cumulates time from the first peck on one key to the first peck on the alternate key, *i.e.*, from one changeover to the next. This method was not used in the present experiment for two reasons. First, the time spent with both keylights white, before emitting the first FR peck on either key, cannot be unambiguously allocated to the time spent emitting FR responses on either key. It is, as it were, dead time. Second, the present procedure, by requiring a response that takes up some considerable period of time, allows the direct measurement of the time spent emitting the response. This measure was discussed and recommended by Baum and Rachlin (1969).

The data on time allocation (Figure 3) measured in this way changed according to changes in reinforcement rates, in much the same way as did the data on FR completions (Figure 2).

The data were also similar to those obtained by the more usual type of measurement, except that the latter usually require the independent variable to be raised to a power closer to 1.0 (Lobb and Davison, 1975). For the group data, when the FR requirements were equal,

$$\frac{T_r}{T_1} = 0.94 \left(\frac{R_r}{R_1} \right)^{0.74}$$

and changing the requirements to FR 5 *versus* FR 10 gave:

$$\frac{T_r}{T_1} = 0.89 \left(\frac{R_r}{R_1} \right)^{0.64}$$

Over the change from equal to unequal FR requirements, the changes in both bias and sensitivity were not statistically significant. However, a conclusion of no change in these measures cannot be sustained by the data obtained when the FR requirements were systematically varied (Figure 4). As noted above for completion measures, if the changes shown

in Figure 4 are *only* bias changes, then bias measured in time-allocation terms (c_T) was related to the FR requirements in this way:

$$c_T \propto \left(\frac{FR_1}{FR_r} \right)^{-0.34}$$

Thus, as the FR requirement on one key was increased, so the total time spent responding on that key increased, although the number of FR completions on that key fell (Equation 5). A composite equation, analogous to Equation 6, could be constructed to show the joint effects of FR requirement and reinforcement rate. But this could also be premature, as the present data do not unambiguously rule out a sensitivity change arising from an FR requirement change.

These results, then, do not support Bauman, Shull, and Brownstein's (1975) conclusion, made on the basis of *conc* VI VT (variable-time) schedule performance, that "the relation between time and reinforcement distributions was the same whether or not the same response was occurring for both schedules". Perhaps when *no* response requirement is arranged for one schedule, time allocation to that schedule can vary with more freedom than when, as in the present case, requirements were set for both schedules. The implication of this would be that no bias in time measures would be shown even in *conc* [VI(FR 5:SP)] VT schedule performance. A second possibility is that had we allocated time spent before commencing an FR requirement to the key on which the animal had been last responding, as in the usual concurrent schedule procedure, time allocation would have been independent of response requirements. However, the pause before commencing FR performance cannot reasonably be allocated to the previously emitted FR schedule (Davison and Over, 1966).

Is choice to be seen as basically the distribution of responses between schedules (Herrstein, 1970, 1974), or as the distribution of time between schedules (Baum and Rachlin, 1969; Baum, 1975)? Neither measure gave simple matching (a sensitivity of 1.0) in the present experiment, although sensitivities of this order are usually found for the more common time-allocation measure (Baum, 1975; Lobb and Davison, 1975). When response requirements were changed in this experiment, both the bias and sensitivity of response completion measures changed. For time measures, possibly

only the bias changed. If further research shows that changing response requirements changes bias and sensitivity of both measures, two options are available. Either more basic measures of performance must be obtained that show simpler changes, or changes in both sensitivity and bias must be quantitatively predicted from other independent variables.

A second problem arises from the directions of the response-requirement effects on FR completion and time measures. Intuitively, one would expect that increasing one response requirement relative to another, concurrently available, would decrease preference for the first response. This is what we found (Figures 2 and 4). But in time measures, increasing an FR requirement actually increased the time allocated to emitting that response relative to another. The latter result is quite incompatible with a commonsense notion of choice. It implies that if an animal spends more time emitting response A than response B, it may be because either (a) the responses are similar but A has a higher reinforcement rate, or (b) both responses have the same reinforcement rate but the requirement for A is greater. A little reflection, though, shows that life is like this. People do allocate inordinate amounts of time to boring and arduous behaviors, and they grumble continuously while doing so.

The present counter-intuitive results on time allocation could, of course, be a product of the specific procedure used. The negative slopes for the time data in Figure 4 may result from the use of nonindependent concurrent VI schedules, or from the method of measuring time allocation. Further research will no doubt clarify this.

It is difficult to compare our results with those of Cohen (1975) who, though using concurrent second-order schedules, used a very different procedure. He arranged fixed-interval, rather than FR, response requirements, allowed switching to the alternate component at any time, but recommenced the interval requirement after each switch between schedules. Cohen did not report the numbers of completions of interval requirements, as this was not a reasonable measure for his procedure. But in terms of both numbers of pecks and time spent responding (presumably measured in the usual way), increasing the interval requirements on one key increased both the relative numbers of pecks and the relative time

spent responding on the other key. If increasing the interval requirements is equivalent to increasing the ratio requirements in the present experiment, the results of the two experiments are consistent with respect to response measures. But they are in opposing directions with respect to time measures.

Our results may be generally applicable to concurrent schedule performance with different responses (*e.g.*, pecking and lever pressing) required on each schedule. The only available evidence on this point comes from an analysis of data on chained schedules (Davison, 1974). Using response measures, both bias and sensitivity were different when different responses were used in each link, supporting the present results.

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Received 9 October 1975.

(Final Acceptance 2 August 1976.)