BEHAVIORAL CONTRAST AND RELATIVE REINFORCEMENT FREQUENCY IN TWO MULTIPLE SCHEDULES¹

T. M. BLOOMFIELD

UNIVERSITY OF EXETER, ENGLAND²

After preliminary variable-interval training, one group of pigeons was trained on a series of multiple variable-interval low-rate reinforcement schedules, while another group was trained on a series of multiple variable-interval fixed-ratio reinforcement schedules. Contrast effects were observed as variable-interval baseline rate changed in a direction away from the change in reinforcement frequency in the other component. The effects of the variable-interval component on performance in the low-rate and fixed-ratio reinforcement components in the multiple schedules were assessed by comparing the birds' performances on each of these schedules alone. Fixed-ratio reinforcement schedules showed a susceptibility to contrast effects, low-rate reinforcement schedules did not. The rate of reinforcement in fixed-ratio schedules at which no interaction occurred in the multiple schedules was higher than that in variable-interval 1-min schedules, suggesting that pigeons may prefer time-based, rather than response-based, reinforcement.

A number of studies have been made of the interactions in multiple schedules termed "behavioral contrast". Reynolds (1961a) describes the contrast effect produced in some multiple variable-interval extinction (*mult* VI EXT) schedules: a later paper (Reynolds, 1961b) reports the effects of the extinction schedule in multiple variable-ratio extinction (*mult* VR EXT) schedules on the VR performance in *mult* VR VR. Reynolds (1961c) describes studies of multiple variable-interval fixed-ratio (*mult* VI FR) schedules in which contrast appears. Also, Reynolds and Catania (1961) demonstrated contrast with fixed-interval (FI) and low-rate (DRL) reinforcement schedules.

The present experiments extend this work in a systematic study of *mult* VI FR and *mult* VI DRL schedules over a wide range of reinforcement frequencies in the FR and DRL components. In FR schedules, the frequency of reinforcement varies directly with the rate of responding; in DRL schedules, these variables are inversely related. It should therefore be possible to decide, by comparing performance in these multiple schedules, whether response rate or reinforcement rate is the major

determinant of contrast. The present experiments also examine and compare responding in the FR and DRL components of the multiple schedules with responding in each of these component schedules alone.

METHOD

Subjects

Seven adult homing pigeons, locally obtained and experimentally naive at the outset, were maintained at 80 to 85% of their free-feeding body weights. Four birds were used in Exp. I and three in Exp. II.

Apparatus

Two standard experimental boxes were used (Ferster and Skinner, 1957). Stimuli were projected on a translucent response key by In-Line Digital Display Units. The keys were $\frac{3}{4}$ -in. in diameter and required minimum pressure of 15 g for operation. Reinforcement consisted of 4-sec access to a grain mixture.

Preliminary procedure

Subjects were adapted to the box over a two-day period, magazine trained on the third day, then trained to peck the key on the fourth day. After the birds learned to peck, each response was reinforced (FR 1) until 30 reinforcements had been delivered. On the fifth day, 60 reinforcements were given on the same

¹This work was carried out under a Science Research Council Studentship.

²Reprints may be obtained from the author, Laboratory of Experimental Psychology, University of Sussex, Falmer Brighton, Sussex, England.

schedule. Next, VI 1-min training began (for details of schedule see Bloomfield, 1966). This was continued for 20 days, by which time the response rates of all the birds appeared to have stabilized. During the conditioning of the peck, the FR 1 and VI 1-min schedules, an $\frac{1}{8}$ -in. wide, vertical (0°) illuminated line on a dark background was projected on the key.

The preliminary procedure was identical in both experiments. Later procedures are described below.

Experiment I

Procedure. Four pigeons, 42, 51, 54, and 56, were used. After training, they were run through a series of *mult* VI DRL schedules. The VI 1-min component remained constant, the DRL component was varied. The two components alternated for 2-min periods in a daily session of 1 hr. The 0° line was present during VI 1-min, as in preliminary training, while in DRL a 45° line was projected on the key. The order and value of the DRL schedules used, the stimuli present, and the number of sessions spent on each are shown in Table 1.

One of the four DRL schedules used was VI 1-min (DRL 10-sec), in which a response following an interresponse time (IRT) of 10 sec or more is reinforced on a VI 1-min schedule (Ferster and Skinner, 1957, pp 460-463). This schedule was used to reduce the maximum reinforcement rate to 60 per hr, while retaining the characteristics of a DRL schedule.

The birds were rested for seven days before the next part of the experiment began. Here, the same DRL schedules were used, but in isolation, not as part of *mult* VI DRL. The stimulus present throughout was the 45° line, which had previously been correlated with DRL. Each session was terminated after 1 hr or 100 reinforcements, whichever came first. The number of sessions at each DRL value is shown in the lower part of Table 1.

Results. Figure 1 shows the response rate for each bird in VI plotted against the reinforcements per hour obtained in DRL. Four points were plotted at each DRL value by averaging three successive days' performance. The results show clearly that VI response rate in *mult* VI DRL is a function of the rate of reinforcement in DRL. In each case, a straight line is a good fit to the data. However, there is a certain magnitude of contrast associated with VI

Table 1

Contingencies Programmed for Birds 45, 51, 54, and 56

Schedule	Stimuli	Sessions
Part I		
VI 1	0	20
<i>mult</i> VI 1 VI 1 (DRL 10)	0/45	15
<i>mult</i> VI 1 (DRL 15)	0/45	20
<i>mult</i> VI 1 (DRL 10)	0/45	16
<i>mult</i> VI 1 (DRL 5)	0/45	12
<i>mult</i> VI 1 (DRL 10)	0/45	20
Part II		
VI 1 (DRL 10)	45	10
DRL 15	45	7
DRL 10	45	9
DRL 5	45	6

rates in *mult* VI EXT for the particular stimuli used (Bloomfield, 1966). Since the abscissa is scaled logarithmically, and $\log x$ tends to minus infinity as x tends to zero, a straight line cannot fit the points that would be obtained at very low reinforcement frequencies. Instead, the line of best fit may approach asymptotically the value of contrast associated with *mult* VI EXT as the reinforcement frequency approaches zero.

Figure 2 shows results from the same four birds. In *mult* VI DRL the DRL rates were erratic, and it proved difficult to obtain stable performances from all birds. The attempted replication of DRL performance in *mult* VI 1 min (DRL 10-sec), which gives the second

Fig. 1. Response rates in the VI component of *mult* VI DRL are plotted against DRL reinforcement frequencies for four birds. Each point is the mean of three days' results. Note that the abscissa is a logarithmic scale, and that neither abscissa nor ordinate reach zero.

point at this value, was successful in only two cases, Birds 51 and 56. For Birds 42 and 54, once the response rate had risen from DRL 10 to DRL 5, it proved impossible to return the performance to its previous level on DRL 10. The change from DRL 10 to DRL 5 produced a decline in the DRL rates of Birds 51 and 56, but the previous DRL 10 rate was then easily reestablished. The DRL response rates in isolation (open circles, top panels) present a more ordered picture. As the value of the DRL schedule moves from VI 1-min (DRL 10-sec) through DRL 15 to DRL 5, the response rate changes smoothly. The response rate in DRL in isolation is lower for all birds than that in DRL as a component of *mult* VI DRL. This does not apply to the VI (DRL) schedule used. Here, only Bird 56 shows a lower rate to VI (DRL 10) in isolation. Birds 42, 51, and 54 give higher rates to VI (DRL) in isolation than to this schedule in *mult* VI (DRL).

The center panels in Fig. 2 show reinforcements per hour plotted against the four DRL schedules used. These results fall into much the same pattern, but in reverse, as the response rates shown in the top panels. However, comparison of response rates and reinforcement rates for VI (DRL 10) reveals an apparent anomaly. Bird 56, as expected, shows a higher response rate and a lower reinforcement rate when VI (DRL) forms one component of the multiple schedule. But the other birds, 42, 51, and 54, show higher rates of reinforcement and higher rates of responding to VI (DRL) in isolation. A possible explanation is given in the Discussion.

The bottom panels in Fig. 2 show an "efficiency ratio". This was calculated by dividing the number of reinforcements obtained per hour by the number that could have been obtained by optimal responding. For DRL performances in the multiple schedules, in no case does the ratio rise above 0.2 (filled circles), whereas for DRL performances in isolation (open circles) Bird 42 reaches 0.6 on DRL 5, and Birds 54 and 56 both reach ratios of 0.4. Bird 51 remains quite low, at 0.27, although giving a higher ratio than to DRL 5 in *mult* VI DRL (0.20). In these panels the discontinuity between VI (DRL) and DRL is apparent. This may be due in part to the limitation on possible reinforcements per hour in VI 1-min (DRL 10-sec), and in part to the irregu-

lar response patterns which this schedule produced.

Responding in DRL schedules in isolation occurs with increased "efficiency" as the DRL time is shortened; but no such clear effect occurs when DRL is a component in *mult* VI DRL. Bird 51 was little affected by changes in DRL schedule: its response rate (top panel, open circles) remains almost unchanged at below 0.3 responses per sec as the DRL schedule moves from DRL 15 to DRL 10 and DRL 5.

Experiment II

Procedure. The remaining pigeons, 7, 48, and 52, were used. Table 2 shows the schedules put into effect and the number of sessions spent on each. After the 20 sessions on VI 1-min in preliminary training, the birds were put through a number of *mult* VI FR schedules with 0° stimulus correlated with VI and 45° with FR. In the second part, as in Exp. I,

Fig. 2. Responding in the DRL component of *mult* VI DRL. Upper panels give the response rates for four birds as a function of DRL schedule. VI 1-min (DRL 10-sec) is marked as "VI 10". Center panels show the rate of reinforcement for each bird, and bottom panels give an "efficiency ratio" (see text). Reinforcements/hr (center panels) is a logarithmic scale.

the various FR schedules were tested in isolation from the multiple schedule. An apparatus failure after the sessions on FR 20 prevented a precise duplication of the FR requirements

Table 2

Contingencies Programmed for Birds 47, 48, and 52

Schedule	Stimuli	Sessions
Part I		
VI 1	0	20
mult VI 1 FR 10	0/45	25
mult VI 1 FR 50	0/45	17
mult VI 1 FR 100	0/45	22
mult VI 1 FR 500	0/45	20
mult VI 1 FR 200	0/45	15
mult VI 1 FR 20	0/45	18
Part II		
FR 20	45	14
FR 40	45	13
FR 80	45	18
FR 200	45	15
FR 500	45	10
FR 10	45	17

used in the multiple schedules, so FR 40 and FR 80 replaced the previous values of 50 and 100. In *mult VI FR*, the VI and FR components alternated. Each VI period was terminated after 2 min, but each FR period remained in effect until the ratio requirement was completed. Times spent in FR periods varied from a few seconds to more than 10 min.

Results. Figure 3 shows a plot of response rate in VI as a function of the rate of reinforcement in FR. Five points were plotted at each FR value, from the last five sessions spent at that value. The solid lines with a broken continuation at low reinforcement frequencies show a possible function relating these two variables. Bird 47 apparently has a maximum contrast effect for an intermediate FR reinforcement frequency of about 20 reinforcements per hr. Bird 48 bears out this interpretation to a lesser extent, and Bird 52 shows only a slight tendency in this direction.

Figure 4 shows performances for the three birds on the FR component of *mult VI FR* (filled circles) and on FR in isolation (open circles). The upper panels have an ordinate of ratio runs per hour and an abscissa of FR requirement. Both these scales are logarithmic scales. This does not change the shape of the

Fig. 3. Each panel shows the VI rate in *mult VI FR* against FR reinforcement rate (log scale). The solid best fit to points above 20 reinforcements per hr on the abscissa. The value of FR reinforcement rate given in the text at which VI response rate is equal to preliminary baseline rate, is calculated, not drawn, from the data. The broken line illustrates how this value was obtained: it is drawn from the ordinate at the VI response rate for birds during preliminary training. Drawing a vertical line from the intersection of this line and the solid line gives the FR reinforcement rate at which no interaction occurs with VI.

lines drawn in these panels, but it does alter the distribution of points along them. If log scales are not used, a cluster of points appears at low ratio requirements, obscuring the almost linear relationship demonstrated for birds 47 and 48. Bird 52 is an exception, since a change in slope of the line occurs between FR 20 and FR 50. However, over most FR requirements, a linear relationship holds, the two lines drawn providing a good fit to the points. For each bird, it is clear that the VI component in *mult* VI FR interacts with FR to increase responding with small FR requirements (10, 20, and 50) and to decrease it at higher requirements (200 and 500). This is a typical case of behavioral contrast. When the rate of reinforcement falls appreciably lower in VI 1-min than in FR, the response rate in FR in *mult* VI FR is higher than the rate in FR in isolation. The reverse follows when the FR reinforcement rate falls below that on VI 1-min.

In Fig. 4, the lower panels show response rates in FR in the multiple schedule (closed circles) and in isolation (open circles). These panels reveal much the same relationship between the two lines drawn as in the upper panels. At low FR requirements, FR response rates are higher in *mult* VI FR; at high requirements, FR rates are higher in isolation. The FR rates in isolation were determined from FR 10 to FR 500. Response rates have been determined for FR 1 to FR 64 by Weissman and Crossman (1966), and from FR 50 to FR 150 by Felton and Lyon (1966). These results indicate that response rate increases up to FR 16, then levels off through FR 32 and FR 64. Felton and Lyon show that from FR 50 to 150 the postreinforcement pause increases. These authors took a measure of FR response rate by dividing total responses per session by session time minus the postreinforcement pauses, and showed that it declined over the FR values used. The mean rate for the session must also decline from FR 50 to FR 150. The results in Fig. 4 support both these sets of data. For all birds, response rate rises from FR 10 to FR 20, levels off, then declines from FR 50 to FR 500.

The function obtained in the upper panels for FR runs per hour against FR requirement shows a uniform decline as FR requirement increases. The reinforcement for an FR run remains constant for all FR requirements, but

Fig. 4. Upper panels give ratio requirements completed per hour against FR size for FR in isolation and in *mult* VI FR. Solid lines through the points relate to FR in the multiple schedule; broken lines to FR in isolation. Lower panels show FR response rate against FR size (log scale). Broken lines illustrate how the VI-FR column in Table 3 was calculated.

as FR size increases, the effort made or work done in completing the ratio rises. Hence, a steady drop in the rate of completing ratios would be expected. Since the response rate is linearly related to FR run-size, response rate for each FR requirement may be derived from the product of two straight lines: FR runs per hour against FR size, and FR size against FR size. Hence, the resulting function will show a maximum point, its position depending upon the particular constants involved. For the birds used, this point is about FR 20.

DISCUSSION

Defining Behavioral Contrast

Reynolds (1961b, p. 115) distinguished contrast and induction as follows: "... an interaction is called a *contrast* if it is a change in rate in a direction away from the rate prevailing in the other component . . . , or an *induction* if it is a change in a direction towards the rate prevailing in the other component." In another paper (Reynolds, 1961a, p. 57), he stated that "if the rate of responding with a red key decreases when the rate with a green increases (or increases when the other decreases), the change in rate during the presence of red is called a contrast." Hence, a change in response rates in a multiple schedule in the same direction would be termed induction. But this definition does not include the phe-

nomena referred to as "contrast" in the results described above. In *mult* VI DRL, when the rate of responding in DRL declines, the rate in VI tends to decline also. In Reynolds' terms, this is induction, not contrast. In *mult* VI FR, a reduction in FR rate leads to an increase in VI rate, so this will count as a case of contrast. But the only feature of FR and DRL schedules which gives rise to this difference is that response rates correlate with reinforcement rates inversely in DRL, directly in FR. However, it is possible to argue that a response in DRL t , say, is an IRT of t sec terminated by a peck. In this case DRL response and reinforcement rates are correlated directly. But the problem of response specification in DRL performances is avoided if contrast is defined in terms of reinforcement frequencies.

Although the changes in VI rates in the two multiple schedules investigated could be called, separately, contrast and induction, in both cases an increase in VI response rate follows a decline in reinforcement frequency in the other component. The useful changes to compare are not response rates in both components of the schedule, but the response rate in one component and the reinforcement rate in the other. Changes in the same direction in these two variables may be called contrast, changes in the opposite direction induction.

The above experiments show that behavioral contrast appears both as an increase and a decrease in baseline VI rate: if the rate of reinforcement in FR or DRL is appreciably higher than in VI, then VI rate is depressed below the rate sustained by VI in isolation. In the multiple schedules used, contrast is a regular function of the relative reinforcement rate in the component in which it appears.

DRL and FR Responding in Multiple Schedules

In interval schedules, the rate of reinforcement is largely independent of the animal's rate of responding. But in DRL and FR schedules, the animal controls its own reinforcement rate. In DRL an inverse relation holds between reinforcement and response rates, and the results suggest that there is a considerable difference between DRL rates in isolation and in *mult* VI DRL. DRL rates tended to decline in isolation as the required pause length was decreased. This result is at

variance with data obtained by Wilson and Keller (1953), who found that as the value of the DRL schedule was changed, the response rates changed in the same direction. It is possible that the sequence of schedules in this experiment affected the results obtained, but it must also be noted that the DRL times in the present experiment (15, 10, 5 sec) overlap only partially with the times used by Wilson and Keller (10, 15, . . . 30 sec). This case is strengthened by the tendency for the earlier data to show levelling off of response rates as the value of the schedule was reduced to 10 and 5 sec.

In the multiple schedules, no appreciable decline in rates was observed as the DRL time was shortened. In VI 1-min, the response pattern reinforced is a relatively simple one, but in DRL a more complex response of waiting, then pecking, is reinforced. The waiting response was not well defined in terms of physical movements, and did not display a clear topography in the four birds. Figure 2 (top panels) shows that DRL response rates are higher in *mult* VI DRL than in isolation. From the center panels in Fig. 2, it is clear that reinforcement frequencies in DRL in *mult* VI DRL (filled circles) do not exceed about 60 reinforcements per hr, the reinforcement frequency in VI 1-min. In this case, behavioral contrast should appear as less responding in the DRL component of the multiple schedule than in DRL in isolation. In fact, the reverse occurs. Response rates to DRL in isolation are lower than those to DRL in the multiple schedule, with the exception of the VI (DRL) rates. In this case, the effect of the VI schedule on DRL performance may be described as induction.

In FR schedules, the reinforcement frequency is directly proportional to the rate of responding. This gives rise to a complex situation. If the VI reinforcement rate is much below that on FR, then FR response rate will tend to rise. But such an increase in FR response rate increases FR reinforcement rate, with the result that the difference in reinforcement rates between FR and VI components is larger still. This could produce a further increase in FR responding. If this process is visualized as adding decreasing increments to FR response rate, then a limit will be reached, and performance will stabilize.

This analysis prompts the question: is there any difference between the functions relating

VI rate to FR and DRL reinforcement frequencies in the two multiple schedules used here? In Fig. 1 and 3, such a difference may be present at low rates of reinforcement. In *mult* VI DRL, as the reinforcement rate in DRL falls below 10 per hr, the VI rate appears to level off, approaching asymptotically the VI rate in *mult* VI EXT. But in *mult* VI FR, as the reinforcement rate in FR falls low, the response rate in FR may begin to decrease again.

It is known that FR schedules become relatively more aversive as the ratio requirement is increased (Thompson, 1964, 1965; Azrin, 1961; Appel, 1963), and in the present *mult* VI FR schedule the time spent in FR increases as reinforcement frequency falls. It may be that, given these two conditions of larger ratio requirements and longer time in FR, the result is induction rather than contrast. Reynolds (1961*d*) has suggested that in discrimination learning, the extinction procedure during the negative stimulus (S-) not only depresses responding to S-; but also excites responding to the positive stimulus (S+). From the *mult* VI FR results reported above, it seems that large FR schedules no longer excite VI responding, but rather inhibit it.

Contrast and Preference

Table 3 presents results taken from the upper panels of Fig. 4. Since FR runs per hour are the same as FR reinforcements per hour, it is possible to calculate the reinforcement frequencies at which FR response rates are the same in *mult* VI FR and in isolation. At the point of intersection of the two lines in each panel, the VI 1-min component in *mult* VI FR does not affect FR responding: there is no interaction from VI to FR (Table 3, VI-FR column). From the data in Fig. 3, the reinforcement rate on FR where there is no interaction from FR to VI may be evaluated. Once more, this point is calculated from fitted lines, not drawn from the data. The FR reinforcement rates where VI rates were the same as in preliminary training, when VI was present in isolation, is the rate at which no interaction occurs in this direction. Table 3 shows that where the FR reinforcement rate, which has no effect on VI response rate, is higher than the VI reinforcement rate, then the FR reinforcement rate, which prevents VI reinforcement rate affecting FR response rate, is higher also.

TABLE 3

"No-Interaction" Points in *mult* VI FR Schedules

Bird No.	Rft/hr in VI	Rft/hr in FR	
		FR-VI	VI-FR
47	60	85	91
48	60	71	68
52	60	63	61

The two estimates of the same figure (FR-VI and VI-FR columns) are in close agreement. For two of the three birds, more reinforcements are required on FR than on VI before the two components fail to interact. This result may appear strange, in view of the relativity of response rate and reinforcement rate hypothesis suggested by Reynolds (1961*d*) and supported by the present experiments. However, it has already been argued that FR schedules are aversive at high ratio requirements, and the studies quoted show that to increase the ratio requirement of an FR schedule is to make the schedule more aversive or less reinforcing. The results in Table 3 support the view that, whatever the ratio requirement, an FR schedule is more aversive (or less reinforcing) than a VI schedule which delivers reinforcements at the same rate. This could reflect a more general preference of the pigeon for reinforcement schedules which operate on a basis of units of time, rather than units of responses.

REFERENCES

- Appel, J. B. Aversive aspects of a schedule of positive reinforcement. *J. exp. Anal. Behav.*, 1963, 6, 423-428.
- Azrin, N. H. Time out from positive reinforcement. *Science*, 1961, 133, 382-383.
- Bloomfield, T. M. Two types of behavioral contrast in discrimination learning. *J. exp. Anal. Behav.*, 1966, 9, 155-161.
- Felton, M. and Lyon, D. O. The post-reinforcement pause. *J. exp. Anal. Behav.*, 1966, 9, 131-134.
- Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.
- Reynolds, G. S. Behavioral contrast. *J. exp. Anal. Behav.*, 1961*a*, 4, 57-71.
- Reynolds, G. S. An analysis of interactions in a multiple schedule. *J. exp. Anal. Behav.*, 1961*b*, 4, 107-118.
- Reynolds, G. S. Relativity of response rate and reinforcement frequency in a multiple schedule. *J. exp. Anal. Behav.*, 1961*c*, 4, 179-184.
- Reynolds, G. S. Contrast, generalization, and the process of discrimination. *J. exp. Anal. Behav.*, 1961*d*, 4, 289-294.

- Reynolds, G. S. and Catania, A. C. Behavioral contrast with fixed-interval and low-rate reinforcement. *J. exp. Anal. Behav.*, 1961, 4, 387-391.
- Thompson, D. M. Escape from S^D associated with fixed-ratio reinforcement. *J. exp. Anal. Behav.*, 1964, 7, 1-8.
- Thompson, D. M. Punishment by S^D associated with fixed-ratio reinforcement. *J. exp. Anal. Behav.*, 1965, 8, 189-194.
- Weissman, N. W. and Crossman, E. K. A comparison of two types of extinction following fixed-ratio training. *J. exp. Anal. Behav.*, 1966, 9, 41-46.
- Wilson, M. P. and Keller, F. S. On the selective reinforcement of spaced responses. *J. comp. physiol. Psychol.*, 1953, 46, 190-193.

Received May 12, 1966