CONTRAST AND UNDERMATCHING WITH REGULAR OR IRREGULAR ALTERNATION OF COMPONENTS

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Behavioral contrast and response-ratio sensitivity to reinforcement were compared in multiple schedules in which components alternated strictly or according to a pseudorandom sequence. Average component durations in the two regimes were always 60 s, and order of presentation of component alternation regimes was counterbalanced across subjects. In Part 1, the reinforcer rate in one component was reduced from 60 per hour to zero, while that in the other component was unchanged. Positive behavioral contrast occurred in the constant component in that response rates increased, but neither the reliability nor the magnitude of contrast was affected by the manner in which components alternated. Part 2 was similar, except that a number of different reinforcer rates were used in the varied component. Neither contrast nor sensitivity of response ratios to changes in reinforcer ratios depended on the regime of component alternation. Thus, the predictability in time of future reinforcement conditions, which is a feature of regular multiple scheduling, does not appear to be a determinant of multiple-schedule performance.

Key words: behavioral contrast, undermatching, component alternation, multiple schedules, key peck, pigeons

In a multiple schedule of reinforcement, two or more components are presented successively, each in the presence of a distinctive stimulus. With pigeons as subjects, the stimulus may be a color or pattern that is projected onto a response key and remains present for some time period (known as the component duration). At the end of this period, the presentation of the component ends and is followed by a new component presentation. Experimental sessions usually involve a large number of presentations of two components, but three- and four-component arrangements are also sometimes used (e.g., Williams, 1979, 1981).

Two aspects of performance in multiple schedules have been studied in detail, namely the relation between absolute response rates and reinforcer rates in components and the extent to which the distribution of responses between components varies with the distribution of reinforcers. Response rate in a component is clearly affected by the rate of reinforcement in the same component, and the phenomenon of behavioral contrast (Reynolds,

1961) reveals that it also depends on reinforcer rate in the alternate component. Behavioral contrast is found when one component is kept constant over several conditions in which the reinforcer rate in another component is varied. Contrast refers to a change in response rate during the constant component that is in the opposite direction from a reinforcer-rate manipulation in another component, and is generally taken as evidence that successively presented components of multiple schedules interact in determining response rate in any particular component (see, e.g., Herrnstein, 1970). The occurrence of contrast seems to depend on a change in relative reinforcer rate in the constant component (i.e., rate in the constant component relative to that in the varied one). Changes in response rate during the varied component that are not accompanied by changes in relative reinforcer rate (e.g., those produced by signaling reinforcement in the varied component) are not generally effective (for a review, see Williams, 1983).

Study of response distributions between components normally makes use of reinforcer-rate manipulations in both components, and the emphasis has been on quantifying the extent to which behavior distributions vary when reinforcer distributions are manipulated. A power relation between response ratios over components and reinforcer ratios was suggested by Lander and Irwin (1968); this means that a linear relation is observed on log-log

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coordinates:

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

In Equation 1, which is for a two-component multiple schedule, response rate in a component is given by P and reinforcer rate by R , and their subscripts identify the components in which these events occur. The constant a is estimated empirically and measures the sensitivity with which response ratios vary as a function of reinforcer ratios. Typical values fall in the range that describes "undermatching" of response ratios to reinforcer ratios (McSweeney, Farmer, Dougan, & Whipple, 1986), and the mode of individual-subject estimates is in the range of 0.35 to 0.55. Although the occurrence of behavioral contrast may increase estimates of sensitivity to reinforcement, the two are, in principle, independent, because sensitivity may vary even if contrast is consistently absent. $\log c$ measures bias towards one or the other component, perhaps arising from color preferences idiosyncratic to subjects. These interpretations of the free parameters are the same as in Baum's (1974) description of performances in concurrent schedules, in which components are simultaneously, rather than successively, available to the subject. Indeed, the behavioral processes that govern the control of response rates and ratios in multiple schedules have often been considered to be similar to those operating in concurrent schedules (e.g., Herrnstein, 1970; see Williams, 1982, for a discussion).

Determinants of the extent of contrast and sensitivity have been sought among procedural details relating to the way in which multiple schedules are arranged, such as the alternation of components (see especially Charman & Davison, 1982). Despite much experimental work, however, these procedural features have rather uncertain status as determinants of the extent of contrast, especially when different species are compared. The extent of contrast with pigeons pecking keys appears to be determined partly by component duration (e.g., McSweeney, 1982; Williams, 1979, 1989), but this effect is not always replicated with rats (e.g., Dougan, McSweeney, & Farmer, 1985). Contrast has also been related to the reinforcer rate or magnitude in the constant component (e.g., Harper & McLean, 1992; Nevin, 1974;

Spealman & Gollub, 1974) with stronger contrast found in a low-valued constant component, although Dougan et al. (1985) and McSweeney, Dougan, Higa, and Farmer (1986) have reported exactly the opposite relation with rats and pigeons as subjects, respectively. With regard to response-ratio sensitivity to reinforcement, there are similarly conflicting results bearing on the effectiveness of component duration; Shimp and Wheatley (1971) and Todorov (1972) obtained results consistent with very high sensitivity for short components (see White, Pipe, McLean, & Redman, 1985, for a reanalysis of Shimp and Wheatley's data), but comparisons with different component durations have not always supported this effect. For example, White et al. (1985) and Charman and Davison (1982) found no evidence of an effect of component duration on sensitivity when series of reinforcer-ratio conditions were compared, and Charman and Davison suggested that the effect may be restricted to conditions in which reinforcer rates are held constant. On the other hand, Williams (1989) varied reinforcer ratios and reported high sensitivity with 10-s components, especially when first exposures to conditions were considered, and more standard sensitivity with 120-s components. He suggested that the short-component effect may dissipate with repeated experience. Other variables studied include the level of deprivation and the overall amounts of reinforcement used in components. Reduced deprivation has been found to increase sensitivity (Charman & Davison, 1983a) but has not yet to our knowledge been satisfactorily investigated in relation to behavioral contrast. Overall amounts of reinforcement have been manipulated using different schedule values or different magnitudes of reinforcement over series of conditions in which reinforcer ratios are varied. Data reported by Charman and Davison (1982), Williams (1989), and Harper and McLean (1992) indicate no effect on sensitivity.

A number of different regimes of component alternation have been used with multiple schedules. For example, component presentations may be controlled by strict or random regimes of alternation, and may be determined by the passage of time (e.g., McLean & White, 1981, and many others), by the arrival of reinforcers (e.g., Hearst, 1961; Lobb & Davison, 1977), or by the number of responses emitted

since a component presentation began (Davison & Charman, 1987). Despite the variety of arrangements, there is little available information about how this feature of multiple scheduling may affect contrast or sensitivity.

An indication that regimes of component alternation might affect multiple schedule performance comes from consideration of the effects of component duration on behavioral contrast in pigeons. The effects of component duration may indicate that subjects responding during, say, the constant component are sensitive to the amount of time remaining before the varied component is next presented, and this time is entirely predictable in multiple schedules when components alternate regularly. When components alternate irregularly, however, the remaining time to the next component is less predictable. There are numerous situations in which the predictability of future events exerts considerable influence over behavior (such as the different patterns of responding on variable-interval and fixed-interval schedules), and the same may be true of component changes in multiple schedules. Moreover, the review of multiple-schedule performance by McSweeney, Farmer, Dougan, and Whipple (1986) provides a more empirical rationale for examining regimes of component alternation. These authors suggested, on the basis of cross-experiment comparison, that random presentation of components may affect both undermatching and bias in multiple schedules. Accordingly, the work we report here furthers the study of procedural features of multiple schedules with respect to undermatching, bias, and contrast by providing within-subject comparisons of different component alternation regimes. In Part 1, we arranged conditions in which one variable-interval (VI) component was constant and the alternated component was repeatedly reduced to extinction. In one series, components alternated regularly at intervals of 60 s. In another series, successive components were selected according to a pseudorandom sequence at intervals of 30 s. The sequence had the constraint that no more than three successive presentations of the same component could occur. Thus, the procedure effectively arranged fixed component durations of 60 s in one series and variable component durations of 60 s (on average) in the other, and behavioral contrast was compared in the two series. In Part 2, the

same regimes of component alternation were used, but the VI schedule in the varied component was varied over five values (not including extinction). Contrast and response-ratio sensitivity and bias were compared in conditions with regular versus irregular component alternation.

METHOD

Subjects

Four homing pigeons (D1, D2, D3, and D4), with brief prior experience in the same conditions as were used here, served in Part 1. In Part 2, 4 other pigeons (C1, C2, C3, and C4) with experience in strictly alternating multiple schedules were used. All birds were maintained at between 80% and 85% of their ad lib weights. Water and grit were continuously available in their home cages, and supplementary grain, given shortly after experimental sessions, helped maintain prescribed body weights.

Apparatus

Four similar experimental chambers (33 cm by 31 cm by 35 cm) each contained an interface panel. The panel had three response keys, one mounted centrally and the others 10 cm to either side of it, and each was 20 cm above the grid floor. Pecks on the center key that exceeded approximately 0.15 N produced a relay click and turned off for 50 ms the green or red lights illuminating the key from behind. Centered in the interface panel was a hopper containing wheat, which was mounted 8 cm above the floor. The hopper was operated and lit with white light for 2.5 s during reinforcement, which was arranged using Fleshler and Hoffman (1962) schedules. The remaining keys and the chamber houselight were inoperative during the experiment. Scheduling and recording of all experimental events used an IBM®-compatible computer running MED-PC® software.

Procedure

Subjects were studied daily, 7 days per week, in sessions lasting 40 min. The VI schedules, regimes of component alternation, orders in which subjects were exposed to conditions, and the number of training sessions in each condition are summarized in Tables 1 and 2. In both parts of the experiment, two series of

Table 1

Schedules used in the varied component, with orders of exposure and numbers of training sessions in each condition, for Parts 1 and 2 of the experiment. The constant component was always VI 50 s in Part 1 and VI 60 s in Part 2.

Condi- tion	Alternation	Varied component schedule (Part 1)	Varied component schedule (Part 2)
1	strict	VI 50 s	VI 15 s
2	strict	ext	VI 30 s
3	strict	VI 50 s	VI 60 s
4	strict	ext	VI 120 s
5	strict	VI 50 s	VI 200 s
6	irregular	VI 50 s	VI 15 s
7	irregular	ext	VI 30 s
8	irregular	VI 50 s	VI 60 s
9	irregular	ext	VI 120 s
10	irregular	VI 50 s	VI 200 s

conditions were used. In one series, components were presented for 60 s at a time in a strictly alternating sequence. In the other, 30-s presentations of components occurred according to a pseudorandom sequence that had the constraint that no more than three consecutive presentations of a given component could occur. Two of the 4 subjects were exposed first to the series that used irregularly alternating components, and the remaining 2 were exposed first to the series using strictly alternating components. Within each series, reinforcer rate was varied in one component and kept constant in the other. In general, subjects were trained for at least 20 sessions in each condition. In our experience, performance may fluctuate from session to session, but does not change systematically after this much training.

RESULTS

Average response rates, corrected for the time occupied by reinforcement, were calculated for each of the final 5 or 10 training sessions in each condition. For Part 1, response rates were calculated for the final five sessions; for Part 2, in which there were more training sessions in each condition, response and reinforcer rates were both averages of rates calculated for each of the last 10 sessions in a condition. Reinforcer rates were always calculated using 10 sessions' data, because daily reinforcer totals were rather variable and the larger sample provided more stable estimates.

Part 1

In Part 1, reinforcer rate in the varied component was twice reduced to zero and then returned to its baseline level in both the strict and irregular alternation series. When extinction was scheduled for the varied component, subjects always showed clear discriminations, in that response rate in this component decreased, usually to less than 20% and always to less than 50% of the rate in the constant component. There was no systematic difference in the strength of the discrimination between regimes of component alternation.

Figure 1 gives a plot of responses per minute in the constant component over the sequence of reinforcer rates in the varied component in each of the two series. Error bars give the standard deviation of response rates calculated for each of the last five sessions, and filled symbols were used to indicate those conditions in which response rate was statistically significantly ($p < .05$) different according to a t test from response rates pooled over preceding and following baseline conditions. The left part

Table 2

Conditions, with numbers of training sessions in parentheses, listed in order of exposure for each subject in Parts 1 and 2 of the experiment.

Subject		Conditions
Part 1	D1	1(34), 2(20), 3(20), 4(20), 5(20), 6(15), 7(20), 8(20), 9(20), 10(20)
	D2	1(34), 2(20), 3(20), 4(20), 5(20), 6(15), 7(20), 8(20), 9(20), 10(20)
	D3	6(34), 7(20), 8(20), 9(20), 10(20), 1(15), 2(20), 3(20), 4(20), 5(20)
	D4	6(34), 7(20), 8(20), 9(20), 10(20), 1(15), 2(20), 3(20), 4(20), 5(20)
Part 2	C1	3(30), 5(30), 2(33), 4(31), 1(38), 8(31), 10(34), 7(34), 9(31), 6(36)
	C2	3(30), 1(30), 4(33), 2(31), 5(38), 8(31), 6(34), 9(34), 7(31), 10(36)
	C3	8(30), 10(30), 7(33), 9(31), 6(38), 3(31), 5(34), 2(34), 4(31), 1(36)
	C4	8(30), 6(30), 9(33), 7(31), 10(38), 3(31), 1(34), 4(34), 2(31), 5(36)

Fig. 1. Responses per minute in the constant component over conditions in Part 1. Error bars show standard deviations of response rates calculated for each of the last five sessions in a condition. Data are shown separately for the series with strict and irregular alternation of components, and filled symbols indicate instances in which response rate in multiple VI extinction was statistically significantly different ($p < .05$) from that in the preceding and following baseline determinations. Numbers along the abscissa in each panel give response rate in the constant component as a proportion of the average rate in preceding and following baseline determinations.

of each panel gives data from the series with strict alternation, and the right part gives data obtained with irregular alternation. All birds showed some clear instances of positive behavioral contrast, in that responding during the constant component increased when the varied component was changed to extinction and decreased again when VI reinforcement was reintroduced in the varied component. However, contrast was not entirely reliable within either series, because some subjects showed contrast in only one of the two determinations used with any component alternation regime.

Across series, the extent and reliability of

contrast were similar, regardless of the component alternation regime. Over subjects, there were four statistically significant instances of positive behavioral contrast (out of eight determinations) with strictly alternating components and four with randomly alternating components (one additional instance, for D2, was ignored because of its very small magnitude). There were two statistically significant instances of induction, one of which occurred with strict alternation and the other with irregular alternation. To facilitate the comparison of contrast in the two series, response rates in the constant component were averaged for the multiple VI VI conditions conducted before

Fig. 2. Responses per minute in the constant (unfilled circles) and varied (filled circles) components, plotted as a function of reinforcers per hour in the varied component. Solid curved lines are best fitting hyperbolas. Error bars show the standard deviations of response rates in the constant component, calculated over the final 10 sessions in each condition. Upper and lower panels give data for a given subject from series with strict and irregular component alternation, respectively. (Data from Part 2.)

and after each multiple VI extinction condition, and constant-component response rates in multiple VI extinction were expressed as a proportion of this average. The resulting 16 "contrast ratios" quantify increases in response rate relative to baseline rates of responding in the two series, and are given along the abscissa in each panel of Figure 1. Contrast ratios were not statistically significantly different for strict alternation versus irregular alternation on a dependent t test ($t = -0.004$, $p = .997$).

Part 2

Part 2 was similar to Part 1, except that a number of reinforcer rates were used in the varied component in each of the two series. Figure 2 gives responses per minute in each

component, plotted as a function of reinforcers per hour in the varied component. The standard deviations of these rates over the last 10 sessions are shown by the error bars for the constant component. Upper panels give data from the series with strict alternation of components, and lower panels give those for the irregular alternation series. Data from the varied component are given as filled circles, and best fitting hyperbolas are drawn as descriptions of behavior change. There were instances of behavioral contrast in both series, in that response rate in the constant component decreased as reinforcers per hour increased in the varied component. Comparison of the two series for the 4 subjects reveals three clear differences. Birds C1 and C4 showed greater reductions in response rate for the constant com-

Fig. 3. Base 10 logarithms of response ratios plotted as a function of log reinforcer ratios. Upper and lower panels give data for a given subject from series with strict and irregular component alternation, respectively. Best fitting straight lines are drawn for each series, and the slope (a) and intercept ($\log c$) of the line is given in each case. The numbers in parentheses after parameter estimates are their standard errors.

ponent when components alternated strictly, and Bird C3 showed a greater reduction when components alternated irregularly. For Bird C2, no difference was apparent. For this subject, we studied response rates in the constant component, expressed as a proportion of average rate in that component over the entire series, to take account of a difference in overall responding in the two series. Again, contrast seemed to be identical in the two series. Thus, the results are consistent with those in Part 1, in that similar frequencies and similar magnitudes of contrast were observed whether multiple schedule components alternated regularly or irregularly.

Variation of reinforcer rates in only one component produced moderately large variation in reinforcer ratios for the study of matching performances. Figure 3 shows logarithms (base 10) of ratios of response rates plotted as a function of log reinforcer ratios. For each subject, upper panels give data from the series with strictly alternating components, and lower panels give those from the random alternation series; regression lines give plots of Equation 1. Values for a and $\log c$ are given in each

panel, and their standard errors are given in parentheses. These fits of Equation 1 provide quite good descriptions of matching performances. In particular, estimates for a (sensitivity) generally had small standard errors.

Comparison of sensitivity estimates between the two series reveals only one clear difference; Bird C2 clearly showed greater sensitivity in the series with irregular alternation. Otherwise, the functions were strikingly similar over determinations with different regimes of component alternation. Values for bias ($\log c$) were small and idiosyncratic, and changes in bias between series were not systematic. In general, the matching analyses, like those for contrast here and in Part 1, reveal no difference in performance dependent on regimes of component alternation.

DISCUSSION

When components of multiple schedules alternate regularly, the subject's responding always occurs at a known time since the previous exposure to the alternate component, and the next arrival of the other component is predictable in time. When alternation is irregular,

however, the time remaining before the next component is generally unpredictable (except during the third successive presentation of a component). The results of our comparison of these conditions revealed no differences in contrast dependent on whether components alternated regularly or irregularly. This result was obtained in two procedures involving different groups of subjects and different overall reinforcer rates. Effects on response-ratio sensitivity were assessed only once, but its value was always well estimated (the standard errors of slopes in Figure 3 were small), and differences in slopes were unsystematic and very small indeed for 3 of the subjects.

Might it be that the present procedures were atypical in some way, and that differences in contrast might yet be observed? It seems unlikely, because in many ways the performances observed here were quite typical of multiple-schedule performance. First, response rates in the varied component were a clear function of reinforcer rates (Figure 2), and the relation between them was adequately described by a hyperbolic function, as has frequently been reported. Second, log response ratios were related to log reinforcer ratios by a straight line, the slope of which was within the range reported in a review of the multiple-schedule literature. Third, although contrast was rather unreliable in Part 1, clear instances were observed in both experiments. Contrast was stronger and more reliable in Part 2, and was close to the magnitude reported elsewhere. Thus, although the work produced a null result, the phenomena of contrast and response-ratio sensitivity were well estimated here and were typical of multiple-schedule performance generally; thus, the failure to find an effect of component alternation regimes seems likely to be robust.

The within-subject assessment of component alternation regimes helps to clarify an effect noted by McSweeney, Farmer, Dougan, and Whipple (1986) in their review of the matching law applied to multiple-schedule performance. Several effects suggested by their analyses of performance in different studies did not admit tests of statistical significance for various reasons, but were noted in relation to the adequacy of Equation 1 as a theory of multiple-schedule responding. In particular, cross-experiment comparison suggested that irregular sequencing of components, the use of

a signal-key procedure, and the use of different simple schedules in components seemed to affect both the bias and undermatching parameters of Equation 1, and McSweeney et al. commented that the effect of these variables on both parameters casts some doubt on the interpretation that bias and undermatching represent independent effects on behavior. Our analysis suggests that, at least with regard to component alternation, the effect on sensitivity and bias is not robust in a within-subject procedure. Sensitivity was unaffected, and bias changes were small and not systematic in magnitude or direction, when the method of sequencing was changed. The effect noted by McSweeney et al. was based on a comparison of median parameter estimates from many studies using regular alternation versus data from one study (Dysart, Marx, McLean, & Nelson, 1974) using irregular alternation. Presumably, individual differences or other features of Dysart et al.'s procedure were responsible for the higher sensitivity estimates found in their study.

Regimes of component alternation may be of increased interest because of evidence, produced primarily by Williams (1979, 1981), that contrast is determined by forthcoming reinforcement conditions. For example, Williams (1979, Experiment 1) used four-component multiple schedules in which two equal-valued "target" components were preceded by the same reinforcement conditions, but one was followed by extinction and the other by VI 60-s reinforcement. In a second series, the order of component presentation was reversed so that the target components were both followed by the same reinforcement conditions, but were preceded by extinction in one case and VI 60 s in the other. Thus, either the following or the preceding reinforcement conditions (but not both) were different for the two target components. Differences in response rate between the two target components were more convincing when the following schedules were different than when the preceding conditions were different. Similarly, Williams (1981, Experiment 2) used a three-component schedule in which only one was varied over conditions. Changes in the value of the varied component produced contrast effects in both target components, and these were greater and more reliable in the one that preceded the varied component. Similar anticipatory effects have been

reported by Nevin, Smith, and Roberts (1987) and by Pliskoff (1963). Based on this evidence, Williams (1981, 1988) and Williams and Wixted (1986) advanced the view that contrast with pigeons as subjects is anticipatory in nature (although apparently not with rats as subjects; Williams, 1990).

Anticipatory contrast is enhanced by the use of highly discriminable stimuli (Williams, 1988), varies with component duration, and is robust over extended periods of training. Contrast due to changes in the reinforcement rate in the preceding component, on the other hand, is maximized by the use of marginal stimuli, is not always convincingly related to component duration (e.g., Williams, 1979), and is thought to dissipate with extended training. Anticipatory contrast cannot be isolated in the present procedure, but the conditions arranged here are consistent with the training and stimulus conditions known to produce it. That is, according to Williams's account, the use of highly discriminable color stimuli (see Charman & Davison, 1983b, for an empirical assessment of the discriminability of colors) and the extended training in conditions should be sufficient to ensure that the majority of the contrast observed here is anticipatory in character. If this is so, the present results suggest that anticipatory effects are not reliant on the predictability in time of forthcoming reinforcement conditions, and are reliant only on the predictability of what those conditions will be. The sensitivity of anticipatory contrast to changes in component duration may therefore be independent of the subject's ability to localize in time the change in reinforcement that occurs when components alternate; rather, sensitivity is dependent only on the average time between components.

To conclude, this work has extended the range of procedural features of multiple schedules studied in relation to behavioral contrast and to response-ratio sensitivity by comparing these aspects of multiple-schedule performance in conditions with regularly and irregularly alternating components. Contrary to the suggestion in McSweeney, Farmer, Dougan, and Whipple's (1986) review of multiple-schedule performance, we found no difference in multiple-schedule sensitivity or bias that was dependent on whether components alternated regularly or irregularly. Similarly, behavioral contrast in a constant multiple-sched-

ule component was unaffected by making component alternation irregular, and seems therefore to be independent of the predictability in time of the forthcoming reinforcement conditions.

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