BEHAVIORAL CONTRAST DURING MULTIPLE AVOIDANCE SCHEDULES¹

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Changes were observed in the rate of avoidance responding in both components of a multiple schedule of Sidman-avoidance after the shock frequency was changed in only one component. The rate change in each component was positively correlated, in direction and magnitude, with the change in the relative rate of reinforcement (percentage of total shocks) in that component.

When an animal is maintained on a two-component multiple schedule of reinforcement, performance in each component may be influenced by the conditions prevailing in both components. Extensive documentation (*e.g.*, Ferster and Skinner, 1957; Keller and Schoenfeld, 1950; Skinner, 1938) confirms a positive correlation between the performance changes in both components following a change in the reinforcing conditions (*e.g.*, the rate of reinforcement) in only one of the components. Because of the ubiquity of such generalization effects, many psychological theories of learning (*cf.*, Hilgard, 1956) have considered generalization to be the only major component interaction that may occur. More recently, however, the experiments of Reynolds (1960 *et seq.*) and Catania (1961) have directed attention to an interaction completely opposite to generalization. This interaction has been labeled contrast. During contrast, following a change in, *e.g.*, the rate of reinforcement in one multiple schedule com-

ponent, the direction of the rate changes in the two components typically is negatively correlated. For example, if the rate of positive reinforcement is increased in one component, the response rate may increase in that component but will then decrease in the other.

Contrast effects have been demonstrated in several different operant experimental situations. Contrast has been observed after a change in the frequency of reinforcement in one of two alternating schedules of positive reinforcement (*e.g.*, Findley, 1958; Schuster, 1959; Reynolds, 1961c), including the case in which extinction occurs in one stimulus (*e.g.*, Reynolds, 1960 *et seq.*; Herrick, Myers, and Korotkin, 1959; Smith and Hoy, 1954). Contrast has also appeared in behavior under aversive control by punishing stimuli (*e.g.*, Azrin, 1956; 1960; Azrin and Holz, 1961; Brethower and Reynolds, 1962). No experiments, however, have demonstrated contrast during free-operant avoidance conditioning. In studies utilizing two-component multiple schedules of Sidman-avoidance, Appel (1960a; 1960b) found the predominant rate interaction to be generalization: if the shock rate in one component was decreased, then the response rate generally decreased in both components.

The present experiment investigated whether contrast could be demonstrated during Sidman-avoidance conditioning, and sought to determine whether the effect would be modulated by parameters previously found effective during positive reinforcement. If contrast could be obtained, then appropriate empirical and theoretical conceptions of the contrast phenomenon would need not to be

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specific to the type of reinforcing situation employed.

METHOD

Subjects

Six naive adult white rats, selected from the colony maintained by the Stanford Psychology Department, were individually housed and provided with unlimited home-cage access to food and water.

Apparatus

The experimental chambers were two standard Foringer rat boxes. The two levers in each box, which were mounted on telegraph-key bases, activated normally-open microswitches to indicate responses. Stimuli were programmed and responses recorded by automatic switching circuits. The shock, delivered to the grid floor and to the levers of each box, was at a level of 1.3 ma, at 350 v dc. A scrambler reversed the polarity of the shock on each grid bar at a rate of 15 times per sec. The discriminative stimuli in each box were two GE-313 pilot bulbs, each mounted above one of the levers.

Procedure

Phase 1. Baseline Multiple Schedule Avoidance. Subjects learned to avoid shock via a modified Sidman technique (Sidman, 1953a). Each response (lever-press) postponed shock for a fixed period of time, the response-shock (RS) interval. Once the shock was turned on, a lever-press was necessary to turn it off; this (escape) response also began the next RS interval. Initially, each subject was run for 2 hr on 28 consecutive days. Each daily session consisted of 24 cycles of a two-component multiple schedule. Each cycle consisted of 5 min in component S1 and 5 min in component S2. During S1, the pilot bulb over the right-hand bulb was illuminated, while in S2 the left-hand bulb was illuminated. The lever beneath the illuminated bulb served for shock avoidance and escape. Responses on the darkened lever had no effect. Half of the subjects were trained on Mult 20-8, and half on Mult 8-20. (All time intervals are in seconds, and since all refer to RS intervals, they will not be further designated each time a schedule is described. The first number refers to the RS interval in component S1, while the second

refers to the RS interval in S2.) The RS interval was changed at the onset of each of the components, so that the first RS interval in each component was timed from onset of that component.

After the first 28 daily 2-hr sessions, the session length was increased to 48 cycles (4 hr) per day. After five days at the increased length, the next phase of the experiment was initiated.

Phase 2. Multiple Schedule Shifts. During this phase, on days designated "shift days" (usually every other experimental day), several different multiple schedules were presented during the same session. On shift days, the first 2 hr consisted of reinforcement on the baseline schedule. During the third hour, the RS interval in one component (the variable component) was altered, while the schedule was unchanged in the other component (the constant component). During the fourth hour, the baseline conditions were re-established. For example, during 4 consecutive hr on a shift day, the schedules might be Mult 8-20, Mult 8-20, Mult 12-20, Mult 8-20. On several shift days, two additional hours were included, the first of which consisted of another new multiple schedule, followed by a return to the baseline for the final hour. Table 1 indicates

Table 1
THE MULTIPLE SCHEDULES TO WHICH EACH S WAS EXPOSED

SUBJECTS	MULTIPLE SCHEDULE	NUMBER OF PRESENTATIONS
30, 83, 154	20 8	baseline
	16 8	15
	12 8	15
	8 8	15
	20 12	15
	20 16	14
	20 20	16
	20 Ext.	14
	8 20	baseline
	8 16	15
84, 151, 153	8 12	15
	8 8	14
	12 20	16
	16 20	15
	20 20	14
	Ext. 20	15

the number of times that each multiple schedule was presented to each rat, *i.e.*, the number of sessions during which a given

schedule was among those to which the rat was exposed. All the schedule shifts were accomplished without removing the subject from the experimental chamber, or by any other interruption of the experiment in progress. The several values of the RS interval in the variable component were administered to each rat several times in a non-systematic order.

RESULTS

Individual response rates for the last 14 days of baseline stabilization are shown, for two illustrative cases, in the panels of Fig. 1. The two curves in each panel are for the RS 8 component (top curve) and the RS 20 component (bottom). Differences in absolute response rates between the subjects are evident, but each rat's rates exhibit relatively low day-to-day variation. The response rates were uniformly higher during RS 8 than during RS 20; this result, similar to that reported by Sidman (1953b) and by Verhave (1959), is further

Fig. 1. Response rates for the last 14 days of initial baseline conditioning, for two subjects. The upper line indicates response rate during RS 8, the lower line during RS 20.

illustrated by some representative cumulative records (Fig. 2). Comparison with earlier findings (*e.g.*, Sidman, 1955; Verhave, *op. cit.*) indicates that the shock rates shown in Fig. 2 are higher than those obtained during prolonged single-component Sidman-avoidance. The present shock rates are comparable, however, to those obtained in a previous study of two-component multiple schedule Sidman-avoidance (Appel, 1960a). While the present shock rates might thus be due to some aspect of the multiple schedule, they were not due to responding on the incorrect lever; all subjects became adept, early in conditioning, in responding on the appropriate lever, so that fewer than 10 "errors" per session occurred after the first few training sessions.

Small "spontaneous" daily fluctuations were observed in the baseline response rates. These rate changes exhibited a mild positive correlation, although the detail in Fig. 1 is insufficient to reveal this. The tetrachoric correlation coefficient for the direction of these rate changes was +.28, which, with 78 cases, is significantly different from zero ($p < .014$). This small positive correlation could be an example of generalization, or the result of daily variations in uncontrolled factors that had a common effect upon performance in both components. The etiology of this positive correlation is immaterial at present. Its importance lies in its subsequent comparison with the extreme negative correlation of response rates observed during the shift-schedule (contrast) procedure.

The response rate curves in Fig. 3 illustrate the performance of two rats during a series of schedule shifts. These rates, calculated from the last half of the session time during which each schedule was in effect, indicate the presence of large schedule effects on the response rates in both components. In the variable component, the rate of responding changed markedly with changes in schedule. Thus, when the RS interval in the variable component (RS_v) increased, the response rate in that component (R_v) decreased; conversely, when RS_v decreased, R_v increased. Of greater interest is the consistent occurrence of contrast in the constant component response rate (R_c). For example, when RS_v increased and R_v decreased, rate R_c increased; likewise, when RS_v decreased and R_v increased, rate R_c decreased. The regularity of this negative cor-

Fig. 2. Cumulative response records during 2-hr sessions on the baseline schedule. In Fig. 2a, S-83 is pictured during Mult 20-8; Fig. 2b is the record of S-84 during Mult 8-20. The slash marks on the records indicate shocks. The width of the slash is the shock duration. The horizontal line beneath each record indicates which component was present: the line is raised during S2, and is lowered during S1. The response pen reset at the end of component S2, i.e., every 10 min.

relation between the rate changes in the two components, evident in Fig. 3, was found uniformly in the records of all six rats.

The degree of change in the response rate in the variable component, R_v , was propor-

tional to the degree of change in RS_v . This result is illustrated in Fig. 4a. The upper curve in this figure indicates the changes in R_v effected by shortening RS_v from the baseline value of RS 20. Each of the points on this

Fig. 3. Response rates during multiple schedule shifts. Representative samples from several successive shifts are presented for two subjects. Two curves appear on each rat's record, one for each schedule component. The successive RS intervals in each component are indicated on the figure.

curve represents an average value, for the six subjects, of the ratios of the response rate during a shift in value of RS_v , to the rate in that component during RS 20 baseline performance. For example, when RS_v was changed from RS 20 to RS 12, Fig. 4a shows that R_v increased to an average value 1.73 times greater than the rate during the RS 20 baseline. In an analogous fashion, the lower curve in Fig. 4a illustrates the decrease in R_v when RS_v was shifted from the baseline value of RS 8 to longer RS intervals.

A similar set of ratios, calculated from the rate changes in the constant component, is illustrated in Fig. 4b. These results indicate that the magnitude of the change in rate R_c , like the change in rate R_v , is correlated with the amount of change in RS_v . The upper curve in Fig. 4b shows the increase in R_c in the RS 20 component when RS_v was lengthened from its baseline value of RS 8. This curve may be compared to the lower curve in Fig. 4a, which illustrates the concurrent decrease in R_v when RS_v was lengthened from RS 8. In a

Fig. 4. Average change in response rate in each schedule component as a function of the change from the baseline schedule in the variable component. Each point is the average rate during one RS interval, relative to the average rate during the baseline RS interval in that component. Fig. 4a illustrates the rate changes in the variable component, while Fig. 4b shows the rate changes in the constant component. The abscissa label for each point gives the sequence of values of RS_v that produced the observed rate change. The upper row of RS_v sequences corresponds to the upper curve in each of the two panels of the figure.

similar fashion, the lower curve in Fig. 4b illustrates the decrease in R_c in the RS 8 component when RS_v was shifted from RS 20 to shorter RS intervals. This latter curve may be compared to the upper curve in Fig. 4a, which depicts the concurrent increase in R_v correlated with decreases in RS_v .

The two curves in Fig. 4b indicate that the rate changes in the constant component are opposite in sign and also smaller in magnitude than the rate changes in the variable component. The differential magnitude of the rate changes may be partly understood in terms of the observation that in the variable component there were changes both in the RS interval and in the relative shock rate (percentage of total shocks), whereas in the constant component only the relative shock rate changed. The relative shock rate in each component was found to be a powerful variable in controlling the relative rate of avoidance responding in that component. An index of this control may be obtained by a plot of the relative response rate r in a component, against

the relative shock rate a in that component. The relative response rate in the constant component, S1, during the n^{th} in a series of multiple schedules defined as $r_{1,n} = R_{1,n} / (R_{1,n} + R_{2,n})$, where R_1 and R_2 are the response rates in components S1 and S2, respectively. The relative shock rate in S1 is likewise defined as $a_{1,n} = SH_{1,n} / (SH_{1,n} + SH_{2,n})$, where SH_1 and SH_2 are the shock rates in the two schedule components. A scatter plot of $r_{1,n}$ against $a_{1,n}$ is shown in Fig. 5, where each baseline session and each schedule shift contributed single points to the plot. The relation between these variables was found to be approximately linear: a least-squares fit of a straight line to the data yielded a positive slope of .75 and an intercept of .08. This linear relation resembles that reported by Reynolds (1961c) for such a function during multiple schedules

of positive reinforcement, where the slope of the best-fit line was .80 and the intercept was .13.

Although the relation between $r_{1,n}$ and $a_{1,n}$ is an index of the degree of control maintained by the reinforcement schedule over the subject's behavior, it is not a measure of contrast. The variables, r and a , are calculated from the response and shock rates prevailing during a single multiple schedule. Contrast, however, refers to a particular relationship between the changes in the response and reinforcement (shock) rates during two successive multiple schedules. The occurrence of contrast requires the difference between the response rates in the constant component of two successive multiple schedules to be opposite in algebraic sign to the difference between the response rates in the variable component. This defini-

Fig. 5. Relative response rate as a function of relative shock rate. Individual data points are plotted for the six subjects. The solid line was calculated by the method of least squares.

tion requires that several conditions be met, *viz.*, that during at least some short period after a shift in schedule, (a) the shift in RS_v changes the shock rate in that component, SH_v ; (b) there is a change in R_v that is positively correlated with the change in SH_v ; and (c) the shock rate in the constant component, SH_c , remains fixed. That is, if the schedule shift in the variable component did not produce at least some transitory change in SH_v , then there would be no change in the effective schedule against which to assess any concurrent changes in response rate. And, under these conditions, if R_v were to change, then variables other than shock rate would need to be invoked as the determinants of response rate. Further, if R_v were to remain constant after a change in RS_v and SH_v , then the degree of control exercised by the nominal conditions of reinforcement would be questionable (*cf.*, Sidman, 1953b). Lastly, if changes were observed in both R_c and SH_c after a schedule shift, then the changes in R_c could be explained largely by reference to the

changes in SH_c , and explanatory concepts such as contrast would not need to be invoked.

If the above conditions are found or are assumed to be met, then contrast is illustrated in Fig. 4b, in which the average magnitude of the change in R_c is shown to covary with the magnitude of the difference between the baseline and shift schedule values of RS_v . Likewise, given these same conditions, Fig. 5 illustrates that contrast is a function of the relative shock rate in the constant component. The first of these conditions may be inferred from Fig. 1, the second is met by the data presented in Fig. 4a, and the third is illustrated in Fig. 7 (below). However, a more powerful demonstration of contrast would be provided by a demonstration of a positive correlation between the change in a_c and the corresponding change in R_c , during each shift from any multiple schedule, n , to the next multiple, $n + 1$. In this description, no requirement is placed upon the changes in the shock rates in the two components, since the values of these variables would be used in the calculation of $a_{c,n}$ and $a_{c,n+1}$. Such a description would also clearly illustrate contrast as a

Fig. 6. Absolute response rate as a function of relative shock rate. On the abscissa is indicated the ratio of the percentages of total shocks during the constant component of any two successive multiple schedules, n and $n + 1$. Individual points are plotted for the six subjects. The solid line is an average fit of these points.

sequential effect that occurs after a schedule shift, since no averaging of rates during various exposures to each schedule (*cf.*, Fig. 4b) would influence the correlation between the successive changes in R_c and in a_c . This conception of contrast is presented in Fig. 6, where the ratio, $R_{c,n+1}/R_{c,n}$ is plotted as a function of $a_{c,n+1}/a_{c,n}$. Fig. 6 shows that during two successive multiple schedules, n and $n + 1$, the direction and magnitude of the changes in the response rate in the constant component are positively correlated with the changes in the relative shock rate in that component.

It is further shown, in Fig. 7, that the average value of SH_c does not change in such a way as to contribute to the changes in R_c . The relatively flat functions in Fig. 7 indicate that the absolute number of shocks in the constant component does not vary systematically with the concurrent changes in the relative shock rate in that component. This finding implies that the changes in the relative shock rates are determined principally by the changes in the number of shocks in the variable component of the schedule. Hence, the changes in R_c that are observed when a_c is changed (*cf.*, Fig. 4b, 5, 6) are truly examples of contrast.

DISCUSSION

The present results demonstrate several aspects of performance during two component multiple schedules of Sidman-avoidance. The findings illustrated in Fig. 5 show that from the changes in the relative shock rates in the two components, the magnitude (but not the direction) of the changes in the avoidance response rates may be predicted. From this finding, it may be inferred that the changes in the relative shock rates are determined principally by the changes in the number of shocks in the variable component of the schedule. This similarity indicates the presence of some degree of functional apposition in the control of free-operant behavior by aversive and by appetitive stimuli.

The occurrence of contrast after each schedule shift is depicted in Fig. 6. This figure shows that a change in the relative shock rate in the constant component produces a reliable change in both the magnitude and the direction of the absolute rate of avoidance responding in that component. Thus, the ratio of the response rates, $R_{c,n+1}/R_{c,n}$ is increas-

ingly greater or less than unity in accordance with like changes in the relative shock rate. However, the magnitude of the change in R_c for a given change in a_c does not seem to be much affected by the direction of the change in a_c . In comparison, Reynolds (1961b, p. 115) reports that during positive reinforcement contrast, the rate change in the constant component is greater when the relative rate of reinforcement in that component increases. The findings depicted in Fig. 6 are consistent, however, with the observation by Sidman (1953b) that absolute response rate is a function of the RS interval (proportional to the shock rate) during single schedules of Sidman-avoidance.

Fig. 7. Average number of shocks in the constant component of a multiple schedule as a function of the average percentage of shocks in that component. The points on each curve are average values of the shock rates for all subjects.

While contrast may be described by indices derived from response averages (*cf.*, Fig. 4, 5, 6), it would be of interest to isolate the precise event sequence that produced the overall changes in response and shock rates. Although no apparatus was available for the quantitative recording of such sequential information, close examination of the cumulative records suggested that the changes in R_c , *i.e.*, the contrast effects, were largely due to changes in the length of post-shock bursts. Such changes in burst length may account for the result that SH_c was roughly constant despite changes in R_c (*cf.*, Fig. 7), since changes in length would affect overall response rate but would negligibly influence average shock frequency.

The present finding of contrast during avoidance conditioning, when compared to the results of previous studies, suggests that contrast may be a relatively general phenomenon that occurs during discrimination formation in behavior under aversive control. For example, Appel's results illustrate a small but consistent contrast effect during the first few days of exposure to a multiple schedule of Sidman-avoidance and extinction, following initial conditioning during which either the avoidance contingency was present in both components (1960a, Fig. 1, 2), or during which free shocks occasionally appeared during the extinction component (1960b, Fig. 9). Likewise, Azrin (1960, p. 606) has reported that contrast appeared as a "temporary increase in responding" during VI positive reinforcement, after each response was no longer followed by a punishing shock. In another study, Azrin (1956) found that if intermittent free shocks were superimposed upon responding during one component of a Mult VI VI schedule of positive reinforcement, then the response rate tended to increase during the other component. When operant behavior is under the control of positively reinforcing stimuli, contrast likewise occurs during the learning of a discrimination of the conditions of reinforcement associated with several sequentially-presented stimuli (Reynolds, 1961d).

Outside the free-operant conditioning situation, apparently similar sequence effects have been reported in psychophysics since Fechner (in Woodworth, 1938) first observed that the second of two equal weights lifted in succession was apt to be reported as heavier. Another such finding was that by Bacon,

Rood, and Washburn (1914) of the "law of affective contrast", *viz.*, that an aversive situation may be reported by human subjects as "pleasant" if a more aversive situation has preceded it, *etc.* In more recent experimentation, Bevan and Adamson (1960) have shown that human subjects' reports of "apparent shock intensity" changed with the amplitude of a pre-test "adapting" shock. These experimenters also showed that effectiveness of a given shock intensity as a punishing stimulus (for errors during learning of a stylus maze) varied inversely with the intensity of the adapting shocks. Black, Adamson, and Bevan (1961) similarly found that the speed of running by rats in a straight alley to escape an electrified grid floor varied inversely with the intensity of a series of adapting shocks administered just before runway performance.

If the processes of discrimination and contrast are in fact thus closely linked, then contrast magnitude should be influenced by the discriminability of the stimuli associated with each schedule component. Since generalization decreases as the disparity between two stimuli increase (*e.g.*, Kimble, 1961, p. 331, *ff.*), the likelihood and the magnitude of contrast should increase with an increasing difference between the stimuli associated with each schedule component. No direct tests of this effect have been reported, but it has been shown that, during positive reinforcement, if the stimuli and the responses are the same in both components (yielding a mixed schedule), then generalization, rather than contrast, occurs (Reynolds, 1960). A similar result was obtained with mixed avoidance schedules in preliminary work in the present study, in that only generalization effects were observed. When the stimuli were different but the responses the same (*i.e.*, only one lever available in both components), small contrast effects appeared on somewhat more than half of the schedule shifts. Similarly, the small and transitory contrast effects observed in Appel's and Azrin's data (*op. cit.*) were obtained with a single lever in both components of the multiple schedule. And, in the present experiment, where the stimuli and responses both differed, large contrast effects uniformly appeared. It thus seems that two different operanda, one for each component, facilitate the appearance of a large and consistent contrast effect during Sidman-avoidance, while only

one operandum is necessary for this effect during positive reinforcement (Reynolds, *op. cit.*). This result may indicate that responding during Sidman-avoidance is under less exteroceptive discriminative stimulus control than during some schedules of positive reinforcement. Such an interpretation would be consistent with the results obtained by Hearst and his co-workers (1960 *et seq.*), which show that gradients of stimulus generalization are broader during Sidman-avoidance than during, *e.g.*, VI schedules of positive reinforcement. Since Reynolds (1961d) has found the processes of contrast and discrimination to be closely linked during positive reinforcement, it would appear that, in general, similar properties are manifested by the contrast phenomenon in its occurrence in behavior under the control of positive and negatively reinforcing stimuli.

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