AN ANALYSIS OF INTERACTIONS IN A MULTIPLE SCHEDULE

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Multiple schedules of reinforcement may bring several different rates of responding under the control of several different exteroceptive stimuli (Ferster & Skinner, 1957). Occasionally, the rate of responding during the presentation of one of the stimuli may be altered by changing only the schedule of reinforcement associated with one of the other stimuli (e.g., Herrnstein & Brady, 1958). A change in the rate of responding during the presentation of one stimulus, brought about by changing the schedule of reinforcement associated with a *different* stimulus, is called an interaction.

Interactions may be studied by reinforcing an organism on a sequence of two-component multiple schedules. For example, suppose a multiple schedule in which both components are variable-interval reinforcement (mult VI VI) is changed to a multiple schedule in which the first component is variable-interval reinforcement and the second component is extinction (mult VI EXT). In the first component of these two multiple schedules, responding is continually reinforced on the same schedule, whereas in the second component the schedule is changed from reinforcement to extinction. When the second component is changed from reinforcement to extinction, the rate of responding in the first component (maintained on the VI schedule) may be unaffected, or it may increase or decrease. If the rate of responding in the first component increases or decreases when the other component becomes extinction, the components of the multiple schedule are said to interact.

The sequence of schedules, mult VI VI, mult VI EXT, may reveal another interaction: the extinction curve in the second component may itself differ from extinction curves obtained under different conditions.

The present experiment systematically studies the possible interactions in a two-component multiple schedule. In the first series of procedures, the component schedules in the multiple schedule were either reinforcement on a variable-interval schedule (mean interval of 3 minutes) or extinction (VI series). In the second series, the component schedules were either reinforcement on a variable-ratio schedule (150 to 1) or extinction (VR series).

METHOD

Apparatus

The experimental chamber was a modified picnic icebox similar to that described by Ferster and Skinner (1957). A standard response key, 0.75 inch in diameter, was mounted on one wall of the chamber. The minimum effective force for operating the key was about 20 grams. The key could be transilluminated by red, green, orange, or blue lamps fixed behind it. Beneath the key was a 2-inch-square opening through which the pigeon was occasionally given access to grain for 3 seconds. The chamber was illuminated by two 6-watt lamps. White noise masked most extraneous sounds.

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Subjects

Four adult, male White Carneaux pigeons, numbered 34, 35, 36, and 37, were maintained at 80 per cent of their free-feeding body weights. They had previously been trained to peck a key for food reinforcement on several schedules. All four pigeons were used in the VI series. Pigeons 36 and 37 were used in the VR series.

Procedure

A daily, 3-hour experimental session consisted of 30 cycles of a two-component multiple schedule. Each cycle was 6 minutes long; the key was illuminated with light of one color (red or orange) for the first 3 minutes and with light of a different color (green or blue) for the last 3 minutes. Various sequences of multiple schedules were studied. Tables 1 and 2 present the sequences and show also the number of sessions for which each schedule was in force. The schedules were changed when the performance appeared to have reached stability. During all sessions in which one component was extinction, reinforcements that were set up but not collected during the first VI component were not carried to the next VI com-

Table 1

Variable-interval Series

Pigeons 34 and 35		Pigeons 36 and 37	
Schedule	Number of Sessions	Schedule	Number of Sessions
VI VI	7	VI VI	5
EXT VI	5	EXT VI	5
EXT EXT	3	EXT EXT	3
VI VI	5	VI VI	3
EXT VI	5	EXT VI	3
VI EXT	6	VI EXT	11
EXT EXT	4	EXT EXT	2
EXT VI	3 (5 for 35)	EXT VI	6
EXT EXT	4 (3 for 35)	EXT EXT	2 (3 for 36)
EXT VI	4	EXT VI	2 (3 for 37)
VI EXT	5	EXT EXT	2
VI VI	4 (3 for 35)	VI EXT	4
EXT EXT	3 (4 for 35)	VI VI	4
EXT VI	6	EXT EXT	4
		EXT VI	6
		VI EXT	5
		VI VI	6
		VI EXT	7
		EXT EXT	4
		EXT VI	5
		VI VI	5
		VI EXT	6
		VI VI	4

Table 2

Variable-ratio Series

Pigeons 36 and 37		Pigeons 36 and 37	
Schedule	Number of Sessions	Schedule	Number of Sessions
VR VR	7	EXT VR	4 (3 for 37)
EXT VR	5	EXT EXT	3 (4 for 37)
EXT EXT	4	EXT VR	4
VR VR	6	VR EXT	5 (4 for 37)
EXT VR	4	VR VR	4
VR EXT	6	EXT EXT	4
EXT EXT	4	EXT VR	4

ponent. When both schedules were VI, all reinforcements were carried to the next component.

RESULTS

The number of responses emitted in each component of the multiple schedule during each session is shown in Fig. 1 for a representative bird from the VI series and in Fig. 2 for a representative bird from the VR series. In each graph the abscissa is divided into daily sessions, the ordinate into units of 1000 responses.

The data have been broken down into the four possible sequences of successive conditions in one component of the multiple schedule. A component may be maintained on the reinforcement schedule (VI or VR) during two successive phases of the experiment (shown in Part A of Fig. 1 and 2); it may be maintained on extinction (Part B); it may be changed from reinforcement to extinction (Part C); or it may be changed from extinction to reinforcement (Part D). Each graph shows the responding in a component whose sequence of schedules was one of these four. The particular sequence appears in the heading at the top of the graph. The first schedule in the heading was in effect during the session labeled 0; the second schedule was in effect during all subsequent sessions.

For each of these four possible sequences of schedules in one component of the multiple schedule, the data are further broken down in terms of the sequence of two schedules in the *other* component of the multiple. For example, Part A contains two curves, both showing responding in the component that is maintained on reinforcement. The experimental procedures giving rise to the two curves differed only in the sequence of schedules in the other component. This sequence appears as a label for each curve. A comparison of the two curves may show that responding in a component that was maintained on reinforcement is influenced by changes in the sequence of schedules associated with the other component.

Every change in the multiple schedule yields two curves. For example, let mult VI VI be changed to mult VI EXT. One curve is based on responding in the first component. Since the schedule in this component was maintained as VI, the curve is plotted in Part A. This curve's label would be VI-to-EXT, which is the sequence of schedules in the second com-

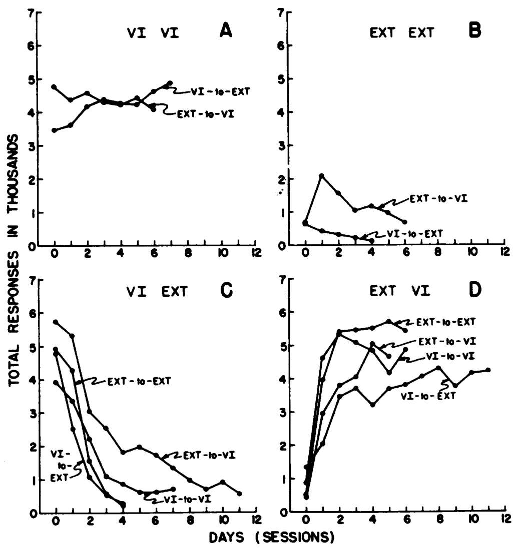

Figure 1. The total number of responses per session in one component of a two-component multiple schedule in the VI series. The sequence of schedules in that component is given as the heading of each part of the figure. The sequence of schedules in the other component is given as the label of the separate curves.

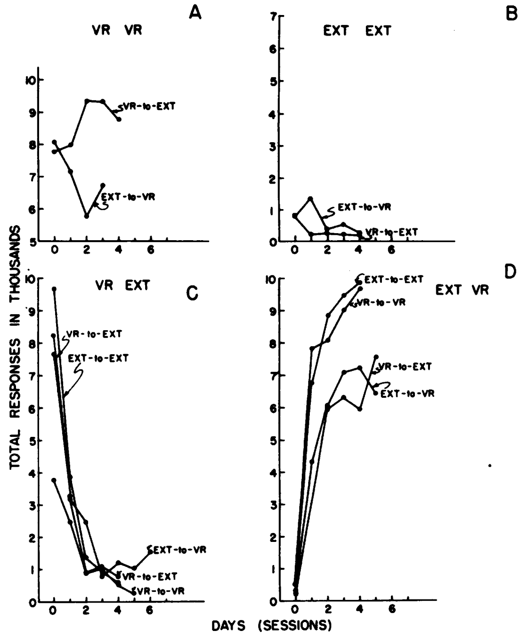

Figure 2. The total number of responses per session in one component of a two-component multiple schedule in the VR series. The sequence of schedules in that component is given as the heading of each part of the figure. The sequence of schedules in the other component is given as the label of the separate curves.

ponent. Another curve, based on responding in the second component, would be plotted in Part C and would be labeled VI-to-VI. The first point on the curve is for the original multiple schedule (in the example, mult VI VI), and the remaining points are for the second multiple schedule (mult VI EXT).

The individual functions from all birds are summarized in Fig. 3 for the VI series and in Fig. 4 for the VR series. These two figures show normalized curves, averaged over birds, for each procedure. For example, the VI-to-EXT curve of Part A in Fig. 3 was obtained by normalizing and averaging four VI-to-EXT curves, one of which is shown in Part A of Fig. 1. Normalization consisted in dividing the number of responses in each session by the number of responses in Session 0.

In order to facilitate comparison between the curves generated by similar procedures in the VI and the VR series, each part of the results will be presented first for the VI series and then for the VR series.

Interactions with VI VI

Part A of Fig. 1 shows the number of responses per session in the component of the multiple schedule that was maintained on the VI schedule. The average curves are shown in Part A of Fig. 3. There are two curves because the sequence of schedules in the other component of the multiple was either from VI to extinction or from extinction to VI. If this change of schedule in the second component had no effect upon responding in the component that was maintained on VI reinforcement, then two identical horizontal lines would be found in Part A. That is to say, the responding under VI would be constant and independent of the schedule with which it was alternated. There would be no interactions.

The lines are neither identical nor horizontal, indicating that there is an interaction. The curve of VI responding is partly a function of the schedule in the other component. In Sessions 1 to 7, when VI was changed to extinction in one component, the number of responses in the component that was unchanged gradually increased (VI-to-EXT curve). When extinction was changed to VI, the responding in the first component decreased (EXT-to-VI curve). A VI schedule of reinforcement generates a higher rate of responding when it is alternated with an extinction component than when it is alternated with a

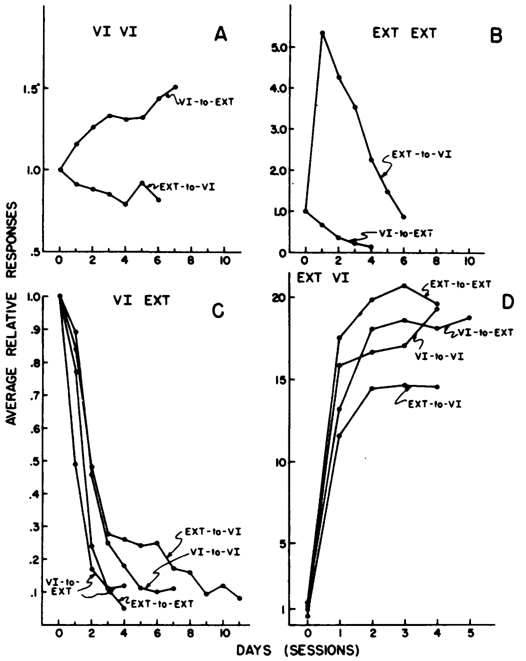

Figure 3. Average normalized curves for the VI series.

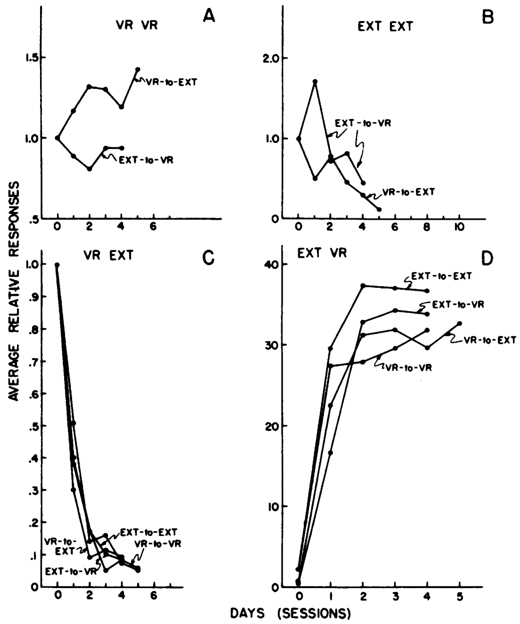

Figure 4. Average normalized curves for the VR series.

VI component. The same effect is seen at Session 0, where the final ordinates of the curves are reversed.

Interactions with VR VR

Part A of Fig. 2 shows the number of responses per session in the component that was maintained on the VR schedule. The curve of VR responding is also partly a function of the schedule in the other component of the multiple. A higher rate of responding is maintained by a VR schedule when it is alternated with an extinction schedule (VR-to-EXT curve) than when it is alternated with a VR schedule of the same mean value (EXT-to-VR curve). The same effect is seen at Session 0, where the final ordinates of the curves are reversed.

Interactions with EXT EXT (VI series)

Part B of Fig. 1 shows the number of responses per session in a component whose schedule was maintained as extinction. The presence of interaction is again shown by deviations from straight, horizontal lines. The change from VI to extinction in the second component decreases the rate of responding in the unchanged extinction component (VI-to-EXT curve). The sequence EXT-to-VI in the second component generates a transitory increase in responding in the unchanged component. Note that the EXT-to-VI curve ends approximately when the VI-to-EXT curve begins.

Interactions with EXT EXT (VR series)

The change from VR to extinction in the second component decreases the rate of responding in the first component (VR-to-EXT curve Part B, Fig. 2). The change from extinction to VR in the second component generates a transitory increase in responding in the unchanged component. The increase in responding in the EXT-to-VR curve occurs only in Session 1. By Session 2, the number of responses is below the number of responses in Session 0.

The EXT-to-VI and EXT-to-VR curves may be broken down further, according to the multiple schedule that just preceded extinction in both components. Any one of the multiple schedules, VI VI, EXT VI, and VI EXT, may precede the sequence EXT EXT, EXT VI. When the penultimate multiple schedule is VI VI, the performance under the final EXT VI schedule is simply the formation of a discrimination after extinction in both components. When the penultimate schedule is EXT VI, the performance under the final EXT VI schedule is the re-formation of a discrimination after extinction in both components. And when the penultimate schedule is VI EXT, the performance under the final EXT VI schedule is the reversal of a discrimination after extinction in both components.

The separate curves for every bird are shown in Parts A through F of Fig. 5. The ordinate is divided into units of 1000 responses, and the abscissa into sessions. Graphs A, B, C, and D show the responding of the four pigeons in the VI series; Graphs E and F show the responding of Pigeons 36 and 37 in the VR series. The curves in each graph show responding for a component whose sequence of schedules was EXT-to-EXT, while the sequence in the other component was EXT-to-VI (or -VR).

Each graph contains three curves. The procedures that produced the separate curves differ only in the penultimate multiple schedule to which the organism was exposed. The curves are labeled with this schedule. In addition, the curves in Part C are labeled with the type of discrimination that they represent: formation, re-formation, or reversal of a discrimination. For example, the EXT VI curve shows the responding in the first component of the third schedule in the sequence of multiple schedules: EXT VI, EXT EXT, EXT VI. Since this procedure is the re-formation of a discrimination after extinction in both components, the curve is also labeled re-formation.

The average normalized curves for each procedure are shown in Fig. 6. Before averaging, the curves for each bird were normalized by dividing the number of responses in each session by the average number of responses in the three curves in Session 0. This method of normalization tends to exaggerate the distance between the curves.

These results show that responding during the formation of a discrimination after mult EXT EXT is partly a function of the schedule to which the organism was exposed prior to extinction in both components. The VI EXT curve is above the EXT VI curve in each graph of the VI series; the VR EXT curve is above the EXT VR curve in each graph of the

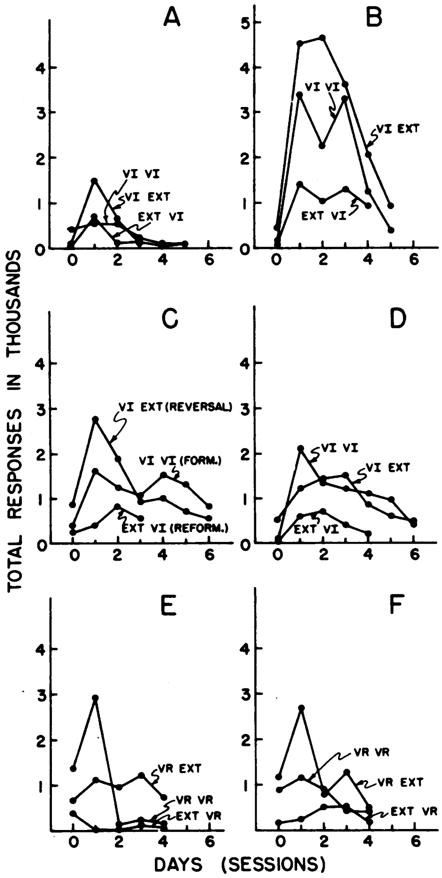

Figure 5. The total number of responses per session in one component of a two-component multiple schedule. The schedule of reinforcement in the first component, from which responding is plotted, was extinction in all sessions. The schedule in the second component was changed from extinction to VI (Parts A, B, C, and D) or VR (Parts E and F) reinforcement at Session 1. The label of each curve is the penultimate multiple schedule to which the pigeon was exposed before the change from extinction to reinforcement in the second component. Parts A, B, C, and D show the responding of Pigeons 34, 35, 36, and 37, respectively; Parts E and F, of Pigeons 36 and 37.

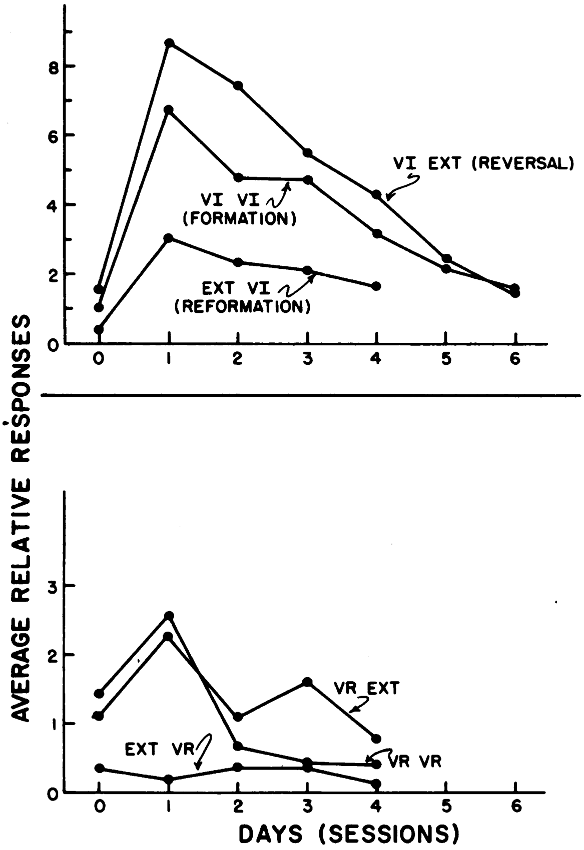

Figure 6. Average normalized curves for each procedure in the VI series (Part A) and the VR series (Part B). The curves are derived from those in Fig. 5.

VR series. The VI VI and VR VR curves are variable but usually lie between the other two curves. The amount of responding in the component maintained on extinction during the final EXT VI schedule is greatest for discrimination reversal and least for the re-formation of a discrimination. The simple formation of a discrimination generates an amount of responding that is usually intermediate between re-formation and reversal.

Interactions with VI EXT

In the first two parts of the results (A and B of Fig. 1), responding has been plotted from a component whose schedule was the same for all sessions. The interactions were deviations from a hypothetically constant number of responses per session in the component with a constant schedule, when a change of schedule was made in the other component of the multiple. In Parts C and D, a change in schedule is made in the component that is examined for interactions. The schedule in the other component is either changed or kept constant. Since the component that is plotted undergoes a change in schedule, interactions will be deviations from a regular adjustment of responding to the new schedule. For example, an extinction curve in one component of a multiple schedule may depend upon the schedule in the component with which it is alternated.

Part C of Fig. 1 shows four extinction curves, all of which come from components in which the schedule in Session 0 was VI reinforcement and in subsequent sessions was extinction. Each curve represents a particular sequence of schedules in the other component. This sequence is listed beside the curve to which it refers. Again, the first schedule refers to Session 0, the second to the subsequent sessions.

The extinction curves differ in slope. Those generated by the sequences VI-to-EXT and EXT-to-EXT in the second component have a steeper slope than those generated by the sequences VI-to-VI and EXT-to-VI. The decrease in responding in a component that is extinction after VI reinforcement is influenced by the schedule in the component with which it is alternated. The decrease is most rapid—extinction after reinforcement is most accelerated—if the other component also changes from VI to extinction or is maintained on extinction. The decrease is less rapid if the other component is maintained on VI or is changed from extinction to VI.

Interactions with VR EXT

Part C of Fig. 2 shows responding from a component in which the schedule in Session 0 was VR. The schedule in subsequent sessions was extinction. There are no consistent differences among the extinction curves.

Interactions with EXT VI

Part D shows the number of responses per session in a component of a multiple schedule that is extinction at Session 0 and is changed to VI for all subsequent sessions. The number of responses in Session 0 is least for the curves labeled EXT-to-VI and EXT-to-EXT. For each of these curves, Session 0 consisted of the schedule mult EXT EXT. The subsequent curves of responding under VI show that the number of responses per session is highest when the schedule in the other component is maintained as extinction (EXT-to-EXT curve, Part D).

Interactions with EXT VR

Part D of Fig. 2 shows the four reconditioning curves from the VR series. The EXT-to-EXT curve is higher than the other three curves in the last three sessions.

The interactions with VI VI and VR VR (Part A), EXT EXT (VI and VR series) (Part B), VI EXT (Part C), and EXT VI and EXT VR (Part D) show that responding under a schedule of reinforcement or nonreinforcement in one component of a multiple schedule is affected by the schedule or sequence of schedules in the other component. The fundamental effects of reinforcement and extinction still occur, however. Responses that are followed periodically by reinforcement increase in frequency; responses that are not followed by reinforcement decrease in frequency. The number of responses in each session in Part A, where responding is reinforced, is higher than the number of responses in any session in Part B, where responding is not reinforced. All the curves in Part D have positive slopes since responding is reinforced, and all of the curves in Part C have negative slopes since responding is extinguished after having been reinforced. Interactions are deviations from the curves regularly generated by the procedures of reinforcement and extinction.

DISCUSSION

The number of responses emitted on a schedule of reinforcement during the presentation of one stimulus may be altered by changing the schedule associated with a *different* stimulus. A change in the rate of one discriminative operant, brought about by changing the schedule of reinforcement of a different discriminative operant, is called an interaction.

Each of the various interactions in the results may be classified in terms of the *direction* of the interaction (rate change) with respect to the rate of responding (1) in the component in which it occurs and (2) in the other component. In the component in which it occurs, an interaction is either an increase or a decrease in the rate of responding. An interaction may also be classified as a change in a direction toward or away from the rate generated in the other component of the multiple schedule.

Each of these two classifications of changes of rate distinguishes two types of interactions. In the classification based on the rate of responding in the component in which it occurs, an interaction is called *positive* if it is an increase in responding or *negative* if it is a decrease in responding. In the classification based on the rate prevailing in the *other* component, 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 (cf., Skinner, 1938), or an *induction* if it is a change in a direction toward the rate prevailing in the other component. A *positive contrast*, for example, would be an increase in the rate of responding in one component in a direction away from the rate prevailing in the other component.

Positive and negative contrast may occur with behavior in a steady state or with behavior in the process of changing. Part A of Fig. 3 and 4 shows these contrasts with steady-state behavior maintained by VI or VR reinforcement. The rate of responding increases in a component whose schedule is maintained as reinforcement when the schedule in the other component is changed from reinforcement to extinction (VI-to-EXT and VR-to-EXT curves of Fig. 3 and 4). This increase in rate is called a contrast because the rate in the other component does not also increase. Since the interaction is also a net increase in responding, it is called a positive contrast. A decrease in responding (a negative contrast) occurs when the schedule in the other component is changed from extinction to VI or VR reinforcement (EXT-to-VI and EXT-to-VR curves, Fig. 3 and 4). The decrease in negative contrast is typically not so great as the increase in positive contrast.

Part D of Fig. 3 and 4 shows a contrast during the process of reconditioning. The change from extinction to reinforcement in one component naturally results in an increase in responding. The increase in responding in reconditioning is greatest when the schedule in the other component is maintained as extinction throughout, and the rate of responding is consequently low (EXT-to-EXT curves, Part D, Fig. 3 and 4).

An induction may also occur with behavior in a steady state or with behavior in the process of change. Part B of Fig. 3 and 4 shows the responding from a component whose schedule is maintained as extinction. No responses are reinforced. The rate of responding varies, however, and always in a direction toward the rate generated in the other component. When the schedule in the other component is changed from VI or VR reinforcement to extinction, responding in the first component also declines (VI-to-EXT and VR-to-EXT curves, Part B, Fig. 3 and 4). Since this induction is a net decrease in responding, it is described as a negative induction. When responding is reinforced only in the other component, responding in the first component temporarily increases (positive induction: the EXT-to-VI and EXT-to-VR curves, Part B, Fig. 3 and 4). These effects occur with both VI and VR reinforcement.

Part C shows an induction during the process of extinction. This induction occurs only with VI reinforcement. There is a slower decline of responding in extinction in one component when responding is reinforced rather than extinguished in the other component. The VI-to-VI and EXT-to-VI curves have shallower slopes than the VI-to-EXT and EXT-to-EXT curves.

No sign (positive or negative) is given to the contrast and induction that occur with behavior in the process of change (Parts C and D, Fig. 3). The sign would depend upon the direction of deviation of the empirical functions from curves that show no interaction. Such curves are not available. That is to say, the present data do not show whether the difference between the two extinction curves in Part C is brought about by a net increase in responding when the schedule in the other component is VI reinforcement (positive induction), or by a net decrease in responding when the other schedule is extinction (negative induction), or by both.

One of the differences between a VI and a VR schedule of reinforcement is that a VI schedule tends to reinforce differentially responding that occurs after a pause. This difference between VI and VR schedules may account for the different amounts of induced responding that the two schedules produce in an alternated extinction component. During reinforcement on a VI schedule, pausing (not responding) becomes a discriminative stimulus for responding, since the responses that terminate the pauses are frequently reinforced. This process does not take place during VR reinforcement. Reinforcement of responding after pausing during the VI component tends to increase the frequency of responding after pausing in an alternated extinction component. Thus, a VI schedule generates shallower extinction curves (Part C, Fig. 3, and an increase in the unreinforced responding (EXT-to-VI curve, Part B, Fig. 3) in the alternated component. When reinforcement is no longer available in either component, the control of responding exercised by pausing as a discriminative stimulus disappears (VI-to-EXT curve, Part B, Fig. 3 and 4, and cf., Morse, 1955). On the other hand, when responding in one component is reinforced on a VR schedule, pausing does not become a discriminative stimulus for responding, and there is no induced responding during extinction (Part C, Fig. 4).

The change from extinction to VR reinforcement does, however, generate some induced responding in an alternated extinction component (EXT-to-VR curve, Part B, Fig. 4). This instance of positive induction may also be brought about by reinforcement of responding after pausing. The first reinforced responses on the VR schedule follow the pauses brought about by the previous extinction schedule. Since pause-response sequences do not continue to be differentially reinforced *during* the VR schedule, VR induction does not last for as many sessions as does VI induction. (Compare the EXT-to-VI and EXT-to-VR curves of Part B, Fig. 3 and 4.)

Interactions during Discrimination

The interactions of contrast and induction occur in addition to conditioning and extinction during the formation of a discrimination. In the present experiments, a discrimination is formed either by extinguishing responding during the presentation of one of two stimuli, or by reinforcing responding during one of two stimuli, or by both (discrimination reversal). In the first discrimination, responding is reinforced in the presence of both red and green and then only in the presence of red. The rate of responding during the presentation of red increases (positive contrast), and the rate during green decreases. When the schedule in red is VI (rather than VR), the decrease of responding in green is slower than if responding is extinguished during both red and green (induction). Induction also occurs during discrimination reversal (cf., the EXT-to-VI curve, Part C, Fig. 3).

The formation of a discrimination by reinforcing responding during the presentation of green only, after extinguishing responding during both red and green, is marked by different amounts of induced, unreinforced responding during red (Fig. 6). The organism's history of reinforcement before extinction appears to control the responding after extinction. The amount of induced responding during the presentation of red varies directly with the rate of responding maintained during red *before* responding was extinguished in both components. The rate of responding before mult EXT EXT is greatest for mult VI EXT (because of a positive contrast), intermediate for mult VI VI, and least for mult EXT VI (and their VR parallels). The amount of induced responding in mult EXT VI (or VR) *after* mult EXT EXT also follows this order. Thus, the previous rates of responding in the presence of two stimuli affect the formation of a discrimination between the two stimuli, even after responding has been extinguished in the presence of each.

SUMMARY

The interactions in a multiple schedule composed of a VI (or VR) component and an extinction component, or two VI (or VR) components, were studied. Four pigeons were reinforced on a series of multiple schedules containing VI components. Two of the same pigeons were reinforced on a similar series of multiple schedules containing VR components.

The results show that responding under a schedule of reinforcement or extinction during the presentation of one stimulus was affected by the schedule or sequence of schedules associated with a different stimulus with which the first stimulus was alternated. The characteristics of on-going, steady-state behavior, generated by VI or VR reinforcement in one component of a multiple schedule, were altered by changes in the schedule of reinforcement in the other component. In addition, the processes of extinction (in the VI series) and of reconditioning (in both the VI and VR series) in one component were shown to depend in part upon the schedule or sequence of schedules in the other component.

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