SIGNALLED REINFORCEMENT AND MULTIPLE SCHEDULES¹

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The responses of four pigeons were first reinforced in the presence of two different wavelengths (green and red) on a two-ply multiple schedule with identical variable-interval 3-min schedules of reinforcement associated with each component. While the constant-component reinforcement schedule remained unchanged during the experiment, the schedule associated with the variable component was changed to (1) signalled variable time, (2) unsignalled variable time, or (3) signalled variable interval. The probability with which the availability of the reinforcer was signalled in the variable-interval schedules was either 0.5 or 1.0. Positive contrast occurred in both signalled variable-interval and variable-time schedules, but only when the availability of all the variable-component reinforcers was signalled. Signalling the availability of only 50% of the reinforcers in signalled variable-interval schedules resulted in negative induction. The present data suggest that positive behavioral contrast resulting from signalled reinforcer availability is due to the presence of an extinction-correlated stimulus.

Key words: behavioral contrast, signalled reinforcement, blackout, multiple schedules, key peck, pigeons

Much of the recent research on multiple schedules has examined the extent and preconditions of the interactions that may occur between the components of the schedule. The traditional procedure is to establish a stable baseline and then to manipulate one component (variable component) and to observe the effects of this manipulation on the rate of responding in the other component (constant component). Following Reynolds (1961a), whenever the rate change of the constant component is in a direction opposite that of the variable component, the interaction is referred to as "positive" or "negative" contrast. Positive contrast is said to have occurred when the response rate in the constant component increases as the response rate in the variable component decreases. Negative contrast is obtained when the response rate in the constant component decreases as the rate in the variable component increases. If the change in the re-

sponse rate of the two components covary in the same direction, the interaction is labelled "positive induction" (rate increases in both components) or "negative induction" (rate decreases in both components).

Reynolds (1961a) proposed that the occurrence of positive and negative contrast is a function of the relative reinforcement frequency of the two components. That is, the response rate in the constant component varies inversely with the reinforcement frequency in the variable component. Decreasing the reinforcement rate in the variable component results in positive contrast, while increasing the variable-component reinforcement rate results in negative contrast. Indeed, subsequent research has shown that the relative frequency of reinforcement in the multiple components is a powerful predictor of the magnitude of contrast effect (Bloomfield, 1967; Nevin, 1968; Reynolds, 1961b; Reynolds and Limpo, 1968).

An alternative position has been offered by Terrace (1972). He proposed that the necessary and sufficient condition for occurrence of positive contrast is a suppression in the response rate of the variable component, which results as an emotional reaction to the discrimination situation. In this formulation, decreasing reinforcement density is understood to be only

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one of the many operations that suppress response rate.

One way of assessing the relative contribution of each of these variables is to reduce the variable-component response rate without altering reinforcement frequency. Such reductions have been obtained by altering the variable-component schedule of a multiple variable-interval variable-interval (*mult VI VI*) so that either the reinforcers are delivered noncontingently on a variable-time (VT) schedule (Halliday and Boakes, 1971; Wilkie, 1972) or the availability of the reinforcer is signalled (signalled VI) by the onset of an additional discriminative stimulus (Brownstein and Newsom, 1970; Brownstein and Hughes, 1970; Wilkie, 1973). Although the introduction of both operations reduces the variable-component response rate without reducing the overall reinforcement frequency, only the signalled VI procedure results in positive contrast.

There are several important differences between signalled variable-interval and variable-time schedules. First, signalled VI schedules contain both a response requirement and a stimulus that serves to signal the availability of the reinforcer. Secondly, the addition of the signal changes the simple VI schedule of the variable component to a multiple schedule in which the stimulus previously associated with the variable component becomes an extinction-correlated stimulus. The present study demonstrated that positive contrast resulting from signalling reinforcer availability is due to the presence of this extinction-correlated stimulus.

METHOD

Subjects

Four male, experimentally naive pigeons (three White Carneaux and one Homer) were maintained at 80% of their free-feeding weights. Water was available only in the home cage.

Apparatus

The experimental apparatus was a standard pigeon test chamber (Gerbrand's Model #G5610) containing three clear response keys; only the center key was used. Pecks on the center key, transilluminated by an Industrial Electronics Engineers in-line projector, of at least 0.15 N were recorded and operated a

feedback relay mounted behind the front panel. The reinforcer was 4-sec access to mixed grain delivered by a food hopper located below the center key. For three of the four pigeons, a 7-W houselight remained on, except during reinforcement cycles. The houselight was off during the session for Pigeon 1356 to facilitate introduction of a blackout procedure. During the reinforcement cycle, both the houselight and keylight were turned off and a 7-W lamp illuminating the food hopper was operated. Masking noise was provided by a white noise generator and an exhaust fan. Relay programming equipment was located in an adjacent room.

Procedure

The responses of Pigeons 75, 76, and 761 were first reinforced in the presence of two different wavelengths (green and red) on a two-ply multiple schedule with identical variable-interval 3-min schedules associated with each component. The values of the 20 intervals used were derived from Catania and Reynolds (1968). Both components were of 3 min duration and were presented in strict alternation with no blackout interspersed between components. A daily 3-hr session consisted of 30, 3-min presentations of each wavelength. Scheduled reinforcements were cancelled at completion of a component.

While the reinforcement schedule associated with the green stimulus (constant component) remained unchanged during the experiment, the schedule associated with the red stimulus (variable component) was, at different times, changed to either (1) signalled VI 3-min, (2) VT 3-min, or (3) signalled VT 3-min. All subjects were returned to *mult VI VI* (unsignalled) after exposure to each experimental condition. The sequence of schedules is summarized in Table 1.

Signalled variable interval (VI S). The availability of the reinforcer was signalled by superimposing a white triangle on the red key. While the probability of reinforcement of a response in the presence of red plus triangle was always 1.0, the probability that an available reinforcer would be signalled by red plus triangle was either 0.5 (VI S 0.5) or 1.0 (VI S 1.0). At the 0.5 value, the onset of the triangle signalled the availability of only 50% of the reinforcers that had become available in red. Thus, 50% of the reinforcers were obtained in

Table 1

Sequence of conditions. Numbers in parenthesis refer to the number of sessions each pigeon was exposed to the various conditions.

Condition	#76 + 77	#761	1356
1	<i>mult</i> VI VI NS (16,13)	<i>mult</i> VI VI NS (7)	<i>mult</i> VI VI NS (38)
2	VI VI S 1.0 (13,13)	VI VT S 1.0 (12)	VI VT NS (80)
3	VI VI NS (15,15)	VI VI NS (13)	VI VT NS BO (7)
4	VI VI S 0.5 (11,9)	VI VT NS (9)	VI VT S 1.0 BO (10)
5	VI VI NS (24,18)	VI VI NS (8)	VI VT NS BO (6)
6	VI VT S 1.0 (7,5)		VI VI NS (13)
7	VI VI NS (10,11)		VI VT S 1.0 BO (5)
8	VI VT S 1.0 (13,13)		VI VI NS (16)
9	VI VI NS (15,11)		VI VT S 1.0 (20)
10	VI VT NS (11,11)		
11	VI VI NS (10,9)		

the presence of red alone. At the 1.0 value, all reinforcers were obtained in the presence of red plus triangle. Thus, in effect, red alone was correlated with extinction.

Variable time (VT NS). In the variable-time 3-min schedule, the reinforcer was presented independently of responding, at various intervals with a mean interval of 3 min. The values of the intervals derived from Catania and Reynolds (1968) were identical to those used above.

Signalled variable time (VT S). In addition to the standard variable-time procedure (above) of presenting the reinforcer independently of responding, delivery of the reinforcer was signalled by superimposing a triangle on the red key 0.5 sec before scheduled delivery of the reinforcer. The signal preceded delivery of all the available reinforcers. The selection of a 0.5-sec signal duration was determined by the existing variable-component response rate. It was necessary to select a signal duration that would have the desired effect, yet minimize the possibility of responses occurring in its presence. If responding occurred in the presence of the signal, the signalled VT schedules, from the subject's viewpoint, would have been indistinguishable from the signalled VI schedules. Since an occasional response did occur in the presence of the 0.5-sec signal, Birds #76 and #77 were exposed to the VI S 0.5 condition (see above) in order to examine the effect on the constant-component rate of signalling the availability of only a percentage of the reinforcers.

In addition, Pigeon 1356 was exposed to a sequence of signalled and unsignalled schedules (Table 1) in which the stimulus associated with the variable-component VI schedule was

a dark key. Since the houselight was off during the entire session for Pigeon 1356, the variable-component reinforcers (signalled or unsignalled) were delivered in total darkness (blackout). The stimulus associated with the constant-component VI schedule remained the same. Thus, in effect, all variable-component responding was eliminated before the 0.5-sec signal was introduced.

Introduction of the signalled VT blackout procedure was accomplished in two ways. The necessary changes in the variable component were either made simultaneously (Condition 7, Table 1) or separately (Conditions 2, 3, and 4, Table 1). That is, the variable-component schedule was first changed to VT, then the keylight was turned off, and finally the signal was added.

RESULTS

Figure 1 shows the normalized response rates for schedules in which the variable-component schedule was nonsignalled variable time (top) and signalled variable time (bottom). Response rates for both constant (solid lines) and variable components (dashed lines) are included in Figure 1. The open circles in the bottom half of Figure 1 represent redeterminations. The normalized rates were calculated by dividing the response rate in a component for each session by the median response rate of the five baseline sessions immediately preceding each schedule change. Median response rates for baseline sessions are shown in Table 2. If the response rate during a component increased over the baseline VI rate the normalized response rate would be greater than 1.0.

Fig. 2. Normalized response rates for both constant (solid lines) and variable (dashed lines) components of the multiple schedules during sessions in which the variable-component schedule was variable interval. Response rates when the availability of 50% ($S = 0.5$) of the reinforcers was signalled are shown in the top half of the figure, response rates when the availability of all the reinforcers was signalled ($S = 1.0$) are shown in the bottom half. The normalized response rates were calculated by dividing the response rate in a component for each session by the median rate of the five baseline sessions (Session 0) immediately preceding each schedule change.

of prior exposure to signalled VI, since Pigeons 1356 and 761 were not exposed to that condition (Table 1).

Figure 2 shows the normalized response rates for Pigeons 76 and 77 for both components during sessions in which the variable-component schedule was signalled VI. Solid lines represent constant-component rates and dashed lines variable-component rates. Response rates when the availability of 50% of the reinforcers ($S = 0.5$) was signalled, are presented in the top half of Figure 2; the bottom half contains the data from sessions in which the availability of all variable-component reinforcers was signalled ($S = 1.0$). Signalling the availability of all reinforcers during the variable com-

ponent of the *mult* VI VI schedule results in both a decrease in the variable-component response rate and an increase, over baseline, in the constant-component rate. These results are consistent with those of Brownstein and Newsum (1970), Brownstein and Hughes (1970), and Wilkie (1973). Much less across-session variability in the constant-component rates was obtained with signalled VI than with signalled VT schedules. Breaking up the consistency with which red alone and red plus triangle are associated with extinction and reinforcement ($S = 0.5$) reduces the variable-component rate but does not increase the constant-component rate. Note that when 50% of the available reinforcers are obtained in the presence of red alone, the decrease in the variable-component rate is considerably less than that obtained when the availability of all the reinforcers is signalled.

Figure 3 shows both the constant- and variable-component response rates of Pigeon 1356 for the last five sessions of unsignalled VI VT and baseline VI VI and for those sessions in which Bird 1356 was exposed to the blackout (B.O.) conditions. The solid lines represent constant-component rates and the dashed lines the variable-component rates. It is apparent from the data of Figure 3 that signalling the delivery of the reinforcers when the stimulus associated with the variable-component VT schedule is blackout does not appreciably affect the constant-component response rate. Regardless of whether the signalled blackout procedure is introduced gradually or abruptly, the constant-component rate remains constant. Since contrast was later obtained when Pigeon 1356 was exposed to signalled VT with keylight on, the present result cannot be attributed to the failure of this bird to exhibit contrast in general.

DISCUSSION

The present data demonstrate that changing the variable-component schedule from VI to either signalled VI or signalled VT results in positive contrast. It is unlikely that the occurrence of contrast during the signalled VT condition was due to the pigeon's failure to discriminate differences in the contingencies between signalled VI and signalled VT schedules. Since very few responses occurred during the 0.5-sec signal presentations of the signalled

Fig. 3. Response rates for both constant (solid lines) and variable (dashed lines) components for Pigeon 1356 for Sessions 110 to 153. The symbol B.O. refers to sessions in which the stimulus associated with the variable component was blackout. S designates that the delivery of the variable-component reinforcers was signalled and NS not signalled.

VT condition, the response contiguous with the delivery of the reinforcer was rarely a key peck. During the signalled VI condition, however, since all reinforced responses occurred in the presence of the signal the response immediately preceding reinforcer delivery was always a key peck. It is also unlikely that those few responses that did occur in the presence of the signal during the signalled VT condition were sufficient to produce contrast. Figure 2 shows that contrast does not result when as many as 50% of the reinforced responses occur in the presence of the signal.

Instead, these data suggest that the variable responsible for occurrence of contrast when reinforcer availability is signalled in the variable component of *mult* VI VI schedules (Brownstein and Hughes, 1970; Brownstein and Newsom, 1970; and Wilkie, 1973) is the presence of a stimulus correlated with nonreinforcement. In effect, introducing the signal changes the simple VI or VT schedule of the variable component to a multiple schedule that contains an extinction component.

One possible alternative explanation of the present results is that the occurrence of contrast is dependent on the degree of rate reduc-

tion in the variable component, *i.e.*, in those conditions during which contrast was observed (Figures 1 and 2), the variable-component response rate was lower than in those conditions during which contrast was not observed. Although consistent with the results of the present experiment this interpretation is not convincing for several reasons. First, Halliday and Boakes (1971), (Figure 1) reported several examples of *mult* VI VT performance where the variable-component response rates were at a near-zero level, yet contrast was not observed. Secondly, the data of Wilkie (1973) do not support either the degree of response-rate reduction or the reinforcement frequency reduction interpretations of contrast. He demonstrated that signalling all the variable-component reinforcers produced contrast even if the variable-component reinforcement frequency was increased to four times that prevailing during baseline conditions. Since the effect of increasing the variable-component reinforcement frequency was to also decrease the degree of response-rate reduction in that component, Wilkie also provided evidence against an interpretation of contrast in terms of the degree of rate reduction obtained. That is,

contrast was obtained even if the reinforcement frequency in the variable component was increased and the variable-component response rate reduction was less than that obtained in the present experiment during the unsignalled VT conditions.

The present results are in partial agreement with Terrace (1972). Terrace proposed that an active withholding or suppression of responding in the presence of one component of a multiple schedule is necessary for contrast to occur. A reduction in the variable-component response rate is sufficient to produce contrast only when it results as an emotional reaction to the discrimination situation. Such emotional reactions can be produced by (1) punishing variable-component responding (Brethower and Reynolds, 1962; Terrace, 1968) (2) introducing a less-preferred schedule of reinforcement, *i.e.*, DRL (Terrace, 1968), or (3) changing the variable-component schedule to extinction (Reynolds, 1961a). When no emotional reaction is generated by introducing unsignalled VT schedules (Wilkie, 1972) contrast would not be expected. Thus, according to Terrace (1972) the occurrence of contrast in the present experiment resulted from the consequences of nonreinforced responding in the presence of the extinction-correlated stimulus that resulted when all the available reinforcers were signalled. However, it is necessary to assume that changing the baseline variable-component VI schedule to either signalled VI or signalled VT will generate an active withholding of responses even in the absence of any reduction in the overall reinforcement frequency of that component.

Gamzu and Schwartz (1973) and Rachlin (1973) have suggested an alternative explanation of behavioral contrast that emphasizes the role of the response-eliciting effects of the constant-component stimulus, rather than either a suppression in the variable-component response rate (Terrace, 1972) or a reduction in the variable-component reinforcement frequency (Reynolds, 1961a). Brown and Jenkins (1968) and Williams and Williams (1969) demonstrated that a stimulus that reliably predicts reinforcement will elicit key pecks. Gamzu and Schwartz (1973) observed that the alternation of two stimuli associated with different reinforcement frequencies resulted in the occurrence of these elicited pecks. They noted that these same conditions are present in

response-contingent multiple schedules whenever the components are associated with different reinforcement rates. Thus, positive contrast is viewed as a combination of operant responses maintained by the constant-component reinforcement schedule (response-reinforcer relation) and of additional responses elicited by the constant-component stimulus (stimulus-reinforcer relation).

The present data are consistent with this analysis. The effect of signalling all variable-component reinforcers was to introduce a stimulus correlated with extinction. Since this extinction stimulus alternated with the constant-component stimulus (associated with a higher reinforcement rate), a differential stimulus-reinforcer relation was introduced and pecks were elicited by the constant-component stimulus. The theory would then correctly predict the occurrence of contrast when the availability of all the variable-component reinforcers was signalled, regardless of whether the variable-component schedule was VI or VT. Secondly, since these differential stimulus-reinforcer relations were absent from the unsignalled VI VI and VI VT schedules, contrast would not have been predicted. In addition, the failure to observe contrast when the signalled VT blackout procedure was introduced is also consistent with the additivity theory of contrast. Wasserman (1973) demonstrated that elicited pecks do not occur in situations in which the signal is the sole source of illumination in the chamber, because the signal acts as a diffuse stimulus that will not generate pecking directed at the response key. However, since only Pigeon 1356 was exposed to this condition in the present experiment, its performance may be atypical.

Whether the results of signalling the availability of only 50% of the variable component reinforcers support the additivity theory of contrast is not as clear. It is possible that the high rates of responding in the variable component (Figure 2) indicate that the signal exercised almost no control over responding so that the schedule, in effect, remained VI VI. Thus, contrast would not be expected. Yet such an analysis neglects the clear and consistent rate differences between the components. The fact that the variable-component rate was substantially above zero is reasonable, since the reinforcement frequency in red alone was reduced to only 10 reinforcers per hour

and not to zero, as was the case when the availability of all the variable-component reinforcers was signalled. Thus, these small but consistent rate differences between components can be interpreted as an indication that the pigeons were in fact discriminating the decrease in the reinforcement frequency associated with the red stimulus. Thus, contrast should have occurred if a sufficient condition for the elicitation of key pecks is the alternation of two stimuli associated with different reinforcement rates.

In summary, changing one component of a multiple schedule to either signalled VI or VT resulted in positive contrast. It cannot be stated with certainty, at the present time, whether the addition of the signal produced contrast by suppressing variable-component responding or by introducing a differential stimulus-reinforcer relationship into the experimental situation.

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