LINE-ORIENTATION GENERALIZATION FOLLOWING SIGNALLED-REINFORCER TRAINING

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Three naive and three nonnaive pigeons key pecked for food on a multiple variable-interval 1-minute variable-interval 1-minute schedule with a black zero-degree vertical line on a white surround associated with one component and a black line shifted 30 degrees to the right (+30 degree) associated with the other component. Subsequently, a signalled-reinforcer procedure was introduced in the +30 degree component, *i.e.*, whenever the reinforcer was available for the next response, the key changed to blank white. Following this training, the original unsignalled-reinforcer condition was re-instated. Line orientation generalization tests were given at the end of signalled-reinforcer training and after the second unsignalled-reinforcer condition. The signalled-reinforcer procedure reduced response rate in the +30-degree component in all subjects but facilitated responding during the zero-degree component (behavioral contrast) for two of the naive subjects only. However, average generalization gradients following signalled-reinforcer training indicated peak shift in two subjects and area shift in all five subjects that completed the experiment. There was no apparent relation between contrast and peak shift or degree of area shift. The data were interpreted as supporting the notion that the signalled-reinforcer procedure segments a variable-interval schedule into extinction and fixed ratio 1 segments.

Key words: signalled reinforcement, area shift, peak shift, behavioral contrast, key peck, pigeons

Signalled reinforcement refers to a procedure in which a signal occurs whenever the reinforcer will be produced by the subject's next response. This procedure typically reduces response rate if it is imposed on either variable-interval (VI) schedules (Brownstein and Hughes, 1970; Lander, 1971; Thompson and Corr, 1974; Wilkie, 1973) or fixed-interval schedules (Brownstein and Newsom, 1970). Further, since the interreinforcement interval is not affected, Brownstein and Hughes (1970) and Brownstein and Newsom (1970) have suggested that the signalled-reinforcer procedure provides a method of reducing response rate without concomitantly reducing frequency of reinforcement.

Lander (1971) and Thompson and Corr (1974), however, have proposed an alternative interpretation of the suppressive effects of signalled reinforcement. They suggested that response rate declines because the absence of the

signal is correlated with extinction (EXT). For example, if the signalled-reinforcer procedure is imposed on a VI schedule, it segments the schedule into EXT and fixed ratio 1 (FR 1) components. That is, the unsignalled portion of the signalled VI schedule (SIGVI) functions like EXT because the reinforcer does not occur, and the signalled portion functions like FR 1 because the reinforcer always follows the response. Thus, although total reinforcement frequency remains unchanged, the relative frequency in the unsignalled portion of SIGVI is reduced to zero.

The preceding account of the suppressive effects of signalled reinforcement also bears upon explanations of positive behavioral contrast. In the paradigmatic procedure for producing such contrast (*e.g.*, Reynolds, 1961), one component (S-) of a multiple variable-interval variable-interval schedule (*mult* VI VI) is changed to EXT, which results in a decrease in response rate in that component. Contrast occurs if a concomitant increase in response rate is observed in the unchanged VI component (S+). Reynolds (1961) attributed the facilitation of S+ response rate to the decrease in relative reinforcement frequency in S-;

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Terrace (1968) attributed the facilitation to the decrease in responding in S—. Subsequent experiments have provided support for both positions by suggesting that either a decrease in reinforcement frequency or a decrease in response rate would produce contrast (see review in Freeman, 1971).

The previously cited experiments using signalled reinforcement imposed the procedure in one component of a multiple schedule, and in all cases contrast was reported. Further, Brownstein and Hughes (1970) and Brownstein and Newsom (1970) suggested that the signalled-reinforcer procedure produced contrast by reducing response rate in S— without a change in reinforcement frequency. The counter position, holding that signalled reinforcement segments a schedule into EXT and FR 1 segments, argues that both the suppression of responding in S— and the facilitation of responding in S+ are due to the imposed EXT condition. Thus, the latter account suggests that the signalled-reinforcer procedure produces contrast by reducing relative reinforcement frequency and that the occurrence of contrast in this situation should not be taken as evidence that response-rate reduction alone is sufficient. This interpretation in terms of reinforcement frequency is also consistent with recent research that indicates that contrast does not occur in other situations that involve reductions in response rate without reductions in reinforcement frequency (Boakes, Halliday, and Mole, 1976; Halliday and Boakes, 1971). Finally, the notion that signalled reinforcement imposes an EXT period seems to make these contrast effects more interpretable by the recent stimulus-reinforcer or "autoshaping" approaches (e.g., Keller, 1974; Rachlin, 1973; Redford and Perkins, 1974).

Both to clarify the operation of the signalled-reinforcer procedure and to assess interpretations of behavioral contrast, it is important to determine the validity of the notion that signalled reinforcement segments a schedule into EXT and FR 1 segments. One approach to this problem utilizes the stimulus generalization gradient to index the nature of the assumed EXT segment. Either the generalization gradient following interdimensional discrimination training (S+ and S— are associated with orthogonal stimulus dimensions) or the gradient following intradimensional discrimination training (S+ and S— are associ-

ated with different points on the same stimulus dimension) can be used. In the case of interdimensional training, a number of investigators (see review in Hearst, Besley, and Farthing, 1970) have reported a U-shaped gradient around the S— stimulus following *mult* VI EXT training. Such a result is usually taken as indicative of conditioned inhibition to S— and is characteristic of EXT schedules. Thus, if the unsignalled portion of a signalled-reinforcement schedule is functionally an EXT schedule, similar effects should occur. That is, in a *mult* VI SIGVI schedule, if the unsignalled portion of SIGVI (S—) and the unsignalled VI schedule (S+) are associated with orthogonal dimensions, a subsequent generalization test with the S— dimension should yield a U-shaped, inhibitory gradient centered at the S—. Lander (1971), however, reported an excitatory gradient, i.e., responding was peaked at S—. This experiment, along with methodological issues that temper the interpretation, is examined in detail in the discussion.

The present experiment was concerned with assessing signalled reinforcement via the intradimensional generalization gradient. Hanson (1959) and others (see review in Purtle, 1973) reported that the generalization gradient following *mult* VI EXT training was not peaked at S+; rather, the mode was shifted away from S+ in a direction opposite to S— (peak shift). In addition, the entire gradient on the contra S— side of S+ was elevated. The latter effect is termed area shift (Terrace, 1966) or distribution shift (Hearst, 1969). In the case of signalled reinforcement, such effects should occur if the extinction argument is correct. That is, if the unsignalled portion of SIGVI (S—) and the unsignalled VI component (S+) of *mult* VI SIGVI are associated with different points on the same dimension, a subsequent generalization gradient should indicate peak and area shift away from the putative S—. The present experiment examined this possibility.

METHOD

Subjects

Six adult, male Silver King pigeons were maintained at 80% ($\pm$ 2%) of free-feeding body weights. Subjects P1, P2, and P3 had histories of key-peck training with a green

key and auditory stimuli. Subjects P4, P5, and P6 were experimentally naive.

Apparatus

The area of the experimental chamber was 30.5 by 34.6 by 27.9 cm. An aluminum response panel formed one end of the chamber and contained a 2.5-cm diameter response key centered 23.2 cm above the chamber floor. Operation of the key required a minimum force of 0.16 N. A 5.1- by 4.4-cm aperture centered 13.7 cm directly below the key allowed access to mixed grain during 5-sec reinforcement periods. During these periods, the aperture was illuminated with a 7-W, 115-V ac white light. The response key could be transilluminated with orientations of a 0.2-cm wide black line on a white surround or by the white surround alone. The stimuli were provided by a modified Industrial Electronic Engineers in-line readout projector. The key was transilluminated throughout each session, except during reinforcement periods. When the keylight was on, key pecks resulted in a brief click of a 28-V dc relay located behind the response panel. An exhaust fan provided continuous ventilation and masking noise. Supporting electromechanical control and recording equipment was acoustically isolated in a separate room.

Procedure

Following magazine training and response shaping, Subjects P4, P5, and P6 were exposed to a series of *mult* VI VI schedules in which the VI value was increased over sessions. Subjects P1, P2, and P3 were exposed to these schedules directly. The final, baseline schedule (Condition A) was *mult* VI 1-min VI 1-min with a 5-sec timeout separating 65-sec components. The intervals comprising all VI schedules were obtained with the Catania and Reynolds (1968, p. 381) constant probability progression. Each daily session consisted of 41 components presented in a semi-random order with the constraint of a maximum of three like components in succession. Since the birds often paused a few seconds before responding after a session started, data were not recorded during the first component of each session. Excluding this first component, each component occurred 20 times per session. During shaping, initial training, and baseline, a

black vertical line (zero degrees) (0 deg) was projected on the white key during one component and a black line shifted 30 degrees to the right (+30 deg) was associated with the other component.

When responding stabilized, the signalled-reinforcer procedure was imposed in the +30-deg component (Condition B). Whenever the reinforcer was available for the next key peck, the key changed from the +30-deg line to blank white. No alteration was made to the 0-deg component. When stable separation in response rates was obtained (39 to 59 sessions across subjects), a generalization test (described below) was given. Several sessions of retraining and a second generalization test followed. Due to procedural error, Subject P5 received three generalization tests during this condition.

The signalled-reinforcer condition was then removed and the birds were retrained on the original baseline schedule (Condition A) until performance was stable. Two generalization tests, with intervening retraining, were then given. The number of sessions under each condition is indicated in Figures 1 and 2. One subject (P3) died before this phase was complete.

In the A conditions, stable responding was defined in terms of the difference between the mean rate over six consecutive sessions and the mean rate over the last three of these sessions. A difference of less than 5% of the six-session mean was required in all component transitions, *i.e.*, 0 deg following 30 deg, 0 deg following 0 deg, 0 deg following two 0-deg components, *etc.* A quantitative stability criterion was not used in Condition B. This condition was terminated when response rates exhibited stable separation as evidenced by daily overall response rates and cumulative records.

Generalization tests. All generalization tests were preceded by a 520-sec warm-up period during which each component was presented four times and all conditions were like those in the immediately preceding training condition. Following warm-up, the reinforcer was no longer available and each of seven test stimuli, including the training stimuli, was presented. Each stimulus was presented for seven, 60-sec trials according to a Latin square with seven randomized blocks. Stimulus presentations were separated by a 5-sec timeout. The

test stimuli were -60 , -45 , -30 , 0 (vertical), $+30$, $+60$, and $+90$ deg (horizontal) orientations of a black line on a white surround.

RESULTS

Figure 1 clearly indicates that the signalled-reinforcer procedure (Condition B) effectively suppressed response rate in the $+30$ -deg component for Subjects P1, P2, and P3. Equally clear is the absence of a consistent increase in

response rate in the 0 -deg component. Figure 2 indicates that response rate in the $+30$ -deg component was also suppressed in the naive subjects. However, consistent facilitation of responding in the 0 -deg component was evident in Subject P5 and during the final sessions in Subject P6. Thus, behavioral contrast occurred in two of the naive subjects and in none of the subjects with previous training.

As the data in Figures 1 and 2 reflect total response rates, effects due to component se-

Fig. 1. Response rates during *mult* VI 1-min VI 1-min (Condition A) and during *mult* VI 1-min SIGVI 1-min (Condition B) for the nonnaive subjects. Closed circles indicate rates in the component associated with a 0 -deg black line on a white surround and open circles indicate rates in the component associated with a line shifted 30 deg to the right ($+30$ deg).

Fig. 2. Response rates for the naive subjects. See legend to Figure 1 for details.

quence cannot be delineated. To examine these effects, response rates during the 0-deg component when it followed a 30-deg component ($N = 10$) and when it followed one 0-deg component ($N = 7$), *i.e.*, exclusive of 0-deg-0-deg-0-deg sequences, were examined. This analysis yielded no systematic differences between rates. However, since it could be that the sequence affected response rate only if con-

trast occurred, the rates for Subjects P5 and P6 were examined for those sessions in which contrast occurred. In Subject P5, response rate in the 0-deg component was 36 responses per minute following a 30-deg component and 34 responses per minute following a 0-deg component. In Subject P6, response rate was 29 responses per minute following a 30-deg component and 30 responses per minute following

Fig. 3. Mean responses to the line orientation stimuli. Each individual subject gradient represents the mean over two generalization tests. The mean gradients exclude data from Subject P3. 0 deg was always associated with a VI 1-min schedule and +30 deg was associated with either VI 1-min (No Signal, Condition A) or signalled reinforcement (Condition B).

a 0-deg component. Thus, this analysis also revealed no systematic effect of component sequence.

The results of the generalization tests are presented in Figure 3. For Subject P5, only the first two gradients following signalled-reinforcer training were used because responding during the third test was extremely low (total responses = 376). The data for Subject P3, which died following Condition B, are excluded from the mean gradient.

Following signalled-reinforcer training, responding was suppressed in the vicinity of +30 deg and responding to orientations less than 0 deg was enhanced, relative to no-signal training, in all subjects. Statistical analysis of the difference between the mean gradients indicated a significant test by orientation interaction ($F(6,24) = 11.83$, $p < 0.001$). Further analysis of simple effects (Tukey q , *cf.*, Kirk, 1968, p. 112) indicated that the gradient following signalled-reinforcer training was significantly higher than the no-signal gradient at -30 deg ($p < 0.01$) and significantly lower at +30 deg ($p < 0.01$) and +60 deg ($p < 0.05$). These same analyses were conducted with the appropriate gradients summed but not averaged and with proportion of total response gradients. The results were in agreement with those based on the mean response gradients, with the addition of significantly greater ($p < 0.05$) responding at -45 deg following signalled-reinforcer training. Thus, Figure 3 presents the data in the most conservative form.

Although the gradient area was clearly affected, the mode changed (peak shift) in only Subjects P1 and P6. Further analysis of the two generalization tests comprising the signalled-reinforcer gradients in Figure 3 indicated a peak shift on test 1 for Subjects P1, P2, and P6 and a peak shift on test 2 for Subjects P3 and P6. It is noteworthy that only Subject P6 had also shown behavioral contrast.

The preceding analyses are based upon absolute generalization gradients, *i.e.*, the ordinate is mean number of responses. Alternatively, the ordinate could be per cent of total responses (relative gradient). The latter approach is often suggested so that changes in level of responding are not confused with changes in gradient shape (*e.g.*, D'Amato, 1970, p. 423; Hearst, 1969; Marsh, 1972). On the other hand, Dysart, Marx, McLean, and Nelson (1974) pointed out that distribution shift of a relative gradient may be trivial, since only a decrease in responding at S- would be required. The absolute gradients in Figure 3 avoid the latter problem. However, the extent to which the distribution effects reflect only changes in level of responding is not clear. Therefore, the following analysis was performed to determine if the shape of the Condition B gradient differed from the Condition A gradient once the difference in amount of responding was taken into account.

Because area shift and peak shift are concerned with the effects of S- on responding to S+ and beyond, this analysis considers only

the contra S- portion of the gradient (-60° through 0°). Thus, the direct, suppressive effects of S- are not considered (*cf.*, Dysart *et al.*, 1974). It was assumed that signalled-reinforcer training would have simply elevated the no-signal, contra S- gradient without changing the shape if the Condition B gradient could be reasonably approximated by a gradient that was composed of the same number of responses as the Condition B gradient,

and was either a simple additive or multiplicative transformation of the Condition A gradient. The transformations of the Condition A gradient were obtained by, first, determining the difference in total contra S- responses between Conditions B and A. Next, this difference, *i.e.*, the additional contra S- responses that occurred in Condition B, was added to the Condition A gradient so that either the additive relation or the multiplicative relation

Fig. 4. Responding to stimuli on the contra S- side of the 0-deg S+. Closed circles indicate the obtained number of responses to each stimulus divided by the total number of responses to stimuli -60° through 0° after signalled-reinforcer training (Condition B). Open circles indicate the proportions that would be obtained if the gradient following Condition B maintained the multiplicative (ratio) relation in the Condition A gradient. Triangles indicate the proportions that would be obtained if the Condition B gradient maintained the additive relation in the Condition A gradient.

(ratio) in the Condition A gradient was preserved. Thus, the obtained contra S— gradient in Condition B could be compared with additive and multiplicative transformations of the Condition A gradient that were composed of the same number of responses as the obtained Condition B gradient.

Figure 4 presents the results of this analysis. Since the ordinate is per cent of contra S— responses, the gradient that preserves ratios is equivalent to the Condition A gradient. In all subjects, responding to -30 deg was greater than expected and responding to 0 deg (S+) was less than expected by either addition or ratio preservation. The other differences were less consistent. It seems reasonable, then, to assume that the present effect was not due only to changes in absolute level of responding but reflected a change in gradient shape.

DISCUSSION

When reinforcer availability was signalled in one component of *mult* VI 1-min VI 1-min, response rate declined in the signalled-reinforcer (SIGVI) component. However, contrary to earlier experiments, response rate did not increase in the unaltered component in four of six pigeons. This absence of behavioral contrast is somewhat perplexing, since the procedure was similar to Lander's (1971) in which contrast occurred in two of three pigeons. Further, the procedural differences that did exist such as discrimination difficulty (*cf.*, Hearst, 1969; Mackintosh, Little, and Lord, 1972) and simple alternation *versus* random component sequence (see Results section of this paper; Amsel, 1971; Rachlin, 1973; Wilton and Clements, 1972) cannot easily account for the lack of contrast. The prior training of the subjects, however, may be important. Earlier experiments with signalled reinforcement used naive subjects; two of the three naive subjects in the present experiment did show contrast, while subjects with prior training showed either no change or a slight decrease in S+ response rate. Since the effects of previous training on contrast have apparently not been examined in detail (but see Bloomfield, 1967; Couch, 1975) and since detailed histories of the nonnaive birds were unavailable, attributing the lack of contrast to previous training is quite speculative. However, in view of the substantial effects of experimental history on

aspects of stimulus control such as attention (*cf.*, Thomas, 1970), it may be worthwhile for future research to examine similar effects on contrast.

Regarding the generalization gradient, area shift occurred in all subjects for which data were available. This effect was not due simply to suppression of responding at S— nor could it be completely accounted for by elevation of the contra S— side of the unsignalled reinforcer gradient. Thus, signalled-reinforcer training produced a change in the shape of the contra S— gradient. In addition, four subjects showed peak shift on at least one of the two generalization tests following signalled-reinforcer training and two subjects showed peak shift in the gradient average over these tests. The generalization data, then, support the notion that the unsignalled portion of SIGVI functioned as EXT.

There was no simple relation between degree of contrast and the extent of area shift. Further, only one subject that showed peak shift had also shown contrast. These results are congruent with recent experiments (*e.g.*, Wheatley and Thomas, 1974) indicating that the relation between contrast and peak shift is not as simple as was once thought (*e.g.*, Terrace, 1968).

The extinction interpretation of signalled-reinforcer effects also predicts that the unsignalled portion of SIGVI would generate an inhibitory generalization gradient if it were associated with a dimension orthogonal to the reinforcer signal and the unsignalled VI dimensions. Lander (1971) reported the opposite, *viz.*, the gradient was peaked at the training value. Lander's stimulus arrangement was rather complex, however, and the inhibitory effects may have been masked. In the SIGVI component, three vertical white lines on a red surround changed to three white vertical lines on a black surround whenever the reinforcer was available for the next key peck. The unsignalled VI schedule was associated with a blank red key. Notice that the unsignalled portion of SIGVI was associated with a compound stimulus and the elements of the compound, when presented alone, signalled either VI (red key) or FR 1 (white lines). Thus, the compound was composed of stimuli that exerted excitatory control when they occurred singly. Even though the compound suppressed responding during training, during the gen-

eralization test, the excitatory control by the elements could have masked the inhibitory control by the compound. This might be expected because the reinforcer signal did not occur during the test to indicate that the signalled-reinforcer procedure was in effect and there was no signalled-reinforcer warm-up. This notion assumes that the inhibitory control by the compound was rather ephemeral and waned, since the reinforcer signal did not occur to indicate that the compound was still associated with EXT.

The preceding suggestion seems to make a rather clear prediction. If the inhibitory control in Lander's experiment waned during the generalization test, responding to the compound stimulus during the test should have increased dramatically above the rate prevailing at the end of training. This outcome is exactly what Lander reported with an average change of +260% in the compound response rate. In the present experiment, responding to the training value changed by only +7.7% between training and testing. This analysis supports the idea that inhibition developed but was masked; however, a really adequate assessment awaits repetition of Lander's procedure with independent stimuli.

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