RESPONSE RATE, REINFORCEMENT FREQUENCY, AND BEHAVIORAL CONTRAST¹

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Pigeons responded for food on a multiple schedule in which periods of green-key illumination alternated with periods of red-key illumination. When behavior had stabilized with a variable-interval 2-min schedule of reinforcement operating during both stimuli, low rates of responding (interresponse times greater than 2 sec) were differentially reinforced during the green component. Conditions during the red stimulus were unchanged. Response rates during the green component fell without changing the frequency of reinforcement but there were no unequivocal contrast effects during the red stimulus. The frequency of reinforcement during the green component was then reduced by changing to a variable-interval 8-min schedule without reducing the response rates in that component, which were held at a low level by the spacing requirement. Again, the conditions during the red stimulus were unchanged but response rates during that stimulus increased. These results show that reductions in reinforcement frequency, independently of response rate, can produce interactions in multiple schedules.

Reynolds (1961a) was the first investigator to draw attention to behavioral contrast in operant discrimination learning with pigeons. In that experiment, pigeons were trained to respond for food on a multiple schedule in which two alternating stimuli (S1 and S2) were both correlated with a variable-interval 3-min (VI 3-min) schedule of reinforcement. Subsequently, the schedule during S2 was changed to extinction. As the rate of responding decreased in S2, Reynolds found that response rate in S1 increased, although the schedule of reinforcement in that component was unchanged. Reynolds termed this interaction "behavioral contrast" since the changes in response rate observed in S1 were in the opposite direction to the changes in response rate produced in S2.

Further studies (*e.g.*, Reynolds, 1961b) established that an increase in response rates in the S1 component is not dependent on the schedule in the S2 component being changed to extinction. Smaller reductions in reinforcement frequency to lower but non-zero values in S2 can also produce contrast in S1.

Reynolds' contrast effects could be the re-

sult of either the reduction in reinforcement frequency in S2 or the accompanying fall in response rates in S2. Attempts to determine the relative importance of these two factors in producing contrast have often involved holding reinforcement frequency constant in the S2 component while reducing response rate in that component by some other means. However, the experimental evidence on this point is conflicting. For example, Terrace (1968) used a differential-reinforcement-of-low-rates (DRL) schedule to reduce response rate in the S2 component while maintaining the same frequency of reinforcement as before, and this procedure produced contrast in the S1 component. A number of other experiments have confirmed that reductions in response rate in S2 appear crucial for the production of contrast in S1 (*e.g.*, Brethower and Reynolds, 1962; Reynolds and Limpo, 1968; Weisman, 1969, 1970).

However, Halliday and Boakes (1971) and Weisman and Ramsden (1973) found that no contrast occurred in S1 when the introduction of response-independent reinforcement in S2 gradually lowered response rates to that stimulus but maintained the original overall frequency of reinforcement. Apparently, reducing response rate in the S2 component independently of reinforcement frequency in

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that component sometimes does and sometimes does not result in a contrast effect in the S1 component.

A number of studies have varied reinforcement frequency in S2 without attempting to hold S2 response rates constant. For example, Reynolds (1961a) maintained a high frequency of reinforcements during S2 by presenting food for periods of no responding; a procedure termed *differential-reinforcement-of-other-behavior* (DRO). With this arrangement, S2 response rates were low and contrast effects in S1 were eliminated. Other studies have employed a variety of schedules of reinforcement in S2 and varied S2 reinforcement frequency by manipulating the schedule parameters; Bloomfield (1967) used different DRL schedules, Nevin (1968) used DRO schedules, Reynolds (1961b) used fixed-ratio (FR) schedules, and Zuriff (1970) used variable-ratio (VR) schedules. All these studies showed that responding on a constant VI schedule in S1 was inversely related to the frequency of reinforcement in S2. However, in all cases, response rates in S2 were not held constant and the possibility that the interaction with S1 was based on S2 response rates cannot definitely be excluded.

The present experiment attempted to investigate further the causes of contrast (and similar interactions) by manipulating reinforcement frequency in the S2 component of a multiple schedule when the response rate in that component was separately controlled by a response-pacing procedure (Ferster and Skinner, 1957).

METHOD

Subjects

Three adult male homing pigeons (P1, P2, and P3), experienced on VI schedules of food reinforcement, were housed individually with water and grit freely available in the home cages but not in the test chamber. For the duration of the experiment they were maintained at 85% of their previously determined free-feeding body weights.

Apparatus

The birds were tested daily in a sound-insulated two-key operant conditioning chamber for pigeons (Lehigh Valley Electronics,

Model No. 141-15). Only the left response key was operative and could be illuminated green, red, or white. Each peck on this key was recorded and produced an audible feedback click. The reinforcer was 4-sec access to grain from a hopper located just below and to the right of the operative response key. The chamber could be illuminated by an overhead light and continuous white noise was presented to mask any extraneous sounds. The experiment was automated by conventional relay and timing apparatus located in a separate room. The results were recorded on digital counters and a cumulative recorder.

Procedure

The daily experimental sessions began and ended with the test chamber in darkness. Throughout the experiment, the birds were tested on a multiple schedule in which 3-min periods when the response key was red (S1) alternated with periods of the same duration when the key was green (S2). During both components, the chamber was also illuminated by an overhead light. Three-second periods of blackout, when all the lights were extinguished, were interposed between successive components of the multiple schedule. Normally, each session ended after S1 and S2 had each occurred four times. The component with which each session commenced alternated from day to day.

Independent VI schedules arranged reinforcements in each component, and reinforcements set up by the schedule in one component were "lost" if they were not gained before the change to the other component. During reinforcements, the grain hopper was illuminated and the key- and houselights were extinguished.

Phase 1. In both components, reinforcements were arranged by nominal VI 2-min schedules to which response-pacing requirements had been added. But in this phase the pacing requirements specified that all responses spaced more than 0.03 sec from a preceding response could be reinforced on the VI schedule, so that in both components responding was practically unconstrained. During the brief "dead" periods after each response, when further responses prolonged the "dead" period but were otherwise ineffective, the key was always illuminated by a white light. The only purpose of the white signal was to accentuate the effect of the pacing requirement in subse-

quent phases of the experiment (see Discussion). Phase 1 ended after 10 sessions.

In Phase 2, the procedure during S1 was unchanged but in S2 the response-pacing requirement and its associated white-key signal were gradually lengthened from 0.03 sec to 2.0 sec over the course of three experimental sessions. The change was made gradually to avoid affecting frequency of reinforcement, arranged as before by a VI 2-min schedule. Phase 2 ended after a further 10 sessions.

In Phase 3, the response-pacing requirement in S2 was kept at 2.0 sec but the value of the VI schedule in that component was changed from 2 min to 8 min over the course of three sessions. The procedure in S1 was unchanged and this phase ended after a further 10 sessions.

For the 10 sessions of Phase 4, the procedure from Phase 2 was re-instated with VI 2-min and a 2.0-sec pacing requirement in S2. Finally, in Phase 5, the original procedure from Phase 1 was re-introduced for a further eight sessions (VI 2-min and pacing requirements of 0.03 sec in both S1 and S2).

RESULTS

The white-key periods (used to space responses in S2) were inevitably intermingled with the key color that signalled each component, and it was assumed that each component was a functional unit for the purposes of measuring interactions between components. Consequently, reinforcement and response rates have been averaged over the total time that each component was in effect.

Figure 1 presents rates of responding to S1 and S2 separately and the frequency of reinforcement in S2 only. The values for response rates shown in Figure 1 were calculated from the total number of responses made in each component and include any responses made ineffective by the pacing requirements. In Phase 1, all birds responded steadily under the VI 2-min schedule and response rates to S2 were consistently slightly higher than those to S1. The pacing requirement (0.03 sec in both components) did not appear to constrain responding significantly and the number of ineffective responses made to the key when it was white was negligible (always fewer than five per session).

Figure 1 shows that in Phase 2, increasing

the pacing requirement to 2.0 sec in S2 gradually reduced response rates in that component to approximately half their Phase-1 levels. Reinforcement frequency in S2 was essentially unchanged. There were no corresponding contrast effects in the unchanged schedule (*i.e.*, during S1) for P1 and P3. However, P2's response rates in S1 increased slightly and this might be construed as a small contrast effect. For all birds the number of ineffective responses in S2 rose sharply, but did not significantly affect overall reinforcement frequency.

In Phase 3, changing the schedule of reinforcement in S2 from VI 2-min to VI 8-min reduced reinforcement frequency in that component but did not further reduce response rates to S2, which were held at a low level by the pacing requirement of 2.0 sec. In fact, the reduction in reinforcement frequency appeared to weaken control by the 2.0-sec pacing requirement and overall response rates to S2 rose slightly. This rise was more marked in the performance of P1 and P3, but was only temporary for P1. Each bird's response rates to S1 rose to levels that were often considerably above those observed in Phases 1 and 2, although the schedule in S1 was unchanged. This interaction in S1 was also accompanied by a slight rise in the number of ineffective responses made in that component.

When the original VI 2-min schedule was restored in S2 (Phase 4) reinforcement frequency in that component increased again. The only major effect on S2 responding was a slight reduction in rate. For each bird, Figure 1 shows that S1 response rates fell again to levels that were comparable with those observed under identical conditions in Phase 2. Ineffective responding in this component also fell again to negligible levels.

In Phase 5, the pacing requirement in S2 was changed from 2.0 sec to its original value of 0.03 sec and response rate to S2 rose sharply. Figure 1 shows that the initial rise was very large for P2 and P3, but that in subsequent sessions the rate returned gradually to levels similar to those observed in Phase 1. A further small decline in S1 response rate during Phase 5 also occurred for P2 and P3.

Finally, throughout the experiment there is evidence that nonsystematic changes in response rate in S1 were sometimes positively correlated with similar changes in rate of

Fig. 1. Daily overall rates of responding for each bird in the red component (S1, open circles) and in the green component (S2, filled circles). Frequency of reinforcement in S2 only is also shown (filled triangles). Throughout the experiment, the schedule in S1 was constant (VI 2-min, 0.03-sec pacing requirement). The schedule in S2 in each phase is shown at the top of the figure. Data in the columns between Phases 1 and 2 and Phases 2 and 3 are from transitional sessions, during which the conditions in S2 were gradually changed.

responding in S2 (see performances of P1 in Phase 1, 3, and 5, for example).

DISCUSSION

The main findings of the present study are that reducing response rates in S2 independently of reinforcement frequency in S2 produced only slight contrast effects in S1 and that subsequent reductions of S2 reinforcement frequency with S2 response rates held approximately constant produced contrast effects in S1. However, several previous studies (*e.g.*, Brethower and Reynolds, 1962; Reynolds and Limpo, 1968; Terrace, 1968; Weisman, 1969, 1970) have found that reducing response rates in S2 with reinforcement frequency held constant can result in contrast in S1. Several authors (*e.g.*, Terrace, 1968) have suggested that contrast in S1 may occur because conditions that suppress responses in S2 are aversive. Thus, the methods used to reduce response rates may be crucial. There is some evidence that response-pacing requirements similar to DRL schedules (used, for example, by Terrace and by Weisman) can be aversive (Fantino, 1968). Consequently, many reported contrast effects may be a product not of the suppression of responding *per se* but of the methods of achieving this suppression, all of which may have aversive properties (punishment, nonreinforcement, DRL, and similar DRO schedules).

The response-pacing requirements used to suppress S2 responding in the present experiment were smaller (2.0 sec) and possibly less aversive than those used by Terrace and by Weisman (variable but always greater than 4.0 sec); hence the relatively small contrast effects in Phase 2 and in Phase 5.

Signalling the "dead" time by following each response with a white light was intended to facilitate a smooth decline in S2 response rates when the pacing requirement was introduced. When similar pacing requirements were used without a signal, in a separate unpublished experiment, it was difficult to reduce response rates without grossly affecting reinforcement frequency, which would have frustrated the object of the present experiment. The white key may also have acted as a mild punisher, since reinforcement was not available in its presence (Ferster, 1957). The initial peak in S2 response rates when the pacing requirement

and signal were shortened at the start of Phase 5 resembles the punishment contrast reported by Azrin (1960) when punishment of responding by electric shock was terminated. Such punishing effects may have contributed to the control of S2 responses and the slight contrast in S1 when the length of the pacing requirement and its signal were varied in S2. Response and reinforcement rates were averaged over the entire duration of each component because it did not seem appropriate to treat the dispersed, response-produced and brief periods of the white key as a separate functional component. Neuringer and Schneider (1968) found that when brief response-produced stimuli were used to space responses, then overall frequency appeared to be the relevant measure of reinforcement frequency.

When S2 reinforcement frequency was reduced in the present study, with response rates in S2 held at a low level by the pacing requirement, the accompanying increases in S1 response rates show that interactions can occur from changes in reinforcement frequency alone. In this respect, the present study is consistent with earlier suggestions that contrast in S1 may be related to reinforcement conditions in S2 (*e.g.*, Bloomfield, 1967; Nevin, 1968; Reynolds, 1961*b*; Zuriff, 1970). However, these data raise some problems of definition. Originally, "behavioral contrast" was defined by Reynolds (1961*a*) as an interaction in which the change in rate of responding in one component of a multiple schedule is in the opposite direction to a change in response rate in the other component. But if reinforcement conditions in S2 are the important factors producing contrast, then it makes more sense to define positive contrast as an increase in S1 response rates as an accompaniment of decreasing S2 reinforcement frequency, and negative contrast as a decrease in S1 response rates as an accompaniment of increasing S2 reinforcement frequency (Rachlin, 1973).

The present study, then, supports reinforcement interpretations of behavioral contrast. In particular, Herrnstein (1970) proposed that contrast in multiple schedules can be represented as the adjustment of rate of responding in each component to match the changed relative frequency of reinforcement in that component resulting from a change in absolute frequency of reinforcement in just one of the components. More recently, Rachlin

(1973) suggested that when different frequencies of reinforcement are arranged in the components of a multiple schedule, then certain responses are excited and others are inhibited, (e.g., Gamzu and Schwartz, 1973). Behavioral contrast (and induction) result from the interaction of these responses and the instrumental responses required for reinforcement. Both hypotheses are consistent with the present data. However, neither hypothesis appears to accommodate readily the findings of studies that reduced response rates in S2 without changing S2 reinforcement frequency and found contrast in S1. One possible conclusion is that there may be two separate kinds of contrast; one due to response suppression and the other due to changes in reinforcement frequency. A second possibility is that response suppression (or techniques used to produce it) and reinforcement frequency reduction may be functionally equivalent in that their aversiveness is a common factor that produces contrast.

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