

*RESPONSE ADDITIVITY: EFFECTS OF SUPERIMPOSED
FREE REINFORCEMENT ON A VARIABLE-INTERVAL
BASELINE¹*

R. A. BOAKES, M. S. HALLIDAY, AND M. POLI

UNIVERSITY OF SUSSEX

Three experiments examined the effects of superimposing free reinforcement (Free VI 30-sec) on behavior maintained by a response dependent *mult* VI 2-min VI 2-min schedule of reinforcement. Experiment I used pigeons as subjects, key pecking as the response, and colors of response key as the stimuli associated with the multiple-schedule components. When free reinforcement was added during only one component (Differential condition) a large and highly significant *increase* in response rate developed in this component. Adding free reinforcement during both components (Nondifferential condition) produced smaller and far less-consistent effects. An entirely different pattern of results was obtained in two subsequent experiments, where similar procedures and reinforcement conditions were used with rats as subjects and bar pressing as the response. In both Experiments II and III, response rates *decreased* to the stimulus associated with added free reinforcement in the Differential condition. These findings are interpreted as the result of interactions between behavior maintained by response-reinforcer contingencies and behavior maintained by stimulus-reinforcer contingencies. As such, they support the main assumption of an auto-shaping theory of behavioral contrast, that additivity of responding generated by the two kinds of contingency can occur only in situations favorable to autoshaping.

Recent research on autoshaping suggests that the behavior of animals in operant-conditioning situations may be determined as much by the relationships between stimuli and reinforcers as by the relationships between the animal's responses and reinforcers. Brown and Jenkins (1968) showed that, in the absence of any instrumental contingency, pigeons will peck a response key on which is displayed a stimulus associated with a high probability of reinforcement. Such autoshaping is obtained both with the discrete-trials procedure used by Brown and Jenkins, where the stimulus is of short duration and is always followed by reinforcement, and with a procedure in which the stimulus is of relatively long duration and free reinforcement can occur at any time in its presence (Gamzu and Schwartz, 1973). There are two main rea-

sons why this behavior is probably dependent on stimulus-reinforcer contingencies. First, the topography of the response made to the key depends on and is similar to the consummatory response to the reinforcer being used (Jenkins and Moore, 1973); this corresponds to the relationship between the conditioned response and the unconditioned response in classical conditioning. Secondly, the pecking response does not disappear under an omission, or "negative-automaintenance", schedule (Schwartz and Williams, 1972; Williams and Williams, 1969); such a contingency would be expected to eliminate an instrumental response.

Gamzu and Schwartz (1973) proposed that a direct summation of pecking generated and maintained as in autoshaping, and pecking maintained by instrumental contingencies, may be responsible for the phenomenon of behavioral contrast observed in multiple schedules. This idea is best explained by the following simplified example, which is based on the conventional paradigms used for studying behavioral contrast.

During an initial baseline phase, a pigeon is trained to peck at a response key that is alternately red and green, and a variable-interval schedule of reinforcement, a VI 1-min,

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say, is associated with both stimuli. After 10 to 15 sessions, response rates will typically have reached a level of about 50 responses per minute; discrimination conditions are then introduced by no longer reinforcing pecks on the red key, while maintaining the reinforcement schedule for pecks on the green key. As responding on the red key declines, that on the green key increases (the contrast effect) and is maintained at, say, a level of 80 responses per minute. The important feature to note is that the discrimination condition contains a stimulus-reinforcer contingency not previously present, which would produce pecking in the *absence* of any instrumental contingency. The theory proposes that this contingency produces the contrast effect. In other words, the extra 30 responses per minute are generated by a process akin to autoshaping, whereas the continuing instrumental contingency maintains the other 50 responses per minute.

In a standard operant discrimination, the response key can be viewed as serving two functions; it is at once the place to which pecks are directed, because of the instrumental response-reinforcer contingency, and also the place to which pecks are directed because of the classical stimulus-reinforcer contingency. In a study by Keller (1974), these two functions were separated by making reinforcement contingent on pecks on one response key, the "instrumental" key, while the availability of reinforcement on this key was associated with color changes on a second key, the "signal" key. Under discrimination conditions, no contrast effect was observed in terms of pecking on the instrumental key, but pecking was also directed at the signal key during positive periods, even though such responses had no effect. These results are consistent with the autoshaping theory of contrast, which assumes that in the conventional single-key situation, the effects of the key's two functions summate. It is this "additivity" assumption that the present experiments were designed to test.

In all three experiments, two stimuli, S1 and S2, were associated with the same instrumental conditions, a variable-interval schedule of response-dependent reinforcement, but with different reinforcement densities, in that extra response-independent (free) reinforcement was added during the S2 periods. The

additivity assumption predicts that in the conventional pigeon situation used in Experiment I, where the instrumental response is a peck on a response key on which the stimuli are displayed, response rates during S2 periods should be higher than those during S1 periods.

Rachlin (1973)² reported data from four pigeons that support this prediction. The procedure used in Experiment I is similar to his, with the addition of a control condition to assess the possibility that an increase in S2 response rates could be accounted for in terms of superstitious conditioning (Herrnstein, 1966). Whereas in the Differential condition only S2 was associated with additional free reinforcement, in the Nondifferential condition, free reinforcement occurred with equal frequency in the presence of both stimuli. Since the effectiveness of a stimulus in an autoshaping situation is affected by its duration (Ricci, 1973), this variable was also manipulated in the experiment, as in that of Rachlin.

The Differential condition can be viewed as superimposing an autoshaping procedure on top of behavior maintained by response-dependent reinforcement. As such, it allows the detection of a possible suppressive effect on baseline behavior of the stimulus (S1) associated with the lower reinforcement density.

EXPERIMENT I

METHOD

Subjects

Sixteen male, adult homing pigeons with no previous experimental experience were maintained at 80% of their free-feeding weights throughout the experiment.

Apparatus

Two standard pigeon chambers each contained an end wall, painted matt black, on which a single response key was mounted centrally at a height of 17 cm. The keys could be lit from behind by either green or red light. A Gerbrands grain hopper was situated below the response key. A white bulb mounted high

²Both the present experiments and the Rachlin experiment arose from extremely profitable discussions between Howard Rachlin and the authors. These are herewith acknowledged with appreciation.

on the rear wall of each chamber served as the houselight.

The chambers were contained in separate sound-attenuating cubicles in which white noise was present throughout the experimental sessions. Conditions were controlled by conventional relay and timing equipment.

Procedure

During a pretraining phase, subjects were first trained in a separate chamber to eat from a grain hopper and were shaped by hand to peck at a white response key. Once 40 reinforced responses had been made, they were transferred on the following day to the experimental chamber, where pecking was reinforced on a schedule that was progressively increased over a period of four sessions from continuous reinforcement to a variable-interval schedule with a mean interval of 2 min. During these four sessions, and throughout the remainder of the experiment, the stimulus conditions in the chambers were as follows. The houselight was on throughout a session, except when the hopper was activated, and the keylight alternated between red (S1 stimulus) and green (S2 stimulus). Sessions always began with an S1 period and terminated after the tenth S2 period. For all subjects, S1 periods were of 2 min duration throughout the experiment. For eight subjects, the duration of S2 periods was also always 2 min ("Long" condition), while for the other eight subjects, S2 periods were always of 20 sec duration ("Short" condition).

Following the pretraining phase, response-dependent reinforcement was always available on a variable-interval schedule with a mean of 2 min in both S1 and S2 periods. Under Base-

line conditions, there was no other source of reinforcement. Under Differential conditions, additional response-independent (free) reinforcers were delivered only during S2 periods at variable intervals with a mean of 30 sec. The variable-interval schedule was that described by Catania and Reynolds (1968) as the "Harvard Golden Tape". Under Nondifferential conditions, additional free reinforcers were delivered on the same schedule in both S1 and S2 periods. Thus, where free reinforcers were added to a component, four reinforcers, on average, were delivered independently of the pigeon's behavior for every reinforcer produced by a peck.

Since there seemed a strong possibility that sequential effects might be important, the order in which subjects were exposed to the Differential and Nondifferential conditions was counterbalanced. Half of the subjects were given "Early" exposure to the Differential condition before the Nondifferential condition. For the "Late" subjects, this order was reversed. Details of the sequences of conditions are shown in Table 1.

The design was thus a factorial one with four groups, each containing four subjects: Early-Long, Early-Short, Late-Long, and Late-Short. Subjects were arbitrarily assigned to the groups at the end of the pretraining phase, with the constraint that within each group, two subjects worked in one chamber and two in the other.

Both response-dependent and free reinforcements were 3-sec access to the grain hopper; during this time, both houselight and keylight were off. If a free reinforcer was delivered when a response-dependent reinforcer was

Table 1

Sequence of conditions for the Early subjects in Experiments I and II. For the Late subjects the procedure was identical except that the order in which Differential and Nondifferential conditions occurred was reversed.

| Condition | Reinforcement Schedule | | No. of Sessions | |
|-----------------|----------------------------------|----------------------------------|-----------------|---------------|
| | S1 Periods | S2 Periods | Experiment I | Experiment II |
| Baseline | VI 2-min | VI 2-min | 8 | 9 or 30 |
| Differential | VI 2-min | VI 2-min, plus Free VI 30-sec | 8 | 12 |
| Baseline | VI 2-min | VI 2-min | 8 | 9 |
| Nondifferential | VI 2-min, plus Free VI 30-sec | VI 2-min, plus Free VI 30-sec | 8 | 12 |
| Baseline | VI 2-min | VI 2-min | 8 | 9 |

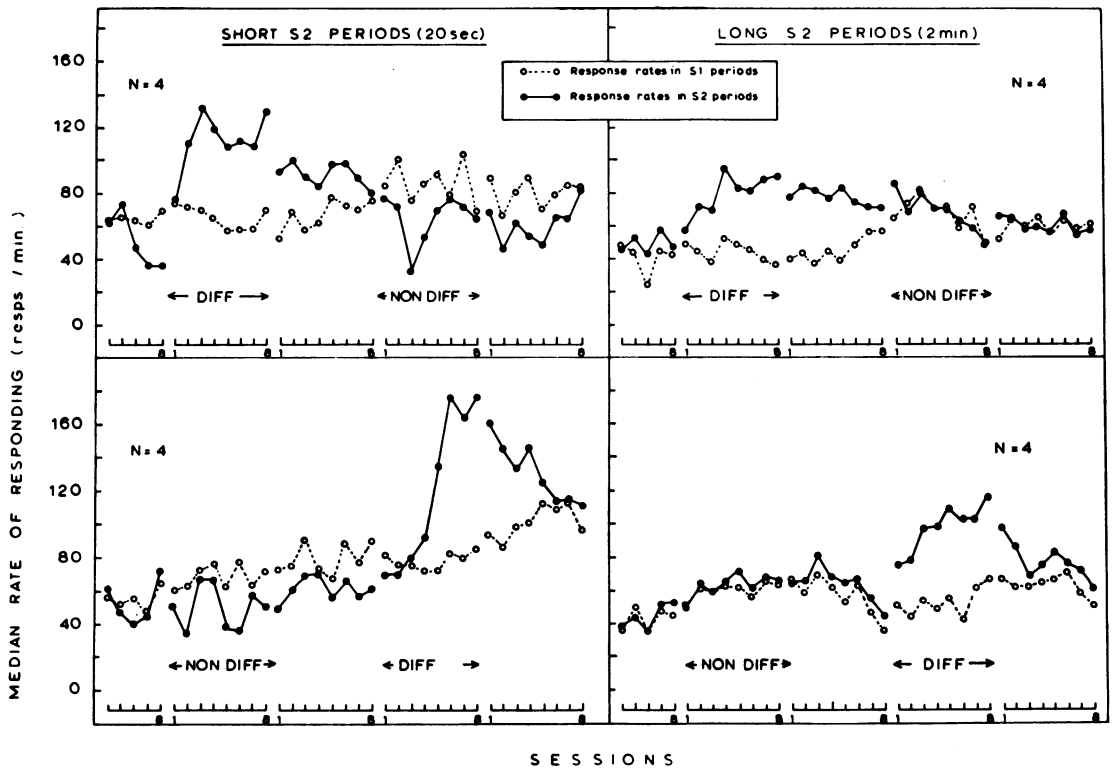


Fig. 1. Median rates of responding in S1 and S2 periods for the four groups of pigeons in Experiment I. "DIFF" indicates sessions with the Differential condition of added free reinforcers in S2 periods only. "NON DIFF" indicates the Nondifferential condition where free reinforcers occur in both S1 and S2 periods. Unlabelled sessions are those in the baseline condition. "Early" groups are shown in the upper panels and "Late" groups in the lower panels.

available, but not yet produced, the response-dependent reinforcer was again available at the end of the free reinforcer period. Throughout the experiment, daily sessions were given six times per week.

RESULTS

The median rates of responding during both S1 and S2 periods are shown for the four groups in Figure 1. The most marked result is that all four groups showed a large increase in response rate during S2 periods under Differential conditions; this was accompanied by a slight decrease in response rates during S1 periods. Under Nondifferential conditions, response rates did not change markedly, but S1 rates tended to increase. Data for individual subjects corresponded closely to the averaged data shown in Figure 1 under Differential conditions, but under Nondifferential conditions, the behavior of individual subjects varied widely.

Changes in response rates of individual subjects produced by a given condition were measured by the difference between the terminal rate in that condition and the projected baseline rate. The derivation of this measure is given in Table 2, where the values for each subject in the Differential condition are shown. As is seen in this table, all 16 subjects showed an increase in S2 response rate in the Differential condition. This increase was greater in the Short groups: a two-way analysis of variance of these data (Sequence \times S2 duration) showed a significant effect of S2 duration ($F = 5.49$; $df = 1,12$; $p < 0.05$), but the Sequence effect failed to reach a significant level ($F = 4.44$; $df = 1,12$; $p > 0.05$) and there was no interaction ($F < 1$). The change in S1 response rates was not significantly affected by either S2 duration or Sequence. However, although the decrease in S1 rates, compared to the projected baseline rate, was small and not found in all subjects, it was statistically significant ($t = 2.54$, $df = 15$, $p < 0.05$).

Table 2

Experiment I: Differential Conditions (Free Reinforcers During S2 Periods Only)

Effects of duration of S2 periods and sequence of conditions on changes in response rate during S2 periods (corresponding changes during S1 periods are shown in parentheses). Increases in response rate in responses per minute are expressed as $B - \frac{A+C}{2}$, where A is the median response rate over the final five sessions of the preceding baseline phase, B is the median response rate over the final five session of the Differential phase, and C is the median response rate over the final five sessions of the following baseline phase.

| | Early | Late | Means |
|---------------------|---------------|----------------|---------------|
| SHORT | +50 (-10.5) | +86.5 (-28.5) | |
| S2 periods (20 sec) | +46.5 (+ 2.5) | +25.5 (- 5.5) | |
| | +31.5 (-19.5) | +68.5 (-14) | |
| | +45 (- 9) | +120.5 (- 5.5) | +59.2 (-11.2) |
| LONG | +39.5 (- 9) | +60 (-33) | |
| S2 periods (2 min) | +17 (0) | +57 (+17) | |
| | +16.5 (+ 4.5) | +24 (- 8) | |
| | +20 (0) | +21 (- 6) | +31.9 (- 4.3) |
| Means | +33.2 (- 5.1) | +57.9 (-10.4) | |

A similar analysis of the comparable data for the Nondifferential condition, which is shown in Table 3, revealed no significant effect of either Sequence or S2 duration in either S1 or S2 periods. In this condition, the increase in S1 rates, as compared to the projected baseline rate, was a reliable effect ($t = 2.56$; $df = 15$; $p < 0.05$), but it was much smaller than the increase that occurred during S2 periods in the Differential condition: all but two subjects showed a greater increase in response rate (as compared with the projected baseline) in the latter condition than they did during S1 periods under Nondifferential conditions, ($t = 3.9$; $df = 15$; $p < 0.005$).

Possible changes in the rate at which re-

sponse-dependent reinforcement occurred were checked by comparing, for each subject, the number of reinforcers obtained on the VI 2-min schedule during S2 periods in the final five sessions of the Differential condition with that during the final five sessions of the preceding baseline condition. There was no indication of any change: for the Short subjects, the median total was eight in the Baseline condition and 8.5 in the Differential condition, and the equivalent figures for the Long subjects were 45 and 46.5.

DISCUSSION

The results in the Differential condition are consistent with the additivity assumption.

Table 3

Experiment I: Nondifferential Conditions (Free Reinforcers Throughout a Session)

Effects of the duration of S2 periods and of the sequence of conditions on response rates are shown as in Table 1. Note that "EARLY" indicates that the Differential conditions precede the Nondifferential condition.

| | Early | Late | Means |
|---------------------|---------------|---------------|--------------|
| SHORT | +18.5 (+10) | -14.5 (+42) | |
| S2 periods (20 sec) | +10.5 (+36) | - 1 (+11) | |
| | -22.5 (+9.5) | -12 (-27) | |
| | - 9.5 (-13) | +18.5 (+16.5) | -1.5 (+10.6) |
| LONG | -10.5 (+19.5) | + 8.5 (+70.5) | |
| S2 periods (2 min) | - 7 (+ 3.5) | +16.5 (+12.5) | |
| | + 1 (+20.5) | + 2.5 (+ 3) | |
| | + 8 (+ 4) | +24 (+ 8) | |
| Means | - 1.4 (+11.2) | + 2.7 (+17.1) | +5.4 (+17.7) |

They show that, when additional free reinforcement is associated with only one of the two stimuli, there are large and consistent increases in response rate in the presence of that stimulus. At the same time, response rates decreased by a small amount in the presence of the second stimulus. The results agree with those reported by Rachlin (1973), who also found that short S2 periods resulted in greater rate increases than long ones. Whatever the cause of the effect of the length of the S2 interval, the finding supports the autoshaping account of contrast, since autoshaping seems to be more effective with short stimulus periods, for a fixed interstimulus period (Ricci, 1973).

In the Nondifferential condition, the effects of adding free reinforcement were more variable; no consistent effect was observed in S2 components, while response rates rose slightly in S1. When pigeons are transferred from a simple VI schedule to an equivalent Free VI schedule (with key pecking as the response) a decrease in response rate *eventually* occurs; however, the decrease is slow, there is much between-subject variability, and increases in responding are not uncommon initially (Boakes, 1973). In the present experiment, the continued availability of response-dependent reinforcement and the changing stimulus conditions could be expected to increase variability and to delay response decrements; it should also be noted that the total exposure to the Nondifferential condition in this experiment was only about half the time that Boakes' birds took to reach a low criterion level of responding. Taking all these factors into account, the absence of response decrements in the Nondifferential condition seems to be compatible with previous results. The slight, but significant, increase in S1 rates under these conditions is puzzling; its explanation remains obscure.

EXPERIMENT II

The pattern of results obtained should, if the additivity interpretation is correct, be specific to the kind of situation used in Experiment I. No comparable increase in S2 rates would be expected if, for example, the discriminative stimuli were not superimposed on the manipulandum. In this and the third experiment, a very different, though equally familiar, operant-conditioning situation was used to ex-

amine the generality of these results. In this experiment, the reinforcement conditions were similar to those of Experiment I, but the subjects were rats, the instrumental response a lever-press, and the discriminative stimuli, compounds containing both auditory and visual elements, were not localized on the lever.

Since under free reinforcement conditions the reinforcer itself can have a response-eliciting effect (Rescorla and Skucy, 1969), differences in response rate during S1 and S2 periods could be a trivial direct effect of different reinforcement rates. Appropriate tests were introduced to assess both this and the degree of control exerted by each element of the stimulus compound when presented alone. The effect of stimulus duration was not investigated in this experiment; instead, the possible importance of the extent of prior baseline training was examined.

METHOD

Subjects

Sixteen male hooded rats with no experimental experience were maintained at 80% of their free-feeding weights (300 to 470 g) throughout the experiment.

Apparatus

Two standard rat operant-conditioning chambers were individually housed in sound-proofed chambers. On the end wall of each box a loudspeaker was mounted centrally at a height of 13 cm, center-to-center, above a pellet-cup aperture. A 4-cm wide lever was mounted to the right of the aperture at a distance of 6.5 cm. At the top of the opposite wall was mounted a light containing a 3-W 24-V dc bulb. The ambient noise levels in the boxes were approximately 45 dB. These levels were increased to approximately 85 dB by white noise fed to the speakers. Conditions were controlled by conventional relay and timing equipment.

Procedure

In every session, S1 periods of 2 min duration alternated with S2 periods of 30 sec duration. During S1 periods, the light was on and the white noise was interrupted at a frequency of 4 Hz, with equal on and off periods; during S2 periods, the light was off and the noise was continuous. The reinforcement contingencies during the three main experimental conditions

were exactly as in the previous experiment, though the number of sessions per condition differed, as is shown in Table 1. Again, eight subjects were given Early exposure to the Differential condition, and eight Late exposure. Four Early subjects were given a brief amount of baseline training before the Differential condition was introduced, and four were given extended initial baseline training. The Late subjects were divided in a similar way. Thus, the design was again a factorial one with four groups of four subjects: Brief-Early, Extended-Early, Brief-Late, and Extended-Late.

In the pretraining phase, sessions consisted of 20 S1 and S2 periods. In the first session, no shaping of the bar press was attempted; the first 40 responses were consistently reinforced with 45-mg food pellets (Campden Instruments Ltd.) and then a VI 30-sec schedule was introduced. Those animals that did not make 40 responses in the first session were given a second session under similar conditions. During this stage, not more than six free reinforcements were delivered to any subject. In the next session, reinforcement was available on a VI 30-sec schedule throughout. One rat failed to make 40 responses by the end of the second pretraining session and was replaced.

After the pretraining phase, each session contained 15 S1 and S2 periods and a VI 2-min schedule was used. After nine sessions of Baseline training, subjects were divided into Brief and Extended baseline groups, so that each contained four subjects in one box and four in the other, and so that response rates were approximately matched in the two groups. The Brief subjects were then divided into Early and Late groups, again matched in terms of boxes and response rates. The Extended subjects were divided in the same way after 30 sessions of baseline training. As shown in Table 1, the four groups differed only in amount of initial training and in the order of Differential and Nondifferential conditions.

At the end of the main part of the experiment, the eight Brief subjects were kept for 18 days in their home cages, where they were maintained at 80% of their free-feeding weights. They were then given a further 12 sessions of training in the Differential condition, followed by two final test sessions.

Each test session contained 16 S1 and S2 periods, and the conditions in each S1 period were exactly as in the Differential condition.

In S2 periods, no response-dependent reinforcement was available and the stimulus conditions could be any of the eight possible combinations formed by the following three factors: Continuous noise (CN) *versus* pulsed noise (PN), Light on (L) *versus* Light off (NL), and Free reinforcement *versus* No reinforcement. When free reinforcers occurred in an S2 period, they were delivered 5 sec and 15 sec from the onset of the period. The 16 S2 periods in each session were divided into two blocks of eight periods and each stimulus combination occurred once within a block. Different random stimulus sequences were used for each block and each subject.

RESULTS

The median rates of responding in each group are shown in Figure 2, where it is seen that in both Differential and Nondifferential conditions, introduction of free reinforcement depressed responding below its baseline level. In the Differential condition, differences were not as marked between the response rates in S1 and S2 periods as in Experiment I; where there were differences, seen more clearly in the Late groups, S2 rates were lower than S1 rates. This is in the opposite direction to the previous experiment.

The length of baseline training proved to be an unimportant variable. Despite the well-known tendency for response rates to increase with extended training, the final baseline response rates of subjects in the Extended groups were not significantly higher than those of subjects in the Brief groups; within the Extended groups, the small increase in median rate of responding between Sessions 5 to 9 (the stage at which baseline training for the Brief groups ended) and 26 to 30 was just significant ($t = 2.2$; $df = 7$; $p < 0.05$ one-tailed).

Changes in response rates, calculated as in the previous experiment, are shown in Tables 4 and 5. In the Differential condition, all 16 subjects showed a decline in responding in S2 periods and 14 of 16 reduced their rates in S1 periods as well. Analysis of variance on these data showed that there were no significant effects of length of training or of the Early/Late factor on the magnitude of these declines.

The discrimination performance of each subject in the Differential condition was measured for each session in terms of a discrimination ratio, namely the ratio between the S1 re-

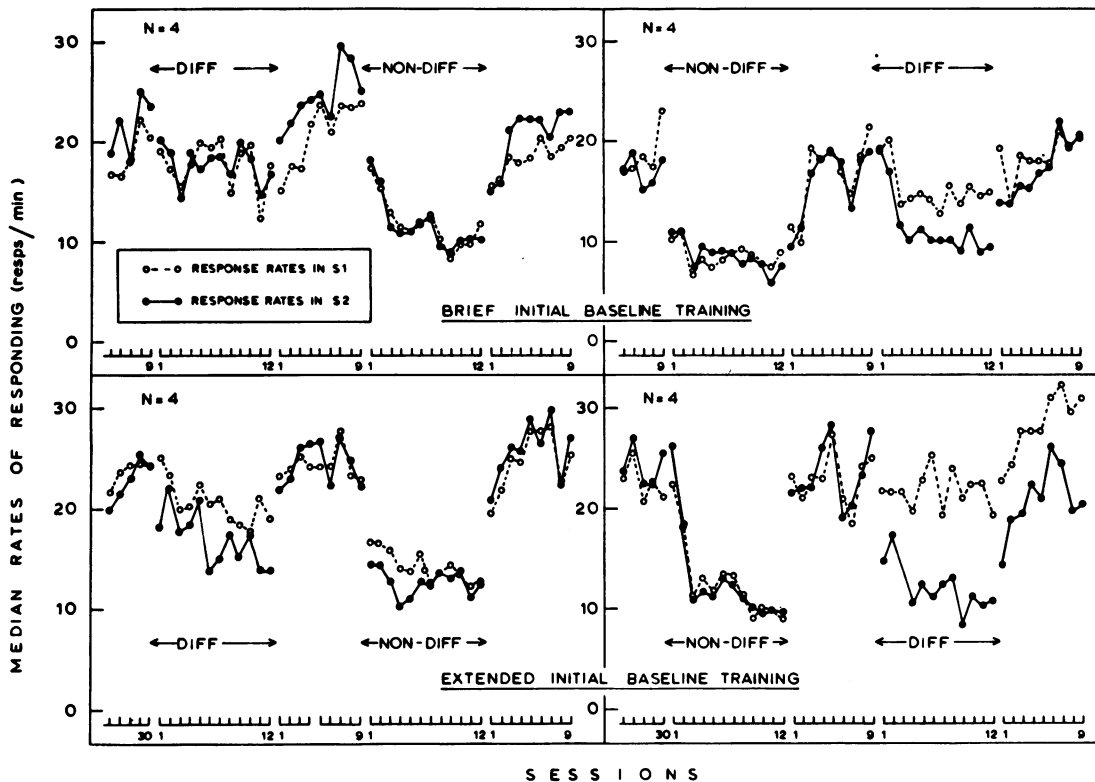


Fig. 2. Median rates of responding in S1 and S2 periods for the four groups of rats in Experiment II. Experimental conditions are indicated as in Figure 1. "Early" groups are shown in the left-hand panels and "Late" groups in the right-hand panels.

Table 4

Experiment II: Differential Condition (Free Reinforcers During S2 Periods Only)

Effects of extent of baseline training and sequence of conditions on changes in response rate during S2 periods (corresponding changes during S1 periods are shown in parentheses).

Increases in response rate in responses per minute are expressed as $B - \frac{3A + 4C}{7}$, where A is the median response rate over the final five sessions of the preceding baseline phase, B is the median response rate over the final five sessions of the Differential phase, and C is the median response rate over the final five sessions of the following baseline phase. This formula differs from that in Table 2 because the "B" measurement period, in this case, does not fall half way between the "A" and "C" periods.

| | Early | Late | Means |
|---------------------|--------------|---------------|-------------|
| BRIEF | - 8.2 (-5.7) | - 4.8 (- 4.9) | |
| 9 sessions initial | - 0.5 (-3.0) | -11.0 (- 3.2) | |
| baseline training | -10.4 (-8.2) | -28.3 (-19.7) | |
| | - 4.6 (-4.4) | -11.6 (- 5.5) | -9.9 (-6.8) |
| EXTENDED | -14.6 (-5.3) | - 9.6 (- 1.7) | |
| 30 sessions initial | - 2.2 (-7.7) | - 0.9 (- 3.1) | |
| baseline training | - 3.6 (+0.4) | - 9.7 (- 8.6) | |
| | - 2.9 (+0.3) | -20.3 (-16.2) | -8.0 (-5.2) |
| Means | - 5.9 (-4.2) | -12.0 (- 7.9) | |

sponse rate and the sum of the S1 rate and S2 rate. The median value of these ratios for the final five sessions of the condition was treated in a two-way analysis of variance, which showed a significant effect of Sequence ($F = 7.16$; $df = 1,12$; $p < 0.025$), but no effect of extent of baseline training or interaction effect ($F < 1$). The mean ratio for the eight Early subjects was 0.51 and that for the Late subjects was 0.63. Only the means for the two Late groups were reliably greater than 0.50 ($t = 4.1$; $df = 7$; $p < 0.01$).

Individual data for the Nondifferential condition (see Table 5), showed a consistent and similar decline in both S1 and S2 periods; all rats decreased their rate in S1 periods and 15 of 16 in S2 periods. As the Table shows, there was no difference in the magnitude of the decline in S1 and S2 periods. Again, no significant effects of either sequence of conditions or extent of training were detected in an analysis of variance.

The results from the test sessions given to the eight subjects that had additional training in the Differential condition are shown in Figure 3. The tests indicated that the light was the main source of stimulus control. In a four-way analysis of variance (Light \times Noise \times Reinforcement \times Blocks), a highly significant effect of the Light factor was obtained ($F = 57.3$; $df = 1,7$; $p < 0.001$), whereas no other factor or interaction was significant.

Possible changes in the rate of response-dependent reinforcement were checked as in Experiment I. There was no indication that the depression of S2 response rates in the Differen-



Fig. 3. Test performance in Experiment II. Mean rates of responding, averaged over the eight subjects, are shown for the various stimulus combinations that occurred in S2 periods during the two test sessions. "L" indicates that the houselight was on and "NL" indicates that it was off; "PN" indicates pulsed noise and "CN" continuous noise. Thus, the left-hand columns show the stimulus arrangement normally present during S1 periods (L + PN), while the corresponding right-hand columns show the stimulus arrangement normally present during S2 periods in the Differential condition (NL + CN).

tial condition affected the rate at which reinforcement was obtained on the VI 2-min schedule.

DISCUSSION

In the Differential condition, when response rates in S1 and S2 differed, the S2 rates were

Table 5

Experiment II: Nondifferential Condition (Free Reinforcers Throughout a Session)

Effects of extent of baseline training and sequence of conditions on changes in response rates are shown in Table 4. Note that "EARLY" indicates that the differential conditions preceded the Nondifferential condition.

| | Early | Late | Means |
|---------------------|---------------|---------------|---------------|
| BRIEF | | | |
| 9 sessions initial | -13.3 (-13.9) | - 7.0 (- 7.5) | |
| baseline training | - 8.5 (- 6.6) | - 8.9 (- 9.1) | |
| | -18.4 (-19.4) | -18.1 (-20.9) | |
| | -11.4 (- 7.1) | -13.4 (- 9.6) | -12.4 (-11.8) |
| EXTENDED | | | |
| 30 sessions initial | -16.8 (-18.8) | - 7.2 (- 7.6) | |
| baseline training | -10.4 (-11.6) | + 2.3 (- 4.2) | |
| | -11.0 (- 9.4) | -12.2 (-13.3) | |
| | -12.1 (-10.0) | -28.7 (-32.4) | -12.0 (-13.4) |
| Means | -12.7 (-12.1) | -11.6 (-13.1) | |

lower than the S1 rates. This is in the opposite direction to the effect found in Experiment I.

A further difference was that introduction of free reinforcement during both Differential and Nondifferential conditions reduced response rates in both S1 and S2 components. This is most clearly seen in comparing performance in the Nondifferential condition of both experiments (see Figures 1 and 2): overall, the pigeons showed little change in response rate, but there was a consistent, marked, and rapid reduction in response rates of the rats.

This finding is consistent with the results obtained when rats are transferred from a simple VI schedule to the equivalent Free VI schedule. This change produces a rapid decrease in response rates (Rescorla and Skucy, 1969; Boakes and Halliday, *in press*), in contrast with the slow and erratic decline found under similar conditions with pigeons (see above). One possible reason for this difference, and for performance in the Differential condition of the second experiment, is that when free reinforcement is added, rats begin to pause after each reinforcer. The results from the test sessions make this unlikely, since response rates were entirely under control of the light and were unaffected by occurrence of reinforcers.

Only subjects in the Late groups clearly showed a discrimination between S1 and S2. This raises the possibility that prior exposure to a Nondifferential condition is necessary for such a discrimination to develop. A final experiment tested this.

EXPERIMENT III

Here we determined whether different rates of responding to S1 and S2 would develop with longer exposure to the Differential condition than that given in Experiment II, even when no Nondifferential condition occurred earlier. Since the results for the latter condition were straightforward in the previous experiment, it was omitted here.

The tests indicated that the effective controlling stimulus in Experiment II was the light. To check the generality of these findings, other stimulus arrangements were used.

METHOD

Subjects

Fourteen male hooded rats with no experimental experience were maintained at 80% of their free-feeding weights (270 to 420 g).

The same apparatus was used as in Experiment II. In addition, a 60-W 240-V ac strip-light, 20 cm long, was mounted in a horizontal plane diagonally above the translucent ceiling of each box. This is called the ceiling light, to distinguish it from the wall light used in the previous experiment.

Procedure

At the start of the experiment, subjects were arbitrarily assigned to either the Noise (N = 7) or the Light group (N = 6). One subject assigned to this last group was discarded when, after two sessions of pretraining, it failed to make the criterion number of responses. Pretraining, Baseline, and Differential conditions were exactly as in Experiment II. After three pretraining sessions at most, subjects were given nine Baseline sessions, followed by 28 sessions of the Differential condition, and finally, nine further Baseline sessions.

For both groups, the wall light was on throughout a session and no other stimulus was present during S1 periods. During S2 periods, the ceiling light was on for Light subjects and continuous white noise at 85 dB was on for the Noise group. Apart from this stimulus difference, all subjects were treated identically.

Single test sessions were introduced between Differential Sessions 16 and 17 and between Differential Sessions 24 and 25. Each test session contained 16 S1 and S2 periods divided into four successive blocks. Each block of four S2 periods contained each of the four possible combinations formed by the two factors: Free reinforcement *versus* No reinforcement, and Stimulus *versus* No stimulus. Apart from the fact that there were only four types of S2 period in the present test, and thus four blocks per session, the procedure was the same as that in Experiment II.

RESULTS

Over the first 12 sessions of the Differential condition, the performance of both groups was very similar to that of the subjects in the Early groups of the previous experiment. There was little indication of different rates of responding in S1 and S2 periods: mean discrimination ratios over Sessions 8 to 12 were 0.51 in the Light group, and 0.49 in the Noise group, where the comparable ratio for the eight subjects in the previous Early groups had been 0.51. In the four to five sessions before the first

test session, response rates during S2 periods dropped below those in S1 periods, though the difference was not significant. Even after 20 sessions of Differential training, as shown in Table 6, though S2 rates were lower than S1 rates in all but two subjects, the differences were still slight. It should be noted that the data in this table are not presented as in Tables 2 to 5, because in the present case, the large number of Differential sessions and the insertion of two test sessions made baseline rate projections of doubtful validity.

Table 6

Experiment III: Median response rates in responses per minute during S1 and S2 periods for the five sessions preceding the second test session (Differential Sessions 20 to 24).

Each pair of S1 and S2 values represents the data from an individual subject.

| Noise Group | | Light Group | |
|-------------|------|-------------|------|
| S1 | S2 | S1 | S2 |
| 9.9 | 9.4 | 16.4 | 12.7 |
| 11.6 | 9.0 | 18.2 | 12.0 |
| 19.2 | 15.4 | 18.1 | 15.1 |
| 12.3 | 17.1 | 16.7 | 16.6 |
| 19.9 | 17.3 | 20.9 | 17.5 |
| 15.3 | 11.1 | 9.0 | 12.3 |
| 20.6 | 11.6 | | |

Responding during the S2 periods of the test sessions was examined in a four-way analysis of variance (Stimulus \times Reinforcement \times Blocks \times Sessions) carried out separately for the two groups. In the Light group, no significant effect of any factor was found. In the Noise group, there was a significant Stimulus effect ($F = 8.66$; $df = 1,6$; $p < 0.05$), a Sessions effect ($F = 21.7$; $df = 1,6$; $p < 0.01$), and a Stimulus \times Blocks interaction ($F = 4.01$; $df = 3,18$; $p < 0.025$). As in the previous experiment, no consistent effect of reinforcement was found. Also, there was little indication of a development of stimulus control over the eight sessions separating the tests, which would have been indicated by a reliable Stimulus \times Sessions interaction.

The averaged results for both tests are shown in Figure 4. It can be seen that, though the stimulus effect in the Light group was not reliable, the general tendency was again for response rates to be depressed in the presence of the S2 stimulus. This effect was more pronounced in the Noise group, though not in the first block of S2 periods. It is not at all clear why there was a development of stimulus con-

rol within the test sessions, as indicated by the Stimulus \times Blocks interaction; such a development may be a fairly general phenomenon, but within-session differences are rarely examined in tests of this kind. In this group, the Sessions effect, noted above, reflected a decrease in the overall level of responding from the first to the second test session.

Individual subjects in the Light group showed greater variability than those in the Noise group. For example, in the second test session, the mean performance of the two groups, expressed in terms of a discrimination ratio based on S2 responding only, was almost identical: 0.56 in the Light group and 0.55 in the Noise group. However, the ratios of two subjects in the Light group were considerably less than 0.50 and those of two other subjects were the highest of all 13 subjects; in the Noise group, all seven subjects gave ratios greater than 0.50. The mean discrimination ratio for the Noise group increased reliably ($t = 2.02$; $df = 6$; $p < 0.05$ one-tailed) from 0.52 in the first test to 0.55 in the second. The Light group showed no change in terms of this measure. As in the previous experiments, no effects were detected of changes in condition on the rate at which response-dependent reinforcers were obtained.

DISCUSSION

These results extend the generality of those of Experiment II. The depression of response

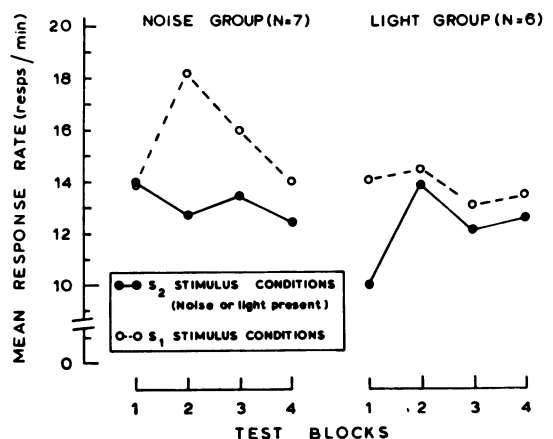


Fig. 4. Test performance of the two groups in Experiment III. Mean rates of responding are shown separately for S2 periods with the stimulus present and for those with it absent. The rates are presented for successive blocks of four S2 periods and averaged over the two test sessions.

rates in the presence of a stimulus associated with added free reinforcement is not dependent on prior exposure to a Nondifferential condition and occurs with a variety of stimulus arrangements.

The failure to find any evidence for stimulus control in the Light group as a whole was an unexpected aspect of the results. Both in terms of a physical measure or of salience for the human observer, the 60-W houselight was a far more intense stimulus than the 3-W wall light, the effective stimulus in Experiment II.

Neither the test results nor any trends in response rates over sessions suggested that the discrimination performance of the Light group would have improved with longer training. As for the Noise group, the increase in the discrimination ratios and the decrease in the overall level of responding between the test sessions indicate, in the absence of a Stimulus \times Sessions interaction, that once a separation in S1 and S2 response rates has occurred, it remains fairly constant as both S1 and S2 rates decline.

GENERAL DISCUSSION

The main result of this series of experiments was that essentially the same reinforcement conditions produced opposite effects in two of the more conventional situations in which operant conditioning is studied. These effects occurred in the absence of any explicit response-reinforcer contingency; in no case were the changes in response rates sufficiently large to affect the frequency with which reinforcement was delivered on the response-dependent schedule.

The effects cannot be accounted for in terms of implicit response-reinforcer contingencies. Though the addition of free reinforcement provides the occasion for development of superstitious responding, such a process could not give rise to the finding in Experiment I that large increases in S2 response rate occurred in the Differential, but not in the Nondifferential, condition. Furthermore, any explanation based on superstitious reinforcement would seem to predict changes in S2 rates in the same direction in all three experiments.

There are many pitfalls in comparing the behavior of two very different species. Nevertheless, there are a number of reasons for supposing that the difference between the situa-

tions was produced by stimulus and response factors of a general nature, and not by some particular characteristics of the species being studied. As discussed earlier, the pigeon situation used in Experiment I may be viewed as one in which additivity of responding produced by response-reinforcer contingencies and responding produced by stimulus-reinforcer contingencies can occur. Two properties of the situation are potentially critical: the stimuli are located on the manipulandum and the instrumental response is similar to the consummatory response elicited by the reinforcer. If the direct effects of stimulus-reinforcer contingencies are of general importance, then *behavior in any instrumental situation, in which different stimuli are associated with different reinforcement densities, may be critically affected by (a) the similarity between the operant and the consummatory response³, and (b) the spatial relationship between the discriminative stimuli and the manipulandum*. It may therefore be useful to classify conditioning situations in terms of the scheme shown in Figure 5, which shows the possible combinations of location. We are suggesting that the opposite response-reinforcer relationships and stimulus results obtained in the Differential condition for the pigeon and rat experiments occurred because different types of situations were com-

RELATIONSHIP OF OPERANT TO CONSUMMATORY RESPONSE

| POSITION OF STIMULUS | RELATIONSHIP OF OPERANT TO CONSUMMATORY RESPONSE | |
|------------------------------|--|-----------|
| | similar | unrelated |
| located on manipulandum | A | D |
| located elsewhere in chamber | B | E |
| non-localized | C | F |

Fig. 5. Types of operant conditioning stimulus formed by various combinations of stimulus and response factors.

³This can be stated more precisely in terms of whether the manipulandum is such that a consummatory response directed towards it can be an operant, that is, classified as an effective response.

pared: Experiment I used a situation of Type A and Experiments II and III situations of Types E or F.

Apart from the research on autoshaping from which it is derived, two further classes of evidence argue for the usefulness of this classification and its relevance to the present results.

The study of behavioral contrast in pigeons usually employs situations of Type A, where typically the effect is large. Keller's results have been cited as indicating that when the stimulus is located somewhere other than on the manipulandum (Type-B situation), contrast no longer occurs. In addition, there is some doubt as to whether the effect occurs with nonlocalized stimuli⁴ (Type-C situation). For example, though Westbrook (1973) and Boakes (1972) reported contrast in situations where the stimuli were auditory or changes in house-light flash frequency, the increase in S1 rates in these studies was small and arguably no greater than an upward drift that could have occurred in the absence of any change in conditions. Using a better control, Redford and Perkins (1974) observed no contrast effect when the discriminative stimuli were changes in house-light color. In the two relevant studies (Hemmes, 1973; Westbrook, 1973) in which treadle pressing by pigeons was the instrumental response (Type-F situation), negative induction, rather than contrast, was reported. Thus, at present, it seems that only in situations of Type A is contrast reliably obtained in pigeons, although in the absence of data from Type-D situations, the importance of the response factor is not yet known.

The study of behavioral contrast in other species is relatively fragmentary. In the case of rats, where only situations of Type E and F have been studied, the evidence is less clear-cut

than for pigeons. In some studies (*e.g.*, Pear and Wilkie, 1971) about as many subjects showed decreases in S1 rates as showed increases, and in others (*e.g.*, Freeman, 1971), no contrast effect was obtained. On the other hand, the effect appears to have occurred reliably in other studies (*e.g.*, Henke, Allen, and Davison, 1972; Mackintosh, Little, and Lord, 1972). At present, the evidence suggests that the effect is smaller and less consistent; there is a clear need for further research on factors determining the occurrence of behavioral contrast in rats.

The second class of evidence relevant to the scheme shown in Figure 5 is from studies that have explicitly investigated the effect of superimposing conditioned stimuli (CSs) classically conditioned to appetitive reinforcers on an instrumentally maintained baseline of responding. As a recent review of this evidence indicates (Mackintosh, 1974; pp. 224-227), the majority of such studies, starting with an experiment by Konorski and Miller in 1936, who used panel-pressing as the response and dogs as subjects (see Konorski, 1967, pp. 371-372), have found that appetitive CSs depress responding, particularly when this is maintained by a variable-interval schedule. In the present experiments, the S2 stimulus in the Differential condition can be regarded as an appetitive CS; from this point of view, the results of Experiments II and III can be seen as being consistent with the evidence on superimposed CSs. Exceptions to the usual suppression effect seem to occur when the response is maintained by a DRL schedule (Henton and Brady, 1970; Smith, 1974). However, with responding maintained by a variable-interval schedule, the only major exception was obtained in a Type-A situation: LoLordo (1971), using key pecking in pigeons and a CS located on the response key, found that the CS accelerated responding. LoLordo, Macmillan, and Riley (1974), using pigeons as subjects, found that a treadle-pressing response (Type-F situation) was depressed by a stimulus associated with additional free food.

Thus, both the evidence from behavioral contrast in pigeons and that from superimposing appetitive CS on instrumental responding suggest that the scheme shown in Figure 5 is a useful one, and that the opposite effects found in the Differential condition for pigeons and rats in the present study arise from the differ-

⁴Special problems arise in considering "nonlocalized" stimuli, and it is far from clear at present what the solutions are. For example, are auditory stimuli to be considered "localized" (since presumably the subject can normally locate their source, the loudspeaker) or "nonlocalized" (since the effect of the stimuli on the subject's receptor organs is relatively independent of orientation)? Furthermore, in the case of a diffuse light source, a pigeon, for example, may be looking at the response key most of the time and therefore any changes may, for the pigeon, be local to the key (Jenkins, personal communication). Further complexities arise from the finding by Schwartz (1973) that a nonlocalized stimulus may become an effective autoshaping stimulus, if it has been previously paired with a localized stimulus.

ence in type of situation, not the difference in species.

There remains the further difference between the two sets of results, namely performance in the Nondifferential condition. The above discussion does not apply here, since reinforcement densities remained constant throughout a session in this condition. As already noted, this difference is similar to that observed when a change is made from a VI schedule to the equivalent Free VI schedule: this produces a rapid response decrement in rats (*e.g.*, Rescorla and Skucy, 1969), but a slow, erratic decline in pigeons (*e.g.*, Boakes, 1973). A crucial factor may be that of baseline response rate: in the above studies and in the present experiments, the response rate of a pigeon was typically at least twice as high as that of a rat. This factor, and the consequent difference in the incidence of long response-reinforcer intervals, could affect the decline of responding by leading to a greater effectiveness of adventitious reinforcement in maintaining responding in the pigeon than in the rats.

A second alternative does not depend on differences in baseline response rates. Using the terminology of the present experiments, one can conceive of the experimental chamber as the S2 stimulus, the experimental session as the S2 period, and the remainder of the day, in which reinforcement is infrequent, as the S1 period. Thus, the stimulus-reinforcer contingencies over a 24-hr period are, by analogy with autoshaping, ones that will make pecking a highly probable response in the absence of any response-reinforcer contingency. This is not unlike Staddon and Simmelhag's (1971) analysis of "superstitious" responding generated by free reinforcement. However, an experimental chamber is in no sense a "localized" stimulus, and it is not therefore clear why pecking produced in such a way should continue to be directed at the response key, following a transition from response-dependent to response-independent reinforcement. One possible solution is suggested by the work of Schwartz (1973), who found that a nonlocalized stimulus may come to control autoshaped pecking on a response key if it has been previously paired with a localized stimulus on the key.

At present, there is insufficient evidence to assess these possible reasons for the different performance in the Nondifferential condition. However, interesting as this difference may be,

the procedure was introduced here as a control condition, and the main purpose of the research was to study behavior in the Differential condition. The finding of a large and consistent increase in S2 responding by pigeons in this condition confirmed the assumption, implicit in the autoshaping theory of behavioral contrast, of additivity of responding generated by two types of contingency, while the opposite result for rats indicated the limited generality of the pigeon result.

The additive effect in Experiment I was greater with the short stimulus duration, thus confirming Rachlin (1973) and suggesting further parallels with autoshaping (Ricci, 1973) and the superimposition of appetitive CSs (Meltzer and Brahlek, 1970; Miczek and Grossman, 1971). Overall, the results increase the plausibility of the autoshaping theory of contrast and support the general proposition that, because of possible interactions between stimulus- and response-reinforcer contingencies, behavior in any conditioning situation may be affected in an important way by specific stimulus and response factors.

REFERENCES

- Boakes, R. A. Frequency of houselight interruption as a dimension for inhibitory generalization testing. *Psychonomic Science*, 1972, 26, 249-251.
- Boakes, R. A. Response decrements produced by extinction and by response-independent reinforcement. *Journal of the Experimental Analysis of Behavior*, 1973, 19, 293-302.
- Boakes, R. A. and Halliday, M. S. Disinhibition and spontaneous recovery of response decrements produced by free reinforcement. *Journal of Comparative and Physiological Psychology* (in press).
- Brown, P. and Jenkins, H. M. Autoshaping of the pigeon's key peck. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 1-8.
- Catania, A. C. and Reynolds, G. S. A quantitative analysis of the responding maintained by interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 327-383.
- Freeman, B. J. The role of response independent reinforcement in producing behavioral contrast effects in the rat. *Learning and Motivation*, 1971, 2, 138-147.
- Gamzu, E. and Schwartz, B. The maintenance of key pecking by stimulus-contingent and response-independent food presentation. *Journal of the Experimental Analysis of Behavior*, 1973, 19, 65-72.
- Hemmes, N. S. Behavioral contrast in pigeons depends on the operant. *Journal of Comparative and Physiological Psychology*, 1973, 85, 171-178.
- Henke, P. G., Allen, J. D., and Davison, C. Effects of lesions in the amygdala on behavioral contrast. *Physiology and Behavior*, 1972, 8, 173-176.

- Henton, W. W. and Brady, J. V. Operant acceleration during a reward stimulus. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 205-209.
- Herrnstein, R. J. Superstition: a corollary of the principles of operant conditioning. In W. K. Honig (Ed.), *Operant behavior*. New York: Appleton-Century-Crofts, 1966.
- Jenkins, H. M. and Moore, B. R. The form of the autoshaped response with food or water reinforcers. *Journal of the Experimental Analysis of Behavior*, 1973, **20**, 163-182.
- Keller, K. The role of elicited responding in behavioral contrast. *Journal of the Experimental Analysis of Behavior*, 1974, **21**, 249-257.
- Konorski, J. *Integrative activity of the brain*. Chicago: University of Chicago Press, 1967.
- LoLordo, V. M. Facilitation of food-reinforced responding by a signal for response-independent food. *Journal of the Experimental Analysis of Behavior*, 1971, **15**, 49-55.
- LoLordo, V. M., MacMillan, J. C., and Riley, A. L. The effects upon food-reinforced pecking and treadle-pressing of auditory and visual signals for response-independent food. *Learning and Motivation*, 1974, **5**, 24-41.
- Mackintosh, N. J. *The psychology of animal learning*. London: Academic Press, 1974.
- Mackintosh, N. J., Little, L., and Lord, J. Some determinants of behavioral contrast in pigeons and rats. *Learning and Motivation*, 1972, **3**, 148-162.
- Meltzer, D. and Brahlek, J. A. Conditioned suppression and conditioned enhancement with the same positive UCS: an effect of CS duration. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 67-73.
- Miczek, K. A. and Grossman, S. P. Positive conditioned suppression: effects of CS duration. *Journal of the Experimental Analysis of Behavior*, 1971, **15**, 243-247.
- Pear, J. J. and Wilkie, D. M. Contrast and induction in rats on multiple schedules. *Journal of the Experimental Analysis of Behavior*, 1971, **15**, 289-296.
- Rachlin, H. Contrast and matching. *Psychological Review*, 1973, **80**, 217-234.
- Redford, M. E. and Perkins, C. C. The role of auto-pecking in behavioral contrast. *Journal of the Experimental Analysis of Behavior*, 1974, **21**, 145-150.
- Rescorla, R. A. and Skucy, J. C. Effect of response-independent reinforcers during extinction. *Journal of Comparative and Physiological Psychology*, 1969, **67**, 381-389.
- Ricci, J. A. Key pecking under response-independent food presentation after long simple and compound stimuli. *Journal of the Experimental Analysis of Behavior*, 1973, **19**, 509-516.
- Schwartz, B. Maintenance of key pecking by response-independent food presentation: the role of the modality of the signal for food. *Journal of the Experimental Analysis of Behavior*, 1973, **20**, 17-22.
- Schwartz, B. and Williams, D. R. The role of the response-reinforcer contingency in negative automaintenance. *Journal of the Experimental Analysis of Behavior*, 1972, **17**, 351-357.
- Smith, J. B. Effects of response rate, reinforcement frequency, and the duration of a stimulus preceding response-independent food. *Journal of the Experimental Analysis of Behavior*, 1974, **21**, 215-221.
- Staddon, J. E. R. and Simmelhag, V. L. The "superstition" experiment: a re-examination of its implications for the principles of adaptive behavior. *Psychological Review*, 1971, **78**, 3-43.
- Westbrook, R. F. Failure to obtain positive contrast when pigeons press a bar. *Journal of the Experimental Analysis of Behavior*, 1973, **20**, 499-510.
- Williams, D. R. and Williams, H. Automaintenance in the pigeon: sustained pecking despite contingent nonreinforcement. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 511-520.

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