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REINFORCEMENT DURATION AND THE PEAK SHIFT IN POST-DISCRIMINATION GRADIENTS[1]

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Pigeons were trained to key-peck for food, first with single-stimulus training and then with successive discrimination (multiple schedule) training. In the multiple schedule, two different wavelengths were each correlated with equally frequent variable-interval reinforcement but different durations (6 sec *vs.* 2 sec) of access to grain. For some birds, the different durations of feeding cycle were cued by different intensities of the food hopper light. For some of these "cued" birds, single-stimulus training had been carried out with 6-sec feedings and when multiple-schedule training was introduced, the novel stimulus was correlated with 2-sec feedings. For the others, 2-sec feedings were originally used, and the novel stimulus was then present during the 6-sec reinforcement duration. The cueing procedure enhanced discrimination performance, and was necessary for the consistent production of a peak shift. In addition, the condition in which original training had been carried out with 6-sec feedings, and thus reinforcement duration was reduced in the presence of the novel stimulus, led to the best performance.

When responses are reinforced in the presence of one wavelength (S_1) and extinguished in the presence of an alternately presented wavelength (S_2), the result is typically a displacement of the mode of the post-discrimination gradient away from S_2 (*cf.* Hanson, 1959; Thomas, 1962; *etc.*). This "peak shift" has also been demonstrated when responding to both stimuli is reinforced on different schedules of reinforcement. Both Guttman (1959) and Terrace (1966) reported a peak shift away from a stimulus correlated with variable-interval reinforcement with a 5-min average interreinforcement interval (VI 5-min) after training on a VI 1-min VI 5-min multiple schedule.

Premack (1965) asserted that manipulations of reinforcement frequency and magnitude are interchangeable procedures for producing behavioral effects which vary with total reinforcement amount. If this view is correct, then it should be possible to demonstrate a peak shift in a situation in which two wavelengths are correlated with equally frequent reinforcement but of differing magnitude. Dickson and Thomas (1963) reported such an experiment, but with negative results. For one group of subjects, lights of 550 and 570 nm were respectively correlated with VI 1-min reinforcement of 10-sec *vs.* 2-sec duration, and yet no peak shift was observed in subsequent generalization testing. While the absence of a peak shift may have been due to the wide (20 nm) spacing of the test stimuli, the high level of responding maintained by both training stimuli suggests alternative interpretations.

At least two methodological problems complicate the interpretation of the Dickson and Thomas (1963) experiment. (a) The magazine light and the sound of magazine operation doubtlessly came to serve as conditioned reinforcers. To the degree that these conditioned reinforcers acquired control over behavior, differences in response rate might have been reduced because the same conditioned reinforcers were present in both components of the schedule, *i.e.*, in the presence of both training stimuli. (b) The sequence of events involving reinforcement was as follows: key-peck—magazine onset (with accompanying stimuli)—magazine approach—sight of food—eating—magazine offset (with accompanying stimuli). When reinforcement duration varies, differences in the delay of the end of the magazine cycle constitute differential reinforcement. In other

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words, the first 2 sec of each reinforcement duration were the same; only when at least 2 sec had elapsed could the pigeon be differentially affected by the two different feeder cycles. This delay of differential consequences of responding would be expected to reduce the effect of the difference between reinforcement durations.

The following experiments attempted to overcome these methodological problems by correlating different intensities of the food-magazine light with different durations of reinforcement. In this procedure, the different magazine light intensities were presented immediately after a reinforced response and were maintained until the end of the magazine cycle. The two intensities could thus serve as the basis for immediate discrimination of the reinforcement durations and could therefore function as differential conditioned reinforcers.

EXPERIMENT 1

This experiment compared discrimination performances and post-discrimination gradients of subjects which either received or did not receive different intensity magazine-light cues paired with different reinforcement durations in the presence of the two training stimuli used in the multiple schedule.

METHOD

Subjects

Eight experimentally naive homing pigeons, obtained from a local supplier, were maintained at 70 to 75% of their free-feeding weights.

Apparatus

The single key of an operant conditioning chamber (*cf.* Thomas and Lopez, 1962, for a more complete description) was transilluminated by light from a Bausch and Lomb monochromator, Model 33-86-25. The monochromatic stimuli used in training and testing had been approximately matched in brightness by two human observers before the experiment; the brightness was varied by manually altering the width of the slit in the monochromator through which the light entered from the tungsten light source. The stimuli used in training (535, 550, and 565 nm) were approximately equally bright when the slit width was set at the same intermediate value. The more peripheral stimuli used in generalization testing, however, required adjustment to make them comparable to the training stimuli. Masking noise was provided by a Grason-Stadler noise generator, Model 901. During its operation, the food magazine was illuminated by a 15-w bulb. Two rheostats in circuit with the magazine light arranged the two different intensities: bright and dim (97.2 and 3.6 apparent ft-c, respectively).

Procedure

All pigeons were magazine and key-peck trained, and 30 responses were then reinforced with 6-sec access to mixed grain. Thirty more reinforcements were scheduled in a similar manner on the subsequent day, followed by two daily 15-min sessions of VI 0.5 min and seven daily 30-min sessions of VI 1 min. The next three days of VI 1 min were each given with 54 stimulus-on periods of 30 sec each separated by 10-sec periods of darkness. This alternation of 30-sec stimulus-on periods and 10-sec timeout periods was maintained throughout all subsequent training and testing. The key was illuminated by a 550-nm light throughout this initial training. The magazine light intensity was bright for four subjects and dim for the other four.

Training on the multiple schedule was then begun. The 550-nm training stimulus remained correlated with 6-sec feedings and was therefore designated as S_1. An S_2 correlated with 2-sec feedings (which was either 535 or 565 nm) was introduced for each subject. S_1 and S_2 were each presented for 27 periods each day, and during both, VI 1-min reinforcement was scheduled. All scheduled reinforcements not produced by the end of a given stimulus-on period were cancelled. The training schedule, with equal frequencies but different durations of reinforcement in each component, is designated as *mult* 6-sec 2-sec.

For the four "cued" subjects, the magazine light intensity used in single-stimulus training remained correlated with 6-sec feedings and S_1, while the other magazine light intensity was correlated with 2-sec feedings and S_2. The bright magazine light was correlated with S_2 for two subjects; the S_2 was 535 nm for one and 565 nm for the other. The dim light was correlated with S_2 for the other two subjects. Observation revealed that the introduction of a novel magazine light intensity in S_2 caused only a few failures to eat during reinforcement. In these few cases, the reinforcements were rescheduled manually at a randomly selected time in the next S_2 period. No failures to eat occurred after the first day of the *mult* 6-sec 2-sec schedule.

For the four "non-cued" subjects, the magazine light intensity used in single-stimulus training continued to be used in *mult*-schedule training with both 6-sec and 2-sec feedings. The bright magazine light accompanied both S_1 and S_2 for the other two subjects. For one of these, S_2 was 535 nm; for the other it was 565 nm.

Five days of training on the multiple schedule were given. On the next day, a generalization test in extinction was administered after 10 randomized, reinforced presentations of each of the two training stimuli. The test stimuli, 520, 530, 535, 540, 550, 560, 565, 570, and 580 nm, were randomized within a block and six blocks were presented to each subject. It was decided in advance that any subjects not showing a substantial peak shift would be given 10 additional training sessions on the *mult* 6-sec 2-sec schedule and a second generalization test.

RESULTS AND DISCUSSION

Starting from the left, the first three data points in Fig. 1 (for cued subjects) and Fig. 2 (for non-cued subjects) show single-stimulus response rates before timeouts were introduced. The first three points following line A shows response rates to S_1 with timeouts. Following line B, the discrimination performance for the first five sessions of *mult* 6-sec 2-sec are shown. The points for Session 6 of the *mult* schedule (at point C) show response rates during the abbreviated session which immediately preceded generalization testing. The curves after point C in Fig. 2 show discrimination performance during extended training after the first generalization test. Point D indicates rates in the abbreviated session before the second generalization test. The response rate to S_1 divided by the rate to S_2 is given as the S_1/S_2 ratio for each session of the *mult* schedule. All response rates were corrected for feeding time. The generalization gradients obtained after initial training (solid lines) and after retraining (dotted lines) may be seen on the right of Fig. 1 and 2.

All birds in Exp. 1 responded at a higher rate after the introduction of timeouts, although the increase was, in some cases, very small. In addition, part of the rate increase (or all of it) may be illusory, because responding to S_1 may not yet have stabilized. With the introduction of the *mult* schedule for the cued birds (see Fig. 1), W6, W7, and W8 showed clear-cut rate increases in S_1 with either a leveling off or a decrease in rate to S_2. The fourth bird, W5, showed little rate increase in S_1 but a steady and substantial decrease in responding to S_2. Thus, all four cued birds showed an increasing divergence in response rates to S_1 and S_1, with the greatest S_1/S_2 ratio obtained in the abbreviated session that preceded the generalization test. The performance within each session also improved markedly for the birds in this group, each of which showed a peak shift in its generalization gradient.

The picture for the non-cued birds (see Fig. 2) was quite different. When the *mult* schedule was introduced, for three of the birds, B2, B3, and B4, response rate increased not only to S_1 but also to S_2. Bird B4 showed a subsequent rate reduction to S_2 such that the S_1/S_2 ratio before the first generalization test was higher for this subject than for the other members of the non-cued group. Note that B4 also yielded a peak shift (based on a difference of only one response) but that the behavior of this bird was unstable. With additional training, the rates to S_1 and S_2 converged and there was no suggestion of a peak shift in the second generalization gradient. By the end of 16 days of *mult* schedule training, Bird B1 showed an S_1/S_2 ratio comparable to that obtained with B4 on Day 6, yet the subsequent generalization gradient showed no peak shift. It was also the case that the non-cued birds typically showed little or no improvement in discrimination performance within sessions. The mean S_1/S_2 ratio never exceeded 1.4 for these subjects, even with extended training. This is comparable to the ratio of approximately 1.5 estimated from a function reported by Shettleworth and Nevin (1965), who used various combinations of reinforcement durations in a *mult* schedule with no added cues. It should be noted here that the frequency of reinforcement in S_2 was virtually identical to that in S_1 for both cued and non-cued subjects; the response rate in S_2 was sufficiently high that no differential effect on reinforcement frequency in S_1 and S_2 occurred. Further, it is unlikely that discrimi-

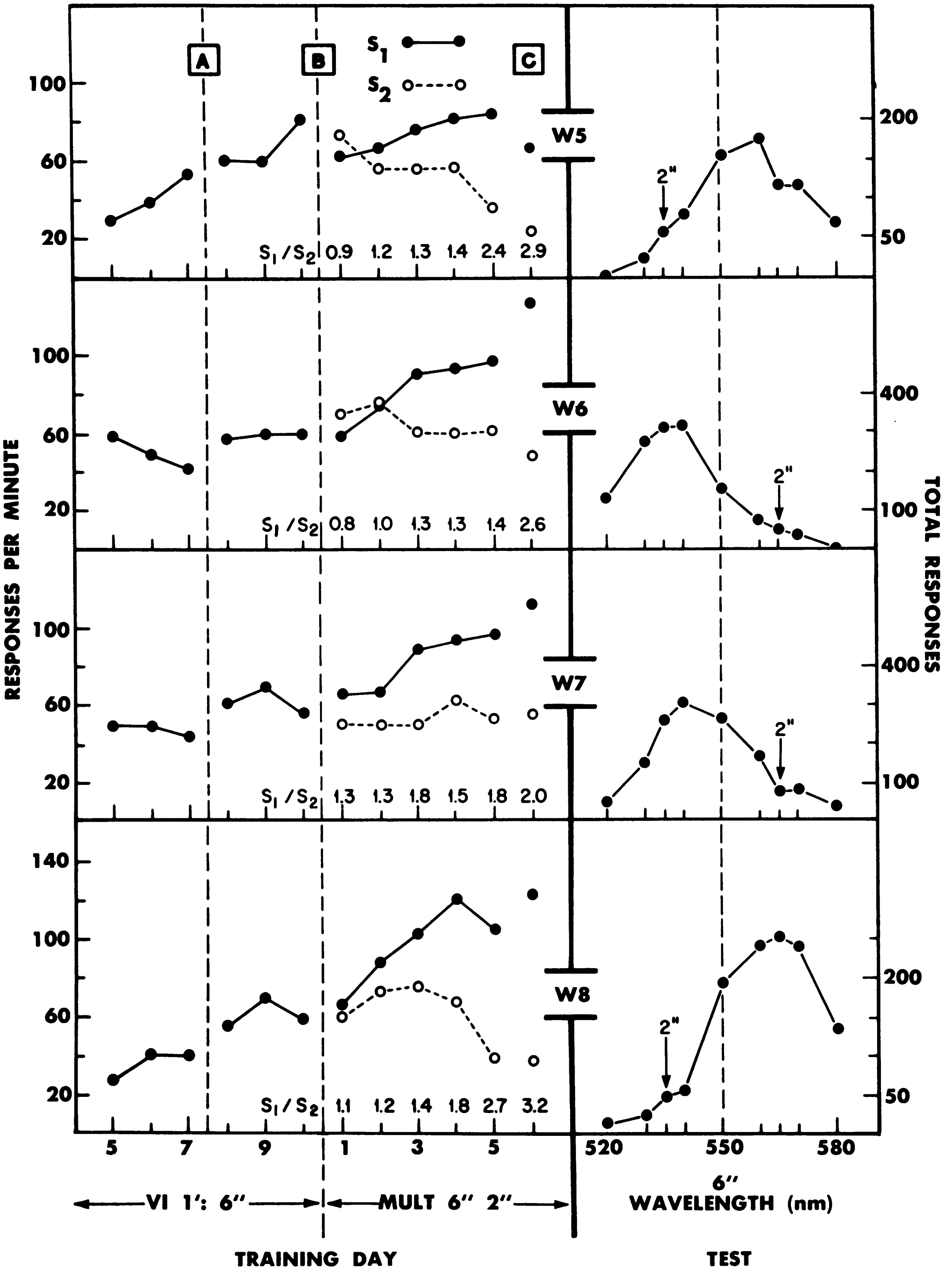

Fig. 1. Response rates and post-discrimination generalization gradients for the four cued subjects in Exp. 1.

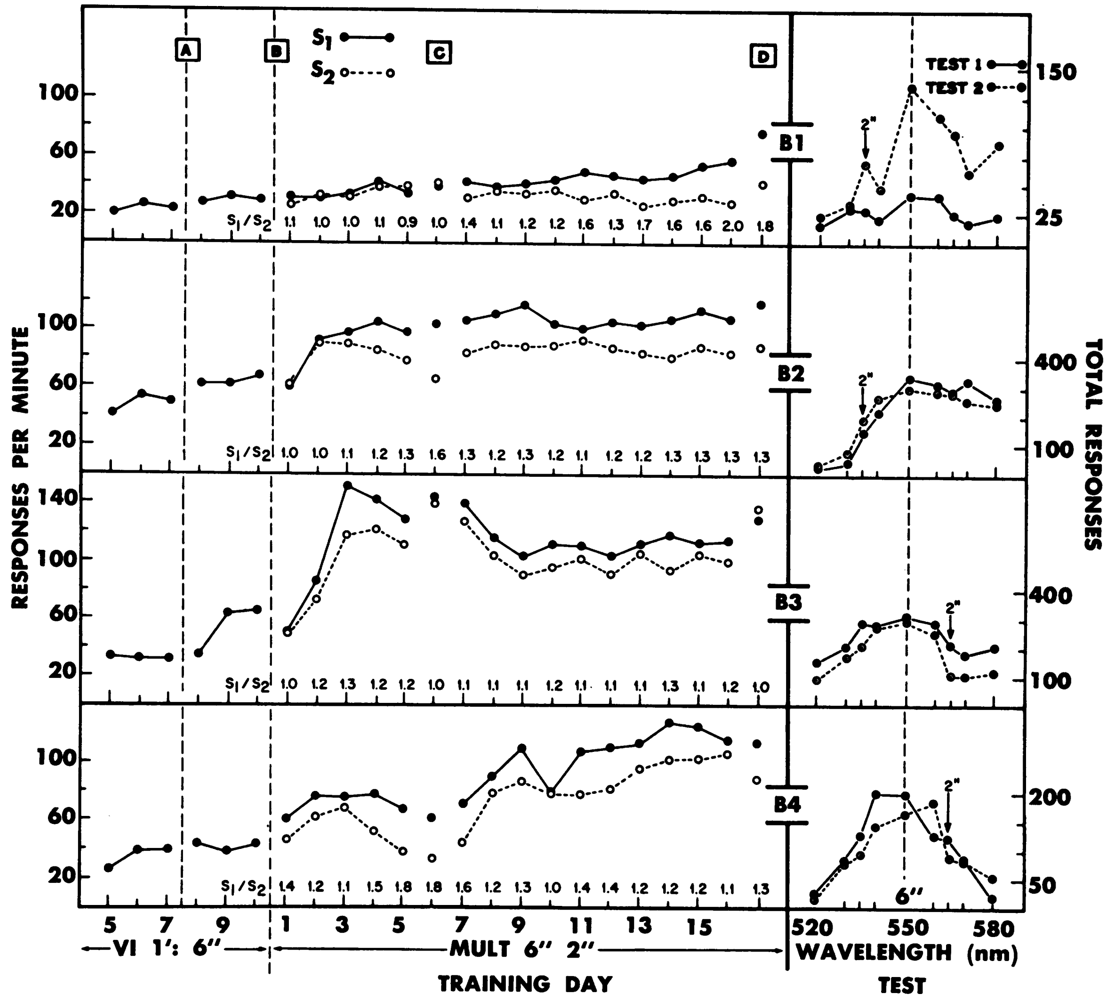

Fig. 2. Response rates and post-discrimination generalization gradients for the four non-cued subjects in Exp. 1.

nation performance was retarded by the first generalization test, since Thomas (1962) found no apparent effect of repeated testing on discrimination performance when testing pigeons repeatedly during the formation of a discrimination between stimuli correlated with VI reinforcement and extinction.

These findings indicate, then, that in Exp. 1, the different intensities of magazine light both enhanced discrimination performance and produced consistent peak shifts in the post-discrimination gradients.

EXPERIMENT 2

Guttman's (1959) experiment showed that a peak shift in a generalization gradient may be obtained after *mult* VI 1-min VI 5-min training, after continuously reinforced single-stimulus training. Terrace's (1966) replication and extension of that finding demonstrated that the training received before the *mult* VI 1-min VI 5-min schedule is important. Specifically, a peak shift was obtained only from subjects that had been trained first on a *mult* VI 1-min VI 1-min schedule. When prior training had been given on a *mult* VI 5-min VI 5-min schedule, no peak shift was obtained. To extend Terrace's finding from reinforcement frequency to reinforcement duration, subjects in Exp. 2 were trained initially with 2-sec feedings for responding in the presence of the stimulus which was to become S_2 in the *mult* schedule. Subsequently, S_1 was introduced with a different magazine light intensity and with 6-sec reinforcements. This procedure, in which reinforcement duration in the presence of a stimulus increases at the introduction of differential reinforcement, is thus analogous to Terrace's switch from *mult* VI 5-min VI 5-min to *mult* VI 1-min VI 5-min.

There was an additional reason for performing Exp. 2. In the first experiment, when *mult* training was introduced, a novel stimulus was correlated with the 2-sec feedings. Any aversive effect of the novelty of this stimulus might have summated with the effect of the shorter reinforcement duration. In Exp. 2, the novel stimulus introduced in *mult* training was correlated with the 6-sec feedings.

METHOD

Subjects

Four experimentally naive homing pigeons were obtained and maintained as in Exp. 1.

Apparatus and Procedure

The procedure, in the same apparatus as in Exp. 1, differed from that for the cued subjects in Exp. 1 in that initial single-stimulus training provided 2-sec reinforcements for responses to 535 nm for two subjects and to 565 nm for the other two. With this procedure, the novel stimuli introduced at the beginning of the *mult* schedule were those correlated with 6-sec feedings, *i.e.*, 550 nm as S_1, and the magazine light intensity was different from that correlated with 2-sec feedings. The counterbalancing of the two S_2s and the two magazine light intensities was thus the same as for the cued subjects in Exp. 1.

RESULTS AND DISCUSSION

The data from this experiment are shown in Fig. 3, which is similar to Fig. 1 and 2 except that the points on the left side of the figure indicate response rates for 2-sec reinforcements in the presence of the stimulus which then became S_2 in the *mult* schedule. The response rates were corrected for feeding time.

In this experiment, in every case the introduction of *mult* schedule training initially produced induction, *i.e.*, response rate in S_2 increased as response rate to S_1 increased, despite the fact that there was no change in the reinforcement contingency correlated with S_2. After several days on the *mult* schedule, response rate to S_2 decreased, whereas response rate to S_1 had stabilized.

The divergence in response rates during the *mult* schedule was intermediate to the divergence in rates observed with the two groups in Exp. 1. The mean S_1/S_2 ratios in Exp. 2 for Session 5 and the abbreviated session at Point C were both 1.8. This is higher than the maximum mean ratio of 1.4 obtained from the non-cued subjects in Exp. 1, but lower than the 2.0 and 2.7 for Session 5 and the abbreviated session, respectively, obtained from the cued subjects in Exp. 1.

The generalization gradients plotted on the right of Fig. 3 show peak shifts in three of the four gradients. The erratic performance of subject B11 in training and testing has no obvious explanation. This bird showed better discrimination performance than did B10, yet the latter yielded a peak shift, whereas the former did not. Similarly, it is interesting to note that Birds B10 and B12 in this experiment yielded peak shifts while performing no better (either in terms of S_1/S_2 ratio or in absolute difference between response rates) than did Birds B1 and B2 from the non-cued group in Exp. 1, yet neither of the latter birds showed peak shifts. Thus, it is clear that a peak shift cannot reliably be predicted from the discrimination performance immediately preceding the generalization test. Other factors, like the course over which that discrimination performance developed, must be taken into account. This might be expected on the basis of Terrace's (1966) finding of the significance of the training administered before introduction of the *mult* VI 1-min VI 5-min schedule.

Terrace (1968) has argued that the sufficient condition for peak shift is behavioral contrast, and that a reduction in reinforcement frequency is but one of many operations which accomplish this end. Presumably, a reduction in reinforcement duration would be another. Unfortunately the present data were not obtained in such a way as to allow a reliable determination of when behavioral contrast was present. No *mult* schedule baseline was obtained before differential reinforcement, and responses to the two component stimuli were simply summated over each training session.

Experiment 2 indicates that the peak shifts obtained from the cued subjects in Exp. 1 were not dependent upon any aversiveness of the novel stimuli (S_2 and magazine cue) introduced at the outset of the *mult* 6-sec 2-sec schedule. If aversiveness of these novel stimuli

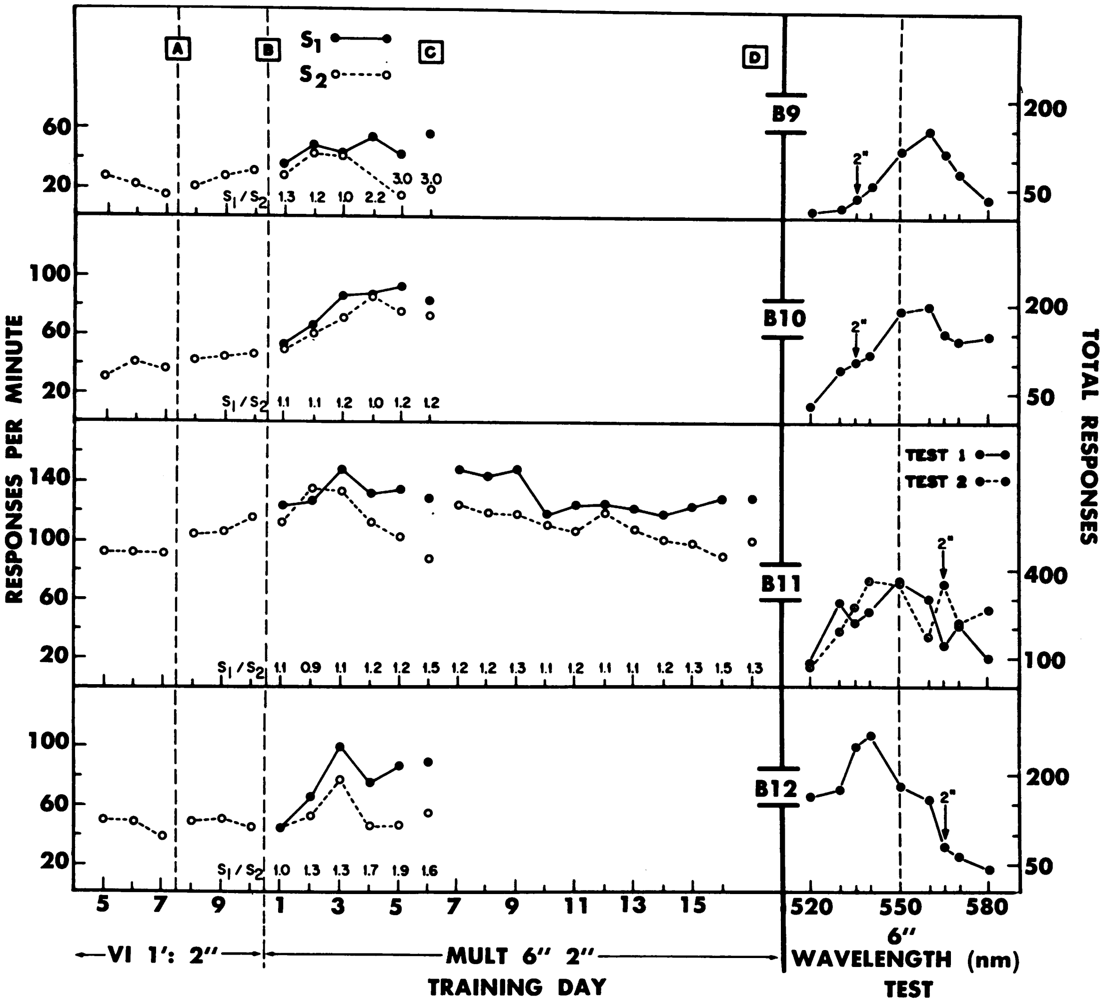

Fig. 3. Response rates and post-discrimination generalization gradients for the four subjects in Exp. 2.

were important, then S_1 in Exp. 2 should have been aversive and there is no evidence to suggest that it was.

It seems clear from these experiments that the use of magazine light cues correlated with different reinforcement durations facilitates discrimination performance. Furthermore, discrimination performance is better when reinforcement duration is reduced in the presence of the new training stimulus than when it is increased. Both of these factors also affect the likelihood of obtaining a post-discrimination peak shift, but there is reason to believe that discrimination performance and peak shift are not simply and directly related. Two non-cued subjects (in Exp. 1) failed to show peak shifts while demonstrating better discrimination performance than that of two cued birds (in Exp. 2), both of which showed peak shifts.

It is commonly considered that response rate in pigeons is relatively insensitive to manipulations in amount of reinforcement. Pyron and Wyckoff (1961) varied both the frequency and the duration of reinforcement in such a manner that the total amount of reinforcement over a given time period remained constant. Only the frequency of reinforcement proved to affect response rate. Keesey and Kling (1961) failed to show an effect of reinforcement amount on response rate unless a probe stimulus or other procedure which interrupted the steady flow of responses was employed. With the use of *mult* schedules, Dickson and Thomas (1963) and Shettleworth and Nevin (1965) were more successful in demonstrating a positive relationship between reinforcement duration and response rate, but very large differences in the former accounted for only very small differences in the latter. Indeed, the data points from the non-cued subjects in Exp. 1 fall in line with those reported by Dickson and Thomas (1963) and those estimated from the function plotted by Shettleworth and Nevin (1965) in indicating that with a three-to-one difference in reinforcement duration, less than 58% of total responses are made in the presence of the stimulus correlated with the greater reinforcement. Experiment 1 reveals, however, that with the use of differential conditioned reinforcers, the sensitivity of response rate to manipulations in reinforcement frequency is strikingly increased. It seems clear that the degree to which conditioned reinforcers exercise control over behavior in *mult* schedules has not been fully appreciated. This suggests that caution be employed in interpreting the results of past experiments and in designing new ones on magnitude of reinforcement. Where differential primary reinforcement is associated with similar or identical conditioned reinforcers, the effectiveness of the experimental manipulation may be substantially attenuated.

REFERENCES

Dickson, J. F., Jr. and Thomas, D. R. Operant discrimination learning and stimulus generalization as a function of reward exposure. *Journal of Comparative and Physiological Psychology*, 1963, **56**, 829-833.

Guttman, N. Generalization gradients around stimuli associated with different reinforcement schedules. *Journal of Experimental Psychology*, 1959, **58**, 335-340.

Hanson, H. M. Effects of discrimination training on stimulus generalization. *Journal of Experimental Psychology*, 1959, **58**, 321-334.

Keesey, R. E. and Kling, J. W. Amount of reinforcement and free-operant responding. *Journal of the Experimental Analysis of Behavior*, 1961, **4**, 125-132.

Premack, D. Reinforcement theory. In D. Levine (Ed.), *Nebraska Symposium on Motivation: 1965*. Lincoln: University of Nebraska Press. Pp. 123-180.

Pyron, B. and Wyckoff, L. B. The rate of pecking by pigeons as a function of amount and frequency of reinforcement. *American Journal of Psychology*, 1961, **74**, 278-282.

Shettleworth, S. and Nevin, J. A. Relative rate of response and relative magnitude of reinforcement in multiple schedules. *Journal of the Experimental Analysis of Behavior*, 1965, **8**, 199-202.

Terrace, H. S. Stimulus control. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 271-344.

Terrace, H. S. Discrimination learning, the peak shift, and behavioral contrast. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 727-742.

Thomas, D. R. The effects of drive and discrimination training on stimulus generalization. *Journal of Experimental Psychology*, 1962, **64**, 24-28.

Thomas, D. R. and Lopez, L. J. The effects of delayed testing on generalization slope. *Journal of Comparative and Physiological Psychology*, 1962, **55**, 541-544.

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