*RELATIVE AND ABSOLUTE DENSITY OF
REINFORCEMENT AS FACTORS INFLUENCING
THE PEAK SHIFT¹*

KIMBAL L. WHEATLEY AND DAVID R. THOMAS

UNIVERSITY OF COLORADO

Four groups of six pigeons each were given nondifferential training on multiple variable-interval variable-interval reinforcement schedules and then were switched to differential training involving a multiple schedule in which reinforcement density was reduced in one of the two components. The multiple schedules used in the four groups had mean inter-reinforcement intervals of 1 min and 1 min in the two components changed to 1 min, 5 min; 2.5 min, 2.5 min changed to 2.5 min, 5 min; 12 sec, 12 sec changed to 12 sec, 24 sec; and 12 sec, 12 sec changed to 12 sec, 60 sec. In subsequently administered wavelength generalization tests, some peak shifts were observed in each condition and occurred occasionally in the absence of behavioral contrast or rate reduction in the less-reinforced component. The best predictor of peak shift was a high proportion of total responses emitted during the more-reinforced component at the end of differential training.

Hanson (1959) trained pigeons to discriminate between two monochromatic stimuli that were successively presented on a response key, one signifying variable-interval (VI) reinforcement (S+) and the other signifying extinction (S-). Subsequently administered wavelength generalization tests yielded gradients in which the subjects emitted the maximal (peak) number of responses to a stimulus value displaced from the S+ value so as to be farther removed from the S- value.

Such a shift in the peak of responses can be derived from the theory of discrimination learning offered by Spence (1937), in which a gradient of excitation centered around the S+ is algebraically combined with a gradient of extinction centered around the S-. The appeal of Spence's model was reduced however, when Guttman (1959) found peak shifts following training in which a VI 1-min S+ (referred to here as S1) was alternated with another stimulus associated with VI 5-min schedule of reinforcement (S2). In such a schedule, responses are reinforced in the presence of both stimuli and the assumption of a theoretical gradient of extinction is therefore a questionable one. Guttman hypothesized

that S2 is rendered "functionally negative" because of "extinction-like" effects that result from responding to S2.

Using a similar multiple reinforcement schedule, Terrace (1966, 1968) demonstrated that subjects that exhibit "extinction-like" behavior in the S2 component (*i.e.*, a reduction in the rate of responding to S2 when the relative frequency of reinforcement in S2 is reduced) exhibited both positive behavioral contrast and peak shift, whereas subjects that did not show response rate reduction in S2 showed neither of these effects. Positive behavioral contrast may be defined as an increase in response rate during S1 following a change in reinforcement contingencies during S2. For present purposes, the change of interest in reinforcement contingencies is a decrease in the reinforcement density correlated with S2.

Terrace (1968) demonstrated that subjects given multiple (*mult*) VI 5-min VI 5-min reinforcement schedule training and then switched to a *mult* VI 1-min VI 5-min schedule did not usually exhibit either response reduction or peak shifts, whereas a change from *mult* VI 1-min VI 1-min to *mult* VI 1-min VI 5-min produced both of these effects. It would appear then, that an absolute reduction of reinforcement density during S2 in conjunction with the resultant relative increase in reinforcement frequency during S1 is a condition that reliably produces behavioral contrast, response reduction, and peak shift. In both the

¹This research was supported by N.I.H. Research Grant HD-03486 and Training Grant MH-10427 under the direction of David R. Thomas. Reprints may be obtained from Kimbal L. Wheatley, Department of Psychology, Weber State College, Ogden, Utah 84403.

Guttman (1959) and Terrace (1968) studies, the density of reinforcement during S2 was reduced from VI 1-min to VI 5-min, resulting in a five-to-one increase in the relative frequency of reinforcement associated with S1. The present study was designed to delineate further the determining conditions of the peak shift and related phenomena. Specifically, we were interested in: (1) whether a smaller two-to-one increase in relative reinforcement frequency in S1 would also result in a peak shift and (2) whether similar differences in relative reinforcement frequencies, but with schedules with much higher absolute densities of reinforcement, would also result in a peak shift.

METHOD

Subjects

Twenty-four experimentally naive domestic pigeons were maintained at 75% of their free-feeding weights.

Apparatus

Four pigeon chambers were employed. White noise and exhaust fans provided masking of extraneous laboratory noise at all times. Each chamber was equipped with a 22-mm diameter translucent response key that could be illuminated from behind by an Industrial Electronics Engineers in-line display cell. Kodak Wratten filters nos. 65, 74, 99, 73, and 72B provided peak wavelength stimuli of 501, 538, 555, 576, and 606 nm respectively. Simultaneous transillumination of adjacent pairs of the filters produced peak wavelengths of 517, 549, 559, and 587 nm (Lyons and Klipec, 1971). As Lyons and Klipec pointed out, the wavelength values listed should be viewed as ordinally related. Measurements of luminance of the pecking keys with a Gamma digital photometer (model 2400) indicated that the stimuli also differed in luminance. The nine stimuli had luminance levels of 3.4, 5.8, 2.4, 6.9, 4.5, 5.9, 1.5, 3.8, 2.3 ml (re: 3.18 cd/m²) for the stimulus values 501 through 606 respectively. However, several studies using these filters indicate that responding varies systematically with wavelength and not luminance (*cf.* Dukhayyil and Lyons, 1973). Miniature lamps (G.E. #1815) supplied with 200-mA current were used in the display cells. The only illumination in the experimental chambers was provided by the response keys and the

food-hopper lights during magazine cycles. The reinforcing event consisted of 2-sec access to a hopper of mixed grain.

Procedure

On the first day of training, the key peck was trained while the key was alternately illuminated every 60 sec by the 555-nm and 576-nm stimuli. Immediately after key-peck training, 12 subjects were placed on a *mult* VI 12-sec VI 12-sec schedule of reinforcement. The remaining 12 subjects were placed on a *mult* VI 1-min VI 1-min schedule. After 50 reinforcers had been collected, the animals were returned to their home cages.

On Day 2, the same schedules in effect at the end of Day 1 were used except that for six subjects, the schedule was changed from *mult* VI 1-min VI 1-min to *mult* VI 2.5-min VI 2.5-min. From Day 2 on, sessions for the VI 12-sec VI 12-sec subjects lasted 20 min. Thirty-minute sessions were used for VI 1-min VI 1-min and VI 2.5-min VI 2.5-min subjects. Stimuli were alternated in a quasi-random sequence every 60 sec with the stipulations that no more than two of the same components occurred in sequence and that each schedule component was in effect for one-half of the duration of each session. Throughout the experiment, all reinforcement schedules used were the constant-probability-of-reinforcement-per-opportunity type constructed according to the progression suggested by Catania and Reynolds (1968, p. 381).

Stage I. All subjects continued on the same reinforcement schedule established on Day 2 for at least 20 days. If response rates were noticeably variable or still increasing across the sessions immediately preceding Day 20, additional Stage I training was given until response rates had stabilized.

Stage II. At the initiation of Stage II, the reinforcement density was reduced in one component of the multiple schedules for all subjects. Table 1 depicts the groups and VI schedules employed. The ratio of S1 to S2 reinforcement frequency was either high (five-to-one) or low (two-to-one) and the absolute S2 reinforcement density was either high (VI 24-sec or VI 60-sec) or low (VI 5-min). For six of the subjects, the group designated high density-low ratio (HL), the *mult* VI 12-sec VI 12-sec schedule was changed to a *mult* VI 12-sec VI 24-sec schedule. For a second group of

Table 1
A Schematic Representation of the Experimental Conditions

Low density-Low ratio	VI 2.5-min	VI 2.5-min to VI 2.5-min	VI 5-min
Low density-High ratio	VI 1-min	VI 1-min to VI 1-min	VI 5-min
High density-Low ratio	VI 12-sec	VI 12-sec to VI 12-sec	VI 24-sec
High density-High ratio	VI 12-sec	VI 12-sec to VI 12-sec	VI 60-sec

six animals, the high density-high ratio (HH), the *mult* VI 12-sec VI 12-sec schedule was changed to *mult* VI 12-sec VI 60-sec. For a third group, designated low density-low ratio (LL), the *mult* VI 2.5-min VI 2.5-min schedule was changed to *mult* VI 2.5-min VI 5-min. For the remaining six subjects, the low density-high ratio group (LH), a change was made from *mult* VI 1-min VI 1-min to *mult* VI 1-min VI 5-min. For all groups, the 576-nm stimulus was correlated with the lower density of reinforcement schedule. Stage II training lasted for 10 days.

Stage III. Following a 10-min warmup with the appropriate Stage II training conditions in effect, generalization tests were administered to all subjects in extinction. The test stimuli were 501, 517, 538, 549, 555, 559, 576, 587, and 606 nm. Six blocks of the randomly permuted wavelength stimuli were presented successively for 60 sec at each presentation with no intervening timeouts.

RESULTS AND DISCUSSION

The number of responses emitted in Stages I and II were converted to responses per minute emitted during each component. The amount of time that the food hopper was operative during each component was subtracted from the duration of component exposure used in calculating rates.

The results from Group LH are shown in Figure 1. As in all groups, some individual subjects responded more to one of the two stimuli during Stage I, although such differences were small and unrelated to group. All subjects in the LH group responded consistently more during S1 than during S2 by the end of Stage II of training. The mean discrimination index for the group (responses to S1 divided by total responses) was 0.644 averaged over the last three days of Stage II (range:

0.552 to 0.808). The discrimination index for each subject is indicated in the Stage II panels of the figures. Subjects 35, 36, and 45 yielded peak shifts from S1 in the direction away from S2, while the gradients of the other three subjects peaked at S1.

Figure 2 presents the data obtained from the HH group. As in Group LH, reinforcement density in the presence of S1 was five times that available in the presence of S2. As in Group LH, all subjects responded at a higher rate to S1 than to S2 during Stage II of training (mean discrimination index = 0.647 on Days 8 to 10, range: 0.584 to 0.714). Furthermore, five of the six generalization gradients obtained from this group yielded peak shifts. Only Subject 26 failed to exhibit such an effect.

It is informative at this point to compare the performance of the LH and HH groups. Both groups performed comparably in Stage II, responding systematically more in the presence of that stimulus correlated with the higher reinforcement density. Five of the LH subjects yielded gradients with peak shifts, whereas only three of the LH subjects did so. Note however, that the less-dense schedule for Group HH (*i.e.*, VI 1-min) was the same as the more-dense schedule in Group LH. These group differences suggest that the VI 1-min schedule in Group HH was at least as "functionally negative" as the VI 5-min schedule in the LH group. Clearly then, neither discriminative performance nor the peak shift can be attributed to any absolute property of the VI 5-min schedule. Rather, the relative reduction of reinforcement frequency in S2 and/or the resultant relative increase in S1 reinforcement frequency must account for these effects.

In an attempt to provide a stronger test of this conclusion, Group HL was tested to determine whether peak shift could be obtained with an S2 that signified a richer VI schedule

Fig. 1. Response rates for each subject in the low density of reinforcement-high ratio group (LH) obtained in the three stages of the experiment. The values in the parentheses are the (Stage II) discrimination indexes. The vertical lines in the wavelength generalization panels (Stage III) indicate the stimulus that signalled VI 1-min reinforcement (555 nm) and the arrows indicate the VI 5-min stimulus (576 nm).

Fig. 2. Response rates for each subject in the high density of reinforcement-high ratio group (HH) obtained in the three stages of the experiment. The values in the parentheses are the (Stage II) discrimination indexes. The vertical lines in the wavelength generalization panels (Stage III) indicate the stimulus that signalled VI 12-sec reinforcement (555 nm) and the arrows indicate the VI 60-sec stimulus (576 nm).

Fig. 3. Response rates for each subject in the high density of reinforcement-low ratio group (HL) obtained in the three stages of the experiment. The values in the parentheses are the (Stage II) discrimination indexes. The vertical lines in the wavelength generalization panels (Stage III) indicate the stimulus that signalled VI 12-sec reinforcement (555 nm) and the arrows indicate the VI 24-sec stimulus (576 nm).

than that used with S1 in any previous research. As indicated in Figure 3, all subjects responded at a higher rate in the presence of the VI 12-sec schedule, signified by S1 than in the presence of the VI 24-sec schedule (mean discrimination index for Days 8 to 10 = 0.618, range: 0.589 to 0.659). Four of the six subjects in this group, 28, 29, 30, and 32, yielded gradients with peak shifts. This exceeds the number of peak shifts obtained from the LH group, where the ratio of reinforcement frequencies in S1 and S2 was five-to-one and the absolute density in S2 was one-tenth as great as in Group LH. Thus, even a VI 24-sec schedule may become "functionally negative" when switched from a VI 12-sec schedule and altered with a second VI 12-sec schedule.

Figure 4 presents the data obtained from the LL group. The most apparent aspect of Stage II performance is that the LL subjects were not responding as differentially to the schedule components as the HL subjects, even though the same ratio of S1 to S2 reinforcement frequency was in effect (mean discrimination index = 0.573 on Days 8 to 10, range: 0.532 to 0.679). A likely source of this effect is the greater difficulty of discriminating the differences in the low-density schedules relative to those in the high-density ones. That is, the LL reinforcement densities required the discrimination between three (S1) and six (S2) reinforcers per session, whereas the HL densities required the discrimination between 25 (S1) and 50 (S2) reinforcers per session. A contributing factor may be the smaller number of stimulus-reinforcer pairings received during Stage II training by the LL group. Subjects in the HL group received more stimulus-reinforcer pairings in the first two days of Stage II training (150) than the LL group received in all of Stage II (90). Of the six subjects in the LL group only #40 yielded a peak shift.

In his 1968 study, Terrace interpreted the results as indicating a reliable correlation between the occurrence of behavioral contrast, response reduction in S2, and the subsequent peak shift. Since the present data do not indicate such a strong relationship, perhaps Terrace's interpretation should be re-examined. It is difficult to evaluate Terrace's position in the absence of an explicit criterion for deciding what constitutes a reliable rate increase or decrease. Nowhere in the literature

is it stated how large or long-lasting the change must be in order to be considered reliable. Even if we ignore daily fluctuations and consider overall trends, the classification of a subject as showing or not showing contrast and/or response reduction is still often ambiguous. In our Group LH, for example (see Figure 1), Subject 35 showed behavioral contrast but (perhaps) not response reduction, since an initial reduction in response rate to S2 was followed by an eventual increase such that rate to S2 was higher on the last two days of Stage II training than it had ever been.

It should be recognized that without any explicit guidelines for classifying questionable cases, it is difficult to determine the degree of relationship between behavioral contrast and the peak shift. There were 13 cases of peak shift obtained in this study but no more than two or three unequivocal joint occurrences of behavioral contrast and response reduction. In each of *these* two or three instances, a peak shift was observed. On the other hand, there were enough cases of peak shift in the unequivocal absence of behavioral contrast and response reduction that Terrace's (1968) claim of a necessary relationship between the two is seriously questioned.

Other investigators have reached similar conclusions. Yarczower, Dickson, and Gollub (1966) controlled S1 and S2 response rates by imposing a differential-reinforcement-of-low-rate (DRL) contingency in tandem with the VI arrangement associated with the multiple schedule components. These authors were thus able to manipulate response rate independently of the VI schedules in effect in each component. By imposing the DRL contingency on S1 and changing the S2 reinforcement schedule to extinction, Yarczower *et al.* demonstrated subsequent peak shift in the absence of an increase in response rate to S1 (positive contrast) and concluded that the occurrence of contrast is not a necessary condition for the occurrence of peak shift. Dukhanyil and Lyons (1973) also analyzed the relationship of peak shift to behavioral contrast. By administering repeated generalization tests at different points after discrimination training was initiated, these authors were able to demonstrate peak shifts in subjects for which behavioral contrast was not apparent.

Reynolds (1961) presented a definition of contrast that described the divergence of re-

Fig. 4. Response rates for each subject in the low density of reinforcement-low ratio group (LL) obtained in the three stages of the experiment. The values in the parentheses are the (Stage II) discrimination indexes. The vertical lines in the wavelength generalization panels (Stage III) indicate the stimulus that signalled the VI 2.5-min reinforcement schedule (555 nm) and the arrows indicate the VI 5-min stimulus (576 nm).

sponse rates during the two components of a multiple schedule. Terrace (1968) modified this definition when he wrote: "According to this classificatory scheme, an increase in the rate of responding to S1 *that accompanies or follows a decrease in responding to S2* that results from a change in the schedule associated with S2, would be called a positive contrast" (p. 728, italics added). Terrace interpreted his 1968 experiment as demonstrating a necessary correlation between peak shift, response reduction, and behavioral contrast as he defined it. In Experiment I of that study, Stages I and II of training were the same as our Group LH (*i.e.*, *mult* VI 1-min VI 1-min changed to *mult* VI 1-min VI 5-min) for some subjects and the reverse arrangement for the others (*i.e.*, *mult* VI 5-min VI 5-min changed to *mult* VI 1-min VI 5-min). Terrace found that all three of the former subjects exhibited subsequent peak shifts, whereas only one of the latter subjects did. The one subject that yielded a peak shift under the VI 5-min VI 5-min changed to VI 1-min VI 5-min conditions also yielded response reduction and behavioral contrast. In Experiment II, Stage II responses in the presence of S2 were followed by electric shock, while reinforcement density remained the same as in S1. Here, all three subjects showed peak shift, response reduction, and behavioral contrast. Experiment III reduced response rate in the presence of S2 during Stage II by imposing DRL schedule on S2. Here again, reinforcement density was approximately the same for both components of Stage II and the same as previous Stage I density. A *post hoc* separation of subjects according to the presence or absence of peak shifts also differentiated subjects according to the occurrence or nonoccurrence of both response reduction and positive contrast.

Both behavioral contrast and response reduction contribute to a high discrimination index, so that this measure could also be considered as a possible predictor for the occurrence of subsequent peak shift. In the Terrace (1968) study, the Stage II discrimination index is, in fact, a very good predictor of peak shift. If subjects are divided on the basis of whether or not a peak shift occurred and their Stage

II discrimination indexes² subjected to analysis, strong relationships are apparent. No overlap of discrimination indexes exists between the two groups of subjects (no shifts: range, 0.500 to 0.645; shifts: range, 0.654 to 0.933) and a point-biserial correlation analysis yields an r_{pb} of 0.757.

An analysis of our data suggests a similar relationship between discrimination index and peak shift. Pooled over the two high-ratio groups, the eight subjects that exhibited peak shift had an average discrimination index of 0.674 compared to 0.589 for the four subjects that showed no shift. A point-biserial correlation coefficient computed on the discrimination indexes of the peak-shift and no-shift subjects yielded a coefficient of 0.528. Pooled over the two low-ratio groups, the five subjects that exhibited peak shifts had an average discrimination ratio of 0.626 compared to 0.574 for the seven subjects that did not show a shift. A point-biserial correlation on this measure yielded a coefficient of 0.561. This second relationship can only be considered as suggestive in the present study because the LL group contributed five indexes to the no-shift group. However, it is interesting that the one LL subject that did exhibit a peak shift had, by far, the highest average discrimination index before the generalization test. These correlations, taken together with the relationship existing in the Terrace (1968) data, strongly suggest that the discrimination index attained in Stage II is predictive of occurrence or nonoccurrence of subsequent peak shift.

In the present study, we employed that procedure shown by Terrace (1968) to be most conducive to the obtaining of a peak shift, *i.e.*, the reduction of reinforcement density in one component of a multiple schedule. We have not addressed the procedural question of whether or not peak shifts can be obtained with an increase in reinforcement density in one component. Our results indicate that a peak shift can be obtained in a multiple schedule in which S2 is correlated with a very high density of reinforcement as long as S1 is correlated with a still higher one. Long inter-reinforcement intervals in the presence of S2 are not required. Neither does it appear necessary for "extinction-like" behavior (*i.e.*, response-rate reduction) to occur in the presence of S2. Response-rate reduction in S2 contributes to a high discrimination index, but this

²Indexes are based on rates estimated from the figures presented in the Terrace (1968) paper.

latter measure is more predictive of a peak shift than is the rate reduction itself.

REFERENCES

- 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.
- Dukhayil, A. and Lyons, J. E. The effect of over-training on behavioral contrast and the peak-shift. *Journal of the Experimental Analysis of Behavior*, 1973, **20**, 2253-2263.
- Guttman, N. Generalization gradients around stimuli associated with different reinforcement schedules. *Journal of Experimental Psychology*, 1959, **58**, 335-340.
- Hanson, H. Effects of discrimination training on stimulus generalization. *Journal of Experimental Psychology*, 1959, **58**, 321-334.
- Lyons, J. and Klipec, W. D. Color mixing with Kodak Wratten filters. *Journal of the Experimental Analysis of Behavior*, 1971, **15**, 232.
- Reynolds, G. S. Behavioral contrast. *Journal of the Experimental Analysis of Behavior*, 1961, **4**, 57-71.
- Spence, K. W. The differential response in animals to stimuli varying within a single dimension. *Psychological Review*, 1937, **44**, 430-444.
- Terrace, H. S. Stimulus control. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 271-334.
- Terrace, H. S. Discrimination learning, the peak shift, and behavioral contrast. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 727-741.
- Yarczower, M., Dickson, J. F., and Gollub, L. R. Some effects on generalization gradients of tandem schedules. *Journal of the Experimental Analysis of Behavior*, 1966, **9**, 631-639.

Received 1 October 1973.

(Final Acceptance 14 May 1974.)