EVIDENCE OF INTERACTION BETWEEN DEPRIVATION EFFECTS AND STIMULUS CONTROL¹

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Discriminative responding in pigeons was studied under multiple variable-interval extinction and variable-ratio extinction schedules, as deprivation was varied. Generally, the greater the accuracy of discrimination that developed during training, the smaller the effect of deprivation upon subsequent performance. This was true both in terms of changes in response rates, and in the relationship between response rates during food reinforcement and extinction. When discrimination was inaccurate, increases in deprivation resulted in disproportionate increases in responding during extinction, as compared to increases during food reinforcement components of the schedule. The results suggest that as stimulus control (accuracy) of responding increases, discriminative performance becomes less and less susceptible to influence by deprivation.

In multiple schedules, two or more experimental conditions alternate over time, and each condition is correlated with a different stimulus. When a schedule of positive reinforcement is one of the multiple schedule components, and the second component is extinction, the procedure is identified as a discrimination. Animals exposed to this procedure eventually respond at much higher rates during the stimulus correlated with positive reinforcement (S^D), than during the stimulus correlated with extinction (S^A). When nearly all of the subject's responses occur during S^D , performance is said to be very accurate or to show a high degree of stimulus control.

The effect of deprivation upon discriminative responding has rarely been studied. Dinsmoor (1952) varied body weight in six rats following discrimination training, with variable-interval 2 min (VI 2-min) and extinction as the multiple schedule components. He found that response rates under both S^D and S^A increased linearly as deprivation increased (per cent body weight decreased). The discrimination was not affected by deprivation as measured by relative response rates under the two conditions. Coate (1964) reported similar effects upon discriminative responding following different periods of water depriva-

tion. On the other hand, Gray (1965) found disproportionate increases in responding under S^A with increased deprivation, *i.e.*, the percentage increase in responding was much greater during extinction than during food reinforcement at high deprivation. However, the absolute increase in responding was slightly higher during the food reinforcement component, on the average.

The major purpose of the present experiments was to study in detail the effects of deprivation upon discriminative responding. Both variable-ratio (VR) and VI schedules were employed as S^D components in the multiple schedules. These schedules were studied because response rate and reinforcement rate are directly related under VR, whereas reinforcement rate is only slightly influenced by changes in response rate under VI schedules. Thus, the effects of deprivation were studied under schedules where reinforcement rate is differentially affected by changes in response rate.

An area of particular interest was the influence of deprivation upon discriminative performance, given substantial differences in the accuracy of the discrimination. These differences developed during discrimination training before changes in deprivation, having resulted from the use of stimuli of different modalities and intensities that were correlated with the schedules of positive reinforcement and extinction.

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EXPERIMENT I: EFFECTS OF CHANGES IN BODY WEIGHT UPON DISCRIMINATIVE RESPONDING MAINTAINED BY A VR SCHEDULE

METHOD

Subjects

Three experimentally naive White Carneaux pigeons were used. Water and grit were available to the birds at all times in their home cages.

Apparatus

A Lehigh Valley pigeon test chamber, model 1519C was used. Mixed grain was the reinforcer with a grain hopper time of 3.0 sec for each bird. The keylight, which was green, was off during the presentation of reinforcement. Two auditory signals were provided by a Grason-Stadler white noise generator model 901 A. Data were recorded by digital counters and a Gerbrands cumulative recorder.

Procedure

Baseline training Following shaping, the birds were trained under gradually extended VR schedules until a VR 100 was reached. Training continued under this schedule until stable performance was achieved. The criterion for stable performance was variation within $\pm 10\%$ of the mean response rate over 10 consecutive sessions. Experimental sessions were usually 45 min per day.

Discrimination training. A multiple schedule was introduced with 4-min periods of VR 100 and extinction alternating successively. Food reinforcement was correlated with the presence of white noise at 88 db, while extinction was correlated with speech noise at 88db. White noise consists of a presentation of frequencies up to 10,000 Hz, while the frequency range of speech noise is 0 to 2000 Hz. Auditory intensities were measured in the test chamber with a General Radio sound level meter, model 1551C. Experimental sessions were 80 min per day with 10 periods each of food reinforcement and extinction.

The birds were trained at weights that were 86% (Bird 30), 88% (Bird 42), and 83% (Bird 45) of each animal's free-feeding body weight. The accuracy of discrimination was assessed through calculation of a discrimination ratio based upon the formula: (responses during

S^D)/(total session responses). Perfect discrimination would be reflected in a ratio of 1.00; failure to discriminate would result in a ratio of 0.50. Training continued until discriminative performance stabilized. The stability criterion was a range of 0.10 or less in the discrimination ratio over six consecutive sessions, *i.e.*, the highest ratio could not exceed the lowest by more than 0.10. Baseline and discrimination training required 65, 45, and 55 sessions for Birds 30, 42, and 45 respectively.

Body weight was varied by deprivation or supplemental feeding each day for five to seven days. Changes in weight continued through a complete cycle that ranged from approximately 70% to 95% of each bird's free-feeding weight. The birds were food deprived for approximately 23 hr before each session. Five experimental sessions were conducted at each weight level, except for the minimum and maximum weights, where there were 10 sessions. The body weights used throughout the experiment were based upon measurements taken immediately before the experimental sessions.

RESULTS AND DISCUSSION

Figure 1 presents the discrimination ratio and response rates under S^D and S^A as a function of body weight for each bird. Response rates during extinction remained high for each bird throughout this experiment. Discriminative performance did not improve for any of the birds over the course of the experiment, so the low discrimination ratios do not seem attributable to insufficient training. While response rates increased under both the VR schedule and extinction as body weight declined, the per cent of increase in responding was greater under S^A than S^D for Birds 42 and 45. This was shown by Kruskal-Wallis analyses of variance, which compared discrimination ratios during the 20 sessions when body weight was highest with the 20 sessions when it was lowest for each bird. The probabilities that the differences observed could be attributed to chance were as follows: Bird 30 ($p < 0.50$), Bird 42 ($p < 0.05$), Bird 45 ($p < 0.001$).

In addition, each bird discriminated more effectively during the series of sessions in which body weight was increasing gradually as compared to the series in which body weight decreased. The mean discrimination ratios

Fig. 1. Discrimination ratios and response rates under the VR schedule and extinction as a function of body weight. Each data point represents the mean performance over five sessions. Performance was studied for 10 sessions at the extreme weights for each bird, hence the two sets of data points at these values. The asterisk above the abscissa indicates the first weight studied for each bird. Data points relating to the series of sessions over which body weight decreased are connected by solid lines, while those relating to sessions over which body weight increased are connected by dashed lines. The data points have been connected in the same sequence that the weight values were studied during the experiment.

were as follows for each bird for the increasing and decreasing series, respectively: Bird 30 (0.72, 0.66), Bird 42 (0.72, 0.61), Bird 45 (0.91, 0.79). Kruskal-Wallis analyses, which compared discriminative performance in each session during the increasing and decreasing series, showed significant differences for each bird. The probabilities associated with the values of H obtained were as follows: Bird 30 ($p < 0.01$), Bird 42 ($p < 0.001$), Bird 45 ($p < 0.005$).

In general then, discriminative performance became less accurate as deprivation increased, as compared to performance under conditions of decreasing deprivation. The less efficient performance was a function of larger percentage increases in responding during S^A than S^D . The present results also suggest that the animal's recent history of deprivation strongly influences discriminative performance, and must be considered in addition to any absolute measure of deprivation, such as per cent of free-feeding weight.

EXPERIMENT 2: EFFECTS OF CHANGES IN BODY WEIGHT UPON DISCRIMINATIVE RESPONDING MAINTAINED BY VI AND VR SCHEDULES

This experiment was conducted to study the influence of deprivation upon discriminative responding maintained by a schedule (VI) in which response rate and reinforcement rate are relatively independent. A second purpose was to produce more accurate discrimination than had been achieved in Exp. 1, thereby extending the range of the variables.

METHOD

Subjects and Apparatus

In addition to Bird 42, two experimentally naive White Carneaux pigeons (17, 29) were used. Apparatus was the same.

Procedure

Baseline training. Following shaping, the two new pigeons were exposed to gradually extended VR and VI schedules that were present singly during successive sessions. Training was the same for Bird 42 except that VR 75 and VI 45-sec, the terminal schedules, were present throughout this procedure. The VR and VI schedules were correlated with the

presence of green and red keylights, respectively. Training continued for each bird until the variation in response rate under each schedule was less than $\pm 10\%$ of the mean rate for that schedule over five consecutive sessions. Experimental sessions were usually 40 min per day.

Discrimination training. Multiple VR-extinction and VI-extinction schedules were introduced with 6-min periods of food reinforcement and extinction alternating successively. Extinction was correlated with the presence of a white keylight. The VR-EXT and VI-EXT schedules were present singly during successive sessions. Experimental sessions were 36 min per day, with three components each of food reinforcement and extinction.

Body weights during training were 85% (Birds 17, 42) and 77% (Bird 29) of each animals' free-feeding weight. The sequence of weights studied after training was as follows for each bird: Bird 17-77, 70, 77, 85, 93, 100, 93, 85%; Bird 29-85, 92, 100, 92, 85, 77, 70%; Bird 42-77, 70, 65, 70, 77%. The accuracy of discrimination and the criterion for stable performance were assessed as in Exp. 1 for responding under each schedule. The effects of changes in body weight upon discrimination were studied as in Exp. 1 except that there were generally 10 sessions at each weight level. All other procedures were the same.

Baseline and discrimination training required 43, 45, and 44 sessions for Birds 17, 29, and 42, respectively.

RESULTS AND DISCUSSIONS

The complete performance for each bird is summarized in Fig. 2. Birds 29 and 42 developed very accurate discrimination during training and maintained discrimination ratios above 0.90 under both schedules throughout the experiment. Bird 42 was not studied for a complete cycle of body weight changes, when it was observed that severe deprivation had no discernible effect on the discriminative performance of this animal. The discrimination of Bird 17 was less accurate at the completion of training, and unlike Birds 29 and 42, performance changed systematically with variations in body weight.

Response rates under the VR and VI schedules did not change systematically with changes in body weight for Bird 42; Bird 29

Fig. 2. Discrimination ratios and response rates under the VR and VI schedules, and the extinction periods associated with each schedule as a function of body weight. Values along the abscissa appear in both a descending and ascending sequence in order to facilitate presentation. The sequence of weights along the abscissa does not correspond to the experimental sequence, except for Bird 42. The experimental sequence of weights studied is given in the text. The arrow beneath the abscissa indicates the lowest weight level studied. Each data point represents the mean performance over five sessions.

had fairly stable rates under the two schedules except for noticeable decreases at 100% body weight. On the other hand, changes in response rates occurred under the two schedules for Bird 17, and they were directly related to changes in deprivation. The relationship between response rate and deprivation was slightly more systematic under the VR than the VI schedule for this bird.

The performance of Bird 17 here, and those of the three birds studied in Exp. 1, were quite similar, with discrimination changing as a function of changes in deprivation. A Kruskal-Wallis analysis for Bird 17 revealed a significant difference under each schedule ($p < 0.001$) between discrimination ratios during sessions at the highest and lowest body weights (100% and 93% versus 77% and 70%).

The performance of Birds 29 and 42 was nearly unaffected by changes in deprivation in this experiment, even though discrimination for Bird 42 had been strongly influenced by deprivation in Exp. 1. The most obvious difference between the various performances was the high degree of stimulus control for Birds 29 and 42 here, whereas the performances of the three birds in Exp. 1 and Bird 17 here were characterized by substantially lower levels of control.

EXPERIMENT 3: EFFECTS OF CHANGES IN HOURS OF DEPRIVATION UPON DISCRIMINATIVE RESPONDING MAINTAINED BY VI AND VR SCHEDULES

This experiment was performed to study the effect of a more acute deprivation procedure upon discriminative responding. It was also designed to produce highly accurate discrimination as in Exp. 2, so the effects of deprivation on responding under a high degree of stimulus control could be studied further.

METHOD

Subjects and Apparatus

Birds 42 and 45 were used. Apparatus was the same.

Procedure

Discrimination training. The training procedures and terminal schedules were the same as Exp. 2, except that experimental sessions

were 1 hr per day. The VR, VI, and EXT schedules were correlated with the same key-light colors. The stability criterion was the same.

Deprivation was varied by withholding food for 24, 48, or 72 hr before the experimental sessions. The sequence of deprivation periods was generally as follows: 72, 24, 48, 24 hr. Both birds were at approximately 80% of their free-feeding weight when training started. They were given supplemental feeding after each session in order to maintain this weight level. However, each bird's weight declined about 10% (50 g) over the course of the experiment.

Discrimination training required 10 and 15 sessions for Birds 42 and 45, respectively.

RESULTS AND DISCUSSION

Both birds discriminated very accurately throughout this experiment. Figure 3 shows that discrimination ratios were above 0.90 at all times and that hours of deprivation did not systematically affect responding under either the VI, VR, or EXT components. The performances of Birds 42 and 45 here are quite similar to those of Birds 29 and 42 in Exp. 2. Again, there is evidence of a relationship between a high level of stimulus control during training, and the subsequent failure of changes in deprivation to influence discriminative responding.

EXPERIMENT 4: DEPRIVATION EFFECTS UPON DISCRIMINATIVE RESPONDING MAINTAINED BY VI AND VR SCHEDULES WITH EXTINCTION CORRELATED WITH AN AUDITORY STIMULUS

This experiment was performed to study further the two deprivation procedures (changes in body weight and hours of deprivation). An auditory stimulus was correlated with extinction in the expectation that discriminative accuracy would differ substantially between subjects.

METHOD

Subjects and Apparatus

Birds 17, 29, 42, and 45, all previously used, were studied. Apparatus was the same, plus a Precision sine-square wave generator, Model E-310, which provided a square wave tone of

Fig. 3. Discrimination ratios and response rates under the VR and VI schedules of food reinforcement and extinction, as a function of hours of deprivation. The numbers in parentheses indicate the total number of sessions upon which the corresponding data points are based. Data points corresponding to Baseline on the abscissa represent the mean performance over five sessions.

90 db and 1234 Hz that was correlated with extinction.

Procedure

Discrimination training. Training procedures and terminal schedules were the same as Exp. 3, except that extinction was correlated with the presence of the tone. The VR and VI schedules were again correlated with green and red keylights, respectively, and the tone was superimposed on these stimuli in conjunction with extinction.

Deprivation was varied for Bird 45 through systematic changes in body weight as described in Exp. 1. The hours of deprivation were varied for Birds 17, 29, and 42 as described in Exp. 3. The approximate weights during training were as follows: Bird 17, 88%; Bird 29, 85%; Bird 42, 83%; Bird 45, 77%. The experimental sequence of weights for Bird 45 after training was as follows: 70, 76, 85, 90, 97, 90, 83%.

Discrimination training required 48, 29, 31, and 49 sessions for Birds 17, 29, 42, and 45, respectively.

RESULTS AND DISCUSSION

Figure 4 summarizes the performance of the three birds studied with changes in the hours of food deprivation. Bird 29 developed very accurate discrimination during training, and discrimination ratios showed no change with subsequent increases in deprivation. Birds 17 and 42 discriminated less accurately during training and their performance was subsequently influenced by variations in the hours of deprivation. Bird 42 showed decreases in discrimination ratios under both schedules as deprivation increased, which were significant at the following levels: VR ($p < 0.001$), VI ($p < 0.05$). Bird 17 had a significant decrease in discrimination under VR ($p < 0.05$), but there was no change in accuracy under the VI schedule ($p < 0.70$) as deprivation increased. In each case, the decline in accuracy consists of a larger percentage increase in responding during extinction than during food reinforcement. It seems noteworthy that during training Bird 17 had a significantly higher mean discrimination ratio under the VI than the VR schedule ($p < 0.01$). All of the statistics above are based on Kruskal-Wallis analyses.

Birds 17 and 42 both had higher discrimination ratios under the 24-hr period when dep-

Fig. 4. Discrimination ratios and response rates under the VR and VI schedules of food reinforcement and extinction, as a function of hours of deprivation. The numbers in parentheses indicate the total number of sessions upon which the corresponding data points are based. Data points corresponding to Baseline on the abscissa represent the mean performance over five sessions.

rivation was varied than during training when 24-hr deprivation periods also preceded each session. This may suggest that discrimination improved with practice, but it may also be true that deprivation is less severe after a 24-hr period that is interspersed with 48 and 72 hr deprivation times as compared to a long series of 24-hr food deprivation periods. In any case, since the three deprivation periods were equally distributed over time here and in previous experiments, the relationships between deprivation and discrimination are not attributable to order effects.

The data for Bird 45 are presented in Fig. 5. While there were a number of direct changes in discriminative control with changes in body weight there were also several inconsistencies. When discrimination at the highest (90 and 97%) and lowest body weights (70, 76, and 77%) were compared through Kruskal-Wallis analyses, the differences were significant at the following levels: VR ($p < 0.10$), VI ($p < 0.10$).

It seems noteworthy that Birds 42 and 45 acquired low to moderate levels of discriminative accuracy in Exp. 1, and the performance

of both birds was substantially influenced by changes in deprivation. In Exp. 3, each bird developed nearly perfect discrimination during training, and subsequent changes in deprivation had little or no effect on performance. Finally in the present experiment, a moderate degree of discriminative control was acquired during training, and again performance was influenced by deprivation. These results clearly suggest that the effects involved in the relationship between discriminative control and deprivation are reversible.

GENERAL DISCUSSION

As a whole, the present results suggest that the degree of stimulus control that develops during training largely determines the extent to which subsequent variations in deprivation influence discriminative performance. Clearly, when a high degree of stimulus control developed, *i.e.*, discrimination ratios of 0.90 or higher, increases in deprivation did not impair the accuracy of discrimination (Exp. 2, Birds 29, 42; Exp. 3, Birds 42, 45; Exp. 4, Bird 29). In addition, the response rates of these birds

Fig. 5. Discrimination ratios and response rates under the VR and VI schedules of food reinforcement and extinction, as a function of body weight. Values along the abscissa appear in both a descending and ascending sequence in order to facilitate presentation. The sequence of weights along the abscissa does not correspond to the experimental sequence, which is given in the text. The arrow beneath the abscissa indicates the lowest weight level studied. Each data point represents the mean performance over the five sessions.

were not substantially influenced by deprivation under either the VR or VI schedules. In cases where stimulus control was weaker, accuracy tended to decrease as deprivation increased (Exp. 1, Birds 42, 45; Exp. 2, Bird 17; Exp. 4, Birds 42, 45). Bird 17 showed a similar effect in Exp. 4 under the VR schedule only. The decline in accuracy was largely attributable to larger percentage increases in responding during extinction than during food reinforcement. Response rates during food reinforcement components of the multiple schedule were inconsistently affected by increases in deprivation. Some performances showed direct and orderly changes in response rates with variations in deprivation (Exp. 1, Birds 30, 45; Exp. 2, Bird 17). In other cases, there were consistent effects under one schedule, but not the other (Exp. 4, Birds 17, 42). Finally, some birds showed changes in response rates that were either quite minor or inconsistent (Exp. 1, Bird, 42; Exp. 4, Bird 45).

The validity of the apparent interaction effects between stimulus control and deprivation seems amply demonstrated by the differences in performance for the same subjects between experiments (Bird 42, Exp. 1, 4, *versus* 2, 3; Bird 45, Exp. 1, 4, *versus* 3) or within the same experiment (Bird 17, Exp. 4, VI *versus* VR).

In several experiments where the effects of deprivation upon complex schedules (chain, multiple) have been studied, responding was differentially affected. Malott (1966) found that prefeeding had a greater effect upon responding during the initial portions of either a plain or a chained fixed-ratio schedule, than upon subsequent portions. Eckerman (1968) also observed that deprivation had disproportionate effects upon responding under the different components of both chained and multiple schedules. This contrasts with the constant proportion relation observed by

Dinsmoor (1952) under a multiple VI-EXT schedule.

While the present results do not seem to agree with those of Dinsmoor (1952), direct comparisons are difficult because of the differences in procedure. Dinsmoor did not increase and decrease deprivation within the same subject, but did vary this condition across animals. The present results indicate that a subject's recent history of deprivation is an important determinant of current discrimination, particularly where stimulus control is weak as in Exp. 1. Motivational theories often fail to recognize that the energizing properties of a particular state of deprivation must consider both relative and absolute measures of this condition.

In summary, the present results suggest that stimulus control and deprivation interact as determinants of discriminative responding. Deprivation effects are potent, however, only in cases where stimulus control is weak. As stimulus control increases, discrimination becomes less and less susceptible to influence by deprivation.

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