RESPONSE FORCE AS A FUNCTION OF AMOUNT OF REINFORCEMENT

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5 groups of 6 rats each were trained to press an isometric lever and were rewarded with either 1, 2, 3, 4, or 5 20-mg. pellets on responses meeting or exceeding an 8-gm. force criterion. After 10 Acquisition sessions all Ss were shifted to 3 pellets for 6 further sessions and then received 2 Extinction sessions. Both force and variability of bar pressing varied inversely with amount of reward by the end of Acquisition, but not during Shift or Extinction. An account of these results in terms of criterion discrimination is suggested.

The study here reported attempts to determine (a) whether force of bar pressing during acquisition varies systematically with magnitude of reinforcement, and (b) whether shifts in amount of reinforcement are followed by shifts in force emission.

Exploratory data bearing upon these questions have been reported by Notterman and Mintz (1965) who found an inverse relationship between force and amount of reinforcement. Since in this preliminary study the same Ss were tested at all levels of amount of reinforcement, the original effects of reward magnitude were conceivably confounded with the effects of shifts in the same variable. In the present research separate groups of Ss were trained at five independent amounts of reinforcement, were shifted to the middle level, and then placed in extinction.

METHOD

Apparatus.—The apparatus used in this study has been described by Notterman (1965) and by Notterman and Mintz (1965). Essentially, it consists of a Skinner box equipped with a bar connected to a pair of strain gauges. The peak force of each bar press was measured and automatically recorded to the nearest gram. The apparatus was calibrated to record every bar press meeting or exceeding a force of 2.5 gm. (threshold), and to deliver a given number of food pellets following each bar press meeting or exceeding a force of 8.0 gm. (criterion). The experimental room was sound-insulated and was illuminated by a frosted white 7.5-w. indirect lamp located approximately 2 ft. from the experimental cage. Besides the masking noise of an electric fan, the only distinctive sound was the noise of the pellet dispenser which operated upon termination of responses reaching the 8.0-gm. criterion. Water was always available in the experimental cage.

Subjects and procedure.—The Ss were 36 male Wistar rats obtained from the Charles River Breeding Laboratory. They were 90 days old at the beginning of Acquisition and were housed individually. Fourteen days before the beginning of Acquisition all Ss were placed on a 24-hr. feeding schedule with free access to dry Purina laboratory mash for 1 hr. each day and with water available at all times. On each of the 2 days immediately preceding the beginning of Acquisition each S received approximately 20 min. of tray-approach training. On each approach to the
tray $S$ obtained the number of pellets it was scheduled to receive during Acquisition.

The 36 Ss were randomly allocated to six groups of 6 Ss each. The experiment was carried out over 20 successive days (one session per day) divided into three stages as follows: during Acquisition (10 days) Groups I, II, III, IV, and V received either one, two, three, four, or five Noyes 20-mg. pellets, respectively, following each response at or above the 8.0-gm. criterion. As can be seen, number of pellets covaried with the weight of food obtained per response. A control group (Group C) receiving two 45-mg. pellets on responses meeting the 8-gm. criterion was introduced to obtain some indication of the relative effects of weight of food as opposed to the number of pellets. If Ss respond largely to the weight of the reward, Group C should be expected to behave more like Group V (100 mg.) than Group II (40 mg.).

A "self-shaping" procedure was adopted on the first day of Acquisition: each S was placed in the experimental cage where it found the appropriate number of pellets in the food cup, and the bar baited with a small amount of food powder. Subsequent reinforcements depended entirely on the occurrence of responses meeting or exceeding the 8-gm. criterion. A daily session ended upon procurement of 35 reinforcements.

During Shift (6 days) all groups received three 20-mg. pellets following responses meeting or exceeding the criterion. The number of reinforcements per session remained unchanged. During Extinction (2 days) no food reward was delivered, but the sound of the magazine was present as during Shift. An extinction session ended upon emission of 35 responses meeting or exceeding the 8-gm. criterion. Except for Extinction days, each run began with the relevant number of pellets in the food cup. One S in Group III died on the fifth day of shift, and one S in Group I was eliminated because of apparatus failure.

RESULTS AND DISCUSSION

The performance of the control group receiving two 45-mg. pellets was entirely similar to that of the five-pellet (100-mg.) group throughout the experiment. Peak force values on the last days of each of the phases were as follows for Group V and Group C, respectively: Acquisition, 10.2 vs. 9.3; Shift, 10.5 vs. 10.7; Extinction, 27.4 vs. 30.1 gm. Following the demonstration that amount of reward, rather than number of pellets, was the relevant independent variable, the results of the control group were excluded from further consideration.

The mean peak force of the responses emitted by Ss in each group during the last 2 days of Acquisition is shown in the upper set of points (open circles) of Fig. 1.

The two-tailed probability of obtaining an ordered replication of the five reinforcement magnitudes in the force function is $2/5!$ ($p < .02$). This inverse relationship does not appear to be consonant with the direct relationship obtained between amount of reinforcement and either rate of bar pressing (Hutt, 1954; Smith & Kinney, 1956) or speed of response in the runway (Crespi, 1942; Di Lollo, 1964), although it is quite comparable to the force data previously reported (Notterman & Mintz, 1965).

Since the present data were obtained under conditions involving an 8-gm. criterion, evidence of effective performance may be sought in a measure of Ss' approximation of this criterion. Figure 2 shows the distribution of responses for Groups I and V on the last day of Acquisition, and illustrates the greater success of Group V in criterion approximation ($p < .05$, Kolmogorov-Smirnov two-sample test). The variability of the other groups fell between these two extremes as shown in the lower set of points (filled circles) of Fig. 1.

On the basis of these results it may be suggested that the prime effect of amount of reinforcement is to influence Ss' precision of force emission. The hypothesis that amount of reinforcement influences Ss' ability to discriminate the criterion is in agreement with other results showing a positive relationship between incen-
It should be noted that the total amount of food obtained during an experimental session varied systematically across groups: Ss in Group V received 3.5 gm. of food vs. .7 gm. for Ss in Group I. This could have resulted in long-term differences in the level of deprivation and hence in systematic differences in motivation. Analogous data are available to indicate that substantial differences in hours of food deprivation prior to daily runs influence the force of response, and in a direction appropriate to this argument (Notterman & Mintz, 1965). It may also be reasoned that the effect of amount of reinforcement is principally manifested in "energizing" the animals. Thus, Ss receiving lesser amounts of food per response are "energized" more than Ss receiving greater amounts. The emission of forces by the former occasionally reaches higher levels, and consequently variance increases. However, force studies which might support any of these interpretations to the exclusion of others have not been done.

During Shift neither mean peak force nor variability of response differed significantly between groups. There was, however, an overall decrement in the magnitude of both measures over the 6 days of the Shift stage. Table 1 is a summary of the analyses of variance performed on the slope of the linear component of mean peak force and standard deviation, respectively, for each $S$ over the 6 days of the Shift stage. Immediately following the reinforcement shift, Groups I and II showed a rapid decrement in the variability of the distribution of forces, with a clustering of responses about the criterion resembling the distributions of the higher-reward groups. Mean peak force decreased accordingly. Groups IV and V showed an increment in the variability of responses—
and in mean peak force—only at the beginning of the Shift stage, but both measures soon returned to the pre-shift level. Similar findings have been reported by Notterman and Mintz (1965), who obtained permanent decrements in peak force following increments in reinforcement, but only a temporary increment in force following a reinforcement decrement. This pattern of results is not inconsistent with the discrimination hypothesis proposed in the foregoing: while a reinforcement increment leads to improved discrimination between criterion and noncriterion forces, a reinforcement decrement results in only a temporary disturbance of the established discrimination.

Variability of response force during Extinction is depicted in Fig. 3; mean peak force followed roughly the same trends. Notable is the fact that Group III, which experienced no shift in amount of reinforcement, shows the greatest variability. Perhaps the explanation of this finding lies in the fact that all groups with the exception of Group III have had the cutaneous and kinesthetic stimulus correlates of criterion responding associated, by the onset of Extinction, with two values of amount of rein-

<table>
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<th>Source</th>
<th>df</th>
<th>F_0</th>
<th>SD</th>
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<tr>
<td>Between groups</td>
<td>1</td>
<td>5.64*</td>
<td>15.30***</td>
</tr>
<tr>
<td>Error (M_S)</td>
<td>4</td>
<td>.10</td>
<td>.33</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>(22.7)</td>
<td>(4.6)</td>
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* p < .05.
*** p < .001.
forcement. Therefore, these animals have had opportunity to learn that neither increments (Groups IV and V) nor decrements (Groups I and II) in above-criterion force are related to amount of reinforcement received. The discriminative consequences of the Shift procedure are carried over into the Extinction phase, and are reflected in the lower variability characteristic of Groups I, II, IV, and V. Evidence that it is these groups which are lower than might be expected, and not Group III which is higher, is available in a study describing the behavior of a group of rats placed in extinction following 20 days of CRF (45 mg. reinforcement) at an 8-gm. criterion (Notterman & Mintz, 1965). The mean standard deviation in the cited experiment is 24 gm. on the first 2 days of extinction, almost identical to the values of Group III in the present research.

REFERENCES
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