This experiment was concerned with a detailed description of the emission of forces by rats in a substantially conventional Skinner box as the animals proceeded through various stages of the learning process (specifically, operant level determinations, regular reinforcement, and extinction) without any experimenter-manipulated exteroceptive discriminative stimuli.

Rudimentary data of this type were obtained by Skinner (1938, p. 312), but they are—for present purposes—deficient in two respects: the measure of force used by Skinner was not linear with actual force, and the technique employed did not permit measuring the force of single responses. A subsequent major contribution to the systematic description of free force emission was made by Trotter (1956). Unfortunately, although he apparently had the instrumentation capability, Trotter failed to keep records during the acquisition phase of a knob-pressing operant, thereby precluding the kind of response-by-response analysis presented here. Nonetheless, his comments concerning "the physical properties of bar pressing behaviour" remain the clearest exposition of the physics of bar pressing to date.

METHOD

Apparatus. 2—The general apparatus here described provides an analysis of three intensive aspects of bar pressing behavior: force, duration, and time integral of force. The foregoing is achieved without sacrifice of the customary pulse recording techniques, simultaneous measures of digital and continuous response characteristics being possible with this system. In addition, and in anticipation of future research requirements, the same apparatus permits selective reinforcement in proportion to the magnitude of the particular response characteristic sensed.

A standard small animal cage is equipped with a modified bar, the innovation consisting in replacement of the microswitch with a pair of strain gauges. Pressure on the bar produces a minute change in the internal resistance of the strain gauges, thereby unbalancing a Wheatstone bridge to which the strain gauges are coupled. The pressure-proportional voltage thus made available is passed into a preamplifier, from which it enters an analog computer. The computer has several functions, some of which are mutually exclusive, these being exercised at E's discretion. Functions pertinent to the investigation here reported are as follows: (a) determination of the constant number of pellets by which each suprathreshold response is to be reinforced; (b) further amplification of the voltage originating from pressure on the bar, thereby producing a voltage-proportional force readout on a strip-chart recorder; (c) generation of reference voltages used to determine the "response threshold," or the precise level of force required to activate the reinforcement circuit (accomplished jointly with a "Threshold Adjust" unit); and (d) determination of occurrence of suprathreshold responses on a "Yes-No" basis, for pulse counting and cumulative recording purposes.

As Functions c and d indicate, it is possible to obtain conventional operant behavior data, with the Threshold Adjust being set to some value corresponding to the force required to close the microswitch in the usual bar. It should be noted, however, that although the

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visual appearance of that portion of the bar which is within the experimental cage is identical with the conventional manipulandum, the tactual bar is quite different. In the present case, the bar remains more or less immobile during active responding (maximum movement being approximately 1–2 mm.), and was designed this way in order to lay the groundwork for potential experimental separation of movement from pressure cues (or "work" from "impulse").

Figure 1 is a linearity and calibration check between gram weights on the bar, and voltage output of the computer (Function b). As can be seen, the system is linear over a large range of forces. Similar checks with similar results have been obtained for time integral of force (gm.-sec.), and for the excursion of the recorder pens.

Figure 2 is a sample record. For this experiment, the critical threshold for reinforcement was set at 3 gm., this being well above the noise level of the system, but still low enough to provide S with essentially "free" lower and upper force limits. A response was defined as being in effect from the instant S emitted 3 gm. of force to the instant the force level fell below 3 gm., as in "A." In the event that, during continuous contact with the bar, the force exceeded 3 gm., fell off to less than 3 gm., and then again increased past the critical threshold, two responses were counted ("B"). If the force failed to reach 3 gm., as in "C," it was not deemed a response.

The "Reinforcement Indicator" channel served the function of providing a convenient check on when the force level fell below the critical threshold. Each mark indicates delivery of one pellet, and corresponds to the instant that the force drops below critical threshold. (Duration and time integral of force data, although recorded, are not considered in the present paper.)

The foregoing convention concerning definition of a response was adopted in this experiment on the basis of its being most analogous to that of the usual bar pressing situation. (Other response criteria, e.g., calling each force emission a response, regardless of whether it reaches critical threshold are, of course, possible, and are currently being examined.) "B" is equivalent to the case in which S presses twice without releasing the bar, and "C" is similar to a bar contact not strong enough to close the microswitch. In general, then, the present bar is chiefly distinguished from the usual bar by its being much more "sensitive," and by its being an analog, rather than make-break, type of manipulandum.

Procedure.—Six male Wistar rats, approximately 90 days old, were placed on 22-hr. hunger rhythm for 10 days prior to operant level determinations. The experiment proper was conducted over eight successive days (or sessions), as follows: Operant Level, two 35-min. sessions, followed by 20 min. of tray approach training; Conditioning, four sessions of regular reinforcement, one pellet per response, each session terminating upon procurement of approximately 50 pellets; Extinction, two 35-min. sessions. Pellets were standard Noyes Co., 45 mg. each. The Ss were fed Purina Chow for 1 hr. following each experimental session, and then again placed on deprivation.
RESULTS AND DISCUSSION

Figure 3 is a sequential plot of peak force attained by S_i for each of the suprathreshold bar presses emitted during the entire course of the experiment. The data shown are characteristic of the remaining five Ss.

Noteworthy is the obvious drop in magnitude of response during the regular reinforcement sessions; this is accompanied by a decrease in response variability, or the development of "stereotypy." It is not surprising that the level of force characteristic of regular reinforcement is apparently related to the critical threshold. Skinner's data, (1938, p. 312) for example, show that his S came to respond with a force of some 35–40 gm.; this for a bar which apparently required almost 20 gm. of force for activation. The Ss in this study come to press typically, during regular reinforcement, with approximately 5–6 gm.; but the critical force required was only 3 gm. Obviously, this is the result of the same sort of organism-mediated force differentiation which Skinner postulates on the basis of his data. The intriguing possibility exists that, over a significant range, Ss will stabilize during regular reinforcement at a force magnitude which is roughly twice that of the critical threshold, as determined by S's force discrimination difference limen.

![Graph showing sequential emission of peak forces during successive phases of the experiment. Data are for S_i.](image)
Shortly after extinction is begun, both force magnitude and variability show a sharp increase. The trial-by-trial extinction data of Fig. 3 may be in conflict with Skinner's (1938, p. 313) observation that: "Stronger responses generally occur near the beginning of the extinction and give way to an unusually low force which is then steadily maintained." The present data, as represented by S₁, reveal a tendency for emission of fairly high magnitudes of forces well into extinction.

Figure 4 is a tracing of the usual cumulative response record obtained during bar pressing experiments, and is for the same animal as Fig. 3. (Operant Level, Conditioning 1, and Extinction 2 data were omitted from
this figure in order to permit as large a reproduction scale as possible.) The broken line represents the slope of Conditioning 4, and indicates that this phase produced the highest over-all rate. The early stages of Extinction 1 show the customary, momentary increases in rate, followed by an over-all decline. It should be noted that the cumulative recorder’s mechanism was somewhat slower than that of the strip-chart recorder; hence, the latter occasionally indicated responses which were not sensed by the former. In all computations involving number of responses, the strip-chart data were considered definitive.

The four frequency distributions comprising Fig. 5 show, in terms of percentage of total number of responses for each of the indicated experimental sessions, how the peak forces were distributed by the indicated scale intervals. These data are based on all six Ss; individual plots are quite similar. Most striking is the shift in distribution of forces as Ss proceed through the various phases of the experiment. The Operant Level data (“A”) show quite clearly that prior to the response differentiation which takes place during conditioning, Ss exhibit a wide range of “freely” emitted forces. Conditioning 1 (“B”) depicts the beginnings of a differentiation which is fairly sharp by the end of the fourth conditioning session (“C”). Noteworthy in connection with the latter is the decrease in frequency of occurrence of 3–4 gm. forces. The Ss apparently come to “play it safe,” and typically emit forces at a level determined at the lower end by the critical threshold,

Fig. 6. Comparison of force (mean and SD) and rate of bar pressing.
and at the upper end perhaps by the negative aspects of unnecessary force expenditure. The latter speculation is, of course, intimately related to past notions of "least effort" or "work," and it is hoped that later analyses based upon the time integral of force measure (or "impulse") will permit careful sifting of that which may be of value in these earlier formulations.

The Extinction 1 data ("D") reveal the beginning of a return to the type of distribution characteristic of Operant Level. Whether the "random" nature of the latter is actually ever reached is presently uncertain. (The relation of force variability to Schoenfeld's [1950] and Antonitis' [1951] prior work in stereotyping has been investigated recently by Goldberg [1959].)

Figure 6 gives the group means and SDs of the peak forces emitted by all six Ss over the course of the experiment. Mean bar pressing rates are presented for comparison purposes. The mean force data reflect the earlier observations based upon S1's response-by-response performance (Fig. 3). Similarly, the group bar pressing data show the same general trends revealed by S1's cumulative record (Fig. 4). The stereotyping evident in the earlier graphs is again shown here, this time by the approach to asymptotic values of force magnitude and standard deviation during the course of conditioning.

Of particular interest, is the fact that bar pressing rate keeps rising sharply even as the force measures become stabilized. The rate measure, it will be recalled, is based upon approximately 50 responses produced by each S during each of the regular reinforcement sessions. Accordingly, the increase in rate is not the result of a greater number of responses having been emitted during successive, constant total time sessions, but rather the result of the same number of responses having been emitted during progressively shorter sessions. Such being the case, it is clear that it is the dropping out of intervening behavior (i.e., behavior between successive bar presses) which is responsible for the observed rate increases. Considered in this sense, bar pressing rate is a measure of bar pressing response strength relative to the strength of other ongoing behavior. As Skinner puts it: "... the main datum to be measured in the study of the dynamic laws of an operant is the length of time elapsing between a response and the response immediately preceding it or, in other words, the rate of responding" (Skinner, 1938, p. 58).

The point of the preceding comment is that bar pressing rate is inherently a composite measure of a given set of behavioral events separated in time by other (albeit chain-related) behavioral events. The intensive attributes of response, on the other hand, are by their very nature exclusively indices of the actual responses per se. This is not to imply that the one is a "better" or "worse" measure than the other. Obviously, frequency and intensity measures sample different properties of behavior. The former has been shown to bear such a predictable relation to reinforcement operations as to stand relatively unchallenged as a convenient index of these operations, and by definition has come to signify a property called "response strength." The latter, i.e., force, may as Skinner says bear "no simple relation" to response strength, but that may be begging the question. The real issue, as with bar pressing, is: Do lawful relations exist between E's operations and the intensive characteristics of S's response? Here the answer is affirmative as indicated by the foregoing graphs. That such lawfulness is predicated upon response differentiation, and not bar pressing rate, does not diminish its possible importance. It may be of considerable significance, for example, to know that differentiation of force takes place much sooner than stabilization of bar pressing.
rate (Fig. 6), and that this differentiation is maintained at stable levels, even though bar pressing occurs at more frequent intervals, indicating the gradual disappearance of other ongoing behavior.

SUMMARY

A detailed description was made of the emission of forces by rats during acquisition (regular reinforcement) and extinction of the bar pressing response. It was found that the distribution of forces emitted during acquisition peaked at a value approximately twice that of the force required for reinforcement, and that both magnitude and variability of force decreased during acquisition and increased during extinction. The implications of an observed increase in bar pressing rate during acquisition, well after force stabilization had occurred, were examined.

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