THE SUCCESSIVE DIFFERENTIATION OF A LEVER DISPLACEMENT RESPONSE¹

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Maximum displacements of lever presses by rats were recorded under eight successively-smaller reinforcement zones (RZ). The largest RZ included displacements from 3° to 44°; the smallest, from 24° to 29°. As the RZ decreased, displacement distributions reflected a least-effort tendency: distributions peaked at the lower limit of RZ and most non-reinforced presses fell just below the lower limit. Successive distributions (a) differed significantly in shape, (b) showed reduced variability, and (c) indicated more presses and more presses per reinforcement. Prolonged training under the smallest RZ gave no improvement in performance.

The successive differentiation of a response is a procedure by which some particular form or property of a response is approached gradually by selective reinforcement and extinction. Although the concept of successive differentiation is widely accepted and used, there are relatively few experimental data on differentiations. The purpose of this report is to help fill the need for this type of data, with particular reference to the development of a differentiation. A quantitative account is given of the development of a differentiation in which (a) the response classes fall on a continuum, and (b) the reinforced response class is defined by both upper and lower limits. The response property measured is lever displacement. Because of the characteristics of the special response lever used, the work expended by a subject in pressing the lever arm is linearly proportional to the displacement of the lever arm.

METHOD

Subjects

Five male albino rats of Sprague-Dawley strain served. They were about 146 days old on the first test day.

¹Opinions and conclusions in this report are those of the author. They are not to be construed as necessarily reflecting the views or the endorsement of the Navy Department.

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Apparatus

The test box was 8 in. wide, 9 $\frac{1}{8}$ in. long and 7 $\frac{5}{8}$ in. high. To eliminate cues and distractions, it was enclosed in a picnic ice box, and all programming and recording equipment was in another room. A blower attached to the ice box provided air circulation between room air and test box air, and thermostatically-controlled air coolers and heaters maintained temperature within about 1° of 22.5°. The test box was illuminated by two small lamps mounted on the wall above the lever. Water reinforcements were delivered by a 0.014 cc cup which projected $\frac{1}{4}$ in. above the floor at a point 2 in. to the side of the lever arm. A food container was mounted on one wall; the response lever on the opposite wall. In its resting position, the arm of the response lever was at an angle of 23° above the horizontal and extended about $\frac{3}{4}$ in. into the compartment. In this position, the T-bar handle was 2 $\frac{7}{16}$ in. above the grid floor.

The response lever and associated calibration procedures are described in detail elsewhere (Herrick and Karnow, 1962). In short, one end of the lever arm terminated in the form of a horizontal rod (T-bar). The displacement of the T-bar was classified into intervals of arc or "lever positions." The interval between the resting place of the T-bar and 3.29° of arc was called the Home Position. Each of the remaining eight Lever Positions, successively numbered 1 through 8, spanned approximately 5.09° (or 4.51 mm) of arc. The exact arcs represented by Positions

1 through 8 were 5.05°, 5.05°, 5.10°, 5.15°, 5.15°, 4.86°, 5.15°, and 5.19°, respectively. A minimum force of 26,500 dynes (27 g) was required to depress the T-bar. This minimum force requirement remained constant, within about 2%, throughout the total excursion of the T-bar.

With the lever mechanism, the work expended in depressing the T-bar was linearly proportional to its displacement: $Work = 134,620 \theta$, with work in dyne-cm and θ in radians. Conversion factors relating various units are as follows: 1° of arc of the T-bar was equivalent to 0.8863 mm of arc or 2,349 dyne-cm of work or 2.397 g-cm of work. For a description of the relationships between the rat's lever pressing and the physics of the lever mechanism, see the apparatus section of Herrick (1963). For each press, the maximum displacement of the T-bar was measured in lever position units.

The arc covered by each Lever Position was calibrated by a device that yielded measurements accurate to .0476° of arc. The mean size of the drop of water used as reinforcement, *viz.*, .014 cc, was determined by measurement of individual drops by a standard gravimetric method, with precautions that precluded loss by evaporation.

Procedure

On the 25 days preceding the conditioning period, and on most of the days during the conditioning period (see below), each *S* was given access to water automatically in its living cage for 15 min at the same time daily. During the conditioning period, each *S* was tested for 1 hr daily on weekdays. The beginning of the free-watering period followed the end of the test period by 15 min. An equipment malfunction eliminated the 15-min weekday watering period on Test Day 22 (see Results) and thereafter. Purina Lab Chow was available in the living cage and in the test box.

On the first two test days the rats were reinforced for all presses to Positions 1 through 8. On the next two test days only presses to Positions 2 through 8 were reinforced; on the next two test days, only presses to Positions 2-7. This systematic decreasing of the reinforcement zone (RZ) every two test days was continued until only presses to Position 5 were being reinforced. Then, 20 addi-

tional days of training were given on this last condition. Reinforcement for a press within the RZ was delivered at the completion of a press, *i.e.*, immediately after the T-bar returned to the Home Position.

RESULTS

The data from Days 1-16 are given in Fig. 1 and 2. The following conclusions may be drawn.

There was a strong tendency for the distributions to peak at the lower positions within the RZ. For example, with RZ of 3-7 and 3-6, 20 daily distributions were recorded for the *Ss*. For 10 of these distributions the mode was Position 3; for the other 10, Position 4. For RZ 4-6 and 4-5, 18 of the 20 daily distributions peaked at Position 4, and the other two at Position 5.

There was also a strong tendency for the highest number of non-reinforced presses to occur at the position adjacent to the lowest reinforced position. Thus, for the 20 distributions obtained with RZ of 3-7 and 3-6, Position 2 always ranked highest of the non-reinforced positions. For the 20 distributions obtained with RZ of 4-6 and 4-5, Position 3 always ranked highest of the non-reinforced positions.

The elimination of the lower positions from the RZ was reflected by decreases in the daily percentage of presses to the position eliminated, as well as to lower non-reinforced positions. When Position 2 was eliminated from the RZ, all *Ss* showed decreases in the percentage of presses to Position 2 and to Position 1. Similarly, the elimination of Position 3 resulted in decreases in the percentage of presses to Position 3, to Position 2 and to Position 1 for all *Ss*. Also, the elimination of Position 4 caused decreases in the percentage of presses to Position 4, to Position 3, and to Position 2 for all *Ss*. On the other hand, elimination of the higher positions, Positions 6 and 7, from the RZ had no comparable effect. When Position 7 was eliminated, only two *Ss* showed decreases in the percentages of presses to Position 7 and only one in the percentage to Position 8. When Position 6 was eliminated, three showed decreases in the percentages to Position 6, one to Position 7, and one to Position 8.

A related finding concerning percentage decreases in the lower-numbered positions was

Fig. 1. Lever displacement distributions as a function of the size of the reinforcement zone. Shaded sections of the histograms indicate the lever positions within the reinforcement zone. The symbol N indicates a distribution that did not differ significantly (.05 level, Kolmogorov-Smirnov two-sample, two-tail test) from the preceding distribution shown for the same rat.

that the relative decrease in the percentage of presses to a given lever position was less, ordinarily, when reinforcement for that position was eliminated than it was when reinforcement for a higher position was eliminated. A measure of the relative decrease associated with a change in the RZ is obtained by dividing the percentage of presses to a given position under one RZ by the percentage under the other RZ. For example, the percentage of presses of Rat #25 to Position 2 decreased from 33.79 to 16.93% when the RZ changed from 2-7 to 3-7. This decrease yielded a relative value of $33.79/16.93$ or 1.99. When the RZ changed from 3-6 to 4-6 the relative decrease for the same position for the same S was $17.05/2.42$ or 7.04. Thus, for Rat #25, the relative decrease in the percentage of presses to Position 2 was greater when Position 3 was eliminated from the RZ than it was when Position 2 was eliminated. Similar analyses for all rats for Positions 1, 2, and 3 yielded

the following results. The greatest relative decrease in the percentage of presses to Position 1 occurred for one S when reinforcement for Position 2 was eliminated from the RZ, for three Ss when reinforcement for Position 3 was eliminated, and for the remaining S when reinforcement for Position 4 was eliminated. The greatest relative decrease in the percentage of presses to Position 2 occurred for three Ss when reinforcement for Position 3 was eliminated and for the other two Ss when reinforcement for Position 4 was eliminated. The greatest relative decrease in the percentage of presses to Position 3 occurred for two Ss when reinforcement for Position 3 was eliminated and for three Ss when reinforcement for Position 4 was eliminated. No comparable analyses were performed for the higher-numbered portions because, as noted above, few Ss showed decreases in the percentages of presses to these positions when they were eliminated from the RZ.

Fig. 2. Changes in the daily percentages associated with a systematic reduction in the size of the reinforcement zone. A percentage of 0.10 or less was plotted as 0.10. A solid datum point means that the percentage represented was significantly higher or lower (.05 level, two-tail test; Wallis and Roberts, 1956, p. 429) than the preceding percentage. Where two lines cross at a solid datum point the significant difference refers to the line showing the greater vertical displacement.

For the two Ss not included in Fig. 1, comparisons of pairs of distributions, by the method described in the Fig. 1 caption, indicated that every comparison of Rat #30 showed a significant difference, and nine of the 15 comparisons of Rat #25 showed a significant difference. Combining this information with that of Fig. 1 indicated that, of the 75 comparisons of the distributions, 61 showed a significant difference. The non-significant comparisons more often represented comparisons based on distributions under the same RZ, rather than comparisons based on distributions under different RZ; nine of the 14 non-significant comparisons fell in the former category. Also, the non-significant comparisons tended to occur in the later stages of the successive differentiation; 10 of the 14 occurred in the latter half of the successive differentiation.

Figures 1 and 2 indicate that as the RZ decreased in size there were, in general, considerable increases in the daily number of presses, lesser increases in the daily number of reinforcements, and, consequently, increases in the number of presses per reinforcement.

The mean deviation (MD) of displacements was calculated in lever position units for each S for each day of Days 1-16. The maximum and minimum MDs possible were 3.50 and 0.00, respectively. On Day 1, the five MDs ranged from 1.43 to 2.36; on Day 2, from 1.34 to 1.47. During the course of the differentiation, the MDs for each S gradually decreased. On Day 16, the MDs for the five ranged from 0.48 to 0.68.

On the last 20 experimental days, Days 17-36, 100 daily distributions were obtained for the five Ss. In each of these distributions the mode was Position 5. In 84 of the 100, more of the non-reinforced presses were to Position 4 than to any of the other non-reinforced positions. In the remaining 16 distributions, 10 of which were obtained from Rat #26, Position 6 was the non-reinforced position with the highest percentage. A runs test (Wallis and Roberts, 1956, p. 573) was employed to determine whether the general level of the series of Position 5 percentages changed during Days 15-36. Only Rat #24 showed a significant (.05 level, two-tail test) change, an increase, in the general level of the series. Figure 3 presents the data of Days 17-36 grouped into five-day periods.

Fig. 3. Lever displacement distributions based on presses during 5-day periods when the only presses reinforced were those to Position 5.

DISCUSSION

The last column of distributions in Fig. 3 may be considered examples of a near-equilibrium state resulting from the combined influences of reinforcement for Position 5 presses and extinction for presses to all other positions. The percentages of presses to Position 5 given in Fig. 3 are not the maximum percentages of which rats are capable: when presses to a position other than Position 5 resulted in a 10-sec time-out period, distributions were decidedly more peaked than those of the present experiment (Herrick, 1964).

It is worthwhile to consider the analyses in the results section with regard to theoretical and practical applications to differentiations. One conclusion is that a powerful tendency toward least-effort exists. This same tendency can be seen in the data of other differentiation studies in which the response property measured was displacement (Herrick, 1964), force (Arnold, 1945; Notterman and Mintz, 1962), and duration (Molliver, 1963). Murphy's displacement differentiation study (1943) with humans did not show this least-effort tendency. It is likely, however, that the least-effort effect is a function of the absolute amount of effort required. A human subject, for example, may not tend toward the least force possible when the forces required range from 10 to 20 g, but he would probably do so when the forces required range from 10 to 20 kg. The above considerations suggest that in designing a differentiation procedure the experimenter should consider and, if possible, exploit S's tendency toward least-effort.

A second, expected finding is that, by gradually approaching the final form of the response, many reinforcements are given for responses that later become ineffective for procuring reinforcement. If the resistance to the extinction of a response is, in fact, a function of the number of reinforcements received for the emission of that response, any procedure

that strengthens responses that are to be extinguished subsequently is undesirable. A preferred differentiation procedure should provide minimal strength to all but the final form of the response.

A third point to be noted is the relationship between the size of the RZ and the number of presses per reinforcement. As Murphy (1943) has noted, this relationship may be described roughly by a positively accelerated curve: as the RZ decreases by steps of equal size, the number of presses per reinforcement goes up in increasingly larger steps. In other words, the differentiation becomes increasingly difficult. This relationship suggests that, early in the differentiation, a shift from one RZ to the next could occur more quickly without risking extinction (*cf.* Herrick, 1964). It would also seem desirable to provide an increasingly greater amount of training with each successively smaller RZ.

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