AMPLITUDE-INDUCTION GRADIENT OF A SMALL-SCALE (COVERT) OPERANT¹

RALPH F. HEFFERLINE² AND BRIAN KEENAN

COLUMBIA UNIVERSITY

An invisibly small thumb-contraction was conditioned under secondary positive reinforcement (money) in four adult human subjects without their observation of the response. Electromyographic detection enabled the experimenter to reinforce the response by advancing on the subject's illuminated scoreboard the count of nickels earned. A light-beam galvanometer recorded on photosensitive paper not only those instances of the response which were of the size pre-selected for reinforcement but also those too small or too large to qualify. From the developed record cumulative response curves were constructed for each of the variously sized subclasses of the operant. Histograms, too, were plotted showing response-frequency by subclass for each 10-min interval of the experimental session. Before conditioning, response frequency was radically skewed toward the large-amplitude end of the distribution. The effect of conditioning was to normalize the distribution, with the middle-sized subclass (the one reinforced) becoming modal. This entailed reduced frequency of responses in subclasses smaller than the one reinforced. In extinction the original skew was strikingly restored in three of the four cases.

The systematic importance of operants so small as to require instrumentation for their public detection has been recently discussed (Hefferline, 1962). The question of the parametric comparability of such miniature responses to those large enough to constitute overt movement and forceful enough to produce a direct effect on the external environment, such as closure of a microswitch, is now being studied. Thus far only a single small operant, an extremely minute twitch of the human thumb, has been examined under several different experimental conditions. Its operant level, conditionability, and extinguishability have been reported for an escape-avoidance situation (Hefferline, Keenan and Harford, 1959). Also, using a secondary positive reinforcer (money), it has been shown that the twitch, small as it is, produces stimuli sufficient to control discriminatively an overt response such as a key-press (Hefferline and Perera, 1963).

The problem of response definition is particularly acute for operants which can be detected only by instrumentation. As an

electronically measurable class of events the thumb twitch extends from the point where its signal peak emerges clearly from the system's noise level, through the range where it is covert (invisible to direct vision), and on through those amplitudes where it is readily visible as an increasingly gross movement. To be sure of working within the covert range it is necessary to establish arbitrarily an upper amplitude boundary, expressed in electrical units, which is well below the visible (overt) range. Also, since the covert range so delimited comprises responses which still vary widely with respect to size and frequency, it is further necessary to specify an amplitude bandwidth in microvolts which will include all reinforceable instances.

For present purposes the amplitude category (bandwidth in microvolts) chosen for experimental manipulation may be regarded as a sub-operant, with the whole covert range constituting the operant. Scale intervals equal to that of the reinforced category may be laid off above and below it to define other sub-operants.

Since the reinforced sub-operant obviously shares many properties, topographical or otherwise, with neighboring sub-operants, it is of interest to determine to what extent these latter also share inductively the effect of reinforcement. An amplitude-induction gradient

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²Reprints may be obtained from Ralph F. Hefferline, Dept. of Psychology, Columbia University, New York 27, N. Y.

constructed from data for a single subject in an escape-avoidance situation has been presented (Hefferline and Keenan, 1961), and some of its characteristics will be referred to later. The present investigation was undertaken to examine the amplitude-induction gradient as it might appear under secondary positive reinforcement, as well as to remove some of the design limitations of the study just mentioned.

METHOD

Subjects

Two men and two women served; the men were 27 and 35 years of age, and the women 21 and 40.

Apparatus

Subject's cubicle. The subject (S) sat in a reclining chair in a triple-shielded, air-conditioned, sound-deadened chamber, 8 ft long, 4 ft wide, and 8 ft high. The S could talk to the experimenter via an intercom. As the cubicle was lighted, although dimly, the experimenter could observe S through a one-way window of electrically conductive glass. Directly in front of S was a panel for presenting large, luminous numerals. Also on this panel was a small red light for use, as described later, in maintaining rest level.

Electrodes. A paint-on type of electrode was used. The S's skin was prepared by first removing dead cells with fine sandpaper and then reducing skin oils by means of an acetone scrub. Electrode jelly was next rubbed in. Over the jelly was painted an emulsion consisting of 27% silver particles (200 mesh) and 73% collodion. When this had dried for about 30 sec a second coat of emulsion served to "weld" in the amplifier lead.

Three pairs of electrodes were used, but two pairs were simply dummies intended to distract the subject from undue attention to the locus of the recording electrodes. The latter were positioned at the palmar base of the thumb and on the medial edge of the left hand. The left ear lobe served as a ground.

Amplifying system. A block diagram of the experimental setup is presented in Fig. 1. Muscle potentials from S's left hand were fed into the differentially balanced input of a Tektronix 122A low-level pre-amplifier. The output of this unit was conducted, via a variable impedance-matching network, to the single-ended input of a second Tektronix pre-amplifier. At this stage of amplification the signal was led outside the shielded cubicle and through an attenuating network to an impedance-matching amplifier.

The next unit had three functions: (1) to limit the signal so that meters and recorders would not be damaged by the relatively high voltages from occasional gross movements; (2) to rectify the signal; (3) to improve the linearity of the lower range of the frequency response curve.

One portion of the rectified signal was fed to an Esterline-Angus recording milliammeter. Although this instrument provided a permanent record, its response was too slow to be fully adequate for data analysis, and it was retained in the system only as a monitor. That portion of the signal which produced a record for later analysis was conducted, via a DC amplifier, to a light-beam galvanometer which wrote on photosensitive paper. By means of a key the experimenter could record reinforcements on an event-marker channel of the photo-recorder, and at the same time produce a numerical increment on the lighted panel

Fig. 1. Block diagram of apparatus.

in *S*'s cubicle. A third portion of the signal went to a DC vacuum-tube voltmeter, which, in addition to serving as a monitor, controlled a limiting relay. The latter turned on a red light on the *S*'s panel if his output drifted a few microvolts above rest level.

The system was calibrated at the beginning and end of an experimental session by means of a dummy subject. This consisted of a Hewlett-Packard audio generator driving a 100 cps sine wave through a General Radio microvoltage (adjusted to zero decibels.)

The time-constant of the system was .1 sec. Thus, the signal as recorded was the envelope of whatever AC spikes occurred within that interval. A more recent method developed for working directly with single AC spikes is described in the discussion section.

The system met the following specifications: amplitude non-linearity less than 1%; frequency range .1 cycle to 250 cycles; loss of less than 1 decibel over the whole range.

Procedure

When *S* was seated in the reclining chair and the leads connected, the experimenter presented a card bearing the following instructions:

"We are measuring your ability to relax. Consequently, it is important that you notify the operator before the start of the session if you are at all uncomfortable. Lie back, relax, and try to move as little as possible. But do not go to sleep!

"If, during the session, you find that you are uncomfortable because your nose itches, your position is cramped, or whatever, take care of the matter by scratching, shifting position, *etc.*, as quickly as possible. Then relax again.

"After 30 or 40 min numbers will begin to appear on the lighted box in front of you. These numbers represent your total score. For each increase in the score you will receive a nickel. For example, if at the end of the session, your score is 113, you will receive 113 nickels, or \$5.65."

Only 2 to 5 min of "settling down" were needed, as an efficient means of "shaping" relaxation had been discovered in preliminary work. As mentioned earlier, there was a red light on *S*'s panel which flashed on when the upper limit of the relay circuit controlled by the vacuum-tube voltmeter was exceeded. At

the start of the session the light was off as long as *S* continued to drift into a more relaxed condition. If *S* reversed course in the direction of greater tension, as indicated by the voltmeter, the experimenter turned on the light and left it on until *S* again started to relax. When *S* had stabilized at a low level, typically between 10 to 20 microvolts at the electrodes, the experimenter set the relay upper limit slightly above this value. From this time on the red light was controlled automatically by *S*'s tension level. This tended to remain throughout the session just a few microvolts below the level which would switch on the light.

It is of interest that the red light served its purpose only if *S* was told nothing about it. In earlier informal experimentation it had been found that to mention the light destroyed its effectiveness, presumably by putting it in control of behavior incompatible with that desired. This means of manipulating relaxation will be studied further.

The experimental session, conducted with no intermissions, lasted either 80 or 120 min. It consisted of operant level determination, conditioning, and extinction. In all *S*s operant level was taken for 10 min. Conditioning lasted 60 min in two *S*s, 85 in one, and 90 in one. Extinction was for 10 min in two cases, 20 in one, and 23 in one.

While operant level was being recorded, the experimenter watched the beam of light move back and forth across the scale of the photo-recorder. Rest level was adjusted to be near the bottom of the scale. As long as *S* maintained rest level, the beam flickered over a scale distance of a few microvolts, varying in number from *S* to *S* due to individual differences in the amount of "firing." Occasionally the beam would swing sharply upward above rest level, and then quickly back to rest level. This represented an instance of the operant under study, produced by muscle action potentials in the left thumb. It took nearly 300 microvolts to cross the threshold of "overtiness" in the least responsive subject—*i.e.*, to produce a barely visible twitch—and much more in those who "fired" heavily. The upper limit of the largest sub-operant measured for any *S* in this study was 140 microvolts, about half the microvoltage needed to produce a visible contraction in the most responsive subject.

Fig. 2. Amplitude-induction gradients of a small-scale operant (thumb contraction) in S No. 1 (female, 21 years old). Left: cumulative response curves for the reinforced value (heavy line) and for values larger and smaller. Each record begins at the point on the ordinate which corresponds to the midpoint of its microvolt-age category. (O.L. is operant-level determination and EX. is extinction.) Right: frequency response histograms for the various suboperants plotted by 10-min intervals, with the reinforced value shown in solid black. (C. 1, C. 2, etc., are successive 10-min conditioning periods.)

Fig. 3. Amplitude-induction gradient of a small-scale operant (thumb contraction) in S No. 2 (male, 35 years old). See legend of Fig. 2 for description.

Fig. 4. Amplitude-induction gradient of a small-scale operant (thumb contraction) in S No. 3 (female, 40 years old). See Fig. 2 for description.

Fig. 5. Amplitude-induction gradient of a small-scale operant (thumb contraction) in S No. 4 (male, 27 years old). See Fig. 2 for description.

During operant level determination an amplitude category was chosen that was suitable for reinforcement. It was desirable that the reinforceable responses be no more frequent than once every minute or so, and that there be a number of small sub-operants of the same bandwidth between it and rest-level so that the amplitude-induction gradient to

be plotted later might contain a number of sub-operants both larger and smaller than the reinforced value.

During conditioning, whenever the experimenter saw an excursion of the light-beam which peaked within the amplitude-interval selected for reinforcement and then immediately returned to rest-level, he pressed a key.

This put a mark on the event-channel and advanced by one digit the score on *S*'s panel, thus informing *S* that another nickel had been earned. (The statement in the instructions that "after 30 or 40 min numbers will begin to appear" was purposely conservative on the chance that a subject might be long delayed in obtaining the first reinforcement.) During extinction the situation remained unchanged except for the withholding of the reinforcement.

When *S* had been released from the cubicle and while the electrodes were being removed, the experimenter asked what *S* had done to earn the nickels and noted any verbal report on this or any other matter related to the experiment.

From the developed photographic record cumulative response curves were hand-constructed for each sub-operant. Cumulation was by 1-min intervals.

RESULTS

Results are displayed in Fig. 2-5. On the left in each figure is the family of cumulative response curves for the various sub-operants, with the one reinforced shown as a heavy line. On the right is a series of histograms in which instances of each sub-operant are cumulated by 10-min intervals throughout the experimental session, with the reinforced value shown in solid black. The number of sub-operants plotted for a particular subject varies from six to 10.

During conditioning procedure the reinforced sub-operant increased in rate for all *S*s over that prevailing during operant level determination, and at the end of extinction its rate had returned approximately to its pre-conditioning level. Only in Fig. 2 and 3, however, does it show the relatively steady positive acceleration during conditioning which characterized the single case reported earlier from an escape-avoidance situation (Hefferline and Keenan, 1961).

By and large, the sub-operants of greater amplitude behaved like the reinforced value, showing rate increase during conditioning and rate decrease during extinction, although, as expected, in lesser degree. What had not been anticipated was that the sub-operants of lesser amplitude should, with few exceptions, display the opposite effects—rate decrease during

conditioning and increase during extinction. This is seen most clearly in Fig. 5.

Prior to conditioning, the frequency distribution of the sub-operants is skewed markedly toward the high-amplitude end. Conditioning tends to normalize the distribution. In all cases the reinforced value becomes the most frequent, and in three of the four cases the non-reinforced sub-operants fall off more or less symmetrically from this peak. Despite this radical shift in the shape of the distribution, a brief period of extinction sufficed in three cases to restore the initial skewing.

There is some suggestion of a relatively constant frequency of the operant over the range studied, with conditioning serving to augment the high-amplitude categories by depleting the low. A partial exception is shown in Fig. 2, where the sub-operant just smaller than the reinforced value seems to reflect the effects of reinforcement in almost identical degree, with the result that their cumulative records ascend almost in parallel.

Because the experimenter was obliged to watch the moving light-beam of the photo-recorder continuously and to decide quickly whether a particular excursion met the criteria of a reinforceable response, it was a matter of some importance to determine the accuracy of the experimenter's performance. It might be supposed, for instance, that the two parallel curves of Fig. 2 resulted from a substantial number of reinforcements being administered erroneously to the smaller sub-operant. All instances of reinforcement were therefore checked on the permanent photographic record.

It was found that once in 10 times a reinforced response actually fell outside the appropriate bandwidth. In several instances it fell just short of being large enough, but in most such cases it was too large by a small amount. This procedural error thus presumably had negligible effect.

A second type of error was failure to reinforce when the response did meet the criteria. This occurred one time in eight. The schedule might therefore be termed intermittent, but it seems more appropriate to call it continuous with an occasional missed reinforcement.

When questioned later, no *S* revealed the slightest idea of how reinforcements were

earned. All reported intense annoyance when the nickels stopped coming. The subject of Fig. 5, a 27-year old male, who had been scheduled to receive 25 min of extinction, insisted on being released from the cubicle when 2 min still remained to go. Although urged to wait just a little longer, he tore off the electrodes and forced his way out. A short time later he was apologetic, but claimed: "I felt I just couldn't stand it another instant."

DISCUSSION

This study broadens somewhat the still meager information available with respect to small-scale (covert) operants. They are conditionable, not only as escape or avoidance responses as found earlier (Hefferline, Keenan and Harford, 1959), but also when money is used as a secondary positive reinforcer.

The amplitude-induction gradients presented here are roughly comparable to the single case reported from an escape-avoidance situation (Hefferline and Keenan, 1961). Observed differences between the two conditions, however, cannot be safely discussed from such an inadequate sample.

More precise analysis of the small-scale (covert) response makes it imperative to work directly with the AC signal. The apparatus in the present study introduced some degree of artifact by rectifying and then meter-damping the signal. With its integration interval of .1 sec it would be possible for two low-amplitude sub-operants to occur in quick succession, summate, and then appear on the meter as a single sub-operant of higher amplitude. Even our concern to have *S* maintain a steady rest-

level has been in part a product of the system's time-constant, since the occurrence of any rapid low-amplitude "firing" would appear as a lifting of the "noise-level" above that previously established as the baseline for measurements.

We have now been able to develop a control and data processing system which eliminates all the technical difficulties mentioned. The *S*'s amplified AC muscle signal is fed to an automatic response analyzer which reliably detects, reinforces and records responses of a particular size and rejects all others. Also, since an analog record is made at the same time by recording the muscle signal on magnetic tape (pulse frequency modulated), the response analyzer may be used again at different voltage settings on repeated playbacks of the tape to detect and record the various non-reinforced sub-operants.

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