OPERANT CONDITIONING OF A SMALL-SCALE MUSCLE RESPONSE¹

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Six naive male subjects were reinforced for responses in the 20-30 microvolt range, and two each for those in 10-20 and 30-40 microvolt ranges. Records were taken of 15 min of "settling down," 15 min of initial operant level responding, 30 min of conditioning, and 45 min of extinction, 30 min with light present and 15 min without. The results were: (1) small-scale muscle potentials from the thenar eminence, in the 10-20, 20-30, and 30-40 microvolt ranges, were conditioned, using pointer movement as the reinforcement; (2) the response rate in adjacent ranges of greater and lesser amplitude also increased during such conditioning and decreased during the subsequent extinction; (3) during conditioning the frequency of response distribution shifted toward the reinforced range; (4) subjects were unaware of the reinforced response; (5) observing a noncontingent moving pointer increased the response rate in the 20-30 microvolt range, but did not lead to conditioning.

It has been shown (Hefferline, 1958) that, using visual feedback from a meter, subjects can be trained to make a movement of the masseter muscle so small that they are unable to give any verbal report of the movement. Moreover, with adequate training they can continue to produce the selected response on demand, even after the meter is removed and only proprioceptive feedback is available.

Responses from the thenar eminence may be utilized equally well. Hefferline, Keenan, and Harford (1959) defined a response in terms of the ballistic swing of a pointer, and selected one which occurred "not more than" once in 1-2 min before conditioning. This response was conditioned to avoid and escape a 60-cycle hum superimposed on music. Again, following conditioning and extinction, subjects were unable to report what the effective response had been. They were unaware that they had had anything to do with terminating

the aversive condition. The responses from one subject were divided into 26 equally-spaced steps (Hefferline and Keenan, 1961) all but one of which were larger than the reinforced value. In conditioning, "subclasses just slightly larger than the reinforced one . . . settle to a steady slow rate" of responding, and in extinction, "the subclasses nearest the reinforced one display the form of typical extinction curves."

These results led to the study of a possible induction gradient (Hefferline and Keenan, 1963). Again, the selected response was taken from the thenar eminence. "Correct" responses increased the subject's score one point, worth one nickel. The records of all four subjects showed an increase in the reinforced range, and in two cases the rate during conditioning showed the same steady positive acceleration as found by Hefferline and Keenan (1961). It was found that the rate of response ranges of amplitude greater than the reinforced one increased during conditioning and decreased during extinction, while the rate of the response ranges of lesser amplitude decreased during conditioning and increased during extinction. Further, conditioning tended to normalize response distribution toward the reinforced range.

The responses utilized were muscle action potentials recorded by surface electrodes. These electrodes undoubtedly recorded electrical activity from a large population of

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muscle fibers within the thenar eminence, without indicating which specific muscle fibers were involved, which produced which action potential, or even the actual number involved. Nevertheless, each of these individual muscle action potentials, reflecting the activity of some motor neuron, could be observed, recorded, counted, and measured.

As the apparatus used had a time constant of 0.1 sec, the signal actually recorded was the envelope of whatever individual action potentials occurred within this interval. Since the duration of motor unit action potentials ranges between 4 and 17 msec (Petérsen and Kugelburg, 1949) it is possible that response summation of an unknown degree may have occurred. The problems inherent in this situation have been discussed by Hefferline and Keenan (1963). They concluded that the need to analyze small-scale responses more precisely made it imperative to work directly with individual muscle action potentials rather than with an integrated signal.

The present study attempted to condition individual small-scale muscle action potentials, within three 10-microvolt-wide ranges, utilizing an automated system to evaluate responses. Further, it examined the effect of such conditioning, and the subsequent extinction, upon adjacent 10-microvolt ranges of both greater and lesser amplitude than the reinforced range.

METHOD

Apparatus

Two equipment configurations were employed, one for recording data during experimental sessions, and one for playback and selective examination of such data.

Record configuration. This consisted of the subject booth plus amplifying, recording, and monitoring equipment. The general arrangement is shown in Fig. 1.

The subject booth consisted of a double-doored steel equipment rack laid on its side. A foam mattress in the upper portion supported the subject in a manner similar to a contour chair—flat on his back, with legs elevated from the hips and flexed at the knees.

Directly above the subject's head was a circular dial face, the pointer of which made 12 regularly-spaced steps per revolution. The counter was rear-illuminated by two clear

28 v dc instrument lights. Another pair of lights, covered with blue plastic caps, was positioned one on each side of the subject's counter. The four lights were connected to a three-position switch, so that either the two blue lights could be turned on (operant level determination), the dial illuminated (conditioning and extinction), or the entire system turned off.

A pair of 2-in. speakers inside the booth was placed one on either side of the subject's head. Random noise, generated by the dielectric breakdown of a capacitor, was fed through the speakers to mask distracting outside noise. An intercom unit enabled the subject to speak to the experimenter at any time. A switch on the experimenter's unit permitted him to speak to the subject when desired and suppressed random noise during communication.

The lower portion of the subject booth contained a pair of Tektronix type 122A low-level differential preamplifiers and their battery power supplies. The three shielded leads from the subject went directly to the first preamplifier, which was set at a voltage gain of 1000. This was directly coupled to the second preamplifier, which was set for a voltage gain of 100, giving a combined gain of 100,000. Both preamplifiers were set at a low-frequency cutoff of eight cycles, and a high-frequency cutoff of 1 kc. By placing the preamplifiers and associated power supplies within the booth, and connecting all components with shielded cable, distortion of the extremely small signals being investigated was held to a minimum.

From the second preamplifier the signals were fed to the channel one input of a Tandberg series 6 stereo tape deck, operating at $1\frac{7}{8}$ in. per sec, and recorded on 1-mil thick Mylar tape (Audiotape, type 1861). Channel two recorded experimenter's and subject's comments.

Simultaneously, the signal from the second preamplifier was fed to a Hewlett-Packard type 450A amplifier, set for a voltage gain of 100. This amplified the signals so that they were adequate to operate the response definer, to which the signal was fed next.

The response definer² consisted of the amplitude defining circuitry of a transistorized

²Trevor, J. B., III. An automatic transistorized response analyzer for detecting and recording amplitude, duration and interresponse times. 1965, in preparation.

Fig. 1. Equipment configuration for recording and playback.

logic network which defined a base line and the lower and upper limits of the acceptable response range. The upper range limit was the maximum peak value, in microvolts, of the acceptable response, while the lower range limit was the minimal peak value. The base line was set two microvolts below this lower range limit. This insured that the signal had risen from at least two microvolts below its minimal acceptable value, and was not an anomalous one which hovered just above or below the lower limit, wandering back and forth across it. Also, since the system had a noise level of one microvolt, it prevented a signal which rose to within one microvolt of the lower limit from combining with this noise and registering as an acceptable response. The definition of a signal by this method is shown in Fig. 2.

Each time the response definer detected an acceptable response it produced an output

pulse which triggered a digital counter, visible to the experimenter. This maintained a count of the number of reinforceable responses during the session. During conditioning, the response definer output pulse also was connected, via a patch panel, to the mechanism driving the pointer of the subject's counter. The response definer could follow accurately up to 10 kc per sec, while the subject's counter could follow only up to 15 per sec. However, since response rates rarely exceeded half this rate, this limitation did not affect the study.

A Tektronix type 561 oscilloscope, incorporating a Tektronix type 72 dual-trace amplifier and a Tektronix type 67 time-base unit, monitored the system. The output of the Hewlett-Packard amplifier was fed to input A of the oscilloscope, and the channel one output of the tape deck was fed to input B. This made it possible to compare visually the signal being delivered to the response

Fig. 2. Definition of a signal in the 20-30 microvolt range by the response definer. To be acceptable the signal must come from below the base line (18 microvolts) and rise to a peak value greater than the lower range limit (20 microvolts) but less than the upper range limit (30 microvolts). Examples: (A) acceptable response. (B) unacceptable response—peak value greater than 30 microvolts, the upper range limit. (C) unacceptable response—peak value less than 20 microvolts, the lower range limit.

definer with the recorded signal, and to determine that they were identical. This indicated that negligible distortion had occurred along either of the two paths the signals followed after leaving the second preamplifier. That is, there was negligible distortion in recording and in the final stage of amplification. This assumed that the probability of equal distortion along the two routes was so small that it might be disregarded. In addition, since the oscilloscope face was calibrated, such monitoring made it possible to determine that the amplitude of responses being accepted as "correct" remained the same throughout the session.

Playback configuration. This configuration is shown in Fig. 1.

To examine selectively the recorded data the channel one output of the Tandberg tape deck was connected to the Hewlett-Packard amplifier, set for a voltage gain of 100. The amplifier output was fed to the response definer, whose output pulses were fed to a Gerbrands model C-2 Harvard cumulative recorder. This recorder accurately followed response rates up to 18 per sec, and was equipped with an additional event pen, triggered by a 1-min timer, which provided a time-base line. In addition, the response de-

finer output pulses were fed to the digital counter visible to the experimenter, so that an accurate minute-by-minute count of the responses could be made.

To monitor this arrangement, the output of the Hewlett-Packard amplifier was fed to input A of the Tektronix oscilloscope. This made it possible to determine that the amplitude of the "correct" responses remained the same throughout the session, and was the same as the amplitude of the signals which had been used to calibrate the response definer.

Calibration of the response definer was essentially the same for recording and playback. For recording calibration a Tektronix type 105 square wave generator, set at 100 cps, was coupled to a General Radio type 546C microvolter, whose output was fed into the first preamplifier. The microvolter was set to the value of the desired base line setting, and the base line variable resistor of the response definer adjusted until the base line trigger ceased firing. Then, the lower and upper band limits were adjusted in the same manner. To calibrate for playback, microvolt values recorded on the tape at the beginning of a session were played back on the tape deck, sent through the Hewlett-Packard amplifier and fed into the response definer. Then, the base line and lower and upper amplitude limits of the response definer were set in the same manner as they had been for recording.

Procedure

Before each session all equipment was given a half-hour warm up. Then, the response definer was calibrated for the range to be reinforced. Following this, the microvolt values required to calibrate the response definer for each of the bands to be examined during playback were recorded on the magnetic tape.

The subject was then brought into the laboratory. The skin on which the electrodes were to be attached was wiped with acetone on rough paper towels, and then with acetone on cotton, to remove the dead skin cells and oil. Then, conformal electrodes, filled with Sanborn electrode jelly, were attached with Davol surgical cement. As an added precaution, electrodes were taped in place with Hy-Tape surgical adhesive.

The desired signal electrode was placed on the thenar eminence of the right hand, which

is formed by three of the short muscles of the thumb, *i.e.*, the adductor pollicis brevis, the flexor pollicis brevis, and the opponens pollicis (Brash, 1951, pp. 504-505). The undesired signal electrode was placed on the hypothenar eminence of the right hand, which is formed by the three short muscles of the little finger, *i.e.*, the abductor digiti minimi, the opponens digiti minimi, and the flexor digiti minimi brevis (*ibid.*, pp. 504-507). The ground electrode was attached to the right ear lobe.

In addition to these functional electrodes, dummy electrodes were placed on the thenar and hypothenar eminences of the left hand and on the left ankle.

While the electrodes were being applied, the following instructions were given to the subject:

"As you know, the muscles of the human body continuously give off small electrical charges—charges on the order of one or two-millionths of a volt. This study is an attempt to measure the exact charge given off by several muscle groups of the resting body over a period of one and three-quarter hours.

"Since gross movements produce so much activity that they mask the very tiny signals being looked for, please try to keep such movements to a minimum. When you do move, please say so over the intercom. The intercom will be on all the time, and if you have anything you wish to say during the time that you are in the booth, please use it. Remember to lie still, but above all, do not go to sleep.

"While you are in the booth, you will never be in complete darkness. Part of the time two small blue lights will be lit. Part of the time the white dial face directly above your head will be lit. When the dial face is lit, the dial pointer can move. During the time that the dial face is lit, the purpose is to see how rapidly the pointer can move."

The first 15 min of the session were allotted as a settling-down period. During this period the blue lights were on and the operant level was recorded. Then, a second 15 min of operant level responding was recorded. The responses recorded constitute the operant level determination. At the end of this period the

blue lights were extinguished. Simultaneously, the white face of the subject's counter was illuminated, and conditioning began. During this 30-min period, each time the subject responded within the preassigned limits, the pointer on his counter advanced one step, a movement of 30 degrees. At the end of this period the connection between the response definer and the mechanism driving the pointer was broken, and the 30-min extinction period with dial light present began. During this period the dial face remained lit, and the pointer remained fixed in place, the subject's responses having no effect on it. Finally, the dial face illumination was extinguished, the blue lights turned on, and a final 15-min recording of extinction without dial light present was taken.

After this 1¾-hr session, the subject was removed from the booth and asked to report what had happened and what he had done.

Immediately after each run the response definer calibration was checked. Final settings never differed from initial settings.

Then the apparatus was converted to the playback configuration, and the recorded tape was examined six times. The first time, the band selected for conditioning was examined and recorded. This had not been possible during the run because the cumulative recorder made too much noise, both audible and electrical. The next four times, adjacent bands were examined and recorded. The sixth time, all responses 50 microvolts and above were examined and recorded. After each run the response definer calibration was checked.

In all, 10 male subjects were run on this schedule. The age range was 23-42 years. Activity in the 5-10, 10-20, 20-30, 30-40, and 40-50 microvolt ranges was examined for all subjects. Subjects 1 through 6 were reinforced for responses in the 20-30 microvolt range, subjects 7 and 8 for responses in the 10-20 range, and subjects 9 and 10 for responses in the 30-40 range.

Finally, subjects 11 and 12, were run under different conditions as a control against the possibility that the results were attributable to a phenomenon akin to sensitization or pseudoconditioning (Kimble, 1961, pp. 482-483). It was necessary to rule out the possibility that the initial response during conditioning had caused the pointer to move, and that the pointer movement itself had elicited

Fig. 3. Cumulative records, subject 1: (a) 5-10 microvolts; (b) 10-20 microvolts; (c) 20-30 microvolts, the reinforced range; (d) 30-40 microvolts; (e) 40-50 microvolts.

the subsequent responses, pointer movement being the cause, rather than the result, of the increased responding.

For these two sessions the equipment was reconfigured so that the taped recording of a subject reinforced for responding in the 20-30 microvolt range (subject 5) could be played back on a second Tandberg tape deck. The output of this tape deck was fed to the Hewlett-Packard amplifier, which fed the response definer. This was calibrated to define responses in the 20-30 microvolt range, and the output pulses were used to drive the pointer of the subject's counter during the 30-min "conditioning" portion of these sessions. The recording from the subject was done in the usual manner, the output from the second preamplifier being fed directly to the channel one input of the original tape deck. The instructions and procedure for these two sessions were the same as in the other 10. After each session, the tape recorded during the session was played back in the usual manner, and responses in the 20-30 microvolt range were examined and recorded.

RESULTS

The cumulative records obtained from subject 1, shown in Fig. 3, are representative of those obtained from subjects 1 through 6, who were reinforced for responses in the 20-30 microvolt range. As this shows, shortly after the onset of conditioning, at the end of the 30th min, the response rate in the reinforced range—20-30 microvolts—increased abruptly. This high response rate continued fairly evenly throughout conditioning and into extinction. After several minutes of extinction, response rate abruptly declined. A second, more abrupt decline in responding occurred later during extinction. From this point until the end of the session, responding continued at this new low rate. Although all six subjects displayed this same basic pattern of responding in the reinforced range, there were some variations. Subject 3 showed slight pauses in responding at 50 and 56 min. Subject 5 showed a slightly decreased rate from the 39th to the 41st min, while subject 4's responses began to decline at the 44th min. A somewhat more erratic record was produced by subject 6, whose response rate increased and decreased several times during conditioning.

The response rate in the adjacent ranges followed the same basic pattern seen in the reinforced range. In the range of amplitude lower than the reinforced range—the 5-10 and 10-20 microvolt ranges—response rate was higher before conditioning and throughout the session than it was in the reinforced range. Before conditioning, the 5-10 microvolt range showed a higher response rate than the 10-20 range for three of the six subjects. Subjects 2 and 4 showed a higher rate of responding in the 10-20 microvolt range, before conditioning, than they did in the 5-10 range, while in subject 6 the two rates were about equal. However, during conditioning and early extinction all six subjects showed a higher rate of responding in the 10-20 microvolt range than in the 5-10 range.

In the ranges of greater amplitude than the reinforced range—the 30-40 and 40-50 microvolt ranges—the response rate was lower throughout the session than that shown in the reinforced range. These ranges showed the same basic pattern as the reinforced range, but in them, conditioning commenced at a slower pace. The highest range—40-50 microvolts—always showed the lowest rate of responding.

The relations of the rates in the five ranges to one another may be seen more clearly when the minute-by-minute counts, taken from the digital counter, are cumulatively plotted. The curves so constructed for subject 1 are shown in the right-hand portion of Fig. 4, while those for subjects 2 and 6 are shown in the right-hand portions of Fig. 5 and 6, respectively. The five curves of these subjects appear as a family, each having the same flattened S shape. For subject 1 (Fig. 4), as for subjects 3 and 5, the curves lined up with that for the lowest amplitude range, the 5-10 microvolt range highest, and those for successively higher amplitude ranges in descending order. For these subjects the total number of responses in the 5-10 microvolt range was greater than that in the 10-20 range, even though the number of responses during conditioning was greater in the latter than in the former. In subject 2 (Fig. 5), as in subject 4, the 10-20 microvolt curve lay above the 5-10 curve, as the response rate before as well as during conditioning was greater in the former than in the latter. In Fig. 6, for subject 6, the 5-10 microvolt curve and the 10-20 curve ran to-

Fig. 4. Left: Responses cumulated by 1-min intervals in the various amplitude ranges, subject 1. Right: distribution of responses in the various amplitude ranges by 15-min intervals, subject 1.

gether until well into the conditioning period, when the higher rate in the 10-20 microvolt range became apparent.

The rapidly rising rate during conditioning and early extinction, followed by the abrupt decrease later in extinction, in each of the 20-30 microvolt range curves, resembles

hundreds of curves showing rates of responding during conditioning and extinction which have appeared in the literature. Obviously, conditioning occurred in the 20-30 microvolt range, and extinction followed it. Equally obvious is the fact that similar patterns of responding occurred in the two adjacent ranges

of lesser amplitude and in the two adjacent ranges of greater amplitude.

Two further items of interest appeared in these records. "Settling down" was seen in subjects 2, 4, and 6. That is, during the first

15 min, these subjects showed an abrupt decrease in response rate in all ranges recorded, with the new lower rate being maintained until the higher rates associated with conditioning appeared (see Fig. 5). Also, marked,

Fig. 5. Left: Responses cumulated by 1-min intervals in the various amplitude ranges, subject 2. Right: distribution of responses in the various amplitude ranges by 15-min intervals, subject 2.

Fig. 6. Left: Responses cumulated by 1-min intervals in the various amplitude ranges, subject 6. Right: distribution of responses in the various amplitude ranges by 15-min intervals, subject 6.

simultaneous bursts of responding across all ranges were seen twice in the record of subject 3 and once in that of subject 6 (see Fig. 5). In all three instances this burst of activity, which was greatest in the lowest amplitude range and successively decreased in progressively higher amplitude ranges, coincided with the subject's voluntary report of gross movement of the right hand.

The percentage of total responses in all five ranges which occurred in each of these ranges, summarized by 15-min intervals, for subject 1, is shown in histograms in the right-hand portion of Fig. 4. Similar constructions for subjects 2 and 6 are shown in Fig. 5 and 6 respectively. From Fig. 4 and 6, it can be seen that during the first two 15-min periods, before reinforcement began, the frequency of response distribution was heavily skewed toward the lower end of the microvolt range. During conditioning the relative frequency of the response shifted toward the reinforced range, the distribution of the total responses becoming more rectangular. During extinction the original shape of the frequency distribution reappeared, and the distribution during extinction without light was the same, for all intents and purposes, as that before conditioning. Subject 2 (Fig. 5) was the only one who failed to show this clearly discernible shift in frequency of response distribution during conditioning. Conditioning occurred, but the shift of the frequency of response distribution seen in all of the other subjects was not apparent.

Subjects 7 and 8 were reinforced for responses in the 10-20 microvolt range. The cumulative minute-by-minute response counts plotted for subject 8, shown in the left-hand side of Fig. 7, are representative of those obtained from both subjects. As with the subjects discussed above, a family of related curves was obtained. Shortly after the beginning of the conditioning period, the rate of responding increased abruptly in the reinforced range (10-20 microvolts), in the single recorded range of lesser amplitude (5-10 microvolts), and in the three ranges of greater amplitude (20-30, 30-40, and 40-50 microvolts). Both of the subjects conditioned in this range showed a slight decrease in rate of responding across all recorded ranges midway through conditioning. Both showed an abrupt decrease in responding in all ranges during ex-

tingtion. Subject 7 showed one such abrupt break, while subject 8 showed two, the second being the more pronounced.

The response rate in the 5-10 microvolt range, for subject 8, was higher than that in the 10-20 range before conditioning, but lower during conditioning and extinction. Subject 7 showed a higher rate of responding in the 5-10 microvolt range than that in the 10-20 range throughout the session. This subject was the only one to show a higher rate of responding at the 5-10 microvolt level than at the 10-20 microvolt level during conditioning.

For both subjects 7 and 8 the response pattern in the ranges of amplitude greater than the reinforced range was the same as that in the reinforced range. Rate of responding, and consequently total number of responses, was less in the 20-30 microvolt range than in the reinforced range, lower in the 30-40 microvolt range and lowest in the 40-50 range.

The histograms in the right-hand portion of Fig. 7 show a frequency distribution initially skewed toward the lower end of the microvolt range, which shifted toward the reinforced response during conditioning. During extinction, the original shape of the frequency distribution reappeared. This pattern was the same as that in the subjects previously discussed.

Subjects 9 and 10 were reinforced for responses in the 30-40 microvolt range. The cumulative minute-by-minute response counts plotted for subject 10, shown in the left-hand portion of Fig. 8, are representative of those obtained from both subjects. As with all subjects previously discussed, a family of related curves was obtained. In the conditioned range—30-40 microvolts—an abrupt increase in the rate of responding occurred early in conditioning. The same increase was seen in the three ranges of lesser amplitude than the reinforced range—5-10, 10-20, and 20-30 microvolts—and in the single range of greater amplitude, 40-50 microvolts. All five ranges showed an abrupt decrease in response rate during extinction. While the subject illustrated, subject 10, showed one such decrease, subject 9, also conditioned in this range, showed two such decreases during the extinction period.

Ranges of amplitude less than the reinforced range displayed lower response rates. The rate in the 20-30 microvolt range was less

Fig. 7. Left: Responses cumulated by 1-min intervals in the various amplitude ranges, subject 8. Right: distribution of responses in the various amplitude ranges by 15-min intervals, subject 8.

than that in the reinforced range but greater than that in the 10-20 microvolt range. The 5-10 microvolt range response rate was lower

than that for the 10-20 range throughout the session for subject 9. Subject 10, shown in Fig. 8, displayed a higher response rate in the

Fig. 8. Left: Responses cumulated by 1-min intervals in the various amplitude ranges, subject 10. Right: distribution of responses in the various amplitude ranges by 15-min intervals, subject 10.

5-10 microvolt range than in the 10-20 range before conditioning, but during conditioning the 10-20 microvolt rate was higher.

Both displayed the same pattern of responding in the 40-50 microvolt range as in the 30-40 range (reinforced range) but at a considerably lower rate.

The shift of the frequency of response distribution from the lower end of the response frequency toward the reinforced range during conditioning, seen in the subjects previously discussed, was more marked in these two subjects. This is shown in the histograms in the right-hand portion of Fig. 8. Again, during extinction, the frequency distribution shifted back toward the lower end of the distribution.

The five response ranges examined so far were selected on the basis of pilot work which indicated that responses normally occurred in these ranges, and so were available for study. This pilot work demonstrated that few responses of 50 microvolts or greater occurred in operant responding, although some were observed. Examination of the response rates in the 40-50 microvolt range revealed that although the number of responses of this magnitude emitted during operant responding was very small, it increased considerably during conditioning. Therefore, it became necessary to examine the 50 microvolt and above range for all 10 subjects to determine if this range also increased considerably and to determine exactly what had occurred in this range.

Examination of the cumulative record of each subject's responses of 50 microvolts or greater showed that subjects 1, 2, 5, 7, and 10 displayed few of this magnitude before con-

ditioning and that all subjects, except subjects 8 and 10, displayed almost none in this range during extinction without light. The pattern of those responses which did occur was similar to that for the same subject in the 40-50 microvolt range, but at a greatly reduced response rate.

The exact number of responses 50 microvolts or greater was determined for each subject and added to the total responses in all five of the ranges previously examined. This yielded the total number of responses in each phase of the session, divided into 15-min periods. The percentage of all responses 50 microvolts or greater was computed for each subject for each 15-min period. These values, shown in Table 1, were lower than the concurrent percentage of responses in all five examined ranges which had occurred in the 40-50 microvolt range, in all but one case. The one exception was subject 8 during extinction without light, where the percentage of responses 50 microvolts or greater was 0.87 per cent higher than those in the 40-50 microvolt range.

Subjects 11 and 12 were the two control subjects who watched the pointer being driven by the playback of reinforced responding in the 20-30 microvolt range recorded from subject 5. The record from subject 5 was selected because he displayed a very high response rate during conditioning and more pauses in responding than any other subject. It was felt that if either the starting or stopping of the pointer or its speed of movement could affect response rate, the effect would most likely be seen by using this tape to drive the pointer.

Table 1
Percentage of Responses 50 Microvolts and Above, Compared to Total Number of Responses, by 15-Min Intervals, Subjects 1 through 10

Subject	Percentage of Responses						
	Min 0-15	Min 16-30	Min 31-45	Min 46-60	Min 61-75	Min 76-90	Min 91-105
1	0.55	0.00	1.69	1.51	0.15	0.14	0.65
2	0.73	1.60	0.64	0.77	0.90	0.81	1.29
3	2.76	2.37	1.92	2.98	0.65	0.00	0.10
4	0.89	0.62	2.99	1.29	1.11	3.56	1.03
5	0.25	0.13	2.43	1.94	6.12	1.43	0.00
6	1.01	1.29	1.69	3.95	0.93	0.62	0.21
7	0.13	0.15	3.05	1.54	1.25	0.72	0.30
8	1.45	0.95	3.11	3.27	2.05	3.87	1.90
9	0.87	1.14	3.35	2.85	1.56	0.29	0.17
10	0.30	1.59	3.44	5.39	3.52	1.00	1.46

The minute-by-minute cumulative counts of responses in the 20-30 microvolt range for both control subjects, as well as for subject 5, are shown in Fig. 9. From this it can be seen that subjects 11 and 12 showed neither of the phenomena displayed by subject 5, *i.e.*, an abrupt increase in responding shortly after the onset of conditioning (end of the 30th min) and an equally abrupt decrease in response rate shortly after the onset of extinction (end of the 60th min), indicating conditioning and extinction.

However, the response rate for both subjects was so low that the details of responding were not visible from the curves. A detailed minute-by-minute examination of the response rate more clearly revealed the pattern of responding for subjects 11 and 12. In both, the

Fig. 9. Response rates (20-30 microvolt range) of subjects 11 and 12, who observed the counter pointer being driven by tape previously recorded from a conditioned subject (subject 5), compared to response rate (20-30 microvolt range) of the conditioned subject whose tape was used. For the conditioned subject the time divisions are as follows: 0-15 min, settling down; 16-30 min, operant level determination; 31-60 min, conditioning; 61-90 min, extinction with light present; 91-105 min, extinction without light present.

pointer movement did increase responding, doubling and even tripling the initial rate. However, this activation phenomenon was nothing like the rate increase seen in conditioning. Further, under these conditions extinction was not seen, but rather an abrupt return to approximately the original response rate as soon as the pointer movement ceased. While this activation phenomenon was not the same as conditioning, it must be assumed that it occurred in the 10 subjects previously discussed, in addition to the conditioning which so obviously occurred in all of them. The probability of its occurrence must be noted and should be taken into account when evaluating the records.

Neither of the control subjects reported feeling that they had had anything to do with controlling the movement of the pointer. Both stated that they initially attempted to control the pointer's movement, and believed they might be doing so. However, as the session progressed they became aware that the pointer stopped and started independently of any activity on their part. Contrarily, all but one of the conditioned subjects reported that they had attempted to control the pointer's movement, and that they had exercised some control over it although none was able to report correctly their controlling response.

DISCUSSION

The rate of individual muscle action potentials was shown to increase when responses were reinforced and to decrease when reinforcement was discontinued, indicating the possibility of operant conditioning of individual muscle action potentials. These results are consistent with those of Hefferline and Keenan (1963). The present results agree with the earlier finding that responses of amplitude greater than the reinforced range increased during conditioning. However, the present study found that responses of amplitude less than the reinforced range also increased during conditioning, whereas Hefferline and Keenan found that they decreased. The reason for this difference is not apparent, but may lie in the different type and amplitude of the signals studied, in the equipment utilized, or in the procedure.

In the present study, all subjects showed a higher response rate in the 10-20 microvolt

range than in the 20-30 range before conditioning, and 6 of 10 showed an even higher rate in the 5-10 microvolt range than in the 10-20 range. During conditioning, all but one showed the highest response rate in the 10-20 microvolt range. Subject 9 showed the highest response rate in the 5-10 microvolt range throughout the session.

One possible explanation of this pattern is that conditioning in any range sets up an induction (response generalization) gradient which interacts with the operant response gradient to produce the response pattern seen in conditioning. The high operant rate of the 10-20 microvolt range may have interacted with the response generalization gradient to produce a higher conditioning rate than that in the conditioned range—where the conditioning effect was greater but the operant rate less—or than that in the lowest amplitude range, where the operant rate was greater but the response generalization effect less.

Another possible explanation is that the motor units which produce the lower amplitude responses are more populous than those which produce the higher amplitude responses. If this were so, it would mean that more of these low amplitude response producing units were available for recruitment, and the response distribution in conditioning merely might represent the population distribution of the various motor units.

The rapidity of extinction is of interest. Shortly after the contingency between the subject's responses and the pointer movement was removed, response rate in all ranges fell abruptly. After 15 min of extinction with the dial light still present, most subjects were emitting response rates almost comparable to the operant level rates. After 30 min of extinction with the dial light present, the response rates of all subjects were so similar to those seen in operant level that the curves could be overlaid with little visible discrepancy. The response rates recorded during the final 15 min of extinction, after the dial light had been extinguished and the operant level determination conditions reinstated, were almost identical with those in the second 15 min of extinction with the light present, and those in operant level. Again, in almost all cases, all three sets of cumulative curves could be overlaid with little visible discrepancy.

The reinforcement was secondary in nature.

The instructions to the subject stated that, "(when) the dial face is lit, the purpose is to see how rapidly the pointer can move." This implied, but did not explicitly say, that the subject might be able to control the speed at which the pointer moved. The result of the subjects' interpretations of these instructions was that all but one deliberately attempted to exert such control.

In view of this effect of the instructions, the question could be raised as to whether or not the observed effect might be due to the effect of the instructions alone. If this had been so, the effect should have taken place immediately upon illumination of the dial face, rather than displaying the development that it did. Further, since the instructions were not changed in extinction, nor the dial light initially extinguished, if the instructions alone had been the causative agent the subjects should have continued to make the same responses throughout this period, rather than exhibit the gradually declining response rate they all did.

The activation effect seen in subjects 11 and 12 is of considerable interest. To evaluate more precisely any activation effect which might have occurred during conditioning, it would be of interest to condition these muscle responses under the specific control of a DRL schedule and to examine whether the results would differ, in either the reinforced or adjacent ranges, from the present results.

Goldberg (1959), studying the magnitude of bar pressing, reported that "the number of extinction responses in each subclass should be functionally related to the acquisition strength of that subclass." The results of the present study agree with this finding. The number of responses in extinction were greater in those ranges having more responses in conditioning than in those having fewer during conditioning. Taken in conjunction with the present finding that gross movement showed the greatest burst of responses in the lowest amplitude range and decreased in progressively larger amplitude ranges, this would seem to imply that the small muscle responses examined here, and the gross movements of skeletal muscles involved in such activities as bar pressing, are qualitatively similar though quantitatively different.

Should this be so, small amplitude responses which behave in the same manner as

other more thoroughly-studied operant responses, and which may be conditioned using secondary reinforcement without the subject's awareness of the nature of the reinforced response, might enable a study of operant conditioning in human subjects which would be relatively uncontaminated by the so-called "higher level" mental processes. The present study merely suggests this possibility. Much basic work remains to be done, as in the areas of duration, negative reinforcement, and discrimination.

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