*BRAIN-STIMULATION INTENSITY, RATE OF SELF-STIMULATION, AND REINFORCEMENT STRENGTH:
AN ANALYSIS THROUGH CHAINING¹*

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Reinforcement strengths of different intensities of brain stimulation were assessed by means of a two-member behavioral chain. A variable interval schedule of 30 sec was the first-member, and five lever presses, each rewarded with stimulation, was the second. It was found that response rate on the VI schedule continued to increase beyond the intensity value which produced peak rate on the second-member, self-stimulation lever. It was concluded (1) that brain-stimulation reinforcement strength cannot be assessed adequately by means of self-stimulation rate, and (2) the chaining technique employed in the present experiment appears promising as an analytical tool in brain-stimulation research. Finally, some aspects of the data suggested a fatigue or stimulation-adaptation phenomenon.

It has been assumed that changes in the intensity of rewarding electrical stimulation of the brain alters behavioral reinforcement strength (Sidman, Brady, Boren, Conrad, and Schulman 1955). One of the earliest tests was to observe changes in self-stimulation rate on a continuously available response lever as a function of stimulation intensity. (Throughout this report, "self-stimulation rate" refers to the procedure of determining response rate when each lever press is followed by electrical stimulation with the animal pacing its own responses.) In extensive studies of the problem (e.g., Reynolds, 1958), it has been found that self-stimulation rate increases with increases in intensity up to a point. Beyond a point for each animal, self-stimulation rate declines with further increases in intensity. The question remains as to whether the decline in self-stimulation rate at higher intensities reflects a decrease in reinforcement strength and/or the development of aversive properties. Possibly the decrease in self-stimulation rate at high intensities reflects neither of those events, but rather a slowing of the rate due to some other effect of stimulation, such as seizures or respondent interference with ongoing operants. Valenstein (1964) has discussed the problem in some detail.

It is apparent that other techniques for assessing reinforcement strength are necessary to attack the problem. Hodos and Valenstein (1962) employed a preference test and concluded that self-stimulation rate does not adequately reflect reinforcement strength. Another technique, the one employed here, involves the use of a two-member behavioral chain (Ferster and Skinner, 1957). A two-member behavioral chain, with self-stimulation in the second member, permits a comparison between self-stimulation rate and the characteristics of first-member performance. The first member of the behavioral chain employed in the present paper was a variable interval of 30 sec, and changes in VI response rate were compared with changes in self-stimulation rate as the intensity of brain stimulation was varied.

METHOD

Three male albino rats with chronically implanted, stainless steel electrodes aimed at the vicinity of the mammillary bodies of the posterior hypothalamus were adapted to the experimental situation and given preliminary training in a two-lever rat box. The final baseline chain performance was as follows. The left-hand lever was continuously available while the right-hand lever was retracted out of the box. Responding on the left-hand lever resulted in the insertion of the retracted lever on a variable interval schedule of 30 sec. The rat was permitted five presses on the

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right-hand lever, each rewarded with a 225 msec train of biphasic, square-wave brain stimulation, and the lever was then withdrawn from the box. Responding on the left-hand lever again produced the stimulation lever after another interval of the irregular series averaging 30 sec. Note that responding on the left-hand VI lever never produced electrical stimulation of the brain. Its sole consequence was access to the right-hand lever on which traditional self-stimulation responding occurred as the second member of the chain. The experimental variable manipulated was intensity of stimulation on the right-hand lever. The data collected were response rates on both the left-hand VI lever and on the right-hand, self-stimulation lever. The latter rate was computed from the occurrence of the first of the five responses in order to correct for both lever insertion time and the animals' approach times.

Each of the three rats was run at several intensities of brain stimulation in both an ascending and descending series. For each rat, the ascending series was run on one day and

the descending series three days later. VI rates were permitted to stabilize for 45 min at each intensity, and stabilization was followed by 45 min of data collection. A 20-min home-cage rest was permitted following each intensity determination.

At the end of the experiment, the three rats were sacrificed and perfused with saline and a 10% formalin solution. The brains were removed and frozen sections 50μ thick were prepared and stained with chresyl violet.² Figure 1 contains photomicrographs of brain sections from the three rats. The placements for 21LS and 24LS were at approximately the same anterior-posterior level. The electrode tip for 21LS rested alongside the mammillary bodies of the posterior hypothalamus. For 24LS, the electrode tip was slightly more lateral and dorsal, resting in the region of the medial lemniscus and the nucleus of the transverse peduncular tract. The placement in 108LS was further posterior and was resting

*Histological preparations were by Mrs. Joan Cohen. Our thanks.

Fig. 1. Micrographs of brain sections showing the electrode placements in the three rats. 21LS: just lateral to the mammillary bodies of the posterior hypothalamus; 24LS: in the region of the medial lemniscus; 108LS: just dorsal to the ventral tegmental nucleus. Abbreviations used are: H—Habenulo-Interpeduncular tract, CP—Cerebral peduncle, SN—Substantia nigra, ML—Medial lemniscus, MP—Mammillary peduncle, MB—Mammillary bodies, V—Ventral tegmental nucleus, RN—Red nucleus.

in the red nucleus, just dorsal to the ventral tegmental nucleus.

RESULTS AND DISCUSSION

Figure 2 shows the results of the experiment for the three rats. The upper panel shows self-stimulation rate on the right-hand lever in responses per second as a function of intensity (100's of μ A). The lower panel of Fig. 2 shows the corresponding first-member VI rate in responses per second. Thus, changes in second-member, self-stimulation rate can be compared for each rat with changes in first-member VI rate as a function of the changes in stimulation intensities. The solid, filled-circle curve is for the ascending series and the dashed, X-curve is for the descending series. Rat #21LS shows a peak in the self-stimulation curve for both the ascending and descending series, the former peaking at 300 μ A intensity and the latter peaking at 500 μ A intensity. Note, however, that in both cases where the self-stimulation rate is decreasing due to

higher stimulation intensities, the first-member VI rate continues to rise. This indicates increasing reinforcement strength of the second chain member in spite of decreasing self-stimulation rate in that member. Particularly instructive is a comparison of the rates at the highest intensity. While the VI rates remain high, the self-stimulation rates are well below their maximum. The same conclusion can be reached in the case of Rat #108LS, although for this rat the ascending and descending series produced different self-stimulation rate functions. The former peaked at 300 μ A and the latter at 100 μ A. Again, however, first-member VI rates were considerably higher at the higher intensities of stimulation where the self-stimulation curves were below their peaks. The same is true for Rat #24LS in the case of its ascending series. Rat #24LS's descending series showed little change in self-stimulation rate over the range from 300 to 600 μ A. Note, however, in conformity with the general conclusion, *viz.*, that self-stimulation rate can be a poor if not misleading indicator of reinforcement strength, vast changes in VI rate were observed over the range from 300 to 600 μ A.

The reinforcing strength of a stimulus can be defined in several ways. Chaining procedures, as suggested by Kelleher and Gollub (1962), offer a relatively sensitive, meaningful and versatile method of assessing reinforcement strength, inasmuch as changes in the reinforcement strength of a given member of a chain can produce easily detectable changes in behavior during earlier members. The use of the chaining procedure described above indicates clearly that rewarding electrical stimulation of the brain increases in reinforcement strength in the range of intensities which produce lowered self-stimulation rates. The lowering of the self-stimulation rate at higher intensities, judged by itself under the assumption (erroneous) that it is a valid index of reinforcement strength across intensities, might result in the conclusion of decreased strength or an increase in the aversive properties in the range of intensities beyond the peak of the self-stimulation rate-intensity function. The present results, produced by a completely different procedure, are entirely in agreement with those of Hodos and Valenstein (1962).

Another aspect of the present data deserves mention. Examination of the three sets of VI rate curves reveals a consistent relationship

Fig. 2. Two-member chain performance for three rats. The lower panel shows the first-member, variable interval 30-sec response rate in Resp/Sec. The upper panel shows response rate on the self-stimulation lever in Resp/Sec. The abscissa is in hundreds of μ A stimulation current, delivered for each of the five presses permitted on the self-stimulation lever per chain run-through.

between the ascending and descending intensity series. The VI response rate is higher at the higher intensities in the descending series and higher at the lower intensities in the ascending series. The only exceptions to that relationship are for 24LS, where at the lowest intensity, 100 μ A, the VI rates are zero and at the highest intensity, 600 μ A, where the two rates are virtually identical. Between the extremes, the curves for 24LS are almost identical to those of 21LS.

The relationship between the ascending and descending curves might reflect either of, or a combination of, two factors. Since the VI rate determined at a particular extreme of the stimulation-intensity variable is lower when that determination was made later, rather than earlier, in a day's series of determinations, it is possible that the differences between the ascending and descending series were produced by a fatigue-like factor. On the other hand, the same differences between the ascending and descending series could represent an adaptation-to-stimulation effect. The higher intensities may have been less reinforcing because they were preceded by the lower intensities of stimulation (ascending series), and the lower intensities may have been less reinforcing because they were preceded by the higher intensities of stimulation (descending series). The first interpretation stresses the effects of previous responding, while the second stresses the effects of previous stimulation-reward. In either case, it would have to be assumed that the 20-min home-case rest (see above) between successive rate determinations was not sufficient to eliminate the effects of earlier determinations in the series.

The generality of these findings is a question of some interest. Reynolds' (1958) data were obtained with electrode placements in the ventromedial region of the anterior hypothalamus. It is impossible to state how his rats would have behaved in the first-member of a chain had such a procedure been attempted; it is instructive to note, however, that his self-stimulation functions were much the same as ours. Our placements were in the region of the mammillary bodies of the posterior hypothalamus and even further posterior at the ventral tegmental nucleus. Hodos and Valenstein (1962) reached the same conclusion with regard to self-stimulation rate as an index of reinforcement strength; they employed elec-

trode placements in the septum and posterior hypothalamus. The differences in electrode placements in the studies cited, plus the present study, together with the complementary nature of the results of the three studies, suggest that the relationship obtained here between response rates in the two chain members can be demonstrated over a wide range of rewarding electrode placements.

Aside from the generality of the data is the generality of the chaining technique itself. We have applied the chaining procedure in several studies on rewarding electrical stimulation of the brain. The procedure is useful over a broad range of variables, and the first member, VI rate has been found to be quite sensitive to changes in the values of experimental variables. As an analytical tool in the study of rewarding electrical stimulation of the brain, the chaining procedure nicely isolates the index of reinforcement strength from the side effects of stimulation. In addition, it makes contact with the techniques frequently employed in the experimental analysis of behavior employing more conventional reinforcers. In contrast, continuous reinforcement, which has been the dominant tool in brain-stimulation research, is rarely employed in the analysis of conventionally maintained behavior. Finally, the chaining procedure has been useful in generating intermittent schedule performances (maintained by brain-stimulation reward) at the values of schedule parameters often used with food reward.

REFERENCES

- Ferster, C. B. and Skinner, B. F. *Schedules of Reinforcement*. Appleton-Century-Crofts: New York, 1957.
- Hodos, W. and Valenstein, E. An evaluation of response rate as a measure of rewarding intracranial stimulation. *J. comp. physiol. Psychol.*, 1962, **55**, 80-84.
- Kelleher, R. T. and Gollub, L. R. A review of positive conditioned reinforcement. *J. exp. Anal. Behav.*, 1962, Supplement to Vol 5, 543-597.
- Reynolds, R. W. The relationship between stimulation voltage and rate of hypothalamic self-stimulation in the rat. *J. comp. physiol. Psychol.*, 1958, **51**, 193-198.
- Sidman, M., Brady, J. V., Boren, J. J., Conrad, D. G., and Schulman, A. Reward schedules and behavior maintained by intracranial self-stimulation. *Science*, 1955, **122**, 830-831.
- Valenstein, E. S. Problems of measurement and interpretation with reinforcing brain stimulation. *Psychol. Rev.*, In press.

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