Effects of Feedback and Reinforcement on the Control of Human Systolic Blood Pressure

Abstract. *An automatic procedure providing information about human systolic blood pressure at each successive heartbeat under routine laboratory conditions is described. Twenty normal male subjects were given feedback of their own systolic pressure, half operantly reinforced for increasing and half reinforced for decreasing their pressure. Significant differences in pressure were obtained in a single session. The apparatus and results suggest a possible approach to the treatment of essential hypertension.*

Learning theorists have assumed that autonomic responses cannot act on the external environment and are therefore incapable of being modified by their consequences, such as reward or punishment (*1*). Now, many studies offer positive evidence that the autonomic nervous system can be conditioned instrumentally (*2, 3*). The work of Miller and associates on rats treated with curare shows that the effects of the conditioning do not depend on mediating changes in skeletal behavior but are specific to the responses that are reinforced (*4*).

One promising area of potential application of operant conditioning is in the treatment of disorders mediated autonomically (*5*). Essential hypertension, elevated blood pressure without a demonstrable cause, is a disorder in which the autonomic nervous system may play an important role.

The purpose of this research is to develop a method for the treatment of patients with essential hypertension. This requires instrumentation which can provide an individual with continuous external feedback of his own systolic pressure. Arterial cannulation, the most accurate means of recording blood pressure, is not satisfactory for repetitive laboratory experimentation. Cuff-type intermittent recording procedures are inadequate because they offer insufficient opportunity for feedback and reinforcement.

We developed automatic instrumentation that yields a continuous approximation of a subject's systolic pressure on each successive heartbeat. The essential elements of the recording and reinforcement procedure are shown in Fig. 1. A conventional blood-pressure cuff is wrapped around the upper arm and pumped up to a given pressure by means of a regulated, low-pressure, compressed-air source. The pressure can be held constant or changed in 2-mm steps. The pressure applied to the cuff is measured by a Statham (P23AC) transducer and recorded on one channel of an Offner type R polygraph.

A crystal microphone to detect the Korotkoff sounds (*6*) is mounted in the cuff over the brachial artery, and the output of this microphone is fed into an audio system and displayed as a pulse on a second polygraph channel. When the pressure in the artery is high enough to overcome the occlusive pressure of the cuff, the Korotkoff sound is produced. By setting the cuff at a constant pressure close to the measured systolic pressure of a subject, this system gives information of upward and downward changes in systolic pressure at each successive heartbeat. When Korotkoff sounds occur, the systolic pressure is at or above the cuff pressure; when the sounds disappear, the systolic pressure is below the cuff pressure.

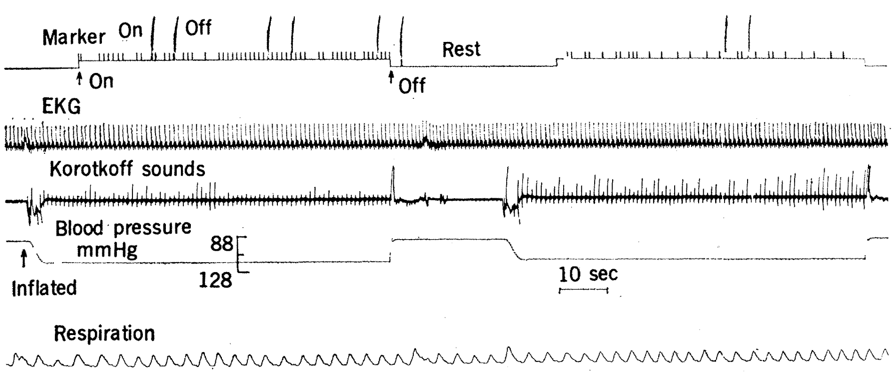

Fig. 1. Segment of polygraph record of a subject in the *down* group, reinforced for lowering his pressure. Two trials are shown. Marker channel indicates onset of blue light (first arrow), feedback (small marks), and slide presentations (large spikes). Rest period begins when blue light is turned off. For this subject in the *down* condition, feedback was administered when Korotkoff sounds were below critical amplitude. Blood-pressure channel shows cuff inflation and deflation. Applied pressure was 116 mm on first trial shown. During this trial there were 76 percent successes. On second trial shown, applied pressure was changed to 114, making task more difficult. Note reduction in success rate to 37 percent on this trial.

The electrocardiogram is recorded on a third channel of the polygraph, and the R-wave in each successive heart-cycle pattern is detected by an electronic switch. The Korotkoff sounds are also detected automatically by a second switch. Inasmuch as the interval between the R-wave and the Korotkoff sound is approximately 300 msec, the joint occurrence of a heartbeat and the presence, or absence, of the Korotkoff sound in the prescribed time can be automatically determined with appropriate logic modules. Respiration was recorded on a fourth channel by means of a strain gauge belt fastened around the waist.

The operant conditioning of systolic blood pressure was studied in 20 normal male college students between 21 to 27 years of age. The subjects were seated in a semireclining position in a sound- and light-controlled room and were told that (i) the experiment was concerned with the ability of individuals to control certain physiological responses, and (ii) people could often achieve such control when given information about their own responses. Subjects were asked not to move about or tense their muscles during the session and to keep their breathing as regular as possible. Any subject with initial blood pressures above 135 mm systolic or 85 mm diastolic was eliminated from the study.

Subjects were given 25 trials. Each trial period was 65 seconds long, preceded by 11 seconds during which time the cuff was inflated. The beginning of a trial period was signaled to the subject by a blue light. After each trial, the cuff was deflated and there was a rest period of from 20 to 25 seconds (Fig. 1).

Two experimental conditions were studied to control for possible unconditioned effects of the reinforcer. In the *up* condition, ten subjects were reinforced for raising their systolic blood pressure. In the *down* condition, ten subjects were reinforced for lowering their pressure. During each trial, a success was defined by the presence of a Korotkoff sound for *up* subjects, and the absence of this sound for *down* subjects, after each heart beat. This information was fed back to the subject by the programming apparatus, which produced a 100-msec flash of red light and a simultaneous 100-msec tone of moderate intensity for each success (*7*). The reinforcer was a slide of a nude from *Playboy* magazine projected on a screen in front of the subject for 5 seconds after every 20 flashes of light (*8*) (Fig. 1). Each slide was different. Subjects were instructed that the slides offered an incentive for them to try to make the light flash and the tone beep as often as possible.

Five preliminary blank trials were used to obtain a cuff pressure which resulted in Korotkoff sounds on 50 percent of the heartbeats. Thus, all subjects started with exactly the same probability (50 percent) of being above or below this initial cuff pressure and the same probability of receiving feedback and reinforcement. Pairs of subjects were matched on this starting blood-pressure level and assigned at random to each experimental condition.

During each trial, the applied pressure was maintained constant. If more than 75 percent of the heartbeat-Korotkoff sound contingencies were successful on two successive trials, the pressure applied to the cuff was increased by 2 mm for *up* subjects and decreased by 2 mm for *down* subjects on the next trial. This change made the task correspondingly more difficult in each condition (Fig. 1). In the case of success on fewer than 25 percent of the heartbeats, the task was made easier by 2 mm. No change was made if a trial showed 25 to 75 percent successes. These shaping criteria were chosen empirically, and enabled the tracking of the subject's pressure to be rapid and accurate. The purpose of the procedure was to try to maximize the differences between experimental groups and also take into account the possible changes in blood pressure unrelated to the experimental treatment, such as habituation or adaptation to the situation.

The data are cuff pressures on each trial, indicating approximate systolic pressure. The average curves for each condition, grouped for simplicity in blocks of five trials, are shown in Fig. 2. An analysis of variance (*9*) (two experimental treatments, 25 repeated trials) shows that the main effect for

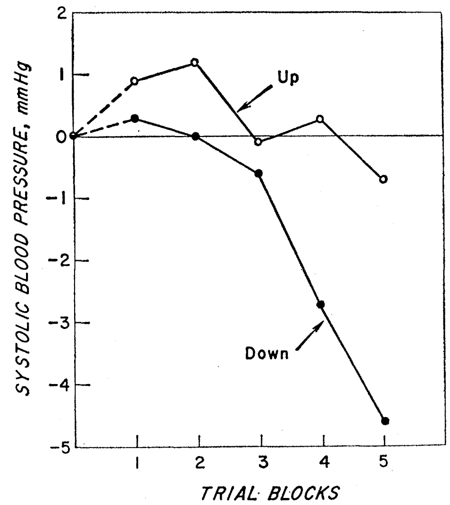

Fig. 2. Average approximate systolic pressures in groups reinforced for increasing (*up*) and decreasing (*down*) blood pressure. Each point is the mean of ten subjects, five trials each. The means were adjusted for slight differences in starting pressure between the two groups (*up*, 120.9 mm; *down*, 120.1 mm) which were set to zero.

conditions is not significant. The main effect for trials and the interaction between trials and treatments are significant beyond the .01 probability level. On the first two trial blocks, in eight of the ten matched pairs, *down* subjects showed a larger decrease in pressure than *up* subjects (see Fig. 2). The greatest differentiation between the two groups appeared during the last two trial blocks. From the third to the fifth trial block, *up* subjects show a decrease of 0.6 mm compared to 4.0 mm for *down* subjects. A *t*-test (matched pairs) of the average difference between these changes is significant beyond $P < .01$. Thus, the *up* group tended to maintain their base line pressure or decrease slightly during the session. The decrease was significantly and consistently more marked in the group reinforced for lowering their pressures. The pattern of these results has much in common with instrumental effects obtained for other autonomic responses. Subjects reinforced for increasing response rate of a particular autonomic function show an initial increase and then either maintain their initial base line levels or show a slight decline. Subjects reinforced when not responding show a considerable lowering of activity (*10*).

The number of heartbeats was counted automatically during each trial period to provide information on changes in a related cardiovascular function. Both *up* and *down* groups showed a decline in heart rate over time. According to the analysis of variance, this trial effect is highly significant ($P < .005$). The main effect for treatments and the interaction between trials and treatments are not significant, indicating no systematic relationship between heart rate and the conditioned blood-pressure changes. Breathing patterns were indistinguishable in the two experimental conditions, and irregularities in breathing appeared with equal frequency in both.

On the basis of these indices of related functions, no particular causal or mediating effect of one system on another accounts for the differentiation of blood pressure observed. Verbal reports elicited from subjects after the session were inconsistent. A few *down* subjects stated that the flashing light probably meant a state of relaxation. Most subjects in both conditions seemed to infer that the experimenter wanted them to get excited. With one or two exceptions, subjects said that they had no control over the physiological response (the flashing light) and no knowledge of what specific bodily function we were trying to condition.

The results of this study indicate that systolic blood pressure can be modified by the use of external feedback and operant reinforcement. The apparatus and techniques described here should prove of value in research on modification of blood pressure in hypertensive patients. The methods also merit consideration in other areas of psychophysiological investigation in which continuous evaluations of systolic blood pressure are desired.

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4. N. E. Miller, *Proc. N.Y. Acad. Sci.*, in press. L. V. DiCara has reported successful instrumental conditioning of blood pressure in curarized rats, with the use of escape from and avoidance of electric shock as a reward (L. V. DiCara, paper presented at a meeting of the Eastern Psychological Association, Washington, D.C., April 1968).
5. Only one such application has been reported. B. T. Engel achieved marked improvement in patients with atrial fibrillation by providing them external feedback of their cardiac activity and reinforcing slower heart rate (B. T. Engel, paper presented at Pavlovian Society, Princeton, N.J., November 1967).

6. Cuff-type methods depend on the detection of the turbulent flow of blood through the artery under the cuff which is produced when the cuff pressure is slightly lower than the arterial pressure. This turbulence produces an audible sound, the Korotkoff sound.
7. Exteroceptive feedback was used to facilitate the development of control of blood pressure. Augmented sensory feedback has been used extensively in studies of the control of heart rate. See (3).
8. These slides have been shown to be an effective operant reinforcer of the galvanic skin response. See G. E. Schwartz and H. J. Johnson, *J. Exp. Psychol.*, in press.
9. This was treated as a two-factor experiment with two levels of one factor (*up*, *down*) and repeated measures on the second factor (25 trials). For experimental treatments, d.f. = 1/432; for trials and the trial × treatment interaction, d.f. = 24/432. See B. J. Winer, *Statistical Principles in Experimental Design* (McGraw-Hill, New York, 1962), p. 302.
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11. Supported by K3-MH-20,476-06, MH-08853-05, and MH-04172-08 (NIMH); also by contract Nonr-1866(43), group psychology branch. We thank Mrs. M. Chartres for her assistance.

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Learning in Fish with Transplanted Brain Tissue

Abstract. *Material taken from fish embryos during gastrulation was implanted at prospective tectal sites in host embryos of the same age and species. When mature, the hosts were trained in a series of habit reversals. Two of six animals showed progressive improvement in reversal (a phenomenon not typically found in fish, but characteristic of higher animals), two showed unusually few errors, and two behaved normally. Differences in performance were correlated with differences in brain structure.*

One way to study the role of the brain in learning is to study the learning of animals with less than the normal amount of brain tissue. The function of the missing tissue is inferred from differences in the learning of normal animals and animals whose brains are altered by ablation. The ablation method has been used to analyze differences in the learning of vertebrates of different classes (*1*). For example, adult rats, extensively decorticated at an early age, show fishlike behavior with respect to habit reversal. Now it is possible to reverse the logic of the ablation experiment—to study the learning of animals with more than the normal amount of brain tissue. The first results of such a "supplementation" experiment suggest that transplantation of brain tissue may facilitate learning in simple vertebrates and even endow them with capabilities normally present only in more complex forms.

Although transplantation has not yet been accomplished in adult animals, Oppenheimer in work with *Fundulus* has shown that brain tissue can be supplemented by grafting during early stages of development (*2*). In some cases, the grafting procedure produced suppression or rearrangement of primary brain structures; in others, there was duplication of structure. Oppenheimer described certain aspects of the behavior of her altered embryos, but killed them for histological study soon after they hatched (*3*). We report here some observations on the learning of supplemented animals which we reared to maturity.

Our work was done with *Tilapia macrocephala* (the African mouthbreeder), a species of fish more easily bred in the laboratory than *Fundulus* and about whose learning more is known (*4*). The surgical technique was a modification of the one developed by Oppenheimer. Embryos at stages 10 through 12 (*5*) were removed from the mouth of an adult male and rinsed repeatedly in sterile aquarium water to reduce bacteria. The specimens were placed in a dish of sterile water, and the operation was performed aseptically under high-power magnification of a dissecting microscope. Watchmaker's forceps sharpened to needlepoints were used to dechorionate host and donor embryos. Material from posterior regions of the donor embryo was removed with steel needles sharpened to knife-edges and implanted in the prospective tectal tissue of the host. Healing was so rapid that no mechanical device was necessary to keep the implant in place. The host then was transferred to a large covered petri dish containing a 1 percent solution of sulfadiazene in sterile aquarium water. After absorption of their yolk, the fry were fed, first Micrograin, and later trout chow. As they grew in size, the animals were transferred to progressively larger containers.

Although survival rates increased as the surgical technique was perfected, postoperative mortality was at best rather high. Many embryos starved because the grafting interfered with the normal development of mouthparts. In others, the grafts differentiated into nonnervous tissue (notochord, eye, or ear) which may have suppressed the development of brain structures necessary for survival. Tectal abnormalities may also have resulted in respiratory failure (*6*). We reared only ten experimental subjects to sexual maturity. Of the ten, two died from unknown causes while they were being trained to strike a target and take worms from an automatic feeder, and two failed to adjust satis-

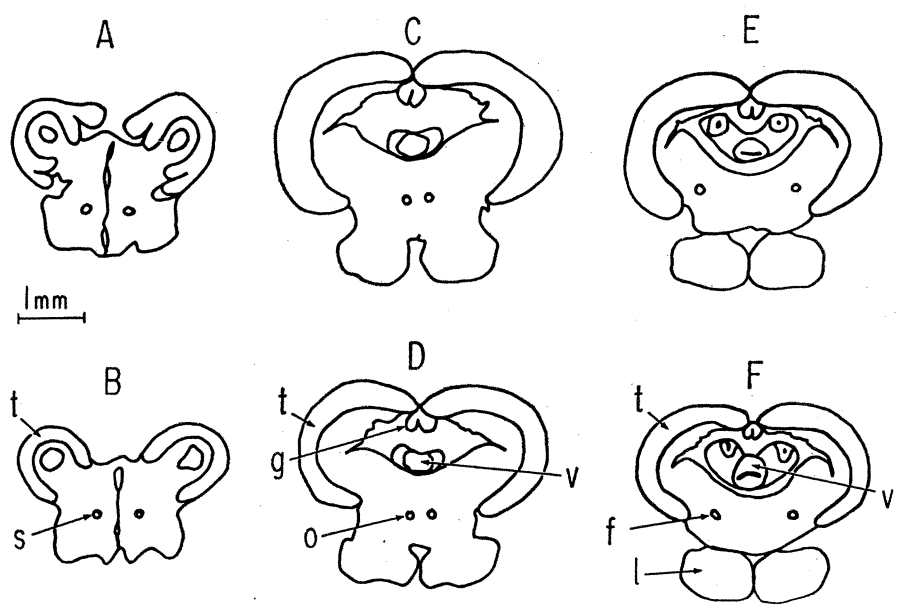

Fig. 1. Coronal sections through the mesencephalon showing (A) a supplementary tectal structure in animal No. 10; (C) tectal thickening in animal No. 4; (E) tectal thickening in animal No. 8; and (B, D, F) the normal brain of animal No. 1 at corresponding levels; (*t*) tectum opticum; (*s*) tractus striothalamicus and hypothalamicus; (*g*) torus longitudinus; (*o*) tractus octavothalamicus; (*v*) valvula cerebelli; (*f*) fasciculus longitudinus lateralis; and (*l*) inferior lobes.