THE ROLE OF FEEDBACK IN VOLUNTARY CONTROL OF BLOOD PRESSURE IN INSTRUCTED SUBJECTS¹

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Forty normal male volunteers were randomly assigned to one of four experimental conditions and instructed to raise and lower their systolic blood pressure. Subjects received either beat-to-beat feedback contingent on pressure changes, noncontingent beat-to-beat feedback, noncontingent feedback presented randomly with respect to the occurrence of each heart beat, or instructions alone. The order of increase and decrease trial blocks was counterbalanced across groups. Subjects receiving contingent feedback were monetarily rewarded for appropriate pressure changes. Subjects receiving noncontingent feedback received rewards and feedback equal to the mean received by the contingent group. Subjects in the instructions-only condition were also paid this bonus but were informed of their earnings only at the conclusion of the experiment. Results indicated that in the presence of instructions, feedback, whether contingent or noncontingent, added little to subjects' ability to control pressure during a single session. Theoretical and clinical implications are discussed.

DESCRIPTORS: systolic blood pressure, biofeedback, visceral learning, behavioral control, instructions, reinforcement, monetary reinforcers, adult males

It is well established that human subjects can learn to control either systolic or diastolic blood pressure through the use of feedback and reward for variations in pressure with each beat of the heart (Shapiro, Tursky, Gershon, and Stern, 1969; Shapiro, Tursky, and Schwartz, 1970; Shapiro, Schwartz, and Tursky, 1972). In these experiments, blood pressure is tracked and feedback provided by inflating a cuff to a constant pressure, set to either the systolic or diastolic level for a brief trial interval, and providing a feedback signal at either the presence or absence of Korotkoff (K) sounds recorded from the brachial artery distal to the cuff. This procedure, known as the constant-cuff method (Tursky, Shapiro, and Schwartz, 1972), tracks and

shapes systolic blood pressure by raising the cuff pressure between trials (cuff inflations) if K sounds appear on 75% or more of the heart beats, or lowering the cuff pressure if K sounds appear on 25% or less of the heart beats in a given trial. The reverse relationship between pressure and K sounds is used to track diastolic pressure.

Experiments with this method have normally shown that when subjects are not informed of the specific response or direction of change required of them, noncontingent or random feedback is inferior to contingent feedback in producing blood-pressure changes. This is not surprising, because uninstructed subjects given noncontingent feedback have no information about what they are being asked to do. Characteristically, these subjects show a tendency for blood pressure to decrease over a session (Shapiro *et al.*, 1970).

In most clinical applications of blood pressure feedback, however, patients are, often unavoidably, informed of the response to be controlled and the direction of the desired change

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(*e.g.*, Benson, Shapiro, Tursky, and Schwartz, 1971; Goldman, Kleinman, Snow, Bidus, and Korol, 1975; Kristt and Engel, 1975). In these studies, large blood-pressure reductions have been reported over numerous sessions. However, none of these investigations employed a control condition to assess the contribution of contingent feedback in the presence of instructions. Steptoe and Johnson (1976) compared instruction with instruction plus feedback using a pulse-wave velocity index of blood pressure, obtaining equivocal results on the importance of feedback. Although there is a controversy as to the extent of voluntary blood-pressure regulation without feedback (see Shapiro, Mainardi, and Surwit, 1977) several reports indicate that pressure can be controlled with instructions alone (Ogden and Schock, 1939; Shapiro, 1973). If some, even limited, control is possible with instruction alone, then it is not at all clear that contingent beat-to-beat feedback is necessary when instructions are given.

Shapiro *et al.* (1970) postulated that the appropriate unit of behavior in blood-pressure regulation is the phasic variation of pressure at each beat of the heart; hence beat-to-beat feedback. This appears to be the case in uninstructed subjects (Shapiro *et al.*, 1969, 1970). However, because the constant-cuff method tracks blood pressure so that subjects receive feedback 25 to 75% of the time on most trials, there could be a substantial partial reinforcement schedule operating for whatever cognitive strategy instructed subjects are employing. Other feedback paradigms have successfully employed reinforcement for tonic changes in pressure (*e.g.*, Blanchard, Young, Haynes, and Kallman, 1974; Miller, 1975). If instructed subjects are employing some sort of tonic process (*e.g.*, cognitive strategy) as opposed to making phasic beat-to-beat changes, then beat-to-beat feedback may serve, at best, as partial reinforcement for this tonic process.

The fact that contingent beat-to-beat feedback enables uninstructed subjects to control blood pressure does not, therefore, imply that a beat-to-beat contingency is necessary when

instructions are employed. The present investigation was designed to test this question. Specifically, it was hypothesized that if contingent feedback were operating partially to reinforce the tonic effects of instruction, both contingent and noncontingent beat-to-beat feedback should be equally effective in controlling blood pressure when subjects are instructed as to the response to be performed. Additionally, it was hypothesized that both contingent and noncontingent feedback would be superior to instruction alone in producing blood-pressure changes because of their reinforcement value.

METHOD

Subjects

Forty college-age males (age 18 to 27 yr) were paid \$2.50 for one training session. They were informed that they would be able to earn a bonus based on performance. The 40 subjects were randomly assigned to one of four groups: a contingent feedback group, two noncontingent feedback control groups, and a no-feedback control group.

Apparatus

Subject was seated in a reclining chair in a sound-attenuated, temperature-controlled, 5.7 by 1.8 m, carpeted and panelled chamber. A standard blood-pressure cuff, crystal microphone, EKG electrodes, and a Korotkoff microphone were used to relay psychophysiological signals to the experimenter's room next door. Connecting the two chambers were a feedback display, an intercom, a television camera, and monitor. Cuff pressure and EKG were processed by a Lexington Instruments blood-pressure device. Trial and feedback signals were delivered and counted by Grason-Stadler Logic.

Procedure

Each subject was trained in one session. An experimental session consisted of 20 trials, each 50 heartbeats in duration, with intertrial intervals of approximately 30 sec. The 20 trials were

divided into two, 10-trial blocks. Subjects were counterbalanced for the order of increase and decrease training blocks. Subjects receiving contingent feedback were tested first. The constant-cuff method of blood-pressure determination and beat-to-beat feedback was used (Tursky *et al.*, 1972). Before the first trial of the first block, the Korotkoff microphone was calibrated to the remote electronic stethoscope and three blood-pressure readings were taken remotely. The mean of the three systolic pressures was considered the baseline for that trial block and used to set the cuff pressure for the first trial. During each trial, subjects received feedback for each beat of the heart on which a K sound was present (for increase trials) or absent (for decrease trials). Feedback consisted of a flash of a triangular light, a tone (high for increase, low for decrease) and a \$0.01 increment on a digital meter. When subjects received feedback for 38 or more of the 50 heartbeats in a trial, cuff pressure was altered by 2 mm Hg in the direction of the desired pressure change on the next trial, to permit tracking of continued improvement. When fewer than 13 feedbacks were received, pressure was changed by 2 mm Hg in the opposite direction to make the task easier. After the first block of trials, there was a 2-min rest period followed by three more remote-pressure readings used to determine the baseline and initial cuff-pressure level for the next (reverse direction) trial block. Following the second block of trials, three final remote bleed-downs were taken.

After the 10 contingent feedback subjects were tested, the mean number of feedbacks received for each trial of each direction of each order (up-down, down-up) was computed. A Grason-Stadler probability generator was used with each of the next two control groups of 10 subjects each to generate feedback with the frequency obtained by the experimental subjects for that trial, order and direction, but randomly distributed over heartbeats. This allowed the noncontingent feedback groups to receive approximately ($\pm 5\%$ —the error of the probab-

ity generator) the same number of feedback signals within and across trials (*i.e.*, the same reinforcement level), but removed the information value of the feedback. The first noncontingent feedback group received random feedback within 0.5 sec of the triggering heartbeat, as did the experimental subjects. The second noncontingent feedback group also received random feedback, with equal frequency, but with feedback onset randomly occurring 0.75 or 1.5 sec following the triggering heartbeat. This condition was designed to eliminate the possibility of inadvertent partial reinforcement of phasic blood-pressure changes occurring with each beat of the heart. The actual beat-to-beat performance of both noncontingent groups was monitored and cuff changes made accordingly. With the exception of cuff-pressure regulations, trials, trial blocks, feedback, and instructions were identical for experimental and noncontingent control groups. A no-feedback control was also presented in a similar manner, but with no feedback during the trial blocks.

Instructions

The subjects in the three feedback groups were told that the experiment was designed to examine the role of biofeedback on a person's ability to control systolic blood pressure voluntarily. The no-feedback control group was told that the purpose of the experiment was to determine the extent to which people were able to control voluntarily their systolic pressure. All subjects were told that there would be two blocks of 10 trials, with the square trial light signalling each trial. Between the second and third bleed-downs, subjects were informed of the condition they would be in during the succeeding block of 10 trials (increase condition or decrease condition) and instructed to try to alter their systolic pressure in that direction during trials. No strategies were suggested. Subjects were instructed not to use motion or manipulation of breathing as a strategy to change their blood pressure. Feedback groups were instructed that to accomplish the task they should aim to

maximize the amount of feedback they received (this was in reality only possible for the contingent feedback group); they were told that cuff pressure would track their own systolic pressure and that they could earn up to \$0.50 per trial for appropriate pressure changes (the digital meter was reset after each trial). The no-feedback group was informed that they could earn up to \$0.50 per trial based on their performance, but were not informed of their success until the experiment ended.

After the experiment, all subjects were asked to describe what strategies they had used for increasing and decreasing their blood pressure, and which they believed to be the most effective for each condition.

RESULTS

Data Analysis

A fixed-model five-way ANOVA, order of direction $\times$ direction $\times$ feedback mode $\times$ trial $\times$ baseline pressure group (systolic greater than 120 mm Hg or less than 120 mm Hg), was applied to systolic pressure difference scores (change from baseline) over trials.

Analysis of variance confirmed that subjects in the four conditions did not differ in initial pressures. ANOVA revealed significant main effects for direction [$F(1/24) = 11.08, MS_e = 121.86, P < 0.003$] and for trials [$F(9/216) = 2.68, MS_e = 8.06, P < 0.006$], as well as significant interactions of order of training $\times$ direction [$F(1/24) = 5.18, MS_e = 121.86, P < 0.003$] and direction $\times$ trials [$F(9/216) = 4.28, MS_e = 5.02, P < 0.001$]. That is, subjects' systolic pressures were significantly higher and changed more during increase than decrease trials, with marked improvement over trials (see Figure 1). Further, this difference was maximized in the up-down order (see Figure 2).

As predicted, there were no significant differences in ability to raise or lower systolic pressures among contingent and noncontingent feedback groups ($F = 1.2, MS_e = 121.8$). But, contrary to expectations, the no-feedback control

group was also not significantly different from the other groups. As Figure 1 illustrates, subjects in all groups raised systolic pressure roughly 4.5 mm Hg (*i.e.*, roughly 4%), but were unsuccessful in lowering pressure (except with respect to the pressure rise produced during initial "decrease" trials). This lack of significant effect cannot be attributed simply to variability of subjects within groups. Although the variability was considerable, the type of feedback was seen to account for only 1.8% of the variance (sum of the squares) in the data, which attests to the weakness of this effect.

During debriefing, contingent-feedback and instructions-only subjects cited with virtually equal frequencies the following strategies for increasing pressure: thinking about being upset, threatened, under stress, or anticipating exercising. Although the frequencies are not significantly different, more than twice as many contingent-feedback subjects (eight *versus* three) mentioned thinking of being anxious or afraid; they also mentioned controlling their breathing and thinking of sex with greater frequency. Instructions-only subjects mentioned thinking of feeling angry more often; three of them mentioned racing their thoughts, which none of the contingent-feedback subjects mentioned. There were no differences in frequencies (greater than one) of pressure-decreasing strategies cited by contingent feedback and instructions-only subjects: letting mind go blank, relaxing, being passive, feeling drowsy, feeling pleasant, having pleasant images, meditating, being passive; one subject in each group mentioned controlling breathing.

DISCUSSION

Since subjects receiving contingent beat-to-beat feedback were not significantly superior to subjects receiving beat-to-beat noncontingent or variable-interval noncontingent feedback in controlling their systolic pressure, the information value of beat-to-beat feedback for instructed subjects is called into question. Further, since none

Fig. 1. Mean systolic blood-pressure change from baseline over trials for each of the four experimental conditions. Increase and decrease pressure changes represent within-subject manipulations. (Up-down and down-up orders are collapsed).

Fig. 2. The effect of order of training (up-down versus down-up) on voluntary blood-pressure control collapsed over feedback conditions and trials. Note that all mean pressure changes were increases from baseline.

of the feedback groups was significantly superior to subjects given instructions alone, even the reinforcement value of beat-to-beat feedback in instructed subjects appears dubious. While subjects receiving beat-to-beat noncontingent feedback could have been partially reinforced for phasic changes, this could not have occurred in the noncontingent variable-onset group. There was admittedly a tendency toward superiority of contingent feedback over noncontingent feedback and instructions alone in both raising and lowering pressure. Although this appears to have reached asymptote by the last three trials, the possibility exists that it could become significant with repeated sessions. Two other studies recently completed in this laboratory cast even this possibility in doubt, at least in the case of lowering pressure in essential hypertensives. An eight-session laboratory feedback study, and a four-week home feedback study both failed to

find significant differences between performance of instructed subjects given contingent beat-to-beat feedback and subjects instructed to use relaxation techniques (Hager and Surwit, 1977; Surwit and Shapiro, 1976). In the Surwit and Shapiro study there was also a tendency for contingent beat-to-beat feedback to produce greater pressure changes, but the clinical usefulness of these small differences seems doubtful. Steptoe and Johnston (1976) reported a similar failure of phasic feedback to improve on instructions in altering blood pressure from an initial baseline. Although they noted that feedback alterations are made significantly superior to instructions alone when a running baseline is subtracted, the clinical appropriateness of "correcting out" features that vary with the technique is questionable.

There is reason to believe that failure of phasic feedback to augment pressure control as either information or reinforcement is due to the tonic nature of the responses being made by instructed subjects. The strategies cited in debriefing appear predominantly tonic, rather than phasic. These strategies did not vary markedly across feedback groups. Shapiro (1973) found similar strategies in instructed subjects.

Subjects in all our groups exhibited greater ability to elevate than to decrease systolic pressure. This has been previously reported for feedback in normal subjects when care is taken to use change scores and counterbalanced designs to correct for habituating base levels (Shapiro, Mainardi, and Surwit, 1977). Surwit, Shapiro, and Feld (1976) noted that it is typical of voluntary control in autonomically-regulated systems that subjects show greater ability to increase "arousal-like" responses than to decrease them.

The exaggeration of this ease of increasing systolic pressure in the up-down order, and the greater difficulty of decreasing in the down-up order (see Figure 2) we attribute to probable heightened levels of arousal at the beginning of the session with subsequent habituation, fatigue, and boredom. Although it is also possible that

altering pressure in one direction is more easily learned if one has already been trained to alter it in the other, it is difficult to sort out the contributions of this postulated effect from the effects of habituation in this study. In either case, however, such order effects may have clinical utility in training voluntary blood-pressure control.

In summary, these data cast doubt on the utility of beat-to-beat contingent feedback in the control of blood pressure in instructed subjects. The data from this and other studies suggest that when instructed to change their blood pressure, subjects use tonic cognitive strategies that are not aided by the presence of phasic feedback. Because in clinical applications of feedback to hypertension subjects are unavoidably instructed as to the response they are supposed to make, this study calls into question the utility of discrete beat-to-beat feedback in the voluntary regulation of high blood pressure.

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