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Clinical uses of biofeedback:
A review of recent research

Richard M. Lee, PhD*, Scott E. Baldwin, BS*
and Julia A. Lee, MS**

Biofeedback refers to a special type of operant conditioning (i.e., a category of learning) in which subjects acquire control over physiological processes through the feedback of information. Its methodology is based upon principles of behavioral science developed in the laboratory through experimentation. It has been conclusively demonstrated that humans (and other animals) can learn to control such actions as EKG parameters, blood pressure, body temperature, EEG, individual motor units, and glandular secretions. Clinically, biofeedback has been applied to a wide variety of psychophysiologic disorders in which a measurable response requires alteration. The best established applications are tension and migraine headaches, muscle retraining (e.g., paretic and spastic muscles), and anxiety symptoms. Other potential treatment areas are epilepsy, cardiac arrhythmias, hypertension, speech disorders, correction of subvocalization in reading, and gastrointestinal disorders of psychogenic origin.
BIOFEEDBACK is a special type of learning or, more specifically, a type of operant conditioning (to use the terminology of the behavioral scientist). In operant conditioning, the frequency or amplitude of an "emitted" (as opposed to "elicited") response is increased through the use of reinforcing stimuli. For example, we put a coin into a coke machine (the response) and subsequently receive a coke (the reinforcing stimulus). What makes biofeedback special is the nature of the response: a physiological action which is traditionally thought to be "involuntary" and one which is in most cases controlled by the autonomic nervous system. It has been well established that humans and other animals can be conditioned to control such physiological actions as certain parameters of the electrocardiogram (EKG), blood pressure, body temperature, EEG, individual motor units, glandular secretions, and other responses.

The important factor in learning such control is the use of appropriate display of information regarding the physiological response.

To clarify this procedure, let us consider a specific example. Suppose we wish to train someone to increase his finger temperature. A thermistor (temperature-dependent resistor) is taped to the finger. The thermistor resistance is displayed to the subject by the use of a sensitive ohm-meter (the "biofeedback"). The subject is instructed that for every tenth of a degree increase in finger temperature, he will be given 50¢ (the reinforcement). The session begins with a 10-minute adaptation and baseline recording period in which the subject is occupied with a simple task. He is then instructed to observe the meter and concentrate on the temperature of his finger. This temperature is, of course, controlled by the dilation of blood vessels and corresponding flow of blood into the finger. This whole process is very much under the control of the nervous system. Through the use of various instructions and suggestions by the experimenter, in a short period of time the subject will notice small deflections of the meter. By concentrating on these deflections and whatever "internal events" are related to them, the subject quickly learns the response. The results of such an experiment are illustrated in Figure 1. After a few seconds of suggestions related to hand warming, the subject showed a surprisingly rapid temperature increase of several degrees. The clinical usefulness of this particular procedure will be discussed below.

Our review of clinical biofeedback applications will cover the literature subsequent to the last major review, that of Blanchard and Young. We will cover in detail the four major areas which are most widely known and extensively researched: headaches and other pain, hypertension, muscle disorders, and psychological disorders (ie, anxiety, tension etc.). Other applications will be discussed briefly in a fifth section. In this review, we will emphasize the evaluation of design features: control procedures, numbers of subjects, and clinical relevance. The classification of designs will follow for the most part that used by Blanchard and Young. We have set up the following classification scheme in order of increasing design efficacy:

Class D: Anecdotal case report
Class C: Systematic case report
Class B: Multiple systematic case report or single group outcome study
Class A: An experimental study involving at least one appropriate control group or a "single subjects design" in which each of several subjects serves as his own control
Class AA: Similar to A (both types), but including a placebo or attention control procedure.

Most of the classifications are self explanatory. The systematic case report involves careful measurement, baseline recordings and recordings during and after treatment. The single subjects design is one which includes at least one return to baseline after
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treatment (the ABA design). Of course, an ABAB or ABABA design would be even stronger. The difference between a Class AA and Class A study is an important distinction. In much of the early work, the only control group was one in which there was no treatment at all. This type of design did not consider any possible placebo effects or effects simply due to the attention of the experimenter. More recent studies have included a control group in which some sort of placebo or false feedback was used.

Another important issue of experimental design is concerned with “confounding.” In the studies described below, we will consider other variables besides biofeedback which may have influenced results. In some cases, more than one type of treatment was used; in other cases, factors such as home practice were involved.

Headache and other pain

Perhaps the most common clinical usage of biofeedback has been in the reduction of different types of pain. The technique for tension (muscle contraction) headache is probably the best known and most straightforward. In this treatment, surface electromyograph (EMG) electrodes are attached to certain head muscles, usually the frontalis. Feedback is provided by amplifying the muscle potentials and presenting them as sounds or by processing them with an averager and displaying the signal with a chart recorder or providing a frequency-modulated tone or click rate. By alternately tensing and relaxing the frontalis and observing the feedback, the patient learns how to maintain this muscle in a relaxed state. This type of muscular control is learned very rapidly and tends to generalize to other head muscles.

The first study which provided evidence for the effectiveness of this treatment for actual headache patients was performed by Budzynski, Stoyva, and Adler. That pilot study was supported by a better controlled investigation which showed that the combination of EMG biofeedback and home relaxation practice was more effective than pseudofeedback or no treatment at all. Unfortunately, this study did not show whether EMG biofeedback by itself was effective.

Recently, there have been additional case reports and controlled studies. Adler and Adler report the result of a five-year follow-up study of 19 tension headache cases in which a combination of psychotherapy and EMG biofeedback was used. They concluded that their high rate of success is due to the combination of treatment methods.

Two independent Class AA studies appeared in 1975 with the same results: EMG biofeedback and relaxation training were both significantly superior to control groups in reducing tension headache symptoms. Cox et al studied three groups of nine chronic tension headache patients for eight sessions. Their control group subjects were given a medicine placebo. The experimental subjects, given EMG biofeedback or progressive relaxation instructions, were superior to the control subjects on a number of different measures immediately after training and after a four month follow-up. Haynes et al performed a similar experiment except that control subjects were simply told to “become as relaxed as possible” and were given no training. Again, both experimental groups were superior and effectiveness of the procedures was maintained at a five to seven month follow-up. Thus, the literature clearly establishes the efficacy of EMG biofeedback in tension headache control and also indicates that relaxation training is equally effective.

The biofeedback treatment for migraine headaches was discovered by Sargent, Green and Walters while they were performing experiments concerned with temperature control (see Figure 1). One of the subjects of their study noticed that when her hands were warm, headache symptoms were reduced. The physiological basis for hand warming (or differential warming of the hand with respect to the forehead) as
Demonstration of temperature control (R. M. Lee, unpublished observation). A chart recording of hand temperature change is illustrated. The subject initially appeared somewhat tense, which might account for the low baseline level shown at left. At the first up-arrow, the subject was instructed to try and raise her hand temperature. She was told, for example, to “try and imagine that your hands are heavy and warm.” After a few seconds, the thermistor registered a rapid rise of almost 6°C. At the first down arrow, the hand warming instruction was terminated and the subject was asked to discuss a mildly aversive subject. At the second up-arrow, hand warming was repeated until the second down-arrow.
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The technique for migraine control is the assumption that the sequence of cerebral vascular constriction followed by dilation is responsible for the headache. It is possible, therefore, that increased blood flow to the arms and hands (during hand warming) could lessen the excessive flow of blood to the head. An additional factor in the efficacy of this method might be the generalization of hand warming to the feet and legs, thus increasing the amount of blood leaving the head.

The early studies of Sargent et al were replicated by Wickramaskera and Adler and Adler. However, no Class AA studies were performed until 1976, when Turin and Johnson reported a well-designed experiment which is somewhat limited by the small number of subjects. In order to control for placebo or expectancy effects, three of the seven subjects used were given initial training in hand cooling while the remaining four received the usual hand warming procedure. All seven subjects, when exposed to the latter treatment, showed substantially reduced migraine headache symptoms. However, the three trained in hand cooling remained at baseline or showed increases in symptoms, even though they had been told that cooling would be a benefit to them.

There have been a number of anecdotal reports on the use of biofeedback for pain other than headache. One study with a Class A design compared hypnotic training with EEG alpha rhythm biofeedback. The patients suffered from back pain, peripheral nerve injury, cancer pain, arthritis, phantom limb and stump pain, post-traumatic pain and head pain (one case). The results indicated that the combination of the two techniques was superior to either separately.

Hypertension

There is a large volume of research on blood pressure (BP) biofeedback, and much of it is directly oriented towards clinical applications. The earlier studies have been reviewed by several researchers. The results reported in these early papers can be summarized as follows. BP self-control can be demonstrated in both normotensive and hypertensive subjects. Individuals can learn to raise and lower both systolic and diastolic BP. They can learn to vary their BP without awareness of the direction of change or of the fact that BP is involved. And, subjects can learn to vary heart rate and BP independently. These early studies have been much criticized for lack of appropriate control groups, confounding, lack of a rigorous clinical demonstration, and for demonstrating only small BP changes. More recent work, which will be described below, has covered many of these criticisms.

The question of clinical efficacy for hypertension treatment is a complicated one involving many factors. First of all, we must consider the size of the BP decrease which a hypertensive patient can produce. Small decreases, such as demonstrated in the early studies, would not have any medical significance. Secondly, hypertensive patients must be able to apply their learned technique outside the laboratory for extended periods of time. And, third, we may ask what are the most efficient biofeedback methods of BP reduction, and how do they compare with other behavioral techniques.

The study which comes closest to answering the question of clinical efficacy was performed by Krist and Engel. Certain aspects of this study fall into the Class AA category (single subjects design) and other aspects fall into lower categories. This experiment is important because it includes extensive measurements both inside the laboratory and outside, and because it includes rigorous design features in which subjects serve as their own controls. Five subjects were studied in a three phase design: seven weeks baseline with home BP recording, three weeks biofeedback training in both lowering and raising systolic BP, and three...
months of post-training evaluation through home measurement. During training, all of the subjects demonstrated BP control (15% average increase and 11% average decrease). Of more clinical importance, however, is the pre-to post-training reduction of 18/8 mm Hg for average BP measured at home.

These are impressive results, but even this study has certain unfortunate weaknesses. Even though the laboratory situation includes excellent control procedures, there is essentially no rigorous control procedure for the all important pre- and post-training home BP measurements. We must also point out that the home BP measurements were subject to patient bias since the measurements were simply made by the patients themselves; and that only five subjects were studied (only four with complete data). Another study by Elder et al is a clinical trial with promising results, but also suffers from serious design limitations. In the remainder of this discussion of hypertension, we will focus on studies which have relevance to specific topics.

Magnitude of BP reduction. The earliest study performed with actual hypertensive patients was by Benson et al. This is a multiple systematic case study (Class B) with eight patients. In five of them, decreases of systolic BP of 16 to 34 mm were obtained in the laboratory. In the study of Krist and Engle, discussed above, home BP fell 18/8 mm. Blanchard et al reported decreases of 9 to 55 mm systolic and Elder et al reported the largest decreases, 20 to 30% diastolic BP for 18 subjects. These are very substantial decreases which would be of clinical significance. However, none of the studies include the necessary design features discussed above.

Application outside the laboratory. This is perhaps the most complicated question. If successful training is conducted in the laboratory, will it automatically result in a substantial, daily reduction of BP outside the laboratory; or will additional techniques have to be learned to accomplish this extension? Will patients have to learn certain times to apply reduction techniques? Will this require some warning device indicating periods of elevated BP, or can patients recognize somatic cues related to high BP? These are all complicated questions which have been studied in our laboratory and by others.

The duration of training effect has received little attention. Krist and Engle (discussed above) showed that the effectiveness of training lasted at least three months, and Shannon, Goldman and Lee showed that training persisted at least one month.

If it is found in future studies that subjects must learn when to apply a BP lowering technique, the question of BP discrimination will become important. This question is also interesting from a strictly scientific view: can an autonomically controlled, "involuntary," physiological response be discriminated with appropriate training? A recent study by Luborsky et al has some bearing on this question. Twenty-one subjects with a high range of BP variability were trained to estimate systolic BP, once per day. This study demonstrated that subjects could learn to improve their estimations, but does not really bear on the question of discrimination, since they could base their estimations on the occurrence of environmental events. A study more related to the question of discrimination was that of Shapiro et al who studied the discrimination of short term BP changes. They reported a certain degree of accuracy in estimation, but only the direction of change was discriminated not the absolute value.

A study entirely devoted to the investigation of the discrimination of absolute values of systolic BP was performed in our laboratory by David Falk. His findings, however, were inconclusive because of the influence of procedures designed to produce the variability in BP necessary to demonstrate discrimination. Alternating task and rest
periods were used to increase and decrease BP for discrimination trials. Although this factor was considered in the design, nevertheless, the possibility of task-rest cues influencing discrimination could not be eliminated. We are presently performing a similar study with a superior design which may settle the question of BP discrimination.

Procedural questions. Two types of procedural questions can be discussed. First, is BP biofeedback the best behavioral method of BP control, and second, what variations in BP biofeedback methodology are most efficacious?

A number of studies have been designed to answer the first question. One issue is whether verbal instructions are just as effective as biofeedback. Redmond et al. reported that a subject could vary his BP by following the experimenter’s instructions; although no feedback was given, the effects were just as great as in biofeedback studies. However, two factors weaken the impact of this finding. One is that the subjects had received “some experience in perception of blood pressure change” (not clarified in the report) and the other is that no direct comparisons of biofeedback and instruction methods were performed. A better designed study by Steptoe suggests a different conclusion. He found that a biofeedback group was superior to an instruction group in BP control during an “increase” condition and was superior in both directions when compared to a “running baseline.” A study by Fey and Lindholm also bears on the question of biofeedback efficacy. They demonstrated that contingent biofeedback was effective in lowering BP, but that non-feedback or random feedback procedures were ineffective.

Another question which has been investigated is whether other types of biofeedback are more or equally effective in reducing BP. Patel and Datey used a number of different methods including galvanic skin response (GSR) feedback to manage hypertension, but no direct comparisons were made. Schoemaker and Tasto compared muscle relaxation with “noncontinuous” biofeedback. Biofeedback and muscle relaxation procedures significantly lowered diastolic BP between premeasures and postmeasures. Additionally, muscle relaxation lowered systolic BP and was effective when comparing the first period of a treatment session with the last period.

A number of different methods for BP biofeedback have been employed and in some cases have been directly compared. Most BP biofeedback studies have been performed with a “constant-cuff pressure” system described by Tursky et al. An arm cuff is inflated for 50 heart beats to the approximate BP (either systolic or diastolic) of the subject. The number of K sounds is recorded and displayed to the subject for feedback. The cuff is then deflated for 30 seconds and then reinflated with an adjustment in pressure according to the number of K sounds. The subject learns to control BP by trying to increase or decrease (depending on the use of systolic or diastolic BP) the number of K sounds he produces while the cuff is inflated at constant pressure. BP control has also been trained using continuous tracking methods such as those developed by Brener and Kleinman, Dworkin and Lee. An advantage of the tracking systems is that more continuous information regarding the subject’s BP can be obtained.

Most BP training has been performed with one instruction for the entire session, eg, try to lower your BP. A disadvantage of this method is that part or all of the reduction in BP might be due to adaptation to the experimental situation. Caldwell, Lee and Lee developed a method in which alternating 5-minute periods of lowering and not lowering instructions are used. The result of one such experiment is illustrated in Figure 2. Krist and Engel also used this method. Another methodological question is concerned with the type of feedback
which is most efficacious. Investigating three different types of feedback, Lee and Lee\textsuperscript{35} found that a chart recording, which makes a visible record of BP changes, was superior to a BP-dependent tone or meter as feedback.

A final question is concerned with the possible use of "physiological mediators" in developing BP control. Several researchers have measured physiological concomitants during BP biofeedback training and have recorded substantial correlations. Steptoe\textsuperscript{26} noted correlations with heart rate, respiration and general activity, particularly early in training. Krist and Engle\textsuperscript{17} did not notice any systematic correlations for their five subjects. Lee and Goldman\textsuperscript{36} performed an experiment specifically designed to measure physiological concomitants using 12 subjects. In these experiments, individuals were trained with alternating 5-minute periods in which they were instructed to lower or not to lower BP. Correlations between the two instructions and heart rate, respiration rate and amplitude, and three measures of muscle activity were computed (See Figure 3). Generally, higher correlations were found for subjects with good BP control than for poor control. The measure most consistently correlated with good performance was respiration volume, although it was found that such a correlation was not necessary for good performance.

A second experiment performed by Lee and Goldman\textsuperscript{36} tested the efficacy of respiration volume as a mediator in enhancing the development of BP control. Three groups of subjects were used. One was given ordinary biofeedback training with alternating per-
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Physiological concomitants of blood pressure biofeedback training. For each of the 12 subjects (12 rows), the number of sessions during which there were significant correlations (P < .05) between instructions ("lower" and "don't lower") and the seven physiological measures is illustrated. Numbers of positive correlations are above the line, and negative correlations below the line. The best "learners" (high BP correlations) are toward the top of the figure. Note the close correspondence between numbers of BP correlations and other physiological correlations, particularly respiration volume. MF, frontalis muscle; MP, platysma muscle; ME, extensor digitorum muscle; HR, heart rate; RR, respiration rate; RV, respiration volume; BP, blood pressure.
iods as described above, the second was given alternating periods of frontalis EMG biofeedback, and the third was given alternating periods with the instruction to lower and not lower BP by breathing in different patterns. The latter two groups were also given BP feedback. It was found that the group given respiratory instructions achieved superior control of BP (see Figure 4). This result indicates that the appropriate use of a mediator can greatly enhance the development of BP control.

The first study reported in this area was performed by Marinacci and Horande in 1960. They described cases in which there was return of function in patients with stroke and peripheral nerve injuries. Needle EMG electrodes were inserted into the appropriate muscles and the patients were provided auditory feedback. Little attention was paid to this study or to one or two isolated reports within the next few years. Perhaps this is because all of these works were essentially anecdotal.

**Muscle disorders**

The first clinical applications of biofeedback were in the area of muscle disorders. The wide variety of disorders which have been treated with biofeedback include peripheral nerve injuries, quadriplegia, hemiparesis, spasmodic torticollis, hemifacial spasms, dystonias, muscle atrophy, and spinal cord injuries. For example, in the case of a paretic muscle, surface or needle EMG electrodes are used for recording. Feedback can be provided by auditory representations of recorded muscle potentials or the display of integrated EMG signal to the patient. The initial goal in treatment is to elicit any small voluntary activity from the muscle. This might be accomplished by instructing the patient to contract nearby functional muscles. As soon as some activity is recorded from the muscle, the patient is encouraged to increase this activity as much as possible, usually with alternating periods of contraction and relaxation.

Figure 5 illustrates such training in our laboratory for a hemiparetic patient with a paralyzed wrist and hand. Small initial activity was elicited in the palmaris longus by bending the patient’s wrist. After the patient observed this activity for a few seconds, he was able to increase it dramatically. After short rest periods, there was a loss of control, but on successive occasions, control was more rapidly regained. After several sessions the patient regained almost complete use of his wrist and partial use of his hand.

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In their 1974 review, which was highly critical of the literature, it is notable that Blanchard and Young came to the following conclusion: “The work on EMG feedback for muscle retraining has established the therapeutic effect of biofeedback training. Although there are no controlled group outcome studies in the literature, the prolonged base line periods, during which no function is apparent, and the failure of previous attempts at traditional rehabilitation procedures probably make the data from the single-group studies almost as strong in terms of its reliability and validity as would come from a controlled group outcome study.”

Since their review, additional systematic case reports have demonstrated the efficacy of biofeedback for muscle retraining. Two studies are notable for their control procedures. Swaan trained hemiplegic patients to inhibit activity of the peroneus longus muscle which interfered with gait. The purpose of the training was to relax the peroneus longus while the leg was actively extended. Seven patients were studied, each serving as his own control, ie, each patient received both ordinary treatment and biofeedback. The latter resulted in substantially better inhibition of the unwanted muscle activity.

The other controlled study (Class AA) was performed by Basmajian et al. The subjects were 20 hemiparetic patients with chronic foot drop. They were randomly divided into
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two groups, one receiving ordinary therapeutic exercises, the other receiving the exercises plus biofeedback. It was found that the increase in range of motion and strength of dorsiflexion was approximately twice as great in the biofeedback group.

Anxiety

Many patients suffer with a feeling of general malaise. They may describe episodes of racing heart beat, insomnia, stomach aches, nausea, partial blackouts, feelings of fatigue, and dizziness. Each of these complaints deserves medical evaluation, and frequently in the face of negative findings, it can be concluded that these symptoms reflect an anxiety syndrome.

The biofeedback treatment for chronic anxiety is generally based on relaxation training assisted with EMG feedback. The patient is given specific instructions to tense and relax various muscle groups in a systematic fashion. Feedback for the level of EMG activity has been shown to enhance the learning of this muscle relaxation. Several recent studies address the question of the relative efficacy of relaxation training and EMG feedback for effecting lowered EMG levels. Not surprisingly, the studies generally show that EMG feedback results in the lowest levels of muscle tension. Coursey did a study with Class AA design, using three groups: one received EMG feedback, one received general relaxation instructions, and the other was merely told to relax. There were 10 subjects in each group. After a habituation-baseline session, there were six training sessions, followed by a testing session. This study found the EMG feedback (a tone) to be more effective in lowering muscle tension than either specific relaxation instructions or the instruction to relax. It should be noted, however, that the specific relaxation instructions were very general, and given only at the beginning of each session. Therefore, this study does not provide a comparison of EMG feedback with the traditional relaxation training which would be provided throughout the session.

A study by Reinking and Kohl, also with a Class A design, did use the Jacobson relaxation technique. Their study provided a comparison of EMG feedback and relaxation training in lowering tension in the forehead muscles. Fifty subjects, 31 females and 19 males, were divided into four experimental groups and one control group. The four experimental groups had the following conditions: Jacobson relaxation training, EMG feedback, EMG feedback plus relaxation training, and EMG feedback plus monetary reward for reduction in muscle tension. All four experimental groups had significantly greater reductions in forehead muscle tension than the control group which received only the instruction to relax. And among the four experimental groups, all three EMG feedback groups achieved a lower level of forehead muscle tension than the relaxation, non-feedback group.

The results of these studies, though not direct clinical applications, suggest that if the goal of treatment is to effect reduction of tension in a specific muscle group, biofeedback is superior to relaxation training. But for anxiety symptoms there is typically a need for general relaxation, and the question might very well be asked as to how much generalization there is to other muscle groups with feedback for only one group. Alexander was concerned with the question of whether reduction in the level of tension in one muscle group (frontalis) would result in lower tension in two other muscle groups (extensors in the forearm and leg). He used a Class A design with 19 subjects in the experimental group and 9 in the control group. The experimental group received an initial baseline, no feedback session, followed by four sessions with feedback in the form of auditory clicks (frequency varied with muscle tension). Over the sessions, this group showed a reduction of EMG frontalis tension while the control group (no feedback) showed no change.
Figure 4
Comparison of three different biofeedback methods for blood pressure reduction. Three groups of seven subjects were compared for effectiveness of BP biofeedback training: (1) frontalis muscle (M) relaxation training, (2) respiration (R) training, and (3) ordinary BP biofeedback (B) training. Correlations between instructions ("lower" and "don't lower") and systolic BP (a measure of learning) for each subject during their final (fifth) training session are illustrated. Note the superior performance of the group trained in respiration control.
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Figure 5.
Palmaris longus biofeedback training in a hemiparetic patient with a paralyzed wrist and hand (R. M. Lee, unpublished). EMG signal processed by an averager is illustrated (arbitrary units). At the far left, the wrist was flexed by the experimenter and small EMG signals resulted. The patient was instructed to observe these signals and try to amplify them. After about 40 sec, he made his first response (large deflections), which lasted for about a minute. He then stopped for a moment and lost the control, which was shortly regained and demonstrated for 2 min.
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There was no generalization of relaxation to the other muscle groups. The results of Alexander's study suggest the need to combine EMG feedback with relaxation instructions or to provide feedback for a group of physiological responses in order to effect generalized relaxation.

A study by Raskin et al. used a combination of relaxation training and EMG feedback in an excellent demonstration of the clinical effectiveness of the combined procedure in reducing symptoms of anxiety. The 10 patients in this single group design study had documented symptoms of anxiety for at least three years, and their symptoms had been refractory to two years of traditional psychotherapy and, in some cases, minor tranquilizers. The patients were given eight weeks of baseline EMG recording before relaxation training with frontalis muscle feedback was initiated. Then, when the EMG had decreased to a low level with feedback, the feedback was faded out, and the patients were able to sustain muscle relaxation without feedback. At this point, an eight-week assessment period was begun during which the patients were instructed to practice relaxation at home. Data from this period were then compared to pretreatment measures. While there was no significant reduction in reports of anxiety, there was considerable improvement in anxiety symptoms such as headache and insomnia.

Lang recently reviewed his heart rate biofeedback work in relation to its implications for anxiety. He observed that heart rate slowing could be achieved just as easily with EMG feedback as with heart rate feedback, and that high density feedback might actually interfere with heart rate slowing. On the basis of these and other observations, Lang concluded that biofeedback need not be used as a routine treatment for anxiety; that relaxation training, for instance, was likely to be effective.

However, Lang's conclusions can be questioned on the grounds that they are based upon research with feedback for only one visceral response, heart rate. Previous work already described indicates that a combined biofeedback and relaxation training program should be utilized in the treatment for anxiety. We suggest that because there are numerous individual differences in the physiological responses associated with anxiety, it is necessary to plan an individualized treatment for each patient. A case report (J. Lee, unpublished) will illustrate this point.

A young woman, with the diagnosis of anxiety neurosis, who had hyperventilation attacks, was referred for relaxation training. She responded well to the relaxation instructions, but had difficulty complying with the deep breathing exercises. Therefore, specific feedback for respiration was incorporated into her treatment. Recordings did reveal shallow, rapid breathing. However, within the first session she reduced the rate and increased the volume of her respiration. The changes were small, but quite consistent, and the patient was very much encouraged by the objective evidence that she could effect changes in a physiological response she had previously considered intractable (and difficult to discriminate).

Other applications

There are reports of clinical applications of biofeedback in many other areas. The most noteworthy of these are epilepsy, cardiac arrhythmias, and speech and reading disorders. In some cases, well-controlled studies demonstrate clinical efficacy in these areas.

Epilepsy. There are clinical reports of patients who claim they can abort seizures. It might be assumed that the patients are somehow altering electrical brain activity so as to suppress a pattern associated with an epileptic attack. Another tactic would be for the patients to produce an electrical pattern which is incompatible with seizure patterns. This was the approach that Sterman and his associates took in the clinical application of
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their work on the sensorimotor rhythm. Working with cats, Sterman and coworkers noticed that a 12-14 Hz EEG rhythm (called the sensorimotor rhythm) recorded from the sensorimotor area was associated with periods of suppression of motor activity in a quiet, alert animal. It was subsequently learned that food reinforcement of this pattern in cats resulted in immobility, an increase in the amount of sensorimotor rhythm during wakefulness, an increase in the amount of spindle burst activity during sleep, and longer periods of undisturbed sleep. Furthermore, sensorimotor rhythm training delayed or prevented the occurrence of motor seizures following injections of convulsive doses of monomethyl hydrazine. Subsequently Sterman and Friar applied the procedure of training the sensorimotor rhythm in a clinical trial. Their subject was a young female with a convulsive disorder dating back seven years. Visual feedback (light display) was provided for EEG signals of a criterion amplitude and duration. The patient learned to emit the sensorimotor rhythm after three sessions, and then seizure frequency was markedly reduced. Sterman et al report similar findings with other epileptic patients.

Kaplan attempted a similar study with four patients. Less than half the subjects showed a reduction in seizures, but it was not possible to relate this reduction to the sensorimotor rhythm since none of the subjects learned to produce the rhythm. However, Finley and Smith point out that Kaplan may have used a digital filter that was inadequate. These researchers did a study using an extremely narrow band filter which avoided the possibility that higher frequency waves might have been reinforced. Using one epileptic subject, they provided feedback for the sensorimotor rhythm, as well as for epileptiform EEG activity. The amount of sensorimotor rhythm increased from 10% to 65% after the 34th training session. The authors report a decrease in a factor of 10 in the rate of clinical seizures, as well as a reduction in percentage of epileptiform activity. We can conclude that the area of EEG feedback in the treatment of epileptic seizures does hold promise, and is worthy of further research. It should be noted that it is a controversial area, with many researchers withholding a final judgment.

Cardiac arrhythmias. The first published work on biofeedback applications to cardiac arrhythmias was by Engel and colleagues. This early work suggested that arrhythmias such as atrial and ventricular tachycardia and preventricular contractions could be treated. However, a serious flaw in the experimental designs was a lack of baseline to gain information on pretreatment frequency of the arrhythmia. A later study did include a baseline with a return to baseline following improvement in chronic sinus tachycardia in two patients.

These results are encouraging, but extensive clinical application of biofeedback procedures to patients with heart disease and other abnormalities must be questioned. In a recent report, Weiss and Engel described a study showing that feedback for increases in ventricular heart rate did not result in consistent rate increases above baseline levels in patients with complete heart block. Weiss and Engel concluded that operant conditioning of ventricular heart rate is possible only when the conduction path between the atria and ventricles is not interrupted. And Lang et al found that patients with ischemic heart disease showed the poorest ability to change heart rate in any direction in response to feedback, when compared to college students and age-matched non-patients. The results were interpreted as a reflection of the patients' lower cardiovascular ability and perhaps special characteristics of the patients' respiratory-cardiovascular dynamics. Another interesting hypothesis is that the person whose cardiovascular system is less labile is actually more susceptible to cardiovascular illness.

Speech and reading disorders. There is some evidence that biofeedback may be
used as a treatment in the area of speech and reading disorders. Hanna et al. noticed that in stutterers, EMG spikes from the throat differentiated periods of stuttering from periods of normal speech, thus providing some basis for the notion that the stuttering block is accompanied by a spasm of the laryngeal muscles. They report a short experiment in which one subject served as his own control. Marked improvements were found after EMG biofeedback training in the reduction of laryngeal tension.

Subvocal speech during reading interferes with the achievement of a higher reading speed. Hardyck et al. developed a procedure using auditory EMG feedback for activity in laryngeal muscles. After only one 30-minute session, 17 subjects showed a reduction in EMG activity to baseline, non-reading levels. Followup tests at one and three months showed no further subvocalizations during reading. Aarons was able to replicate the Hardyck et al. study. Both studies found increases in reading comprehension following the biofeedback training. But as Blanchard and Young point out, there has been no documentation that the training does indeed increase reading speed, although subjects do report that their extended reading is accompanied by much less fatigue than before.

Conclusions

Biofeedback should not be confused with various popular remedies which are in current vogue. Its techniques are based on the experimental method and have been developed out of the findings of behavioral science. Most of the procedures in current use were originated from principles developed in laboratory experimentation with animals.

Certain clinical applications of biofeedback have been well established through controlled studies; in other areas, encouraging case reports still must be confirmed with such studies. Before discussing these applications, it must be pointed out that in many cases, the basic biofeedback phenomena have been demonstrated, but proof of clinical efficacy still requires further research (eg, BP biofeedback).

The techniques which are best established are those involving EMG feedback. Controlled studies have demonstrated effectiveness in the treatment of tension headache and various muscle disorders and as an aid in general relaxation training. Another area where there is substantial evidence is in the temperature feedback treatment for migraine headaches. Since the earlier reviews there has been new evidence from controlled studies for its clinical efficacy. Psychological problems (ie, anxiety, tension, nervousness) have been treated with biofeedback-assisted relaxation training; associated physiological symptoms have also been treated with appropriate biofeedback methods.

Blood pressure biofeedback is one of the most extensively investigated areas. Although it has been conclusively demonstrated that animals and humans can control BP, it has not really been shown by a controlled study that hypertensives can learn to substantially decrease their ongoing mean, daily BP. Such experiments are very difficult to perform because they require special equipment or techniques for home BP measurement and reliable volunteers over long periods.

Other promising areas which require further investigation include the elimination of cardiac arrhythmias, the reduction of epileptic seizure activity through the reinforcement of EEG patterns, and the use of EMG biofeedback in speech and reading disorders.

To summarize, for certain disorders, biofeedback (or in a broader sense, any method involving learning) now seems to offer the best solution — for common sense reasons
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and because of controlled studies. For example, it makes more sense to learn to relax muscles which have been tensed to the point of pain than to take a drug which can have harmful side effects. For muscle retraining, it has been demonstrated that if the patient has more direct information as to his progress he can learn faster. EMG biofeedback offers a very sensitive measure of muscular action for the patient to observe. Thus, on the basis of controlled experimentation and clinical experiences, biofeedback is proposed as the treatment of choice for a number of disorders.

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