Behavioral approaches including biofeedback are part of the integrative medicine model that is increasingly being recognized and utilized by mainstream medicine. Biofeedback is being applied clinically and researched for an ever-widening range of disorders including chronic pain conditions, hypertension, incontinence, and attention deficit/hyperactivity disorder (ADHD).

Definition of Biofeedback

The Association for Applied Psychophysiology and Biofeedback (AAPB) defines biofeedback as a process that provides “real time information from psychophysiological recordings about the levels at which physiological systems are functioning.”¹ (See box entitled Resources.)

The AAPB points out that, while computers or other electronic devices are typically used in biofeedback, such instrumentation is not required. For example, a mirror can function as a biofeedback device to provide external cues in gait retraining. The organization also notes that the feedback loop is complete only when the patient whose target function is being monitored attends to, and uses, the displayed information.

Historical Background

Biofeedback can be traced to experiments in the late 1950s and early 1960s showing that the autonomic nervous system is amenable to voluntary control via application of the principles of operant conditioning.² The major biofeedback tool—the electroencephalograph (EEG)—was developed by a German psychiatrist, Hans Berger, M.D., in the 1920s. Dr. Berger believed that abnormalities measured by the EEG reflected clinical disorders.

This modality began filtering into clinical practice after Joseph Kamiya, Ph.D. (who was at the University of Chicago, Illinois, at the time) succeeded in training volunteers to recognize a specific brainwave pattern (namely, the alpha pattern). Dr. Kamiya’s landmark work, reported in a 1969 paper,³ demonstrated the standard phases of the feedback loop: (1) recording of a physiologic function of interest by a device (e.g., the EEG); (2) reinforcing patients by informing them each time the desired pattern of functioning occurs; and (3) patients achieving voluntary control of this activity.³

The basic principles of electromyography (EMG), another widely used biofeedback measure, were discovered in the early 1960s.³

Biofeedback Techniques

In EEG biofeedback, sensors placed on the scalp record the patient’s brainwaves, which are converted into amplified visual or auditory signals via a human–computer interface. Data amplitude is measured in microvolts. Based upon the treatment objective and plan, a protocol specifies the technical aspects of biofeedback training.¹

The EMG, a graphical representation recording neuronal activity in muscles anywhere in the body, provides feedback to patients about their levels of muscle tension and relaxation. EMG biofeedback records the electrical activity coming from the surface of the skin. EEG and EMG recordings can occur simultaneously.

Research Support for Clinical Applications

Attention Deficit/Hyperactivity Disorder

Neurofeedback, a subspecialty of EEG biofeedback, was developed by several practitioners, including Joel F. Lubar, B.S., Ph.D., a professor of psychology at the University of Tennessee, Knoxville. In neurofeedback, biofeedback is used to enhance attention and treat patients’ cognitive and behavioral problems as an alternative to conventional pharmacologic treatments.

Dr. Lubar, a past president of the AAPB, has conducted extensive research on treating pediatric and adult patients with ADHD since the mid-1970s. In 1992, Dr. Lubar and his colleagues reported that boys with ADHD differ significantly in their EEG patterns from boys without ADHD. The researchers compared EEG readings from 25 boys, ages 9–12, with ADHD to 27 age-matched controls.⁴ A neurofeedback protocol that Dr. Lubar developed has been used by many schools and health care organizations worldwide.⁵

A review paper applying the efficacy guidelines developed by the AAPB (jointly with the International Society for Neuronal Regulation) determined EEG biofeedback to be “probably effica-
cous" for treating ADHD. Despite significant clinical improvement being reported in approximately 75 percent of the patients in each of the published studies, the reviewers called for additional randomized, controlled group studies.6

The Low Energy Neurofeedback System (LENS), a variant of neurofeedback using EEG biofeedback plus weak electromagnetic fields to stimulate brainwave activity, has also been applied in treating ADHD and other brain-function disorders.7

Canadian researchers recently studied the effect of neurofeedback on neural substrates of selective attention in children with ADHD. Functional magnetic resonance imaging (fMRI) studies of patients with ADHD had identified abnormal functioning of the anterior cingulate cortex (ACC) during tasks involving selective attention. Twenty (20) children with ADHD participated; 15 of these children were assigned to a training group. After 1 week of neurofeedback training, significant activation was shown in the right ACC only in the children in the training group when they performed a counting task.8

In a Chinese study of 60 children older than 6 who were diagnosed with ADHD, EEG biofeedback was 92 percent effective after 40 training sessions. Performance on an integrated visual and auditory continuous performance test was significantly improved whether patients had predominantly hyperactive, inattentive, or the combined type of the disorder.9

Chronic Pain Disorders

Migraine is one of the complex pain disorders for which biofeedback treatment has been discussed in the literature since the mid-1970s. New evidence from a large, prospective cohort of women indicates that treating migraine—at least in women diagnosed with migraine with aura—is particularly important because migraine is associated with an increased risk profile for cardiovascular disease.10

Biofeedback can help in the prevention or treatment of migraine by promoting diaphragmatic breathing and systematic relaxation. In a randomized study of 192 patients with migraine, resurgence of symptoms was significantly reduced at 1-year follow-up by training in EMG and temperature biofeedback compared with patients taking 80 mg per day of propranolol. Such an intergroup difference was not significant at 6 months.11

A recent systematic review of 19 controlled clinical trials (from databases up to June 2004), reporting the effects of nonpharmacologic prophylactic treatment in children with migraine, indicated that biofeedback in tandem with relaxation and/or cognitive behavioral treatment was more effective compared with wait-list controls.12

Biofeedback combined with cognitive behavioral skills training prevented the symptoms of patients at high risk for acute temporomandibular (TMD)-related pain from progressing to chronic

How biofeedback works. Diagram used with permission from Richard A. Sherman, Ph.D., of the Association for Applied Psychophysiology and Biofeedback (AAPB). Diagram on AAPB website at: www.aapb.org Components are described in the text on the website.
TMD disorder. At 1 year, the patients in the early intervention group had significantly lower levels of self-reported jaw pain and depression than patients in the nonintervention group.13

A review of 30 studies of physical therapy modalities for treating TMD concluded that biofeedback may be more effective than placebo or occlusial splints.14

A study of 9 patients with phantom-limb pain suggested that thermal biofeedback may be useful for treating this problem, which occurs in the majority of patients who have amputations.15

A preliminary study with 5 women patients suggested that thermal biofeedback is able to diminish pain associated with endometriosis.16

Biofeedback may contribute to reducing the risk of painful work-related musculoskeletal disorder development by providing information on exertion of the upper trapezius muscle during computer work.17

Behavioral therapies such as biofeedback have also been shown to be more effective than medications in pain management for hospice patients.18

Researchers at the Vanderbilt University School of Medicine, in Nashville, Tennessee, recommend that patients with complex regional pain syndrome be treated with a multi-disciplinary approach including relaxation training with biofeedback.19

Hypertension

A recent review of more than 100 randomized clinical trials of the efficacy of behavioral treatments for hypertension suggested that behavioral treatments reduce blood pressure to a modest degree compared with what occurs in patients in wait-lists or in other inactive control groups. Among biofeedback treatments, thermal and electrodermal activity feedback fared better than EMG or direct blood-pressure feedback.20

Biofeedback and other behavioral treatments for hypertension are particularly indicated in patients who are hypersensitive to stress and who have difficulty in tolerating or complying with antihypertensive drug regimens.21

A pedometer has been used as a “low-tech” biofeedback device for reducing coronary risk factors in an integrative program of exercise, weight management, and pharmacologic medications.22

Seizure Disorders

The treatment of epilepsy via conditioning of the sensorimotor EEG dates back more than 3 decades. Such neurobiofeedback-assisted learning of sensory motor rhythm production, representing an inhibitory state, results in an upregulation of excitation thresholds associated with reduced susceptibility to seizures. Independent laboratories have documented the clinical benefits of such a training protocol, especially for patients whose conditions are nonresponsive to standard anticonvulsant medications.23

Nonepileptic seizures of psychogenic origin in children have also proved amenable to biofeedback training. For example, a 13-year-old girl with such seizures experienced good therapeutic results when she was treated with electrodermal biofeedback combined with cognitive–behavioral therapy. After 10 sessions, the patient experienced no further seizures.24

<table>
<thead>
<tr>
<th>Table 1. AAPB Efficacy Ratings of Biofeedback-Based Treatments for Selected Conditions</th>
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<tbody>
<tr>
<td>Condition</td>
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<tr>
<td>Efficacious and specific</td>
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<tr>
<td>Urinary incontinence in females</td>
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<tr>
<td>Efficacious (based on randomized studies)</td>
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<tr>
<td>Attention-deficit disorder</td>
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<td>Headache—adult</td>
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<tr>
<td>Hypertension</td>
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<tr>
<td>Temporomandibular disorders</td>
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<tr>
<td>Urinary incontinence in males</td>
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<tr>
<td>Probably efficacious (based on multiple nonrandomized studies)</td>
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<tr>
<td>Alcoholism/substance abuse</td>
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<tr>
<td>Chronic pain</td>
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<tr>
<td>Epilepsy</td>
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<tr>
<td>Fecal elimination disorders</td>
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<tr>
<td>Headache—pediatric headache</td>
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<tr>
<td>Insomnia</td>
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<tr>
<td>Possibly efficacious (based on at least one study of sufficient statistical power with a well-identified outcome but lacking randomization)</td>
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<tr>
<td>Asthma</td>
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<tr>
<td>Cerebral palsy</td>
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<tr>
<td>Irritable bowel syndrome</td>
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<tr>
<td>Raynaud’s disease</td>
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<tr>
<td>Stroke</td>
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<tr>
<td>Tinnitus</td>
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<tr>
<td>Not empirically supported to date</td>
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<tr>
<td>Autism</td>
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<tr>
<td>Eating disorders</td>
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<tr>
<td>Multiple sclerosis</td>
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<tr>
<td>(excepting disorder-related incontinence)</td>
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<tr>
<td>Spinal-cord injury</td>
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</tbody>
</table>

See ref. 1. This is a truncated list of the AAPB categories for disorders that have been investigated by recent research. In the second column, — indicates that there is no reference in this article about the disorder.

AAPB = Association for Applied Psychophysiology and Biofeedback.

Neuromuscular Rehabilitation

Originally, biofeedback was used to train single-muscle activity in static positions or movement unrelated to the motor-function needs of patients with central nervous system injuries and conditions. But recent technological advances have led to systems that address multiple parameters in task-oriented biofeedback.25

In a within-subject clinical intervention, 28 patients who were 2 months post total hip arthroplasty were assigned to a biofeedback, no feedback, or control group to improve their gait. Both the feedback and nonfeedback groups walked on a treadmill for 15 minutes, 3 times per week, for 8 weeks while attempting to reduce their asymmetrical favoring of one leg. This preliminary
studied suggested that treadmill walking, with or without biofeedback, can be of benefit to such patients.26

In a randomized study of 26 French patients within 3 months of onset of stroke with left hemiplegia, 13 received conventional physical therapy and 13 were treated with the addition of standing-balance training by biofeedback in a rehabilitation unit. While patients in both groups had improvement in walking, patients who received biofeedback training had greater improvement in the ability to move their affected limbs.27

Children with spastic cerebral palsy and dynamic equinus (spine) deformity were able to improve their gait via biofeedback training. Compared with 15 children in a conventional exercise program, 21 children who received EMG biofeedback in addition to the exercise regimen had significant improvements in range of motion of the ankle joints, muscle tone of plantar flexors, and overall gait function.28

**Mind-Operated Devices for People with Other Disabilities**

An exciting potential use of biofeedback being developed is to enable patients with disabilities to control assistive devices mentally. A preliminary study investigating whether people could learn to control a computer using a biofeedback interface answered this question in the affirmative. The majority of 20 volunteers were able to learn to play a computer game using biofeedback, and they learned to use the device after a single training session. The biofeedback interface integrated their galvanic skin responses (GSRs), heart rates, and temperatures, with the GSR measure being the most sensitive measure of control.29

**Bladder Dysfunction**

Bladder dysfunction affects up to 90 percent of patients with multiple sclerosis, but little research has been conducted on biofeedback as an intervention for this problem in this population.

A randomized, double-blinded pilot study of 30 female patients examined the effectiveness of several modalities including EMG biofeedback, neuromuscular electrical stimulation, and pelvic-floor training and advice. After 9 weeks of treatment, the group that received EMG biofeedback training, either in combination with pelvic-floor training or with pelvic-floor training plus neuromuscular electrical stimulation, had greater improvement than the patients who had pelvic-floor training alone.30

A systematic review of 24 controlled trials between 1995 and 2005 of treatments for the common condition of stress urinary incontinence in women concluded that pelvic-floor muscle training, with or without adjunctive therapies including biofeedback, proved to be effective.31

Urinary incontinence is also frequently experienced by men who undergo radical prostatectomy to treat prostate cancer. In a prospective, controlled study of 125 men, ages 53–68, who elected to have this surgery, patients were randomized to either receive preoperative biofeedback-assisted behavioral training for decreasing the duration and severity of incontinence or the usual preoperative instructions to interrupt the urinary stream. Preoperative training significantly decreased the time to recovery of urinary control, and the proportion of patients with severe or continual leakage at the 6-month endpoint (5.9 percent versus 19.6 percent) of the study.32

In a randomized, controlled study of 192 children, ages 6–16, with nonneurogenic bladder-sphincter dyssynergia, home uroflowmetry biofeedback training proved to be a useful adjunctive treatment to standard therapy for this voiding disorder. The biofeedback training produced greater relief than either standard outpatient behavioral therapy or a home educational video together with standard therapy.33

In a Brazilian pilot study of 17 children, ages 3–14, with lower urinary-tract voiding dysfunction, complete clinical improvement was seen in 10, significant improvement occurred in 2, and mild improvement occurred in 5, after a mean of 6 biofeedback sessions. Another 22 children with urge incontinence were treated with transcutaneous electrical stimulation. Of 21 children with nocturnal enuresis, bedwetting continued in 13 whether they received biofeedback or electrostimulation.34

**Anorectal Dysfunction**

A Dutch cohort study of 281 patients (252 of whom were females) with fecal incontinence explored pelvic-floor muscle rehabilitation via 9 sessions of biofeedback training and electrical stimulation. Outcomes, as measured by Vaizey score (which ranges from 1-continuent to 24-totally incontinent), improved from baseline in 60 percent of patients who completed the study, remained unchanged in 23 percent, and deteriorated in 17 percent.35

Eighty-four patients (84; 63 females, 21 males) in an Italian rehabilitation program for functional constipation were treated by biofeedback of the pelvic floor in combination with electrostimulation and physiokinesitherapy. Patients underwent three 1-hour sessions per week for 15 consecutive sessions, followed by 6 sessions every 3 months. At 1 year, 77 patients (92 percent) reported achieving regular intestinal activity without using laxatives and/or cathartics.36

Other researchers have also concluded that biofeedback is superior to laxatives for treating constipation that results from pelvic-floor dyssynergia (PFd), a common type of constipation defined by the inability to relax pelvic floor muscles during defecation.
In a study comparing biofeedback with laxatives plus patient education, 5 biofeedback sessions were more effective than continuous use of polyethylene glycol (14.6–29.2 g per day) for treating PFD for at least 2 years.\textsuperscript{37}

Because of the high risks involved in surgery for treating internal rectal intussusception (a type of prolapse), safe and effective alternative treatments are being sought. In 34 patients (27 women, 7 men) with this disorder who underwent at least 2 biofeedback sessions, 33 percent experienced complete resolution of their symptoms, 19 percent had partial improvement, and 48 percent had no improvement. Patients with constipation symptoms lasting less than 9 years had a 76 percent success rate versus 13 percent in patients who had experienced constipation problems for a longer time. In 7 patients with incontinence, the frequency of daily episodes decreased somewhat after biofeedback.\textsuperscript{38}

Substance Abuse

One hundred and twenty-one (121) volunteers from a mixed substance-abusing inpatient population were randomly assigned to an EEG biofeedback or control group. The patients in the biofeedback group received training in effecting beta and alpha–theta brainwave patterns and sensorimotor rhythm to address attentional variables. Baseline data were obtained on a double-blinded basis as to group placement on standard cognitive and psychometric measures.

Patients in the experimental group had significant improvement on the Test of Variables of Attention and remained in treatment longer than the control group. Of participants who completed the protocol, 77 percent were drug- and alcohol-abstinent at 12 months compared with 44 percent in the control group.\textsuperscript{39}

Other Conditions

In the case of Raynaud’s disease, in which patients experience cold, painful extremities caused by circulatory problems, biofeedback may help mitigate these symptoms via training to raise hand temperature. Successful acquisition of this skill, however, varied by biofeedback protocol. Whereas 67 percent of patients learned hand-warming via feedback on normal temperature, only 55 percent of the EMG biofeedback group learned this physiologic response.\textsuperscript{40}

In a review of research on biofeedback for phonatory disorders and phonatory performance, in only 3 of 18 studies (few randomized, controlled ones) did biofeedback therapy fail to improve voice quality or not yield better results than other therapies.\textsuperscript{41}

In a study of biofeedback applications for visual problems, patients with reduced visual acuity resulting from macular degeneration or other ocular disorders underwent visual rehabilitation using a specially adapted biofeedback instrument. Of the 144 patients/224 affected eyes, training improved visual acuity in 73 percent of the patients’ eyes. (Of the total patients/eyes, 34 patients/47 eyes had received placebo training.)\textsuperscript{42}

Biofeedback also shows some promise as a modality in treating asthma,\textsuperscript{43} tinnitus,\textsuperscript{44} irritable bowel syndrome,\textsuperscript{45} fibromyalgia,\textsuperscript{46} insomnia,\textsuperscript{47} and vestibular loss–related balance impairment.\textsuperscript{38}

Efficacy Versus Clinical Effectiveness: The AAPB Guidelines

Practitioners are well-aware that, while a treatment’s efficacy is determined by evaluating formal studies; its efficacy thus assessed may be greater or lesser than its effectiveness in treating their patients. Taking this reality into account, the AAPB has established ratings of efficacy for biofeedback in treating many conditions. (See Table 1.)

Mechanisms of Action

Biofeedback provides assistive tools that help patients become aware of how their bodies are functioning and, consequently, enables them to learn to self-regulate the targeted pattern of physiologic functioning. For example, treatments for pain teach patients to control blood flow and muscle tension. Patients with urinary incontinence are instructed to control pelvic-floor muscles to prevent frequent or uncontrolled urination. Changing brainwave patterns, or operant conditioning of the brain, is the goal of treatment for ADHD and other cognitive disorders.

Karen Olness, M.D., a professor of medicine and pediatrics at Case Western Reserve University, in Cleveland, Ohio, has demonstrated that children can be taught biofeedback techniques to reduce the number of migraines these children experience.

Dr. Olness noted that Herbert Benson, M.D., a professor of medicine at Harvard University, Cambridge, Massachusetts, and founding president of the Mind-Body Medical Institute, Chestnut Hill, Massachusetts, had said that he could not differentiate among different relaxation techniques such as biofeedback, meditation, self-hypnosis, and imagery in terms of brainwave pattern, heart rate, or other physiologic indicators. What they appear to share in common is the process of self-regulation.\textsuperscript{49}

Given the association of relaxation techniques with such changes in vascular tone as decreases in heart rate, metabolism, blood pressure, and rate of respiration, and an increase in skin temperature, one hypothesis holds that nitric oxide, a demonstrated vasodilator, contributes to the physiologic activities of approaches including biofeedback.\textsuperscript{50}

Conclusions

Biofeedback provides tangible representation of subjective observations. Via the principles of operant conditioning, self-regulation, and relaxation, biofeedback is a therapeutic technology that empowers patients to be active participants in their own health care by providing them with immediate insight into the functioning of their bodies.

Biofeedback’s various techniques are safe and adaptable for use by pediatric as well as adult patients. Biofeedback is well-established as an adjunctive treatment modality for chronic pain conditions such as migraine, and support is accruing from recent studies of the efficacy of biofeedback alone or in conjunction with other modalities for treating other conditions, including ADHD, hypertension, and incontinence.
Additional research is warranted on the treatment of the various conditions for which biofeedback has shown potential efficacy. Further studies are also needed to identify which patients are most likely to benefit from specific biofeedback approaches.

References


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