EEG Biofeedback: A Brief Introduction

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The application of biofeedback and related technologies to the therapeutic modulation and alteration of the electromagnetic energy that emanates from the human brain is, in my opinion, one of the more theoretically and clinically interesting brain-behavior technologies to develop in the last 30 years. A variety of brain wave biofeedback protocols have been applied to the treatment of a number of psychological and physiological conditions. Applications range from seizure disorders, traumatic brain injury, stroke, dementia, Parkinson's, chronic fatigue syndrome, Lyme disease, Tourette syndrome, stuttering, sleep difficulties, migraine and tension headaches, and fibromyalgia, to autism, addictive disorders, attention deficit/hyperactivity disorder, learning disabilities, posttraumatic stress disorder, dissociative disorder, and a full range of other psychological conditions including most of the anxiety disorders and depression. EEG biofeedback procedures also have been applied to creativity training and the optimization of performance in competitive sports.

The brain's electromagnetic energy was first systematically measured and studied by Hans Berger (1929), a German physician, who labeled the wavy line representation he obtained the electroencephalogram (EEG). The EEG label is now loosely used to refer to the energy field itself, regardless of how it is measured or represented. The EEG is a weak energy field made up of very complex, interrelated waves. It typically is measured by placing electrodes on selected locations on the scalp. The International 10-20 system for specifying scalp locations is used to describe recording sites. The energy recorded at these sites is assumed to emanate from the cortex, influenced by deeper thalamic region activity. Interestingly, the origin of the EEG is not the all or none action potential propagated by a neuron or collection of neurons, but rather is the graded slow potential found at the dendritic junctions of neurons (Pribram, 1971). In Pribram's words, it is a "neural state" influenced by arriving nerve impulses and influencing outgoing impulses.

Important descriptors of the EEG include the strength or amplitude in microvolts, and the frequency per second or Hertz (Hz) of the component waves that make up the raw EEG. Traditional groupings of the component waves, described in Hz bandwidths, include delta (1 - 3 Hz), theta (4 - 7 Hz), alpha (8 - 12 Hz), and beta (above 12 Hz). Later differentiations have been made within beta, including sensorimotor rhythm (SMR), or low beta (12-15 Hz); midrange beta, now simply called beta by most practitioners (15 - 18 Hz); high beta (above 18 Hz); and gamma (40 Hz). However, precise definitions of these terms vary across research or clinical groups, and finer-tuned spectral analyses also now are available through digital and Fast Fourier Transformations (FFT's). These new methodologies have provided the field with more precise recordings of the component amplitudes of the EEG, sorted in discrete one Hz bins. The older Greek terms for a number of the bandwidths continue to be used, but their use is slowly giving way to more precise definitions, as important distinctions are found within the traditional bandwidths. Other important systemic descriptors of EEG activity have been incorporated into a number of evaluation and training protocols, including coherence and comodulation of waveforms across recording sites, phase structure, and complexity of the raw EEG.

The EEG continues to be useful in the medical sciences to diagnose seizure disorders, metabolic conditions, stroke, central nervous system infections, degenerative conditions such as multiple sclerosis, head trauma, headaches, and brain tumors. Excessive amplitude in the slow wave bands, or "EEG slowing," often is found, for example, when the brain has been damaged. Sudden bursts of brain activity, or spikes, are found in seizure disorders. More recently, in a seminal study, John, Prichep, Fridman, and Easton (1988) were able to use quantitative analysis of the EEG to differentiate between normal subjects and persons with psychological conditions, including mild cognitive impairments, dementia, unipolar depression, bipolar depression, alcoholism, and schizophrenia.

The first demonstration that the EEG could be systematically altered occurred in the late 1950's by Joseph Kamiya, Ph.D., a psychologist at the University of Chicago. He used an operant conditioning-like procedure, in which he contingently paired the increase in amplitude of alpha wave activity with a tone. Subjects were easily able to increase alpha wave production. Publication of this and related work appeared in a 1968 *Psychology Today* article (Kamiya, 1968). Dr Kamiya and colleagues termed this procedure EEG biofeedback, now also known as neurofeedback or neurotherapy.

In the late 1960ís and 1970's a number of research laboratories began to experiment with the use of operant conditioning procedures to train EEG bandwidths other than alpha, particularly theta, and SMR. This led to the serendipitous discovery by Barry Sterman and colleagues that a group of cats who had been trained in an earlier study to produce high amplitude SMR had dramatically fewer seizures when exposed to a toxic chemical (Sterman, Lo Presti, & Fairchild, 1969). Clinical application of SMR Biofeedback procedures for seizure disorders in humans quickly followed (Sterman, & Friar, 1972). Others began to experiment with the use of alpha training, for example, to assist desensitization training (discussed in Budzynski, 1999). Joel Lubar and associates also began to work with children with attention deficit/hyperactivity disorder by simultaneously training them to produce SMR while suppressing theta (Lubar & Shouse, 1976; Lubar & Lubar, 1984).

The advent of the personal computer and increasing availability of more sophisticated EEG recording and feedback software has spawned a slowly growing cottage industry of EEG biofeedback practitioners. The professional organization devoted specifically to EEG biofeedback, the International Society for Neuronal Regulation (iSNR), now numbers 575 members, roughly half of whom are doctoral level psychologists. The Biofeedback Certification Institute of America (BCIA), the professional accreditation board for certification in biofeedback training, has begun to offer an EEG biofeedback specialty. Approximately 400 clinicians are accredited in the use of EEG biofeedback by this organization, 66% of whom are psychologists. Other EEG biofeedback clinicians can be found in membership in the Association for Applied Psychophysiology and Biofeedback (AAPB).

A variety of EEG biofeedback software systems and procedures presently is available to both evaluate and alter characteristics of the human EEG. Sophisticated quantitative EEG (QEEG) evaluation programs have been developed to compare characteristics of a particular person's EEG to a normal population or database. Although complicated and expensive, QEEG analyses sometimes are useful for pre and post treatment analyses, as well as to guide locality-specific interventions that might be used, for example, in the treatment of seizure disorders. Training software and procedures are available which provide the ability to simultaneously increase desirable bandwidths such as SMR and beta (associated with physiological relaxation and attention, respectively), while decreasing undesirable bandwidths such as delta and theta (often associated with depression and cognitive inefficiency). Some approaches, such as the NeuroCare Pro program recently developed by Valdeane Brown, Ph.D., a supplanted Pennsylvania psychologist, use bilateral attachments to simultaneously target the augmentation and inhibition of up to 12 bandwidths. Feedback systems used by most of the newer programs use sophisticated visual screens, combined with sound tracks that dynamically change in a pleasing manner as target goals are met.

Another interesting, but not well understood, EEG biofeedback system has been developed by Len Ochs, Ph.D., also a former Pennsylvania psychologist. He developed a system whose feedback involves brief, low intensity electromagnetic waves that are matched to locality-specific dominant EEG waves. As a result of this treatment, brain wave amplitude, particularly in the lower Hz ranges, is decreased and brain flexibility is increased (Ochs, 1997). Initially described as EEG-driven stimulation (EDS), then the Flexyx Neurotherapy System (FNS), and, in its latest variation, Low Energy Neuronal Stimulation (LENS), this system has had well documented success, published in several mainstream journals, with traumatic brain injury and fibromyalgia (e.g., see Mueller, Donaldson, Nelson, & Layman, 2002; and Schoenberger, Shiflett, Esty, Ochs, & Mathers, 2001). A second derivative system, Roshi, developed by Chuck Davis, an engineer, uses EEG-guided light to therapeutically alter EEG patterns. There also has been increasing interest in the use of audio-visual entrainment procedures to augment more traditional EEG biofeedback training (see Siever, 2003)

Although the efficacy of EEG Biofeedback for helping to manage seizure disorders is nicely documented in well-controlled studies, its application to many other conditions remains less well documented by the rigorous standards required for acceptance as empirically supported treatment procedures (see Lohr, J., Meunier, S., & Parker, L., 2001, for a critical, but only partial review of the literature applying EEG Biofeedback to psychological disorders). A closer reading of this literature reveals that the reported paucity of support is due to a lack of sophistication of many of the published studies. Often carried out by small clinical practices, these studies often are simply case reports rather than properly controlled studies. They also sometimes suffer from overly enthusiastic interpretations and generalizations. Guidelines for researchers in the area of EEG biofeedback were recently published to aid future studies (La Vaque, et al., 2002), and the quality of research is expected to improve. Nevertheless, there is clear evidence that EEG biofeedback procedures do produce predictable and lasting changes in the EEG (e.g., Strawson & Gruzelier, 2002), and that characteristics of the EEG are correlated with important psychological conditions (John, Pricep, Friedman, & Easton, 1988). In addition, a growing and substantial body of evidence consisting of case reports, partially controlled studies, and increasingly well-controlled studies is available supporting the usefulness of EEG biofeedback procedures.

EEG biofeedback thus can provide a valuable tool to the practicing psychologist. First, it offers procedures for helping to manage the physiological/central nervous system (CNS) hyperarousal that accompanies most forms of psychopathology. Although it usually is not as quick acting as available medications, this benefit occurs without the potentially harmful effects we continue to be reminded of with most psychotropic medicines. Second, particularly for the rehabilitation psychologist, EEG biofeedback provides interventions that offer the possibility of improvement in capability, rather than simply adjustment and coping strategies. I have been pleased with the addition of EEG biofeedback to my practice, particularly for working with stroke and TBI patients, as well as with persons with pain disorders such as migraine headache and fibromyalgia. Third, involvement in EEG biofeedback has been speculated to increase persons' openness to change and responsiveness to psychotherapy. Although lacking specific empirical support at this time, this speculation is consistent with my own clinical experience.

Acceptance of EEG biofeedback by the mainstream psychological community has been slow to occur. I suspect this is due, not only to the difficulty for practicing psychologists in understanding a new set of technical terms and procedures, but to the lack of understanding about why and how EEG biofeedback should help all the conditions it claims to treat. Explanations of its effectiveness by operant conditioning principles, preferred by many researchers and practitioners, suffer in principle. An operant conditioning approach "explains" by reference to observed orderly empirical relationships between stimulus conditions, and explicitly not by incorporating any understanding of mechanism or process. In addition, EEG learning does not exhibit all the typical characteristics of operant learning such as the variable ratio effect or extinction curves.

More ambitious attempts to explain the effectiveness of neurofeedback have been suggested by reference to its value in restoring healthy CNS regulation (e.g., Othmer, Othmer, & Kaiser, 1999), reducing EEG slowing by averaging the wave form (Ochs, January 27, 2003, personal communication), disrupting stuck states of hyperarousal (Fehmi & Robbins, 2001), or facilitating flexible brain functioning (e.g., Brown & Dermit, 1998; Ochs, 1999). A particularly compelling and comprehensive approach to explaining the dynamics of EEG biofeedback has been provided by Valdeane Brown (e.g., 1995, 2002; Brown & Dermit, 1998), who incorporates findings consistent with current nonlinear analyses of brain dynamics (e.g., Brandt, 2001; Pribram, 2003), control theory, sophisticated signal detection theory, as well as with many of the phenomena found in neurofeedback training and EEG clinical research (e.g., Thomasson, Pezard, Allaire, Renault, & Martinerie, 2000).

As I have attempted to discuss elsewhere (Fink & Small, 2002, Fink, 2003), the EEG presents phenomena that challenge our current understanding of the brain, as well as brain-behavior relationships. It is not surprising that the EEG provides an area of interest for two Nobel Prize winning neuroscientists, Karl Pribram and Walter Freeman. EEG dynamics are not well conceptualized by most contemporary approaches to brain science, particularly by the reductionism found in the currently dominant medical-chemical perspective. In addition, the accumulating evidence that neurofeedback can help alter both psychological and some physical disorders, particularly the less traditional neurofeedback approaches that use linked electromagnetic energy (Mueller, et al., 2001; Ochs, 1997; Schoenberger, et al., 2001), creates a strain on the explanatory adequacy of present mainstream approaches to understanding and treating psychopathology. It may be that the paradigm shift Karl Pribram (e.g., 1986, 1991) and others have been talking about for some time, inspired by both chaos theory and quantum physics, will be necessary to more fully understand the effectiveness of this approach. Our understanding of the universe and the concepts we use to talk about and understand psychological phenomenon will need to move from a world believed to be made up of “things” in motion, to that of a connected universe of energy, energy states, and emergent phenomenon.

A good nontechnical introduction to neurofeedback has been provided by Robbins (2000). A more technical discussion of neurofeedback techniques and applications can be found in Evans and Arabanel (1999), and a discussion of the usefulness of neurofeedback for practicing psychologists was recently provided by Masterpasqua and Healy (2003). Lake and Moss (2003) also recently presented a cogent argument for the legitimacy of neurofeedback in treating psychiatric and neurological disorders. A summary of published clinical applications of neurofeedback through 2001 is provided by Hammond (2001). In addition, an internet Google search using “EEG biofeedback” or “neurofeedback” will provide a wealth of information concerning various approaches to EEG biofeedback, including information about currently available EEG biofeedback systems.

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