# A Basic Biofeedback Primer

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**Abstract**:
*Biofeedback is a longstanding technique whereby voluntary control may be asserted over many seemingly unconscious physiologic and autonomic processes. Neurofeedback is a particular branch of biofeedback using real time information derived through the active monitoring of brain states to allow development of therapeutically efficacious informationally rich results. Our facility and staff are expert in the use of biofeedback as both a direct therapeutic aid, and assessment tool. This document will briefly detail the historical development and underlying principles of bio- and neuro-feedback techniques and their substantial theoretical and experimental basis.*

Biofeedback/Neurofeedback is now well defined by the scientific community. The Association for Applied Psychophysiology and Biofeedback (AAPB), Biofeedback Certification International Alliance (BCIA), and the International Society for Neurofeedback and Research (ISNR), formulated this definition of biofeedback in 2008:

*Biofeedback is a process that enables an individual to learn how to change physiological activity for the purposes of improving health and performance. Precise instruments measure physiological activity such as brainwaves, heart function, breathing, muscle*

*activity, and skin temperature. These instruments rapidly and accurately 'feed back' information to the user. The presentation of this information — often in conjunction with changes in thinking, emotions, and behavior — supports desired physiological changes. Over time, these changes can endure without continued use of an instrument.*

**History, current use, evaluation and empirical substantiation**: Biofeedback has been a mainstay within many cultures and cultural practices for thousands of years, and is still used today in traditional forms such as Yoga and Pranayama. In western science, the progression of biofeedback can be roughly traced as follows: Claude Bernard in 1865 derived the concept of homeostasis [1]. In 1885, J. R. Tarchanoff demonstrated control of heart rate could be direct (cortical-autonomic) [2]. In 1901, J. H. Bair showed that skeletal muscles are self-regulated [3]. Alexander Graham Bell attempted to teach the deaf to speak using two devices — the phonautograph, and a manometric flame. The former translated sound vibrations to show their acoustic waveforms, while the latter allowed sound to be displayed as patterned light [4]. Mathematician Norbert Wiener developed cybernetic theory, that proposed that systems are controlled by monitoring their results [5]. The participants at a 1969 conference coined the term biofeedback from Wiener's ideas. The conference marked the founding of the Bio-Feedback Research Society [6]. In the first experimental demonstration of biofeedback, Shearn used these procedures with heart rate. Effects of the perception of autonomic nervous system activity were initially explored by George Mandler's group in 1958. In 1965, Maia Lisina trained subjects to change blood vessel diameter, eliciting and displaying reflexive blood flow changes [7]. In 1974, H.D. Kimmel trained subjects to sweat using the galvanic skin response. (Text in paragraph above condensed from [8]).

Neurofeedback has the following additional historical lineage: In 1924, German psychiatrist Hans Berger attached electrodes to a patient's scalp and detected a small current using a galvanometer. During the years 1929-1938 he published 14 reports about his studies of EEGs. In 1932 G. Dietsch applied Fourier analysis to seven records of EEG and became the first researcher of QEEG (quantitative EEG) [9]. Joe Kamiya popularized neurofeedback in the 1960s. Later, Barbara Brown wrote several books on biofeedback. The work of Barry Sterman, Joel F. Lubar and others has impacted the study of beta training, pertaining to sensorimotor rhythmic EEG activity [10]. This training has been used in the treatment of epilepsy, attention deficit disorder and hyperactive disorder [11-13]. The sensorimotor rhythm (SMR) is rhythmic activity between 12 and 16 hertz that can be recorded from an area near the sensorimotor cortex. SMR is found in waking states and is very similar if not identical to the sleep spindles that are recorded in the second stage of sleep. Alpha-theta training has been applied to patients with alcoholism, other addictions and to cases of anxiety [14]. This training differs greatly from the high frequency beta and SMR training and is reminiscent of the original alpha training of Elmer Green and Joe Kamiya [14]. Beta and SMR training are a directly physiological approach, strengthening sensorimotor inhibition in the cortex and inhibiting alpha patterns. Alpha-theta training is different and derives from the psychotherapeutic model and so involves the accessing of painful or repressed memories through the alpha-theta state [15].
(Text in paragraph above condensed from [16]).

The substantial efficacy and limits of bio- and neuro-feedback are now well established. In [17] extensive literature was reviewed and the results rated on a 5 tier scale. The results can be quickly summarized in part as follows, for the following applications:

Alcoholism / Substance Abuse Level 3: Probably Efficacious; Anxiety Level 4: Efficacious; Arthritis Level 3: Probably Efficacious; Asthma Level 2: Possibly Efficacious; Attention Deficit Hyperactivity Disorder (ADHD) Level 4: Efficacious; Autism Level 2: Possibly Efficacious; Cerebral Palsy Level 2: Possibly Efficacious; Chronic Obstructive Pulmonary Disease (COPD) Level 2: Possibly Efficacious; Chronic Pain Level 4: Efficacious; Coronary Artery Disease Level 2: Possibly Efficacious; Cystic Fibrosis Level 2: Possibly Efficacious; Depressive Disorders Level 2: Possibly Efficacious; Diabetes Mellitus Level 3: Probably Efficacious; Epilepsy Level 4: Efficacious; Erectile Dysfunction Level 2 Efficacy – Possibly Efficacious; Fecal Disorders in Children Level 3: Probably Efficacious; Fecal Incontinence: Adults Level 3: Probably Efficacious; Constipation: Adults Level 4: Efficacious; Fibromyalgia/Chronic Fatigue Syndrome Level 2: Possibly Efficacious; Hand Dystonia Level 2: Possibly Efficacious; Headache – Pediatric Level 3: Probably Efficacious; Headache – Adult Level 4: Efficacious; Hypertension Level 4: Efficacious; Insomnia Level 3: Probably Efficacious; Motion Sickness Level 4: Efficacious; Post-Traumatic Stress Disorder Level 2: Possibly Efficacious; Raynaud's Disease Level 4: Efficacious; Repetitive Strain Injury Level 2: Possibly Efficacious; Respiratory Failure: Mechanical Ventilation Level 2: Possibly Efficacious; Stroke (Cardiovascular Accident) Level 2: Possibly Efficacious; Tinnitus Level 2: Possibly Efficacious; Temporomandibular Disorder (TMD) Level 4: Efficacious; Traumatic Brain Injury (TBI) Level 3: Probably Efficacious; Urinary Incontinence in Females Level 5: Efficacious and Specific; Urinary Incontinence in Males Level 3: Probably Efficacious; Urinary Incontinence in Children Level 2: Possibly Efficacious; Vulvar Vestibulitis (Vulvodynia) Level 3: Probably Efficacious.

Research on neurofeedback demonstrates it as a valid and effective therapy. It has been used for pain, addiction, aggression, anxiety, autism, depression, schizophrenia, epilepsy, headaches, insomnia, Tourette syndrome, and brain damage from stroke and trauma [18-33]. (Text condensed from [16]).

**General parameters, equipment and approach** (condensed from [8, 16]):

Electromyograph

An electromyograph (EMG) uses electrodes to articulate muscle action potentials which cause muscular contractions. In addition to surface electrodes, intramuscular wires or needles may be used to capture EMG signals. Raw EMG signals are typically processed in three ways: rectification, filtering, and integration. EMG biofeedback is used in treating anxiety and worry, chronic pain, essential hypertension, headache (migraine, mixed headache, and tension-type headache), low back pain, physical rehabilitation (cerebral palsy, incomplete spinal cord lesions, and stroke), temporomandibular joint

dysfunction (TMD), torticollis, and fecal incontinence, urinary incontinence, and pelvic pain.

Feedback thermometer

A feedback thermometer detects skin temperature with a temperature-sensitive resistor attached to a finger or toe. Skin temperature mainly reflects arteriole diameter. Hand-warming involves arteriole vasodilation produced by a beta-2 adrenergic hormonal mechanism. Hand-cooling involves arteriole vasoconstriction produced by the increased firing of sympathetic C-fibers.

Temperature biofeedback is used in treating chronic pain, edema, migraine and tension headache, essential hypertension, Raynaud's disease, anxiety, and stress.

Electrodermograph

An electrodermograph (EDG) measures skin electrical activity directly (skin conductance and skin potential) and indirectly (skin resistance) using electrodes placed over the digits or hand and wrist. Orienting responses to unexpected stimuli, arousal and worry, and cognitive activity can increase eccrine sweat gland activity, increasing the conductivity of the skin for electric current.

In *skin conductance*, an electrodermograph applies current across the skin and measures its flow. When anxiety increases sweat production, conductance increases. Skin conductance is measured in microsiemens. In galvanic skin response (GSR), an electrodermograph applies a current across the skin and measures the result [35].

Electrodermal biofeedback is used in treating anxiety disorders, hyperhidrosis (excessive sweating), and stress. Electrodermal biofeedback is used as an adjunct to psychotherapy to increase client awareness of their emotions. In addition, electrodermal measures have long served as one of the central tools in polygraphy because they reflect changes in anxiety or emotional activation.

EEG:

The electroencephalograph (EEG) measures electrical activity of the brain from sites located over the human cortex. The EEG shows the amplitude of electrical activity at each cortical site, the amplitude and relative power of various wave forms at each site, and the degree to which each cortical site fires in conjunction with other cortical sites (coherence and symmetry) [36].

The EEG uses precious metal electrodes to detect a voltage between at least two electrodes located on the scalp. The EEG records both excitatory postsynaptic potentials (EPSPs) and inhibitory postsynaptic potentials (IPSPs) that largely occur in dendrites in pyramidal cells located in macrocolumns, several millimeters in diameter, in the upper cortical layers. Neurofeedback monitors both slow and fast cortical potentials [37].

Slow cortical potentials are gradual changes in the membrane potentials of cortical dendrites that last from 300 ms to several seconds. These potentials include the contingent negative variation (CNV), readiness potential, movement-related potentials (MRPs), and P300 and N400 potentials [38].

Fast cortical potentials range from 0.5 Hz to 100 Hz [39]. The main frequency ranges include delta, theta, alpha, the sensorimotor rhythm, low beta, high beta, and gamma. The thresholds or boundaries defining the frequency ranges vary considerably among professionals. Fast cortical potentials can be described by their predominant frequencies, but also by whether they are synchronous or asynchronous wave forms. Synchronous wave forms occur at regular periodic intervals, whereas asynchronous wave forms are irregular [37].

The synchronous delta rhythm ranges from 0.5 to 3.5 Hz. Delta is the dominant frequency from ages 1 to 2, and is associated in adults with deep sleep and brain pathology like trauma and tumors, and learning disability.

The synchronous theta rhythm ranges from 4 to 7 Hz. Theta is the dominant frequency in healthy young children and is associated with drowsiness or starting to sleep, REM sleep, hypnagogic imagery (intense imagery experienced before the onset of sleep), hypnosis, attention, and processing of cognitive and perceptual information.

The synchronous alpha rhythm ranges from 8 to 13 Hz and is defined by its waveform and not by its frequency. Alpha activity can be observed in about 75% of awake, relaxed individuals and is replaced by low-amplitude desynchronized beta activity during movement, complex problem-solving, and visual focusing. This phenomenon is called alpha blocking.

The synchronous sensorimotor rhythm (SMR) ranges from 12 to 15 Hz and is located over the sensorimotor cortex (central sulcus). The sensorimotor rhythm is associated with the inhibition of movement and reduced muscle tone.

The beta rhythm consists of asynchronous waves and can be divided into low beta and high beta ranges (13–21 Hz and 20–32 Hz). Low beta is associated with activation and focused thinking. High beta is associated with anxiety, hypervigilance, panic, peak performance, and worry.

EEG activity from 36 to 44 Hz is also referred to as gamma. Gamma activity is associated with perception of meaning and meditative awareness [8].

Neurotherapists use EEG biofeedback when treating addiction, attention deficit hyperactivity disorder (ADHD), learning disability, anxiety disorders (including worry, obsessive-compulsive disorder and post traumatic stress disorder), depression, migraine, and generalized seizures [8].

## Photoplethysmograph

A photoplethysmograph (PPG) measures the relative blood flow through a digit using a photoplethysmographic (PPG) sensor attached by a Velcro band to the fingers or to the temple to monitor the temporal artery. An infrared light source is transmitted through or

reflected off the tissue, detected by a phototransistor, and quantified in arbitrary units. Less light is absorbed when blood flow is greater, increasing the intensity of light reaching the sensor [40].

A photoplethysmograph can measure blood volume pulse (BVP), which is the phasic change in blood volume with each heartbeat, heart rate, and heart rate variability (HRV), which consists of beat-to-beat differences in intervals between successive heartbeats [41, 42].

A photoplethysmograph can provide useful feedback when temperature feedback shows minimal change. This is because the PPG sensor is more sensitive than a thermistor to minute blood flow changes. The photoplethysmograph is used to supplement temperature biofeedback when treating chronic pain, edema, headache (migraine and tension-type headache), essential hypertension, Raynaud's disease, anxiety, and stress [8].

## Electrocardiogram

The electrocardiogram (ECG) uses electrodes placed on the torso, wrists, or legs, to measure the electrical activity of the heart and measures the interbeat interval (distances between successive R-wave peaks in the QRS complex). The interbeat interval, divided into 60 seconds, determines the heart rate at that moment. The statistical variability of that interbeat interval is heart rate variability [43].

Heart Rate Variability biofeedback is used when treating asthma, COPD, depression, anxiety, fibromyalgia, heart disease, and unexplained abdominal pain [8] [44-50].

HRV data from both polyplethysmographs and electrocardiograms are analyzed via mathematical transformations such as the commonly-used Fast Fourier Transform (FFT). The FFT splits the HRV data into a power spectrum, revealing the waveform's constituent frequencies [40]. Among those constituent frequencies, high-frequency (HF) and low-frequency (LF) components are defined as above and below .15 Hz, respectively. As a rule of thumb, the LF component of HRV represents sympathetic activity, and the HF component represents parasympathetic activity. The two main components are often represented as a LF/HF ratio and used to express sympathovagal balance [40]. Some researchers specify a third, medium-frequency (MF) component from .08 Hz to .15 Hz, which has been shown to increase in power during times of appreciation [51].

## Further Cardiovascular specificity:

Emotions are intimately linked to heart health, which is linked to physical and mental health. In general, good mental and physical health are correlated with positive emotions and high heart rate variability (HRV) modulated by mostly high frequencies [52-54]. High HRV has been correlated with increased executive functioning skills such as memory and reaction time [25]. Biofeedback that increased HRV and shifted power toward HF (high-frequencies) has been shown to lower blood pressure [55]. On the other hand, LF (low-frequency) power in the heart is associated with sympathetic vagal

activity, which is known to increase the risk of heart attack [56]. LF-dominated HRV power spectra are also directly associated with higher mortality rates in healthy individuals, and among individuals with mood disorders [8] [57-59]. Anger and frustration increase the LF range of HRV [60]. Other studies have shown anger to increase the risk of heart attack [61].

Because emotions have such an impact on cardiac function, which cascades to numerous other biological processes, emotional regulation techniques are able to effect practical, psychophysiological change [55]. McCraty et al. discovered that feelings of gratitude increased HRV and moved its power spectrum toward the MF (mid-frequency) and HF (high-frequency) ranges, while decreasing LF (low-frequency) power [60].

(The above section text, "General parameters, equipment and approach," was condensed from sources [8] and [16]).

**Conclusion**:

Biofeedback and Neurofeedback are techniques which allow what are ordinarily unconscious and autonomic processes to be consciously mediated, and so, provide non invasive therapeutic options the benefits of which extend well past initial training sessions. Due to the longstanding commitment of our facility and staff to the utilization of this technology, and our specific nonlinear and linear mathematical analyses, we are in a position to gain substantial new ground in this area. It is through the understanding and interpretation of carefully collected data through subsequent linear and nonlinear mathematical analysis, that the future potential of this technology will be most fruitfully made available.

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