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A Brief History of Electroencephalography and Neurofeedback

Observations of electrical activity of the brain were first reported in 1875 when British physician Richard Caton observed electrical signals while probing the exposed cortices of animals. Fifty years later Hans Berger (1929) showed that electrocortical activity could be detected from the surface of the human scalp. It was Berger who first used the term electroencephalogram (EEG) and who identified different frequencies of brain waves measurable from the scalp. He also found that certain frequencies were characteristic of different states of attention. If subjects sat quietly with eyes closed, Berger observed frequencies around 10 cycles per second (10 Hz); if they were asked to focus on a mathematics problem with eyes open, frequencies were more likely to be in the range of 15 Hz.

Berger's work encouraged others to determine whether particular features of an EEG were diagnostic for neurological or psychological disorders (see Robbins, 2000). Although there was some success linking EEG patterns to brain trauma and seizure disorders, early research was largely unsuccessful in relating EEG to psychopathology. Later in this article we report on more recent developments in the use of sophisticated techniques such as quantitative EEG (QEEG) that have revealed electrocortical correlates of a number of psychological and neurological disorders (Cantor, 1999; Hughes & John, 1999).

Following Miller's (1969) seminal work demonstrating that autonomic functions can be operantly conditioned, psychologists were the first to discover that animals and humans could likewise learn to control their brain waves via contingent feedback (Robbins, 2000). A long series of studies by Sterman and his colleagues (Sterman & Friar, 1972; Sterman, Macdonald, & Stone, 1974) demonstrated that both cats and humans were able to learn to increase the amplitude of frequencies in the 12–15-Hz range recorded in the area of the sensorimotor cortex. Sterman (2000) found that patients with seizure disorders could use operant conditioning to increase these so-called SMR (sensorimotor rhythm) frequencies and thereby reduce seizure activity. As we report below, Sterman and Friar's (1972) work with seizure disorders led directly to the first use of EEG biofeedback for ADHD (Lubar & Shouse, 1976).

At about the same time as Sterman and Friar's (1972) work with frequencies in the 12–15-Hz range, Kamiya (1969) reported that the amplitude of slower brain waves in the 8–11-Hz range (socalled alpha waves) could also be increased through contingent feedback. Kamiya attached electrodes to the surface of the scalp to determine whether humans could correctly identify when there was a predominance of alpha waves (8–12 Hz) in the area of the occipital lobe. His participants were able to identify the state associated with alpha in relatively short order and were able to increase the amplitude of the alpha frequency when signaled to do so.

Kamiya's (1969) work precipitated great interest in the operant conditioning of slower frequencies, both alpha and 4–7-Hz (theta), and the 1960s and 1970s witnessed a large number of studies designed to determine the efficacy of alpha/theta operant conditioning. Outcomes assessed ranged from enhancing peak performance, drug and alcohol abuse, and posttraumatic stress disorder (Evans & Abarbanel, 1999).

Neurofeedback could not withstand the multitude of claims made for its efficacy. The modality quickly became associated with the psychedelic, altered states of consciousness movement that was perceived as a fringe element of scientific psychology. It is not surprising then that it only required a few negative findings for neurofeedback to fall out of favor within the mainstream psychological community (Budzynski, 1999).

Neurofeedback in a New Technological Era

At about the same time that early efforts at EEG biofeedback were falling into disrepute, initial strides were being made in brain imaging techniques. In the past 20 years there has been a revolution in neuroscience, resulting in large part from advances in neuroimaging. Neuroimaging as well as progress in computerized neurophysiology, also known as QEEG, provide tools that may elucidate the mechanisms underlying neurofeedback.

Positron emission tomography (PET) and single photon emission computed tomography (SPECT) assess blood flow and activity patterns in the brain. The procedures require injection of small amounts of radioactive material that allow for visual representation of brain oxygen and glucose utilization. Functional magnetic resonance imaging is a more recent noninvasive technique that, along with PET scans, allows researchers to apprehend brain activity during cognitive tasks (see Sarter, Bernston, & Cacioppo, 1996).

In QEEG, electrodes are placed on multiple predetermined sites on the scalp, and data from these sites are submitted to computer analyses and “brain mapping.” The kinds of results available from conventional EEG and QEEG include but are not limited to distribution of electrical frequencies in various brain regions, the amplitude and shape of these frequencies, and the symmetry of frequencies, amplitudes, and wave shapes on homologous sites on each hemisphere. By comparing these measures to normative databases, researchers are able to identify brain wave patterns that are characteristic of various clinical populations.

On the basis of a review of over 200 studies, Hughes and John (1999) concluded that QEEG qualifies as an assessment tool for cerebrovascular disease, dementia, learning and attention disorders, mood disorders, post-concussion syndrome, schizophrenia, and substance abuse.

The neurofeedback procedure. Regardless of disorder, the neurofeedback procedure is relatively consistent across studies. Neuroelectrical activity is detected via surface electrodes; this activity is then amplified and processed by software programs that provide contingent auditory, tactile, and/or visual feedback to the patient via a game simulation on a computer monitor. For instance, a Pac-Man figure advances and sounds a tone whenever a client maintains waves in the 15–18-Hz range above a certain amplitude threshold while keeping waves in the 4–7 Hz range below a certain threshold. Amplitude thresholds are established for each individual so as to optimize motivation and learning. In this example, a reward would occur whenever the client maintains 15–18-Hz above predetermined amplitude 70% of the time while keeping the 4–7-Hz frequency above predetermined amplitude only 20% of the time.

Outcomes using single-case designs. Neurofeedback for ADHD began as an extension of Sterman and Friar’s (1972) groundbreaking work with epilepsy. Lubar and Shouse (1976) reasoned that increasing the sensorimotor rhythm through neurofeedback might serve to quiet motor responses in “hyperactive” children (as they were then called), much as it did for Sterman’s epileptic patients. Using a blinded ABA reversal design, Lubar and Shouse (1976) provided the first empirical evidence for the value of neurofeedback for ADHD. In this ABA design, a 9-year-old child first learned to improve EEG patterns and behaviors associated with ADHD (as assessed by observers who were blind to the procedure), then to return measures to baseline values, followed by a return to improved behavioral and EEG status. The authors reported that medication was permanently ended following the study and that the child continued to function well without medication long after the study's termination. Using the blind ABA design with other children, Shouse and Lubar (1979) and Tansey (1993) replicated these findings. They also reported long-term positive effects of neurofeedback for these clients that lasted years after treatment, a finding with special significance, because the benefits of psychostimulants are known to last only while the patient is medicated.

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In conclusion, there are varying degrees of certainty about what is known. First, we have known for over 100 years that electrocortical activity can be measured and for over 50 years that different frequencies reflect different states of arousal. Second, we have known for 25 years that both animals and humans can learn to alter their brain waves through operant conditioning and thereby reduce seizures. Third, the work of Hughes and John (1999), among many others, documents that a number of psychological disorders, including ADHD, mood disorders, and schizophrenia, may be discriminated by characteristic patterns of the QEEG...

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