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Growing the Evidence Base for Neurofeedback in Clinical Practice

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Neurofeedback refers to a type of biofeedback using brain/computer interface technology that permits an individual to learn to change the pattern of activity of his or her electroencephalogram (EEG). In this technique, relevant aspects of brain wave activity are accessed and converted in real time into visual and/or auditory displays, allowing the trainee to learn to volitionally alter them. The EEG is dynamic and its activity patterns are constantly fluctuating. Ordinarily, a person would not have any direct awareness of his or her brain wave activity and its fluctuations and, thus, would have no idea of how to change it. However, as with other forms of biofeedback, the feedback display provides the information necessary for reinforcement to be received when fluctuations are in the desired direction. Learning to change brain wave activity modifies how the brain is functioning. Initially, these learned modifications may be very short-lived, but as a person continues to practice making desired alterations in their brain waves, the changes begin to last longer.

Investigations and applications of neurofeedback training began in the 1960s. Since then, the technique has been widely used in the treatment of a variety of disorders, including seizures, attention-deficit/hyperactivity disorder (ADHD), substance abuse, posttraumatic stress disorder (PTSD), anxiety, depression, insomnia, learning disabilities, and more (Hammond, 2011; Hirshberg, Chiu, & Frazier, 2005). Additionally, it has been applied as an aid in

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personal enhancement or peak performance training. However, for much of the time since its inception, mental health disciplines and academic training programs have largely ignored it. Some have suggested that "there persists a level of distrust and/or bias in the medical and research communities in the USA toward neurofeedback and other functional interventions" (Orndorff-Plunkett, Singh, Aragón, & Pineda, 2017, p. 95) As a result, neurofeedback has been largely ignored or disregarded in social neuroscience (e.g., Orndorff-Plunkett et al., 2017). Currently, though, this lack of attention is changing, as there is developing interest in the application of technology in mental health practice.

History of Neurotechnology

The flood of neuroscience publications at the end of the last century was largely the result of advances in neuroimaging technology permitting the viewing of the human brain in operation. For the first time, scientists and clinicians were able to see an intact brain performing some of its various functions without invasive procedures that violated its physical integrity. Previously, brain examination largely happened postmortem and typically involved a brain compromised by injury or disease, greatly limiting the applicability of the findings. Initially in the last 2 decades of the 20th century, positron emission tomography and, later, functional magnetic resonance imaging (fMRI) technology became widely available in university medical centers, as well as in other research and clinical facilities. In 1989, then President George H. W. Bush declared the 1990s the "Decade of the Brain," providing government funding for launching a great many studies in the developing field of neuroscience. In 1978, a total of 6,500 papers regarding brain science were published in refereed journals; by 1998, that number had grown to 17,000 (Rose & Abi-Rached, 2013), in large part due to the development of new imaging technologies and increased government funding for basic neuroscience research. The number of published papers and people involved in the study of the brain has continued to grow throughout the new century. Many universities have renamed their psychology graduate study programs to include "neuroscience" in the titles, and it is a rare psychology training program that does not now include a brain science focus. The brain sciences are now informing many areas of study beyond psychology, neurology, and psychiatry, including infant development, education, economics, sociology, politics, and sports performance.

In addition to the advances associated with functional neuroimaging, other novel and exciting brain science findings were occurring during this same period. Eric Kandel, Michael Merzenich, and Marion Diamond were demonstrating the largely unrecognized capacity of brain structures and activities being altered by specific experiences, introducing the concept of *neuroplasticity* to both the academic and public arenas (Diamond & Hopson, 1999; Kandel, 2006; Merzenich, 2013). Although Hebb (1949) had largely described many of the mechanisms involved in the process of brain changes from experience decades earlier, neuroplasticity was not empirically demonstrated until the work of these pioneering scientists—work that resulted in Kandel being awarded the Nobel Prize in 2000. Prior to this time, the brain was considered to be relatively fixed in both its structure and functioning, with the exception of the recognition of gradual cell loss and functional decline over time. The discovery that the brain's structure and functioning are molded by our experiences opened entirely new avenues of thought and exploration, as well as suggesting novel possibilities for intervention.

TECHNOLOGICAL ADVANCES IN BRAIN SCIENCES

During this explosion of technological advances and scientific discoveries involving the brain and its functioning, some important previous work on the learned alteration of brain functioning has gone largely unnoticed, arguably due to being somewhat ahead of its time. Technology had been developed early in the 20th century for recording the EEG, the first physiological measure of the human brain's activity. Its developer, Hans Berger, was convinced that his tool for watching the brain's electrical activity would be embraced by psychiatry, but the field ultimately denied its utility beyond seizure identification (Schirmann, 2014; Ulrich, 2002). In the 1920s, Berger was the first to record and amplify the electrical activity of the brain by placing sensors on the scalp to measure the electrical impulses generated by brain cells. The EEG is measured in frequency and amplitude—*frequency* reflects the speed of the nerve firings and is measured in hertz (Hz) or cycles per second. More activated brain cells typically fire at a faster rate than a brain at rest. This relationship between firing rate and activation of the brain was the first observation Berger noted in the EEG.

Amplitude refers to power and reflects the magnitude of the voltage being generated at the surface of the brain area being monitored. EEG amplitude is typically measured in microvolts, or a millionth of a volt, as the signal acquired at the scalp is actually very small. The number of brain cells firing synchronously at a particular frequency determines the amplitude an individual brain cell discharges with the same voltage each time it fires.

Conventional terminology divides the EEG frequencies into bandwidths. *Delta* refers to activity below 4 Hz and is typically associated with deep, dreamless sleep. *Theta* activity, considered to exist between 4 and 8 Hz, is common when an individual is drowsy, daydreaming, or visualizing internally generated images. *Alpha* activity is defined as 8 to 12 Hz, is rhythmic (regularly oscillating), and has been shown to be associated with meditation or a relaxed focus. It is considered to represent idling in the brain, as it typically increases in amplitude in the visual centers of the brain when the eyes are closed and attenuates with eye opening. *Beta* activity is in the range of 12 to 20 Hz and is commonly associated with active processing of sensory information, as seen when someone is attentive to external stimuli. Faster beta frequencies above 20 Hz are typically seen in higher states of arousal, such as excitement, anxiety, and fear states. All of the different EEG frequencies are present all of the time. It is the proportions of the various frequencies that fluctuate throughout the day. When sleeping, there is a greater proportion (higher amplitude) of delta waves; when alert and engaged in a cognitive task, delta proportions are diminished and beta frequencies are more prevalent. Mental states are reflected in the patterns of activity seen in the EEG frequencies and amplitudes. There are no good or bad brain wave frequencies—they all are important. Adaptive functioning requires flexibility in states of arousal.

APPLICATIONS OF BRAIN SCIENCE DISCOVERIES

Slowly, brain science discoveries are now finding their way into applied psychology.

Alpha Waves and Calming the Mind and Body

In 1968, more than 20 years prior to the launching of the Decade of the Brain, two researchers were beginning to explore the possibilities for training the EEG through the use of biofeedback. Joe Kamiya, at the University of Chicago and later at the University of California at San Francisco, was exploring enhancement of alpha frequencies in the brain (Kamiya, 1968). Elmer Green, at the Menninger Foundation, had been conducting research on self-regulation of the autonomic nervous system and had discovered that adept meditators produced higher alpha amplitudes compared with nonmeditators. Kamiya began to train individuals to recognize when they were in a state where alpha activity was predominating in the EEG. Kamiya discovered that as the trainees' awareness of their state improved, the percent of time the subjects spent in alpha increased. The conscious awareness of the state associated with the brain wave activity resulted in greater access to it. Additionally, the subjects who showed enhanced spontaneous alpha control reported "mental states reflecting relaxation, 'letting go', and pleasant affect associated with maintaining alpha" (Nowlis & Kamiya, 1970, p. 476). A 1968 article published in *Psychology Today* regarding Kamiya's work generated a great deal of public and professional interest in the instrumental training of alpha activity (Kamiya, 1968). The article described the benefits of being able to reduce stress in the brain by essentially training the brain wave activity closely associated with meditation and physiological stress release. Although other forms of biofeedback were already known and were being used in practice, brain wave biofeedback appeared to offer a more fundamental approach to producing a calmer body and mind through learning to alter the functioning of the central nervous system.

In Jim Robbins's book, *A Symphony in the Brain* (2008), he recounts the history and applications of neurofeedback and tells the story of Abraham Maslow calling Kamiya at 6:00 in the morning after learning of his work just a day earlier, stating he had been unable to sleep that night because of his excitement over the implications such unprecedented learned control of the brain could offer. From such exposure, neurofeedback was popularly seen as a possible panacea for overcoming many of the ills associated with modern life. Many articles appeared in popular publications (e.g., "Behavior: Brain Wave of the Future," 1971; "Mind Over Body, Mind Over Mind," 1971), touting the potential increases in self-awareness and self-regulation offered by this newly emerging technique.

Role of Sensorimotor Rhythm

At approximately this same time, M. Barry Sterman (2000), a researcher at UCLA, was taking a less applied approach to studying the training of the EEG utilizing operant conditioning techniques. Sterman, while researching the mechanisms of sleep, discovered a particular EEG activity that occurred during the transition from wake to sleep. He was interested in the process of internal inhibition facilitating the reduction in activation of the brain necessary to trigger sleep onset. In his studies, he identified a particular brain rhythm generated in the sensory-motor circuits of the brain associated with relaxation. He named this activity the sensorimotor rhythm (SMR) and subsequently found that it was not only associated as a precursor to sleep but with motoric quiescence in general. He saw an increase in SMR activity when his research animals became very still physically, whether they were relaxing prior to falling sleep or becoming very still while fully awake and alert (e.g., prior to pouncing when at play or withholding a motor response in learning experiments). The SMR activity he found was in the beta frequency range, but resembled alpha activity in appearance due to its rhythmicity and, unlike most beta activities which signal activation, it was associated with motoric quiescence. During the period when Sterman was studying the functions of SMR, papers were being published demonstrating learned control over many physiological processes that were previously considered outside of volitional control (see, e.g., Miller & DiCara, 1967). So, Sterman wondered if the EEG was amenable to self-control. He designed a study to determine if the EEG activity of cats could be operantly conditioned. The cats were rewarded with food when they increased the amplitude of their SMR activity after being cued by a light. The cats were readily able to learn to increase the occurrence of SMR activity, and a paper was published adding brain functioning to the list of physiological responses amenable to improved volitional control (Wyrwicka & Sterman, 1968).

At the time Sterman's paper describing the conditioning of the EEG was published, biofeedback was becoming very popular as demonstrations showed that individuals could learn to alter their muscle tension, skin temperature, heart rate, blood pressure, and skin conductance, all primarily associated with relaxation and arousal reduction. However, Sterman's work showed that cats could be taught to increase the amplitude of a specific EEG frequency when presented with a reward for making the increase. Sterman's research was the first to demonstrate the alteration of electrical activity in the brain in response to operant learning techniques. Unfortunately, since his discovery preceded the development of interest in brain activity and a greater appreciation in the brain's role in function and dysfunction, the implications of the discovery that training could alter basic brain activities did not receive the immediate recognition it deserved. The prevailing focus of neurofeedback training remained largely centered on alpha training, relaxation, and stress reduction.

Neurofeedback and Seizure Control

Fortunately, as often happens in science, a set of serendipitous circumstances led to Sterman's discovering a clinical application for operant conditioning of the EEG. After he completed his experiment demonstrating the operant conditioning of the EEG in cats, he received a contract from the National Aeronautics and Space Administration to study the emergence of seizure disorders in personnel working around rocket fuel. During exposure of the cats to the seizure-inducing compounds in the rocket fuel, he noticed a group of the experimental subjects having a much longer latency for the onset of seizure activity during exposure when compared with other cats. He then found that the more seizure-resistant cats were the ones he had previously trained to enhance their SMR activity. Sterman decided that since seizures are considered to result from a failure of inhibitory activity in the brain (see, e.g., Ben-Ari, Krnjevic, & Reinhardt, 1979), the enhancement of an EEG activity associated with inhibition and motoric quiescence might prove useful in the treatment of epilepsy. He confirmed this hypothesis when several individuals with intractable epilepsy were trained to increase their production of the SMR rhythm and showed a reduction in both the frequency and the intensity of their seizures (Sterman, Macdonald, & Stone, 1974). Several subsequent studies have shown the utility of neurofeedback training for seizure control (Sterman, 2000). It was this work that helped launch the field of EEG biofeedback, or neurofeedback as it has come to more typically be called, beyond simply enhancing relaxation. However, neurofeedback had to await the explosion of professional and popular interest in the brain to begin to gain more widespread recognition.

INCREASED RANGE OF APPLICATION

The increased awareness of neurofeedback was in large part due to Joel Lubar, a biopsychologist who studied with Sterman, through his extension of the application of neurofeedback to ADHD, a much more common disorder than epilepsy. Since many individuals with ADHD show deficits in inhibitory functioning, the extension from seizure control to attentional and behavioral control seemed plausible to Lubar. With only two neurofeedback approaches having been used to this point—eyes-closed alpha training and eyes-opened SMR training—he applied the same training protocols used for seizure control and, following neurofeedback training, found improvement in both behavioral regulation and cognitive functioning in children and adolescents diagnosed with ADHD. Lubar and Lubar (1984) refined the antiseizure protocols being used for neurofeedback training for addressing ADHD, by reinforcing not only the mid-beta range of frequencies (where SMR is found) but also the frequency range associated with greater engagement with the environment, while inhibiting theta range activity. Theta frequencies are associated with visualization and a more internal focus, such as that experienced during daydreaming. Lubar and his colleagues published a series of articles in the 1970s and 1980s (for a review of these articles, see Sherlin, Arns, Lubar, & Sokhadze, 2010) describing this expanded approach to neurofeedback and the results they were obtaining. Until his retirement from academics, Lubar, in his role as professor at the University of Tennessee in Knoxville, taught the theory and application of neurofeedback to graduate students enrolled in the psychology program. Currently, several of his students are in leadership positions in the field of neurofeedback and within its professional organizations.

Eugene Peniston developed another modification to neurofeedback training after he attended a workshop given by Elmer Green at the Menninger Clinic. As noted previously, Green had observed increased alpha production in adept meditators when they were not in a meditative state. However, when he examined their EEG during meditation, Green noticed that, as the session progressed, the practitioners' theta amplitude eventually became higher than the alpha amplitude. While attending the workshop with Green where this finding was presented, Peniston envisioned a treatment approach combining autogenic peripheral biofeedback training to facilitate improved arousal regulation, and visualization exercises enhanced by neurofeedback training encouraging increases in both alpha and theta. After the workshop at the Menninger Clinic, Peniston eagerly returned to the Veterans Administration facility in Colorado where he was working and implemented the program he had envisioned. Peniston has described the degree of positive response as surprising even to him. The population he chose for his experiment was Vietnam combat veterans admitted with PTSD and alcoholism. Many of these patients had several previous hospital admissions indicating the chronicity of their struggles. The response to his program was extremely positive, with subsequent randomized studies showing reduced symptomatology, marked changes on personality measures, reduced medication usage, reduced readmissions, and changes in blood chemistry (reduced beta endorphins) indicating reduced overall stress (Peniston & Kulkosky, 1989, 1991). Subsequent replications of Peniston's neurofeedback augmented approach to treating substance abuse problems in residential treatment indicate it continues to be the most effective approach to addictive disorders (for a review of these replications, see Trudeau, 2000).

Through the pioneering work of Sterman, Kamiya, Lubar, Peniston, and many others, the application of EEG biofeedback was extended into several areas of clinical practice. From its beginnings with epilepsy, neurofeedback has been employed with ADHD, PTSD, addiction and substance abuse, depression, anxiety, autism, sleep disturbances, and learning disabilities (for a review, see Brenninkmeijer, 2010). The use of largely the same technique in the treatment of such a wide array of issues and problems produced skepticism among many professionals regarding its reported outcomes. Nearly everyone has heard the saying that "if something sounds too good to be true, it probably is." Additionally, some of the claims being made in the popular media regarding biofeedback were both hyperbolic and premature based on the existing scientific evidence of the time. This skepticism, combined with methodological weaknesses for evidence (e.g., weak or absent sham training controls for double-blinding), contributed to difficulty in obtaining grant money to fund large scale, randomized-controlled research of neurofeedback's efficacy. Nevertheless, empirical support gradually began to accumulate for the utility of neurofeedback for several clinical conditions and for optimal performance (see, e.g., Hammond, 2011).

Empirical Evidence

A recent search of Google Scholar produced 7,700 entries for neurofeedback and EEG biofeedback, with 3,800 papers published within the past 5 years. The recent sharp increase in the number of publications regarding neurofeedback reflects a growing recognition of the approach among research groups. Where much of the early research on neurofeedback was produced by clinicians in private practice and generally had many methodological weaknesses (e.g., small group sizes, limited control comparison, absence of blinding, lack of objective outcome measures), higher quality studies are now being conducted in academic settings and recognized research facilities, particularly in European university centers and governmental facilities in the United States and Canada. Much of the current interest in neurofeedback is propelled by an increased professional and popular interest in the brain and neuroplasticity. Additionally, there is a broadening search for more effective nonpharmacologic approaches to mental health treatment as limitations of the commonly used medications become more widely recognized. To quote the then director of the National Institute for Mental Health (NIMH), Thomas Insel, "current medications help too few people to get better and very few people to get well" (Insel, 2009, p. 704). Greater recognition of the limitations and risks associated with psychoactive medications has prompted greater interest in alternative approaches to changing the brain's operations. Despite increased interest in alternative approaches to treatment, medications remain a primary intervention for addressing mental health problems due to convenience and, in many cases, lower expense. Approaches like psychotherapy and neurofeedback involve a time and financial commitment that continues to limit the number of people seeking and utilizing these techniques. However, the number of clinicians offering such services continues to grow as the demand is increasing.

META-ANALYTIC STUDIES OF NEUROFEEDBACK

Several reviews and meta-analyses have addressed the efficacy of neurofeedback. Sterman (2000) examined 18 peer-reviewed studies on neurofeedback for seizure control and found that the studies showed on average a greater than 50% reduction in both the frequency and severity of seizures in people largely determined to have intractable seizure conditions. Arns, de Ridder, Strehl, Breteler, and Coenen (2009) conducted a meta-analysis of 15 published studies of neurofeedback for ADHD and found "large effect sizes (ES) for neurofeedback on impulsivity and inattention and a medium ES for hyperactivity." A review of the literature regarding outcomes for neurofeedback for substance abuse disorders conducted by Sokhadze, Cannon, and Trudeau (2008) concluded that existing work demonstrated that neurofeedback, when used in combination with residential treatment, added significant improvement in outcome through reduced recidivism and met the established standards for probably efficacious (Level 3 evidence).

The American Academy of Child and Adolescent Psychiatry (AACAP) has established guidelines for recommending different levels of evidence-based treatments. The criteria for the level of "clinical guidelines" states the following:

> "clinical guidelines" [CG] are recommendations that are based on empirical evidence (such as open trials, case studies) and/or strong clinical consensus. Clinical guidelines apply approximately 75% of the time. These practices should always be considered by the clinician, but there are exceptions to their application. (Greenhill et al., 2002, p. 24S)

Using the AACAP criteria, after a review of the published studies of neurofeedback, Hirshberg, Chiu, and Frazier (2005), in a special edition of the *Journal of Child and Adolescent Psychiatric Clinics of North America* on emerging interventions, concluded that neurofeedback

> meets criteria for "clinical guidelines" for treatment of ADHD, seizure disorders, anxiety (e.g., obsessive-compulsive disorder, GAD, posttraumatic stress disorder, phobias), depression, reading disabilities, and addictive disorders. This finding suggests that EBF [EEG biofeedback] should always be considered as an intervention for these disorders by a clinician. (p. 12)

Despite the supportive evidence, virtually all the reviewers of neurofeedback studies have concluded that additional and better-designed studies using randomized controlled trials need to be conducted; several of those studies are currently underway.

In contrast to these positive reports, some recent studies have cast doubt on the earlier outcome findings. A meta-analysis of neurofeedback and ADHD, conducted by Cortese et al. (2016), concluded that "outcomes currently fail to support neurofeedback as an effective treatment for ADHD" (p. 444). Marzbani, Marateb, and Mansourian (2016) reviewed existing neurofeedback outcome studies and also concluded that "current research does not support conclusive results about its efficacy" (p. 143). Both reviews were criticized by those in the neurofeedback community for omitting studies that appeared to satisfy the inclusion criteria for analysis or review, for excluding evidence of physiological change, and for overgeneralization of null findings. Regardless of the merit of the criticisms, important issues regarding neurofeedback research methodology were raised.

There are a wide variety of approaches for conducting neurofeedback, including the aspect of the EEG targeted for training, schedule, number and length of training sessions, EEG frequencies trained, thresholds for delivering feedback, discrete or continuous delivery of feedback, and the number of channels of EEG utilized. Further, many published studies do not show objective functional or physiological changes following training, which would permit transfer beyond the training situation. It was even suggested by one group of researchers that most of the reported positive neurofeedback outcome findings can be explained by placebo responses that should be explored for their utility, as neurofeedback may be a particularly potent placebo (Thibault, Lifshitz, & Raz, 2017). Most critical reviewers, though, rather than advocating its abandonment, have concluded that better research methodologies should be employed in investigating neurofeedback.

PROMISING NEUROFEEDBACK RESEARCH OUTCOMES

Neurofeedback's greatest contribution may prove to be in areas where the existing treatments show significant limitations. Due to the prevalence of early abuse, neglect, and trauma, combined with the large number of men and women exposed to the traumas associated with military combat and the increasing exposure to violence and terrorism throughout the world, there are a great many people dealing with chronic and complex PTSD. Several neuroimaging studies have shown significant disruptions of neurobiological functioning from chronic traumatic exposure (for a recent review, see Teicher, Samson, Anderson, & Ohashi, 2016). Some recent publications show a positive response to neurofeedback training when combined with trauma-focused psychotherapy (Gapen et al., 2016; Nicholson et al., 2016; van der Kolk et al., 2016). The studies showed significant improvement through reduction of PTSD symptoms and improvement in affect regulation. The positive outcomes described in these recent studies on complex and chronic trauma have prompted further exploration and implementation of neurofeedback in settings specialized for trauma treatment, such as military and veterans' treatment facilities, and in residential treatment centers for adolescents who experienced trauma during their early development.

A second area garnering interest for additional benefit from the addition of neurofeedback to existing treatment approaches is autism spectrum disorder (ASD). According to statistics from the Centers for Disease Control and Prevention, the rate of diagnosis for ASD more than doubled between 2000 and 2012. Though some optimal outcomes have been reported where treated individuals no longer met criteria for an ASD diagnosis, the condition for most is generally considered to be lifelong, with relatively few people with moderate to severe symptoms ever attaining the ability to fully live independently. Studies involving the addition of neurofeedback to the treatment regimen for individuals with ASD have shown improvement in impulsivity, anxiety, neuropsychological functioning, and educational performance (e.g., Othmer, 2007; Thompson & Thompson, 2003; Thompson, Thompson, & Reid, 2010).

A third area of promise for the use of neurofeedback is schizophrenia, which is generally regarded as a severe and persistent mental disorder. In the Western nations, neuroleptic medications are typically considered to be the first-line choice of treatment for schizophrenia, but several studies over the years have shown some disturbing statistics regarding the efficacy of neuroleptic medications in the long-term outcomes for this population. As reported by Robert Whitaker (2005), a review of research beginning in the 1970s shows increased incidents of relapse in actively medicated patients with schizophrenia, compared with those receiving placebo, and negative side effects associated with the medications frequently led to noncompliance. Two outcome studies involving the use of neurofeedback for schizophrenia show very encouraging results. Bolea (2010) described the outcomes for 70 patients identified as "severe and chronic schizophrenic patients" showing changes in the EEG, along with improved test scores and functional ability with persistence at two-year follow-up. Additionally, Surmeli, Ertem, Eralp, and Kos (2012) reported the use of neurofeedback with 51 patients diagnosed with schizophrenia, showing improvement in both positive and negative symptoms of schizophrenia and improved cognitive functioning. Although there was no randomization and control group comparisons in either of these studies, the outcomes are sufficiently promising to warrant further investigation.

Expanding Approaches to Neurofeedback

In addition to the original neurofeedback protocols of alpha, beta/SMR, and alpha/theta training pioneered by Kamiya, Sterman, and Peniston, a variety of additional protocols for training the EEG have emerged over the past 2 decades. Current neurofeedback applications exist for training aspects of the EEG beyond frequency and amplitude—these include slow cortical potentials, evoked potentials, and variability of the EEG. Additionally, specific areas of the brain can be targeted by using protocols aimed at particular brain regions through source localization procedures and EEG measures obtained from a quantitative assessment of the EEG (where comparisons are made to a normative database). Many of the newer approaches involve the use of multiple channels of EEG data and higher order mathematics. There is less empirical support for these more recent approaches in terms of the number of studies conducted, and, currently, they have not been shown to be superior to the earlier applications. However, as we continue to learn more about the brain and its operations, it is likely that additional, more specialized, techniques will continue to be developed.

Even though there are many studies showing beneficial outcomes from the application of neurofeedback training for a variety of disorders, there is no consensus regarding the specific mechanisms for achieving beneficial changes. In the seizure studies reviewed by Sterman (2000), he concluded that although many of the subjects who showed a good clinical outcome had contingency-related EEG changes and the expected shift toward normalization, others who improved their seizure control did not show the expected changes. Still other studies showed a shift toward normalization of the EEG without a change in seizure frequency or intensity. However, still other studies for different conditions have shown that expected EEG changes positively correlated with symptom improvement (e.g., Gevensleben et al., 2009; Paquette, Beauregard, & Beaulieu-Prévost, 2009). To further complicate matters, more studies using functional imaging measures other than the EEG have shown brain changes in response to neurofeedback in regions not closely associated with the site of training (e.g., Lévesque, Beauregard, & Mensour, 2006; Nicholson et al., 2016). Given the recognized complexity of the brain's organization and operation, it should not be too surprising that many of the mechanisms for change have yet to be fully identified.

Regarding biofeedback procedures, though, the general rationale is that the feeding back of information regarding physiological functioning permits one to learn volitional control over the response. With neurofeedback, the information being fed back relates to the activity of the EEG, and the activity of the EEG is correlated with the arousal level of the brain. The frequency ranges of brain wave activity from 0 to 30 Hz form a continuum reflecting the spectrum of arousal. The slower speeds are associated with lower states of arousal (e.g., deep sleep), while the higher frequencies reflect progressively greater states of arousal reaching excitement or anxiety (in the faster beta ranges). It is this correlation between brain wave activity and arousal that has been most broadly employed in neurofeedback applications and accumulated the greatest amount of empirical support.

THE AROUSAL MODEL OF NEUROFEEDBACK

The Yerkes-Dodson Law, showing the familiar inverted U relationship between arousal and performance, was originally applied to learning via an intensity of punishment paradigm (see Yerkes & Dodson, 1908). The popular understanding of the original research indicates that performance will increase as arousal increases to a point, and then will begin to decrease as arousal continues to climb. This understanding led to the idea of a single optimal arousal level in the middle of the inverted U. Subsequent researchers, however, have developed a more nuanced view of arousal by indicating that optimal arousal is associated with the complexity level of the task. Simpler tasks require a higher level of arousal to be performed efficiently, while more complex tasks require a lower level. These findings may sound somewhat paradoxical initially, but we generally know that a boring task will require us to stay more aroused to complete it quickly and efficiently and, thus, we may tend to have some extra caffeine or resort to playing music with a more upbeat tempo. However, when engaged in a complex task, such as calculations or reading more challenging material, in order to reduce our arousal, we will tend to reduce external stimulation by seeking a quiet space and might choose no music or slower tempo instrumental sounds for our background. The conclusion is that there is no single level of arousal that is optimal for every task. Optimal functioning is associated with flexible arousal and the ability to adjust arousal according to task demands.

Many people struggle with problems associated with being "stuck" at one end or the other of the arousal continuum. Instead of having flexible arousal, they spend much of their day in a similar arousal condition. Excesses of the faster beta frequencies or a deficit of resting activity, such as alpha, as depicted in the EEG, represents overarousal. Problems typical of overarousal marked by elevated fast beta or deficient slower frequency activity, such as low alpha, include anxiety, sleep onset problems, anger and agitation, restlessness and hyperactivity, and pain associated with excess muscle tension. Underarousal is reflected in the brain by excesses of slower frequency activity, such as alpha or theta, especially when an individual is attempting to engage in a task. Issues associated with underarousal include depression, attention and concentration problems, early morning awakenings, low motivation, and excessive daydreaming. Difficulties achieving and maintaining appropriate levels of arousal are ubiquitous among clinical populations but can also be seen in the general public. Emotion regulation is closely associated with arousal regulation and is why many approaches to dealing with dysregulated emotions involve calming the physiology with relaxation techniques, or activation strategies (e.g., exercise, increased interpersonal engagement) are common in the treatment of anxiety or depression. Neurofeedback has primarily been a tool throughout its utilization as a means for training improved arousal regulation. Many of the positive results reported for neurofeedback may well rely on improved self-regulation.

EXECUTIVE FUNCTIONS AND EEG PROFILES

Another important cognitive function that has proven amenable to neurofeedback training is executive attention. Many, if not most, clinical problems have a negative impact on the functioning of executive attention. Certainly, it is an important feature of ADHD, but it is also impacted with depression and anxiety disorders. Humans possess two attention systems in the brain. The evolutionarily older attention system is closely associated with the reticular activating system, originating in the brain stem with nerve fibers primarily projecting to the posterior areas of the brain importantly involved in sensory input and integration. This older system's purpose is to aid in our basic survival by facilitating the orienting reflex responses, quickly recognizing danger, feeding, mating opportunities, and the identification and evaluation of novel stimuli. It appears to be largely instinctively programmed and develops early in life. The executive attention system, on the other hand, is largely mediated by the more recently evolved frontal lobes and helps form the basis of executive functioning. It involves the ability to choose our focus, ignore distractions, and allocate limited processing resources. Modern life places high demands on our attentional capacity, and executive attention is necessary for adaptive and efficient functioning in human societies. From the many outcome studies on the use of neurofeedback for ADHD, neurofeedback training can have a positive effect on executive attention.

Role of Neurofeedback in Clinical Practice

Since arousal dysregulation and attention problems are very common in a variety of clinical conditions, there appears to be a significant role for neurofeedback training in mental health practice given its history of good outcomes for these issues. However, many issues ultimately limit its adoption for use. In addition to still having to overcome lingering skepticism regarding a single technique having such broad applicability, another major factor has been the lack of reimbursement for neurofeedback services from third-party payors. Most insurance companies continue to consider neurofeedback an "experimental" approach or deem it "not medically necessary" given the availability of more recognized therapies (i.e., mainly medications and conventional psychotherapies). This lack of coverage results in many clients having to pay for the services out-of-pocket when their insurance will cover medication and/or psychotherapy services, but not neurofeedback. Another factor is that the training sessions in a practitioner's office are often recommended to occur more than once weekly, requiring the scheduling of multiple appointments. Further, the number of qualified providers of neurofeedback services is still relatively low, often making it difficult to find a conveniently located and experienced clinician. The costs of obtaining training in neurofeedback and purchasing the necessary equipment, as well as the rather steep learning curve for competent operation of the equipment, can pose a challenge to clinicians. The cost of equipment can quickly reach several thousand dollars. These associated costs can be a major deterrent for many clinicians, particularly early-career ones who may be confronting large college-loan debts.

RECENT TECHNOLOGICAL ADVANCES IN NEUROFEEDBACK EQUIPMENT

Fortunately, some recent technological advances provide solutions for many of the major barriers facing clinicians who would like to employ neurofeedback procedures in their practices. Several personal-use neurofeedback training devices have been produced that are affordable and require minimal training to use. As modern societies move to ever greater incorporation of technology in daily life, it seems inevitable that we will be including more of it to help foster improved health and greater well-being. Mass production of EEG measurement and training hardware has resulted in the availability of neurofeedback devices that cost under $300 (with some as low as $100) and are extremely easy for an individual to learn to use. Many established neurofeedback providers have been reluctant to utilize these devices, but others are starting to employ them as a means of providing EEG biofeedback or extending training beyond their offices.

The majority of personal neurofeedback training devices currently available are aimed at relaxation and/or improving focus. Although there are many specialized approaches or applications used in neurofeedback not currently available in personal-use devices, the ones now on the market employ aspects of neurofeedback protocols that have been used in research studies or clinical practice primarily oriented to helping people learn to regulate their arousal and strengthen their focus. The personal-use devices and programs generally provide a limited and fixed number of placement sites for sensing the EEG. The system typically used for EEG recording in both neurology and neurofeedback settings is called the International 10/20 system and involves a series of sites covering 19 standardized locations on the scalp, overlaying each of the major lobes and midline areas of the brain. With the typical approaches to neurofeedback, sites are individually selected on the basis of the therapist's assessment and prepared by using alcohol, a mild abrasive scrub, and the application of conductive gel on the sensors. Care is taken to move the hair, when necessary, to achieve good contact with the scalp in order to facilitate the recording of an electrical signal so small it is measured in microvolts. However, with most of the personal-use devices, placements primarily involve the locations on the forehead to avoid signal connection complications associated with hair and to reduce the need for extensive site preparation. Some equipment manufacturers have developed innovative sensor technologies that allow scalp placements beyond the forehead and still not requiring abrasion or gel. Sensor technology is advancing rapidly, and the current limitations for sensor placement will likely be obsolete in the very near future. However, for the purposes of general arousal and focus training, specific site locations become less critical as global changes for a particular frequency are seen when it is reinforced or inhibited at any particular location. Also, as mentioned previously, studies examining the changes in brain functioning in response to neurofeedback training show alterations in major governing networks that may be anatomically removed from the specific site of training.

There is growing recognition that our old system of diagnosing and treating psychological problems by employing medical model approaches based on specific treatments for specific diagnoses has not served mental health well. The NIMH has adopted a new Research Domain Criteria Initiative to help guide research and treatment initiatives in mental health (with descriptions of the domains posted on the NIMH website). The domains and constructs are transdiagnostic and not unique to a particular disorder. Research proposals submitted to NIMH are expected to reflect a focus on the identified domains and constructs reflecting the current perspectives on emotion, cognition, motivation, and social behavior. In this new model, five domains are currently identified as important for adaptive functioning. The domains include several aspects that have been shown to be responsive to neurofeedback training, including arousal/regulatory systems, anxiety, attention, and social communication.

Neuroscience evidence appears to support the new approach of NIMH for shifting the focus from discrete diagnoses to functional domains. A recently published meta-analysis of MRI studies showed significant overlap in the neuroanatomical abnormalities across a number of different diagnoses, such as major depressive disorder, bipolar disorder, social anxiety disorder, and obsessive–compulsive disorder (see Jenkins et al., 2016). The problem identified in the 37 studies reviewed reflects a common deficit of functional connectivity between the executive control centers of the brain (which helps plan and maintain task focus) and the so-called default mode network (the system responsible for our passive, self-focused thoughts). Since these networks work in alternation—activation of one suppresses the other—the findings indicate the common functional difficulty is excessive engagement of the default mode network. Activation of the central executive network, as happens when volitional attention is engaged, leads to suppression of the default mode network. Recent studies have shown the ability of neurofeedback to impact these critical networks (Lanius, Frewen, Tursich, Jetly, & McKinnon, 2015).

COMMON UNDERLYING NEUROPHYSIOLOGICAL FEATURES

The idea of common neurophysiological features underlying a variety of psychological problems facilitates an understanding of the broad clinical application of mindfulness meditation seen in the past several years. A review of the empirical literature on the effects of mindfulness on psychological health conducted at Duke University (Keng, Smoski, & Robins, 2011) concluded that the practice of "mindfulness brings about various positive psychological effects, including increased subjective well-being, reduced psychological symptoms and emotional reactivity, and improved behavioral regulation" (p. 1041). These are the outcomes most therapists generally seek to achieve in their practice of psychotherapy with clients, and meditation facilitates their development. However, despite the greater acceptance of meditation practices in the West since the work of Jon Kabat-Zinn, Daniel Goleman, and many others (Kabat-Zinn, 2013; Mindful Staff, 2011), they remain somewhat foreign to the Western culture and lifestyles, and many practitioners admit that it is difficult to get their clients to practice meditation on a regular schedule. Here is where inexpensive, convenient, and easy-to-use neurofeedback technology and training can be of particular benefit.

The low cost and low burden of expertise necessary for adoption of neurofeedback training in mental health practices provides an opportunity for professionals to begin to easily and confidently include applied neuroscience approaches in their work with clients. Most clients now are exposed to brain science information through popular media, creating a curiosity and interest that can be tapped by clinicians to help their clients. Clients are also hearing about the brain's plasticity and how this may be applied to develop new capacities or reduce the impact of stress and aging. Also, a large and growing number of people have heard about or even tried to engage in meditation practices and are aware of their potential benefits, but have failed to implement them in their daily routine or have tried but given up for a variety of reasons. All of this creates an unprecedented opportunity for clinicians to introduce applied neuroscience technology with their clients, and neurofeedback has the longest history of clinical application and the most empirical support for its use.

Getting Started—Incorporating Neurofeedback in Clinical Practice

The interested clinician should begin by exploring the personal-use neurofeedback equipment that is currently available. There are more devices and training programs being introduced on a regular basis. Some of the current devices include the Neurosky, BrainLink, Muse, Versus, and iFocusBand. These products come with instructions for their training programs, which generally target improving executive focus, arousal reduction, or both. Some connect with mobile devices, such as tablets and smartphones, while others can connect with computers. The focus of the clinician's practice may influence the choice of a specific device as some, such as Versus or iFocusBand, are primarily aimed at sports and peak performance applications, while the Muse is marketed as an aid for stress reduction and meditation, and the Neurosky and BrainLink have applications for improving and sustaining focus combined with programs for meditation and arousal reduction.

Once a decision is reached regarding the most advantageous available product for the patient, it will be important for the clinician to become thoroughly familiar with the device and the accompanying training protocols. Learning how to wear the device and attain a good connection will better position clinicians to instruct clients in how to get started with their own training. To describe the training experience to clients, the clinician will also need to be familiar with the training experience. Some of the programs use visual displays, some auditory, and some a combination. Some devices even have choices regarding modalities for feedback. Though most of the personal neurofeedback devices are intended for direct sale to consumers, clients will typically feel more confident if they are introduced to the device and its utilization by the therapist recommending its use.

FOCUS OF NEUROFEEDBACK

Further, it will be important for the clinician to be familiar with arousal techniques and their importance for self-regulation. Recognizing which problems are associated with over- and underarousal can help clinicians choose which applications to use for a client's training. Arousal reduction techniques are more often associated with relaxation, stress reduction, or meditation applications. Problems, which are often reduced by arousal reduction approaches, include anxiety, fear, anger, restlessness, impatience, tension, and difficulties falling asleep. Problems associated with underarousal include depressed mood, inattentiveness, poor concentration, fogginess, lack of motivation, and sleep maintenance issues. These issues are often helped by training to increase focus, which tends to increase arousal. The clinician's ability to relate the client's complaints to problems with the regulation of arousal will help motivate the client to be more consistent with their utilization of the training technology.

Psychoeducation is also important when incorporating neurofeedback. It is important for the clinician to convey some of the basics regarding neuroplasticity, which is another concept that can be useful for clients. The increased availability of information regarding the brain's influence on our perceptions, emotions, thoughts, and behavior has not gone unnoticed. The most revolutionary findings from this body of knowledge, though, are those related to neuroplasticity. The fact that the structure and organization of the brain can be altered by experience provides a very realistically hopeful message for most clients. Many members of the general public may have understood that their life struggles may be related to problems in their brain, but fewer will have learned that at least some of these issues can be altered. There are many sources available for learning about neuroplasticity, but two particularly useful sources are Norman Doidge's (2010) *The Brain That Changes Itself: Stories of Personal Triumph From the Frontiers of Brain Science* and Jeffrey Schwartz and Sharon Begley's (2002) *The Mind and the Brain: Neuroplasticity and the Power of Mental Force*. Some books among those that are available do make claims that cannot be substantiated at this time. It is clear that the limits of neuroplasticity are not yet known, but it is important to relay information to clients that can be empirically demonstrated, in order to preserve credibility. Unrealistic expectations by either the clinician or the client are likely to lead to disappointment.

INDIVIDUALIZING TREATMENT

There is no established evidence for the frequency or the length of individual training sessions. However, the personal neurofeedback training devices allow for many more options than appointments with a provider would likely accommodate. One thing that is known regarding neuroplasticity, though, is that frequency, intensity, and duration are important for the process. There are likely individual differences in optimal levels with regard to the frequency of practice sessions, the difficulty of the challenge level, and the length of the training sessions. Most clinicians have to make similar decisions when making assignments for work outside of the office sessions when they are working with clients. The advantage when using neurofeedback is that most of the devices provide feedback on the frequency, duration, and outcome from the sessions to help clinicians with their decision making (see, e.g., Magnavita, 2016).

In clinical practice, most practitioners have found that daily practice of arousal reduction techniques are common, whether meditation, progressive muscle relaxation, diaphragmatic breathing, or other approaches are used. Having access to technology that can be used at home can effectively speed the response to neurofeedback by extending training beyond the therapist's office. For all general purposes, the more an overaroused person can practice reducing arousal, the quicker they are likely to realize relief. With focus training, however, more energy is involved in the training, and the length of training sessions can be graduated, beginning with short and frequent sessions progressing to longer, but less frequent, ones. Research on focus training in neurofeedback typically has involved two to three sessions per week. Again, the use of personal training equipment provides opportunities to use home practice between office visits, but the length of these sessions will need to be tailored to the age and stamina of the individual client.

EXPANDING EXPERTISE AND RANGE OF APPLICATION THROUGH FURTHER TRAINING

Many practitioners who begin to employ personal neurofeedback technology with their clients may decide to expand their neurofeedback capabilities and pursue additional training and equipment that allow for the use of more targeted placement of EEG sensors and protocols aimed at changing other features of the EEG beyond frequency amplitude. As we learn more about the brain and how it functions, more options for training by means of EEG biofeedback will be added. Approved training courses and certification in neurofeedback is available through the Biofeedback Certification International Alliance (http://www.bcia.org). With progressively more clinics and facilities beginning to offer neurofeedback services, options and exposure will likely continue expanding for the foreseeable future. However, the range and quality of the equipment available permits almost all clinicians to begin using this very promising approach in their practices immediately.

Summary

We are entering an era in which technology will be increasingly incorporated into mental health treatment, just as it has become inexorably interwoven in daily life. Advances in brain imaging technology have produced insights into the central nervous system's role in a variety of mental and behavioral disorders. These discoveries have helped to launch a variety of new interventions for use in mental health practice, including EEG biofeedback, transcranial direct current stimulation, cranial electrotherapy stimulation, vagal nerve stimulation, low-level laser therapy, and others. Of the technology-based approaches, EEG biofeedback, or neurofeedback as it is commonly known, has been employed by the largest number of clinicians for the longest time and has the most empirical support for its efficacy, despite continued controversy regarding its outcomes. Using brain–computer interface technology, neurofeedback provides moment-by-moment information to the trainee about EEG functions, which in turn helps patients learn to regulate these functions. Neurofeedback has been used to promote relaxation and stress reduction and in the treatment of epilepsy, ADHD, substance abuse, anxiety, PTSD and many other conditions. There are a large number of studies showing neurofeedback's efficacy. There are promising findings of neurofeedback's utility in some conditions considered difficult to treat, such as chronic PTSD, schizophrenia, and ASD. Many of these studies, though, have methodological weaknesses as they have been conducted primarily in clinical settings; but research using randomized clinical trials is currently underway at several universities and research facilities throughout the world.

Despite the amount of promising evidence for its efficacy, neurofeedback has not been as widely incorporated into typical mental health practices as might be expected. At least one of the limits to its broader utilization is financial. At present, few payors cover the cost of the clients' sessions, requiring them to pay out-of-pocket for neurofeedback sessions. There is also the cost of equipment and training in its use, which can easily reach several thousand dollars. Recently, though, better quality personal-use neurofeedback technology has become available at a much lower cost. These devices are easy to learn to use and can be incorporated into treatment without the need to schedule separate training sessions. Although the personal-use devices have a limited range of placement and training targets, they are generally aimed at reducing arousal, facilitating meditation-type states, or improving focus. Since these are often goals in typical mental health treatment plans, the personal-use devices can readily be used in the treatment of a broad array of presenting problems or for performance enhancement. More specific neurofeedback applications may be necessary for more severe or complicated problems, but personal-use devices may still help clients extend their self-regulation training beyond the office setting. Some of the personal-use applications even permit the clinician to monitor the client's frequency and duration of practice, along with their performance, when practicing at home. It appears very likely that the improved quality, relatively low cost, and ease of use of the new equipment will expand the incorporation of neurofeedback in mental health practices and eventually lead more clinicians to pursue additional training for its use in more specialized applications.

References

Arns, M., de Ridder, S., Strehl, U., Breteler, M., & Coenen, A. (2009). Efficacy of neurofeedback treatment in ADHD: The effects on inattention, impulsivity and hyperactivity: A meta-analysis. *Clinical EEG and Neuroscience, 40*, 180–189. http://dx.doi.org/10.1177/155005940904000311

Behavior: Brain wave of the future. (1971, July 19). *Time*. Retrieved from http://content.time.com/time/subscriber/article/0,33009,905369,00.html

Ben-Ari, Y., Krnjevic, K., & Reinhardt, W. (1979). Hippocampal seizures and failure of inhibition. *Canadian Journal of Physiology and Pharmacology, 57*, 1462–1466. http://dx.doi.org/10.1139/y79-218

Bolea, A. S. (2010). Neurofeedback treatment of chronic inpatient schizophrenia. *Journal of Neurotherapy, 14*, 47–54. http://dx.doi.org/10.1080/10874200903543971

Brenninkmeijer, J. (2010). Taking care of one's brain: How manipulating the brain changes people's selves. *History of the Human Sciences, 23*, 107–126. http://dx.doi.org/10.1177/0952695109352824

Cortese, S., Ferrin, M., Brandeis, D., Holtmann, M., Aggensteiner, P., Daley, D., . . . European ADHD Guidelines Group. (2016). Neurofeedback for attention-deficit/

hyperactivity disorder: Meta-analysis of clinical and neuropsychological outcomes from randomized controlled trials. *Journal of the American Academy of Child & Adolescent Psychiatry, 55*, 444–455. http://dx.doi.org/10.1016/j.jaac.2016.03.007

Diamond, M., & Hopson, J. (1999). *Magic trees of the mind: How to nurture your child's intelligence, creativity, and healthy emotions.* New York, NY: Penguin Putnam.

Doidge, N. (2010). *The brain that changes itself: Stories of personal triumph from the frontiers of brain science.* Carlton North, Victoria, Australia: Scribe.

Gapen, M., van der Kolk, B. A., Hamlin, E., Hirshberg, L., Suvak, M., & Spinazzola, J. (2016). A pilot study of neurofeedback for chronic PTSD. *Applied Psychophysiology and Biofeedback, 41*, 251–261. http://dx.doi.org/10.1007/s10484-015-9326-5

Gevensleben, H., Holl, B., Albrecht, B., Schlamp, D., Kratz, O., Studer, P., . . . Heinrich, H. (2009). Distinct EEG effects related to neurofeedback training in children with ADHD: A randomized controlled trial. *International Journal of Psychophysiology, 74*, 149–157. http://dx.doi.org/10.1016/j.ijpsycho.2009.08.005

Greenhill, L. L., Pliszka, S., Dulcan, M. K., & the Work Group on Quality Issues. (2002). Practice parameter for the use of stimulant medication in the treatment of children, adolescents, and adults. *Journal of the American Academy of Child and Adolescent Psychiatry, 41*(2 Suppl.), 26S–49S.

Hammond, D. C. (2011). What is neurofeedback: An update. *Journal of Neurotherapy, 15*, 305–336. http://dx.doi.org/10.1080/10874208.2011.623090

Hebb, D. O. (1949). *The organization of behavior.* New York, NY: Wiley and Sons.

Hirshberg, L. M., Chiu, S., & Frazier, J. A. (2005). Emerging brain-based interventions for children and adolescents: Overview and clinical perspective. *Child and Adolescent Psychiatric Clinics of North America, 14*, 1–19. http://dx.doi.org/10.1016/j.chc.2004.07.011

Insel, T. R. (2009). Disruptive insights in psychiatry: Transforming a clinical discipline. *Journal of Clinical Investigation, 119*, 700–705. http://dx.doi.org/10.1172/JCI38832

Jenkins, L. M., Barba, A., Campbell, M., Lamar, M., Shankman, S. A., Leow, A. D., . . . Langenecker, S. A. (2016). Shared white matter alterations across emotional disorders: A voxel-based meta-analysis of fractional anisotropy. *NeuroImage: Clinical, 12*, 1022–1034. http://dx.doi.org/10.1016/j.nicl.2016.09.001

Kabat-Zinn, J. (2013). *Full catastrophe living* (Rev. ed.). New York, NY: Bantam Books.

Kamiya, J. (1968). Conscious control of brain waves. *Psychology Today, 1*, 56–60.

Kandel, E. R. (2006). *In search of memory: The emergence of a new science of mind.* New York, NY: W. W. Norton.

Keng, S.-L., Smoski, M. J., & Robins, C. J. (2011). Effects of mindfulness on psychological health: A review of empirical studies. *Clinical Psychology Review, 31*, 1041–1056. http://dx.doi.org/10.1016/j.cpr.2011.04.006

Lanius, R. A., Frewen, P. A., Tursich, M., Jetly, R., & McKinnon, M. C. (2015). Restoring large-scale brain networks in PTSD and related disorders: A proposal for neuroscientifically-informed treatment interventions. *European Journal of Psychotraumatology, 6*, 27313. http://dx.doi.org/10.3402/ejpt.v6.27313

Lévesque, J., Beauregard, M., & Mensour, B. (2006). Effect of neurofeedback training on the neural substrates of selective attention in children with attention-deficit/hyperactivity disorder: A functional magnetic resonance imaging study. *Neuroscience Letters, 394*(3), 216–221. http://dx.doi.org/10.1016/j.neulet.2005.10.100

Lubar, J. O., & Lubar, J. F. (1984). Electroencephalographic biofeedback of SMR and beta for treatment of attention deficit disorders in a clinical setting. *Biofeedback and Self-Regulation, 9*, 1–23. http://dx.doi.org/10.1007/BF00998842

Magnavita, J. J. (2016). *Clinical decision making in mental health practice*. Washington, DC: American Psychological Association. http://dx.doi.org/10.1037/14711-000

Marzbani, H., Marateb, H. R., & Mansourian, M. (2016). Neurofeedback: A comprehensive review on system design, methodology, and clinical applications. *Basic and Clinical Neuroscience, 7*, 143–158. http://dx.doi.org/10.15412/J.BCN.03070208

Merzenich, M. (2013). *Soft-wired: How the new science of brain plasticity can change your life*. San Francisco, CA: Parnassus.

Miller, N. E., & DiCara, L. (1967). Instrumental learning of heart rate changes in curarized rats: Shaping, and specificity to discriminative stimulus. *Journal of Comparative and Physiological Psychology, 63*, 12–19. http://dx.doi.org/10.1037/h0024160

Mindful Staff. (2011, April 20). Why we find it hard to meditate. *Mindful*, 51–52.

Mind over body, mind over mind. (1971, September 12). *The New York Times*, p. SM34. Retrieved from http://www.nytimes.com/1971/09/12/archives/mind-over-body-mind-over-mind-such-is-the-twin-promise-of.html

Nicholson, A. A., Ros, T., Frewen, P. A., Densmore, M., Théberge, J., Kluetsch, R. C., . . . Lanius, R. A. (2016). Alpha oscillation neurofeedback modulates amygdala complex connectivity and arousal in posttraumatic stress disorder. *NeuroImage: Clinical, 12*, 506–516. http://dx.doi.org/10.1016/j.nicl.2016.07.006

Nowlis, D. P., & Kamiya, J. (1970). The control of electroencephalographic alpha rhythms through auditory feedback and the associated mental activity. *Psychophysiology, 6*, 476–484. http://dx.doi.org/10.1111/j.1469-8986.1970.tb01756.x

Orndorff-Plunkett, F., Singh, F., Aragón, O. R., & Pineda, J. A. (2017). Assessing the effectiveness of neurofeedback training in the context of clinical and social neuroscience. *Brain Sciences, 7*, E95. http://dx.doi.org/10.3390/brainsci7080095

Othmer, S. (2007, February). *Progress in neurofeedback for the autism spectrum*. Paper presented at the 38th meeting of the Association for Applied Psychophysiology & Biofeedback, Monterey, CA.

Paquette, V., Beauregard, M., & Beaulieu-Prévost, D. (2009). Effect of a psychoneurotherapy on brain electromagnetic tomography in individuals with major depressive disorder. *Psychiatry Research: Neuroimaging, 174*, 231–239. http://dx.doi.org/10.1016/j.pscychresns.2009.06.002

Peniston, E. G., & Kulkosky, P. J. (1989). Alpha-theta brainwave training and beta-endorphin levels in alcoholics. *Alcoholism: Clinical and Experimental Research, 13*, 271–279. http://dx.doi.org/10.1111/j.1530-0277.1989.tb00325.x

Peniston, E. G., & Kulkosky, P. J. (1991). Alpha-theta brainwave neuro-feedback for Vietnam veterans with combat-related post-traumatic stress disorder. *Medical Psychotherapy, 4*, 47–60.

Robbins, J. (2008). *A symphony in the brain* (2nd ed.). New York, NY: Grove Press.

Rose, N., & Abi-Rached, J. M., (2013). *Neuro: The new brain sciences and the management of the mind*. Princeton, NJ: Princeton University Press.

Schirmann, F. (2014). "The wondrous eyes of a new technology"—A history of the early electroencephalography (EEG) of psychopathy, delinquency, and immorality. *Frontiers in Human Neuroscience, 8*, 232. http://dx.doi.org/10.3389/fnhum.2014.00232

Schwartz, J. M., & Begley, S. (2002). *The mind and the brain: Neuroplasticity and the power of mental force*. New York, NY: HarperCollins.

Sherlin, L., Arns, M., Lubar, J. F., & Sokhadze, E. (2010). A position paper on neurofeedback for treatment of ADHD. *Journal of Neurotherapy, 14*, 66–78. http://dx.doi.org/10.1080/10874201003773880

Sokhadze, T. M., Cannon, R. L., & Trudeau, D. L. (2008). EEG biofeedback as a treatment for substance use disorders: Review, rating of efficacy, and recommendations for further research. *Applied Psychophysiology and Biofeedback, 33*, 1–28. http://dx.doi.org/10.1007/s10484-007-9047-5

Sterman, M. B. (2000). Basic concepts and clinical findings in the treatment of seizure disorders with EEG operant conditioning. *Clinical Electroencephalography, 31*, 45–55. http://dx.doi.org/10.1177/155005940003100111

Sterman, M. B., Macdonald, L. R., & Stone, R. K. (1974). Biofeedback training of the sensorimotor electroencephalogram rhythm in man: Effects on epilepsy. *Epilepsia, 15*, 395–416. http://dx.doi.org/10.1111/j.1528-1157.1974.tb04016.x

Surmeli, T., Ertem, A., Eralp, E., & Kos, I. H. (2012). Schizophrenia and the efficacy of qEEG-guided neurofeedback treatment. *Clinical EEG and Neuroscience, 43*, 133–144.

Teicher, M. H., Samson, J. A., Anderson, C. M., & Ohashi, K. (2016). The effects of childhood maltreatment on brain structure, function and connectivity. *Nature Reviews Neuroscience, 17*, 652–666. http://dx.doi.org/10.1038/nrn.2016.111

Thibault, R. T., Lifshitz, M., & Raz, A. (2017). Neurofeedback or neuroplacebo? *Brain: A Journal of Neurology, 140*, 862–864. http://dx.doi.org/10.1093/brain/awx033

Thompson, L., Thompson, M., & Reid, A. (2010). Neurofeedback outcomes in clients with Asperger's syndrome. *Applied Psychophysiology and Biofeedback, 35*, 63–81. http://dx.doi.org/10.1007/s10484-009-9120-3

Thompson, M., & Thompson, L. (2003). *The neurofeedback book: An introduction to basic concepts in applied psychophysiology*. Wheat Ridge, CO: Association of Applied Psychophysiology and Biofeedback.

Trudeau, D. L. (2000). The treatment of addictive disorders by brain wave biofeedback: A review and suggestions for future research. *Clinical EEG (Electroencephalography), 31*, 13–26. http://dx.doi.org/10.1177/155005940003100107

Ulrich, G. (2002). *Psychiatric electroencephalography* (Rev. ed.). New York, NY: Gustav Fischer Verlag.

van der Kolk, B. A., Hodgdon, H., Gapen, M. Musicaro, R., Suvak, M. K., Hamlin, E., & Spinazzola, J. (2016). A randomized controlled study of neurofeedback for chronic PTSD. *PLoS ONE, 11*: e0166752. http://dx.doi.org/10.1371/journal.pone.0166752

Whitaker, R. (2005). Anatomy of an epidemic: Psychiatric drugs and the astonishing rise of mental illness in America. *Ethical Human Psychology and Psychiatry, 7*, 23–35.

Wyrwicka, W., & Stermah, M. B. (1968). Instrumental conditioning of sensorimotor cortex EEG spindles in the waking cat. *Physiology & Behavior, 3*, 703–707. http://dx.doi.org/10.1016/0031-9384(68)90139-X

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology, 18*, 459–482. http://dx.doi.org/10.1002/cne.920180503