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Neurofeedback and the Brain

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Neurofeedback is an emerging neuroscience-based clinical application, and understanding the underlying principles of neurofeedback allows the therapist to provide referrals or treatment, and provides clients with a framework for understanding the process. The brain's electrical patterns are a form of behavior, modifiable through "operant conditioning," with the excessive brain frequencies reduced, and those with a deficit are increased. The learning curve for EEG has been described (Hardt, 1975).

KEY WORDS: neurofeedback; EEG; ADD/ADHD; operant conditioning.

Neurotherapy using slow cortical potentials also shows promise in the treatment of epilepsy (Kotchoubey et al., 2001; Birbaumer et al., 1981; Sterman, 2000). Neurotherapy has also been used for ADD/ADHD (Monastra, Monastra, & George, 2002) depression (Rosenfeld, 1997), anxiety (Vanathy, Sharma, & Kumar, 1998), fibromyalgia (Donaldson, 2002), and for cognitive enhancement (Budzynski, 2000; Klimesch, et al.). Commonly reported success rates of 60 to 90% are reported (Wright & Gunkelman, 1998).

Neurofeedback is an emerging neuroscience-based clinical application based on the general principles of biofeedback or cybernetics. The Neurofeedback process involves training and learning self-regulation of brain activity. Understanding the underlying principles of this process allows the therapist to provide referrals or treatment to their clients with some added understanding, and provides clients with a framework for understanding the neurofeedback process. The following short paper will provide a quick review of the brain's function, and the underlying process involved in neurofeedback, a technique that will allow the client to better regulate and operate their brain.

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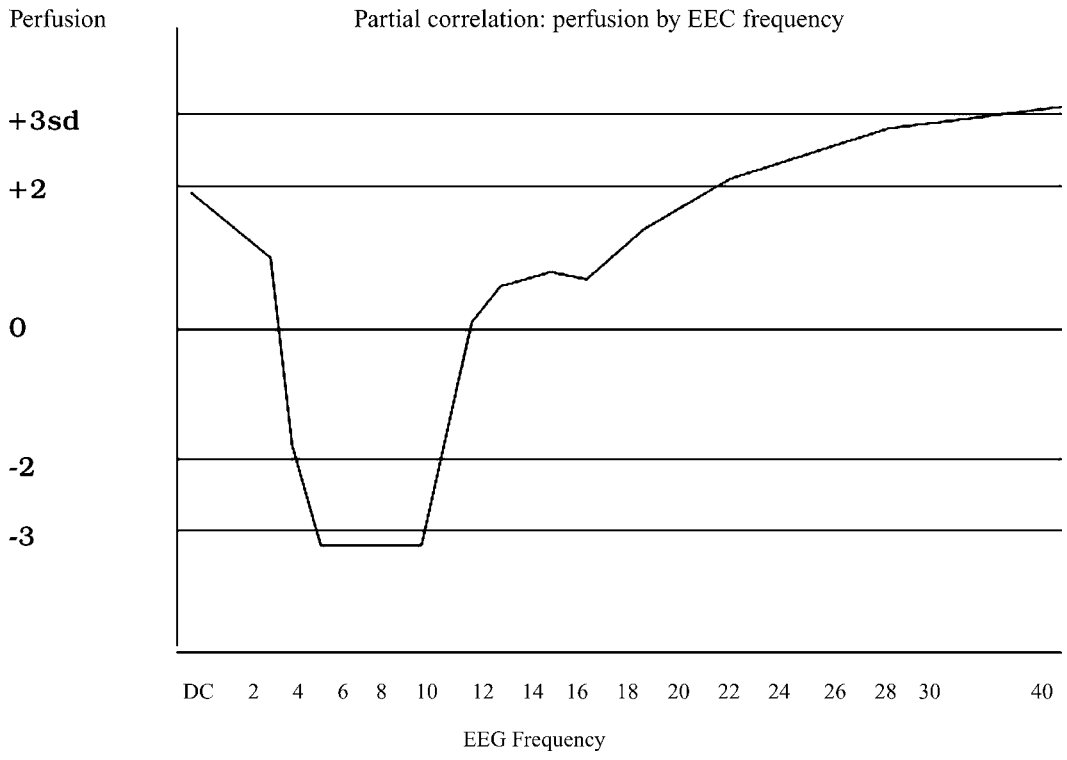
The brain controls its own blood supply through the dilation and constriction of the blood vessels, and the blood flow is directed to areas that are more active through this self-regulation. The blood supply's flow, along with the utilization of the oxygen and glucose the blood carries is measured as "perfusion," a measure that is clearly seen in some of the modern imaging techniques, such as Positron Emission Tomography (PET) and SPECT technology. Though these techniques are invasive, requiring the injection of small amounts of very short half-life radioactive materials, they do give good resolution of the perfusion due to the emission of the positrons, which are emitted from where the brain utilizes the oxygen and burns the glucose carried by the blood flow.

A research project performed at UCLA's Neuropsychiatric Institute (Cook, O'Hara, Uijtdehaage, Mandelkern, & Leuchter, 1998) showed that the brain's electrical activity, or electroencephalogram (EEG), had specific correlates of the brain's perfusion. This is useful in that the EEG is capable of showing when the perfusion is low, such as seen frontally in ADD/ADHD. In these situations, the EEG shows a resting or idling rhythm of alpha (8–13 Hz) and/or theta (4–7 Hz), frequency patterns in the EEG that have rhythmic waveforms. (For a general review of electroencephalography see Niedermeyer & Lopes Da Silva, 1999).

In ADD/ADHD a study of over 400 participants using a neurometric approach (see Prichep & John, 1992; Prichep et al., 1993) showed that there were



generally findings of excess alpha and/or theta in the frontal lobes (Chabot & Serfontein, 1996), which corresponded to the frontal hypoperfusion seen in ADD/ADHD with the PET or SPECT perfusion studies. The frontal lobes are executive areas in the brain, which control attention, emotions (affect) and impulsivity, as well as regulate (inhibit) the motor areas of the brain. The Chabot study (1996) also showed that the EEG could be used to differentiate those with ADD/ADHD from normal clients, as well as differentiating ADD/ADHD from those participants with a learning disability (LD). The LD population was shown to have a slower pattern, with excess activity in the delta frequencies (1–3.5 Hz) over the central and parietal lobes (posteriorly at the crown of the head). These areas are responsible for integrating raw sensory stimuli into perceptually interpretable activity.

More recently, a comparison of children and adults seen in a single neurofeedback practice specializing in ADD/ADHD was performed (Gurnee, 2000). This study showed that unlike the children's study, which showed theta to be the dominant pattern, the adults had an alpha dominance, likely due to maturational changes that have increased the frequencies. In the children the excess theta group is over 50% of the cases, with the adult group showing excess theta to only comprise about 25% of the incidence.

The qEEG data may also be used to select specific medications if a pharmacotherapeutic approach is preferred. The qEEG pattern of frontal theta responds better to stimulants such as methylphenidate (Ritalin), whereas the frontal alpha type responds better to antidepressants. If a specific statistical measure called 'coherence' is deviant (too high or too low), the participant may require an anticonvulsant (Suffin & Emory, 1995). These patterns also may coexist such that an individual may require two or more types of medication.

Physicians generally use behavioral indicators in choosing psychoactive medication. However, it was clear from the work of Suffin and Emory that neurophysiological profiles can be used to guide prescription, even in populations of patients with similar behavioral disturbance (e.g., attentional or affective disorders as defined by *DSM*). Most physicians generally find the proper medication the old fashioned way . . . by trial and error. The "best guess" medication selection method requires more doctor office visits, medication trials, and has the possibility of significant side effects. All this is generally avoided

with the more objective qEEG based method, which is based on the person's physiology, not the behavior. It is not difficult to see why this is the case. The medication treats the physiology, hoping to affect the behavior. The measurement of the physiological indicators should logically be more related to the proper medication choice, since this is what is actually being treated.

The stimulant medications typically decrease appetite, with weight loss commonly noted, as are sleep problems. Long-term use of stimulants have been known to cause teeth grinding (Bruxism), cardiac rhythm changes, blood pressure increases, weight loss, changes in sleep patterns, anxiety/nervousness and even "psychotic" symptoms (such as hearing voices or other sensory hallucinations). There are also those with medical contraindications for stimulant use, such as heart problems, gastro-intestinal and blood pressure problems and other more rare complications that preclude prescribing them. In these individuals, as in those with complications from taking the medications, the presence of an alternative treatment is essential for proper behavioral adjustment and scholastic achievement. For those individuals uncomfortable with using potent medications, or those with adverse side effects, it is fortunate that a non-medication intervention is available.

The choice of medicating the client requires continued treatment, as it is merely a temporary change, due to the drug's effects. Neurotherapy is a treatment, which changes the way the brain works, and once the skill is learned, (unlike medication) it appears to be persistent. Follow-up studies show long-term change in the brain's function following neurotherapy (Monastra, 2003). Both of these methods (medication and neurotherapy) improve the client's attentional and behavioral states. The choice of which method to use is merely a personal choice. Medications, when used long term, may end up being more expensive than Neurotherapy. Neurotherapy has less likelihood of having side effects than does the medication, but it takes a number of training sessions before the effect is noted and becomes more persistent.

It is no surprise that the brain can learn, but what may surprise some is that the brain changes structurally when it learns. This morphologic change is microscopic, the forming and reinforcing of small connections between a part of a neuron, called "dendrite," but it is a structural change, nevertheless. This highly changeable connective nature is referred to as "neural plasticity," based on the original definition of plastic, not as a substance, but as a descriptor of the malleability or change—ability of materials or structures.

The brain has a method of developing and expanding the pathways that are used, and "pruning" the connections that aren't utilized. This process is most dramatic early in life, but continues throughout life. We are born with about twice as many neurons as are present when we become young adults. The pathways that are more consistently utilized are protected from the pruning process through a mechanism still unknown to science, though the fact of the change is irrefutable.

Another time when this process of plasticity is evident is following damage, such as head injury, or disuse of an area, due to "deafferentation," such as when hearing is lost. In these situations the surrounding functions may take over an area not utilized, occasionally causing some subjective changes, which may be uncomfortable. One example of this is tinnitus, or ringing in the ears, following loss of hearing; another is "phantom pain" when a limb is severed and is no longer present, but sensations seeming to come from the missing limb are felt. The functions adjacent to these areas in the brain merely intrude into the area and the person misinterprets these new signals as the older inputs.

These examples are dramatic, but "growth-through-utilization" is the underlying process we want to focus on. This process is how we build additional capacity for the nervous system to do its work. Analogous to exercise building muscle mass, the utilization of the brain builds the mass of the brain's dendritic connections.

Certain intense negative experiences may change the body's chemistry, increasing the stress hormone released from the adrenal cortex of the kidneys. This chemical, cortisol, is a healthy response to stress, though with chronic or overly intense stressors, the cortisol has deleterious effects on the brain, specifically attacking a temporal lobe structure, the hippocampus, which has immune receptors. This structure has important non-immune system functions as a memory comparator, required for both comprehension and recall. The implication for this latter process where stress deteriorates the brain's ability to comprehend and recall has large implications for education. A person with a stressful existence may never reach his or her true potential due to the damaging effects of the stress hormones. If the stress was experienced during pregnancy from the mother's hormonal balance, the newborn will

have a disproportionately intense reaction to stress, causing inordinately large amounts of strain (and thus more cortisol) and ultimately more extensive deterioration of the brain's capacity.

The ability to teach a new response to the situational stressors can change the life course for these individuals, creating a much more favorable outcome. The operant conditioning technique, Neurotherapy, mentioned earlier is one such method of intervention. Similarly to the stress response, there is a relaxation response, which can be trained to counteract these deleterious effects.

The brain's electrical patterns are a form of behavior, which is subject to behavior modification through "operant conditioning," a fact discovered in research done in the late 1960s by Dr Barry Sterman, now a professor emeritus at UCLA. The operant conditioning of the EEG was first demonstrated in cats, where placebo effects are assumed to be absent. Sterman's original work with animals was replicated in humans starting in the 1970s (Sterman, 2000).

Recording and analysis of EEG has been shown to yield reliable results (Fein, Galin, Yingling, Johnstone, & Nelson, 1984). Further, those studies done with control groups have shown the neurotherapy technique to be a robust and valid intervention. Many more studies are of a case series variety, without control groups. Though this latter category is not held in high regard, perhaps this is changing. A recent issue of the New England Journal of Medicine reviews of research design have cast doubt on the need for placebo-controlled designs. Their review has shown that when there is a preponderance of case series reports, the concordance between those results and those of the "gold standard" (double blind placebo-controlled studies) was very high. Many in the field are now arguing against doing a double blind study due to the lack of proper humane treatment of those in the control group (receiving no treatment), an approach which is also now considered unethical by the World Health Organization when known treatments exist. Interestingly, recent work with placebo effect has elucidated brain mechanisms underlying placebo response that were different than those mediating medication response (Leuchter, Cook, Morgan, Witte, & Abrams, 2002).

With the neurotherapy approach, the brain frequencies that are in excess are reduced, and those with a deficit are increased. The technique uses the EEG, amplified from the minute voltages and hooked up with special instruments to control a computer game. The person's EEG is the "joystick" they use to operate the game. Over a series of sessions the person learns to use the EEG to control the game. The clinician slowly adjusts criteria for reward presented to the individual, and thereby "shapes" the behavior of the participant's brain into a more normal pattern.

The neurotherapy technique requires time to learn, and varies depending on the initial condition the individual starts with. In general, the more severe the starting condition, the more learning has to occur to correct the state. Simple relaxation may take as few as 10 sessions to learn; although with more severe cases, a longer training course may be needed, such as with generalized anxiety disorder, or panic attacks. The important point is that the learning is internalized so that the benefit of the training persists, and does not require on-going training. This is unlike the use of medications where symptoms typically reappear after discontinuing medication.

The learning curve for EEG has been described in research done at Langley Porter Neuropsychiatric Institute, at the University of California, San Francisco. The research showed that the curve is a fifth-order curve, which contains an initial increase, followed by a dip, a second increase, followed by the exponential increase at the end of the training (Hardt, 1975). This corresponds to the subjective states reported in some individuals. They are initially presented in a slightly anxious state, which gets better when they habituate to the training situation, corresponding to the initial increase in the curve. The individuals then report that they "try hard to relax," a counterproductive attempt, which corresponds to the dip. They give up trying hard (active volitional attempts), corresponding to the second increase, which is then followed by the learning of the passive volitional state, which is the final exponential increase.

In some cases, the individuals may need more peripheral forms of biofeedback-based intervention, such as muscle relaxation or training of temperature or the electrodermal responses. These will depend upon whether their individual response profile shows their stress in these areas as well. The peripheral training often requires less training time, though the source of the difficulty is universally central, as these modalities are all under the control of the central nervous system.

Training peripherally may be all that is required in more mild cases, but in many individuals, the central training is the only method that will have a

persistent result. In our clinical experience with these more severe cases there may be symptom substitution without the central intervention. In cases with mild stress, the peripheral intervention is often a complete intervention, though when additional complaints such as attentional problems, depression, or hyperactivity are noted, the central intervention is usually the first choice, to minimize the total number of sessions, by getting directly to the common source of the problem.

Prior to starting work with an individual, and in order to design an appropriate operant conditioning intervention, their existent brain function must be known. Optimally, this would entail a full recording of their EEG, with quantitative analysis and comparison of the individual's brain activity to an age matched database. These databases are commercially available from a number of sources, and are described in a recent Journal of Neurotherapy special edition (Vol. 7, No. 3 and 4, 2003). Following such a comparison, areas that deviate from normal may be identified, as well as the direction of the deviation from normal. This shows whether an excess or a deficit of any frequency pattern exists, as well as the location of the deviation. Specific individualized patterns of results are used to guide intervention with neurotherapy.

Following this evaluation, an appropriately customized operant training may be designed which optimizes the training time by focusing on the areas of deviation. The training will take time, with 30 to 40 sessions being quite common before a permanent result is established, and even more are required for more severe or complex cases such as Asperger's/Autism (Thompson & Thompson, 2003). There are commonly reported behavioral changes long before this end point of training is reached, with the early signs of change showing themselves at 5–10 sessions for most individuals, though some have strong changes even after their initial session. It is also common for an individual to not notice the change, as they are occasionally not self-aware, though the changes are easily seen in objective testing and reported by those observing the individual's behavior.

Commonly reported success rates of 60 to 80% are seen in the scientific literature, with up to 90% reported in qEEG based intervention (Wright and Gunkelman, 1998). Using strict criteria (total remission of complaint) the percentage range from 50 to 60%, with those reporting positive results, though with less stringent measurements of success, such as "feeling like you got a positive benefit," ranging in the 80 to 90% rate.

Many therapists are not aware of neurofeedback as an application of operant conditioning, being familiar with more easily observable behavioral operant training than the operant training of "internal states." The neurofeedback literature is most well accepted in the area of operant training of EEG in epilepsy. Well-controlled studies show that the technique can assist in cases where medication alone was shown to be inadequate at controlling the electrical discharges associated with the epilepsy. A review of this application is published in a special edition of Clinical EEG, in the January 2000 issue (Sterman, 2000). Neurotherapy using slow cortical potentials also shows promise in the treatment of epilepsy (see, Kotchoubey et al., 2001; Birbaumer et al., 1981).

Since the EEG in epileptics can be taught to stop the abnormal discharges, leading to the elimination of the behavioral manifestations of the epilepsy, the neurotherapy technique has also been applied in less severe neurological disorders such as ADD/ADHD (Monastra et al., 2002) depression (Rosenfeld, 1997), anxiety (Vanathy et al., 1998), and fibromyalgia (Donaldson, 2002). Budzynski (2000) used neurofeedback to reverse cognitive decline in an elderly population (see also the work of Klimesch et al. for studies of EEG related to memory performance). For recent reviews of neurobehavioral disorders noted to respond to this emerging technologically based operant training technique see Yucha and Gilbert (2004), and Nelson, (2003).

There are two international professional organizations dedicated to the study of this technology and these applications: the Association of Applied Psychophysiology and Biofeedback (AAPB), and the International Society for Neuronal Regulation (ISNR). Both of these societies have annual conferences and often sponsor additional regional workshops. There are also many state and regional organizations, often affiliated with one of these international organizations. ISNR also has international chapters in other countries. Both organizations have web sites (www.aapb.org and www.isnr.org), and both sponsor a professionally published journal with material focused on Neurofeedback: The Journal of Neurotherapy (ISNR), and Applied Psychophysiology and Biofeedback (AAPB).

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